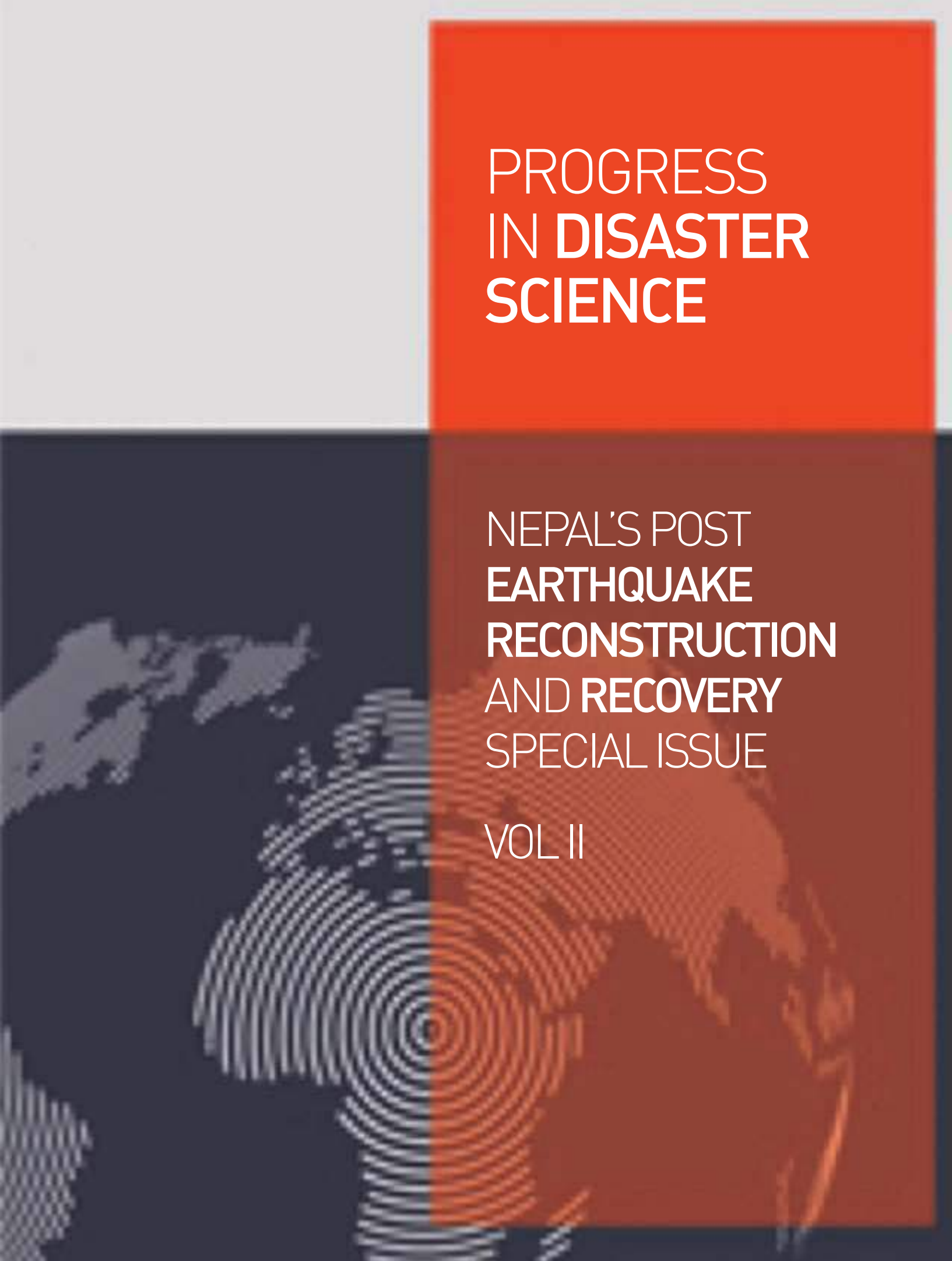




PROGRESS IN **DISASTER** SCIENCE

NEPAL'S POST
EARTHQUAKE
RECONSTRUCTION
AND **RECOVERY**
SPECIAL ISSUE

VOL II

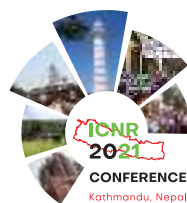
**PROGRESS IN
DISASTER SCIENCE**

VOL II – 2021



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The Prime Minister



Message

It is my great pleasure to learn that the Nepal's reconstruction is featured in the Elsevier Publication's Progress in Disaster Science (PDS). The national and international community will have access to empirically verified conclusions which, I believe, will be useful for handling post disaster reconstruction efforts. Such collaboration between implementing agency and renowned scientific journal publisher Elsevier, I believe, generates synergetic impact for generating readily replicable knowledge.

In Nepal, we achieved broader political consensus in handling reconstruction activities which is manifested in the resounding achievement. All individuals and institutions in this country contributed to the journey of rubble to recovery. Moreover, I am highly appreciative of earthquake affected families who demonstrated resilience and determination to overcome their earthquake induced predicament. At present, it gives me an immense pleasure that life has returned to normal rhythm.

The reconstruction process has left behind a number of lessons. Given our country's vulnerability to multiple disaster risks and hazards, we have no time to waste. A majority of our mountainous settlements are vulnerable to landslides which are further triggered by earthquakes, excessive rainfall and adverse land use pattern. How to sustain in situ will be our first priority. However, if vulnerability is unavoidable, we will relocate them to safer locations. The urban housing is another daunting task which is concocted outcome of the issue of land ownership, access to finance and urban planning and management. We need to address all those issues in collaboration with the local governments.

The leadership of the National Reconstruction Authority was laudable without which we would not have achieved such a grandeur achievement. It would have been extremely difficult if not impossible to deliver reconstruction and recovery interventions without persistent support of the development partners.

The authors of articles included in this volume deserve deep appreciation for their dedication and intellectual prowess. With their contribution, we have been able to create reconstruction knowledge base in the country which can be cashed all the time to come in the future.

I am sure that this piece of work will be a great value to policy makers, academicians and people in all walks of life.

Jay Nepal

Sher Bahadur Deuba

6th October, 2021



National Reconstruction Authority



Foreword

This Vol. II of Progress in Disaster Science – Nepal Special Issue partly covers the lessons that we have learned during the course of the massive reconstruction effort required after the devastating 2015 Gorkha earthquake. We have learned a great deal through the process of reconstructing around 800,000 houses, 50,000 classrooms at 7500 schools, 1200 health institutions and over 1000 cultural and historical monuments. In addition, NRA-led efforts have also resulted in the rebuilding of 650 government offices, including buildings used by security agencies, over 1500 drinking water systems, and also the reconstruction of approximately 800 kilometers of roads.

In the private housing sector, we followed a number of core principles. Build Back Better was the first and foremost one. All those involved in rebuilding infrastructure under the guidance of the National Reconstruction Authority (NRA) have adopted this principle stringently. All reconstructed private houses are characterized by enhanced disaster-resilience. Similarly, our approach to conserving heritage monuments and sites adheres both to principles for protecting our heritage, but also to standards for maximizing earthquake resilience adopting the traditional technologies, materials and architectures. Schools, hospitals and other government buildings constructed under the NRA umbrellas are not only earthquake-resilient, but also are user-friendly, convenient, functional and addressing the future needs.

The “Owner-Driven Approach” was another principle that we adopted, on a scale rarely seen before, if at all in the world. Through this approach, we tried to make individual households fully accountable for the construction of their houses. This sense of ownership, we believe, will help to create an environment conducive to sustainability. Through this approach, we also injected cost-efficient and resilient construction technology into earthquake-affected settlements. From now on, we are hopeful that all houses in Nepal, irrespective of their geographic location, will be constructed with earthquake-resilient technology. The significant progress achieved was made possible by empowering all earthquake-affected households, bolstering the practical, hands-on skills of construction workers and sharpening the technological prowess of our technicians.

Our aim has been to record all these hard-earned lessons, not only for Nepal's future generations, but also for the international community. To help us to achieve that objective, we have chosen to collaborate with Progress in Disaster Science, a scientific journal known for its objectivity and through which we can share lessons that are grounded in rigorous research and analysis. Through this means, we believe that we have been able to achieve our goal of being accountable and responsible to the national and international communities.

I take this opportunity to thank all the government officials associated with our mammoth organizational structure, our development partners, private sector institutions, academic institutions and individual experts, all of whom have contributed to the recovery process. Without their whole-hearted support, reconstruction on such a massive scale would not have been realized. I congratulate all the contributors of articles and others who worked towards preparing this special edition.

Sushil Gyawali
Chief Executive Officer
National Reconstruction Authority



National Reconstruction Authority



Acknowledgements

First of all, I would like to welcome and congratulate Rt. Hon. Sher Bahadur Deuba for assuming the nation's premiership and Chairmanship of the NRA Steering Committee. We wish him a successful tenure and hope that we will be able to comprehensively conclude the NRA's operations under his guidance.

A number of distinguished personalities contributed to bring this Special Issue of Progress in Disaster Science to fruition. NRA initiated preparations for the International Conference on Nepal's Reconstruction in the second half of 2019, when we organized thematic workshops intended to encourage potential authors to work on the scientific articles. These initiatives were meant to assimilate NRA's lessons and to prepare for their presentation in the International Conference on Nepal's Reconstruction (ICNR-2021). We would like to acknowledge all individuals and institutions that have enabled us to reach this far.

Our appreciation is due to Mr. Sushil Gyawali, the NRA Chief Executive Officer, for his strategic acumen. The ICNR Organizing Committee members guided us from the beginning of the ICNR preparatory activities.

The contribution of Prof. Rajib Shaw as a Journal Editor-in-Chief has been a lynchpin of this publication. Prof. Dr. Tara Nidhi Bhattarai (Volume Editor in Chief), Mr. Jitendra Bothara, Dr. Nigel Fisher, and Prof. Dr. Ram Manohar Shrestha assisted us in reviewing the substance and structure of the articles. Mr. Jitendra Bothara, the Volume Editor Manager, not only played the crucial role of interlocutor between the ICNR Secretariat and the PDS Management, but also managed the peer reviewing process. Similarly, all peer reviewers worked to the highest academic and professional standards, to assist the authors in completing their contributions. We thank you all.

Dr. Chandra Bahadur Shrestha, NRA Executive Committee Member and ICNR Convener, has led the ICNR Secretariat since its conceptual stage. We acknowledge his commitment, drive and dedication. Mr. Manohar Ghimire, Under Secretary, contributed as Member Secretary of the Secretariat. We are appreciative of other Secretariat Members: Ms. Sulochana Nepali and permanent invitee members: Mr. Janardan Nepal and Mr. Sandeep Gurung.

Finally, we are grateful to our Central Level Project Implementation Units (CLPIUs - Building, GMaLI and Education), governmental institutions and development partners for their explicit and implicit support.

Sushil Chandra Tiwari
Secretary
National Reconstruction Authority



National Reconstruction Authority



About this publication

As the ICNR Convener, I am grateful to the Conference Steering Committee, Editorial Board, Organizing Committee and ICNR Secretariat. This volume would not have seen the light of day without their contributions.

The National Reconstruction Authority (NRA) has aimed to capture its best practices through four routes: scientific, corporate (known as the Compendium), institutional and open. This publication of the special issue of Progress in Disaster Science (PDS) is one in the scientific category. The results of all these efforts will be concluded and presented in the International Conference on Nepal's Reconstruction (ICNR) which is planned for 7-9 December 2021.

Altogether, there will be two volumes each of the PDS and Vikas – a national journal – with a combined total of 43 articles. All these articles were realized through 11 thematic workshops which took place between November 2019 and March 2020. A National Symposium on Nepal's Reconstruction (NSNR – 2020) was organized during August 24-28, 2020 when all selected articles received feedback from experts in the respective fields. The articles were then peer reviewed and finalized for publication.

Among the 11 articles in this volume, one deals with housing policy, five have analyzed various construction technologies and three have delved on livelihoods. Of the two remaining articles, one has investigated landslides and another has assessed the role of communication in reconstruction.

The article on housing policy has examined constraints of the urban housing which NRA found to be beyond its sphere of influence and policy interventions were required in land and access to finance. Three articles dealing with strengthening of earthquake affected buildings have revealed that cost effective solutions can be achieved through retrofitting technology. Post-earthquake conservation of heritage monuments involved indigenous construction technology with additional earthquake resistant elements, which is demonstrated in one article on conservation technology. Another technology related article has attempted to evaluate seismic hazard in the Kathmandu Valley and the adjoining region.

The article dealing with landslide hazard risk has concluded that the pre-existing and new landslides pose threats to both settlements and arable land. This article has summarized the methodology for safeguarding vulnerable communities from landslides. How communication bolsters recipients' skills are discussed in another article, concluding that communication must be an integral part of all reconstruction interventions.

Last but not the least, the article on social inclusion has shed light on the limitations of the owner driven approach adopted by NRA. The targeted beneficiaries did not benefit from top-up grants and subsidized loans. However, landless households – a segment of vulnerable group – secured ownership of homesteads, which is a significant achievement. The article dealing with resettlement has indicated some policy caveats and recommended the need for addressing livelihood issue more stringently for the resettled people.

All these articles will be of interest to national and international policy-makers, particularly when dealing with the challenges of post-disaster reconstruction. Practitioners, academicians and civil society members will also find the research and lessons learned of interest.

Chandan Bahadur Shrestha
Executive Committee Member, NRA
Convener, ICNR

Editorial

This second special issue of the Progress in Disaster Science (PDS) journal is published jointly with the National Reconstruction Authority (NRA) of Nepal, an organization established by the Government of Nepal to lead and coordinate reconstruction following the 2015 Mw 7.8 Gorkha, Nepal earthquake. The special issue records the achievements of what has been a most complex post-earthquake recovery process. Of equal importance is the presentation of the many lessons derived from the reconstruction experience of the last six years. The aspiration of both the first and second PDS special issues is to make rigorously-researched analysis available to national, regional and international readers. It is hoped that this will assist them in their own disaster preparedness work, in mitigating disaster impacts and in conducting post-disaster reconstruction programmes that will both restore the hopes of affected populations for the future and also strengthen the resilience of people, communities and institutions to address and overcome multi-hazard disaster risks that they may face.

The papers published in this special issue were initially presented at the National Symposium on Nepal's Reconstruction – 2020 (NSNR – 2020). This webinar was organized by the NRA to provide a professional platform to share the lessons learned from Nepal's multi-dimensional reconstruction experience with a national and international audience. In all, 115 abstracts were received for the NSNR - 2020. These were reviewed by the editorial board instituted by the NRA. The analysis and suggestions provided by the board facilitated the writing of full research papers, following the NSNR – 2020 guidelines. Despite the Covid-19 pandemic situation, 62 completed papers were submitted for the NSNR - 2020. These were assigned for a double-blind peer-review process. At the same time, the papers were presented thematically in the NSNR – 2020 webinar, during which authors received suggestions and feedback from audiences, panelists and facilitators. The papers of those authors who addressed reviewers' comments and seminar feedback satisfactorily were given two provisions for the publication of manuscripts: in *Vikas*, a journal of the National Planning Commission (NPC) of Nepal, and in the PDS journal.

The papers submitted to the PDS journal were reassigned for a double-blind peer-review process and accepted following the protocols of the journal. Peer reviewers were selected from an international pool

that included practitioners, researchers, academicians, and disaster managers. Papers of sufficiently high quality and sufficiently numerous have been considered for publication in two special issues of Progress in Disaster Science.

The papers included in this second special issue of the PDS journal again cover several reconstruction themes and complement the collection of papers presented in the first special issue. Reflecting the thematic centrality of housing in the recovery effort, issues arising from reconstruction of private housing are addressed in three of the nine papers presented, ranging from housing policy to analysis of construction technologies. The remaining papers cover restoration of heritage, livelihoods, communication strategies and safeguarding landslide-prone communities. A common thread running through the research is the central importance of communication with affected communities and their involvement in reconstruction decisions that affect them.

We trust that the papers will be useful to researchers, policy makers, students and practitioners working in the field of disaster management, but equally, to those articulating development policies and programmes that must, by definition, be disaster-risk informed. Last but not least, the papers will serve as a historical record and mirror reflecting how Nepal completed its reconstruction after the 2015 Mw 7.8 Gorkha earthquake.

We are grateful to the NRA and to the PDS journal for entrusting us with the role and responsibilities of the guest editorial board. We are also thankful to our distinguished reviewers for their insightful analysis, comprehensive comments and timely responses.

Guest Editorial Board

Rajib Shaw (Journal Editor-in-Chief)

Tara Nidhi Bhattarai (Volume Editor-in-Chief)

Jitendra Bothara (Editor)

Nigel Fisher (Editor)

Ram Manohar Shrestha (Editor)

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Unravelling constraints of urban housing reconstruction

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ABSTRACT

The Nepal's National Reconstruction Authority (NRA), which was established for reconstruction and recovery of damaged infrastructure by 2015 Gorkha Earthquake, achieved only 43% progress in the Kathmandu Valley in comparison to 75% in the Rural Municipalities by April 2020. The broader objective of this study is to unravel reconstruction constraints in urban housing. In addition to collecting information from the secondary sources, this study conducted primary surveys and focused interviews. This study found that the problem of land and access to finance are the structural problems. Hence, the Government of Nepal (GoN) will need to integrate reconstruction activities with a long-term urban renewal strategy. Other non-structural issues can be addressed by NRA itself.

1. Introduction

Lying in a high seismic zone, Nepal has experienced highly damaging earthquakes throughout its history [14]. The Gorkha earthquake of 25 April [18] measuring 7.8 Magnitude and the massive aftershocks that followed a month later on 12 May [18] measuring 7.3 magnitude, brought a heavy loss to life, property and the country's physical infrastructure [18]. The Gorkha Earthquake damaged 288,856 urban houses out of total 604,930 houses [23]. The Government of Nepal (GoN) established the National Reconstruction Authority (NRA) in 2015 to assess damage, to support the reconstruction of the private houses, to reconstruct and conserve infrastructure and heritage sites and to ensure recovery of affected people [10].

Nepal's urban reconstruction has moved at a slower pace. As of April 2020, the NRA achieved only 43% progress in the Kathmandu Valley in comparison to 75% reconstruction in outside of the Kathmandu Valley [32]. In broader classification, the Kathmandu Valley has metropolitan characteristics and rest of the districts have rural features. Land is one of the most complex urban recovery issues, which includes various factors, such as lack of clarity in ownership, multiple-ownership and the land parcels below the Municipality's minimum threshold size. The speed of recovery has been additionally slower in heritage sites, wherein the major issues are the high cost of traditional construction, unavailability of material and labor, and need for adhering to strict heritage rules which normally contradict with the family's requirements. There has been a huge overarching issue of access to finance in the overall urban recovery process, with high costs of construction and little or no access to low-interest housing recovery loans [13]. The Asia Foundation's Independent Impacts and Recovery

Monitoring (IRM) study, carried out from 2015 to 2019, found that only 30% of earthquake damaged houses in urban areas were demolished compared to 57% in rural areas, and many continue to live in partially damaged houses risking their lives. While the pace of retrofitting has been extremely slow, the study indicates that the interest for retrofitting is much higher in urban areas compared to rural areas [39]. One of the primary barriers to urban housing recovery has also been the lack of a comprehensive policy tackling urban recovery in particular. This has impacted the engagement of international NGOs and the clarity on the roles of local governance [7]. Globally, it has been recognized that urban crises are more complex than rural and require flexible and integrated approaches. In developing countries, the response is more challenging in case of weak infrastructure, squatter settlements and housing that does not meet safety standards [37].

In light of the relatively slow-pace of urban reconstruction due to various cross-cutting issues on a technical, socio-economic and political front, the broader objective of this study is to unravel the constraints in the reconstruction of urban housing sector. The specific objectives are to assess magnitude and dimension of each constraint, examine issue-based approaches in the past and to articulate potential mitigating measures.

2. Literature review

There are a number of literatures on the urban housing reconstruction issues. Among them Daly et al. [7] tried to unpack constraints in urban housing reconstruction. They suggested to allow external funding above NRA's limit of US \$ 3000. NRA imposed egalitarian grant approach irrespective of Earthquake Victim's geographic location, ethnicity and economic status. NRA permitted donor's grant on par with the government's

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provision. In spite of overarching positive implications of such policy, a “one size fits all” policy had some limitations. Daly et al. further blamed for the lack of access to low interest financing for low turnout of the housing reconstruction.

Oliver Smith [35] mentioned that social factors are of paramount importance in the urban housing reconstruction. Pamidimukkala et al. [36] analyzed challenges in post-disaster housing reconstruction in urban and rural communities after analyzing 177 articles. They found that communicating with and coordinating the activities of people in a rural area is easier than it is with people in an urban area which is in contrast to the general belief that urban denizens are well informed through exposure to media and proximity to the source of information. Rural people are more active in the reconstruction process. Arefian [1] found that urban housing reconstruction to be more challenging than the rural housing reconstruction. He even argued that there is a gap in theory or best practice for organizing urban reconstruction at global level.

Trohanis and Read [40] mentioned that both India and Pakistan followed fixed government grants which is considered to be a successful approach. They also emphasized capacity development programs to designers, builders and social artisans. Based on the Turkish example, they postulated that the public sector risk has to be transferred to the private sector through insurance financed reconstruction. In addition, pre-existing social networks and livelihood opportunities have to be considered duly for planning during the post disaster period.

Kawase [16] mentioned that Japan linked reconstruction with their long term planning. The reconstruction is financed through the sale of additional space beyond replacing what was there before. Under the land readjustment, each land owner loses some land area but the new infrastructure and improved accessibility add value to each parcel. Byahut [3] mentioned that the residents of Indian city of Bhuj strongly opposed to abandoning their 500-year-old city and relocating to a safer, less-congested area. The plan was prepared with active public participation and included elements ranging from land use, road network, and infrastructure planning, as well as adoption of seismic safety codes. Rather than acquiring land through eminent domain, the plan called for the use of land readjustment (also known as land pooling) in the form of eight town planning schemes (TP schemes) in the old city. The process worked by proportionately deducting some land from each original landholding in the old city to create wider public roads and increase access. This approach helped rebuilding a devastated part of its historic core. Byahut, however, cautions that despite Bhuj's success, such reconstruction tools depend greatly on the existing legal and political systems. There is a spectacular difference between the Japanese model and Indian model. In the Japanese model, additional space is created for floating to the market whereas in the Indian model, only land is readjusted.

The literature review revealed that urban housing reconstruction is highly complex in comparison to rural housing reconstruction. There seem to be three different varieties of policy instruments: government grants, shifting public sector risk to private sector risk through insurance, linking urban housing reconstruction with the city planning. There is another model which is implemented by the Government as manifested during the post-earthquake Wenchuan reconstruction [20]. In this continuum, Nepal adopted strategy of housing reconstruction grant which has to graduate towards insurance regime and to link urban housing reconstruction with city planning. The Chinese model seems extremely challenging due to totally different socio-economic context between Nepal and China particularly on the issue of land ownership.

3. Research methodology

This study collected information from both secondary and primary sources. The secondary research included policy level literature, NRA documents, documents from the line agencies, Housing Recovery and Reconstruction Platform - Nepal (HRRP), bi-lateral & multilateral organizations and Non-Governmental Organizations (NGOs). A substantial body of

international knowledge and information was drawn from the international literature as well.

The primary data was collected using Focus Group Discussion (FGD) and Key Informants Interview (KII). The Urban Technical Working Group (UR-TWG), consisting of partner organizations engaged in urban recovery, facilitated by HRRP and supported by NRA, developed the questionnaire and conducted the survey. The questionnaire was prepared collectively by the UR-TWG based on the identified urban issues from partner's experiences, secondary research and UR-TWG meetings. The districts were selected such that they represented the identified urban issues in diverse kinds of urban areas such as heritage, peri-urban, and core urban areas, RCC structure & retrofitting prevalent areas, and Guthi (Trust) lands. Fig. 1 shows the study area. However, this paper mainly focuses to the urban core areas.

The FGDs were carried out in December 2019 and January 2020 in Lalitpur, Bhaktapur, Ramechhap, Dhading, Dolakha, Kavrepalanchowk and Gorkha districts. The UR-TWG carried out 14 FGDs with beneficiaries who have not been able to complete reconstruction and retrofitting: 5 with males, 4 with females and 5 with mixed groups of both males and females. The Group also carried out 8 KII with ward officials and 1 with a mason, along with neighborhood visits. Three interviews were taken with the NRA officials and Central Level Project Implementation Units (Building and Grant Management and Local Infrastructure). The questionnaire for the FGD and KII intended to acquire information on: 1) Identify and prioritize barriers in urban recovery; 2) Identify the solutions to barriers in urban recovery; 3) Identify gender and vulnerability issues in urban recovery; 4) Information access and ward's capacity and engagement in recovery.

4. Findings

This section presents the outcomes of the primary survey and the secondary sources of information. First the urban issues were identified and clustered from the perspective of affected households according to their own priority order. In this priority order, different variables of one thematic area are included in various issues. For example, there are a number of variables under the issue of “Finance” such as affordability, access to finance, NRA's grant disbursal practice and debt before earthquake. It is easier to develop strategy according to the issue which necessitated to cluster variables around themes. Issue based analysis is undertaken in a comprehensive way.

4.1. Identification and clustering of urban issues

This section presents the outcomes of the primary survey. More than 50 issues emerged through the study that can be categorized into 10 clusters: issues related to finance, heritage, land, masons, NRA process/policy, reconstruction technology, retrofitting, communication, vulnerable beneficiaries and women in reconstruction which are demonstrated in Fig. 2.

Land is one of the most complex urban recovery issues, which includes various factors, such as lack of clarity in ownership, multiple-ownership and the land parcels below the minimum threshold size set by the precedents of the supreme court.

Further, the individual issues were coded using a scoring method, where each identified urban recovery issue from the FGDs and KIIs was coded with the number “1” and the most critical urban recovery issue identified per FGD/KII was coded “99”. After coding 56 urban recovery issues collectively arising for each FGD and individually for each KII, a score was calculated, by assigning a value of 1 to each issue coded “1” and a score of 1.5 was assigned to each issue coded as “99” i.e., the most critical urban issue in that community. Through this scoring process all the 56 identified issues have been prioritized. In order to analyze a wide sample of the issues within the feasibility of this study, the top 7 issues with the highest scores have been categorized in Table 1.

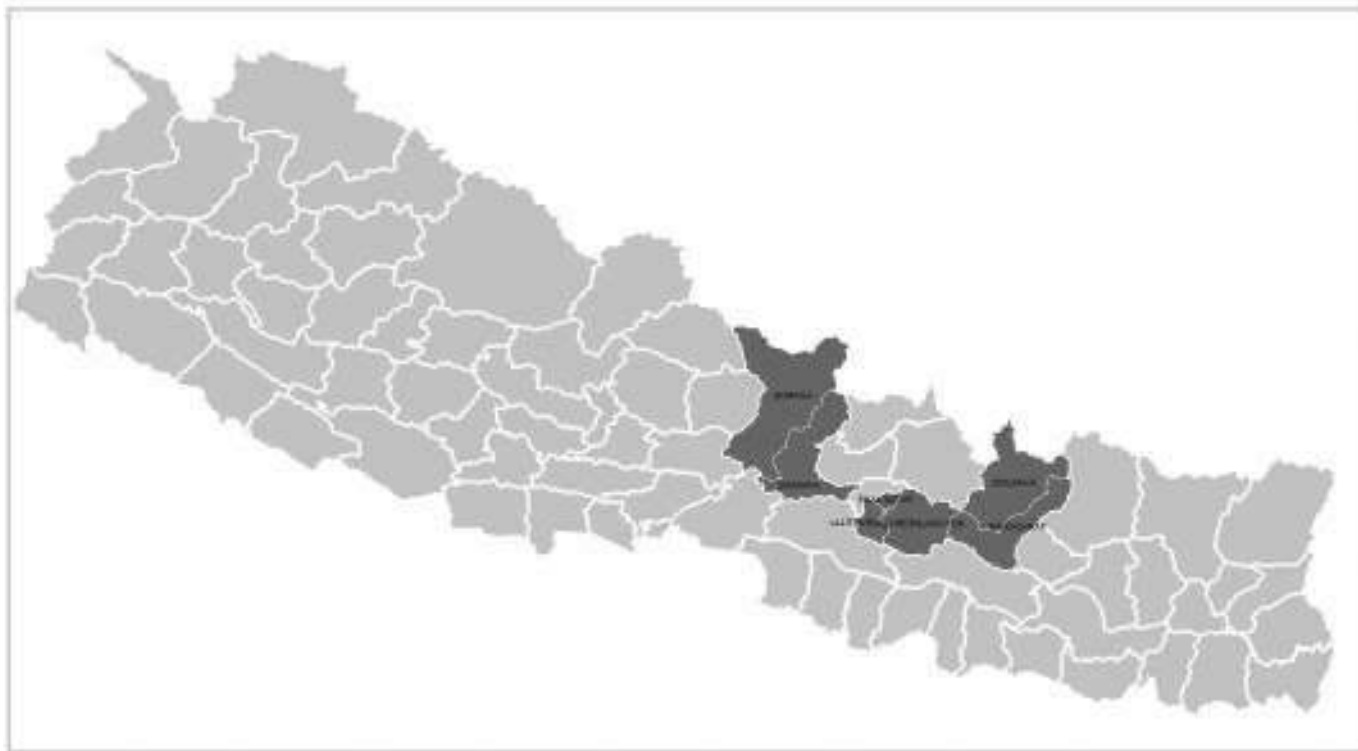


Fig. 1. Survey districts: Gorkha, Dhading, Bhaktapur, Lalitpur, Kavrepalanchowk, Dolakha and Ramechhap.

4.2. Dimensions of the priority issues

The seven constraints that are hindering towards making progress in urban areas are analyzed in this section.

4.2.1. Financial constraint

The financial constraint includes affordability, poor access to finance and slow tranche disbursal. The survey respondents pointed out that they have only been able to access loans from local merchants at very high interest rates. Pre-earthquake debt existed in many cases, and the interest rates varied, ranging from 10 to 14% from the Commercial Banks and up to 21% from cooperatives whereas the merchant interest rate exceeded 24%. Access to soft loans has been recognized as one of the most urgent needs to reconstruct.

As such poor families are under perennial debt burden, they do not have **access to credit** from the formal sector and the informal sector charges an exorbitantly high interest rate. The Nepal Rastra Bank's "Bank and Financial Institutions Regulation Department (BFIRD)", issued directives to the Commercial Banks immediately after the Gorkha earthquake that the Kathmandu Valley based households were entitled to receive US \$ 25,000 and non-Kathmandu based households US \$ 15,000 as soft loan [2]. Such loan was for a period of 5–10 years with 2% interest rate when market rate of loan was above 10%. No additional charges were allowed. However, all other banking regulations would prevail which means the bankable property supported by income from the formal source. The urban poor with income in the informal sector could not take advantage of this facility. In the same directive, there was a provision of community loan which can be released from Category D financial institutions for their own members with zero rate of interest. However, other assessment criteria were similar to the normal loan. The deprived communities could not use this provision as well. On the other hand, the financial institutions were not interested in lending money under this provision because of their psychological risk on investment.

The Ministry of Finance [19] introduced "Unified Procedure for Interest Subsidy on Concessional Loan-2075". Under this provision, the earthquake

affected people who could not initiate house construction until 2018 were entitled to receive this loan under community collateral. The loan duration was for five years and the rate of interest would be determined based on adding 2% on the bank's base rate which is normally 5%. It means the loanee would need to pay approximately a 7% rate of interest which is subject to fluctuate. For the Kathmandu valley, this loan package was too small as minimum reconstruction amount may exceed NPR 2 million. Only 200 households received soft loan under this scheme [22].

The **slow tranche disbursement** may have happened due to some administrative problems of disbursement but such problems are short lived not more than 2 months or so. Had there been such problems, it should have impacted both urban and rural districts. The progress in rural districts except the Kathmandu Valley is more than 75% whereas the Kathmandu Valley progress until 02 May 2020 remained 43% given the exactly similar administrative and disbursement set up [32]. The statistics reveal that the disbursement which respondents mentioned in their response is not the fundamental reason for delaying the progress.

4.2.2. Constraint related to land

Under land issue, there are a number of sub-issues which are: land size, land ownership, land dispute, compliance with heritage regulations, and Right of Ways (RoWs). In all FGDs and KIIs, land emerged as the prominent hindering factor in the reconstruction.

The minimum official threshold of **land size** to construct a house is 860 sq. ft. The municipality does not give approval to build the building below this threshold. Many of the damaged houses in the urban city core have land below the threshold which is causing delay in reconstruction. Wily [42] mentioned that land statistics in Nepal are out-of-date, contradictory by source, and incomplete. There are also many changes at the moment, including movement to urban areas, which makes facts unreliable. Despite the number of attempts of land reform, the land information has remained extremely weak. The dwelling size in urban area decreased from 584 sq. ft. to 571 sq. ft. since 2003/04 to 2011 when census was conducted. In the case of the Kathmandu Valley it has decreased from 589 to 555 sq. ft. CBS [5] shows that there are 5 rooms in average and 571 sq. ft. of dwelling size with 1472 sq. ft. of housing plot. In the Kathmandu Valley, the average

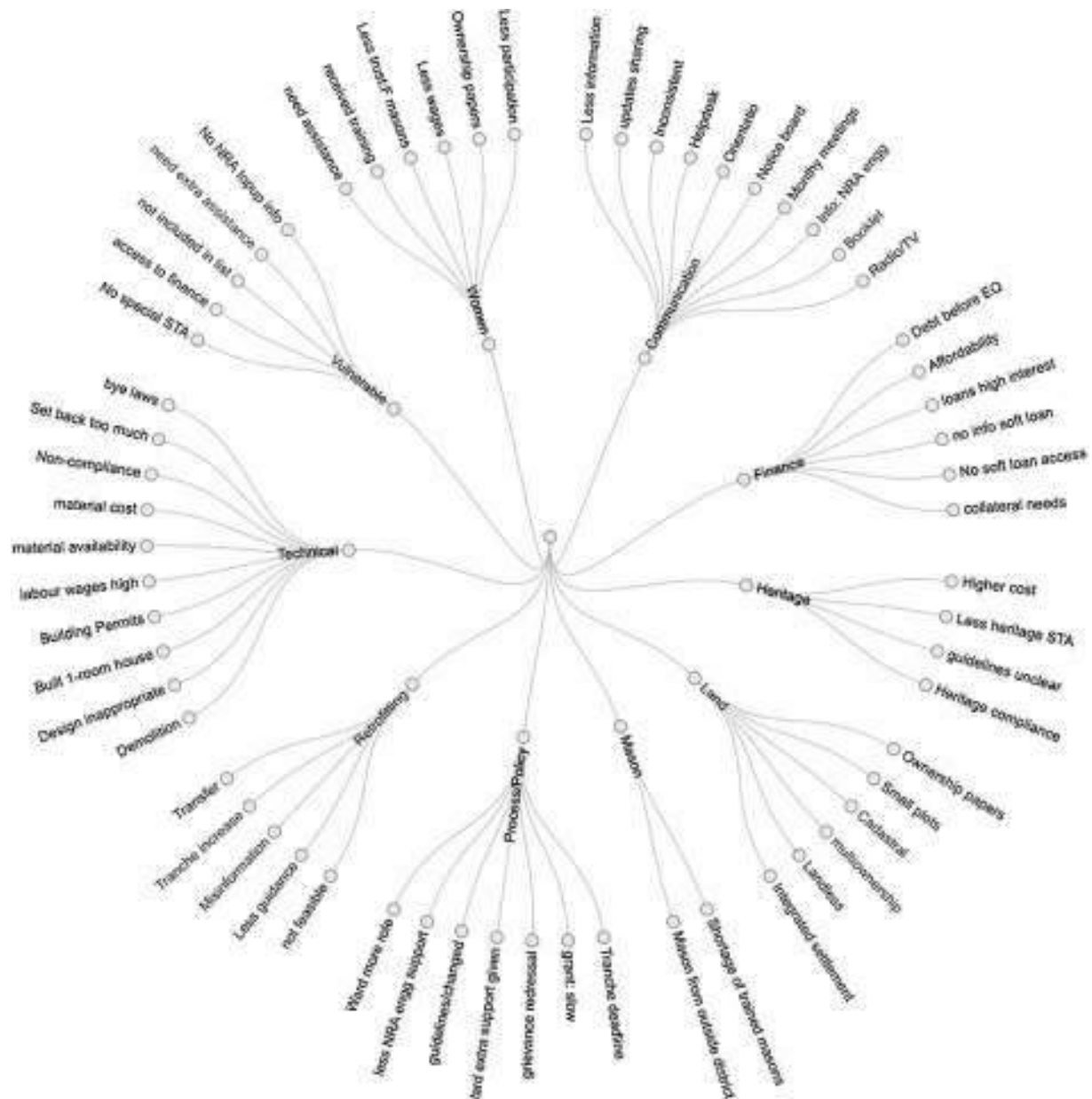


Fig. 2. Dendrogram representing the issues identified through the qualitative.

number of rooms was found as 4.8, with dwelling size of 555 sq. ft. and housing plot of 1224 sq. ft. The average housing plot size means that there are about half the houses below 1224 sq. ft. and minimum threshold

Table 1
Cluster based priority issues.

Category	Priority issues
Financial constraints	Affordability Access to finance Slow tranche disbursement
Constraints related to land	Plot size Land ownership Land dispute Right of Way (RoW)
NRA processes	NRA's handling of grievance
Ineffective policies	Engagement of the local governments Tranche deadline/ time pressure
Reconstruction	Guidelines for single roomed
Retrofitting	Technology, funding and communication
Heritage	Compliance with heritage provisions

area of land is 860 sq. ft. The municipality does not interfere if the given dwelling unit existed there before enforcement of this provision. In addition, if the dwelling is within the officially declared heritage site, this provision is exempted. Based on the anecdotal evidence, there should be around 15% housing stock which have land area below the official threshold size who could not secure approval from the municipality.

There were a number of different **land ownership** status such as *Guthi* land where the land ownership belongs to a certain shrine and the tiller is considered as a tenant. Similarly, another type of land ownership was *Birta* (traditionally state given land to government officers in lieu of their services to the state). The other category was *Swobasi* and *Benissa* where people use the public land for generations without land ownership certificates [12]. The land ownership was prerequisite at the initial stage of NRA which was relaxed later on. The NRA promulgated regulation to provide land ownership for homestead based on the geographic region. In the Kathmandu Valley, the limit was 1368 sq. ft. It was 2052 sq. ft. for all district headquarters except the Kathmandu Valley and for all the rest locations the limit was 3421 sq. ft. In such a way, the NRA resolved land ownership issues. However, the procedure was promulgated on [14] May 30

Table 2

Right of Ways (RoW) determined by various governmental agencies.

Agency	Highway (m)	Feeder (m)	District (m)	Arterial/Trunk (m)	Sub-arterial (m)	Collector (m)	Local (m)	Ring Road (m)	Local Min (m)	Feeder (Urban)
KVDA2064	50				22	14		62		11
DoR 2070	50	30	20							
MoFAGA2072							6		4	
MoUD2076				50	30	20	10			

Source: [8] [17], [21].

after about one and half years of NRA's establishment. It was revised and accommodated all land concerns on 2019 February 11 [24] which shows NRA resolved these issues but it delayed the reconstruction.

Land dispute due to un-delineated land boundary is another factor in the urban areas particularly in the city core of the Kathmandu valley which is delaying the reconstruction process. The Kathmandu city was built over the period of thousands of years and there are houses which are much older than one century. Most of the current inhabitants in the core city are not aware about their land boundaries and manually drawn cadastral maps do not show the exact extent of land. Under these circumstances, about 10% of land owners who have not constructed their houses belong to this group.

There are four main government entities who set **Right of Way (RoW)** standards and there are 10 RoW standards as presented in Table 2. As shown in Table 2, the Department of Roads (DoR) standards are not applicable to the urban roads because DoR administers only Highways and Feeder Roads. The other standards promulgated by MoUD, Kathmandu Valley Development Authority (KVDA) and MOFAGA are not compatible with each other. As per KVDA's standards minimum RoW of Urban Roads is determined as 11 m, whereas MoFAGA and MoUD standards suggest that lowest standard RoW is 6 m and in exceptional cases it can be lowered down to 4 m with setback width of 1.5 m. There is another standard for the heritage settlements which follows existing footprints.

Under the above circumstance, the urban except heritage settlements are affected with these provisions. Moreover, the KVDA has identified streets which need to follow particular RoW standards. Such areas cannot follow the previous housing foot-print for reconstruction. It means the building may have been constructed leaving 6'6" from the central line but according to the KVDA standard, they may need to leave 18' which means additional 11'6". For a small parcel of land of 861 sq. ft., if the building line is defined as 11'6", there is not much land left for the house construction. A number of households are affected with this provision. In heritage sites set back distance is defined as 3'4" which also creates problems for them. In such a way the RoW standards conflict with each other and these provisions leads the land size below the minimum official threshold area eventually making municipal approval process difficult.

4.2.3. Ineffective handling of grievances

The "Grievance Management related to Reconstruction and Rehabilitation Guidelines, 2017" [29] sets procedure for handling all grievances with regards to the private housing grants. The grievances were handled in four stages. In the first stage, grievances were collected from 14 severely impacted districts with submission deadline until 16 July 2017. Until then 216,285 grievances were registered. Out of which 25% were declared as beneficiaries and rest of the households were declared as non-beneficiaries [32]. However, the NRA's Ninth Steering Committee meeting decided to resurvey those households which were declared as non-beneficiaries by the Executive Committee [27] which was the reason for conducting the second survey. Consequently, more than 65% of total grievant were declared as beneficiaries in the second survey. However, as political environment started to become more stable, the beneficiary to registered grievances decreased to 1:0.09 in the third stage and 1:0.13 in the fourth stage. Ultimately the grievance resurvey procedure concluded by June 2020 [34].

4.2.4. Ineffective local government policy and tranche deadlines

The FGDs and KIIs pointed out that NRA did not delegate authority to the local governments sufficiently. The local governments also subscribed this idea. On the other hand, by setting deadlines, the beneficiaries were pressurized to reconstruct their houses sometime in the adverse condition.

NRA initiated its activities in Dec. 2015 in the absence of local governments. The local government's elections were held on 14 May, 28 June and 18 Sep. 2017 which means NRA had to operate about one and half years without them. However, the agreements which the GoN concluded with donors assumed the existence of the local governments. It was the responsibility of the local governments to conclude partnership agreements with the beneficiaries. There was only one village secretary and they used to operate from the district headquarters during and even after the Maoist war which concluded in 2006. NRA relied on bilateral, multilateral donors and NGOs for required human resources in each Village Development Committee, a lowest level of local government which existed until 2015's promulgation of a new constitution [11]. After the election, NRA initiated MoU with the newly formed Municipalities and Rural Municipalities from 2018 November with the objective of delegating some of the NRA's powers and to kick off collaboration with them. The MoU delegated authority of administering Engineers and other technicians to the local level. However, the local governments were willing to handle the housing grant which was not possible due to the Federal financial rules of the Office of Comptroller General.

For the NRA, an institution formed under the sunset law, it was inevitable to set deadlines for disbursing tranches. NRA imposed deadline on 12 July 2016 [25] primarily to accelerate the progress in housing sector. Until 10 July 2016, partnership agreement was concluded with 226,149 households and only 26,726 households received first tranche [26]. With such a dismal progress, it was essential for NRA to pressurize beneficiaries to make faster progress which worked to some extent. However, NRA kept on extending the deadline for allowing all affected households to reconstruct their houses. At present, the deadline extended to Jan 2021.

4.2.5. Guidelines for single-roomed building

The NRA's general assumption was that the people construct their house according to their need which was the reason for NRA not fixing minimum threshold size. The Department of Urban Development and Building Construction [9] promulgated design catalogues, the smallest building size was 171 sq. ft. However, some of the households constructed single roomed houses with lesser than DUDBC's smallest building size. The FGDs and KII revealed that there were three categories of households who constructed the single roomed houses: absentee homeowners, households requiring large space with low level of affordability and single membered households. The absentee house owners reconstructed one-roomed houses for their occasional visit to their ancestral village. The households with large family size with low level of affordability also constructed single roomed houses for satisfying NRA criteria while staying in the old vulnerable house which had to be demolished. The single or double occupants' households also constructed one roomed house which was sufficient for them. Against this background, NRA announced a new requirement of 120 sq. ft. as minimum threshold area. However, the household would need to construct a kitchen and toilet separately. Hence the respondents point that NRA's delayed announcement was correct but it had logic behind doing so.

4.2.6. Retrofitting

During the FGDs and KIIs, the issue of retrofitting was raised prominently. As a significant percentage of retrofit beneficiaries are located in urban areas and retrofit is progressing very slowly, it has eventually impacted the overall reconstruction of the urban areas. The respondents of Panauti and Gorkha questioned technical feasibility of retrofitting and raised the issue of insufficient technical guidance. The FGD respondents from Gorkha and Panauti state that there was not clear information regarding retrofitting. One of the respondents stated that the first tranche, US \$ 500 was spent just to retrofit stairs. It will cost US \$ 6000 to retrofit the 4-story house. In Majhi Tole of the Ramechhap district, the Ward official stated that retrofitting is new for them, is not appropriate and incurs a very high cost. Other raised issues were high cost of hiring of a structural engineer, high cost of retrofit in heritage area in order to maintain the vernacular architecture.

The respondents have certain logic behind the issue of retrofitting. First of all, NRA issued a technical manual in June 2017 [28] whereas the households were declared as retrofitting beneficiaries from the early 2016. As it was issued in 2017 June there was no possibility of kicking of retrofitting during the rainy season. Engineers could not become self-confident even after receiving the training. The retrofitting is technically demanding intervention and NRA's distribution of engineers could not match with that requirement. The engineers would require technical backing which was lagging. The retrofitting cost is another stumbling block which costs around US \$ 6000 whereas the grant among is only US \$ 1000 which is not attractive enough for the beneficiaries. All these facts and figures reveal that NRA's policies and implementation practices required further improvement. Consequently, there was a huge request for changing retrofitting category to full beneficiary. Responding that demand, NRA conceded to change status so long as the beneficiaries demolish the old house and construct new adhering all NRA guidelines [33].

4.2.7. Compliance with heritage provisions

There are Seven Cultural World Heritage Sites [41]: Hanumandhoka, Patan and Bhaktapur Durbar Squares, Bouddha, Changuarayan, Swyombhu and Pashupati Nath where heritage provisions are effective. In addition, NRA has declared other six locations as heritage settlements: Bungmati, Khokana, Sankhu, Nuwakot, Gorkha and Dolakha [30]. NRA has allocated an additional grant of US \$ 500 for those buildings which comply with the provisions as mandated by Working Procedure on Heritage Settlements [31]. The provisions include 80% ground coverage by building, maximum building height of 35' and maximum four floors, setback of 1 m on the front side, façade complying with Nepali traditional architecture, traditional tiled and sloped roof including others. The households find these provisions difficult to observe. House owners intend to construct buildings taller than 35' to match with their space requirement. The most crucial issue is the sloped roof whereas the households prefer flat roofs for enjoying sunshine during the winter season, for drying agricultural outputs and clothes. The non-compliance of building code means no progress in housing reconstruction.

5. Discussions

Altogether 7 issues were discussed in the Section 4. Out of them financial and land related constraints are structural and the rest are the procedural issues. The procedural issues can be resolved with improved strategy within the given legal environment. However, the structural issues require matching socio-economic efforts.

It was revealed that urban recovery and reconstruction issues are very complex and often interlinked. There are more than 50 issues in urban reconstruction and each issue is further associated with many sub-issues which again have many reasons. Moreover, cross-cutting issues such as communication, database, gender persists across all issues. Finance, land, retrofit, heritage and government's policies and procedures are the most prominent issues in urban reconstruction as gleaned from the qualitative

survey and literature review which have slowed the urban reconstruction pace.

The findings sector shed light that the present legal and institutional frameworks do not allow resolving fundamental urban housing problems. It requires paradigm shift. For this Nepal can draw lessons from international best practices. Among them the reconstruction of 2010 Canterbury and 2011 Christchurch Earthquakes [6] and 1995 Great Hanshin Awaji and 2011 Tohoku Earthquakes [38] and 2001 Bhuj Earthquake [4] have some lessons that can be drawn for resolving Nepal's problems.

The second New Zealand model [6] of relying on insurance could be possible way out for the future. For this government needs to introduce compulsory housing insurance policy. Unlike China and New Zealand, Japan linked reconstruction with their long-term planning system which made this operation most sustainable. The Japanese Government operates with two major planning tools—redevelopment and land readjustment. The reconstruction is financed through the sale of additional floor space beyond replacing what was there before [38]. Land readjustment, which subdivides existing parcels, is a complex process involving modification of property boundaries to widen roads and to provide new open spaces and other public facilities. Under land readjustment, each landowner loses some land area, but the new infrastructure and improved accessibility add value to each parcel. These programmes use reconstruction as an opportunity for transforming settlement structure and infrastructure. It promotes high density redevelopment which results in raising additional land. Secondly the intervention takes place with joint ventures between the central and local governments [15]. Tentatively similar approach was adopted in the post-earthquake reconstruction in Bhuj India ([3]. However, it limits itself to the land readjustment and constructing house was the owner's responsibility which is sensible from planning perspective but did not address the issue of poor access to finance.

New Zealand and Japanese models address land and access to finance issues intrinsically. However, both regimes require a long-term commitment and orderly execution of a series of activities which includes introduction of new legislation for redevelopment and land readjustment. In addition, GoN will also need to devise a clear strategy for maximizing housing insurance. Resolving land dispute will require enhanced efficiency of the judiciary.

GoN also needs to build capacity on vernacular architecture by imparting traditional craftsmanship. The engineering work force also needs to be conversant on structural and architectural acumen. The indigenous entrepreneurship has to be nurtured.

Retrofitting of urban housing could be cost effective and will contribute to conserve the traditional architecture. However, it will require amendment in the building code which needs to be followed by development of retrofitting guidelines which has to be communicated to the local people as much as possible. The consultants involved in housing design need to be conversant on retrofitting which demands widening up of the capacity development by also covering the private sector in addition to the public sector.

A number of procedural reforms are required to accelerate efficiency in the urban housing sector. How to create efficient, economic and user-friendly building permit system is seriously challenging and concerning agenda. The system must be objective and easily understandable. Moreover, the reconstruction authority like NRA has to recognize fundamental difference in characteristics of urban and rural housing. More dangerously, the notion that urban housing reconstruction would be easier than rural housing has to be altered. The urban housing reconstruction deserves tailored policies with appreciation of its complexity.

Grievance handling is the issue which has some structural element but largely contains managerial characteristics. Nepal went through a turbulent political transition during the first three years after the 2015 Earthquake. All political parties wanted to use reconstruction from their political interest. The NRA's Ninth Steering Committee's decision for resurveying households which were already categorized as non-beneficiaries indicates that the decision was not purely technical. However, with some level of political will power such problems can be resolved. The limited involvement of local

government was also due to their absence at the initial stage of NRA. When they were elected, the reconstruction activity was already in the full swing. However, in the future they will undoubtedly play a catalytic role in the event of such a natural disaster. The guidelines for the single roomed building were not issued because of the assumption that the households would construct houses according to their requirements which did not turn out to be true.

6. Conclusion

This study revealed that urban issues are extremely complex and often intertwined. This study revealed that there are some structural issues which are beyond the NRA's scope and capacity to resolve. The issues of land and access to capital are in the root of the urban housing problem. It is sensible to adopt redevelopment and land readjustment approach for core urban areas particularly due to GoN's limited fiscal space for funding. The municipalities should implement the urban renewal drive through well-considered master plans. The Federal Government should subsidize the regeneration cost of heritage settlements. In addition, the multitudes of urban standards have to be streamlined and synchronized. This proposal resolves the problems related to land and finance. The procedural issues are linked with good governance. NRA's rather lackluster position in grievance handling was created by socio-political environment which was minimized and managed through NRA's pragmatic approach. The limited mobilization of local government was a result of political transition and they will be mobilized in the future. Avoiding single roomed house construction entails an effective beneficiary identification system and need to devise need-based solutions. It is revealed that NRA was not adequately prepared for the retrofitting which should be planned effectively and taken forward as an earthquake preparedness activity particularly in peri-urban areas. The heritage covenants need to be informed with beneficiary's legitimate aspirations and heritage conventions.

Declaration of Competing Interest

None.

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Regular Article

Structural condition assessment and retrofitting of Shital Niwas building (presidential palace)

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ABSTRACT

Shital Niwas, presently serving as the “Office of the President of Nepal”, is a 96-year-old palace located at Maharajgunj, Kathmandu. It is a Rana-era building mixing Malla architecture with European Palladian (also called neoclassical) style building with a central courtyard system. It suffered damage during 2015 Gorkha earthquake. The block surrounding the northern courtyard was severely damaged, so after the earthquake it was demolished. Significant part of the building that stands is still operational and accommodates critical functions, thus its seismic safety is important. Initially, damage assessment was conducted and damage grade was assigned as per EMS-98 classification. Low strength of mud mortar masonry, heavy weight of the walls and floors, presence of long unsupported walls under flexible diaphragms, high ratio of openings, and absence of earthquake-resistant features are some of the seismic deficiencies of present building. To reduce seismic risk, existing materials were characterized, the present performance of the building was evaluated and deficiencies were identified. Based on the deficiencies, different intervention options were investigated, and finally retrofitting with steel plates and carbon fiber reinforced polymer (CFRP) bands were selected after detailed analysis and design.

1. Introduction

Shital Niwas Palace [1] is located at Maharajgunj in Kathmandu. It was commissioned to be built by the then Prime Minister Chandra Shumsher Rana in 1924 CE. The building has served various purposes in its occupancy history – as a private residence, a state guest-house, the Ministry of Foreign Affairs, and currently the office of the President of Nepal. The building is three-storied and square-shaped in plan with a central courtyard for religious and ceremonial purposes (Fig. 2). It combines Malla architecture with European Palladian (neoclassical) style. The walls in the load-bearing masonry structure are 20 in. to 30 in. thick and made of brick with mud and lime-surkhi mortar (a slurry made of lime and crushed burnt bricks).

The building survived the 1934 CE Nepal-Bihar earthquake [2], even with severe damage to the eastern and southern blocks, and the 2015 Gorkha earthquake of Nepal [3] with some localized damages only on the western side. Photographs taken in the aftermath of the great 1934 earthquake by Brahma Shumsher [2], retrieved from the National Archive of Nepal, suggest that the damage prompted major rehabilitation of the Shital Niwas. Subsequent occupants made significant structural as well as architectural changes to the building, as is evident from the eastside facade (see Figs. 1 & 3).

Furthermore, the damage caused to the western part of the building in the 2015 Gorkha Earthquake, led to the demolishing of a two-storey block (Ranigunj) located on the north-west side of the present palace. All these changes have resulted in the present structural plan of Shital Niwas shown in Fig. 2.

2. Objectives

The main aim of this work is to characterize Shital Niwas in its present form (in pre-earthquake condition), and assess the seismic vulnerability of the building. To mitigate any future seismic risk, carry-out a detailed design of suitable intervention options. The major challenge herein is the archeological constraint in use of construction materials utilized previously. Another challenge is that the building's seismic performance should be upgraded such that it would be capable to serve as the office of the head of the state.

3. Characterization of the building and structural condition

Shital Niwas is a three-storeied masonry structure having archeological importance. It is located in plain terrain (slope < 3°) with ground coverage of 4507 square meters. It is approximately square-shaped in

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Fig. 1. East elevation.

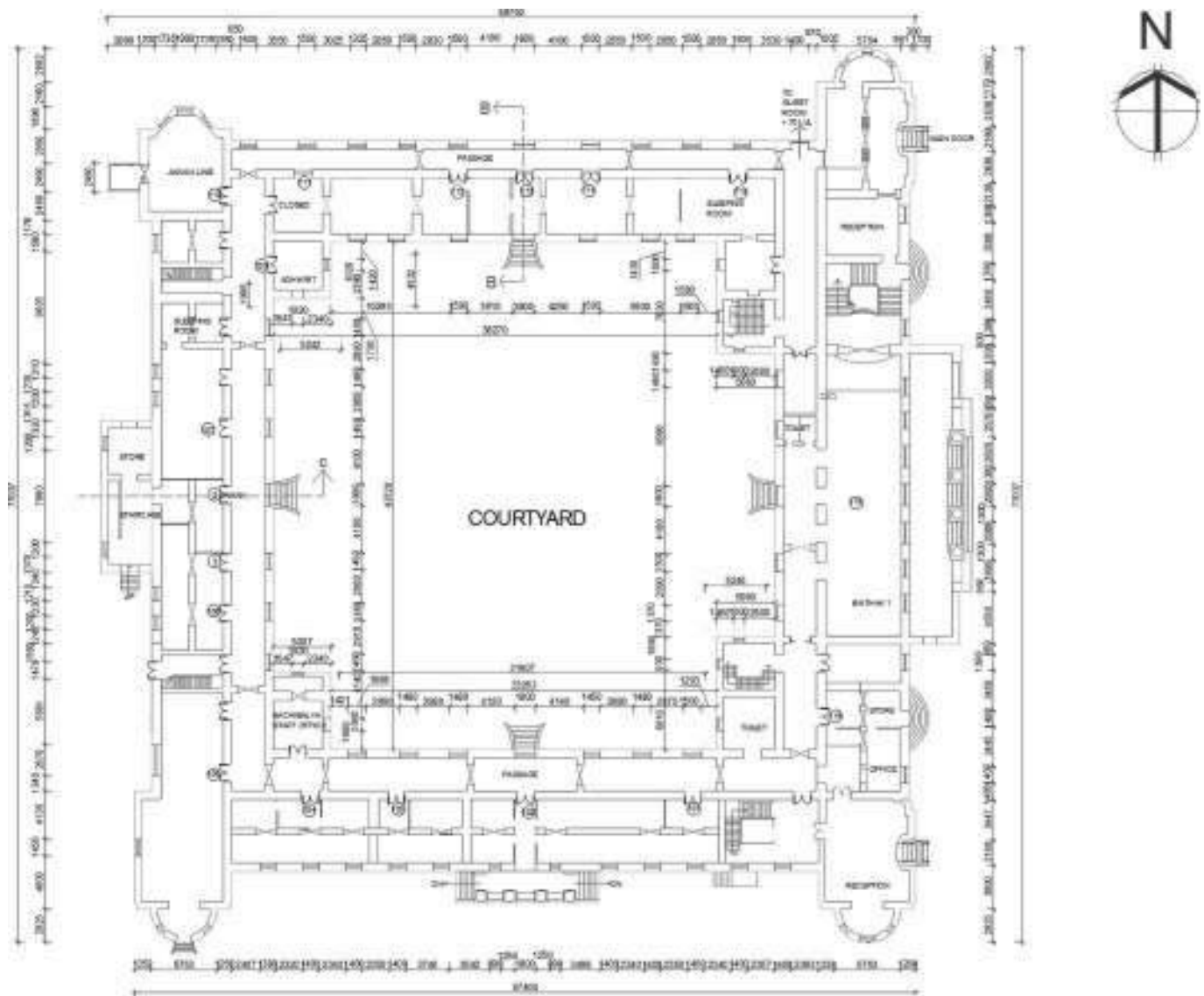


Fig. 2. Ground Floor Plan.



Fig. 3. East elevation of Shital Niwas before 1934 CE Earthquake (Source: Nepal Archives, DOA).

plan (74 m $\times$ 77 m) with an open central courtyard (43 m $\times$ 43 m), and is almost regular along the height. It has thick brick masonry walls which add large inertial mass to the building structure. However, the wall thickness reduces gradually at floor girders (timber and steel I-sections) resting levels. After the 1934 earthquake, the damaged eastern and southern wings were renovated using lime-surkhi mortar, whereas north and west wings remained in original mud-mortar. Outside plaster is in lime-surkhi mortar, while, inside plaster is in the mud mixed with rice husk. Thus, a major portion of the building was constructed with traditional locally available materials with the use of some imported rolled steel sections. In recent times, some rooms are internally divided using timber and aluminum partitions, a RCC staircase and lifts have been added. These construction activities have added to the original mass of Shital Niwas. These observations provided the insight into the probable seismic performance of the building and helped to identify structural deficiencies.

3.1. Structural details

In Shital Niwas, load-bearing masonry walls transfer the gravity and seismic load occurring in the structural system. Timber/steel I-beam girders transfer loads from the floor to the walls. As shown in Figs. 6 and 7 below, the floors act as flexible diaphragm, while the reinforced concrete (RC) slab, supported over steel beams at some locations, act as rigid diaphragm.

3.1.1. Masonry units/masonry joint/mortar types/masonry wall

Bricks used in the building are characterized by the visual observations and images are presented in Fig. 4a & b. These bricks are laid out properly to form English bond - with alternating header and stretcher courses (Fig. 4c). The thickness of wall reduced gradually in storeys above. The

ground storey walls, on which girders rest, are 750 mm thick. The thickness of walls having a solid core reduces gradually in the successive storeys above. Wall thickness reduces to 640 mm in the first storey, 530 mm in the second storey and 500 mm in the third storey. The mortar joints of the north and west wings are made with 10 mm thick mud mortar, while those of east and south wings and all arches are made with lime-surkhi mortar. Similarly, the 20–25 mm thick outside plaster for the walls uses lime-surkhi (Bajra) mortar, while the inside plaster uses mud mixed rice husk.

3.1.2. Floor details

Three types of flooring systems are found in Shital Niwas: a) Timber joists supported by steel I-beam girders resting directly on the walls. The gap between timber joists is bridged by burnt clay bricks. (b) Masonry jack arches supported on steel I-beams resting directly on the walls. This system is used mostly in balconies, corridors, entrance porch, and in few rooms of the west block (Figs. 5–7). (c) RCC slab supported on steel I-beams on the first floor of the south and east block halls (Figs. 6 & 7). Most of the pinewood girders and joists are in a rotten state, mostly due to moisture penetration via seepage at the support area. Most of the rolled steel sections, however, are in good condition.

The existing flooring is relatively heavy as compared to modern flooring. Mud filling above flat bricks, bridging the timber joists, is up to 150 mm thick (Figs. 5 & 6) while the mud filling above jack arches varied between 150 mm and 300 mm. Floor covering is either normal bricks/*telia* tiles or stone blocks/*slates* (mostly in corridors).

3.1.3. Roofing system

Pinewood rafters/joists and battens, with corrugated galvanized iron (CGI) cover at a slope of about five degree and RCC slabs over penthouses,

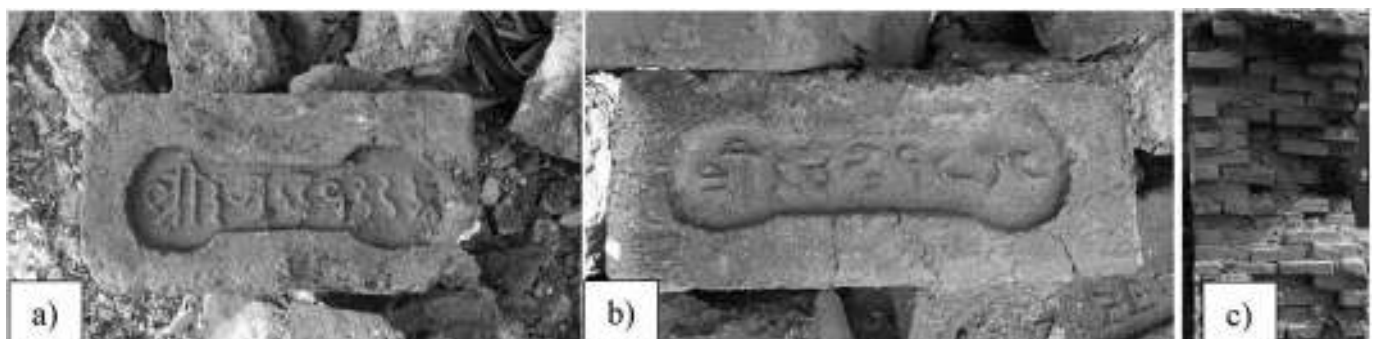


Fig. 4. a) & b) Brick samples extracted from load bearing walls c) Brick laying pattern in load bearing walls using English bond.



Fig. 5. a) Timber floor above steel I-section girder b) Jack-arch floor supported in steel I-section beams above corridor c) Brick and mud layer in the floor above joists.



Fig. 6. Floor details in the building.

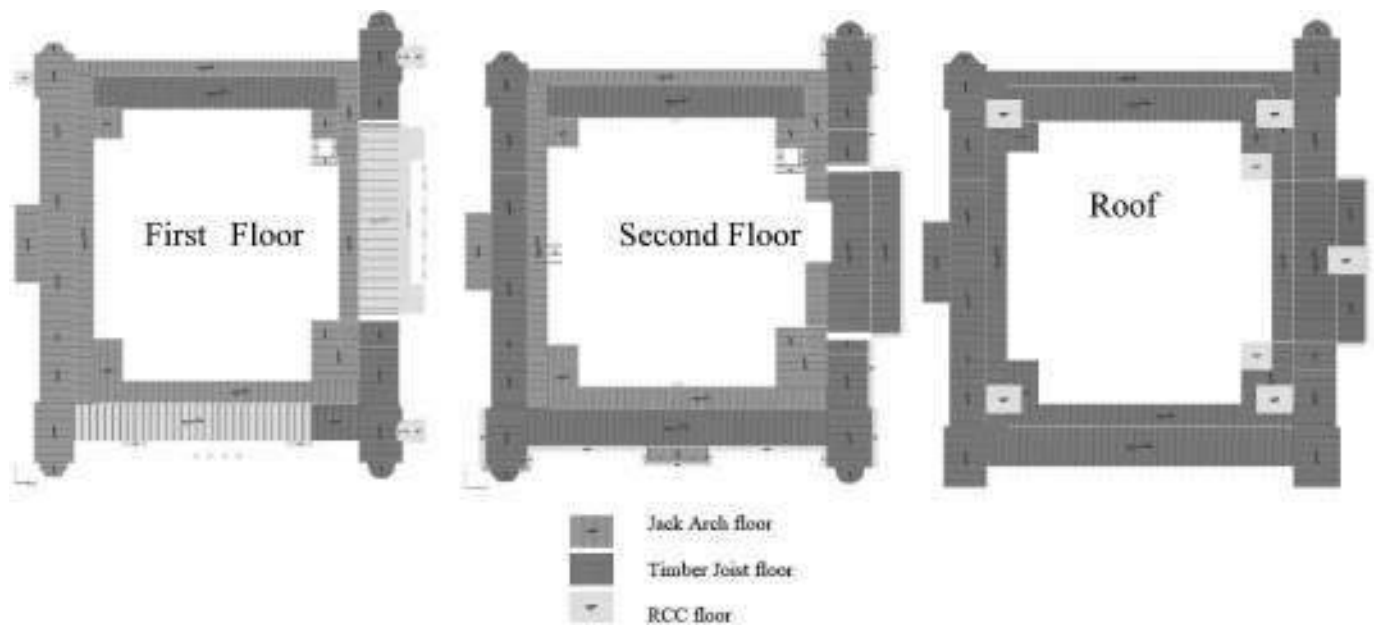


Fig. 7. Different floor systems in the building, both flexible and rigid type.



Fig. 8. Roofing Details: a) Purlins and rafters b) False ceiling, battens and CGI sheet from bottom c) CGI sheet from top.

are used (Fig. 8). The roofing system was assessed to evaluate the damaged rafters and CGI sheet for replacement.

3.1.4. Decorative ceiling and its condition

Two major halls of the building were decorated using artistic carvings and ceilings. These are well maintained and found in good condition (Fig. 9: a & b). Sal wood (*Shorea robusta*) is used for doors and window frames, while shutters are made of sal-or pine-wood. The Eastern wing consists of decorative cornices/columns/windows and other portraits, which needs to be preserved to save the cultural and heritage value of Shital Niwas.

3.1.5. Foundation in the building

Foundation inspection was carried out by excavating pits. It was found that the depth and dimensions of the continuous spread wall footing foundation was sufficient (2.45 m below ground and 1.85 m width), it was intact, and in a good condition (Fig. 10). The adequacy of the foundation is checked against the safe bearing capacity of the founding soil. As per the geotechnical investigation report, the safe bearing capacity for the level and width of the existing foundation is about 230 kPa. And from analysis, the maximum bearing stress under foundation, including seismic load combination, is found to be 201 kPa. To prevent the capillary rise of ground water, the ground floor is suspended over arches forming air tunnels (*hawas*) up to 1 m high. These air tunnels run along the middle of corridors and rooms. They are interconnected at junctions. Floor load on the arch top, via compressive action, is being transferred to the tunnel sidewalls from where it is directly transmitted to the tunnel foundation and the soil beneath.

3.1.6. Load path

It is established that the building with a regular load path performs well during earthquakes [4,5]. So the load path of the Shital Niwas was assessed carefully. Results indicate a regular load flow path exists in most portions of the building. It is disturbed, however, at the east facade's decorative columns, where the load from the floor and the masonry wall of the second storey are transferred via beams to the columns (Fig. 11). The load from the column is transferred to the wall beneath and on to the spread wall footing.

Also, there are a few places where cross walls are erected on the first floor or only on second floor. Such load path discontinuity can cause damage concentration in second and third storeys above these columns and walls (Fig. 13).

4. Structural condition assessment

4.1. Overview of damage assessment

Local causes of damage are due to material degradation with time, inadequate regular maintenance of the palace which aggravated local damages during the 2015 Gorkha earthquake. These damages are classified based on causes of damage as masonry shear (M-S), bed joint in-plane – /out-of-plane sliding (M-B), crack in arches (M-A), corner separation (M-C), crushing of units (M-U), shear cracks in floor (FS) and ceiling damage and each one is subdivided based on crack width, i.e., less than 0.5 mm (1), 0.5 mm to 5 mm (2) and larger than 5 mm (3). For example, M1-S refers to masonry shear crack up to 0.5 mm, M3-A refers to masonry arch crack greater than 5 mm and so on. This helps to decide whether cosmetic repair or restoration via grouting or local demolition and reconstruction is needed. After the Gorkha earthquake, shear cracks were observed extensively in the cross-walls of north block. The reasons are due to the large openings in ground floor cross-walls and very little – /no openings in first and second floors cross-walls and low shear strength of mud mortar joints in the walls. The south block of the building has the least damage followed by the west and east blocks. The main reason for less damage in south and east blocks is the use of strong lime-surkhi mortar to join masonry units. One reason for less damage in the west block is higher redundancy due to four lines of masonry walls as compared to the north block, where three masonry grids exist. Additionally, cross walls on the second floor of the west block were found to be laid in lime-surkhi mortar while those in the north block are in mud mortar. Fig. 12a is the plan of the north block, where floor separation from the north face is indicated (Fig. 12b). The north face outer wall is supported only at the ends making it vulnerable to out-of-plane bending.

Fig. 12c shows the diagonal crack propagation from the cross-wall corner whereas Fig. 12d shows the north side shifting of roof wall plate under

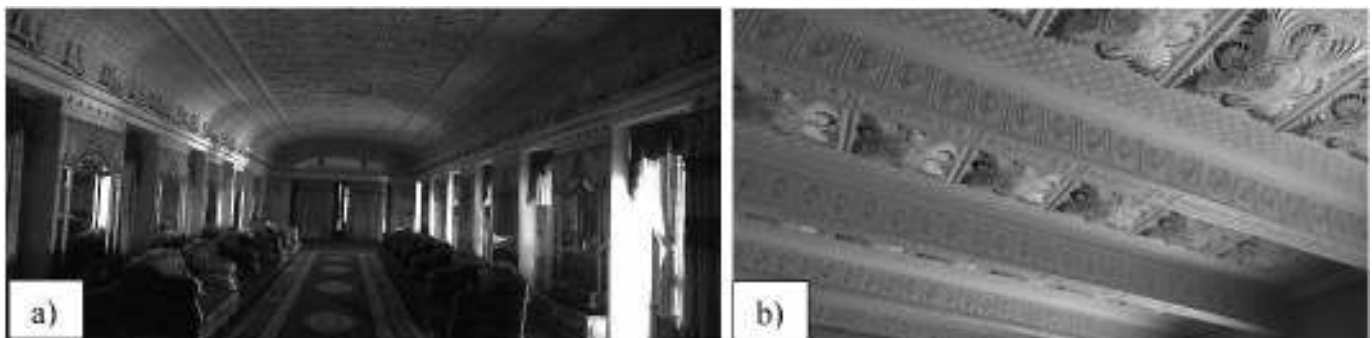


Fig. 9. a) Decorated hall at the first floor of east wing. b) Decorated ceiling.

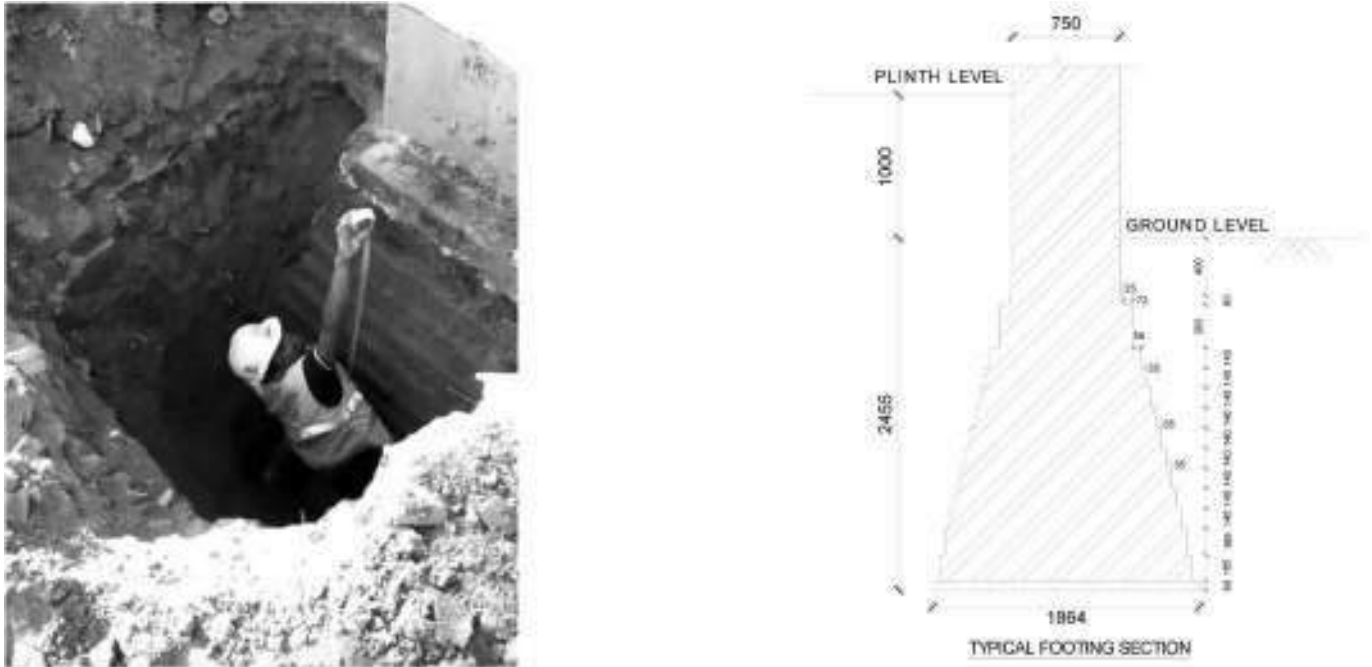


Fig. 10. a) Foundation excavation for inspection b) Typical cross-section of wall spread footing foundation.

rafters at central portion of the north block. Fig. 12e indicates the corner separation of cross-wall along mud mortar joint.

Thus, most of the damage is concentrated in the north/west wings and the second storey of the east wing, where load path discontinuity is observed.

Although, all arches were constructed using lime-surkhi mortar, during the 2015 Gorkha earthquake, most of the arches were damaged, some arches in the north corridor of the third floor were severely damaged and collapsed (see Fig. 15). In masonry arches, support movement during an earthquake is the major reason for damage. Outward support movement tends to flatten the arch causing tension in the bottom face, which leads to the formation of crack. Similarly, the RC floor, over steel I-beams, exists in two halls on the first floor, restrooms and a small roof of penthouses. The RC floor holding the steel girder maintains in-plane stiffness that results in proper distribution of lateral forces on the supporting walls. In flexible timber floors, in-plane stiffness is not sufficient to distribute forces on supporting walls in proportion to their stiffness (which correlates to strength), causing more damage in some walls.

4.2. Qualitative assessment

It was conducted based on Tier-1 of FEMA-310 [6] and the Department of Urban Development and Building Construction's guideline (DUDBC) [7]. Plain terrain, firm ground, low ground water table help to maintain stability during earthquake shaking. So, most of the geological parameters comply. However, Maharajjung falls under a moderate liquefaction potential zone as per the study carried by Japan International Cooperation Agency (JICA) [8]. The building is almost square in geometry. Still, projections at the corners of north-south directions and east-west facades made it vulnerable at those places (see Fig. 14). The building has long unsupported walls at outer facade, corridors and halls. It has 3.8 m storey heights except for east side main halls in the ground and first storeys, where floor is raised 1.4 m above of normal floor level. Long walls are assessed for slenderness ratios (wall length, ℓ to thickness, t). The slenderness ratio of unsupported walls is found within acceptable limits ($\ell/t < 12$), except east hall [12]. Vertical steel posts shall be added as buttress inside the hall situated in the east block to maintained the slenderness ratio limits of the unsupported

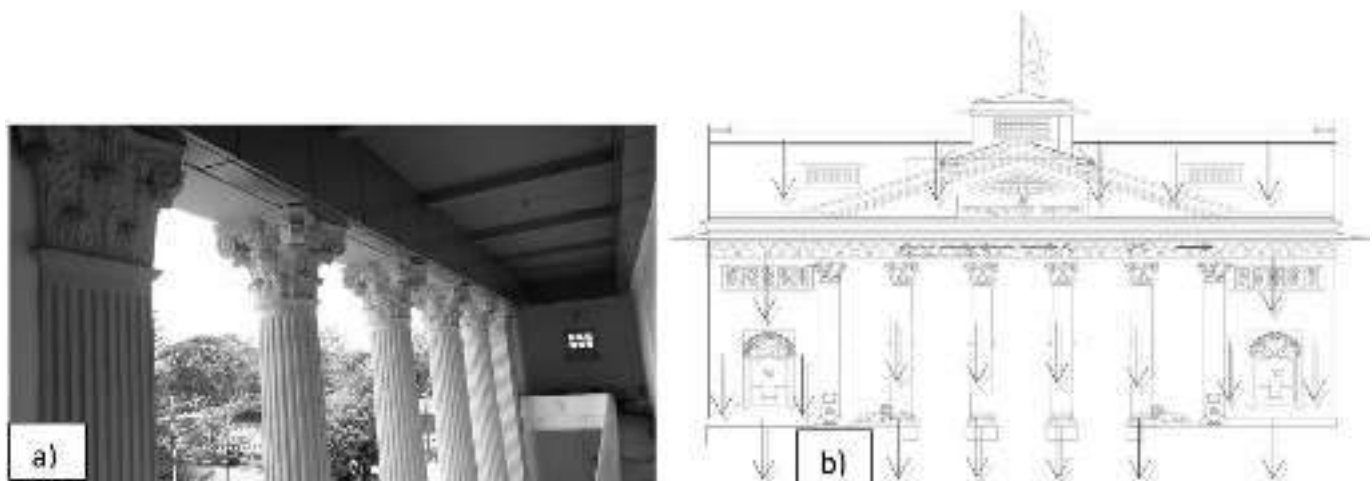


Fig. 11. a) Load path disturbance above decorative columns of east facade. b) Arrows show the load flow path from wall to columns and to wall spread foundation.

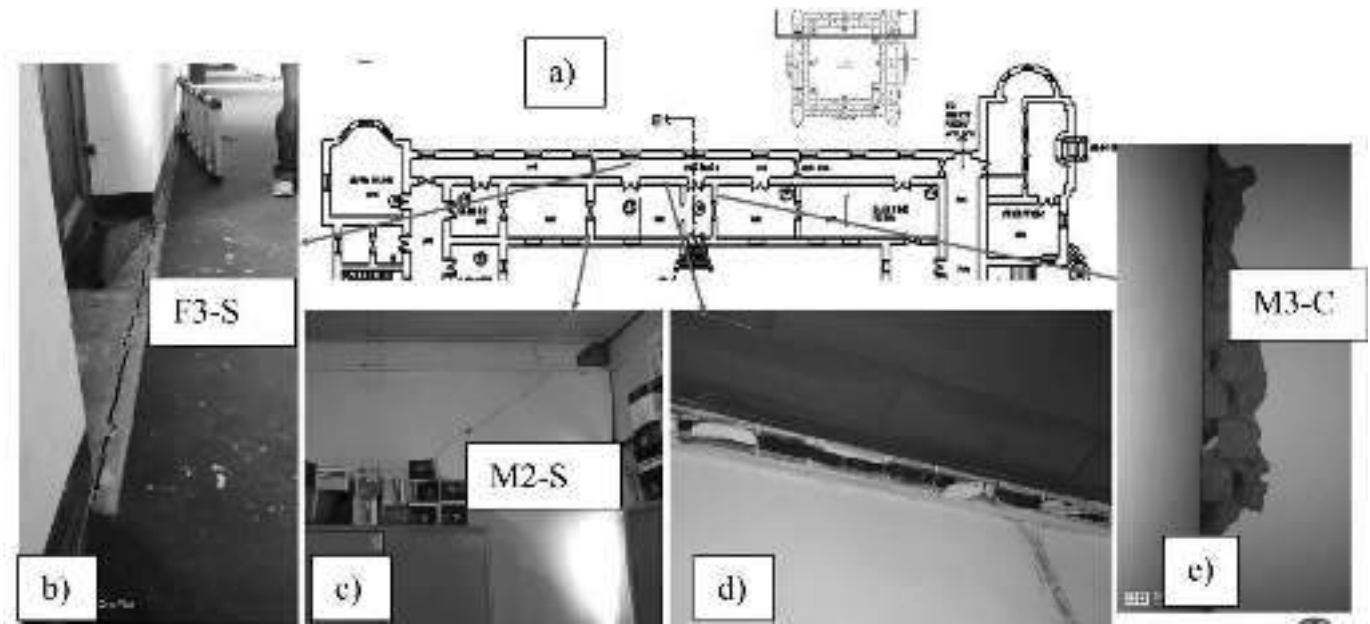


Fig. 12. a) Local damage locations at first storey of North Block in plan. Red arrows show the view of damage b) Floor separation c) Shear cracks at wall d) Corner separation at junction of cross-wall. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

wall. Masonry columns at the east facade are slender since they span over the double storey and transfer load from the floor (Fig. 12). Palace is located on the firm ground since the safe bearing capacity assessed at the level of the present foundation is found to be 230 kPa through geotechnical investigation around the site. A low ground water table (>18 m) also helps

to maintain stability during earthquake shaking. Most of the geological parameters comply. Wall core, thickness, height, the position of openings, vertical discontinuities, masonry units' quality, and unit layup comply. However, earthquake load resisting features such as unsupported wall length, size of openings in the wall, provision of vertical – /horizontal-

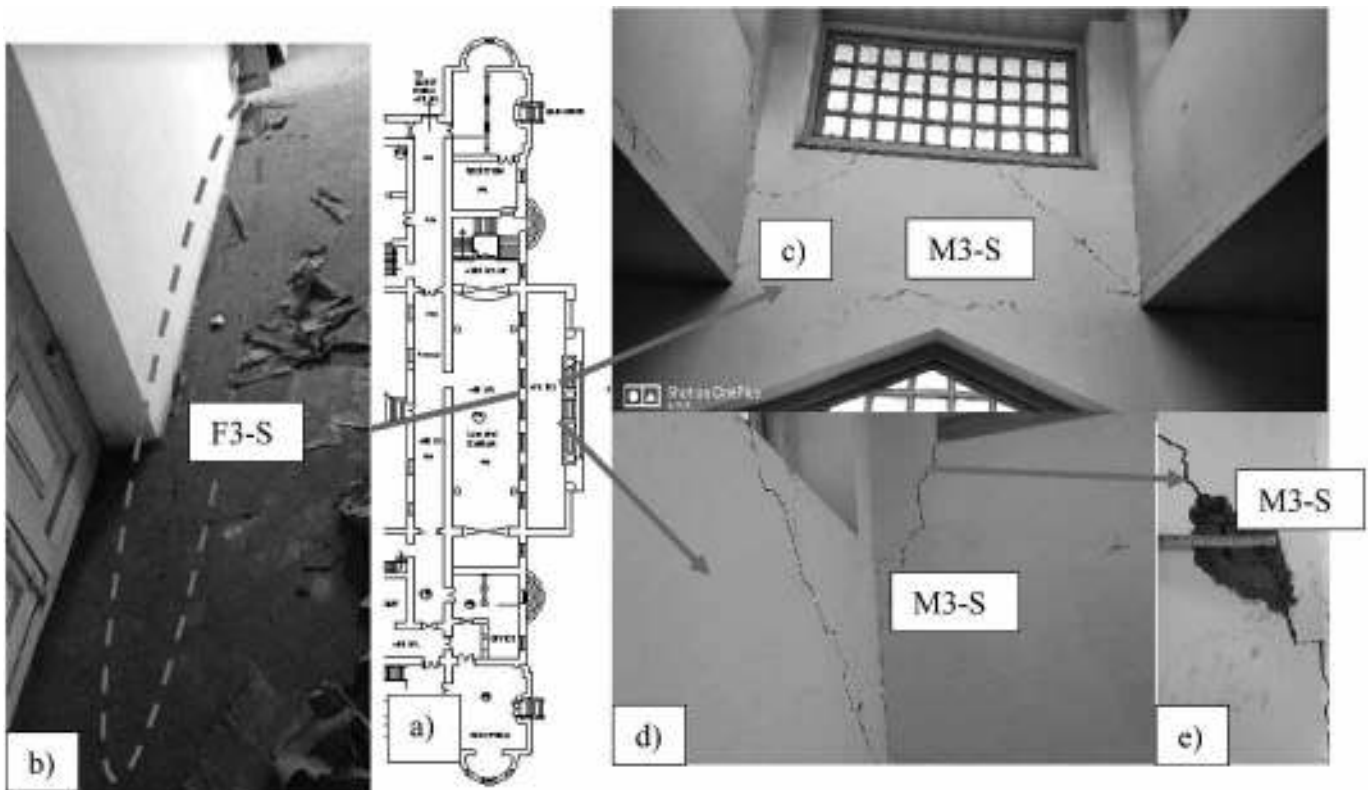


Fig. 13. a) Plan Location of Local Damage at Second Storey (East Block). Red Arrows show the Views of Damage b) Floor separation at second storey c) Diagonal shear cracks at outer wall of east facade d, e) Diagonal shear cracks at the corner of second storey cross and outer walls. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

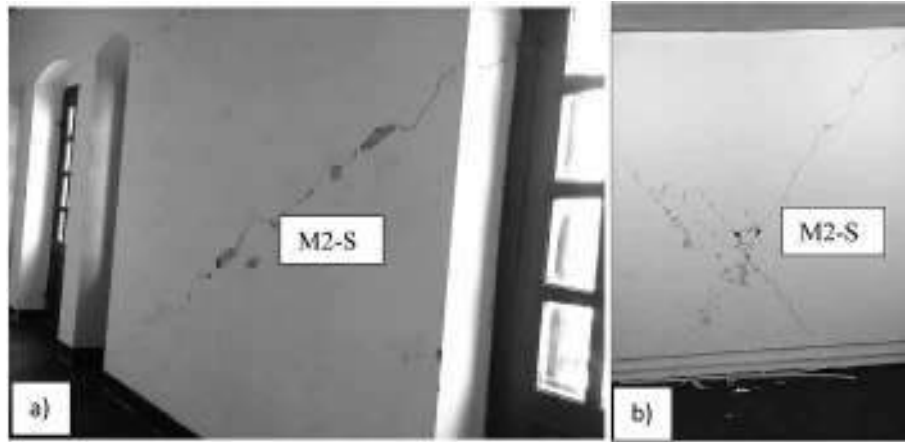


Fig. 14. a) Diagonal shear cracks at first storey central long wall and b) at cross wall of north block.

bands, vertical reinforcements at corners, T-junctions, corner stitches, diagonal bracings at floors do not comply. It has a flexible floor system using different materials without any bracings. These irregularities led to the major structural and non-structural damages in the building during the 2015 Gorkha earthquake.

The building was surveyed and each of the compliant and non-compliant aspects were noted carefully. Summary of qualitative assessment are listed in Table 1.

4.2.1. Damage grading of the building

It is difficult to assign a single damage grade to the building due to the difference in construction materials, style, and damage patterns. The north block has significantly higher damage compared to other blocks. As per the European Macro-Seismic Scale (EMS)-98 the following damages were observed. i) Structural Damage: In the north block, one arch had collapsed and several arch openings had cracks greater than 5 mm. Few walls had cracks larger than 5 mm and several had cracks in the range of 0.5 mm to 5 mm. North façade corridor walls were out of plumb in out-of-plane direction by up to 0.8%. Corner separation was observed at few junctions. Hence, the damage in the north block is judged as “Grade 3, Substantial” on the EMS scale. ii) Non-Structural Damage: In the north block, plaster has spalled off at several places in the ground storey, floor mud plaster cracked at several places. Plaster at the ceiling cracked and fell down at some places on the second floor. Thus, damage of non-structural components is also judge as “Grade 2, Moderate”. Overall, the damage is categorized as “Grade 3, i.e., Substantial Damage” for the north block and second storey of the east block, whereas “Grade 2, i.e., Moderate Damage” for the remaining parts of the building. These

Table 1

Summary of Vulnerability Checklist (DUDBC) [7] for Shital Niwas.

S.N.	Compliant (C)	Not compliant (NC)	Not applicable (NA)
1	Foundation	Shape	Through stones
2	Sloping ground	Proportion in plan	Torsion
3	Wall core	Storey height	
4	Wall thickness	Number of storeys	
5	Height of walls	Plumb-line	
6	Position of openings	Unsupported wall length	
7	Load path	Openings in wall	
8	Vertical discontinuities	Wall cracks	
9	Mass	Vertical reinforcement	
10	Masonry units	Horizontal bands	
11	Masonry layup	Corner stitch	
12	Redundancy	Gable band	
13	Area history	Diagonal bracings	
14	Slope failure	Lateral restrainers	
15		Liquefaction	

judgements made based on field observations also match with the damage grade assigned in the Seismic Vulnerability Evaluation Guideline for Private and Public Buildings [7]. During the 2015 Gorkha Earthquake, the peak ground acceleration (PGA) in Kathmandu was recorded between 0.16 g and 0.22 g [9]. The expected damage grade for the general Brick in Mud typology building with the average condition is damage grade-3 (DG3) as seen in the north block. The expected damage grade for the same typology with the good condition is damage grade-2 (DG2) as seen in other blocks of the building [7].

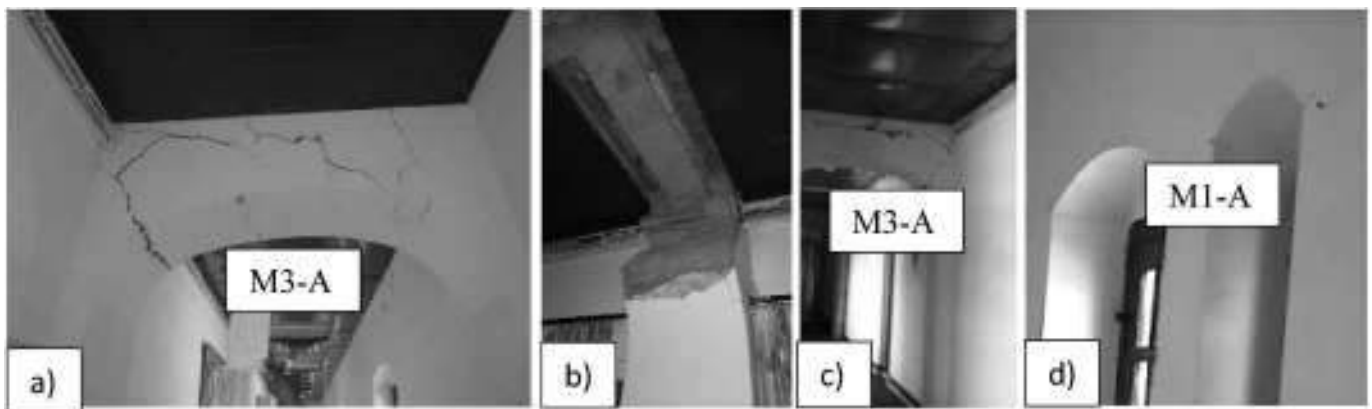


Fig. 15. a) Damaged arch at north side- b) Collapsed arch at north side- c) Damaged arch at north side of third floor d) Cracks at arch support at north side of second floor of the Shital Niwas during the 2015 Gorkha earthquake.

Table 2
Permissible Shear Strength in walls with Different Mortar Types.

S.N.	Type of Mortar	Shear Strength (MPa)		Remarks
		Average (V_{me})	Design (V_d)	
1	Mud	0.206 (CoV = 30%)	0.138	From in-situ shove test
2	Lime-surkhi	0.390 (CoV = 38%)	0.261	From in-situ shove test

Since the building was constructed before the inception of national building codes and building by-laws, no seismic consideration was made in its design and construction, as per codal provisions, the building is vulnerable to moderate to strong earthquakes. Hence, restoration of the damaged components, combined with structural intervention works to enhance the seismic performance, will help in preserving historical monuments from future strong earthquakes.

4.3. Quantitative assessment

As mentioned in sections 4.1 and 4.2 above, the building has several deficiencies at present (Table 2) and is unsafe for the seismic hazard level of the site. The major non-compliance issues (like absence of seismic force resisting elements, absence of bracings in the flexible diaphragm, long unsupported walls along corridors, and large openings) should be addressed in the retrofit design. Hence, a detailed assessment was carried out to judge the best possible intervention option and its intensity to overcome the identified seismic vulnerabilities in the building.

4.3.1. Mechanical properties of materials

To evaluate the capacity of structural elements, material strength is very important. For this, the material strength of brick and mud mortar was determined via lab tests and non-destructive tests as push-shear, double flat-jack and timber resistograph tests were conducted as per standard procedure mentioned on ASCE 41–13 [10], FEMA-274 [11], FEMA-310 [6] following the ASTM guidelines. Sixteen brick samples from different locations were extracted from the exterior wyth of walls and carried to a lab. Frogs were filled with 1:3 cement-sand mortar to provide smooth surface for load application as mentioned in the standards. Bricks were taken from outer wyths of the wall, which are exposed to outer environmental effects, in the interior parts bricks may be in good condition. Brick samples were cured and tested. The compressive strength of units ranges 5.83 MPa to 9.45 MPa yielding an average value of 7.67 MPa. The values obtained are not relatively good as per the codal requirements. Joint mortar from existing walls is collected from locations close to shear test locations at four places. Mud mortar indexing test showed that it composed of 5% gravel, 46% sand, 43% silt and 6% clay with 42.5%, 19.39% & 23.11%, respectively, liquid limit, plastic limit & plasticity index. An in-situ shove test was conducted at 16 locations covering all blocks and storeys (Fig. 16a). The average and design shear strengths of masonry in mud and lime-

surkhi mortar are reported in Table 2. Vulnerability analysis was conducted based on the average shear strength of masonry, whereas retrofit design was carried out based on design shear strength values.

Sophisticated, in-situ, flat jack test was conducted at six locations (Figs. 16: b & c) each in mud and lime-surkhi mortar covering all blocks and storeys. The average ultimate compressive strengths and modulus of elasticity of masonry evaluated in mud and lime-surkhi mortars are given in Table 3. As expected, ultimate compressive strength and modulus of elasticity of masonry in mud mortar are significantly lower than in lime-surkhi-mortar (Fig. 17: a & b). Flat jack test results are plotted in Fig. 17: a & b, respectively, for mud- and lime-surkhi mortars. Different colors in these figures indicate the tests results at different locations of the building.

Compressive strength results are in agreement with values obtained from empirical relations provided by masonry design codes of India [12] and Eurocode [13]. Empirical relations are based on the compressive strength of bricks and joint mortar, which was obtained from a lab test of brick samples and in-situ penetrometer test of joint mortar, respectively. The values of Table 3 are in close agreement with the results of similar tests conducted by Soveja, Olteanu [14] and Boschi, Galeno [15].

The internal condition of timber beams, joists, roof rafters, door/window frames was assessed using resistograph tests at 24 locations. Timber decay test was conducted using a sounding hammer at more than 1000 members. Floor girders, joists, balcony posts, stairs and door/window frames were tested using resistograph coupled with a sounding test with a wooden mallet. Resistograph test helped to differentiate between good and deteriorated timber components in the building [16] and accordingly replacement decision was made. Measurement of moisture content is an important step to ensure the durability of timber structures since the presence of excess moisture accelerates the timber decay rate. However, such test has not been carried out in this structure yet, due to logistic difficulties. Modulus of elasticity and density of timber were referred from “Design of Structural Timber for Building” [17], which provides a “design value” based on the species classification of wood.

4.3.2. FEM modeling

A three-dimensional model of Shital Niwas was prepared using ETABS 2016 software v16.2, as shown in Fig. 18, assuming homogenized wall material. Structural masonry walls were modeled using thick shell elements (isoparametric 4 noded and 3-noded area elements) hinged at the plinth level. Two noded frame elements were used to model floor girders, joists and bottom chords of the roof truss. Floors and roofs are modeled as girders or rafters on which a one-way-load-distributing membrane elements for the floor is overlaid.

Masonry is a non-linear material. To evaluate its real behavior, non-linear dynamic analysis could be performed, which demands high-capacity computing facilities. Nevertheless, increasing number of commercial packages based on macro-element approaches have been used recently to carry out pushover analysis of large masonry buildings with relative ease

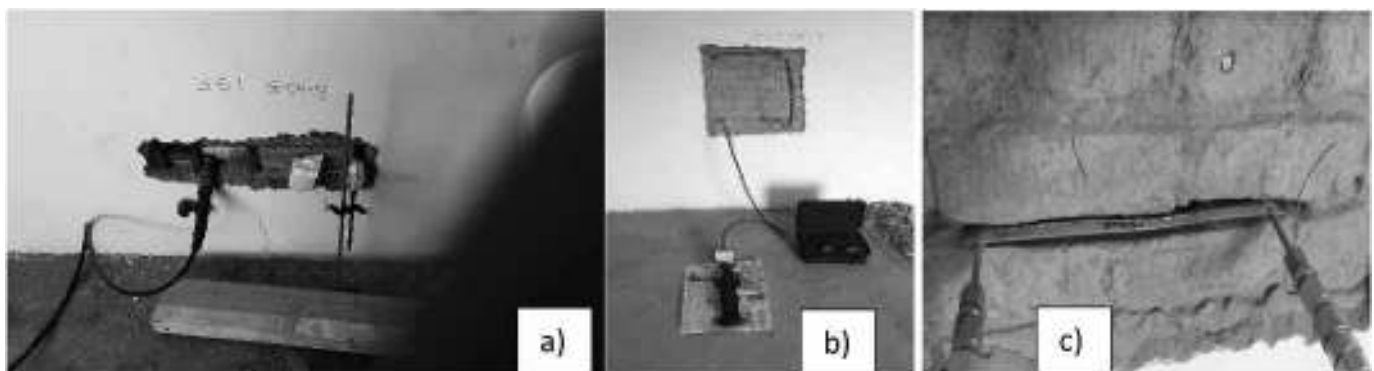


Fig. 16. a) Shove Test of Brick Masonry b, c) Double Flat Jack Test to Evaluate Masonry Strength.

Table 3

Ultimate Masonry Strength with different mortar types using Double Flat Jack Test.

Type of Mortar	Modulus of Elasticity E_m (MPa)	Ultimate Compressive Strength of Masonry f_m (MPa)	Remarks
Mud	542	0.96 (CoV = 22%)	From In-situ Double Flat Jack Test
Lime-surkhi	1358	2.65 (CoV = 15%)	From In-situ Double Flat Jack Test

[14]. Also, international codes such as NZSEE (New Zealand) and NPR9998 (The Netherlands) suggest a simplified version of the pushover (Simplified Lateral Mechanism Analysis - SLAMA) that can be performed via simple spreadsheets. This work however, uses simplified macro-modeling technique for masonry wall modeling. Mechanical properties of materials based on tests as discussed above and listed in Tables 2–4 were used for the modeling.

Materials and masonry strength used are found comparable with the previous studies carried on such palaces. Most of the deficiencies from vulnerability analysis in the structural elements found similar as mentioned in [18].

The analysis was conducted based on the requirements of the Nepal National Building Code (NBC) [19]. Dead Loads were calculated based on geometries and unit weights of materials provided in IS [20]. Dead loads of load-bearing masonry walls were calculated directly within the FEM model, while a dead load of roofing and flooring were averaged uniformly over an area, calculated from details as 4.35 kN/m^2 for floor with timber

girder/joists, 6 kN/m^2 for jack arch floor and 0.97 kN/m^2 for CGI sheet roofing over timber battens/rafter. Live loads on rooms, halls and corridors, roof considered are 3 kN/m^2 , 4 kN/m^2 and 1.5 kN/m^2 , respectively, as per IS [20], and were assigned as area loads on the membrane element of the FEM model.

The design acceleration response spectra along with other considerations for building site and structural characteristics were used to derive the base shear coefficient (C_d) as prescribed in NBC [19]; it was calculated as 0.48. Soil boreholes logs test results at different locations of the site yielded the average SPT value of 15. The foundation soil is classified as type II [19] and for a low period of the building ($T = 0.14 \text{ s}$), the basic seismic coefficient, $C(T_i) = 0.08$. Here, the seismic zone factor (Z) = 1 for Kathmandu, importance factor (I) = 1.5 for important building as it is the office of the Head of State and structural performance factor (K) = 4 for unreinforced masonry are used. Earthquake loads were distributed linearly over the height as prescribed in NBC [19]. For lateral load analysis, masses are not lumped at floor levels but distributed along with the nodes

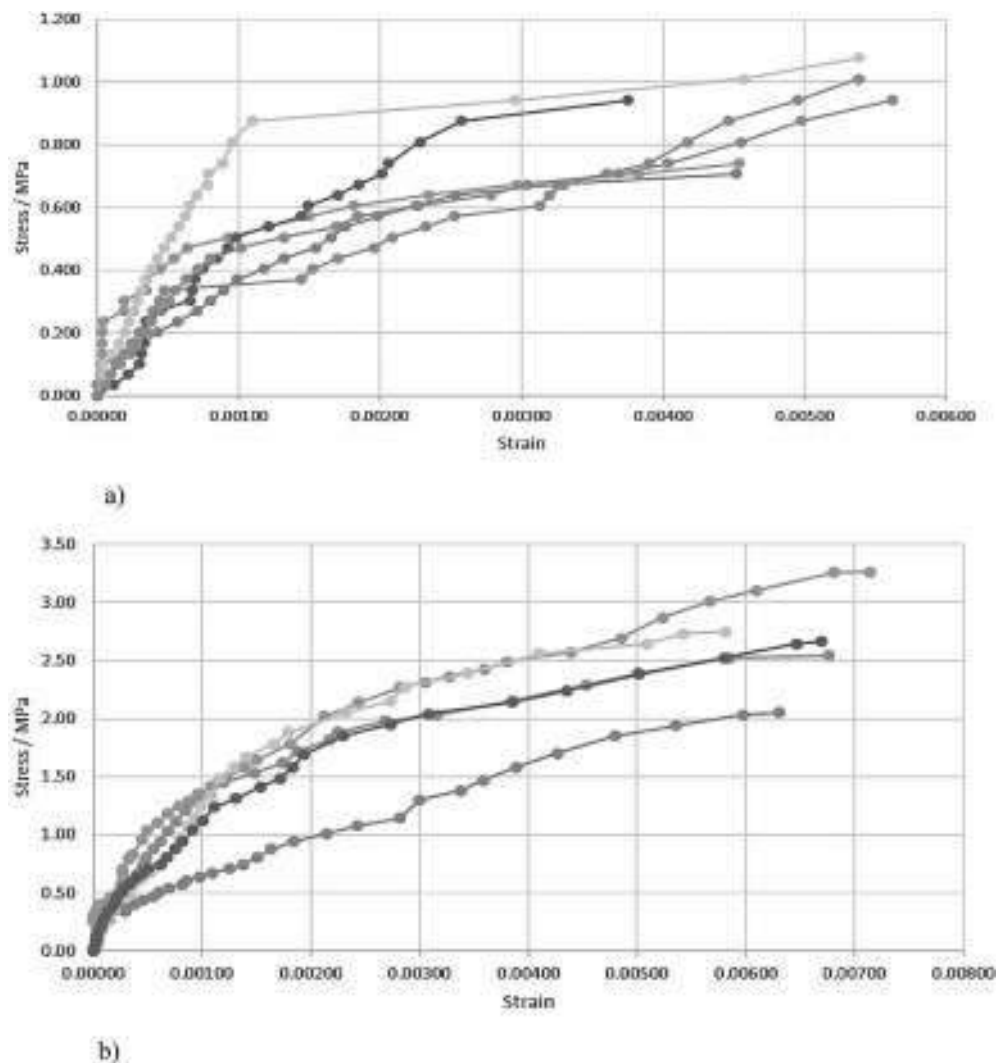


Fig. 17. a) Stress vs strain curve in mud mortar. b) Stress vs strain curve in lime-surkhi mortar.

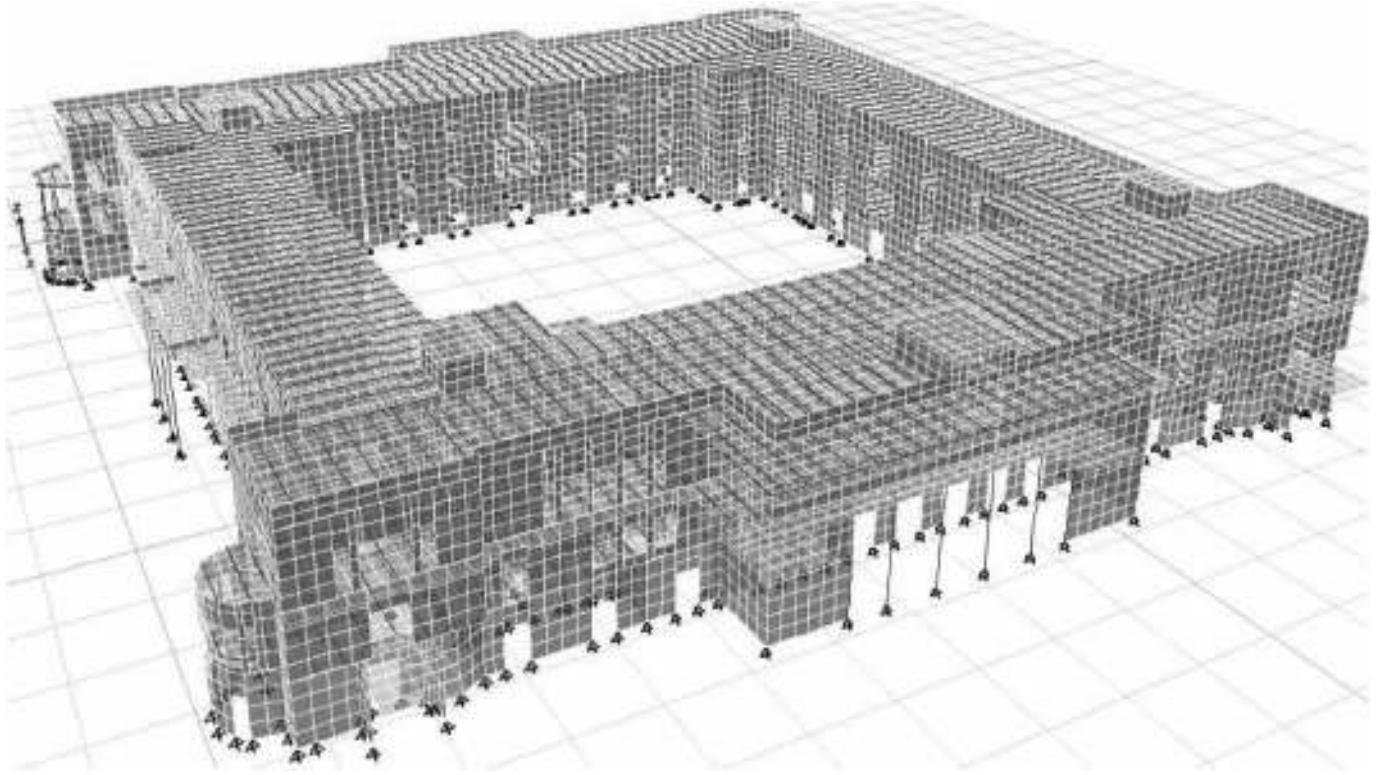


Fig. 18. Three Dimensional (3-D) Finite Element Model of Shital Niwas in ETABS 2016.

of wall shell elements, considering the heavy mass of walls as compared to floors. Linear dynamic analysis using response spectrum was carried out as per NBC [19] in ETABS. Mass participation of more than 90% was ensured by considering an appropriate number of modes.

Compressive stress in masonry was verified via simple stress calculations. Average compressive stress capacities evaluated in mud and lime-surkhi mortars were found to be higher than the average compressive stress demand, whereas in-plane shear capacity in mud masonry (evaluated as per ASCE 41–13 [10], FEMA-274 [11]) found insufficient to meet the demand. However, in-plane shear capacity in lime-surkhi masonry is sufficient to cope the demand [19]. The chance of global rocking is negligible due to the large plan area; however, the rocking of individual wall induced tension and compression in those piers are checked in detail analysis.

Structural plan density of the building (ratio of the area of vertical structural components to the whole plan area of the building structure) is equal to 20% as compared to modern buildings with only 2 to 5% even in high seismic zones. Thus, one may think that a building with such thick walls as Shital Niwas would be safe under earthquake, but it is not the case with walls in mud mortar due to: a) thick walls resulting in heavy weight that attract higher seismic forces, b) very low shear resistance of mud mortar masonry and, c) low ductility of the structure resulting higher base shear coefficient (0.48). Hence, simplified checks indicate that the detail check on shear strengthening should be carried out globally and component-wise. In addition, detailed tension-compression checks need to carry out component-wise. Stresses in individual wall piers were investigated via

FEM modeling. Performance of individual masonry pier checked for most critical load combination as per the NBC 105: 1994 [19].

4.3.3. Model validation

The evaluation of the real performance of mud-mortar masonry buildings is a challenging task. Hence, validation of the linear elastic FEM model is necessary, before detailed analysis. Validation of the prepared FEM model was carried out using linear time history analysis of the building model under the 2015 Gorkha earthquake acceleration-time history (recorded at Department of Geology, TU). The internal stresses induced in wall piers were checked against their respective capacities (Tables 2 & 3) and real condition at the building's site. Despite the limitations of linear analysis, a strong correlation exists among the piers overstress percentage with the crack pattern as well as relative widths (Figs. 19 & 20). Likewise, piers, which were found to be safe in analysis, show little damage in the actual building as well.

It was noticed that the overstressed areas of the building in the FEM model analysis agreed with the observed damage patterns in the corresponding location of real building. The deformed shape of second floor diaphragm under earthquake loading in x-direction (Fig. 21a) shows that the eastern part of the building has relatively high in-plane deformation. That part has large halls in all three storeys with less cross walls, providing less resistance to deformation. Hence, large deformations occurred at that part.

The deformation pattern under earthquake loading in the y-direction (Fig. 21b) shows that the second storey north-west projection has relatively

Table 4
Material Parameters used in Modeling.

S.N.	Material	Density (kN/m ³)	Modulus of Elasticity (MPa)	Poisson's ratio
1	Masonry in Mud Mortar	19.6 (as per IS 875–1: 1987)	542	0.25
2	Masonry in Lime-Surkhi Mortar	19.6	1358	0.25
3	Timber (Pinewood/Deodar)	5.57 (Table 1, IS 883: 1994)	9480 (Table 1, IS 883: 1994)	0.3
4	Reinforced Concrete M15	25	19,365 (5000* $\sqrt{f_{ck}}$, IS 456: 2000)	0.2
5	Floor	18 (compacted mud)	30	0.3

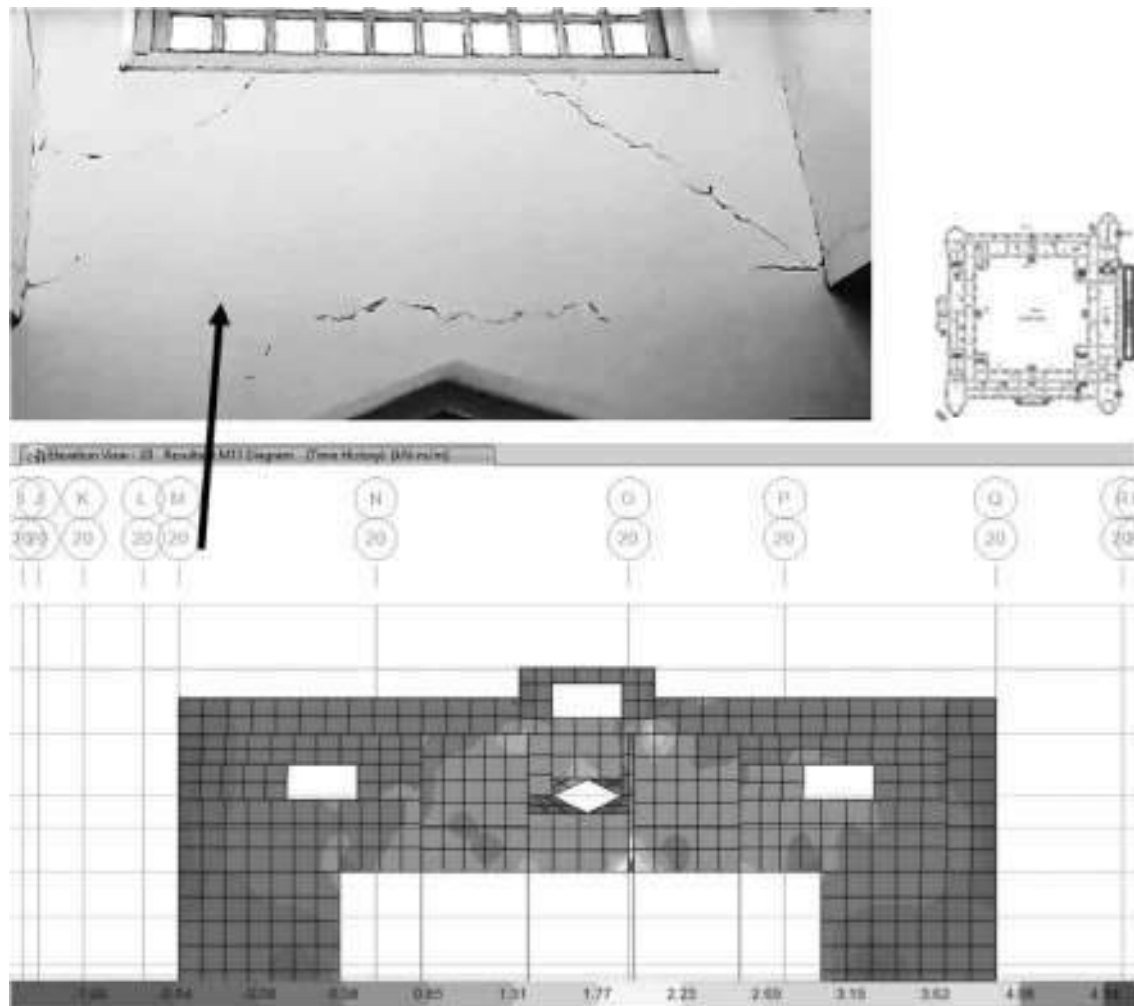


Fig. 19. Validation of FEM model stress with cracks observed at site. Higher Value Stress Contours and Corresponding Shear Cracks in East Facade at Third Storey.

higher deformation. Site observation showed floor separation at first and second storeys, shear cracks observed across walls and north facade walls tilted outward from plumb line.

4.3.4. Drift limitation

The inter-storey drift of 0.4% of storey height [21] is considered as limit for the stability of masonry walls. The model analysis showed that in the east-west direction (along the x-axis), inter-storey drift in the first storey and in the north-south direction (along the y-axis), inter-storey drift in the second storey exceeded 0.4% of the storey height limit. The raised storey height and less number of cross walls in the halls of the east block are the main responsible factors to yield higher drift. Similarly, the second storey of the north block was found to be the weakest in the building as per the damage pattern of the Gorkha earthquake. This is due to the long walls and flexible roof diaphragms.

4.3.5. Component level stress check

Vulnerabilities of structural wall piers were investigated via their stress computations using the results of 3-D model analysis obtained with the load combinations and recommendations of NBC 105 [19]. The demand stresses (axial, shear, and bi-axial bending) under each load combinations were evaluated for all piers. These demand stresses were compared against their capacities determined based on as-built building models, codes and test values (Fig. 22).

The demand-capacity compliance check showed in overall 81% piers were overstressed either in tension, compression, or shear. Overstressed piers in tension, compression and shear are respectively, 71%, 1% and 40%. In mud masonry, 69% wall piers are deficient in tension, 3% in are deficient compression and 63% are deficient in shear. In lime-surkhi mortar, 72% wall piers deficient in tension, 0% in compression and 20% deficient in shear. Results show that most of the piers are capable to overcome compression, however, they are significantly weaker in tension and shear. Lime-surkhi mortar showed relatively better performance compared to mud mortar. It is evident from the fact that few lime-surkhi based piers were damaged during the 2015 Gorkha earthquake.

It is important to note that, if one masonry pier is deficient, forces get redistributed on adjacent piers so that, immediate collapse is prevented. Some tension is acceptable in masonry. When subjected to lateral loads, masonry cracks on the tension side. Thus, the stresses are redistributed in the pier resulting in increased compression. However, some piers are found to be critical in compression even before redistribution. Any tensile force should be eliminated in such piers. Hence, overall evaluation should be based on a judgment of this behavior.

The floor steel beams are found safe to withstand gravity loads. However, the flexibility of the floor diaphragm in many parts of the building may lead to undesirable earthquake behavior. It is found that the majority of the wall piers are structurally deficient (either in tension or shear)

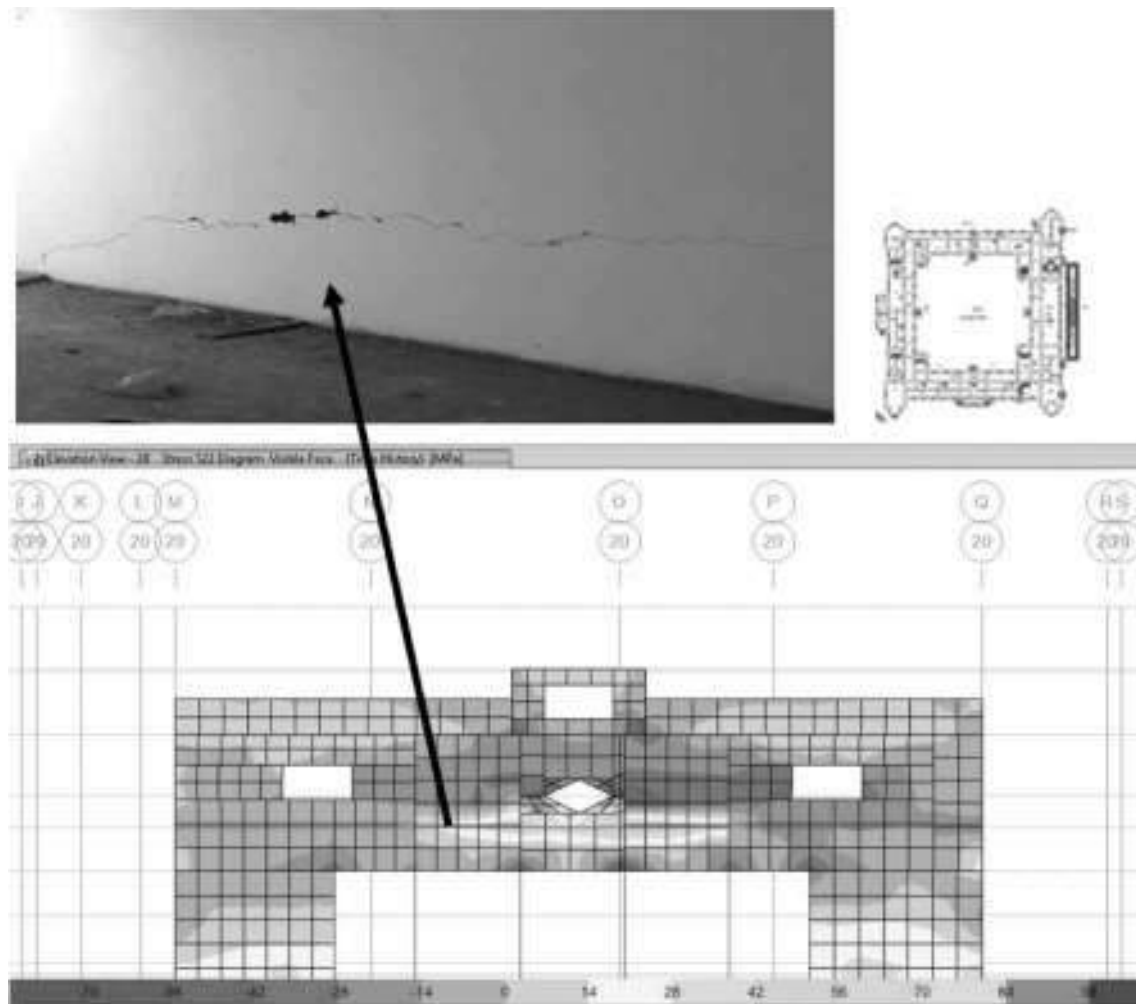


Fig. 19 (continued).

under design earthquake as per NBC 105 [19]. These deficiencies demand ductility enhancement of masonry walls, which are addressed via retrofitting measures using vertical and horizontal reinforcing elements, to take care of tension and shear deficiencies, compatible to the heritage conservation.

5. Structural restoration and seismic retrofit design

Restoration of pre-earthquake structural strength shall be achieved through grouting of medium cracks using lime-surkhi slurry, reconstructing damaged masonry walls by lime-surkhi masonry, replacement of damaged timber/steel girders, joists, planks, frames, rafters, purlins, and damaged CGI sheets in the roof before actual structural strengthening.

The selection of a strengthening option is the critical part for the intervention of heritage structures and it requires knowledge of traditional materials and constructions. Based on building typology and performance requirements after design earthquake, archeological constraints on the use of materials and aesthetics requirement for artifacts/carvings, safety and serviceability conditions of the structure, were considered during comparison and selection of the best-suited option. Different possible options of masonry strengthening as RC jacketing, splints and bandages, timber's splints and bands [22–26], traditional materials combined with steel plates [27], fiber-reinforced polymer (FRP), and mass reduction were analyzed. In the east and west facades, decorative columns and other existing artifacts need to be preserved. To preserve these artifacts/carvings, the least intervention is possible by the use of Carbon Fiber Reinforced Polymer (CFRP)

strips in strengthening work. Hence, outer wall surfaces of east and south facades were decided to strengthen using CFRP strips, whereas inside surfaces of east-south facades and all remaining walls were decided to retrofit using traditional construction materials and steel plates. Bricks, lime, surkhi, timber, steel are the local traditional materials used in previous construction and CFRP is the new material introduced as it was used in the strengthening of heritage structures in other countries. FRP as retrofitting material has been used in many countries to enhance shear, tension and flexure capacities of historical masonry buildings with very weak mortar. Rao et al. [28] used FRP and shear wall system to retrofit Town Hall URM building of Kolkata. Piers' demand in gravity and seismic actions were fulfilled via FRP bands. Ujjayanta Palace (Assembly House of Tripura, India, 110 years old) was severely damaged during Mw 6.4, Dec. 2011 Earthquake. Vertical and horizontal glass fiber-reinforced polymer (GFRP) bands were glued in brick piers using epoxy resin at both side of walls and plastered over the bands [29]. Similarly, Cosenza and Iervolino [30] successfully implemented FRP in retrofitting of very weak historical masonry buildings. Steel plates/CFRP were selected because they can be easily installed and hide inside the walls with plaster causing the least archeological/architectural interventions and can be removed easily if required.

5.1. Design of vertical and horizontal bands

Traditionally used materials as bricks, lime-surkhi, timber, and steel plates/sections were selected for the strengthening works at most of the

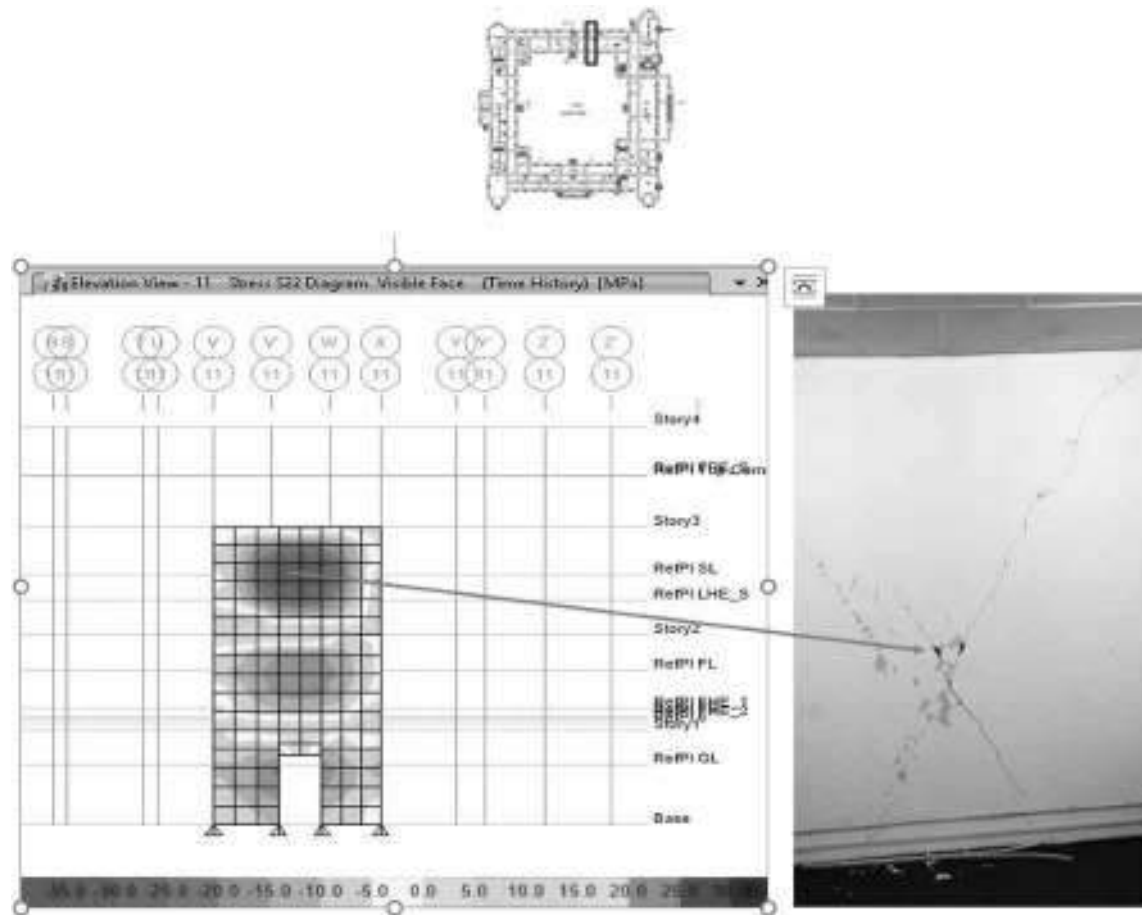


Fig. 20. Validation of FEM model stress with cracks observed at site. High Value Stress Contours and Corresponding Diagonal Shear Cracks in North Block's Cross Wall.

locations. Vertical and horizontal steel plate bands are intended to transfer the in-plane/out-of-plane shear and bending thereby mitigating the in-plane and out-of-plane failure of the masonry walls. In addition, the damaged steel plates and sections can be replaced easily when required.

During large earthquake shaking, it is expected that majority of the shear and tension forces will be transferred to vertical steel bands. Hence, vertical bands are the main retrofitting elements used to overcome the identified shear and tension deficiencies in wall piers. The

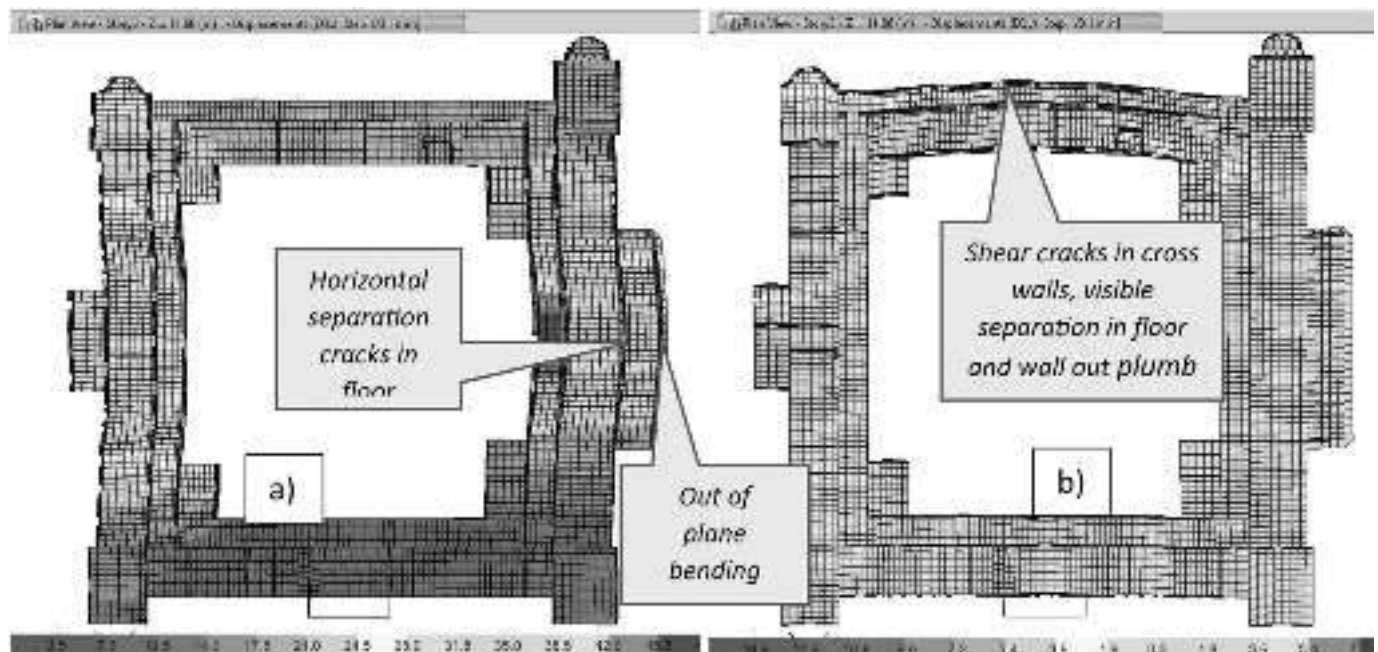


Fig. 21. Deformed Shape of Second floor diaphragm under earthquake loading in a) x- and b) y-directions (mm).

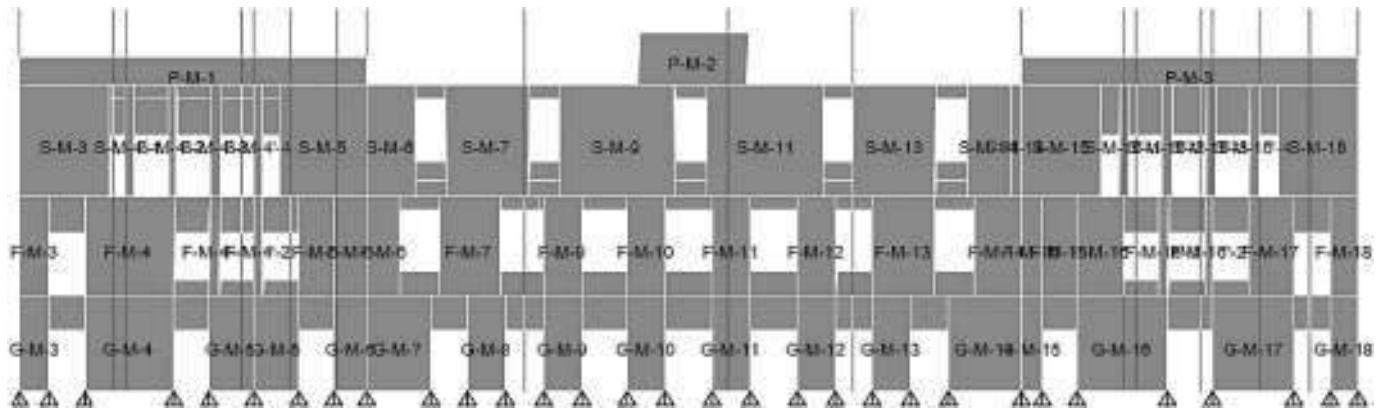


Fig. 22. Pier Identification to Evaluate Individual Forces.

force demand under the design earthquake loading in each wall piers was calculated considering weight of retrofitting elements (about 2% of wall weights). Deficiencies of each pier in tension, compression, shear, and bending were calculated based on demands under earthquake loading and existing pier section capacities. Pier capacities were determined from test results performed in the field from shove tests and double flat-jack tests. Deficient piers were strengthened considering combined stress (direct stress and bending stress due to moment and shear). From combined stress and given length of pier, the total tension force acting on a pier was evaluated. The required section sizes of vertical bands of given grade of steel in each pier was selected to resist total tension force which also satisfies the tension, compression and shear stress. Vertical

bands with steel-plates 8 mm thick of varying widths, 100 mm to 200 mm, are provided to meet the identified deficiencies. These bands are provided near edges and corners of walls and at intermediate locations where necessary as shown in Fig. 23. Further, the vertical bands are provided minimum 300 mm away from the edge of the openings to skip the edge bricks. This reduces the chances that the through bolts will break and dislodge the edge brick when mobilized under earthquake load. All plates need to be anchored to wall and at floor/roof levels with horizontal angle-section that stiffens the floor system (Fig. 24) and enhances resistance to out-of-plane bending. Similarly, to improve the rocking/bending response of the masonry piers, vertical steel bands are properly anchored to the foundation RC beam using a plate, bolts/nuts connection system.

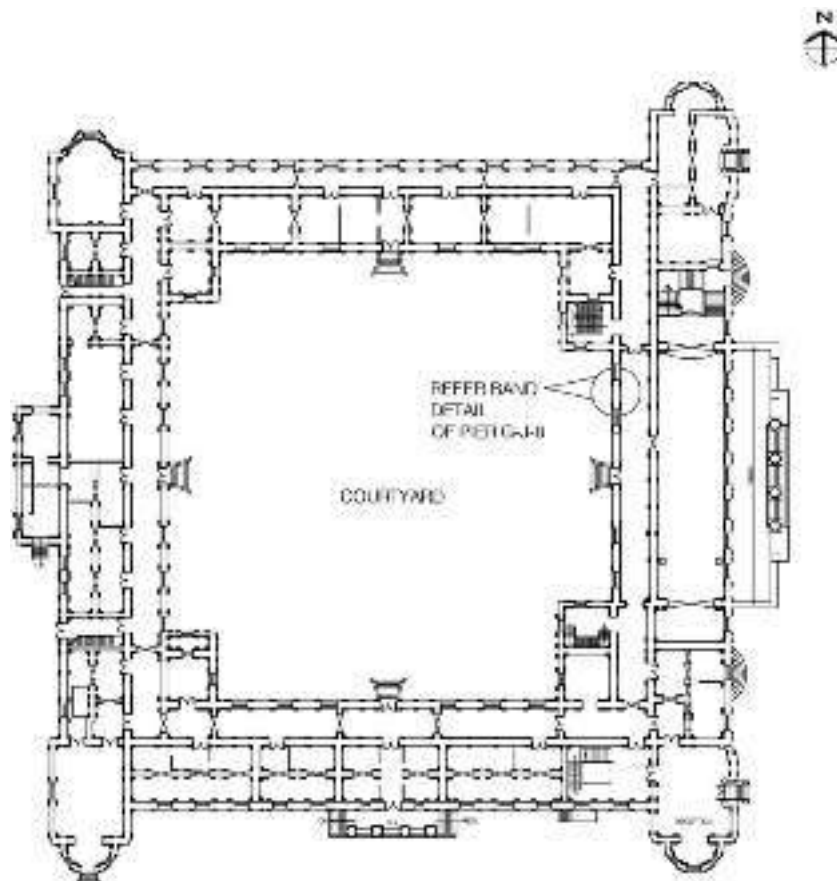


Fig. 23. Retrofitting measures adopted for different Piers of the building.

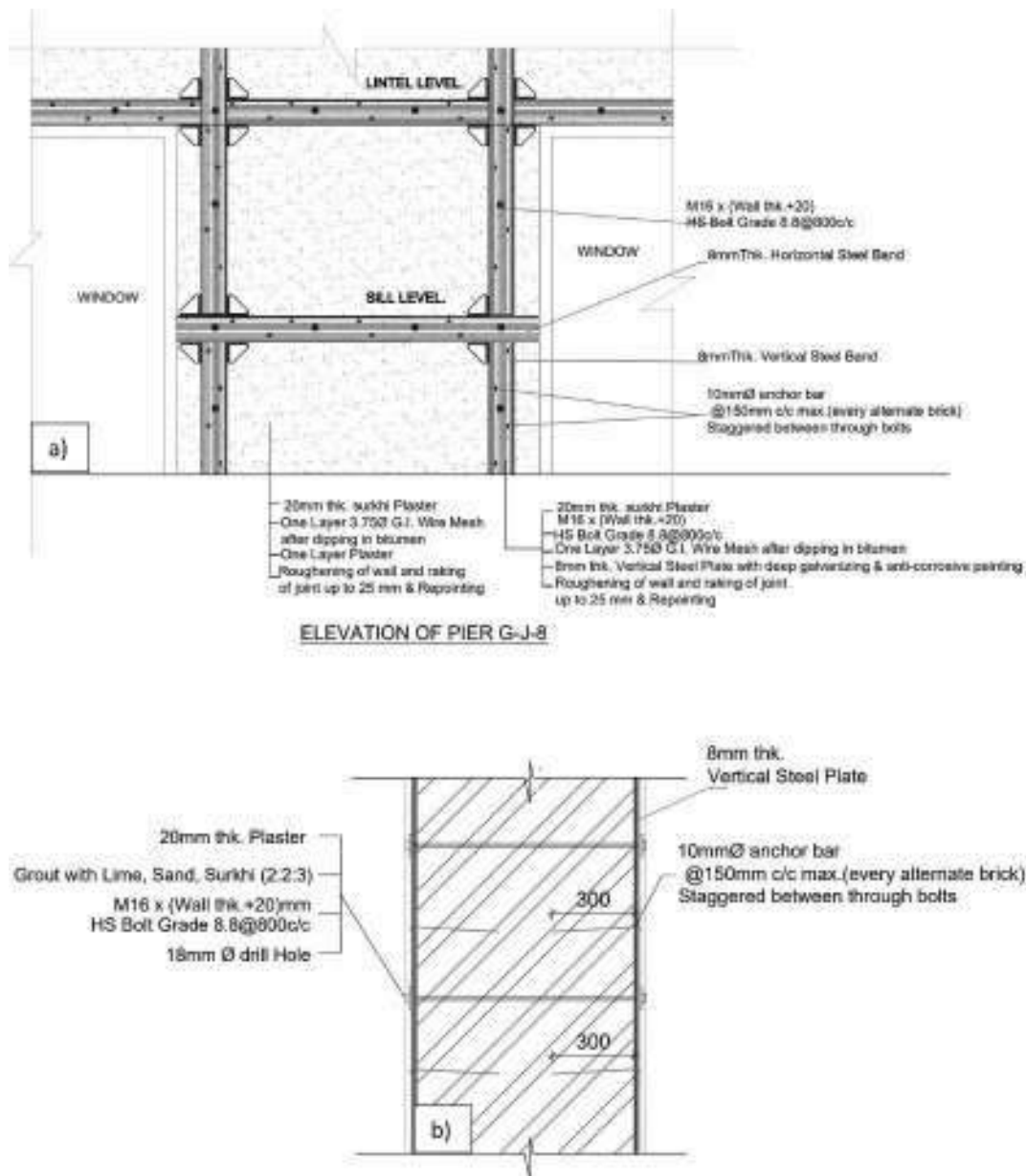


Fig. 24. Vertical and horizontal steel bands with a) lintel and sill bands for the Pier G-J-8. b) through and partial bolt connections.

In case of thick walls, out of plane bending is less vulnerable. However, during the Gorkha earthquake, out-of-plane bending damages were observed in some north and east face wall piers. To enhance “box action”, horizontal bands are provided at lintel and sill-levels on either side of each wall with through connection (Fig. 24). Here, “sill level” denotes halfway between lintel and floor levels, since almost all the window openings extend down to the floor level. Continuous horizontal band with steel plate (200 mm $\times$ 8 mm) at lintel level satisfy out-of-plane bending demand of walls. Here, “sill bands” are discontinuous due to door/window openings (Fig. 24). Sill bands confine the masonry piers in between openings. Moreover, horizontal bands on exterior faces are provided at floor levels to support the action of Indian Standard Angle used as floor stiffeners at all floor levels along the interior face of walls in all rooms and corridors (Fig. 25). Horizontal bands are welded to vertical bands with single bevel butt-welding via gusset plates (Fig. 24a). Horizontal bands on both faces of walls are connected through bolts and additional 10 mm diameter partial anchors provided in a staggered fashion (Fig. 24) to minimize local plate buckling effects.

About 3% of mud masonry piers were found deficient in compression, so steel bands on these piers were designed to resist tension, shear, compression and bending effects. To prevent the local buckling of slender plates held in compression between the through-bolts, the additional anchorage was provided using 10 mm diameter anchor bars at 300 mm c/c spacing (Fig. 24b) as per IS 800: 1984 [31]. Some steel plates should be welded at the site. Though onsite welding is challenging, that cannot be avoided in retrofitting existing construction interventions. Here, the quality of the welding bar and skill of the welder are very important, that must be controlled via lab tests of welded samples.

Herein, most parts of the structure were strengthened using steel plates and some part by CFRP strips both suitably anchored to walls, floors and roofs (Fig. 23). Steel plates/rolled steel sections and parts should be double-coated with high-quality anticorrosive epoxy paints as a measure of corrosion prevention. For through anchorage of steel plates, wall drillings should be carried out at design spacing of 800 mm center to center vertically and connecting bolts should be fixed using epoxy/lime-surkhi grouting.

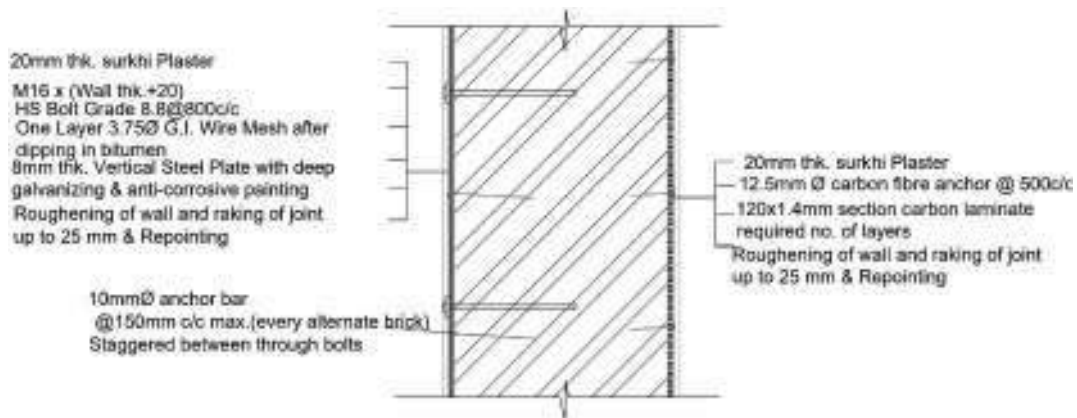


Fig. 25. CFRP bands at outer face and vertical steel bands at inner face with CFRP partial anchor and partial high strength steel bolts of grade 8.8.

5.2. Design of carbon fiber reinforced polymer (CFRP) bands

Fiber Reinforced Polymer (FRP) has been successfully used for repair, rehabilitation and retrofitting of not only RC structures but also of masonry structures [28,29]. These are lightweight and have high tensile strength compared to steel, flexible, easy to install and non-corrosive. The CFRP

bands increase the displacement, load carrying capacity (at which the first major crack develops) and shear strength. The walls with horizontal CFRP bands found more ductile compared to diagonal bands, since the failure patterns with horizontal bands showed several cracks of small thickness, while the masonry walls with diagonal bands had a brittle failure with sudden loss of strength [32]. They can be wrapped to confirm the

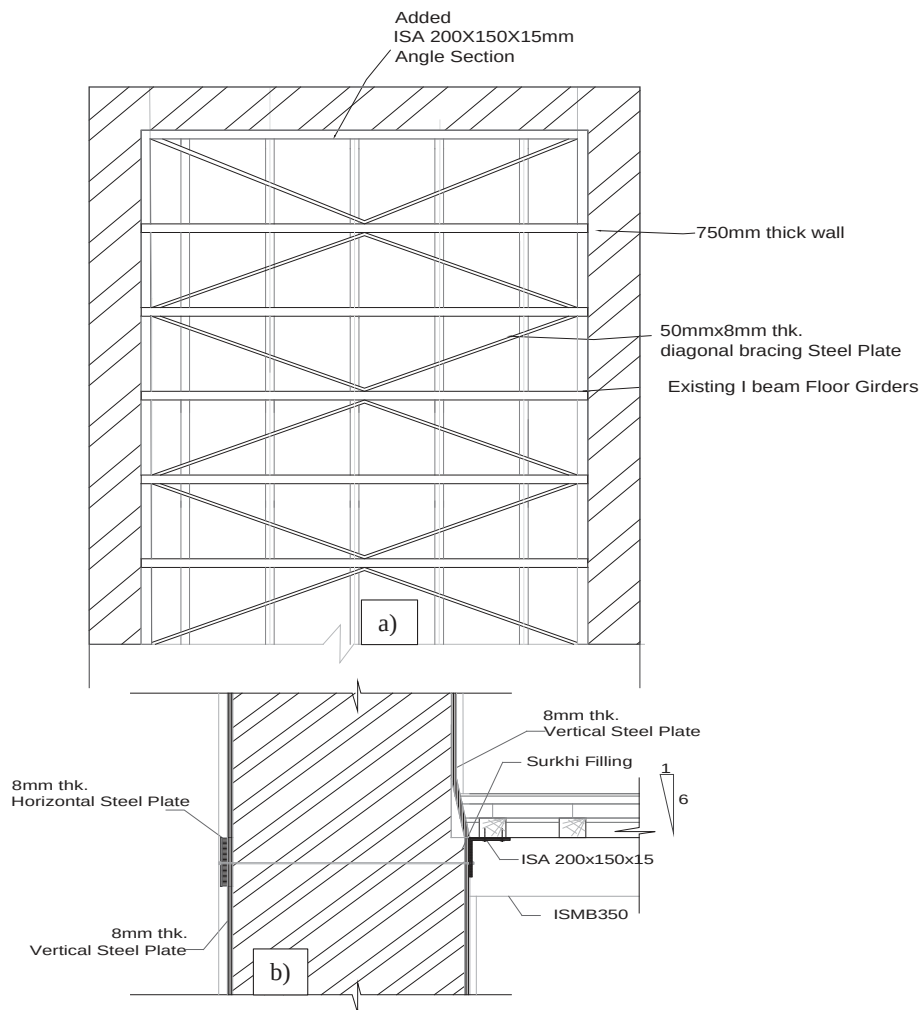


Fig. 26. a) Floor diagonal bracing details b) Connection of outer horizontal and inner angle section at the bottom of joist.

geometry of the structure. Hence, in the east and south facades CFRP bands are designed to preserve different decorative carvings and projections in brick columns and walls. CFRP bands improve the integrity and seismic 'box action' of the masonry building. These bands are glued externally to the existing masonry walls using adhesives.

For the design of CFRP bands, at first the tension – /shear deficiencies in the piers were evaluated from analysis, then the nominal force in the CFRP band was evaluated considering environment reduction factors depending on exposure condition, afterwards width of band, the number of layers and spacing were determined so that capacity

exceeded the demand. Finally, the selected band was checked for force limit based on the effective strain evaluated considering the bond reduction factor [33].

CFRP is gaining popularity because of less disruption during strengthening (less installation and curing time), the marginal increase in the size of a retrofitted member (very thin sheets), high strength-to-weight ratio and superior creep properties, high resistance against electro-chemical corrosion (material is chemically inert) and good fatigue strength (suitable for fluctuating loads). As per CPWD (India) Handbook on Seismic Retrofit [22], vertical CFRP bands significantly increase the shear capacity of members.

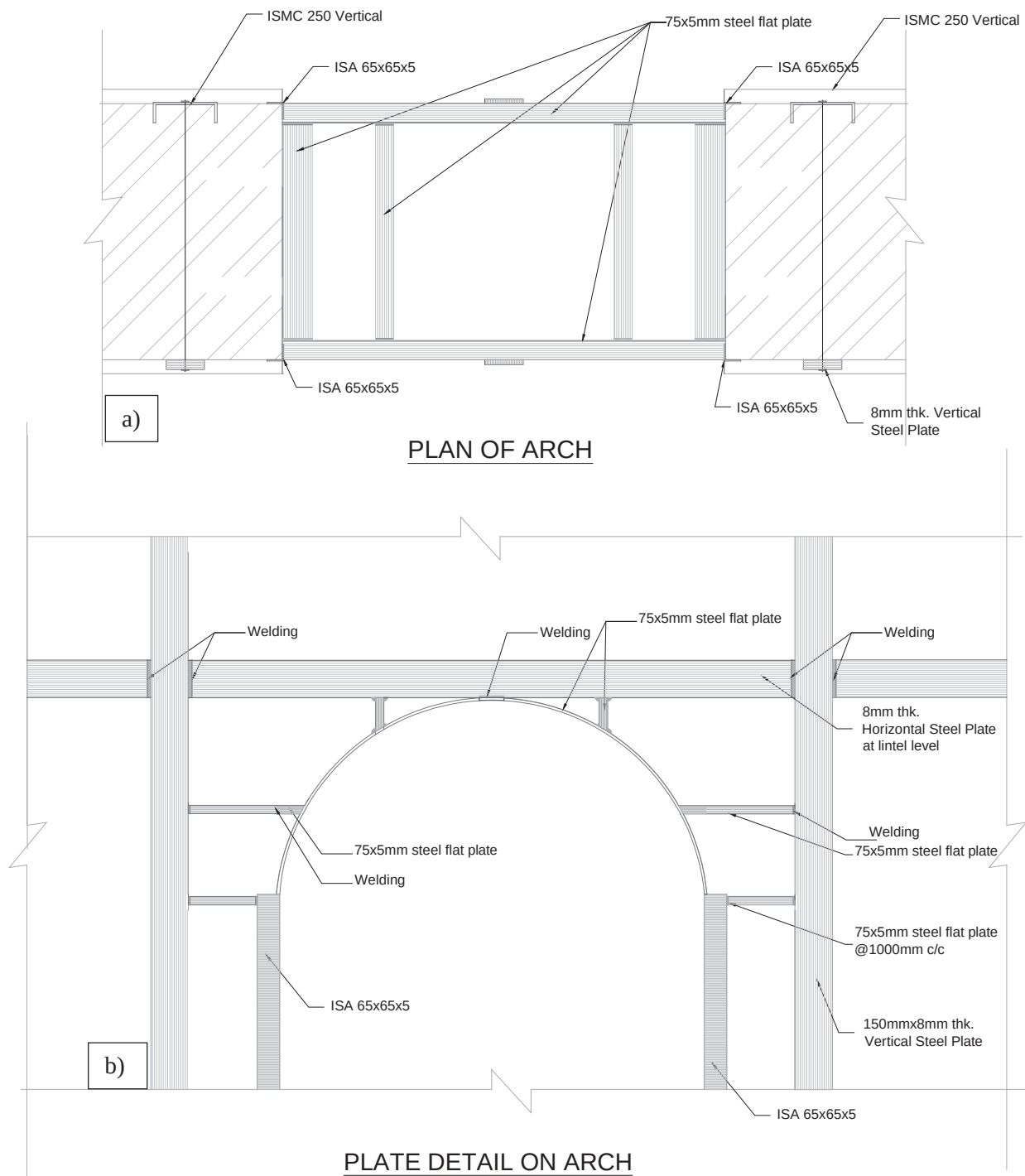


Fig. 27. a) Arch-bottom view with added elements. b) Arch-side view with retrofitting elements.

However, the cost of CFRP material and site preparation for application is more expensive compared to steel plates/sections. Detailed analysis and design report showed that vertical CFRP strips of 1 mm thick fiber and width varying from 200 mm to 1000 mm in 1 to 3 layers in a spacing of 1 m center to center satisfy the deficiencies incurred in the piers. Similarly, most of the horizontal 1 mm thick strips are of width varying 300 mm to 400 mm in 2 to 3 layers at a spacing of 1 m center to center. Required anchorage lengths for CFRP bolts and spacing were also evaluated (Fig. 25). Secure connection and ductility of exterior architectural columns and porch are necessary for life safety. For this, columns are jacketed with vertical CFRP laminates and CFRP ties at regular spacing along with the height and they should be covered by lime-surkhi plaster.

Small steel flat strips can be used to retrofit decorative artifacts, but grooves should be cut in original carvings which may become difficult to restore in original condition, i.e., retain external features and architectural shape. CFRP bands can be easily wrapped on decorative brick projections and other artifacts that improves the in-plane and out-of-plane capacity of the masonry wall. It can easily fulfil the requirements of tension deficient piers, spandrels and confines the masonry that improves ductility. However, high compressive stress will develop debonding of CFRP strips [33], also the presence of dampness and high temperature may lead to debonding of CFRP.

5.3. Retrofitting of floors

In-plane stiffness of floor diaphragm is vital in transferring seismic forces to vertical structural walls; hence, diagonal bracings are provided at floors to increase floor stiffness (Fig. 26). In-plane stiffness of I-beam girders with timber joists-, timber girders with timber joists-, and jack arch-floors enhanced by adding ISA 200x150x15 ring beam along the wall below the floor level. In inner walls, the ISA-band on either side of walls is interconnected by bolts and steel beams in order to achieve an effective section whose depth is equal to the wall thickness, such that the ISA band on either side act as tension-compression flanges. The floor diaphragm is flexible in its present state and the same was considered in the analysis. The diagonal bracing steel members connected to the flange of floor girders and ring beam-ISA shall add further stiffness and ensure the stability of the layered and simply supported flooring system. Furthermore, wooden joists are connected to supporting walls by steel strips welded to horizontal band on the exterior side of the wall. Similar diagonal braces provided between rafters and rafters are connected to the roof band using steel strips. For retrofitted state analysis, vertical/horizontal steel plates, diagonal steel bracings, attached on the floor girders and angle sections at the periphery walls, were modeled to determine the in-plane floor stiffness enhancement. Results confirmed that the load distribution among piers was improved (i.e. piers share the lateral load based on relative size) and lateral deflection of the building was reduced. However, the ratio of in-plane displacements of the floor diaphragm at mid-span and support still does not satisfy the criteria laid out for rigid diaphragm in IS 1893: 2016 [21].

5.4. Protection of openings

It is well noticed that the tensile/compressive stresses found concentrated around openings and at the wall pier edges due to in-plane action of the earthquake load. Vertical bands provided around all openings and horizontal lintel bands above openings help to transfer these stresses concentrated around openings. Arches were found to be the most vulnerable elements during earthquake shaking, hence, additional force transferring elements are provided for arches via steel strips around arches to hold them to the nearby vertical bands and lintel band above (Fig. 27). The sizing of these elements was evaluated based on the stress capacity of the existing masonry piers.

The major intervention system consists of vertical and horizontal steel members/CFRP fibers, which confines the masonry system creating box-action. From the heritage point of view, all strengthening elements should be embedded within the plaster and the same is done to preserve aesthetics using traditional materials.

Finally, building's performance was evaluated with adopted interventions. For this, a separate model of a wing of the building was prepared with the intervention options and its capacity was evaluated. The building's strength in shear enhanced by 10% and storey drift reduced by 60% after the adoption of proposed interventions. Thus, the flexible diaphragm's in-plane rigidity found enhanced to semi-rigid [21] using steel bracing and angle plates which will improve the building's performance during future earthquake.

6. Conclusion

Shital Niwas building, neoclassical architecture of 19th century in Nepal, is a load bearing system with flexible flooring and light slope-roof structure. The building is nearly square in plan with an open central courtyard with thick (750 mm) brick masonry walls in mud mortar. After the 2015 Gorkha earthquake, preservation of heritage structures with their historical and cultural value became an important issue. With this objective structural condition assessment, analyses and design of retrofitting options were carried out. Considering archeological value and structural safety during an earthquake, appropriate strengthening solutions were suggested. Post-earthquake assessment of the building revealed different vulnerable features in the structural system. In the first phase, structural systems were closely observed, architectural/structural details noted, as-built drawings prepared, damages investigated, recorded, and mapped, deficiencies identified and damages were categorized based on national and international standards and guidelines. Based on the damage evaluation, the north block and second floor of the east block fall under grade-3 (DG-3), and the remaining part is categorized under grade-2 (DG-2) as per EMS-98 classification. Meanwhile, the building appears vulnerable due to the heavy mass of the structure, poor earthquake resistant properties/features of the structural system (URM), ageing-related deterioration of the structural systems, multiple changes in occupancy, and lack of periodic maintenance.

In the second phase, the present performance of the building was evaluated using existing material properties in the as-built model with loads. For this, material properties were evaluated from different in-situ and lab tests. Based on the evaluated demands as per the National Building Code of Nepal [19], elementwise deficiencies were identified. Qualitative and quantitative vulnerability evaluation conducted showed that the building is structurally deficient in shear, tension and bending. Hence, different intervention options were investigated with their implications on functionality, aesthetics and archeological/cultural aspects. Finally, the best-suited option of intervention using steel plates and CFRP bands at different locations was chosen and a detailed design is carried out for the same. The building's performance after the intervention was evaluated through a separate model of a wing. The building's strength in shear increased slightly, however storey drift reduced significantly after the adoption of the proposed interventions. The flexible diaphragm's in-plane rigidity was enhanced to semi-rigid [21] through steel bracings supported on the angle sections. Thus, the present work explains field investigation, numerical analysis, and retrofit design procedure, which would be important to preserve such historical monuments in Nepal.

Declaration of Competing Interest

Authors declare that there is no conflicting interest in publishing this paper.

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This is the sole research carried out by the authors in Nepal's reconstruction after 2015 Gorkha, Nepal earthquake.

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Regular Article

Performance evaluation of strengthening options for institutional brick masonry buildings: A case study of Pulchowk Campus

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ABSTRACT

Four masonry classroom buildings of Pulchowk Campus constructed in 1970s were severely damaged during 2015 Gorkha Nepal earthquake and remained out of service. To replace these facilities with modern ones, Campus needed more than eight hundred million Nepali Rupees, which was not manageable at that time. Hence, strengthening of damaged classroom buildings via efficient, low cost and less time-consuming technique was developed and implemented. In these buildings, 7.45 m long prefabricated RC beams rest directly on one and half brick thick piers spaced at 3.7 m, over which prefabricated slab panels rest and on its top 5 cm thick RC overlay to provide monolithic action. During 2015 Gorkha Earthquake, bricks under these beam-piers crushed severely posing serious problem to retrofit. To arrive at the best technique, four possible options of strengthening were identified, simulated and obtained results were analyzed. RC jacketing was found the most effective method of retrofit for masonry structures; however, facade's appearance cannot be preserved. RC columns combined with brick piers via shear-keys, is the new option developed in this study, performed satisfactorily. This option, only at ground storey, improves performance slightly, however, it can be implemented incrementally phasewise when resources permit. Static pushover analyses were performed to evaluate capacities of the restored and four adopted options of retrofitting. The increase in the performance of masonry after application of different retrofitting options were evaluated. After a comprehensive analysis of the obtained results, keeping resource constraint in mind, retrofitting by using RC columns combined with brick piers at ground storey only was selected for final execution.

1. Introduction

Four classroom buildings (B, C, D and E blocks) of Pulchowk Campus, constructed during 1971–1975 CE (2028–2032 BS), were severely damaged and were evacuated after 2015 $M_w 7.8$ Gorkha earthquake. Different alternative arrangements were made and measures were taken to run the classes in post-earthquake situation. In these buildings, major problem was developed due to the large concentrated loads from pre-fabricated floor beams being transferred to relatively narrow brick piers (350mmx700mm). Post-earthquake structural assessment showed the risk posed due to the vulnerable unreinforced masonry (URM) buildings during Gorkha earthquake's aftershocks shaking. These URM buildings were vulnerable mainly due to insufficient capacity of brick piers to cope the effect of heavy vertical and horizontal loadings, lack of integrity between connecting elements (beams and piers), lack of horizontal and vertical bands affecting the in-plane and out-of-plane behavior of walls (lacked box action), and low ductility of masonry piers. During 2015 Gorkha earthquake, bricks under some piers at ground storey crushed severely (Figs. 3, 4) making building vulnerable with increasing risk to carryout teaching/learning activities. Vulnerability

posed by these building structures were needed to be addressed quickly in a rational way and risk posed by them were needed to be lowered to an acceptable level so that daily teaching/learning activities could be resumed in these buildings. At that time, there was a strong sentiment to demolish these buildings and construct modern multistoried buildings in place of them. However, to demolish and reconstruct these facilities with the same space, Campus needed more than eight hundred million rupees. Moreover, Campus was not able to manage such huge economic resources. Hence, low cost restoration/strengthening techniques of damaged buildings remained as the best alternative.

2. Research objectives

The main objective of this study is to select the efficient and cost effective method of strengthening for masonry structures. The specific objectives of this study are to: i) assess the seismic performance of unreinforced brick masonry building via capacity evaluation using non-linear static analysis, ii) determine the seismic performance of viable retrofitting options and determine technically efficient and cost effective

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retrofitting measure. The major challenge here was the safe transfer of large point loads, coming directly on the brick piers from beams, to the foundation. To fulfil the set objectives, structural condition assessment was performed with identification of major deficiencies in the existing building. Finally, the selection of the strengthening option was assessed based on the nonlinear seismic analysis of the studied options.

3. Building description

Three classroom buildings (Blocks B, C & D) are of identical construction (three storied, rectangular in plan and regular vertical load path). Herein, the three-storied D-block of Pulchowk Campus is selected for modeling and detail evaluation (Figs. 1, 2). The D-block is elongated in plan (Fig. 2) having classroom's width of 7.45 m and storey height 3.60 m. The building consists of 350 mm thick wall piers under the beams throughout the building height as shown in Figs. 1, 2. Cement sand mortar less than 1 cm was adopted and is relatively uniform throughout the building. The prefabricated RC main beams (200 mm $\times$ 560 mm), 7.90 m long, rest directly over 350mm $\times$ 700mm brick masonry piers at regular spacing of 3.70 m center to center. Over these beams, prefabricated RC slab panels rests. Secondary beams, inbuilt at the edges of prefabricated slab, are 125 mm $\times$ 150 mm and slab is 130 mm thick. Over secondary beams and slab panels 50 mm thick RC was overlaid to provide monolithic action between secondary beams and slabs. However, simple connection existed between RC beams and masonry piers. The building is long and separated by construction joints, so, it is modeled up to the separation joint only from west (Figs. 2, 5). Outside passage (1.5 m width), having brick masonry piers (350mm $\times$ 700mm) at a spacing of 3.70 m, is covered using lintel beams and prefabricated RC slabs (Fig. 1a). Building's total height is 11.80 m from plinth, storey height is 3.63 m and brick parapet is 0.91 m high (Fig. 1b).

4. Damage overview

As per seismic vulnerability evaluation guideline (published by the Department of Urban Development and Building Construction (DUDBC), Government of Nepal (GoN)) [1], the expected damage is grade-4 (DG-4) in case of IX – intensity earthquake. This indicates appropriate intervention is necessary to prevent casualties during large earthquake. Though 2015 Gorkha earthquake was not so large that expected in the region, the damage caused by it in the investigated structure was important to reach to the appropriate strengthening solution. The major deficiencies observed, that made the building vulnerable, were large point loads coming on brick piers through RC beams (Fig. 1), lack of vertical reinforcement at corners and wall junctions, lack of bands, corner stitches, unreinforced brick columns at corridors and long unsupported walls (length > 11 m).

During 2015 Gorkha Earthquake, bricks under these beams crushed severely, some piers bulged requiring urgent actions, which posed serious problems in selecting retrofitting options (Figs. 2, 3 & 4). Thickness of mortar joint plays important role in the masonry's strength. Here, the thickness of cement sand mortar is less than 1 cm and is relatively uniform throughout the building. In addition, building damage pattern shows the crushing of bricks in majority of the locations, indicating that the mortar strength is satisfactory. Fig. 3a shows the crushing of bricks in piers due to insufficient pier capacity in direct compression. Figs. 3b & 3c indicate the shear failure of brick piers in diagonal tension. In both cases brick crushing took place indicating insufficient brick strength to cope the loads coming on the piers. Similarly, diagonal shear failure is clearly visible in Figs. 4a & 4b too, through brick crushing. This clearly indicates the risk posed by the building to run normal activities. However, 50 cm thick random rubble stone piers at the ends and middle of south face were not damaged during 2015 Gorkha earthquake.

These pre-code buildings were designed for vertical loads considering masonry's compressive strength, and perform satisfactorily as long as the loads were vertical. Since, they were not designed for lateral inertial

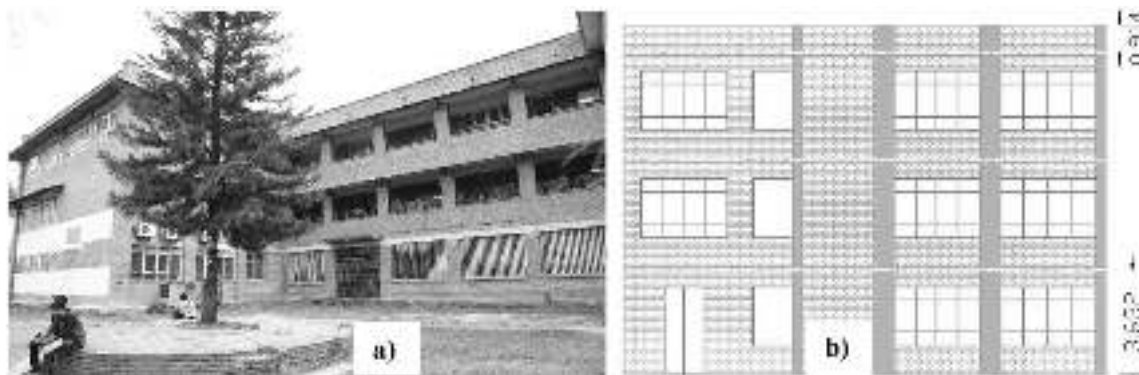


Fig. 1. a) North face image of D-block b) West elevation of D-block.



Fig. 2. D block- south elevation of the Department of Mechanical Engineering.

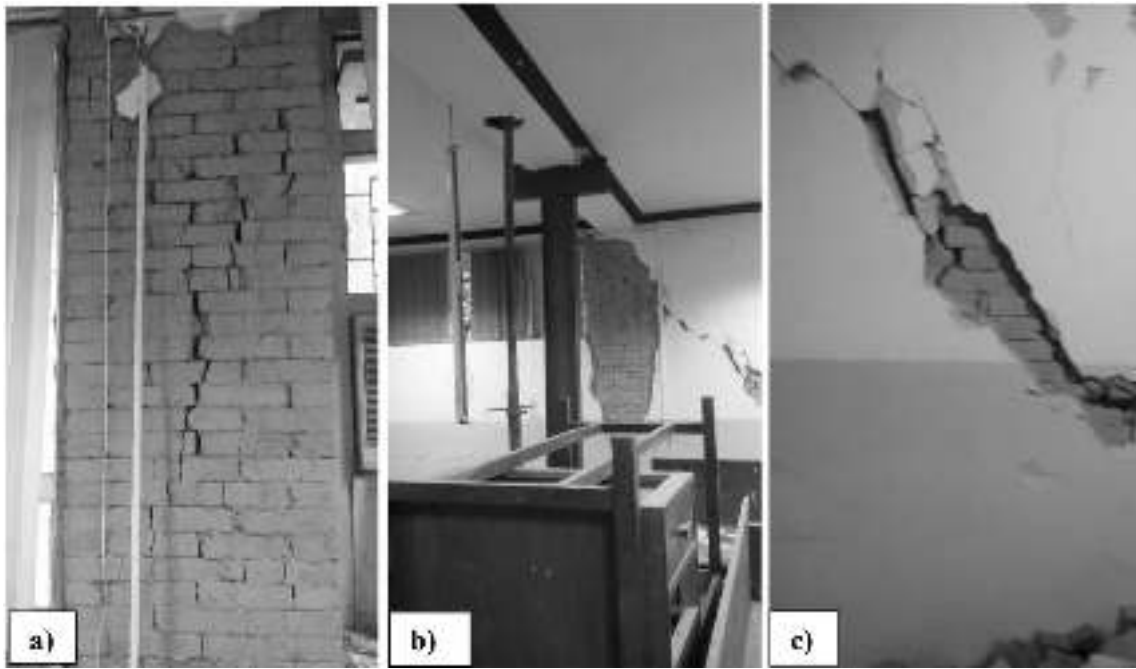


Fig. 3. a) Brick crushing in piers under the beam- outside view b & c) Shear cracking of bricks in diagonal tension- inside view.



Fig. 4. a) Brick cracking in compression and shear in the pier b) View of precast beams which are directly resting over brick piers and precast slab panels resting on beams.

loads, walls developed compressive, shear and flexural cracks during earthquake shaking. The strength of masonry under these conditions often depends on the bond between brick-mortar and connection of in-plane and out-of-plane walls at corners/junctions and the connection of beams with the piers, which was found very poor in the considered building. Six brick piers out of thirty-two at the ground storey of the building were severely damaged as shown in Figs. 3 & 4. Based on EMS-98 scale of damage grading [2], the overall damage was categorized as grade-2 (DG-2, moderate). Appropriate intervention is required to upgrade the seismic performance of the building. Before, structural intervention, restoration works need to be carried out to bring the structure's strength to its pre-earthquake condition.

5. Structural condition assessment

Structural condition assessment was performed via building's FEM modeling. Existing material properties were assessed from the available literatures during the period of study, suitable for the studied building located at Pulchowk Campus. Brick material properties, used in this work, were taken from the experimental test conducted at the Central Material Testing Laboratory of Pulchowk Campus [3]. Various local and machine made bricks of Kathmandu Valley were tested and comparisons were made using empirical relationships. In addition, uniaxial monotonic compressive tests, on the unreinforced brick masonry prisms in cement sand mortar,

Table 1
Masonry Properties.

Properties	Brick Masonry (Shrestha [4])	Stone Masonry (Magenes et al. [5])
Compressive strength of masonry prism (f_m), MPa	2.597	3.28
Modulus of Elasticity of Masonry (E_m), MPa	831.18	2550
Poisson's Ratio (ν)	0.27	0.19
Modulus of Rigidity (G), MPa	327.23	840
Weight per Unit Volume (γ), kN/m ³	19.05	23

were performed and the results are presented in Table 1. It was observed that the compressive strength of the masonry depends on the compressive strength of masonry unit, mortar and slenderness ratio.

Properties of stone masonry were taken from Magenes et al. [4], who performed cyclic tests on stone masonry prisms in cement sand mortar and provided average values of basic mechanical parameters required for the modeling structural elements (Table 1).

Kaushik et al. [5] provided analytical model in terms of stress-strain behavior of masonry to depict the material nonlinearity which can also be modeled in numerical tool using nonlinear link element via user-defined force-deformation relationships, where longitudinal direction of the link defined the axial behavior, while the in-plane transverse direction defined the shear behavior. They idealized the stress-strain curve of masonry using six experimentally observed control points representing respective compressive stresses and strains in the masonry. Based on the experimental results they proposed idealized stress-strain relationship for brick masonry. After a comprehensive study of 84 masonry prisms test results, they have proposed analytical expressions to estimate modulus of elasticity of masonry and an analytical model to plot stress-strain curve for masonry, which is used here for nonlinear static analysis.

5.1. Building modeling

Masonry is a nonlinear material with very complex non-homogeneous anisotropic properties and is good in compression transmission whereas poor in tension, so it's mathematical model is complex and presence of pre-cast beams and slab made it more complex. Abrams [6] mentioned the need of material properties, constitutive relationships of masonry and its constituents (bricks and mortar) for mathematical modeling of masonry walls, however, these are not easily available because of scarcity of controlled experimental tests and wide variation in the material properties geographically. Micro-modeling of masonry structure is used to study local behavior, whereas macro-modeling is useful to model long masonry solid walls where stress along the macro-length is uniform [7,8]. Doudoumis et al. [9], Lourenco [10] studied the behavior of infill panels in multi-storey frames under seismic action. They tested the identical structures with micro- and macro-modeling and found only 2% difference in the response. Magenes and Calvi [11] suggested the methods of evaluation of strength, deformability, and energy dissipation capacity of unreinforced brick masonry walls. They described the rocking, flexure, shear failure mechanisms, also quantified the energy dissipated via hysteretic behavior. Based on the compressive strength of unit, aspect ratio, and vertical axial stress, Yi et al. [12] analyzed a two storied masonry building and identified the failure mechanisms of masonry wall, as rocking failure, sliding shear failure, toe crushing failure, and diagonal tension failure Sharma and Khare [13] performed nonlinear static analysis on unreinforced masonry walls using layered shell element in SAP-2000. The results presented in terms of capacity curve confirmed in the masonry wall's ductility enhancement with intermediate mortar's strength compared to stronger mortar. Moreover, a study of the modeling strategy in SAP-2000 via pushover analysis of masonry structures was performed by Korini and Bilgin [14]. Nonlinearity of the material was considered by providing stress-strain curve from Kaushik et al. [6]. Seismic capacity of a 2-storey unreinforced masonry residential building was assessed using nonlinear-layered shell elements and possible rehabilitation options were suggested.

The current study evaluates seismic capacity of unreinforced masonry building structure using non-linear shell element in SAP-2000 [15]. Based on the deficiency observed, several strengthening measures were modeled and compared to select the best one in order to implement in real construction. Herein, considering the long brick masonry walls, macro-model was carried out in SAP 2000 [15], using area element-shell, and the structure is fixed at the plinth level (Fig. 5b). Uniform mesh depicting the size of brick element was used for modeling the shell element. For selection of mesh size, theoretical displacement of a 3mx3m freestanding wall was calculated. The wall was then modeled in the numerical tool for different mesh size and the obtained lateral displacements were compared with theoretical displacement. The lateral displacements of theoretical and numerical models were obtained to be similar while adopting the size of brick element, which was adopted for all numerical models. Beams were modeled as frame elements representing by lines along the longitudinal axes of the beams, which meet with the adjacent shell element. Strengthening element, RC-jacket was modeled using layered links. In the model, RC columns were added as retrofitting shear-key link elements using RC-hooks inserted in brick piers, which were modeled via independent hook ("tension-only") elements available in SAP 2000 [15]. The independent hook property can be defined for every deformation degree of freedom as tension only property with certain stiffness. The detailed approach for calculation of the advanced property of hook element can be obtained in the research performed by Lepage and Sanchez [16] and manual of SAP 2000 [15].

A simplified non-linear layer model was developed to represent the non-linear behavior of masonry wall. Nonlinear properties of masonry were represented by different layers in different directions and separate properties in each direction. The inherent feature of the modeling tool to depict the behavior of the composite section was adopted for modeling the RC jacketed masonry section. In the modeling, the nonlinear link element used to define material nonlinearity via user-defined force-deformation relationships, where longitudinal direction of the link defines the axial behavior while the in-plane transverse direction defines the shear behavior. The force vs deformation data depend on the tributary area of wall represented by each of the nonlinear links, where the axial response characteristics of the nonlinear links directly control the flexural behavior of the wall. The nonlinearity of the numerical model was ensured by providing nonlinear material property in the form of stress-strain curve to depict anisotropic nature of masonry, layered nonlinear shell element as available in numerical tool and by loading the structure beyond elastic regime. Axial stiffness was calculated from the property of the reinforcement used to connect the RC column and masonry and was provided as input in the numerical model as hook element (tension only element). The detailed modeling approach can be obtained in the research performed by Lepage and Sanchez [16], Korini and Bilgin [17].

6. Selection of retrofit options and modeling

Different retrofitting options from the literatures and practiced in the real field were studied and best ones, based on the specific nature of the building, were selected. However, the building typology used in this study is unique, the problem to solve is also unique, and the retrofit option used is not found in the literatures, and thus the proposed retrofitting method is also unique. Thus, considering its specific nature,

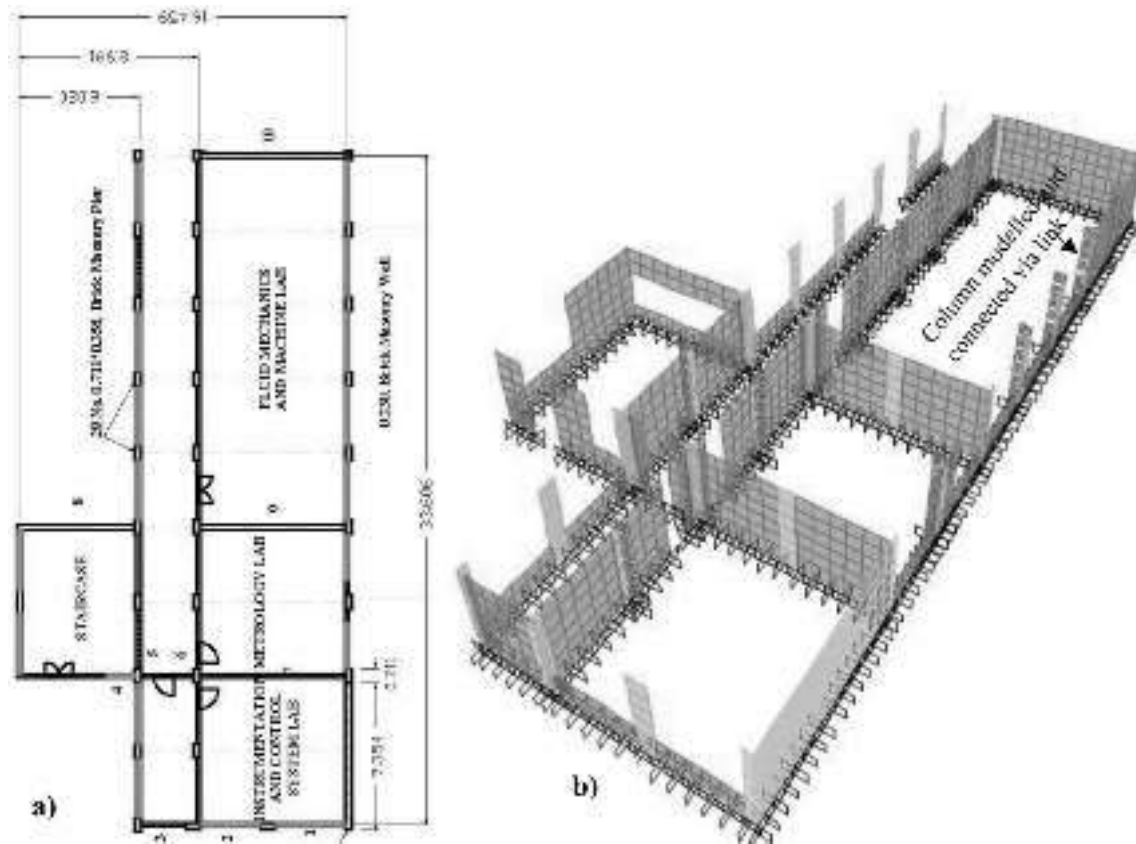


Fig. 5. a) Ground floor plan, b) 3-D view of ground floor with added columns via links in piers.

one option is developed. All these retrofitting options were modeled as discussed below:

1. Option 1: Modeling of restored (in its as built condition) URM building
2. Option 2: Modeling with both-side 50 mm thick RC-jacketing of the whole building as suggested by Tomaževic [18], Churilov [19].
3. Option 3: The combined action of 350mmx700mm brick piers and 400mmx400mm RC columns connected via 200mmx200mm RC shear-keys from brick piers in the whole three storeys (See Fig. 15). RC columns constructed inside the brick piers to transfer gravity as well as horizontal earthquake loads. To achieve combined action between the old brick piers and new RC columns, shear-keys inserted between these two heterogeneous components and their performance should be evaluated.
4. Option 4: Same as option 2, but RC-jacketing in the ground storey only.
5. Option 5: Same as option 3, but RC columns extend only up to the first storey slab.

The three dimensional (3-D) linear model of as-built URM building was prepared in FEM based SAP 2000 software and elementwise demands were evaluated based on NBC 105: 1994 [20] and IS 1893: 2002 [21]. Elementwise capacities in compression, tension and shear, for URM building, were evaluated using existing material properties and masonry's strength. The deficiencies were identified separately for all four retrofitting options. Elementwise deficiencies were addressed considering available materials, manpower and equipment. First retrofit option was designed as both-side 50 mm thick RC jacketing of the whole building using 12 mm dia. Rebar at 150 mm c/c vertically as well as horizontally as per IS 15988: 2013 [22]. In real execution, the outer and inner rebar meshes need to connect to have combined action. Based on the specific construction procedure adopted in these buildings during their construction, the second retrofitting option developed is the combined action of existing brick piers

(350mmx700mm) and proposed new RC columns (400mmx400mm) which are connected via RC shear-keys (200mmx200mm) from brick piers in the whole three storeys (Fig. 15). The designed longitudinal reinforcement in the columns is 8 bars (4nos 20 mm dia. + 4nos 16 mm dia.) with 10 mm dia. Stirrups at 100 mm spacing. In shear-keys, 4 nos 12 mm dia. re-bars were used. The failure of the masonry structure was observed due to excessive stress on brick pier. Hence, RC columns were adopted as a jacket for brick piers to resist the imposed stresses on the brick masonry piers. It is expected that during earthquake shaking, some portion of the horizontal earthquake force from the rigid diaphragm will be transferred to RC columns via floor beams, so as to release the stresses on the brick piers. The third retrofitting option is same as first option, but RC jacketing was done in first storey only. The fourth strengthening option is same as second option, but RC columns extended only in the first storey. The third and fourth retrofit options were selected to see whether they could address major deficiency in the structural system and to see the possibility of incremental retrofitting so that the immediate cost can be curtailed.

Herein, the building's performance was evaluated using "Static Nonlinear/Pushover Analysis" following the procedure of FEMA-356 [23] and Applied Technology Council (ATC-40) [24]. These standards provide the nonlinear static (pushover) analyses procedure for force- or displacement controlled methods. In displacement controlled method, the target displacement is used to verify the pre-established performance levels and displacement limits against the given demand. Then, the deformation capacities of the primary and secondary elements are linked with the failure modes (bed-joint sliding, rocking) of the structure, which ultimately determines the performance level of the structure.

In this study, the global capacity of URM building and retrofitted structures was assessed using non-linear static, i.e., pushover analysis. In this procedure, structural system is subjected to a pattern of monotonically increasing lateral forces/displacements on a nonlinear building model

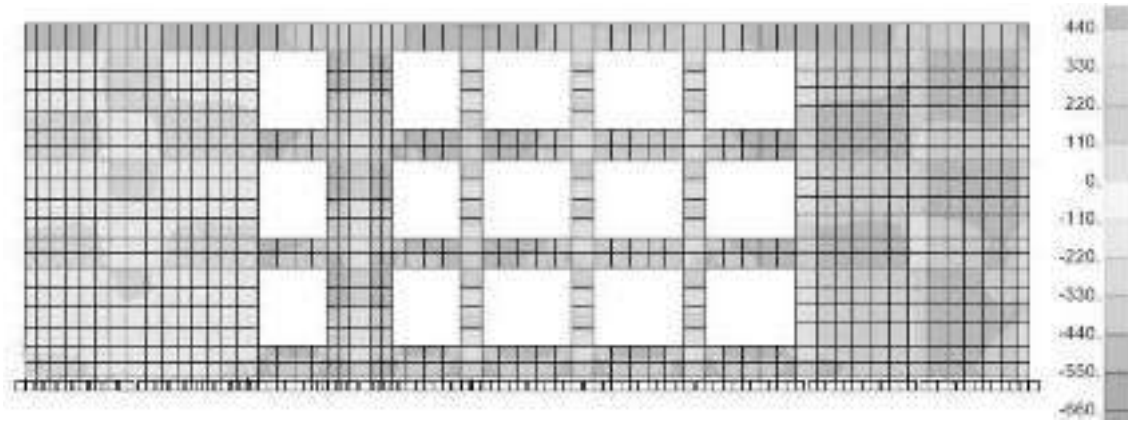


Fig. 6. Normal stress distribution (in kN/m^2) in wall for option-1, URM.

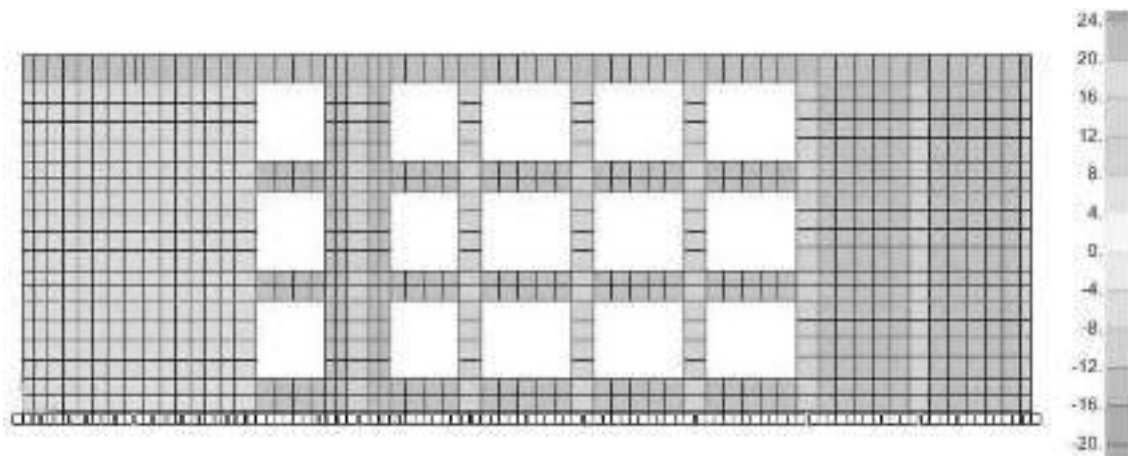


Fig. 7. Shear stress distribution (in kN/m^2) in wall for option-1, URM.

subjected to gravity loads. The lateral monotonic load increases iteratively causing elastic/inelastic deformations in the building until an ultimate condition (attainment of a pre-defined limit state/global collapse/loss of stability) is reached. This produces nonlinear force-deformation (base shear vs roof displacement at target node) relation, which is called pushover curve. Demand was evaluated using response spectrum from IS 1893: 2002 [21] considering seismic parameters at site. Then, the capacity curve combined with the demand curve gives the performance point. Based on the performance point, different performance levels defined in FEMA-356 [23] can be used to evaluate the performance level of the concerned building.

More commonly used methods of pushover analysis are “displacement coefficient method” and “capacity spectrum method”. In current study, displacement coefficient method was adopted based on methodology of FEMA-356 [23]. Displacement evaluated based on elastic analysis at the control node (location of center of mass at the roof level) was compared with the target displacement [25]. In most of the FEM software, base shear versus displacement plot uses a value of 0.4% (inter-storey drift set by IS 1893: 2002 [21]) of total building height as default maximum displacement value, which is elastic displacement. In current study, the target displacement was calculated based on provision of FEMA-356 [23]. The structure is then laterally pushed up to collapse in a way to estimate its evolutionary seismic response. FEMA-356 provides procedures for the determination of stiffness, strength, and deformation of masonry walls, which shall be applied to building systems comprising any combination of existing masonry walls, masonry walls enhanced for seismic rehabilitation, and new walls added to an existing building for seismic rehabilitation.

7. Results and discussions

In the considered building, there was an urgent need to safely transfer beams' load to the foundation soil, since wall piers under beams were severely damaged (Figs. 3 & 4). Restored URM building model analysis showed that the compressive and shear stresses developed along brick piers' bed joint exceeded the permissible values ($f_c = 0.294 \text{ MPa}$ (294 kN/m^2) and $\tau_c = 0.149 \text{ MPa}$ (149 kN/m^2)) evaluated using IS 1905: 1998 [26]. Brick piers' strength, evaluated using URM model and verified via manual calculations, found to be insufficient; hence, to meet demand, four retrofitting options (section 5) were modeled. RC-jacketing as well as RC columns, combined with brick piers via links, modeled to transfer the gravity as well as horizontal earthquake loads safely to the foundation. Brick piers and RC columns are heterogeneous materials, so to achieve combined action between old brick piers and new RC columns, shear-keys designed between these two heterogeneous components and their performance was evaluated.

Periods of vibration for the building evaluated as 0.36 s and 0.39 s along longer and shorter directions, respectively based on NBC 105: 1994/IS 1893: 2002 [20,21]. Model evaluated periods are 0.374 s, 0.284 s, 0.275 s and 0.264 s, respectively for URM (option-1), both-side full jacketing (option-2), both-side jacketing in ground storey only (option-4) and RC columns combined with piers in the whole building (option-3), and as option-3, but in the ground storey only (option-5). Results show the significant reduction in periods of vibration, mainly due to the increase in the rigidity via wall thickness enhancement. However, as expected, increase in the ductility due to the RC wall jacketing is not well captured by the model.

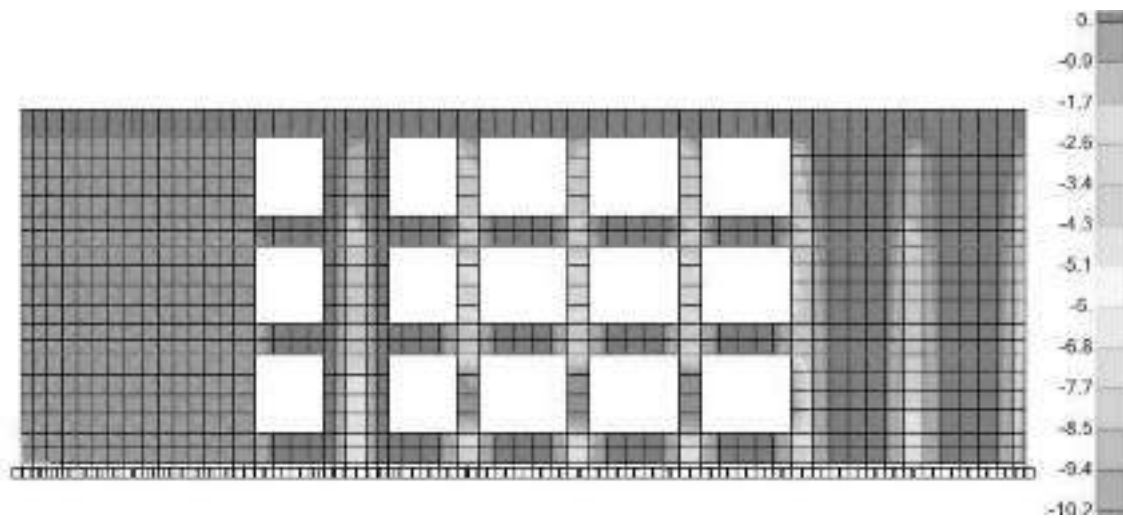


Fig. 8. Normal stress distribution (in kN/m^2) in wall for option-2, RC-jacketing in whole building.

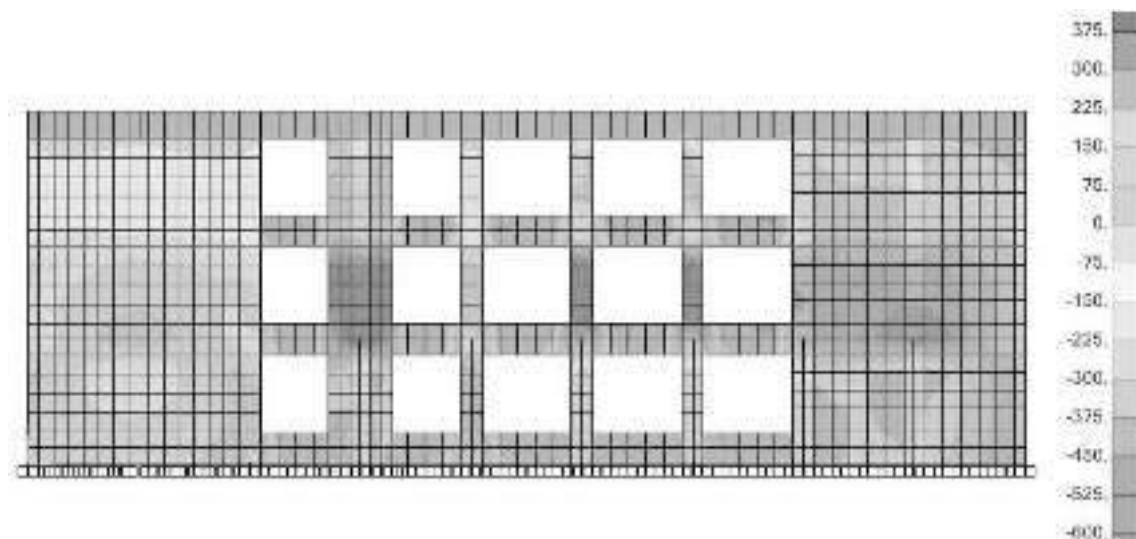


Fig. 9. Normal stress distribution (in N/mm^2) in wall for option-4, RC-jacketing only at ground storey.

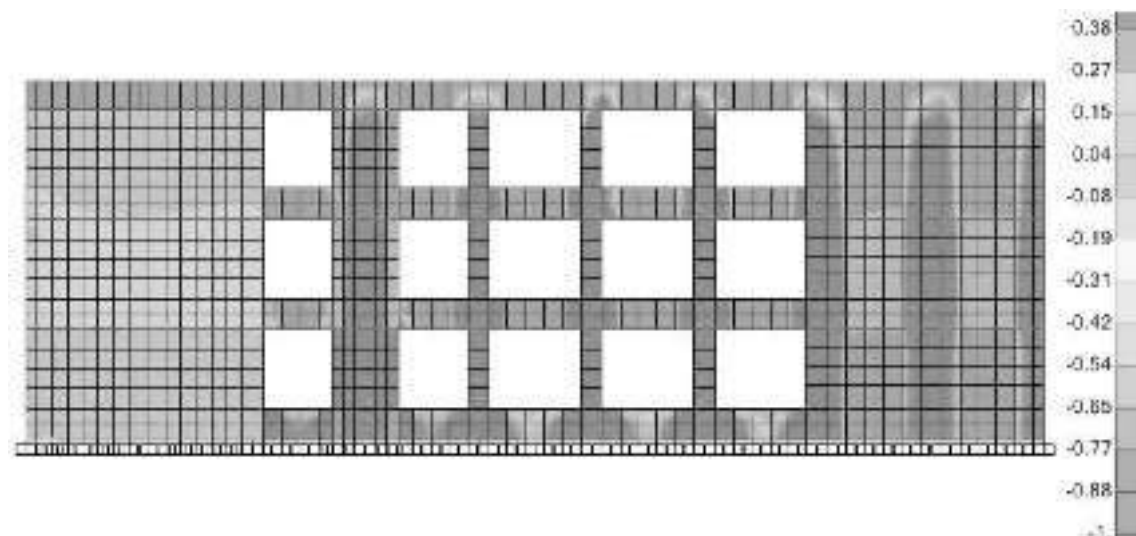


Fig. 10. Normal Stress Distribution (in N/mm^2) in wall for option-3, RC columns combined with wall piers in three storeys.

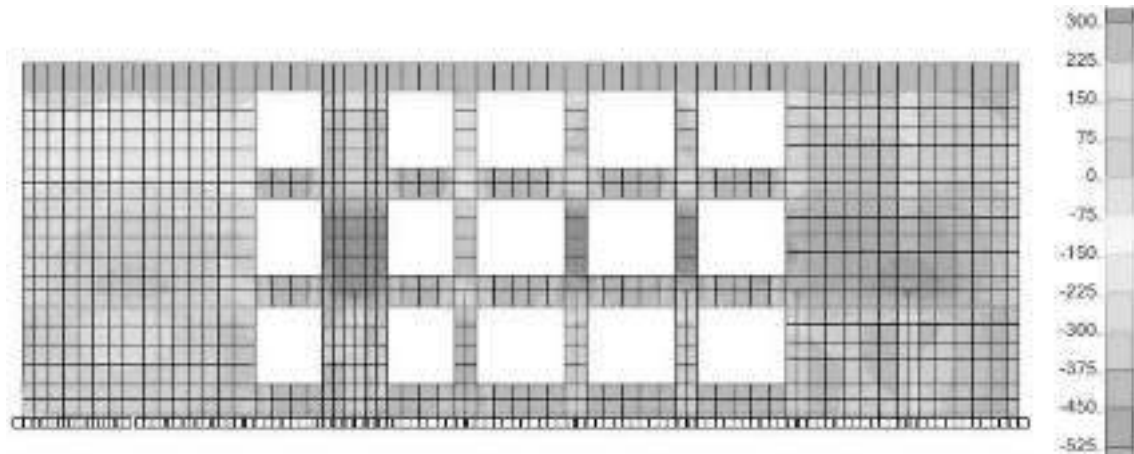


Fig. 11. Normal stress distribution (kN/m^2) in wall for option-5, RC columns combined with wall piers only at ground storey.

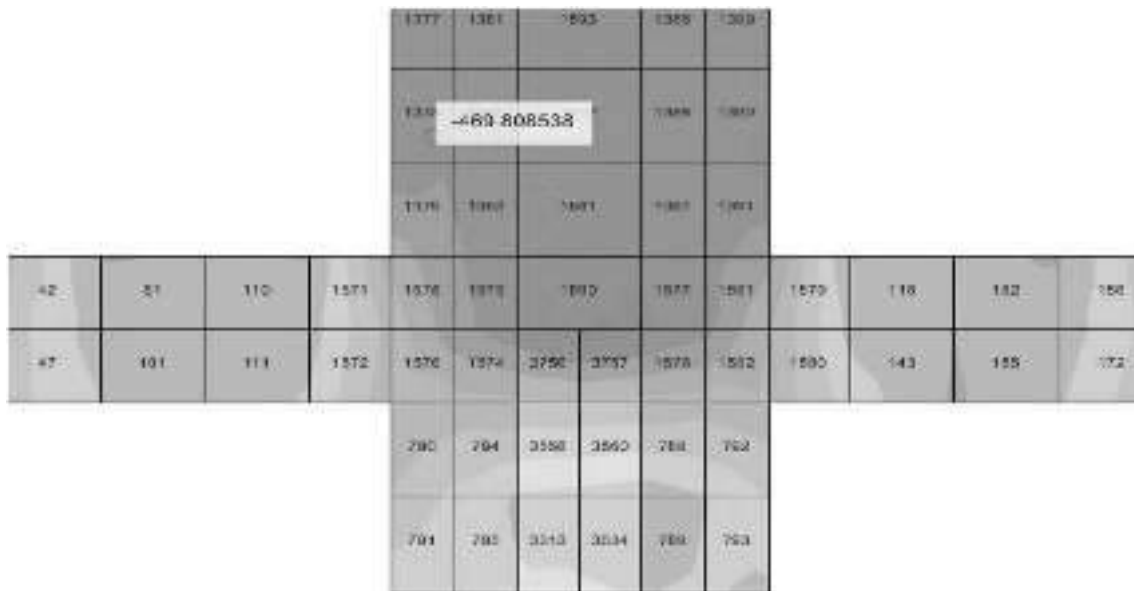


Fig. 12. Normal stress distribution (kN/m^2) in wall for option-5, RC columns combined with wall piers only at ground storey.

Analysis of stress contour from linear static analysis in URM walls show that compressive stresses developed crossed the limit of permissible stress ($0.294 \text{ MPa}/294 \text{ kN/m}^2$) as shown in Fig. 6. Increasing the load, it observed that the stress propagated in diagonal direction towards the top and bottom corner of wall from both sides. At first step, shear stress developed on the walls found to be equal to 0.0246 MPa , which is less than the permissible shear stress of 0.149 MPa (Fig. 7). On further loading, stress was found to be increased more rapidly at the ground storey walls' bottom ends compared to other portion of the wall. Shear stress increased more rapidly at bottom ends and around wall openings, especially at the sill level. In URM (option-1), tensile stresses developed in the walls under horizontal loads. Both sides RC-jacketing (option-2) reduces the stress level, significantly, since stresses are very less than permissible (Fig. 8). In the brick piers under beams, stresses found well below the permissible ranges.

To evaluate the effect of RC-jacketing only at the ground storey, the same was modeled by anchoring the steel reinforcements at first storey slab (Fig. 9). Stress contour in Fig. 9 show that normal stresses in the middle piers and spandrels crossed the permissible limit. It also indicates the stress concentration immediately above the termination point of RC-jacketing. It is due to the sharp change in the stiffness above the RC-jacketing level. As

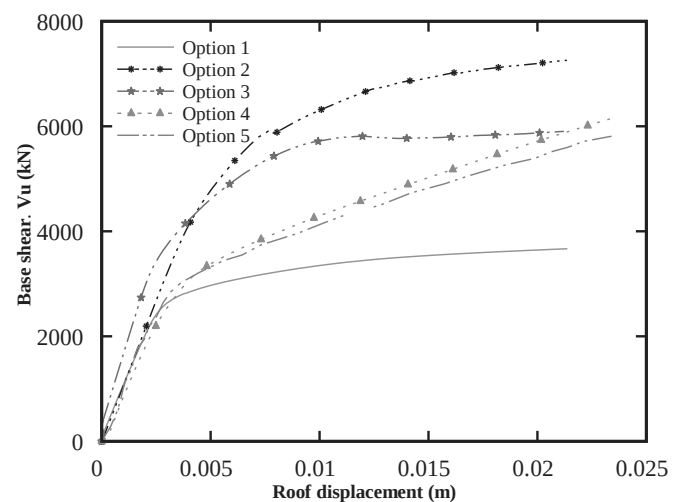


Fig. 13. Capacity curves for different strengthening options.

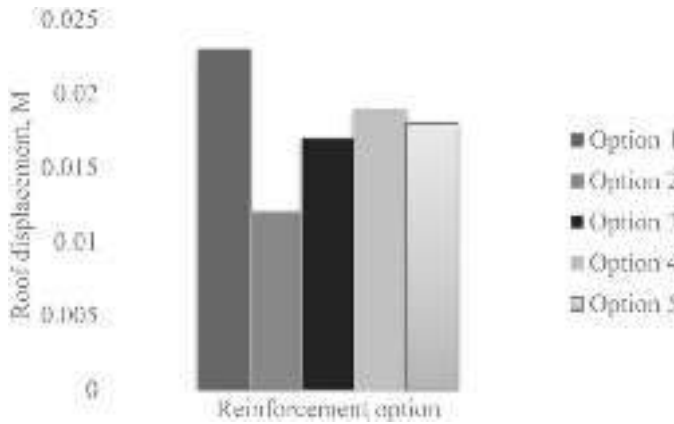


Fig. 14. Roof displacements for different strengthening options.

whole RC-jacketing (option-2), RC columns combined with brick piers via shear-links (option-3) also curtails the stresses well below the permissible values (Fig. 10), however, options-2 & 3 require more investment. RC columns combined with brick piers using links (option-5) in ground storey only show the stress concentration at upper storey piers and at roof level too (Fig. 11). In those zones, compressive stress values crossed the permissible limit of 294 kN/m^2 . In some pier-spandrel junctions, stresses developed crossed the permissible values (Fig. 12). The only point to consider is that these jackets should run from the foundation level up to the designed floor level having proper connection of reinforcements with beam or slab. When applying strengthening techniques, it is important that the walls should be uniformly distributed in both orthogonal directions of the building with sufficient strength required to resist seismic forces. Moreover, the walls should be tied and connected properly together with the floors, which should possess high rigidity in their plane.

Further, the pushover analysis, “Coefficient Method”, based on FEMA-356 [24], ATC-40 [25] and FEMA-440 [27] used to evaluate the capacities of URM building along with four cases of strengthening options. The results

obtained show that there is slight to significant increase in load carrying capacity of masonry walls with different strengthening options. There is 80% increase in lateral load carrying capacity and 48% decrease in the roof displacement of the building when RC-jacketing is used in the whole building (option-2) compared to URM building (option-1) as shown in Figs. 13 & 14. Application of RC-jacketing in ground storey walls only (option-4) increases the load carrying capacity by 11% and decreases displacement by 16% when compared to URM building (option-1). RC columns combined with wall piers in the whole building (option-3) increases the base shear capacity by 57% and decreases the roof displacement by 26% compared to option-1, whereas option-5 increases the base shear capacity by 14% and decreases the roof displacement by 21% compared to option-1.

Fig. 14 depicts the maximum roof displacement from nonlinear static analysis of the studied building. From Fig. 14, it is clear that RC-jacketing has significantly decreased the maximum roof displacement, whereas brick piers combined with RC columns via shear keys (option-3) provides a moderate reduction in roof displacement as compared to URM building. Options-4 & 5 provide slight decrease in roof displacement compared to option-1.

8. Implementation of seismic retrofit solution

Results show that RC-jacketing is the most efficient method of strengthening for masonry buildings; however, it completely changes the brick facades' appearance, which along with cost are the major constraints in using this method. Retrofitting via RC columns combined with brick piers using shear-keys in the whole building seems to be an alternative of RC-jacketing in preserving the brick facade's appearance, since it moderately enhances the capacity of the building. Though, strengthening using.

RC columns combined with brick piers via shear-keys only at the ground storey (option-5) enhances building's capacity slightly, it can be upgraded incrementally in future to option-3, when resources permit. Finally, considering owner's resource constraints, the option-5 was selected for implementation (see Fig. 15). However, special care should be taken while retrofitting ground storey only, since the stress concentration was observed in the walls of the first storey (immediately above the added columns) and

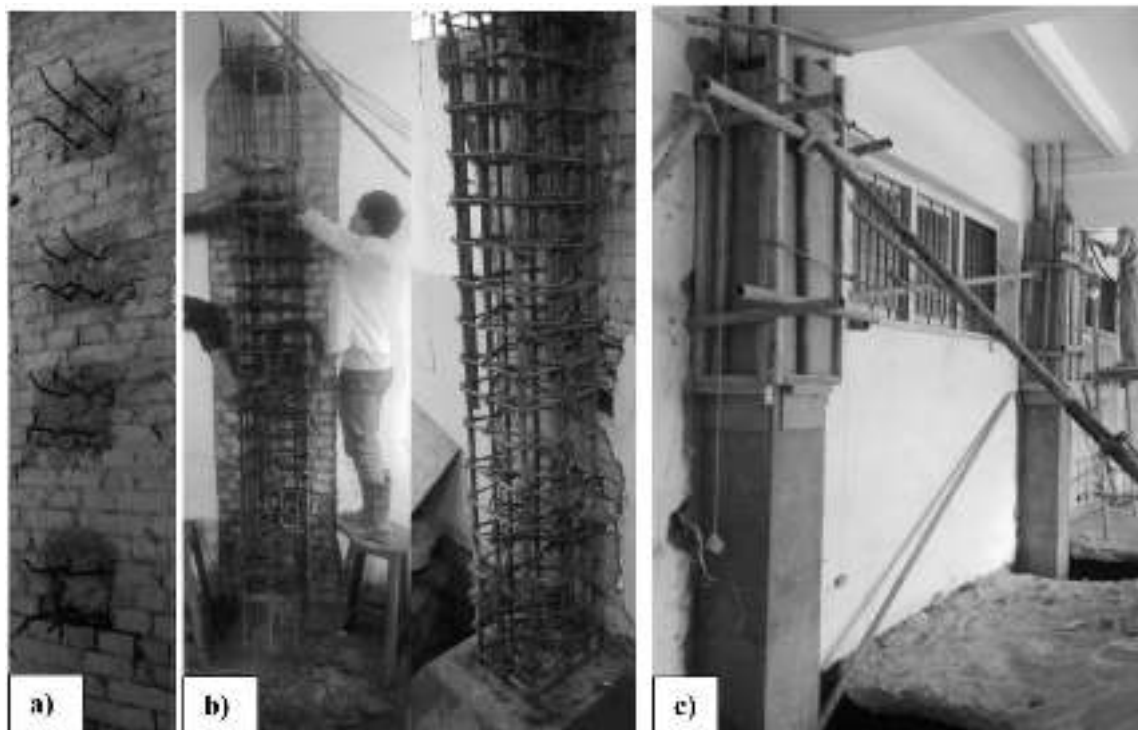


Fig. 15. a) Shear-keys from the Brick Pier to combine RC Column b) Reinforcement in RC Column covering Shear Keys c) Concrete casting in Columns.



Fig. 16. View of labs at the ground floor of D-block (Mechanical Engineering Department of Pulchowk Campus) after strengthening works were over.

at roof level (Figs. 11 & 12). Fig. 16 shows the lab view at the ground storey of D-block after implementation of the option-5.

Seismic retrofitting is a complex process aiming in strengthening individual structural elements and it should enhance the performance of the complete structural system. Hence, after strengthening the lateral resistance, ductility and energy dissipation capacity of a building should be validated.

9. Conclusions, selection of the feasible retrofitting option

The main aim of this study is to select the efficient and cost effective method of strengthening for masonry structures. Four viable options of retrofitting were selected for analysis. Therefore, restored URM building simulated along with four selected options of strengthening and obtained results were analyzed. Both side RC-jacketing significantly reduced the stress level in masonry piers, whereas moderate reduction achieved using RC columns combined with brick piers via shear keys. Options-4 and 5 slightly reduce the stress levels, however stress concentration observed at the termination junction. Finally, static pushover analyses performed to evaluate capacities of the four adopted options of retrofitting along with as-built URM building. The increase in the performance of masonry wall after application of different retrofit options were evaluated. There is moderate decrease in the fundamental period of vibration with strengthening options (24 to 29% compared to URM) indicating the influence on the structural performance via stiffness enhancement. RC-jacketing found to be most efficient option (80% increase in capacity, 48% decrease in roof displacement) of retrofitting for masonry structures; however, facade's appearance cannot be preserved. RC columns combined with brick piers using shear-keys performed satisfactorily, since it moderately increased the capacity (57%) and reduced roof displacement by (26%) compared to URM building. It is the new option developed in this study, and not found in the literatures, is the main contribution of this work. Strengthening via RC columns combined with brick piers only at ground storey introduces stress concentration in the immediate upper storey piers, so proper connection should be provided to maintain integrity and to reduce stress concentrations. It can be implemented in phases via incremental retrofitting when resources permit. After comprehensive analyses of the obtained results and keeping resource constraint in mind, retrofit by using RCC columns combined with brick piers at ground storey only was selected for final execution since it involved minimum cost. This option can be upgraded to option-3, incrementally when resources permit. This was the only way ahead with the Campus and it was immediately implemented (see Figs. 15 & 16).

10. Lessons learned/recommendations

Before the selection of an appropriate retrofitting option, compatible with the type of existing structure, detailed structural condition assessment should be performed to assess the local as well as global behavior and

performance of the structure. It is understood that the masonry wall restoration is not complex; however, it should be accompanied with the creation of box-action among the adjoining walls/elements so that structure's global capacity is enhanced. Heavy point load on the masonry piers are vulnerable and should be avoided. Incremental retrofitting is possible and should be practiced; however, appropriate policy should be in place. Although RC-jacketing is the most efficient method of strengthening for masonry buildings past post-earthquake observations showed that RC-jacketing might delaminate due to corrosion issues with cracking and detachment of concrete cover as mentioned in Meda et al. [28], Binda et al. [29]. Meda et al. [28] adopted high performance fiber RC jacketing to ensure adequate durability to the structure. During introducing the strengthening method of RC jacketing combined with masonry pier, sufficient concrete cover was provided to avoid corrosion. However, a detailed study is recommended to be performed to avoid the corrosion and issues related to delamination resulting from cracking and detachment of concrete cover.

Credit author statement

Gokarna Bahadur Motra: Conceptualization, methodology preparation, field assessment, material testing, modeling and analysis check, design, original draft preparation.

Satish Paudel: Field assessment, material testing, model preparation, analysis and design.

Declaration of Competing Interest

This is the sole research carried out by the authors in Nepal's reconstruction after 2015 Gorkha, Nepal earthquake. Authors declare that there is no conflicting interest in publishing this paper.

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Regular Article

Understanding short-term household recoveries from the 2015 Nepal earthquakes: Lessons learned and recommendations

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ABSTRACT

We assess tangible and intangible disaster recovery dynamics following the 2015 Nepal earthquakes and aftershocks in order to understand household adaptive capacity and transformation. We randomly selected 400 households in four communities across two highly impacted districts for surveys and interviews at 9 months and 1.5 years afterwards and returned at 2.5 years to share and discuss results. We found that household recoveries were heterogeneous, context specific, and changing. Tangible hazard exposure, livelihood disruption, and displacement and intangible place attachment and mental well-being influenced recoveries. We also illustrate challenges related to government programs, housing designs and codes, and outside aid.

1. Introduction

The April/May 2015 Nepal earthquakes and aftershocks caused catastrophic damage to life and property, killing nearly 9000 people, injuring more than 22,300, and damaging or destroying more than 750,000 private houses and government buildings and approximately 30,000 classrooms [54]. Within nine months of the earthquakes, Nepal experienced more than 400 additional earthquakes and aftershocks with a magnitude of 4 or greater, and within one year, more than 4000 landslides triggered by the initial events [75]. In 2015 and 2016, the earthquakes pushed an estimated 2.5 to 3.5% of the population into poverty and caused approximately NPR 706 billion (US\$ 7 billion)¹ in damages [54]. Recovery from these events is complex and multidimensional, unfolding over the short and long-term [60]. Tangible and intangible dynamics help to illustrate a household's ability and intention to adapt to these circumstances, what this adaptation looks like, and the time it takes. Disaster events may also influence transformations in everyday ways of life [80–82]. Better understanding of these multi-faceted short-term recovery dynamics can help to inform policy and future interventions.

To address this need, we conducted research on recovery dynamics during the first two and a half years following the 2015 earthquakes. Our project's main objective is to understand tangible and intangible short-term household recovery dynamics. Specifically, our analysis addresses the following two research questions: 1) what factors contribute to household natural hazard adaptive capacity? and 2) at what point do households transform after disasters? Examples of tangible impacts include exposure to natural hazards, place-based livelihood disruption, and displacement. Place attachment to ancestral settlements and mental well-being are examples of intangible impacts. To illustrate short-term disaster recovery dynamics, we combined a complex, integrated social and environmental systems approach with mixed quantitative and qualitative ethnographic methods and community outreach over two short-term time intervals. Addressing disaster recovery as a multidimensional phenomenon that unfolds over time compels researchers to consider many different factors and their interactions. Borrowing from the resilience literature [87], we selected five *domains of adaptive capacity* composed of many variables using the *rule of hand*, which advises choosing three to five key domains to best understand integrated social and environmental system function and change. Including

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too many domains can make the dataset too fuzzy. We selected our critical recovery indicators, demographics, and domains based on a pilot study, insights from the anthropological and social science literature on disaster [19,20], as well as our team's long-term ethnographic research and community collaborations in Nepal [80–82].

We use Oliver-Smith and Hoffman's definition [60] of a *disaster* as a “process/event combining a potentially destructive agenda/force from the natural, modified, or built environment and a population in a socially and economically produced condition of vulnerability, resulting in a perceived disruption of the customary relative satisfactions of individual and social needs for physical survival, social order, and meaning.” Thus, hazards, such as earthquakes or landslides, act on existing vulnerabilities to create disasters. Vulnerabilities can be bio/geophysical (e.g., constant landslide threat), social (e.g., economic inequalities), structural (e.g., architecture), and procedural vulnerabilities (e.g., state capacity). After a hazard turns into a disaster, it is best to focus on process and not necessarily outcome [42,61]. Returning to a pre-disaster state may not be desirable for a certain population, perpetuating root causes that helped to make the hazard a disaster in the first place [9].

The Nepal Government's Post-Disaster Recovery Framework illustrates the vision and strategic objectives that guided government recovery interventions. It was prepared under the leadership of the National Reconstruction Authority (NRA), in consultation with key stakeholders, to provide a systematic, structured, and prioritized framework for implementing the recovery. The framework aims for a sustainable, resilient, and planned recovery by supporting the country's development agenda [58]. The framework had stakeholder input and instructed the government to conduct a “social impact and vulnerability analysis” to inform their Disaster Risk Reduction strategies; however, vulnerability was by and large related to natural hazards, such as dangers from earthquake activated landslides. The policy seemingly did not account for the situated cultural and spatial heterogeneity in the everyday lives of Indigenous and rural populations in highly impacted areas, evidenced by the development of generic household designs that fail to account for limited livelihood strategies or local knowledge. The framework also had few indicators of vulnerability like geographic marginality, illustrated by the NRA providing the same rebuilding funds to households without road access and with high hazard exposure, where inflation is high from transport costs compared to those in less geographically vulnerable locations. Indeed, the total amount budgeted for the social impact and vulnerability analysis in the 2016–2020 priority recovery plan was 0.00083% of the total budget (NPR 180.6 billion or US\$ 1.8 billion) or NPR 1.5 million equivalent to US \$15,000 [58].

We define *recovery* as a process extending from the immediate relief and restoration of basic services directly following a disaster to the longer-term reconstruction of living conditions and livelihoods (and potential improvement, where appropriate), which can overlap and take many years depending on context [26,35,44]. These phases are fluid. We recognize that externally imposed conceptions of recovery phases may differ from those experienced by survivors [9]. We consider recovery from the earthquakes as dynamic processes with no distinct end point, accepting the constant force of change prior to and after the disaster [49]. It is also important not to accept a certain recovery state as a given, since this may obscure the role of inequality and other power dynamics in creating the disaster in the first place [9]. We recognize variation within and across settlements each with different states prior to the earthquakes, therefore trying to incorporate insider and outsider conceptions of recovery in our approach. We included insider and outsider perspectives in the development of the study, especially in domain and variable selection, through a pilot study at the onset of the project, previous research by the authors (e.g., [76–79]), and published studies. Insider perspectives include those from earthquake survivors; whereas, outsider perspectives encompass those of the researchers and outside actors, such as the government or aid community.

In order to understand tangible and intangible recovery dynamics, we focus on the role of *adaptive capacity*, which signifies the ability and intention of a household to adapt to natural hazards and their cascading effects [40,59,67]. Adaptive capacity can also be multifaceted; for example, a

community may be more resilient immediately following the disaster, though lacking adaptive capacity in the long-term [86]. A longitudinal approach also recognizes that a population may experience additional natural hazards that cascade from the original disturbance (e.g., landslides) or new hazards altogether (e.g., severe weather). We also consider long-term recovery in our analysis since short-term recovery cannot be viewed in isolation [21]. Future research by the authors will add to this discussion.

Each domain of adaptive capacity was comprised of multiple variables identified by researchers and community members as important elements of adaptive capacity. These include: (1) *hazard exposure*, (2) *institutional participation*, (3) *livelihood diversity*, (4) *connectivity*, and (5) *social memory*. Hazard exposure incorporates biophysical vulnerability such as proximity to landslides and threats, and encumbered access to farms, pastures, forests, and firewood collection areas. Institutional participation focuses on the impact of participation in the governance system and other formal and informal institutions. Livelihood diversity focuses on the roles of income heterogeneity and varied patterns of resource use. Connectivity includes connections between households and external actors and agencies in obtaining recovery assistance and the flows of outside ideas. Social memory encompasses knowledge based on experiences with previous natural hazards and the functions of Indigenous and local knowledge and practice in the recovery. The recovery indicators include ability to return to home from temporary shelter, issues rebuilding home, access to basic services that existed in each location prior to the earthquakes (electricity, cell phone, and Internet) and impacts on herding, farming, forest product collection, and market participation (e.g., wage labor and tourism). Fig. 1 illustrates the conceptual relationship between the five domains and recovery indicators. Note that hazard exposure acts on the other four mitigating interrelated domains, which in turn affect the recovery indicators (see [82] for a full list of variables in each domain).

Our research explored demographics, the five selected domains, and critical recovery indicators on the household and settlement levels using information-sharing meetings, surveys, in-depth interviews, and focus groups over two ten-week research phases at about 9 months (phase 1) and 1.5 years (phase 2) after the earthquakes. We also returned at 2.5 years to discuss preliminary results and interpretations. The term “phase” refers to the research-time interval in which we conducted the survey, consistent with other publications developed from this project. The term is not intended to signify the phases of the disaster risk management (DRM) cycle (preparedness, relief, recovery, and mitigation) [85]. This paper focuses specifically on short-term dynamics of the recovery phase in the DRM cycle. The NRA was officially established in December 2015. Prior to this, the Nepal Government used the National Disaster Response Framework to guide their response during the relief phase (Government of Nepal 2013). We waited nine months to start information collection until the NRA was established and the national reconstruction program started. This is the time that the government shifted their operations from relief activities to the short- and long-term recovery phase. This phase primarily centered on the rebuilding of housing and critical infrastructure. We therefore consider the start of the NRA program at nine months to be the transition between relief and recovery phases, which parallels Nepal government operations.

At 2.5 years, nearly all households had received one tranche (incremental payment) of the total NPR 300,000 (US \$3000) promised to each household to build an earthquake-safe home according to the newly developed building codes. The first tranche included eligibility, verification, and enrollment with a payment of NPR 50,000 (US \$500). These payments began in July 2016, between phases 1 and 2 of our research. Two additional tranches were paid out for completion of the house foundation to the *plinth* level at NPR 150,000 (US \$1500). The plinth level is a reinforced cement concrete, timber, bamboo, or other approved construction material band. It was evaluated after the completion of the foundation and covers the entire wall [58]. The third tranche was paid for upon completion of construction up to the roof-band level at NPR 100,000 (US \$1000). The roof-band level is an upper level of reinforced cement concrete, timber, bamboo, or other approved construction material. Evaluation occurred before the placement of the roof beams [58]. Payments were made to households

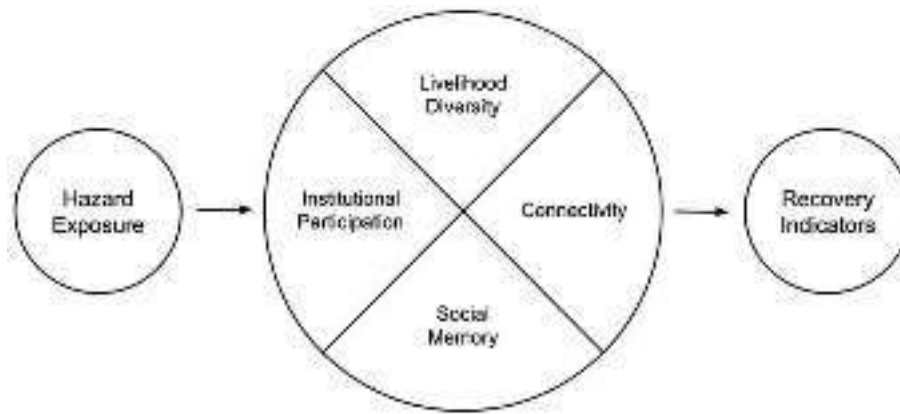


Fig. 1. Conceptual model of five domains of adaptive capacity and recovery indicators. Hazard exposure acts on four mitigating interrelated household characteristics that influence recovery indicators.

only after inspection by the NRA. These funds were typically transferred directly into the beneficiary's bank account [56,84]. Access to bank accounts for our household sample differed depending on the location of the bank or associated automated banking machines, which could be a one- to three-day walk from a household's settlement. Most households had received the second tranche by our research return workshops at 2.5 years. The study therefore focuses only on short-term recovery dynamics (0–2.5 years) and does not provide information on the payouts of all three tranches and the completion of the newly constructed homes. Future research by the authors will focus on long-term recovery in years 5–10 after the earthquakes.

We used non-metric multidimensional scaling (NMDS) ordination to analyze quantitative data [50] and inductive content analysis to analyze the qualitative data [11]. NMDS is a statistical method widely used in ecology to analyze complex datasets comprising many variables and to identify underlying patterns of variation. Here, we use NMDS to identify households that exhibit similar patterns of recovery, and explore how specific recovery indicators contribute to those patterns. Inductive content analysis searches for the frequency and salience of emergent themes in interview and focus-group transcripts (see [80–82] for further discussion on these methods).

At phases 1 and 2, we found that households in each of the four locations had different starting places in the recovery and moved in both positive and negative directions between the two research intervals. Recovery indicators with the strongest associations with patterns of recovery suggested that exposure to natural hazards, livelihood, and displacement influenced recovery success [80]. We explored these associations systematically using NMDS to help “map” the relationships among the recovery indicators, demographics, and domains of adaptive capacity [82]. The inductive content analysis triangulated and enhanced the trends identified in the NMDS, illustrating how inequality shapes tangible and intangible recovery dynamics. Assembled together, the data from the NMDS and content analysis provide a holistic picture of short-term recovery patterns and variations in this context across multiple sites [81].

In this paper, we summarize the key findings from Spoon et al. [80–82] that are relevant to policymakers and practitioners. We also provide new quantitative and qualitative evidence from the NMDS, descriptive statistics, and content analysis of surveys, interviews, focus groups, and research return workshops. The new results include household perceptions of government relief, the national reconstruction program, and outside aid. We also add local conceptions of the government-approved earthquake-safe housing designs, building codes, and disaster preparedness. We conclude with guiding principles and recommendations for applied research and interventions in disaster contexts. We then share Nepal-specific recommendations developed using the guiding principles and recommendations.

2. Methodology

2.1. Site selection

We use a systems perspective to address interdependencies between human populations and the environment with dual feedbacks [87]. A systems view characterizes humans and the environment in constant flux, where humans act on the environment and it in turn acts on humans. In rural and Indigenous contexts, systems approaches help to illustrate critical interrelated social and environmental factors, including hazard exposure and place-based livelihoods with strong place attachment, common to many of the world's Indigenous peoples [13,35,48].

The household is our primary unit of analysis. Many of our impact measures are at the household level, a common focus of monitoring and evaluation where aid and government relief are coordinated. Nepali households are traditionally multigenerational with the eldest member of the family serving as the head of household. Recently, however, nuclear families are becoming more common [88]. In needs assessment reports and in the post disaster recovery framework for the distribution of relief and recovery materials and funds, the Nepal Government used the household unit. However, the Post Disaster Needs Assessment ([54]: 4) did not offer a clear definition for household, stating that in reconstruction “the total number of houses to be reconstructed has been calculated on the basis of number of households made homeless.” Shneiderman et al. [73] argue that the Central Bureau of Statistics adopted the definition of household based on United Nations guidelines, defining a household as: “arrangements made by persons, individually or in groups, for providing themselves with food or other essentials for living.” Thus, a household may consist of one or more persons who may be related or unrelated, and may have a common budget. Two factors must be present in this household definition: 1) dwelling under one roof, and 2) eating together. This definition allowed some households to claim their separate kitchen as a different household unit in practice, obtaining additional benefits. Further, NRA's Private Housing Reconstruction Grant Distribution Procedure, 2072 [58] stipulated that households needed to have legal certificates of land ownership predating the earthquakes to be eligible for the housing reconstruction grant. In some settlements, monasteries own the land that people live on, in an arrangement called the Guthi system [69], leading to some individuals not having legal certificates for land ownership (see [52] for a discussion of land tenure problems after the earthquakes). We therefore define a household as a physical residence under one roof where household members typically, although not exclusively, share economic resources and have kinship relationships. We defined households similarly to the Central Bureau of Statistics in order to identify households to include in our study; however, we diverged from this definition by also including households without legal certificates for land ownership, where the household had maintained

residence in their home for multiple generations. Thus, we treat the settlement and clusters of settlements as secondary foci.

To account for variation in the key parts of our conceptual approach, as well as links to the broader context, we selected two districts, Gorkha and Rasuwa, as study sites (Fig. 2). Both had severe earthquake impacts: Gorkha was the epicenter of the April 2015 earthquake with 412 killed, 1034 injured, and 55% of buildings destroyed [62], and Rasuwa was decimated by earthquake triggered landslides, with 430 deaths (the highest number

of deaths in relation to the entire population), 753 injured, and 95% of buildings destroyed [63]. We selected two administrative areas of that time, called Village Development Committees (VDCs), to contrast in each district. In each district we selected an accessible VDC near the road with more international and national non-governmental organizations (NGOs) and market-based livelihoods and one far from the road with less NGOs and more reliance on agropastoralism. In Gorkha, we selected as representative case studies the more-accessible Aaru Chanaute and less-accessible

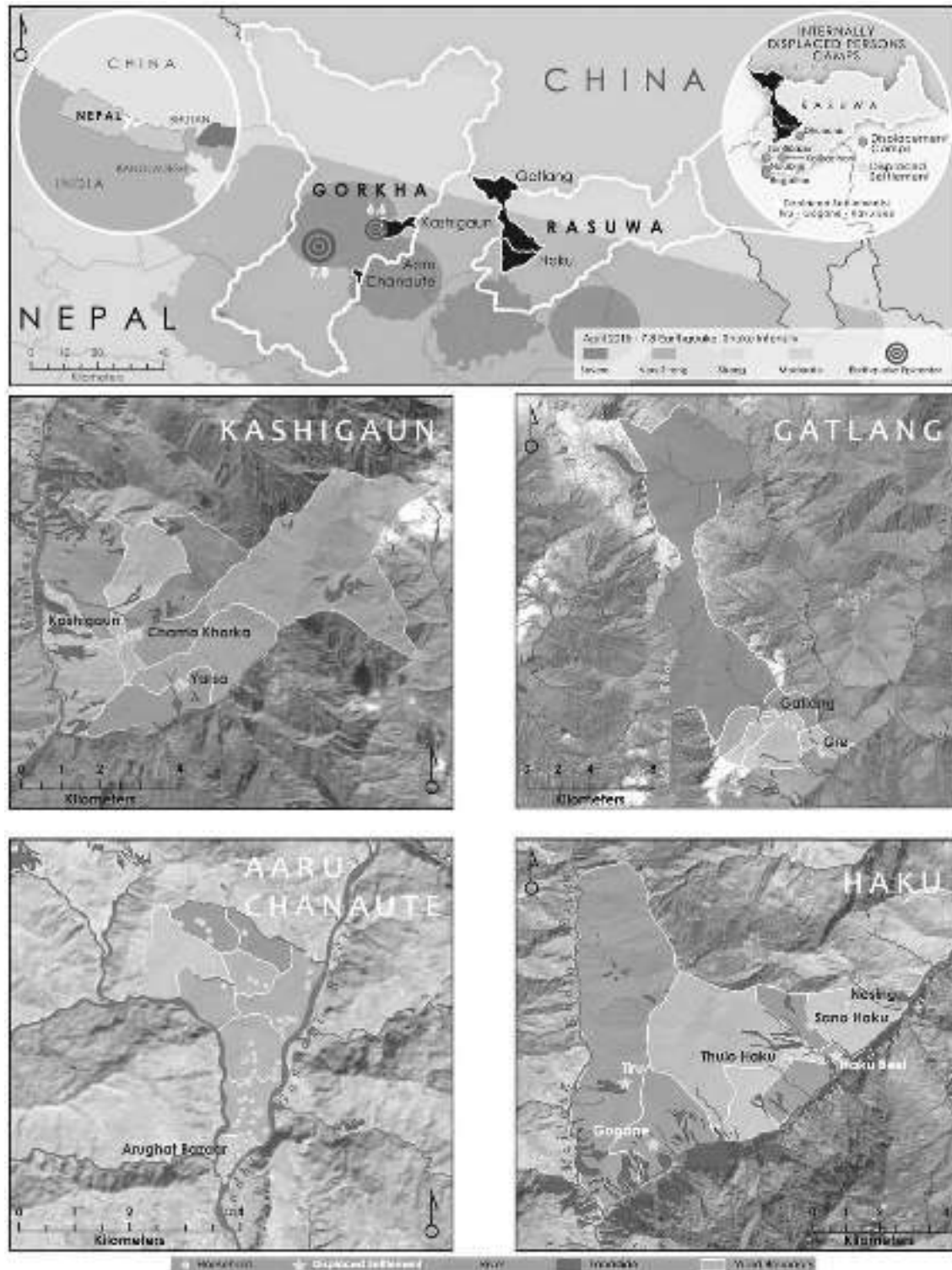


Fig. 2. Map of study area with shake intensity from the April 2015 earthquake with selected Village Development Committees and Internally Displaced Persons Camps (see upper right). Proximity of settlements to landslides also illustrated [38]. Map by Alicia Milligan. Adapted from Spoon et al. [80].

Kashigaun. Aaru Chanaute has the most heterogenous ethnic, linguistic, and religious population in our sample, with primarily Newar, Brahmin, and Chhetri ethnic groups that live with multiple generations in the same home using the same kitchen. Households all have road access and practice mostly *khet* (irrigated) agriculture, limited pastoralism and forest product collection, and have various small-scale businesses. Part of Aaru Chanaute is in the inundation zone of the planned Budi Gandaki dam. Kashigaun is primarily the Buddhist Gurung ethnic group with some Dalit households. Households are multigenerational, with some generations and/or nuclear families living in the same houses but using different kitchens. They practice *bari* (non-irrigated) agriculture, pastoralism, and forest product collection. Conversion to Christianity is increasing in Kashigaun, especially after the earthquakes (see Section 3.2). In Rasuwa, our sites included the more-accessible Gatlang and less-accessible Haku. Gatlang is mostly comprised of Tamang households all accessible by road that practice *bari* agriculture, pastoralism, forest product collection, and some emerging tourism enterprises. Gatlang residents practice more herding than farming. Haku is also primarily Tamang households with largely agropastoral livelihoods on the biophysical margins. Haku had catastrophic landslides that forced three entire settlements into displacement camps for 1.5–2.5 years or more. Haku also experienced an increase in conversion to Christianity after the earthquakes (see Section 3.2). Both Gatlang and Haku residents live primarily in multigenerational homes; however, similar to Kashigaun, there is typically a separate kitchen for different generations and/or nuclear families. Though Aaru Chanaute, Kashigaun, Gatlang, and Haku are currently part of rural municipalities under new administrative divisions, the administrative unit, VDC, is used for convenience. In the new rural municipalities, each VDC selected for this study is now one or two wards. The new municipalities are: Aarughat Rural Municipality (Gorkha District; includes Aaru Chanaute VDC as two wards), Dharche Rural Municipality (Gorkha District; includes Kashigaun VDC as one ward), Aamachodingmo Rural Municipality (Rasuwa District; includes Gatlang VDC as two wards and part of Haku VDC as two wards), and Uttar Gaya Rural Municipality (Rasuwa District; includes part of Haku VDC as one ward).

Once sites satisfied our criteria, we selected locations that appeared more “typical” of earthquake impacted VDCs and not as outliers with exceptionally devastating experiences not comparable to others. Outliers included sites where all households were relocated to internal displacement camps because of catastrophic earthquake and landslide-related impacts. For example, one VDC in Gorkha had the top of a mountain fall and subduct multiple settlements, completely destroying the built environment. We also omitted VDCs that did not have all of the houses and critical infrastructure damaged or destroyed, which we considered typical. Lastly, we omitted

VDCs where an external aid institution offered unique, often charismatic interventions, such as rebuilding an entire village before the national reconstruction program began. To select the random sample households, we utilized local censuses collected by VDC staff after the earthquakes and provided to project staff during the pilot study; we then selected households using a random number generator. We utilized an inductive content analysis in Atlas.ti software to assess the pilot study data in order to guide the design and analysis of our quantitative survey.

2.2. Data collection

Our field team consisted of the Principal Investigator (Spoon), two Project Coordinators (Rai and Basnet), five local and Kathmandu-based Research Assistants, and four Translators. Our Project Coordinators already had some rapport in these communities through previous conservation and livelihood-related NGO projects. We met in Fall/Winter 2015 with local leaders and government representatives to help select study sites and obtain the census for drawing the random sample. We also carried out exploratory interviews and focus groups to select recovery indicators, demographics, and domains of adaptive capacity. The role of the information sharing meetings was to introduce the project to each site and share preliminary results. They were also opportunities to differentiate our research from government and aid-community projects. The first series of information sharing meetings described the research phase in Nepali and the local languages of Gurung or Tamang. Each participant received a one-page project explanation in Nepali and team follow-up contact information. The second series of meetings was held after the first data collection phase. We presented results from the prior research phase and solicited feedback to inform our interpretation. We generally had great interest from those in attendance at the meetings to learn about the project and its preliminary results. Importantly, we attempted to ensure even gender representation and that multiple generations from as many interested families as possible attended regardless of whether they were included in the random sample.

For all surveys, interviews and focus groups, we received prior and informed consent from each participant [11]. The research team gave participants a handout in Nepali explaining the study and its potential risks and intended benefits, with contact information for the research team throughout the study period (see Table 1 for methods summary). The household survey tracked recovery indicators, demographics, and five domains of adaptive capacity. At phase 1, we enrolled 400 randomly selected households from the four communities using the local census provided by the VDC. We selected 100 households from each VDC. At phase 2, we were able to re-contact 397 of the original 400 households. We strove to locate

Table 1
Data collection methods, data types, research periods, sample sizes, data analysis methods, and topics (variables). From Spoon et al. [80].

Data collection method	Data type	Research period(s)	Sample size	Data analysis method	Topics (Variables)
Household survey	Quantitative and qualitative	January–March 2016; October–December 2016	$n = 400$; $n = 397$	Descriptive statistics; NMDS; Inductive content analysis	Recovery indicators (34 total) Demographics (35 total) Hazard exposure (12 total) Institutional participation (12 total) Livelihood diversity (73 total) Connectivity (16 total) Social Memory (27 total) Qualitative follow-up questions based on quantitative survey responses
In-depth interviews and focus groups	Qualitative	January–March 2016; October–December 2016	$n = 40$; $n = 8$	Inductive content analysis	Earthquake impacts Worries, hopes, challenges, and threats Perception of hazard risk Role of institutions in recovery Role of local perspectives in recovery Livelihood impacts and transitions Perception of government and outside aid Role of local knowledge in recovery Emergence of new opportunities
Research return workshops	Qualitative	October–December 2017	$n = 8$	Inductive content analysis	Triangulation of prior results with participant and key consultants' perspectives and experiences Interpretation of key findings and updates

the specific respondent who participated in the first phase, but designed the survey to be taken by any household member over the age of 18. The sample sizes for each VDC from each phase were as follows: Aaru Chanaute (phase 1, $n = 100$; phase 2, $n = 98$), Kashigaun (phase 1, $n = 100$; phase 2, $n = 100$), Gatlang (phase 1, $n = 100$; phase 2, $n = 99$), and Haku (phase 1, $n = 100$; phase 2, $n = 100$). The survey included 34 recovery indicators and 175 variables divided across demographics and the five domains of adaptive capacity. Each domain contained variables identified by researchers and community members as important elements of adaptive capacity. By utilizing a fairly large random sample, our results should represent much of the variation within and support inferences about the broader population in each VDC (see [80,82] for further discussion on the quantitative methods).

In total, we conducted 797 surveys between phase 1 and phase 2, 40 in-depth interviews at phase 1, eight focus groups at phase 2, and eight research return workshops at 2.5 years. In-depth interviews and focus groups used semi-structured interviews to explore the tangible and intangible dynamics of the recovery at greater depth. We enrolled key consultants from the household sample for in depth-interviews from each VDC (10 per VDC) through quota sampling of age and gender. The focus groups used reputational sampling, including key consultants from the household sample as well as representatives from government, local institutions, and aid agencies. We did not mix household members with non-household actors in the focus groups so that we could compare responses from different perspectives without them influencing one another. We carried out interviews in Nepali, Gurung, and Tamang. They were recorded, translated, and fully transcribed for analysis. Qualitative interviews helped to triangulate quantitative results as well as add new insights only observable through qualitative methods (see [81] for further discussion on linked quantitative and qualitative methods).

The eight research return workshops on the local and national scales helped with the interpretation of results and provided updates at 2.5 years after the earthquakes. We invited all of the newly elected government officials from the four VDCs to attend the local workshops. These workshops thus served as a conduit for us to share information with the local government. On the national and international scales, the workshops brought into dialogue local government officials, aid representatives, academics, and the media to discuss project results and next steps.

2.3. Data analysis

Our team examined the quantitative household survey data in the software program PC-ORD, which provides extensive tools for non-metric multi-dimensional scaling ordination [51]. NMDS is an exploratory technique allowing us to identify households that exhibit similar patterns of recovery and to link these patterns to specific hazard exposures and forms of adaptive capacity. Unlike other statistical analyses, NMDS requires minimal assumptions about the relationships among variables (linear or non-linear) and can be used with multiple variable types (numeric, dichotomous, ordinal) [50]. By incorporating information from multiple variables, NMDS is useful in analyzing different aspects of complex, multidimensional phenomenon like disaster recovery. NMDS provides measures for the direction and strength of associations among the recovery indicators, demographics, and five domains of adaptive capacity (see [80,82] for further discussion on the NMDS analysis). Specifically, we use the coefficient of determination (R^2), which measures the amount of variance in overall patterns in recovery associated with a single recovery indicator, to identify which indicators drive patterns of recovery. We use $R^2 > 0.050$ as an indicator of a substantial association and discuss less substantial associations with an $R^2 < 0.050$ where appropriate.

We used Atlas.ti for our content analysis to organize into groups and codes qualitative responses from 797 surveys and transcripts from 60 h of in-depth interviews, 12 h of focus groups, and 10 h of research return workshops. To analyze the qualitative data, we employed grounded theory. Grounded theory is an inductive content analysis technique, viewing the world as complex with each situation affected by multiple factors

[11,18]. To identify emergent themes, we began with open coding [16,22], then used the themes to designate code groups, each with multiple sub-codes. We then identified specific nuances and subcategories using the code groups and sub-codes [91]. The analytic team maintained consistent communication to discuss any issues and maintain transparency throughout the process. Examples of our larger code groups include: social and spatial inequality, hazard exposure, place-based livelihood disruption, displacement, mutual aid, government rebuilding program, outside aid, housing reconstruction, place attachment, uncertainty towards the future, and mental well-being (see [81] for further discussion on inductive content analysis as well as code groups and their definitions).

3. Results and discussion

We now discuss our general quantitative and qualitative results across nine cross-cutting topics useful to policymakers and practitioners, illustrating aspects of adaptive capacity. We discuss the results from topics 1–5 and parts of 8–9 in other publications [80–82], summarizing them here. We introduce new information in Tables 2 and 3, topics 6–7, as well as parts of 2–3 and 8–9. Most of our discussion treats the recovery as a whole, although we do share some results specific to each VDC. We provide select linear associations among recovery indicators, demographic variables, and domains of adaptive capacity in Table 2 and key descriptive statistics from the household survey that help to contextualize the sample in Table 3. We describe the full quantitative and qualitative results in SM 1.

3.1. Recovery indicators

We consider recovery as having multiple dimensions, consistent with results of similar studies on short-term household recovery from the Nepal earthquakes [5]. Fig. 3 is a scatterplot that shows patterns among households in relation to two dimensions of recovery, identified using NMDS with 34 indicators of recovery. Each household's location on the x-y plane is determined by the similarity of their responses to the 34 indicators. By comparing one household's location with another, we can compare patterns of recovery across households. By examining which recovery indicators had the strongest associations and where they exist in the x-y plane (represented by these lines on Fig. 3), we can see what each axis represents. In this case, the x-axis illustrated positive or negative recovery indicators, such as presence or absence and severity of agropastoral impacts. The y-axis showed the degree of displacement from primary house and place-based livelihoods as well as to displacement camps (see [80,82]). In Fig. 4, each household has two points representing their responses at each phase. By comparing a household's location on the figure at each phase, we can see changes in recovery across time. To highlight patterns in recovery across VDCs, we added centroids in Figs. 3 and 4 that represent the average position of households in each VDC.

The results show that each VDC had its own starting place in the recovery and was either static or travelling in a positive or negative direction between the two phases (Fig. 4). Households from Aaru Chanaute (VDC 1) had the best starting point in the recovery of all locations (see Section 3.2); however, they did not change much between the phases. This was largely due to the planned Budi Gandaki dam (see Sections 3.4. and 3.5). Although starting in a compromised position, Kashigaun (VDC 2) was heading in a positive direction in phase 2. We attribute this in part to their operationalizing of Indigenous knowledge through work exchange (see Section 3.8). Gatlang (VDC 3) was heading in a negative direction and Haku (VDC 4) remained relatively stagnant, with a large proportion in displacement camps (see Section 3.5). Gatlang's challenges may be due to dependence on outside aid and the road (see Section 3.6). All settlements took steps to return to their place-based agropastoral livelihoods in phase 2. The 34 recovery indicators thus serve as the base ordination to view associations with demographics and the five domains of adaptive capacity that follow [80,82]. These results are comparable to two nearby districts where early social, economic, and psychological recovery were rare [5].

Table 2

Select linear associations by demographic or domain of adaptive capacity between NMDS dimensions of recovery (Axis 1, Axis 2) and each variable. Linear associations are represented by a correlation coefficient (r) and R square (R^2) for each axis, with bold indicating $R^2 > 0.050$. Full linear and non-linear results for all 209 variables in the study available in Spoon et al. [82].

Select variables by demographic or domain of adaptive capacity Questions are Yes/No unless otherwise noted	Axis 1		Axis 2	
	r	R^2	r	R^2
<i>Demographics</i>				
Aaru Chanaute (VDC 1)	0.400	0.160	0.037	0.001
Kashigaun (VDC 2)	−0.120	0.014	0.228	0.052
Gatlang (VDC 3)	−0.009	0.000	0.087	0.008
Haku (VDC 4)	−0.267	0.071	−0.351	0.123
Internal displaced persons camp (phase 1)	−0.242	0.059	−0.418	0.174
Internal displaced persons camp (phase 2)	−0.245	0.060	−0.413	0.171
Accessibility	0.096	0.009	0.193	0.037
Buddhist	−0.279	0.078	−0.098	0.010
Hindu	0.296	0.088	0.072	0.005
Tamang	−0.229	0.052	−0.211	0.044
Newar	0.234	0.055	0.009	0.000
Brahmin/Chhetri	0.190	0.036	0.108	0.012
Gurung	−0.094	0.009	0.120	0.014
Ghale	−0.021	0.000	0.114	0.013
Home owners (phase 1)	0.029	0.001	0.042	0.002
Home owners (phase 2)	0.171	0.029	0.421	0.177
Microcredit loans	0.163	0.027	0.084	0.007
Literate	0.144	0.021	0.065	0.004
Household size-log (larger)	−0.072	0.005	0.137	0.019
<i>Hazard exposure</i>				
Household has significant impacted access to grazing areas (phase 1)	−0.497	0.247	−0.015	0.000
Household has significant impacted access to grazing areas (phase 2)	−0.328	0.108	0.145	0.021
Household has significant impacted access to firewood collection (phase 2)	−0.289	0.084	0.072	0.005
Household has significant impacted access to forest product harvest (phase 1)	−0.249	0.062	−0.089	0.008
Household has significant impacted access to forest product harvest (phase 2)	−0.150	0.023	0.134	0.018
Household has significant impacted access to agricultural fields (phase 1)	−0.220	0.048	−0.207	0.043
Household has significant impacted access to agricultural fields (phase 2)	−0.197	0.039	0.019	0.000
Household has threats from landslides (phase 1)	−0.186	0.035	0.036	0.001
Household has threats from landslides (phase 2)	−0.211	0.044	−0.053	0.003
<i>Livelihood diversity</i>				
Household total bovine (yak, cow, yak/cow hybrids)-log (phase 1)	−0.469	0.220	0.039	0.001
Household total bovines (yak, cow, yak/cow hybrids)-log (phase 2)	−0.238	0.056	0.267	0.071
Household total sheep, goats, and pigs-log (phase 1)	−0.458	0.210	−0.074	0.005
Household total sheep, goats, and pigs-log (phase 2)	−0.214	0.046	0.184	0.034
Household total chickens-log (phase 1)	−0.289	0.084	−0.219	0.048
Household total chickens-log (phase 2)	0.037	0.001	0.189	0.036
Household has <i>bari</i> (non-irrigated) fields (phase 1)	−0.353	0.125	0.037	0.001
Household has <i>bari</i> (non-irrigated) fields (phase 2)	−0.206	0.042	0.080	0.006
Household has <i>khet</i> (irrigated) fields (phase 1)	0.094	0.009	−0.008	0.000
Households has <i>khet</i> (irrigated) fields (phase 2)	0.211	0.044	0.059	0.003
Household practices work exchange in agriculture (phase 1)	−0.254	0.065	−0.039	0.002
Household practices work exchange in agriculture (phase 2)	−0.074	0.005	0.229	0.053
Household primary livelihood is a business (phase 1)	0.197	0.039	−0.013	0.000
Household primary livelihood is a business (phase 2)	0.149	0.022	−0.055	0.003
Household does not practice herding (phase 1)	0.394	0.155	−0.076	0.006
Household does not practice herding (phase 2)	0.130	0.017	−0.326	0.106
<i>Social memory</i>				
Household used traditional architectural knowledge in recovery (phase 1)	0.097	0.009	0.187	0.035
Household used traditional architectural knowledge in recovery (phase 2)	−0.100	0.010	0.139	0.019

3.2. Demographics and accessibility

The NMDS analysis found that the strongest associations with negative recovery outcomes were for those in Haku and internal displacement camps, as well as Buddhists and Tamang households (Table 2). These findings illustrate how the earthquakes and cascading events amplified existing power dynamics where social inequality and spatial dynamics interrelate—a process common in disaster contexts [24,31]. Many of Nepal's Indigenous and rural populations were characterized by the state institutionalized Hindu hierarchy using the *Muluki Ain*, which categorizes several non-Hindu Indigenous and rural groups as alcohol drinkers, enslavable, and untouchable [29,92]. In the 19th and 20th centuries, the feudal-like Nepal state excluded these groups from regional and national domains of influence and exploited their land and labor [28,36,83]. Indeed, the root causes

of vulnerability prior to the earthquakes were caste, ethnic group, and gender [37]. This social inequality resulted in spatial dynamics, where these populations settled and adapted to extremely challenging biophysical conditions on steep Himalayan slopes. Connections between social inequality and spatial dynamics (e.g., [25, 70]) and their amplification during disasters have been documented in Nepal (e.g., [32]) and elsewhere (e.g., [1,7,31]). These geographies thus create high hazard vulnerability to earthquakes and landslides, which the 2015 earthquake and aftershocks brought to the surface.

The strongest associations with more positive recovery outcomes, indicating some adaptive capacity, included households from Aaru Chanaute, Hindus, Newar, Brahmin, and Chhetri ethnic groups, and households that took microcredit loans (Table 2). These loans were accessible primarily to households in Aaru Chanaute because of their proximity to banking

Table 3Select responses for the entire sample and selected Village Development Committees from household surveys at phase 1 ($n = 400$) and phase 2 ($n = 397$).a, b

Variables	Total sample phase 1	Total sample phase 2	Aaru Chanaute phase 1	Aaru Chanaute phase 2	Kashigaun phase 1	Kashigaun phase 2	Gatlang phase 1	Gatlang phase 2	Haku phase 1	Haku phase 2
Household had a damaged or destroyed primary house	99%	–	99%	–	100%	–	100%	–	98%	–
Household able to return to primary home from temporary shelter	1%	44%	4%	48%	0%	92%	0%	8%	0%	27%
Settlement had damaged or destroyed infrastructure (micro-hydropower plants, schools, hospitals, health posts, monasteries, temples, and communal buildings)	100%	38%	100%	42%	100%	63%	100%	38%	100%	25%
Households relocated to internal displacement camps (64/400 total households)	16%	16%	0%	0%	0%	0%	0%	0%	64%	63%
Household is having issues trying to rebuild house	55%	92%	52%	81%	82%	94%	51%	99%	37%	96%
Household used personal funds to rebuild house	55%	42%	78%	41%	73%	74%	43%	7%	44%	18%
Household took a loan to rebuild house	–	16%	–	12%	–	17%	–	15%	–	18%
Household received aid from the government during the recovery ^a	95%	19%	92%	3%	91%	68%	100%	0%	99%	6%
Household received aid from non-governmental organizations during recovery ^b	89%	4%	89%	0%	86%	8%	89%	2%	91%	5%
Settlement had landslide threats caused by earthquakes	55%	88%	38%	64%	79%	100%	44%	90%	59%	97%
Household herding ability impacted by earthquakes	56%	67%	61%	39%	68%	74%	66%	82%	60%	72%
Household farming ability impacted by earthquakes	–	75%	–	48%	–	78%	–	79%	–	93%
Household <i>bari</i> (non-irrigated field) impacted by earthquakes	53%	71%	27%	32%	64%	82%	43%	76%	78%	94%
Household members participate in credit and savings groups	9%	35%	25%	63%	0%	6%	7%	40%	6%	30%
Household was pessimistic about the recovery	79%	73%	68%	80%	90%	65%	81%	62%	77%	87%
Household sought information about disaster preparedness	3%	18%	10%	8%	1%	24%	1%	27%	0%	13%
Household received information about disaster preparedness	1%	23%	4%	22%	0%	41%	1%	22%	0%	7%
Community opinion is perceived to be taken into account in recovery	40%	66%	53%	45%	67%	82%	20%	40%	21%	58%
Community using new ideas from government in recovery	1%	12%	4%	11%	1%	29%	0%	8%	0%	1%
Community using new ideas from INGOs/NGOs in recovery	1%	17%	4%	19%	0%	30%	0%	16%	0%	3%

^a Aid received up to phase 1 from the government included two types of cash grants to earthquake-affected households: (1) emergency grants for funeral costs (NPR 30,000 or US \$300) and the construction of temporary shelters (NPR 15,000 or \$150); and (2) winter cash grants (NPR 10,000 or USD \$100) to help people make adjustments to their temporary shelters and buy clothes and blankets. Aid received from the government in phase 2 included the first tranche payment in July 2016 as part of a government reconstruction grant. Priority was given to “red-card” holders with “fully damaged” houses. Later, an NRA-led Central Bureau of Statistics survey reassessed damaged houses to identify beneficiaries for private housing reconstruction grants of NPR. 300,000 (USD \$3000) and retrofitting grants of NPR 100,000 (USD \$1000) [73].

^b Aid received in phase 1 from outside aid organizations (international and national non-governmental organizations or NGOs) and international agencies included quick relief materials, temporary shelters materials, maintenance and reconstruction of drinking water, temporary toilets, etc. Aid received in phase 2 included the reconstruction of public infrastructure, health posts, school buildings, drinking water taps, and community buildings as well as trail maintenance.

institutions in the market area of Arughat at the road head (Fig. 2). Indebtedness through loans after the earthquake was common in highly impacted areas [47]. Households with higher literacy also weakly correlated with positive recovery outcomes (Table 2). Factors leading to negative impacts included severity of landslides and livestock survival, health, behavior, and productivity. Households that practiced work exchange to rebuild their homes and work in agricultural fields (e.g., Gurung ethnic group), home owners, and larger households, were able to return to their homes and adapt their agropastoral practices most rapidly in phase 2, illustrating adaptive capacity that helped them restart livelihood activities (Table 2). We also observed increased conversions to Christianity, especially for younger generations of Tamang peoples in Haku. For example, at phase 2, 17.0% of Haku residents were Christian for a mean of 1.3 years with an even shorter duration in the camps at 9.1 months. The content analysis found that households perceived problems of accountability and transparency in government and NGO aid distribution. Local governments felt that they had a lack of understanding of national government reconstruction policies and processes. Tamang, Dalit, and other traditionally lower income ethnic groups shared that they lacked a voice in government actions due to perceived knowledge gaps [80–82].

Regarding accessibility, in our sample 46% of households were considered more accessible near roads, trails, and helipads (54% less accessible). In the NMDS analysis, accessible households were strongly associated with less displacement, indicating they had an easier time adapting and restarting their agropastoral practices (Table 2). Households in inaccessible settlements mostly took reconstruction loans from family and friends with low interest (i.e., 73% of total loans from family and friends); households in accessible settlements mostly took bank and microcredit loans; some felt that these loans should be forgiven by the government. As discussed previously, microcredit and other bank loans were largely unavailable for inaccessible settlements, thus motivating loans from family and friends. Tamang, Gurung, and Dalit peoples were located primarily on the

biophysical margins and lacking access to credit, illustrating how certain Indigenous and low caste populations do not have the same economic opportunities as more accessible and privileged groups, such as Newar and Brahmin/Chhatri ethnic groups. Those with access to bank and microcredit loans had better recovery outcomes, which signals some adaptive capacity. The content analysis illustrated that inaccessible households and settlements lacked access to relief and recovery materials and programs. Road conditions affected access to relief and recovery materials and programs, while distance from the road head influenced reconstruction expenses, especially for sand, cement, and iron rods.

3.3. Hazard exposure

Households with the most hazard exposure were also from the poorest and most marginal ethnic groups and religions (Tamang, Gurung, Dalit, and Buddhists) (see Section 3.2). The marginalization of these populations to the geographical margins has historically impacted their opportunities to participate in local, regional, and national economies beyond subsistence agropastoralism in perilous locations, such as those with landslide vulnerability [29]. Households with impeded access to grazing areas, firewood collection, forest product harvest, *bari* fields, and threats from landslides had the strongest associations with negative recovery outcomes across both phases in the NMDS analysis (Table 2). Research near the earthquake epicenter in proximity to two of our study sites with similar geographies found a comparable result with the earthquakes and cascading effects catastrophically impacting impoverished communities with high geologic hazard vulnerability risk prior to the events [32]. The content analysis added that households perceived danger in returning to pastures, fields, and forests due to extreme earthquake impacts, such as inundation by landslides. Further, households that remained in temporary shelters and camps were being exposed to new hazards, such as severe windstorms, while in their vulnerable states [80–82].

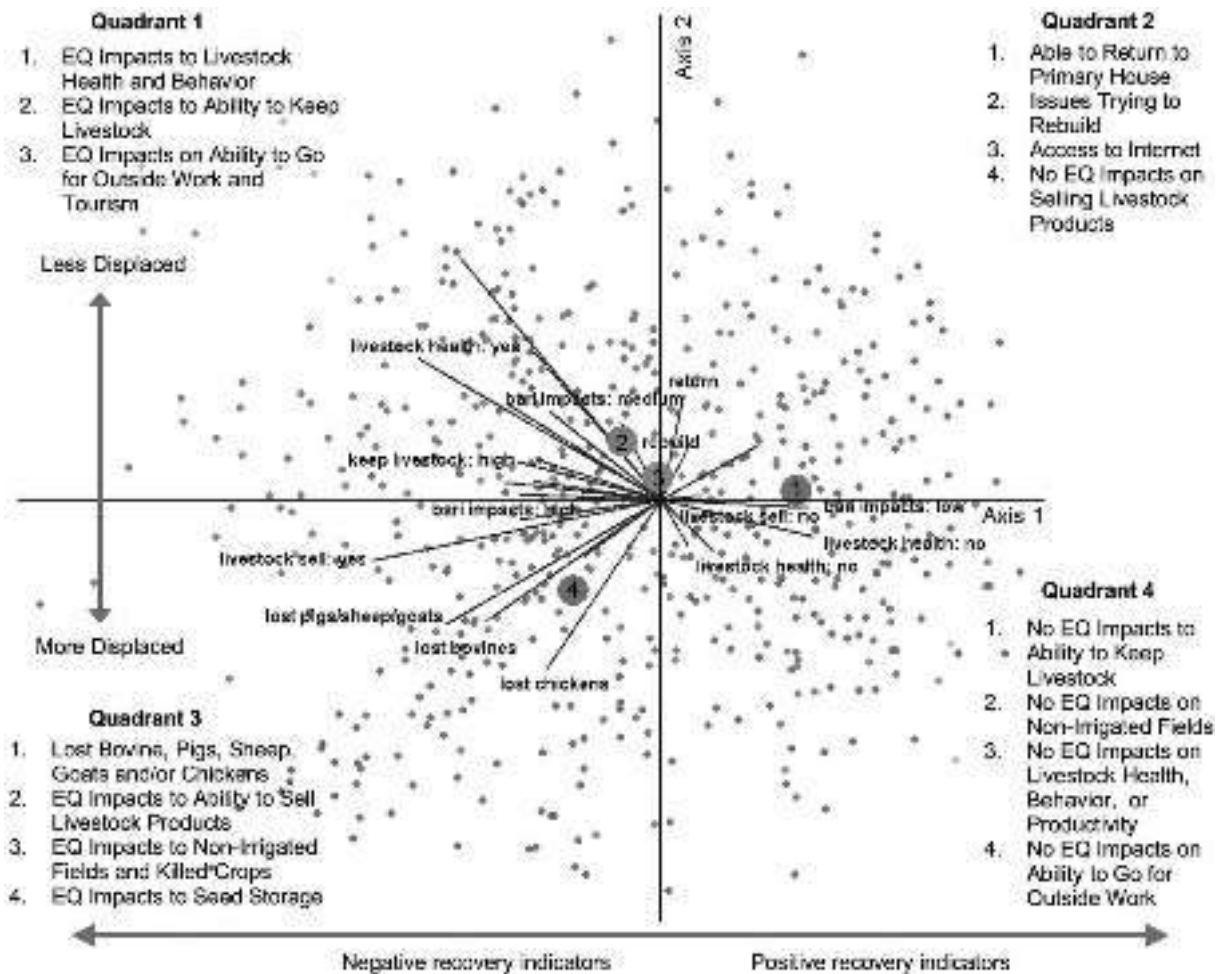


Fig. 3. NMDS scatterplot of recovery indicators for entire sample ($n = 397$ households) across both time periods with centroid (average positions) of households in each VDC. Lines represent indicators that are most strongly associated with the two dimensions of recovery. Notes added to each quadrant highlight variables that characterize these parts of the recovery space (VDC 1 = Aaru Chanaute; VDC 2 = Kashigaun; VDC 3 = Gatlang; VDC 4 = Haku). From Spoon et al. [80].

3.4. Livelihood

Research on short-term livelihood recovery within the first two years of the earthquakes illustrates the interrelation of the household with livelihood. Household assets (e.g., cultural, social, economic, physical, human, and natural) and capital generating strategies played a critical role in recovery [17]. The NMDS analysis indicated that households whose livelihoods focus on livestock (bovines, sheep, goats, pigs, and chickens) and *bari* agriculture had the strongest associations with negative recovery outcomes (Table 2). Households with *khet* agriculture, households that did not practice agropastoralism, and households that participated instead in various businesses and tourism ventures had strong associations with more positive recovery outcomes, suggesting a degree of adaptive capacity (Table 2). The content analysis added that impacts to fields, farms, and forests included cracks, fissures, and landslide cover, and that livestock also had health and productivity issues. Households lost or changed their livelihood because of the expense in restarting after mitigating earthquake impacts. Households with a single livelihood strategy with catastrophic impacts, such as herding in Gatlang, struggled compared to households with more diverse livelihood options containing more adaptive capacity (Table 2 and Fig. 4). Households generally lacked access to capital to start or continue businesses and felt that the earthquakes reversed development progress and created a lot of debt, consistent with other studies [47]. Herders were keeping their livestock in hot, corrugated and galvanized iron sheds, causing them to lose weight. They were also purchasing more low-cost

chickens at phase 1 to replace the cows, goats, and sheep that they lost. In Aaru Chanaute, households that relied on breaking stones and gravel mining in the Budi Gandaki dam inundation zone were concerned about losing their livelihoods after relocating from the area.

3.5. Displacement

Displacement from Indigenous homelands can have profound impacts on recovery, as Nepali identity is intimately connected to place [74] and affects the poor the most [2]. After the earthquakes, some households with catastrophic impacts sought refuge in nearby public and private open areas. As time progressed, households that could not go back to their settlements because of earthquake impacts generally paid rent to private landowners and waited for the government resettlement program to begin. In the camps, the Nepal government and different international and national NGOs provided basic relief materials, including food and drinking water, as well as temporary shelters and schools. These entities did not govern the camp; instead, residents nominated or elected their own leaders. The VDC and district government then provided assistance for any issues not resolvable by the camp leadership. Displacement from homes, settlements, and agropastoral ways of life correlated highly with negative recovery outcomes (Table 2) and the speed of recovery (see Section 3.1) in the NMDS analysis. There was also a lack of flow of new ideas into the camps across both phases (Table 3). Displacement to camps after disasters often impedes recovery and compounds impacts [71]. Research on displacement also

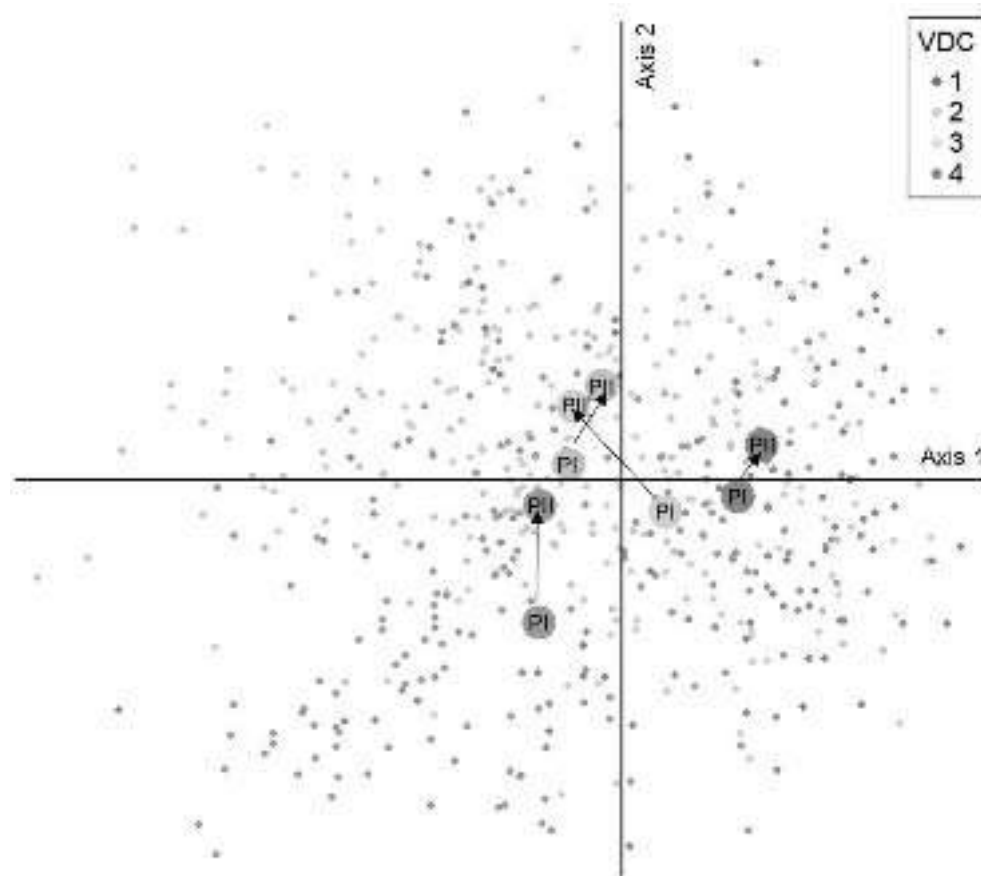


Fig. 4. NMDS scatterplot of recovery indicators for entire sample ($n = 397$ households) at phase 1 and phase 2 with centroid (average positions) of households in each VDC across both time periods (VDC 1 = Aaru Chanaute; VDC 2 = Kashigaun; VDC 3 = Gatlang; VDC 4 = Haku). From Spoon et al. [81].

illustrates that it impacts livelihoods in general outside of disaster contexts [68]. The content analysis indicated that households displaced to camps felt they were living as outsiders in “other’s places” and were often forced to pay rent. Households living in camps were having trouble adjusting to agropastoralism at lower altitudes and some decided to use pesticides to protect their plants against insect threats they were not accustomed to at higher elevations, where they practice organic farming. Households unable to farm on their own lands because they were inaccessible, damaged, or destroyed were engaged in poorly compensated wage labor outside the area. Issues encountered in the camps included difficulties in properly raising children and procuring healthy foods. There was also a lack of privacy. Aaru Chanaute households being resettled from the camps and the future Budi Gandaki dam inundation zone wanted to be relocated together, to continue collectively practicing their culture. They also desired close proximity to former settlements to continue practicing their place-based ancestral traditions [80–82].

3.6. Government relief/reconstruction, outside aid, and institutional participation

The NMDS analysis (Table 2, Gatlang; Fig. 4) and descriptive statistics (Table 3) illustrated that settlements with high representation of outside aid prior to and during recovery did not necessarily have associations with the best outcomes over the short-term. We argue this may result from dependency on outside aid and resources transported by the road. It may also be influenced by the pace of initiating a national rebuilding program, which can be slow [46]. Expectations of resources from the government and outside aid agencies in tandem with road access may have influenced recovery outcomes, as observed at a nearby site [33]. In the case of Gatlang, only 8% of households had returned to their primary house

from temporary shelters by 1.5 years. Instead of rebuilding on their own, these households appeared to wait for expensive resources from the road, such as concrete, sand, and iron rods, as well as outside aid, which was prolific in the area immediately after the earthquakes and then withdrew. Conversely, in Kashigaun, 92% of households had returned to their homes by 1.5 years; however, few, if any, rebuilt to code (Table 3). Waiting for help as victims instead of rebuilding as survivors may, thus, trap populations in a vulnerable state. In Gatlang, this vulnerability became evident during an erratic windstorm that severely impacted temporary shelters while households waited to rebuild [80,82]. Some populations may use their visibility for their own advantages [65]. Communities waiting for aid rather than helping themselves has been documented elsewhere [55].

Outside aid interventions can prevent communities from developing relationships and cohesiveness [66], disrupt social networks [15], create or amplify social inequalities [4], and impede achieving more general sustainable livelihood goals [14]. Some see the combination of natural hazards and development as lessening social capital and eroding social networks [90]. According to Kotani et al. [46], returning from temporary shelters to primary homes did not necessarily create a robust recovery, as living conditions improved minimally after the household return. This reinforces the need for government and/or outside aid interventions. However, these interventions need to be informed about local culture, power dynamics, history, place, livelihood, and institutions.

The origin of household assistance in the recovery did not correlate with recovery outcomes in the NMDS analysis (phases 1 & 2 combined: $R^2 = 0.001$ – 0.016). Households remaining in their villages received more help from family and friends across both phases; whereas, households in camps received help from the aid community in phase 1 and lacked any significant assistance in phase 2. Most households received the initial relief

funds from the government in phase 1 (95%). Households that remained in their settlements used new ideas from the government and aid community in the recovery; however, the camps lacked a flow of new ideas. Overall, outside aid decreased significantly from phase 1 to phase 2. Assistance from the government decreased from 95% to 19% between phases 1 and 2; NGO aid lessened from 89% to 4% (Table 3). Outside aid from international and national NGOs and international agencies included small cash grants, food, basic relief items (e.g., blankets and tarps), and building materials. Roughly half of the households felt that their opinion was being considered in the recovery across both phases, with 40% feeling this way in phase 1 and 66% in phase 2 (Table 3).

The content analysis added that households had strong hopes for the success of the government reconstruction program. Households considered the program confusing, with funds difficult to access and biased towards more accessible settlements with market connections. Fear arose that households misused the first payment and needed to repay it. Indeed, Kotani et al. [46] observed in one location that the slow pace of receiving rebuilding funds caused certain households to remain stagnant in their unrepaired homes without improvement, reinforcing the importance of early financial aid to more effectively navigate the crisis. Some households needed to spend the first tranche on the demolition of their old house and were worried that the next tranche would not be enough, especially in inaccessible settlements. They also feared that using the funds for purposes other than home construction would disqualify them from the program. Households suggested that rebuilding funds expand to include landslide mitigation, trail reconstruction, and the transport of building materials. They also stated that if the government cannot cover these expenses, outside aid organizations should. Government-contracted engineers conducted insufficient assessments of earthquake damages. The long delay in starting government rebuilding programs caused hardships, forcing some households to rebuild their homes on their own with loans in order to restart their lives more quickly. Households also felt that government instability caused the reconstruction program to be unstable.

Research illustrates that the governments and the aid industry can overlook local institutions in disaster recovery contexts using a “one size fits all” approach [9,66]. In our study, households considered most outside aid as temporary and unsustainable, viewing some relief items as irrelevant. According to a participant from Aaru Chanaute, the NGOs “provide a hungry person a comb of banana instead of one mana (half kg) of the roasted soybean and corn that the person actually needs.” Money was considered more useful than relief materials, such as blankets and clothes, which can be co-opted by “clever people with the right connections” leaving others without any. They also felt some outside aid programs engage communities with preplanned programs developed without local input, thus duplicating one another. After these initiatives, the programs did scant follow-up and tracking. The perceived lack of transparency and accountability was especially pertinent with NGOs that arrived in Nepal after the earthquakes. Projects funded by outside aid appeared more interested in accessible areas and community buildings rather than individual homes, especially in Gatlang and Aaru Chanaute. All external aid projects need to coordinate with the government; however, external assistance is not evenly distributed across Nepal's earthquake-impacted populations, with accessible areas receiving more assistance. This may be a result of accessible areas getting more media attention, having more efficient transportation, and being less expensive. These preferences may thus illustrate the interests of the donors and foreign NGO actors more than on-the-ground needs of the affected populations—this being common in disaster recovery contexts [41,93]. Importantly, households preferred skills-based training related to improving livelihoods, such as earthquake-safe carpentry and masonry, rather than receipt of relief materials. For instance, in Gatlang houses rebuilt to code after the earthquakes needed to be constructed by skilled carpenters and masons, which were outsourced due to a lack of local skilled labor. Lastly, representatives from the aid community suggested that local governments coordinate at the District level to address problems faced by inaccessible households.

3.7. Housing designs, building codes, and disaster preparedness

The NMDS analysis (Table 2) and descriptive statistics (Table 3) showed that households utilized some Indigenous and local knowledge of traditional architecture to return to their primary houses faster in both phases; however, these repaired and rebuilt homes did not meet the new building codes. Households had issues rebuilding their homes, which increased from 55% in phase 1 to 92% in phase 2 (Table 3). The content analysis found that households considered rebuilding funds insufficient to meet building codes, causing them to construct extremely small houses that meet the new codes. The NPR 300,000 (US \$3000) allotted to each household in a series of payments was not considered adequate to fund house rebuilding, especially at higher-elevation less-accessible settlements where inflation is significant due to transport charges. Confusion abounded about how to integrate local innovations into the new building codes, such as decreasing the height of the house for safety in future earthquakes. Some households felt that constructing homes that satisfy the new building codes was more problematic than the earthquake itself because of the cost of building materials in inaccessible locations and the difficulty in blending traditional architecture and local knowledge with new housing designs to meet building codes. Culture and architecture are intimately connected in settlements at biophysical extremes, especially for Indigenous and rural populations in our study area (e.g., [30,37]). The traditional built environment has structures suitable to climate, local economy and livelihood, and communal activities. The spiritual world of the population is also situated in this physical space. The new housing designs were created external to the specific settlements and imported through the rebuilding program. The rebuilding program generally focused first on housing, which in turn did not account for other cultural factors, such as livelihood or place attachment, which are critical to Indigenous and rural everyday life.

Participants shared that cheaper traditional architecture made from local materials, such as wood and rocks, was not considered earthquake safe compared to structures built with iron rods, sand, and cement. They added that housing designs did not reflect their traditional architectural style and ways of life and that they appeared to lack local input, such as where to keep livestock. The relationship between culture and architecture was considered vital, expressing the identity of each settlement. Generic housing designs appeared to obscure these relationships. Furthermore, some local residents considered new housing designs unsuitable for the climate at higher elevations. There was interest in learning how to build houses in traditional styles that are earthquake safe. Yet some living in settlements with steep slopes, an abundance of earthquake-triggered landslides, and debris from damaged and destroyed houses, were having difficulty identifying rebuilding locations. Certain households made significant financial investment into their temporary shelters, which affected how much they could invest in new permanent houses. Many households were in debt from rebuilding expenses. The majority of the people desired earthquake-resistant homes but lacked disaster preparedness training and awareness. There was an increase in household information sharing about disaster preparedness, from 1% in phase 1 to 23% in phase 2 (Table 3). There was also a perception that rebuilt homes should be one story, to lessen any damage in the next earthquake.

In Gatlang, social class and housing designs appeared to interrelate. Those with higher socio-economic status rebuilt with concrete and those with lower status rebuilt with wood. This difference changed the aesthetic of the homogenous “black village” that existed prior to the earthquakes where each house had similar construction. Gatlang is a key destination on a cultural heritage themed trekking route. The change may in turn impact tourist desires to see the homogenous “traditional” looking village. Participants in the local research return workshop explained that Gatlang's culture should be protected by letting residents build traditional houses using traditional skills rather than following the new building codes that deviate from the local designs, inhibiting their ability to build their traditional houses. The new designs are indeed causing the aesthetic of the village to change, which may have financial implications on the local tourism industry.

3.8. Cooperation, work exchange, and mental well-being

Certain households in Kashigaun expedited their return to their primary homes through the use of *parma* or work exchange by co-rebuilding (Table 2), evident in the NMDS analysis (see Section 3.5). Some Gurung and Tamang households also utilized *parma* in agriculture to return to their agropastoral practice faster in phase 2, illustrating strong associations with less displacement (Table 2). Many households in Gatlang used this strategy for agropastoralism but not for rebuilding their homes. Indeed, various studies demonstrate social capital and social networks are important components of disaster recovery [3,27,86], including studies in Nepal following both the 1934 [12] and 2015 Nepal earthquakes [23,34,64]. The content analysis also illustrated the adaptive capacity of the Gurung, and to a lesser extent, Newar ethnic groups of varying socio-economic statuses using cooperation and work exchange as unskilled laborers to rebuild homes, pool funds for communal betterment, and to “live more in harmony” in the short-term during the recovery. According to one Kashigaun participant “now holding hands on hands and shoulders on shoulders, we should help each other by practicing *parma*.” Households also cooperated to help the most marginal, such as the elderly and children. In Kashigaun work exchange was utilized as a safety net in a time of need, especially for the poorest and most vulnerable.

Disasters can substantially affect mental well-being in negative ways, particularly when households are in temporary shelters or camps [57,89]. In this study, the majority of the households were pessimistic about the recovery in both phases, i.e., 79% in phase 1 and 73% in phase 2 (Table 3). The content analysis showed key intangible recovery dynamics not visible in the other techniques, especially for the most marginal. Households had strong symbolic place attachment to their physical homes and ancestral settlements, common in many Indigenous and rural contexts [35]. Destruction of the physical home and settlements in turn influenced negative mental well-being through daily re-traumatization. Households perceived the future as highly uncertain in all settlements and camps, and the planned dam inundation zone, negatively influencing mental well-being. New social constructions of *dukkha* (trouble/tension) and *pagal* (a mad person) emerged during the recovery. *Dukkha* in this sense is mental trouble or tension manifested through the emotions of fear, anger, sadness, and anguish. To some, this is understood as taking one's soul or inner spirit away, causing them to not act like themselves. *Pagal* is associated with having suffering or worries and acting “mad” or “crazy.” Both *dukkha* and *pagal* were manifestations of negative mental well-being, especially for rural and Indigenous peoples with strong place attachment and high levels of uncertainty towards the future. Further, active landslides caused by the earthquakes, cracks, and fissures, as well as damaged and destroyed homes and infrastructure, can create re-traumatization for place-based peoples as reminders of the initial trauma and its cascading effects, which threaten these communities years after the first event, evident elsewhere [10]. Indeed, after the Nepal earthquakes post-traumatic stress disorder (PTSD) was documented in rural and Indigenous communities [39,53], which can last years [6].

3.9. Transformations in everyday life

Transformation in disaster contexts may be both deliberate and/or adaptive and can include a fundamental restructuring of individuals, institutions, and regimes [49]. Transformation often relates to root causes of vulnerability, which disasters bring to the surface and amplify [67]. Coupled together, the NMDS and content analysis illustrate that hazard exposure, especially landslides and highly-impacted fields and pastures, place-based livelihood disruption, and displacement may drive transformative change. The static nature of displacement camps may continue the process of transformation started by the earthquakes when resettlement occurs. New skills, such as carpentry and masonry for earthquake-safe housing and sewing/tailoring, learned after the earthquakes may bring opportunities for building adaptive capacity and improving standards of living. Emergent household and settlement disaster preparedness trainings may also assist with future hazard planning and response. Certain households

identified that the catastrophe inspired the building of new earthquake-safe structures, trails, and infrastructure, such as schools and health posts/hospitals. Collectively, these changes may also influence transformations in everyday life over the long-term.

Focusing on each VDC (Fig. 4), Aaru Chanaute, which had the best starting point in the recovery across the sample, appeared to change little across the two phases due to a planned dam which will cause many households to relocate and start new lives. Kashigaun households had the best recovery outcomes between the phases and incorporated outside ideas, which may influence new hybrid knowledge and practices. The settlement's less accessible location further from the road may stimulate the use of social capital through work exchange and openness to new ideas. Gatlang households had the worst recovery outcomes across the phases, taking the longest to return from their temporary shelters to their primary houses, causing them additional hazard exposure. Change or stasis may be influenced by their reliance on herding and dependency on the road and outside aid. Lastly, Haku households—especially those in displacement camps—were stagnant and appeared to lack opportunities to return to their settlements, fields, pastures, and forests. One settlement (Sano Haku) is being relocated because of geological vulnerability. Transformative change triggered by the catastrophic earthquakes may thus occur after resettlement [49].

4. Conclusion and recommendations

Recovery from the catastrophic 2015 Nepal earthquakes and their cascading effects spans years and potentially decades. Conditions were improving for some, while remaining static or getting worse for others. To better understand tangible and intangible recovery dynamics and adaptive capacity in the short-term, we employed a quantitative NMDS analysis and qualitative content analysis. The NMDS analysis found that each household and settlement had a different starting point in the recovery and was either stagnant or moving in positive or negative directions [80]. Socioeconomic status, hazard exposure, place-based livelihood disruption, and displacement influenced recovery outcomes the most. Herders, *bari* farmers, and forest product harvesters had the strongest associations with negative recovery outcomes; *khet* farmers and households that had businesses had the strongest associations with positive outcomes, appearing to have more adaptive capacity [82]. Previous content analysis on the surveys, interviews, focus groups, and research return workshops illustrated inequality-shaping tangible and intangible recovery dynamics. Stagnation and rapid change in the short-term may lead to transformation in the long-term [81]. Here, we add new quantitative and qualitative information from the NMDS, descriptive statistics, and content analysis. The new results include household challenges in accessing government relief and the national reconstruction program as well as perceptions of outside aid as unsustainable. We also add local challenges and opportunities related to the government-approved housing designs, building codes, and disaster preparedness.

Understanding short-term household recoveries in Nepal and rural and Indigenous disaster recovery contexts in general can contribute to crisis- and transformative-learning [43,72], encourage multi- and poly-vocality [9], engender local-global linkages and communication among households, settlements, government institutions, and outside entities [45], and provide development opportunities [8]. These findings and their interpretations can help to change “one size fits all” relief and recovery policies and interventions that do not account for cultural and biological diversity, history, livelihood, place, or inequalities.

Based on these assembled results, we provide the following guiding principles as well as general and specific recommendations to inform short and long-term disaster recovery generally, and recovery in Nepal specifically, and help build household adaptive capacity to future hazards. The guiding principles and general recommendations could be useful to policymakers and practitioners when conducting research or learning about ongoing contextual factors in places where they work. These suggestions could help to shape needs assessments and diverse types of interventions by governments, international agencies, and NGOs.

4.1. Guiding principles

1. Consider how power and history shape current realities to produce disasters by identifying root causes.
2. Consider recovery as a non-linear process that occurs over the short and long-term, with no specific end point.
3. Consider recovery as tangible (e.g., livelihood) and intangible (e.g., place attachment and mental well-being).
4. Consider both where a household starts in the recovery and where they are headed.
5. Consider culture, livelihood, and place as integral to recovery.
6. Consider using an integrated social and environmental systems perspective to understand rural and Indigenous everyday life, and life in disaster recovery.
7. Recognize that recovery includes a combination of planning and swift decision-making.

4.2. General recommendations

4.2.1. Outreach

1. Conduct outreach, information sharing, and rapport building prior to and throughout any research process.
2. Conduct pilot studies or exploratory consultations to ensure site and variable selection as well as analytic techniques are appropriate.
3. Integrate research return as primary method before interpretation of final results.
4. Make results accessible to multiple audiences in diverse forums.
5. Foster relationships with participants and stakeholders after study completion to assist with future collaboration and understanding the dynamics of change.

4.2.2. Methodology

1. Do not take the easy way out to define recovery indicators and drivers of change. Utilize multiple inputs to select domains and variables (e.g., previous experience, pilot studies, literature). Recognize that disaster recovery is multidimensional and changing over time with no specific end-point.
2. Utilize the rule of hand to identify three to five key domains of system function [87].
3. Employ mixed methods to ensure an appropriate research universe (e.g., tangible and intangible dynamics) and opportunities for information triangulation.
4. Select data-analysis techniques appropriate for each context.

4.2.3. Pre-disaster research on vulnerabilities

1. Identify sensitive and vulnerable points (e.g., social inequality, poor state capacity, weak infrastructure, extreme exposure to natural hazards) in integrated social and environmental systems using the best ethical practices.
2. Recognize trend of amplification of preexisting power dynamics when disasters occur.
3. Recognize the relationship between social inequality and spatial dynamics.
4. Utilize research as an opportunity for awareness raising and partnership building.

4.3. Nepal-specific recommendations

We developed the following Nepal-specific recommendations using the guiding principles and general recommendations shared above.

1. Consider integrating into the national reconstruction program landslide mitigation, trail repair and construction, and transport expenses for building materials, which affect the size and design of rural earthquake-safe houses. Outside aid organizations could cover or share these costs if the National Reconstruction Authority cannot.

2. Ensure that assessment of earthquake damages include inaccessible settlements and not solely accessible settlements near or on the road.
3. Ensure that traditionally lower-caste ethnic groups and religions with low literacy receive representation and have a voice in community reconstruction planning. Recognize that these populations of lower socio-economic status are living in inaccessible and vulnerable geographies. They had the most catastrophic earthquake-related impacts and rely on these unstable extremes for their livelihoods.
4. Build capacity of local government representatives to understand the national reconstruction program. Consider enacting co-learning opportunities between local government officials from different municipalities.
5. Ensure that resettled households and settlements stay together in the new locations and in proximity to old settlements, if possible, so that they can practice their place-based culture and traditions.
6. Create opportunities in inaccessible settlements to co-design earthquake-safe low-cost housing that meets the building codes and reflects local traditional building approaches and uses local materials.
7. Build capacity of marginal households with single agropastoral livelihoods to create diversity in livelihood opportunities that will be more resilient to future hazards. Households with market connections also need low interest loans to start or continue businesses.
8. Consider local institutions and their related practices, such as *parma*, cultural traditions that include social capital, such as communal fundraising and sharing on Nepali festivals and holidays, as well as Indigenous and local knowledge of architecture, farming, pasture, and forest management in future relief interventions and recovery programs, especially with inaccessible populations.
9. Require outside aid organizations to provide skill-building along with relief materials and to not duplicate projects. They should also get local input when reconstructing infrastructure instead of using generalized designs. Outside aid also needs to be better tracked so that it is equitably distributed.
10. Focus disaster preparedness on multiple hazards beyond earthquakes, especially landslides.

CRedit authorship contribution statement

Jeremy Spoon: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Drew Gerkey:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Ram B. Chhetri:** Conceptualization, Methodology, Writing - review & editing. **Alisa Rai:** Methodology, Investigation, Writing - review & editing, Supervision, Project administration. **Umesh Basnet:** Methodology, Investigation, Writing - review & editing, Supervision, Project administration. **Chelsea E. Hunter:** Formal analysis, Writing - review & editing.

Declaration of Competing Interest

None.

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Multi-hazards, displaced people's vulnerability and resettlement: Post-earthquake experiences from Rasuwa district in Nepal and their connections to policy loopholes and reconstruction practices

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ABSTRACT

In Nepal, where extreme seismic and severe weather events are frequent, understanding the consequences of different types of hazards (geological, meteorological and human-made) and their impact on people's vulnerability in the aftermath of the 2015 Mw7.8 Gorkha, Nepal earthquake, is crucial for enhanced formulation of policies and reconstruction practices. This paper aims to comprehend localized multi-hazard risks, the interaction between hazards and seasonality which may occur simultaneously, cascadingly and cumulatively, and local peoples' knowledge, experiences and perceptions to explore the effectiveness of resettlement and other reconstruction efforts. To fulfill this objective, a study was conducted in 2018 in Rasuwa, Nuwakot and Kathmandu district comprising 60 semi-structured interviews, three focus group discussions, and two photo-elicitation workshops. Participants included scientists, government officials, humanitarians, and displaced individuals at their original locations or in displacement camps. Findings show that interactions between hazards are not well recognized at policy level, as the geo-hazard assessment highlighted loopholes in its methodology as well as a lack of precision. Hence, interactions between hazards have not been sufficiently considered in the post-earthquake reconstruction process and need to be addressed by the National Reconstruction Authority. Analysis demonstrates that no clear relocation plan for displaced people exists, and that livelihood opportunities in new re-settlement areas receive no attention. Giving communities the opportunity to discuss localized multi-hazard risks with experts, so vulnerabilities, resilience capacity and risk tolerance of individuals and society can be heard and understood, is felt necessary. Moreover, people with limited resources will be more vulnerable, as they are not able to make informed decisions about suitable places for reconstruction, or to evaluate land use options or seasonal living arrangements. Two policy recommendations are proposed: 1) disaster risk-informed development planning in Nepal should include multi-hazard risk assessments as part of disaster risk management policies, and 2) resettlement policies require reform.

1. Introduction

Nepal is the twentieth most disaster-prone nation globally [1], as it is situated in 'one of the most active seismic regions of the world' ([2], p. 1), with a lengthy history of devastating earthquakes since the 13th century (Geotechnical Extreme Events [3]). On the 25th April, the 2015 Mw7.8 Gorkha, Nepal earthquake and its severe aftershock in May, impacted almost eight million people, one third of Nepal's total population [4]. Consequently, 2.6 million people were newly displaced [5]. A country of steep slopes, rough topography, extreme, varying climate and severe monsoons is a complex, fragile and disaster-prone setting [6]. Over 80% of Nepal's citizens are exposed to risk of floods (including glacier lake outburst floods), landslides, droughts, and extreme temperatures [7]. Between 1971 and 2015, 22,372 disaster events were recorded [1]. These were due to

numerous natural and human-made hazards with differing scales of impact [2,8]. Roughly 23 million people were displaced between 2005 and 2015 as a consequence [9].

Hazard exposure in Nepal is manifold and far-reaching. A vast number of people are affected by landslides during monsoon [10], nearly 80% of which happen during rainy season [11]. Moreover, Nepal gets roughly 80% of its annual precipitation during monsoon [12]. The hill districts of the Middle Himalayan terrain make up 68% of the total area of Nepal [13], with peaks of up to 5000 m and valleys less than 500 m including Kathmandu Valley, occupied by 44.2% of the national population [14]. This area is extremely landslide-prone including to earthquake-induced landslides [11,12,15,16]. In such a setting, as development continues, non-engineered infrastructural developments like 'informal' road construction are likely to rise and generate new landslide exposure, soil erosion and

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slope instability [2,17]. This is expected, 'especially as China's Belt and Road Initiative seeks to construct three major trunk roads through the Nepali Himalaya that adjacent communities will seek to tie in to with poorly constructed roads' ([17], p.1). As Wijkman and Timberlake [18] and Lavell and Maskrey [19] claim, disasters must be studied as unresolved development rather than (as is governmentally convenient), being portrayed as uncontrollable, sudden and unpredictable catastrophes, triggered by natural forces [20].

Another risk is Nepal's expansion of large-scale hydropower plants, some in extremely unstable regions [6,21]. Roughly 90% of Nepal's electricity is generated from hydropower [22] and 223 new dam projects are supported across the country [23]. In the study districts of Nuwakot and Rasuwa (Fig. 1), a hazard-exposed, mixed hill and mountain district of the Middle/Upper Himalaya, 18 dam projects were listed in different rivers in the Asian Development Bank (ADB) study [23]. Yet, Murtion et al. [46], recorded 23 hydropower projects in the study district of Rasuwa alone, most of them located alongside the Kyirong-Rasuwa Highway, with '216 MW Upper Trishuli' and 'Trishuli A' particularly close to the Nuwakot district border [25].

As a contribution to these debates, this paper aims to understand the impact of geological, meteorological and human-made hazards (i.e., landslides, monsoon rain, hazard assessments, infrastructure projects) on people's vulnerability during and after the 2015 Mw7.8 Gorkha, Nepal earthquake. It identifies new and amplified chain reactions between different hazards and localized hazard risks in Nuwakot/Rasuwa district, such as those from road/tunnel hydropower plant construction, local 'informal' road construction, and the 2015 Mw7.8 Gorkha, Nepal earthquake and annual monsoon rain experienced by local people. Impacts described by interviewees include perceptions that the land/soil in their living environment became more fragile due to these new or amplified chain reactions between hazards, which increased the localized risk of landslides during the monsoon season, made people more vulnerable and at risk of resettlement. The study examines how risks from natural and human-made hazards and reoccurring seasons were assessed in post-earthquake Nepal, to understand what methodologies were used in designing post-disaster reconstruction efforts.

After a natural disaster, resettlement is common in post-disaster reconstruction as frequently, populations cannot return to their original living environment due to risk exposure that cannot be managed by other means [26]. Ferris [27,28] illustrates forms and causes of displacement and resettlement in relation to disasters and planned relocations, and distinguishes between

climate change-induced, natural disaster-induced and development-forced displacement and resettlement. In Ethiopia, after a major famine in the mid-1980s, the resettlement undertaken by the government was unsuccessful as, being 'politically motivated', it did not respond to the long-term needs of the affected population [28]. Vithanagama et al. [29] emphasized that rather, it is the way in which relocation is implemented that creates discontentment among the resettled population, as relocation itself does not seem to be the problem if there is a 'pressing need' for such a move. Unlike the case in Ethiopia, in Mozambique after the major floods in 2007, the key aspect that hampered the sustainability of the resettlement was livelihood opportunities. Due to difficulties in restoring livelihood opportunities after the floods, particularly growing crops in resettlement areas, people moved back (some seasonally, others permanently) to their fertile but flood-prone river areas [28].

The World Bank's Handbook of Reconstruction after Natural Disasters [30] further examined some of the reasons why relocation is often unsuccessful, and noted factors such as the inadequacy of new sites and socially inappropriate settlement layouts. In addition, emphasis was placed on other factors like distances between livelihood opportunities and social networks, lack of community participation and under-budgeting of relocation costs ([30], p.79–80). In the aftermath of the tropical storm Washi in the Philippines in 2011, resettlement was mostly a top-down approach, which did not provide opportunities for affected people to take part in the decision-making process or foster 'appropriate' local solutions with regard to the design and structure of permanent housing [1]. Another stumbling block in Cagayan de Oro during planned relocation was not only the inappropriateness and safety concerns of the sites, but that they were unfavorable, being too far away from city facilities and main commercial centers, with no priority given to creating new livelihood opportunities for people affected by resettlement [1]. This forced resettled communities to abandon newly built housing units in these hazard-prone areas, while other newly constructed housing units in the area remained unoccupied due to lack of safety and livelihood opportunities [1]. The historical examples shown of communities in Ethiopia (mid-1980s), Mozambique (2007), and the Philippines illustrate a variety of severe challenges and issues connected to resettlement, which mean that people are often willing, once resettled, to move back into risky environments even though they are unsafe.

This paper is based on the author's PhD research. It highlights displaced people's experiences, the uncertainty, financial and emotional stresses and challenges they faced during reconstruction and resettlement. It aims to

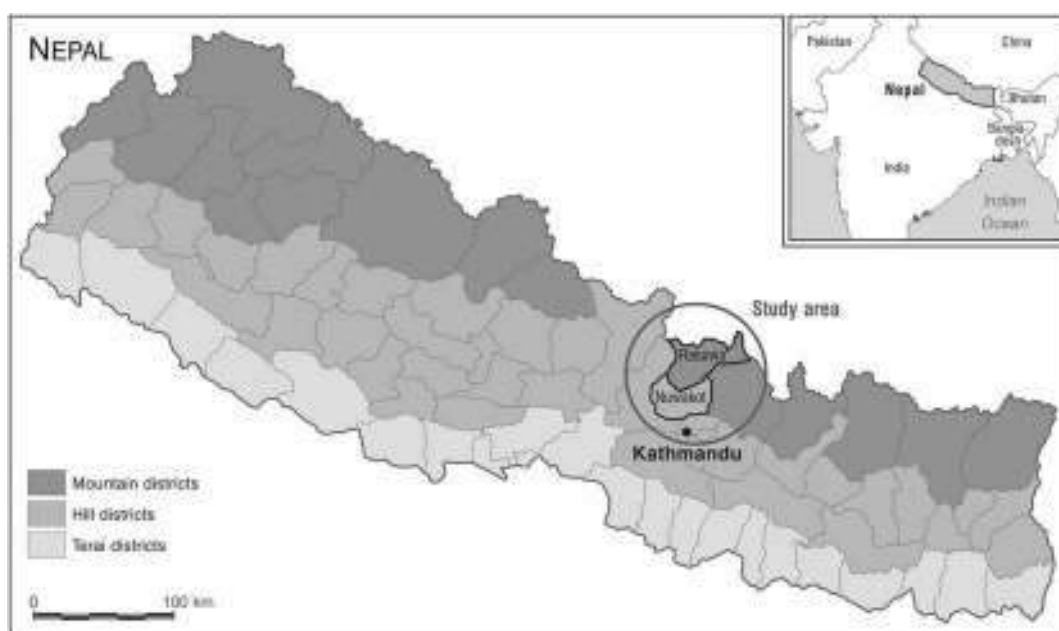


Fig. 1. Map of study area in Nepal [24].

understand people's existing risk environments, the variables involved in natural and human-made hazards, and people's exposure to future risks. The study assesses and illustrates the importance of collaborating with communities throughout the recovery, reconstruction and relocation process, to understand the risks involved in people's living environments, as well as their risk tolerance, and housing/livelihood needs. The research seeks to show the importance of collaboration between multi-stakeholders, engineers and people affected by hazard risks themselves.

Creating a space for discussion and sharing technical knowledge, it is fundamental to understand local people's experiences and knowledge gained over generations by living in the same area, to enable them to make informed decisions for relocation or seasonal living arrangements. Similarly, the protection of people's safety and livelihoods, and the articulation of policies which support their recovery are essential. With these themes in mind, the following two research questions guide the study: a) what was the nature of people's exposure and experience of multi-hazards during and after the 2015 Nepali earthquake? and b) how were reconstruction policies experienced by displaced people, and in what ways did they react?

2. Methodology

The PhD research applied a solely qualitative mixed method approach as it primarily intended to explore the causes of a phenomenon and to answer how and why things are happening [31]. It was important that the methodology enabled exploration and understanding of a range of local and national actors' perceptions, observations, experiences, thoughts, feelings, opinions and impressions. The study was inductive, as the author aimed to understand the social and power aspects in a post-earthquake environment by discovering, in the field, what people were able to relate about the concepts of multi-hazards, reconstruction and vulnerability. The author attempted to make sense of what was happening in the field and to reflect on these concepts and the interconnection of human relations, power relations and nature.

The author triangulated data, as discussed by Paul [32] and Flick [33], to ensure the validity of the results, by leveraging the strengths of several methods, including semi-structured interviews, focus group discussions, photo-elicitation workshops and exhibitions, and to mitigate the weakness of using a single method. The flexible nature of semi-structured interviews has been widely recognized [34,35], as they allow the collection of people's detailed views, practices and interests [36], offer reliable qualitative data and provide a way for interviewees to express opinions in their own words and discuss sensitive topics [37]. Focus groups were conducted, as they provide insight into how people think and feel, their knowledge, abilities, experiences, aspirations and reactions, enabling different points of view to be captured [38]. They allow flexibility in questioning and encourage the exchange of ideas and open dialogue [39]. This study additionally used photo-elicitation as a visual method, as it offers participants the opportunity to photograph their own environment, take pictures that represent their own view and to choose objects that are most important to them, rather than to the researcher [40–43]. This range of vocal and visual methods enabled the author to present a collection of local people's perceptions and experiences on multi-hazards, and their views on the implications of policies and reconstruction measures on people's vulnerability. The extra visual component complements the narrative yielded by the semi-structured interviews as a means to answer the above research questions.

The study area (Fig. 1) is located in the hilly district of Nuwakot and the mountainous district of Rasuwa in Province No. 3, north-west of Nepal's capital Kathmandu. It comprised 13 research sites – 12 in Rasuwa district in the Rural Municipality of Uttargaya, and one in Nuwakot district in Bidur Municipality.

The research sites were identified purposively and comprised six original villages, four temporary settlements and three relocation sites (Fig. 2). GPS data collected during the field study helped to identify the sites including rivers and district border. The study area comprised three communities (Tiru, Gogane and Karumaryang), situated spatially close together in hilly

terrain, that had left their original villages one week after the 2015 Mw7.8 Gorkha, Nepal earthquake. These were compared to three communities (Pairebesi, Kuwapani and Thapatol), geographically close, that stayed in their original villages initially (although some households from Pairebesi decided after the geo-hazard assessment in late 2017 to acquire new land and relocate to nearby Naubise, where households were just in the process of building). The temporary settlements of Khalte, Bogatitar and Satbise are spatially close and inhabited by households from Tiru, Gogane or Karumaryang, while the temporary settlement of Inarpati is located further down and outside Bidur in Nuwakot district inhabited by households from Tiru and Gogane. Some households in the temporary settlement of Bogatitar were allocated relocation sites in Bogatitar near their temporary settlement, but no reconstruction had started at the time, and other households came together for an integrated settlement in Kholabesi where reconstruction was ongoing. The relocation sites for households originally from Tiru and Gogane residing in the temporary settlements of Khalte, Satbise and Inarpati were under discussion, some people intending to relocate or to go back to their original place to Tiru, while the relocation sites for others were still undecided.

Table 1 illustrates the original villages of settlers, their temporary settlements, how land was acquired for temporary settlements, the destination of settlers (such as relocation site or return to their original village) and settlers' main source of income.

Sixty semi-structured interviews allowed participants to express their opinions in their own words, and created possibilities of learning for the author – see Cohen and Crabtree [37]; 41 interviews were held with displaced local people after the 2015 Mw7.8 Gorkha, Nepal earthquake, 19 residing in temporary settlements, 22 in their original villages (Table 2). Seven interviews were conducted with local/central government officials, seven interviews with national/international humanitarians, both in Nuwakot/Rasuwa district and Kathmandu, and five interviews with scientists in Kathmandu (Table 2).

The research was conducted June–October 2018 during monsoon season when roughly 80% of the total annual precipitation takes place [12]. This was an active decision by the author as the monsoon rain is an important and significant criterion for multi-hazards in Nepal and it affects a major part of people's daily life. In Kathmandu, semi-structured interviews were in English and in Rasuwa/Nuwakot, in Nepali or Tamang, with the assistance of a local translator. The researcher and translator visited the community leaders from each village before the research started to obtain permission and explain the study. A selection principle for local people to participate in semi-structured interviews, focus group discussions or photo-elicitation workshops was their displacement after the 2015 Mw7.8 Gorkha, Nepal earthquake, plus one of the following additional criteria: a) people were residing in their original village; b) people were living in temporary settlements after leaving their original village post-earthquake; or c) people had stayed in their original village, and were in the process of buying land and constructing houses for a seasonal living arrangement during monsoon.

Following the ethics guidelines of the University of Manchester, no personal data such as names and ages of specific participants are revealed in this paper and pseudonyms are used.

The semi-structured interview consisted of open-ended questions, tailored to each interviewee depending on their living situation/environment, area of expertise, or their job role. Data were recorded with an iPhone and a digital stereo voice recorder. Each interviewee received a participant information sheet and gave written consent, as either a signature or thumbprint. Interviewees' ages ranged from 16 to 95 years. Additionally, three focus groups were convened, two in the temporary settlement in Inarpati and one in the village of Pairebesi. Focus groups comprised different activities such as group discussions, drawing and visualization exercises, and severe weather ranking exercises.

The sensitivity of conducting research with earthquake survivors required thinking 'outside the box', and using alternative research methods and tools. The participatory photo-elicitation allowed discovery of information through the eyes of participants as suggested by Lombard [42], an



Fig. 2. Location of study area [44].

approach which helped to gain a more complete picture of their situation. The purpose of this activity was to learn more about the impacts of hazards and climate on people's daily lives in their communities after the 2015 Mw7.8 Gorkha, Nepal earthquake. Two photo-elicitation activities were held with four to five participants each, of mixed gender, and aged 20–56 years. Participation sheets and consent forms were signed for ethical requirements. The photography activity began with handing out to participants a variety of laminated pictures with images of different hazards to prompt discussion. A photo workshop guideline created by the researcher in English was translated into Nepali and used throughout the activity (Figs. 3, 4).

Digital cameras were handed out, and names of participants were noted for each allocated camera.

So that participants could become accustomed to using the cameras, time was allowed to practice taking pictures (Fig. 5).

Between the initial meeting and main workshop, participants had four days to take up to 20 photographs in their own time 'of things/places which were meaningful to them, which they valued, and what

things have threatened/impacted these places in the past, now or in the future.' Cameras were collected, pictures downloaded, numbered and printed in color for the main workshop. Workshop participants shared the meanings of their photographs with each other, selected their top five photographs and hung them on a tarpaulin visible to all participants. A discussion was initiated about any overarching topics, and participants grouped their photographs in addition to the themes identified, gave a title to each photograph and a short narrative, explaining the significance of what they illustrated. A photo exhibition was organized by the researcher in the local government office so that people's difficulties and struggles could be displayed, followed by a discussion with photo workshop participants and local political leaders of the municipality facilitated by the author, to raise participants' concerns about pressing issues in their communities.

Qualitative data was transcribed and the analysis included categorizing and identifying similarities and differences across participants, villages and temporary settlements to note and understand patterns. Results were ordered and analyzed systematically in Microsoft Excel based on the content.

Table 1

Temporary settlements and relocation sites.

Original village of settlers	Temporary settlements	How land was acquired for temporary settlements	Destination of settlers	Settlers' main source of income
Tiru	Inarpati Khalte Satbise	Bought Government land Rental lump sum payment	Tiru (original village) not decided not decided	Reconstruction work (houses and roads) Reconstruction work (houses, cutting wood), cultivating other people's fields Reconstruction work (houses)
Gogane	Inarpati Khalte Bogatitar	Bought Government land Rented	possibly Tiru (original village) not decided Khalte (temporarily)	Reconstruction work (houses and roads) Reconstruction work (houses, cutting wood), cultivating other people's fields Reconstruction work (houses, cutting wood), cultivating other people's fields
Karumaryang	Bogatitar Bogatitar	Rented Rented	Bogatitar (relocation site) Kholabesi (relocation site)	Reconstruction work (clearing rubble, carrying sand, breaking stones), cultivating other people's fields Reconstruction work (clearing rubble, carrying sand, breaking stones), cultivating other people's fields
Pairebesi	Pairebesi Pairebesi	their own land or rented their own land or rented	Naubise (seasonal relocation site) not decided	Farming, selling livestock and rice Farming, selling livestock and rice

3. Results

3.1. Natural and human-made hazards before the 2015 Mw7.8 Gorkha, Nepal earthquake

Study participants mentioned a wide range of existing natural hazards in Nepal. The Director of the Department of Hydrology and Meteorology described wind and hailstorms damaging people's harvests, lightning killing, *'more than 200 people per year in Nepal'*, and drought leading to crop failure. The chief of the National Emergency Operating Center mentioned 487 after-shocks which Nepal had experienced since the 2015 Mw7.8 Gorkha, Nepal earthquake. Several local people spoke about multi-hazards in relation to previous earthquakes (1934, 1961), which triggered landslides, killed livestock and destroyed their ancestors' houses. Some villages on steep terrain were affected by landslides during monsoons. Hazards consistently identified across participants and places were seasonal and climate related such as wind, storms, hail, lightning, rainfall. Pre-monsoon and monsoon seasons affected them most. This led to a clustering of the natural hazards mentioned by interviewees into geophysical, hydrological, climatological, meteorological and biological events as suggested by IFRC [45], and to color-coding the different events as a means of identification (Table 3). The analysis indicates that individual government officials and humanitarians did not have a clear picture of the wide range of Nepal's natural hazard exposure, and/or could not see the connections between different hazards. Nepali and international scientists comprising geologists, seismologists and a geo-technical engineer had only mentioned geophysical, meteorological and hydrological events.

However, this might be due to their specific research interests or job roles in the area of geophysical studies.

While scientists and government officials talked about Nepal's geology and steep topography as major causes of multi-hazards, they identified these also as underlying causes of multi-hazards for road construction. The Director General of the Department of Hydrology & Meteorology shared that, *'people don't care about Nepal's geology, how much the slope is, how much the grade is, what soil it is, because they have to construct the road anyway'*. Humanitarians, scientists and government officers raised questions about non-consideration of technical quality standards, sound road designs, compliance with road construction regulations, annual rainfall, tight monitoring and evaluation processes permitting bias/corruption, Nepal's geology and environment, and skilled and technically knowledgeable personnel while building roads. Ganendra, a regional DFID Social Inclusion Officer described, that as proper implementation guidelines were not followed by local governments, engineers at local level are forced to prepare fake bills for road constructions. Another example was biased auditing, with lax monitoring at national or district level by the Government of Nepal, and no collaboration between them. Banju, a humanitarian in Rasuwa district, confirmed the alleged corruption among political leaders, engineers and community people throughout the road construction process with reference to their acceptance of bribes. These claims of government corruption and mismanagement raise questions about the system as a whole. It seemed to be a calculated course of action that contracts were being issued for roads which were not being properly built, and that political leaders could take advantage without being challenged.

Table 2

Methods of data collection.

Community/Actors	Methods of data collection		
	Semi-structured interviews	Focus group activities	Participatory photo-elicitation workshops
Local people in temporary settlements	19	2 (4–7 participants each)	–
Local people in original villages	22	1 (5 participants)	2 (4–5 participants each)
TOTAL	41	3	2
Government officials	7	–	–
Humanitarians (INGOs/NGOs)	7	–	–
Scientists	5	–	–
Total	19	0	0
Overall total	60	3	2



Fig. 3. Photo Workshop guideline in Nepali.



Fig. 4. Photo Workshop guideline in English.

Halfway through this research, participants in four villages in Rasuwa District highlighted that various hydropower projects nearby were started around 2010/2011 with road construction and tunnel blasting. Villagers felt these activities had weakened the topography, the soil of their land and the entire hill/mountain range. Sameet, originally from Gogane, residing in Khalte camp explained, *'that 216 (Korean Hydropower Company) cut the roots and took it. We told them to bring the road/tunnel through the villages. But no, they brought it alongside the river and cut the roots of the hills'*. Thirteen Rasuwa district specific hydropower projects were similarly mentioned by local humanitarians and government staff as causes for multi-hazards. Ganendra stressed that, *'the hydropower companies are not serious about environmental impacts and these kinds of hazard creations, because one day they saw their benefits.'* The map (Fig. 6) from Murton et al. [46], illustrates 23 hydropower projects in Rasuwa district as of 2015.

3.2. Leaving their place of origin

After the 2015 Mw7.8 Gorkha, Nepal earthquake struck [4], all houses in the study area had collapsed, and a huge number of people were buried under their houses and in massive landslides. The villages of Gogane and Karumaryang experienced a life-threatening amount of rock falls and landslides on the day of the earthquake. People from Gogane, Karumaryang and Tiru decided to leave their original villages less than seven days after the 2015 Mw7.8 Gorkha, Nepal earthquake due to ongoing aftershocks, rock falls, landslides and blocked rivers. The following quotations illustrate their experiences: Chinshu, a woman from Gogane explained that, *'in Gogane the river was blocked, and the landslide was coming down. So, we thought, that this village might kill us, so we shouldn't stay here'*. Maya from Karumaryang shared, that many people in her village had died, and they were worried about ongoing aftershocks. Pote, an elderly man from the

same community, recalled, *'my village was scattered, the land cracked and we were in the middle of two landslides'*. Dinesh from Tiru recalled that, *'there were frequent aftershocks that occurred in Tiru, even dry landslides occurred frequently. We felt insecure there, and we decided to leave'*.

After people from the three villages (Gogane, Karumaryang, Tiru), had left their place of origin, they stayed in various private fields in the valley close to the Nuwakot/Rasuwa border. However, they had to move several times in the first three months following the earthquake as land owners needed their fields when planting season started. Furthermore, Chief



Fig. 5. Photo Workshop Introductory Meeting in Thapatol, Rasuwa district 2018.

Table 3

Natural hazards in Nepal.

Natural hazards in Nepal			Mentioned by			
			Scientists	GoN	Humanitarian community	Local people/communities
Natural hazards	geophysical	earthquakes	✓	✓	✓	✓
		landslides	✓	✓	✓	✓
		aftershocks		✓	✓	✓
	meteorological	rainfall	✓	✓	✓	✓
		windstorm		✓	✓	✓
		hailstorm		✓		✓
		lightning		✓		✓
hydrological	floods	avalanches	✓	✓	✓	✓
		glacier lake outbursts		✓	✓	
		shifting water tables		✓	✓	✓
climatological	fires	drought		✓	✓	✓
		heat waves		✓		✓
		cold waves		✓	✓	
biological	epidemics			✓	✓	

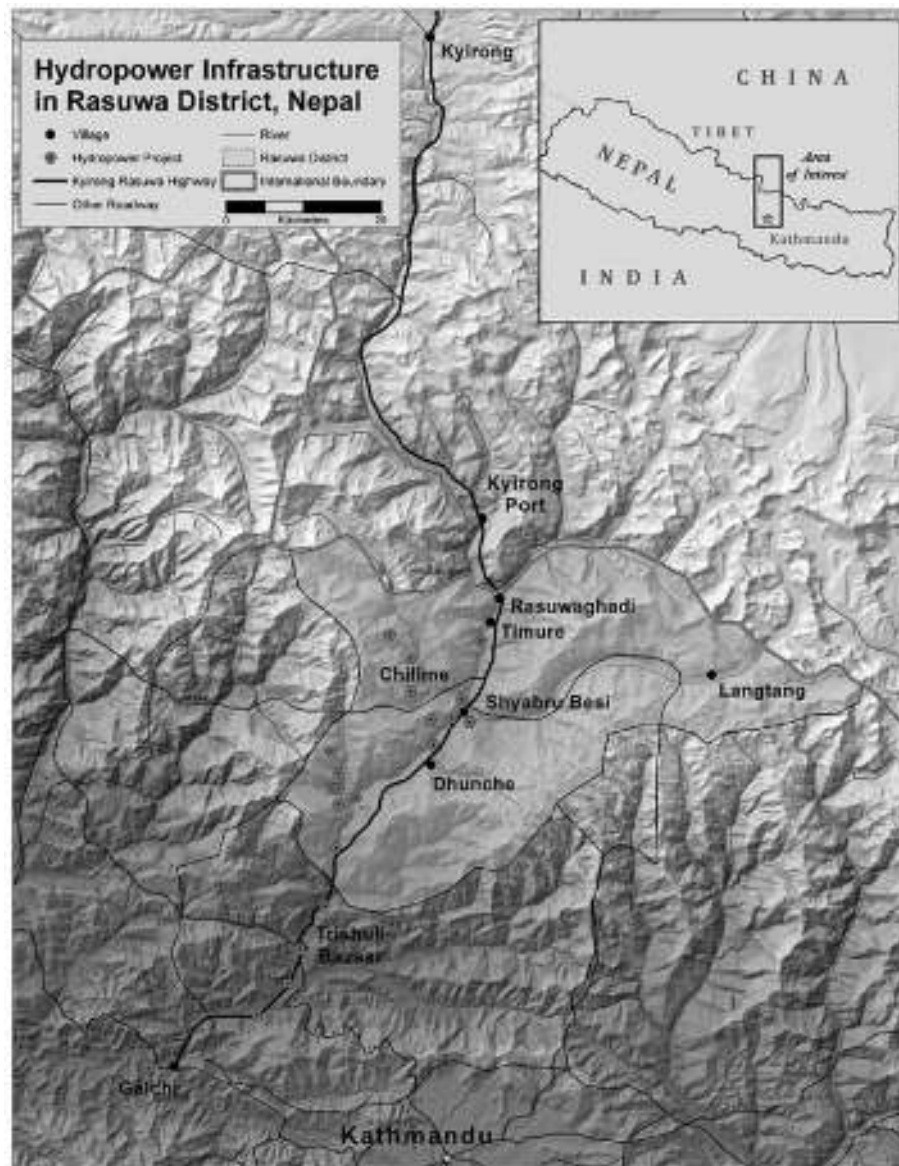


Fig. 6. Hydropower Infrastructure in Rasuwa District, Nepal ([46], p. 6).



Fig. 7. Khalte's temporary settlement, Rasuwa district, July 2018.

District Officers in Nuwakot and Rasuwa demanded that displaced people from Rasuwa move to Rasuwa district to find their own place to stay, even if their temporary shelter in Nuwakot was only a 3 km distance from the Rasuwa border. Chinshu, a displaced person from Gogane explained, *'we searched for land, and a plot was for rent in Bogatitar, so we made camps and stayed.'* However, paying rent added another financial difficulty to the challenges displaced people faced, as they already struggled with a lost livelihood. Previously, INGOs had paid rent for the land in Bogatitar, yet two years after the 2015 Mw7.8 Gorkha, Nepal earthquake they ended their relief support in Nepal, and stopped payments. Meanwhile, the NRA had expressed that the 2015 Mw7.8 Gorkha, Nepal earthquake offered an opportunity to create long-proposed integrated settlements, particularly in Nepal's mountainous regions [47]. A policy was approved in April 2017 by the NRA, supporting and encouraging earthquake survivors to build community-based integrated settlements, where the NRA would support them to construct basic infrastructure [47]. So, displaced people in Bogatitar, who struggled with rental payments, sought, in collaboration with local NGOs, government land nearby, to create an integrated settlement. A three-hectare government site was found in Khalte, and displaced people and a local NGO proposed an integrated settlement to the CEO of the NRA, who gave his support. As the land in Khalte had to be cleared of rocks/stones, Samaritan's Purse provided funding of approximately 52 lakhs to clear the land.

Peculiarly, only after people from Gogane and Tiru had settled in temporary shelters in Khalte, the NRA sent a technical team in early 2018 to carry out a geo-hazard assessment. The purpose of the assessment, initiated by the Ministry of Home Affairs after the 2015 Mw7.8 Gorkha, Nepal earthquake and mandated by the NRA, was to determine whether settlements were safe from geo-risk and suitable for the reconstruction of a permanent settlement or not. The geo-hazard assessment of Khalte showed that the area was at risk, and therefore could not be recommended for the development of a new integrated settlement. Numerous humanitarians and local people doubted the accuracy of the geo-hazard assessment. One of Khalte's camp leaders stressed, *'there is a political agenda behind it. There are many things to be understood.'* Fig. 7 illustrates the temporary settlement of Khalte with 269 households on the right bank of Trishuli river, with existing landslides on the left bank.

In the case of Nepal, the NRA (in co-operation with other organizations) assessed around 1100 settlements for geo-risk. Of these, approximately 500 were classified as CAT I,¹ 300 as CAT II,² and 300 as CAT

III,³ and only a small amount (less than 2%) was reassessed. This resulted in 3168 CAT III households (field notes diary, June 2018), which needed relocation after the 2015 Mw7.8 Gorkha, Nepal earthquake. For the earthquake-induced landslide assessments, the NRA appointed UNOPS as an implementation partner, and about 14 technical teams were formed. In the majority of cases, each team had a geologist, a civil or geotechnical engineer, and a forester or environmentalist. Although in the case of Khalte, one geologist and two geological engineers formed the team, and in case of Gogane, a geologist, a soil and watershed expert and a water-induced disaster management expert carried out the assessment. The teams received approximately five days' training (including 2 days of fieldwork), and most of their members did not have any prior experience of landslide assessment. The assessments were based on visual inspections, without any detailed monitoring of landslides. A landslide assessment guideline was provided to the teams with tables, maps, block diagrams, and charts. According to the training they received, the teams had to assess each landslide and surrounding settlement rapidly without carrying out any subsurface investigation or slope stability analysis based on soil and rock properties.

After Khalte was declared unsuitable for an integrated settlement, new plans and arrangements by the government, NRA and local political leaders were made to establish an integrated settlement in Tiru instead. This integrated settlement was planned for households originally from Tiru and Gogane, residing in the temporary settlements in Khalte, Inarpati and some back in Gogane. Chinshu, Khalte's community leader, expressed his concern that, *'there is not enough space for everybody, as Tiru can only hold 100–150 additional households'*, and Banyu (residing in Gogane) explained, that Tiru had no land left which could be bought for farming. Prashad stressed, *'we need farmland in Tiru, having a house is not enough'*. This was an important aspect for people from Gogane, as they would be left without any farmland in Tiru, which is absolutely essential for their traditional livelihoods.

The ongoing discussions around the controversial integrated settlement in Tiru encouraged some displaced families originally from Gogane (CAT III), to cultivate their farmland again in Gogane. These included Prashad's family, and others like Banyu's family who moved back to Gogane, their original village, to farm so, *'they don't have to starve'*. Prashad expressed his frustration that, *'the government has not looked after anything'* as for him, *'not the entire community in Khalte has to come together'* to live in the same place. *'Those, who have come and want to live in Gogane, have to arrange little pakka's (a dwelling that is solid and permanent)'*. People's frustrations and stress accelerated as they sensed that the planned integrated settlement in Tiru was the result of motivation, power, influence and action of a community leader, spokesperson and political ward president from Inarpati's temporary settlement, who had a personal interest in this integrated settlement. This seemed to affect the entire community in Khalte. Thus, it materialized, that particular community leaders' voices did not represent people's needs, but instead prioritized their own needs to their advantage, and imposed solutions on people which they did not want. This was clearly reflected in the outcome of a survey in Khalte's temporary settlement, which was initiated by the NRA in September 2018 after the community in Khalte had spoken out against the planned integrated settlement in Tiru, to understand *'who wants to go to Tiru (integrated settlement), who wants to stay in Khalte, and who wants to take the 2-lakh land support grant'*. The survey showed that the majority of households (82.4%) residing in Khalte chose to stay there, others (13.5%) preferred to take the 2-lakh land support grant, and only 8 of 193 households (4.2%) preferred to live in an integrated settlement in Tiru. It was puzzling that there was no option to arrange, for example, seasonal living arrangements (during monsoon) for displaced people who wanted to stay in Gogane as the area was most risk-prone during this time.

Moreover, the ongoing discussions about the integrated settlement in Tiru seemed to delay the government housing grant for households in Tiru that had not left, or that had returned since the 2015 Mw7.8 Gorkha,

¹ CAT I = Households whose livelihoods and/or shelters are at a safe location to begin reconstruction (Presentation, 13th June by INGO People in Need).

² CAT II = Households whose livelihoods and/or shelters are unsafe due to the existing state of geo-hazards, but the safety risk of these geo-hazards can be effectively mitigated (Presentation, 13th June by INGO People in Need).

³ CAT III = Households whose livelihoods and/or shelters are unsafe due to the existing state of geo-hazards, and the safety risk of these geo-hazards cannot be sufficiently mitigated for technical or financial reasons (Presentation, 13th June by INGO People in Need).

Nepal earthquake. People raised the issue of the safety of their rebuilt houses. Kashmitha, a local resident in Tiru, explained, that, *'this house will collapse if another earthquake comes, because it doesn't have rods, and is just made with mud and stone'*. However, households in Tiru were not only worried about safety. They also stressed, that none of the households had received any government housing support grant yet, three years after the 2015 Mw7.8 Gorkha, Nepal earthquake, and Tshering from Tiru wondered if it was due to the lack of unified voices in the temporary settlements in Khalte and Inarpati.

Other people residing in Khalte struggled to acquire new land, and to rebuild a home. Ditya, a 65-year-old widow, who had lost her husband during the 2015 Mw7.8 Gorkha, Nepal earthquake, and become disabled when her house collapsed above her, shared, *'they don't give a small plot of land, and if we have to buy, we have to buy by combining money. I can't print money, and who will make the house for me?'* Sumeet, a 75-year-old man explained, that the 2-lakh government grant was not enough for purchasing land, and that it was the duty of the Nepali government to give a small safe place to him to live.

Numerous elderly people seemed to experience emotional and psychological stress while living in temporary settlements. Maya in Bogatitar explained, *'there is no land where I can plant anything, it is others'. There is nothing I can do here. My daughter helps me to eat and to stay here'*. Before the 2015 Mw7.8 Gorkha, Nepal earthquake, elderly people had their fields which they cultivated and their livestock. Several elderly people mentioned that they should have died during the 2015 Mw7.8 Gorkha, Nepal earthquake, and they felt like crying. It seemed that especially widowers and widows were confined to temporary settlements due to their age and/or financial dependencies on sons/daughters.

3.3. Staying in their original villages with amplified risks and new challenges

People from Pairebesi, Kuwapani and Thapatol, who stayed in their villages after the 2015 Mw7.8 Gorkha, Nepal earthquake, witnessed numerous chain reactions and impacts, which followed closely afterwards. They described rock falls, dust, destroyed houses, loss of livestock, buried roads, blocked rivers, and continuous aftershocks lasting up to four weeks. In Kuwapani, people described increased landslide risks; Dipankara shared, *'the earthquake has cracked the land, so when there is heavy rainfall, we have fear that landslide comes'*. Other villagers stressed the long-term impacts on their farmland, being forced to leave it barren due to cracks or landslides, which made the land uncultivable. Gautam and Anandar from Pairebesi similarly observed numerous cracks in the land around their village, and illustrated the hidden danger and threats in the photo workshop (Figs. 8, 9). Anandar explained, *'because of cracked land it becomes dangerous during monsoon season'*.

People had managed to build foundations of new houses, but on 6th August 2017 during monsoon, Pairebesi, Kuwapani and Thapatol were devastated by a massive landslide, killing a family of four and destroying numerous houses and foundations. Charini, a Pairebesi inhabitant, took particular photographs (Figs. 10, 11) for the photo workshop illustrating the landslides and rock falls in Pairebesi and explained, *'my house was buried under this landslide (Fig. 10) and this rock destroyed our house and blocked the drainage of our village (Fig. 11)'*.

People from the three villages described combined damage to their infrastructure, environment and daily livelihoods due to the 2015 Mw7.8 Gorkha, Nepal earthquake, the 2017 landslides, and the annual monsoon rains. Gautam from Pairebesi shared, *'the roads and the drinking water lines were also damaged by the landslides [in 2017]. The irrigation channel was affected by the 2015 earthquake and flood, and then the landslide has damaged it in places and was completely buried. The irrigation pipe on the bridge at Kavre Khola (river next to Pairebesi) was swept away entirely by monsoon rain.'* Fig. 12 shows the bridge, where the irrigation pipe was previously laid, and Anandar's photo caption read: *'with the help of this bridge, people take water for irrigation by laying a pipeline in dry season.'*

In Thapatol, due to road construction after the 2015 Mw7.8 Gorkha, Nepal earthquake, *'the water flow was changed'*, causing flooding.



Fig. 8. Cracked land in Thapatol, Rasuwa 2018.



Fig. 9. Cracked land in Pairebesi, Rasuwa 2018.

Furthermore, the 2017 landslide blocked the drainage channel despite preventive measures like gabion walls, and during heavy rainfall the channel became blocked. After the 2017 landslides, many house foundations were destroyed in the three villages. Prabin, a farmer from Pairebesi, lost his



Fig. 10. – Destructive landslide, Pairebesi, Rasuwa 2018.



Fig. 11. Rock in Pairebesi, Rasuwa 2018.

house in the 2015 Mw7.8 Gorkha, Nepal earthquake, his reconstructed house in the 2017 landslide, and ‘even now (September 2018) me and my family are living in a rented room in someone else’s house across the hanging bridge’. The geo-hazard assessment by the NRA in February 2017 classified his land in Pairebesi as CAT II (Table 4). However, a second assessment after the 2017 landslides declared the entire village of Pairebesi, some households of Kuwapani and additional households in Thapatol as CAT III (Table 4).

Prabin was supposed to resettle, but struggled to find affordable land nearby as land prices sharply increased. However, Prabin’s was not the only household in Pairebesi unable to find affordable land for reconstruction. Chimini, a 66-year-old childless widow, had managed to rebuild her house after the 2015 Mw7.8 Gorkha, Nepal earthquake before the 2017 landslide struck. Nevertheless, her land was assessed as CAT III, and her rebuilt house was not approved for a housing grant. Chimini said, ‘I don’t have the ability to go anywhere else and make house. It’s ok, if I get little money and get land nearby, then I can make a small one-room house, but we can’t get land anywhere near. The land owners are increasing the prices of cheaper land after hearing that it is relief money.’ Ranjit explained, ‘after making my new house, I could not even stay there for six months, again the landslide started creating difficulty for me, as the land got declared as unsafe.’ Prabin, Chimini and Ranjit’s were three of many households that experienced similar problems with finding an affordable safe place to live after the 2015 Mw7.8 Gorkha, Nepal earthquake. The geo-hazard assessment outcome brought another emphasis to the challenges people faced with resettlement.

People in Kuwapani as in Khalte doubted the accuracy of the geo-hazard assessment. Binsa explained, ‘at first, our village was under red signal (CAT III), but the local school was under reconstruction, and the headmaster thought,



Fig. 12. Temporary irrigation in Pairebesi, Rasuwa 2018.

Table 4

Geo-hazard assessment categorization.

Geo-Hazard Assessment Categorization (as of September 2018)			
Village	Altitude in meters	Category (CAT)	
		1st assessment 02.02.2017	Re-assessment after 06.08.2017
Pairebesi	556	CAT II ¹	CAT III ²
Kuwapani	956	CAT II ¹	CAT II ¹ + CAT III ²
Thapatol	1080	CAT II ¹ + CAT III ²	CAT II ¹ + CAT III ²

¹ CAT II = Households, whose livelihoods and/or shelters are unsafe due to the existing state of geo-hazards, but the safety risk of these geo-hazards can be effectively mitigated (Presentation, 13th June by INGO People in Need).

² CAT III = Households whose livelihoods and/or shelters are unsafe due to the existing state of geo-hazards, and the safety risk of these geo-hazards cannot be sufficiently mitigated for technical or financial reasons (Presentation, 13th June by INGO People in Need).

that the school reconstruction budget might not come through, if the land falls under displaced category (CAT III). Due to that reason, they [the geo-hazard assessment] did not put us, these 6-7 houses, in the displaced list (CAT III)’.

However, sixteen CAT III households from Pairebesi managed to acquire land nearby to live on, as Bibek explained it as ‘unified community’ and ‘the houses that we are building in Naubise are to stay for three months in a year during heavy monsoon. The other nine months we will stay in Pairebesi, because we have our fields here.’ Yet, households had to borrow money from friends, neighbors or banks with high interest rates as the land and reconstruction grant from the Nepali government was not enough. In Naubise, one plot of land providing just enough space to fit a small house cost approximately 6 lakhs, without building materials or labor work. This had caused psychological stress as local people were worried how to pay back the loan and to feed their families.

4. Discussion

This section discusses three main themes: first, different multi-hazard risk assessment approaches as disaster prevention or after a particular disaster; second, the stumbling blocks people experienced during the resettlement process of the 2015 Mw7.8 Gorkha, Nepal earthquake; and lastly, policy gaps in the way formal land markets operate in the context of reconstruction.

4.1. Multi-hazard risk assessment approaches

Scholars around the world are not only demanding multi-hazard approaches after a particular disaster like the 2015 Nepali earthquake [48], but also for disaster risk reduction, and the management of interacting natural hazards [49]. The importance of multi-hazard approaches is also stressed within two international frameworks – the Hyogo Framework for Action ([50], p.4), and the Sendai Framework for Disaster Risk Reduction ([51], p.10). However, neither framework states what a multi-hazard approach comprises [52].

Two approaches for multi-hazard risk assessment methods seem to stand out in the literature ([53], p.88): a) assessing individual hazards in a particular geographic location independently [54–57]; and b) evaluating possible interactions and/or cascade effects among the different possible hazardous events [58–60]. The first approach is often highlighted by studies of single natural hazard risk, such as earthquakes [61,62], floods [63,64], landslides [65,66], tropical cyclones [67], sea level rises [68], drought [69], or wildfires [70]. However, this study argues that the second approach seems more applicable as many countries are not only prone to single hazard risk, but prone to hazardous events which may occur simultaneously, cascadingly or cumulatively over time ([71], p.53). This multi-hazard approach can be applied in various ways. The two most prominent ways are disaster prevention to mitigate the risks of future disasters, or multi-hazard risk assessment, done after a disaster hits a particular

area of a country to assess the risk in that area and for possible designated resettlement areas. While the literature on multi-hazards seems to mainly concentrate on examining natural hazard risks, less attention is given to other types of risks faced by communities living in risk-prone areas, for example those arising from infrastructure projects, and more importantly, what risk tolerance and risk perceptions people have in relation to the different hazard risks they face.

Case studies from China [72], Cairns/Australia [73], Costa Rica [74] and in the French Alps [75] have examined multi-hazard risk using a variety of risk assessment approaches as preventive measures for mitigation of risks for future disasters. The purpose of these assessments was not only to enhance understanding of what can be done in terms of risk mitigation/reduction, but also to inform policy-makers and make recommendations for prevention, preparedness and response. Liu et al. [72] explained the purpose of a multi-hazard risk assessment as about having 'a holistic view of the total effects of impacts by assessing and mapping expected loss, due to the occurrence of various natural hazards, in the social, environmental and economic assets of a given area'. Their study of China's Yangtze River Delta focused on the possible interactions among different hazards, and offered information and insights to policy- and decision-makers as well as public planners, on how natural hazard risks need to be managed, so that more targeted and appropriate mitigation measures can be taken to avoid disasters ([72], p.633). In Cairns, a multi-hazard risk assessment was conducted which considered the mitigation of risks to Australian urban communities caused by earthquakes, landslides, floods and cyclones 'taking into account the vulnerability of the whole community' ([73], p.30).

Another multi-hazard risk assessment carried out in Costa Rica, in the city of Turrialba, an area regularly affected by earthquakes, landslides and flooding, made recommendations for prevention, preparedness and response, as well as the reduction of vulnerabilities in urban areas [74]. In the French Alps a multi-hazard risk assessment was conducted for snow avalanches, landslides, floods, rock falls and debris flows for the Barcelonnette Basin [75]. This study not only took 'triggering factors' such as an earthquake and meteorological extremes into consideration, but likewise the 'contributing factors either related to the environmental setting such as topography, soil, geology, geomorphology or anthropogenic activities like deforestation, tourism (skiing areas), road construction and agricultural practices' ([75], p.202).

The assessments in China, Australia, Costa Rica, and the French Alps [72–76], show that various methodologies were used to examine multi-hazard risk. Some studies [72,76] seem to have taken only natural hazards into consideration, while others [75] looked also at additional contributing factors (e.g., geology, topography, road construction, deforestation), while others considered the vulnerability of communities [73,74]. However, the above-mentioned case studies [49,75,77–79] which explicitly considered the interactions among hazards and cascading effects, are rare and limited. Such studies required a significant amount of data for modelling, and the complexity of hazard 'chains' often discourages analysts from considering these comprehensive multi-hazard analyses [58,75,78,80].

Another obstacle in many hazard-prone low-income countries is, that complex data of the quality and quantity required for modelling multi-hazard assessments, are commonly not available [53]. Besides, when major earthquakes, typhoons or flooding occur in these countries, national and local governments are immediately put under immense pressure to start rapid reconstruction processes. How can countries undertake such multi-hazard assessments, which are not only time-consuming, but require assessment of various natural hazards as well as the additional contributing factors arising from various distinct risk environments, infrastructure projects, and which also consider the risk perceptions and tolerances of local communities? Examples of multi-hazard assessments initiated after earthquakes in Pakistan (2005), Haiti (2010), and after a tropical storm in the Philippines (2011) partially shed light on these challenges.

Historical examples of multi-hazard risk assessments after earthquakes in Haiti [81] and Pakistan [82], and the tropical storm Washi in Cagayan de Oro [83], reveal differences. For instance, the Post-disaster Damage and Needs Assessment [81], attempted to analyse Haiti's multiple natural

hazards by paying attention to the possibility of another enormous earthquake with secondary effects, hydrometeorological hazards with secondary effects, and the identification of their intensities [84]. However, this approach was challenged by a lack of relevant data, when Haiti entered into the reconstruction phase [84]. In contrast, after the 2005 Kashmir earthquake, a local environmental and seismic risk assessment was conducted in a Chakhama valley, instigated by the Pakistan government, to evaluate the natural risks people encountered [82]. It comprised community-based discussions and localized risk mapping. This seems to have supported people to think about alternative places to reconstruct their houses and enabled informed decision-making about suitable places for reconstruction [82]. People considered alternative land or found temporary solutions for harsh monsoon and winter seasons. However, questions still remained as to whether people who relocated were provided with other livelihood options and how they managed. Moreover, it left questions unanswered such as what methodology and criteria were used, or what the multi-hazard approach contained. In the aftermath of storm Washi in Cagayan de Oro, the suitability of land for resettlement was determined by a geo-hazard assessment. However, this process had been mostly regarded as a compliance step and not as a critical factor in ensuring the safety of land and minimizing exposure to hazards [83].

History seems to repeat itself in the aftermath of the 2015 Mw7.8 Gorkha, Nepal earthquake, as the combination of interacting physical processes across multiple geographical areas during time periods was not sufficiently acknowledged and considered by national and international agencies, and the National Reconstruction Authority (NRA). The geo-hazard assessments initiated 21 months after the 2015 Mw7.8 Gorkha, Nepal earthquake by the Ministry of Home Affairs and mandated by the NRA, were an important part of the reconstruction process. The purpose of these assessments was to determine whether settlements were safe from geo-risk and suitable for reconstruction of a permanent settlement. However, while an assessment of hazards was critical, the geo-hazard assessment undoubtedly lacked precision and missed the in-depth focus that was required in some places to identify other interrelated hazard exposures as well as additional contributing factors arising from various distinct risk environments and economic/infrastructure projects. This could have been avoided if local people's knowledge of localized hazards and risk perceptions had been considered. For example, local people in Rasuwa district identified increased risk due to damage from the earthquake to their water and irrigation channels, but also to the lack of soundly engineered roads in their living environment, causing diverted water flows, seasonal flooding and increased landslide risk. This study confirmed that what people saw or perceived as hazards, their exposure to risk, and how they were impacted, depended on where they lived, their environment, housing and their exposure to different climates. Equally findings confirm, as Wisner et al. [85] pointed out, people's level of hazard protection, but also the quality and effectiveness of, for instance, protection against landslides measures, influenced their exposure to risk. People in this study described how a combination of hazards and accumulated hazards caused by the 2015 Mw7.8 Gorkha, Nepal earthquake, i.e., steep terrain, topography and monsoon rain, had increased the risk of landslides and flooding similar to the insights of Wisner et al. [85]. Furthermore, explicit multi-hazard risks caused by road/tunnel constructions for hydropower projects were highlighted by local people as combining with the impacts of the 2015 Mw7.8 Gorkha, Nepal earthquake, intensifying the risk of landslides during monsoons and amplifying people's vulnerability.

National/local road construction was also identified by humanitarians, government employees and scientists as a major hazard, describing it as root cause for further hazards in Nepal. Not enough monitoring and rigorous/unbiased auditing during the road construction implementation process to minimize the amplification of hazard risks was identified. Further evidence showed, that there were attempts from government officials, private companies or others who stood to benefit financially or through other incentives, by applying illegal or corrupt practices throughout the road construction process, including road construction for the purpose of hydropower projects. As various scholars [86–89] have highlighted, the

modification of landscapes by humans through road construction is one of the prevailing triggering factors initiating further hazards, predominantly landslides, in tectonically active regions.

Thus, a key finding is that while it may be intuitive to build roads, building roads might actually make people's living environment riskier, and is not always advisable in all circumstances. Clearly, people want to build roads for access and to gain commercial advantages. However, road construction in a tectonically active region like Nepal needs careful consideration, not only in terms of what kinds of roads can be built and where, but also in terms of how the road construction process can be conducted with strict monitoring, auditing and risk-averse practices. However, this is not only significant for Nepal. It is also critical for any mountainous countries located within tectonically active regions exposed to earthquake risks.

The evidence provided in the previous section shows, that there was inadequate consideration by the Nepali government and the NRA of excessive risks when the geo-hazard assessment was carried out, neglecting risks caused through road/tunnel construction for infrastructure projects (especially hydropower) by modifying landscapes in a tectonically active region like Nepal, and thereby damaging people's living environment and livelihood options. Furthermore, doubts were raised by engineers and scientists that the geo-hazard assessment lost significance as it did not clearly outline at which time of year (month or season) the place/area was hazardous and prone to geo-hazards. This could have been avoided if local people's knowledge and risk perceptions had been carefully considered, as they certainly paid attention to seasonality and identified especially the pre-monsoon and monsoon seasons as hazardous. They highlighted the impact of storms during pre-monsoon on their agricultural land and harvest, and the monsoon season was distinctly identified as an amplifier of landslide risk.

Further questions were raised by engineers and scientists about the significance of the methodology used for the geo-hazard assessment, which did not capture new or changing risk, as the assessment was made on one particular day. Neither did it capture other exposure to risk and potential hazards in people's environment. The study found that the geo-hazard assessments caused controversies, biases and disbelief among local people, scientists and humanitarians alike. For instance, communities fragmented, as some households were categorized as CAT II, others as CAT III and it was felt that the categorization (CAT) of land into I, II or III was not feasible. Controversies emerged around these categorizations, as they seemed aligned primarily to political/infrastructure interests, with local people and humanitarians alike demanding transparency and openly accessible geo-hazard reports. Technical outcomes were not openly discussed with affected communities and land was categorized without engaging in dialogue with affected communities to consider their valuable knowledge, which they had gained by living for generations in these areas. Furthermore, if the identified hazardous seasons had been reflected in the geo-hazard categorization, and people's individual risk tolerances had been considered, then open-minded and diverse solutions could have been found, such as seasonal living arrangements to protect and support citizens, instead of harsh CAT III classifications and controversial integrated settlement solutions, which did not reflect people's needs and left the time of the year (month/season) the place/area was hazardous and prone to geo-hazards unconsidered.

In addition, the geo-hazard assessment omitted to assess additional hazard-prone places which were not included in the 1100 settlements assessed for geo-risk, but which were exposed to landslide risk or other types of hazard risks after the 2015 Mw7.8 Gorkha, Nepal earthquake. Hence, the conclusion section contains two recommendations: disaster risk-informed development planning in Nepal containing multi-hazard risk assessments as part of disaster risk management policies, and reform of resettlement policies.

4.2. Resettlement

The outcome of the geo-hazard assessment brought further significance to the challenges for people whose land was categorized as CAT III: the threat of resettlement. One major concern was the lack of involvement of

local communities in decision-making processes, to not only protect people's safety but also their livelihoods. What was missing was a space for discussion, to share technical knowledge, to consider the valuable experiences and knowledge the communities gained over generations in relation to their living environment, to understand people's varied risk perceptions and tolerances and to enable them to make informed decisions for relocation or seasonal living arrangements. If a multi-hazard assessment is done only in terms of what technicians identify as risk, clearly, the wealth of knowledge that local people can contribute to these assessments is neglected and resettlement can end in havoc.

This study has shown that displaced people had different preferences for resettlement and varied risk tolerances which seem not to have been considered by the government in its resettlement practices. For instance, some displaced people in Khalte originally from Gogane, advocated that not all people in Khalte's displacement camp had to come together to live in the same place. Some families' risk tolerances allowed them to move back to Gogane (CAT III), to rebuild their collapsed houses with the old materials, and to look after their farmland. This could have been supported by government grants and seasonal living arrangements during monsoon to protect these families from landslide risk during the most risk-prone season. Others, who had returned to Gogane seemed to have been motivated to cultivate their farmland in Gogane again by discussions around the controversial integrated settlement in Tiru as they had to find a way to feed their families. The integrated settlement in Tiru was not a suitable option for resettlement for the majority of people in Khalte as they would be left only with a house but no farmland, and farmland is fundamental for displaced people's traditional agricultural livelihoods. It was baffling that no alternative livelihood options were offered to people without farmland in Tiru as it would have been advantageous for them to consider relocating to this integrated settlement.

More than three years after the 2015 Mw7.8 Gorkha, Nepal earthquake, people in displacement camps still lived with uncertainty, frustration and challenging emotions, as they did not know where they could resettle. The policy of resettlement within integrated settlements seems to have caused difficulties in itself, but in addition the very implementation of this policy caused chaos and made displaced people more vulnerable. People's much-needed participation in planning and implementation of integrated settlements, access to agricultural land, or to other alternative livelihood programs was neglected. Likewise, planned integrated settlements seemed to block the distribution of money for the reconstruction of individual houses, and caused frustration among people residing in their temporary reconstructed houses, which they described as not earthquake resilient. It is important to recognize that housing is more than just 'shelter', and resettlement approaches need to consider more elements than just hazard exposure. UN Habitat [90] has pointed out the key aspects of the right to adequate housing which contains freedoms and includes '*the right to choose one's residence, to determine where to live and to freedom of movement*'. This key aspect of freedom was clearly illustrated in this study by the need/desire of local displaced people residing in Khalte, to be able to choose where to resettle.

This study illustrated that the relocation of households is a highly sensitive matter. It suggests that a major factor in why resettlements become disordered and increase people's vulnerabilities is the lack of governmental collaboration with affected communities. This was similarly confirmed by Oliver Smith [91]: '*The whole process of resettlement is much more complex than is seen in the approach employed by many reconstruction authorities after disasters*'. The argument of various scholars [92,93], that most of the failures in resettlement are connected to policies which are hardly based on people's culturally and socially derived values and needs seem to also be applicable to Nepal. This study suggests that before any policies are implemented which prohibit or do not support reconstruction in assessed '*unsafe areas*', and decisions taken on behalf of people, risks need to be understood on all levels - community, policy, practitioner, and academic. Policy-makers, humanitarians and geo-hazard experts need to engage with affected communities to discuss land safety assessments and to understand affected people's perceived localized hazard risks in different settings.

Equally important is to understand affected people's individual fears, risk tolerances, livelihood requirements, needs and resilience capacity to deliberate on various possibilities, such as alternative land or seasonal living arrangements and to foster informed decision-making for affected people such as in the aftermath of the Pakistan earthquake in 2005 [82]. The historical approach illustrates a possible way to work with affected communities to understand their localized hazard risk, and to work out suitable, feasible and different settlement options with them. This study revealed that not all affected CAT II/III households in Rasuwa district have the same needs and not all households from the same village perceived the risk of hazards in the same way. Some villagers wanted to stay in their original place due to their livelihoods and cultural adequacy, even if it was hazard-prone, while others felt more comfortable relocating to a safer environment. Various policies and collaborative policy implementation are needed to assist people to rebuild their lives in a safer environment, and with workarounds, so they are able to return to stable lives within their original environment if they wish and to consider seasonal living arrangements during monsoons.

4.3. Policy gaps: land for temporary settlements & changing land markets

This study showed, that displaced people who had fled their place of origin due to increased landslide risk and fear of further hazards, were further faced with rental payments when they were already struggling with access to adequate housing and subsistence. The nonexistence of a clear policy to provide safe and rent-free plots of land to displaced people, sparked further vulnerabilities. Equally, the failure of central/local government officials with the help of local/international humanitarian agencies to consider the hazard-proneness of land before displaced people were resettled in Khathe caused mayhem.

People in Rasuwa district struggled to acquire safe affordable land nearby their original villages or other land further away for a reasonable price. People emphasized that the housing and land government grant was not enough for reconstruction and resettlement. However, the right to adequate housing includes 'security of tenure; housing, land and property restitution; equal and non-discriminatory access to adequate housing; and participation in housing-related decision-making at the national and community levels' ([90], p.3–4). Other criteria for housing to be adequate are: 'Availability to services, materials, facilities and infrastructure; affordability, habitability, accessibility, cultural adequacy and location (i.e., employment opportunities, health-care services, schools, social facilities)' ([90], p.3–4). Yet, only when affected people described their experiences in Rasuwa district did it become clear that land prices had been soaring as the demand for new land acquisitions rose due to resettlement decisions made by the NRA through the geo-hazard assessment, such as the relocation of 836 CAT III households to Rasuwa district. While many landowners benefitted from sharply increasing land prices, only limited affordable land was available, putting people with less financial and economic resources in a rather vulnerable position as they were not able to make informed decisions about suitable places for reconstruction, to evaluate different options of alternative land or seasonal living arrangements. Even people who managed to buy land nearby their original villages to build seasonal homes for monsoons were left with substantial loans, worries and emotional/psychological stress in relation to their financial burden and how they would be able to pay back their loans. The most affected by these policies and changing land markets seemed to be especially vulnerable people such as elderly widows, disabled people but also households with lack of financial resources. One lesson learnt is, that a clear strategy and policy on how formal land markets should operate in the context of reconstruction, to ensure that households exposed to severe hazard risks, who wish to relocate, are provided with affordable, suitable and safe land for permanent resettlement is needed.

5. Conclusion and recommendations

This paper illustrates the importance of understanding people's complex risk environments, local people's risk perceptions and knowledge gained by

living for generations in risk-prone areas. In the context of Nepal, where extreme seismic and severe weather events are frequent, different and alternative assessment methods that go beyond recognition of earthquake as the main driver of risk are required. The multi-dimensional nature of disaster risks was poorly understood by those who designed policies in the aftermath of the 2015 Mw7.8 Gorkha, Nepal earthquake. Policy-makers appeared to have failed to consider multi-hazard risks during reconstruction and resettlement. From the findings of this study, two recommendations for policy reforms emerge.

Firstly, all development planning in Nepal needs to be disaster risk-informed and multi-hazard risk assessments need to be a part of disaster risk management policies. In a highly disaster-prone country like Nepal, multi-hazard risk assessments, within a wider disaster risk reduction and management framework, have to become an integral part of disaster risk-informed development planning; without this, planning for sustainable development and strengthening of local/national resilience in such context will fall short. In the aftermath of the 2015 Mw7.8 Gorkha, Nepal earthquake, multi-hazard risks caused havoc not only to affected people, but likewise to government officials and humanitarians. This requires policy reform that allows planning, managing and minimizing multi-hazard and amplified hazard risks. The suggested policy reform has four main components:

- a) Legal aspects which require the integration of multi-hazard risk assessments into relevant national and local government policies, guidelines and legal frameworks as part of disaster risk management policies and disaster risk-informed development planning. It is not only fundamental that a multi-hazard risk assessment methodology captures compound local and regional changing hazards risks caused by earthquakes, landslides, flooding, management of rainwater flow/drainage systems, infrastructure projects (i.e., road construction, hydropower projects) and other hazard exposures, but that locally affected communities are involved in assessments and play an active role in agreeing whether and which hazard risk categorizations are suitable to capture differences in the intensity of risk. Creating a space for knowledge sharing, technical and community-gained knowledge about localized complex risk environments, to understand local people's valuable experiences of specific times of the year when various hazards are occurring (seasonality), to engage affected local people in the decision-making process to acknowledge, respect and support their varied risk perceptions and tolerances, and to enable them to make informed decisions for suitable seasonal living arrangements or relocation is critical.
- b) Institutional aspects including that the main responsibility for implementation of multi-hazard risk assessments as an integral part of disaster risk-informed development planning should stay with central/provincial/local governments. Yet, it is vital as outlined above, to engage local communities faced with multi-hazard risks into the process as well as several partners like numerous national/international scientists from multiple disciplines, and various national/international humanitarian agencies.

- c) Tasks/projects that the policy should contain:

First, to set up an advisory committee for hazard exposures and risks in Nepal at different levels of administration. The members should comprise local/national/international experts such as government officials from different ministries/departments, humanitarians, scientists and local people residing in complex risk environments. The committee must establish an alternative methodology to assess risks from natural hazard and human activities (i.e., infrastructure projects) in Nepal. This would allow a more accurate understanding of hazard interactions in Nepal, and facilitate disaster responses. This permanent advisory committee can bring knowledge and experience across disciplines (natural science, social science and knowledge of local communities) together, and enhance collaboration between practitioners, government officials, scientists, and local people. This permanent advisory committee could increase preparedness for multiple future hazards with

workable practical approaches to tackle the exposure to risks with feasible and desirable mitigation and risk reduction measures.

Second, all so-called 'development' projects in Nepal which are mainly focused on infrastructure expansion (road construction) and economic growth (energy developments/dam constructions) and frequently driven by political power relations, need to be disaster risk-informed to consider excessive multi-hazard risks by modifying landscapes in a tectonically active region and to make multi-hazard risk assessments an integral part of disaster risk-informed development planning. These 'development' projects must not only be evaluated by the threats they impose on the natural environment, people's living environments and livelihoods and any possibly newly created or intensified multi-hazard risks, but also by the threat of illegal or corrupt practices where government officials, private companies or other community leader might attempt to benefit financially.

Recommendations are:

- i. To revise and amend contracts for development projects until these projects are disaster risk-informed.
 - ii. To amend existing road construction policies at national and local level and to consider the option not to build roads/tunnels unless it is safe to do so.
 - iii. To prohibit and penalize illegal or corrupt behaviors with disciplinary measures by tight monitoring and rigorous unbiased auditing throughout any road construction process or any other developmental project activity.
- d) Financing the policy reforms suggested above that allow managing and minimizing multi-hazard and amplified hazard risks: Funding could be allocated by the GoN and sought from international agencies (UNDP, World Bank or similar sponsors) to ensure that enough resources and competent man-power is made available to build capacity on local/national level among government representatives in numerous ministries/departments involved in Disaster Response, Disaster Risk Reduction, and any development projects by emphasizing the risks and hazardousness imposed by natural and human-made hazards on people's complex risk environments.
- Secondly**, the reform of resettlement policies. In the aftermath of the 2015 Mw7.8 Gorkha, Nepal earthquake, it emerged that the lack of a policy related to land acquisitions caused chaos for affected people, government officials and humanitarians as well as for the implementation of the newly established policy for integrated settlements. Policy reform is needed with the following components:
- a) Institutional aspects that need to be considered: Resettlement plans should be needs-based, and reflect a balance between community-led designs with the support of technical engineers, international/national/local government experts, humanitarians and scientists specialized in resettlement and livelihood strategies. However, the main responsibility for implementation should lie with national/local government in agreement with affected communities, to assist especially vulnerable people, and also to support affected communities with experienced implementation partners comprising international/national humanitarian agencies specialized in community-led design and resettlement and with experience in livelihood strategies;
 - b) Legal aspects that need to be reformed:
 - i. Regulations and legal safety nets for citizens need to be put in place to control land markets during the reconstruction process in all relevant national/local government policies, guidelines and legal frameworks.
 - ii. The policy supporting integrated settlements needs to be revised, to explicitly outline and ensure that affected people's voices and needs are represented during the entire planning and implementation process of integrated settlements.
 - c) Provisions that the policy should contain:
 - i. To support people who face amplified hazard risks in their place of origin with safe, rent-free land for temporary settlements.
 - ii. To assist displaced people whose original land is exposed to amplified hazard risks in case of resettlement with adequate land allocation or alternative affordable safe land, comprising a house with space for an entire family including kitchen, toilet and cultural activities, and to provide them with extra agricultural land or alternative livelihoods.
 - iii. To assist displaced people who want to stay on their original land and whose original land is exposed to seasonal amplified hazard risks (i.e., during monsoon), to find safe, affordable land nearby, where seasonal living arrangements, possibly in form of integrated settlements, can be constructed, comprising a house with space for an entire family including kitchen, toilet and cultural activities.
 - iv. To assist people to create integrated settlements which suit their needs, and to provide support with administrative processes for basic infrastructure.
 - v. To put regulations in place to control land markets in affected areas after a disaster to ensure that land prices are stable during the reconstruction period.
 - vi. To ensure that those who are resettled are not left with greater risks and uncertainties than before.
 - vii. To support affected people with accessible low interest or subsidized loans.
 - d) Financing the policy reform: The reconstruction fund established after the 2015 Mw7.8 Gorkha, Nepal earthquake with funds from the Nepali government, donations from domestic and foreign institutions or any other sources should be used to support the policy reform. If funding is not sufficient, extra support could be sought from the UNDP, World Bank or similar sponsors.

Declaration of Competing Interest

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Regular Article

Changing significance of landslide Hazard and risk after the 2015 M_w 7.8 Gorkha, Nepal Earthquake

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ABSTRACT

The 2015 M_w 7.8 Gorkha, Nepal Earthquake triggered in excess of 20,000 landslides across 14 districts of Central and Western Nepal. Whilst the instantaneous impact of these landslides was significant, the ongoing effect of the earthquake on changing the potential for rainfall-triggered landsliding in the months and years that followed has remained poorly understood and challenging to predict. To provide insight into how landsliding has evolved since the earthquake, and how it has impacted those living in the affected area, a detailed time-series landslide mapping campaign was undertaken to monitor the evolution of coseismic landslides and the initiation of new post-seismic landslides. This was supplemented by numerical modelling to simulate the future potential reactivation and runout of landslides as debris flows under monsoon rainfall, identifying locations potentially at risk. This analysis shows that landslide hazard was higher in November 2019 as compared to immediately after the 2015 earthquake, with a considerable portion of the landscape being impacted by landsliding. We show that, while pre-existing landslides continued to pose the majority of hazard in the aftermath of the earthquake, a significant number of landslides also occurred in new locations. We discuss the value of this type of analysis in informing the reconstruction and management of settlements at risk by summarizing how this work was integrated into the project Durable Solutions II, that supported communities at risk from landslides. Finally, we consider how such data could be used in future to inform risk sensitive land-use planning and disaster recovery, and to mitigate the impacts of future landsliding in Nepal and beyond.

1. Introduction

As of September, the rate and severity of monsoon-triggered landsliding in 2020 in the earthquake-affected districts of Central and Western Nepal has exceeded that witnessed in each year since 2015. Whilst the underlying causes for this extremely severe landslide season are complex, this in part is suggested to reflect the high monsoon strength [37], the negative consequences of extensive poorly planned rural infrastructure development on landsliding [29], and the legacy impacts of ground damage generated by the 2015 earthquake [19]. To the end of September, the 2020 monsoon resulted in 83 fatal landslides resulting in the loss of more than 240 lives,

according to Government of Nepal data collated via the bipad disaster information management system.² These figures suggest both a greater number of fatal landslides than average, and also a greater average impact per landslide during this season, as compared to both the 2015–2019 period and the longer-term historical data for Nepal [14,37].

Several tragic examples from the summer of 2020 exemplify the high level of hazards and risks posed by landsliding in the area affected by the 2015 earthquakes, even five years later. On 9 July 2020, two debris flows occurred in the Almo Thado and Kabre Kholas (*khola*: river) just north of Barhabise, Sindhupalchok, destroying the settlement of Jambu (Barhabise Municipality-5) and resulting in 23 fatalities.³ The settlement had grown rapidly in recent years parallel to the Arniko Highway, associated primarily with the nearby power-house of the Middle Bhote Koshi Hydropower

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² bipadportal.gov.np, the NDRRMA disaster information management system (accessed 13.11.20)

³ <https://www.nepalitimes.com/latest/nepals-deadliest-monsoon-in-recent-times/> (accessed: 7.9.20)

Project, with many houses on land directly adjacent to the khola. The event occurred as a result of a cloud-burst that triggered extensive but shallow landsliding on the hillside above the settlement that transitioned to debris flows that ran out down the channel network (Fig. 1). The landsliding may have been exacerbated by recent road construction that intersected the channel network on the hillside above the settlement.

A second significant event occurred in the village of Lidhi (Jugal Municipality) on 14 August 2020, resulting in the loss of 37 lives and destroying around 37 houses². Here again, a shallow rainfall-triggered landslide failed above the village in an area that had exhibited cracking since the 2015

earthquakes. The landslide entrained soil from the terraces in its path, destroying the flank of the settlement (Fig. 1). Local concerns had been reported about the potential for landsliding in Lidhi before the event, with the community relocating overnight to reduce the risks. The settlement was also identified in the National Reconstruction Authority (NRA) Geohazard Assessment as potentially at risk from landslides, but mitigation rather than relocation was considered the most suitable risk reduction measure at the time of the assessment.

This level of landslide activity raises a series of critical observations that are fundamental to consider if the loss of life due to rainfall triggered

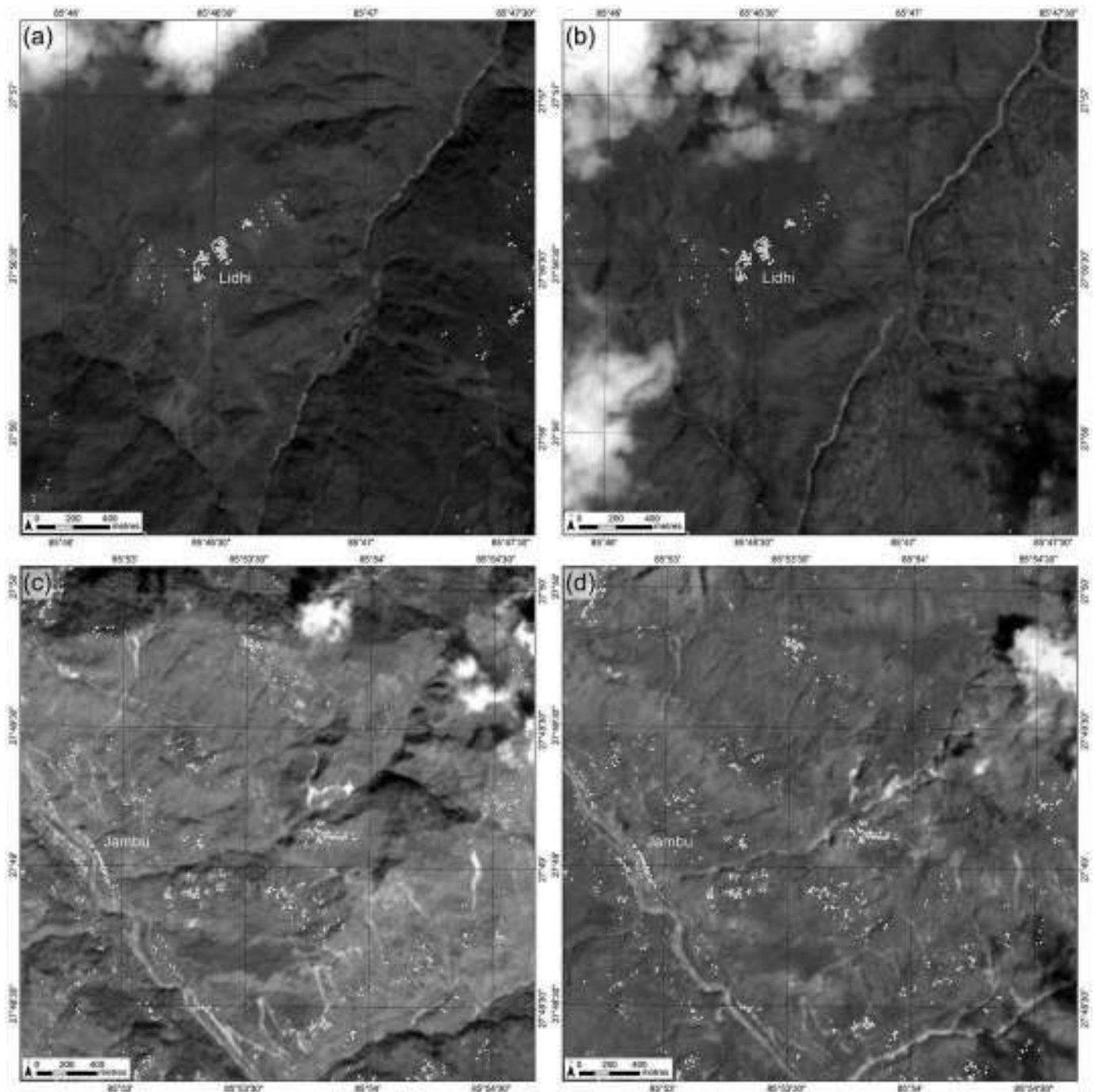


Fig. 1. (a) Sentinel-2 satellite image dated 15/10/19, displayed in false colour (bands 8–4–3) for Lidhi (Jugal, Ward 2, Sindhupalchok) (Copernicus Sentinel data [2020]. Retrieved from: [7 September 2020], processed by ESA). White dots show house locations from OpenStreetMap and Central Bureau of Statistics data. (b) Sentinel-2 satellite image for the same area dated 23/8/20, after the landslide on 14/8/20, showing the landslide that impacted the village, but also several other new landslides in the area. (c) Sentinel-2 satellite image for the area around Jambu (Barhabise Municipality-5) 15/10/19, and, (d) Sentinel-2 satellite image for the same area dated 20/8/20, showing extensive landslide impacts of a cloud burst on 9/7/20.

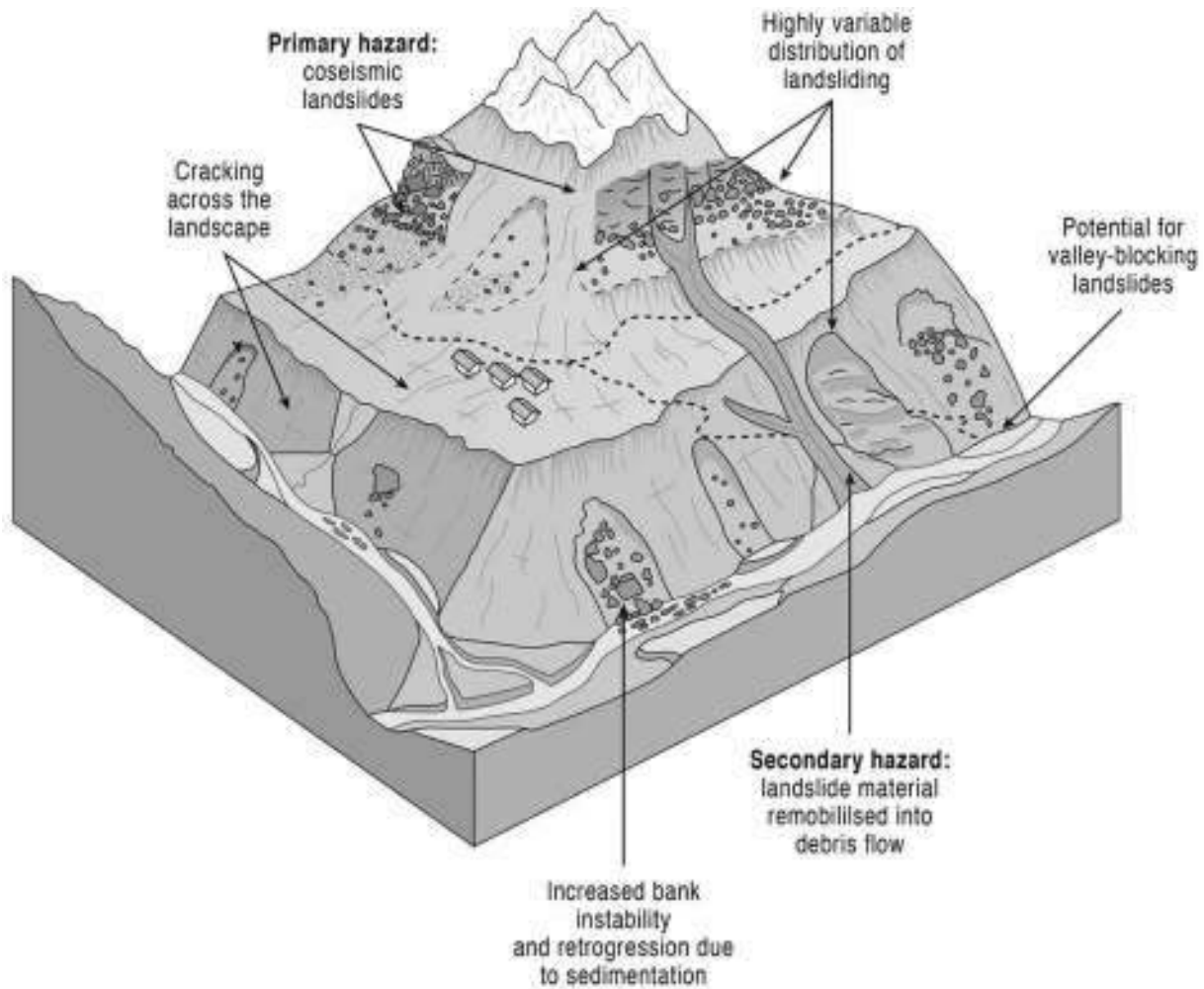


Fig. 2. Schematic block diagram illustrating typical characteristics of coseismic and post-seismic landslides (not to scale).

landsliding in Nepal is to be reduced. Whilst the impacts were devastating and resulted in an exceptionally significant and tragic loss of life, the landslides which led to these events were by no means exceptional both in terms of size and style: both disasters were driven by shallow, rapid, rainfall-triggered landslides that have been demonstrated to drive the majority of the annual losses associated with landsliding in Nepal [14]. Although not large in a geological sense, these landslides are however of a scale where physical mitigation through engineering would be highly challenging in any country, and especially so in a developing country context with limited resource and technical capacity; stopping such a landslide is therefore likely an unrealistic goal.

The timing of the highest landslide risk conditions annually is relatively well-understood [37] and each of these landslides occurred early in the monsoon, when the peak of landslide fatalities has been recorded every year [37]. Despite this, targeted early warnings for such events remain immensely challenging: regional-scale ('territorial') landslide early warning systems [21] lack the local specificity to predict exactly which slope will fail, and in Nepal are limited by the lack of hydrometeorological infrastructure to underpin such warnings. There is also a lack of reliable and affordable approaches to slope-specific landslide early warning systems [42], with arguably no examples of lives actually being saved by a landslide early warning in Nepal. Given this uncertainty, a more precautionary approach of identifying and then supporting at-risk settlements to relocate to safer places is a more reliable risk reduction measure. This requires good geospatial knowledge of landslide risk and a willingness to move. In a context where limited and constrained choices

of resettlement options interleave with competing demands on livelihoods and land-ownership, simply relocating to apparently lower-risk areas is immensely complicated [33].

Finally, the events of the 2020 monsoon demonstrate the dynamic nature of landslide risk in the aftermath of a large earthquake. Whilst landslide hazard assessment is difficult in steep topography with a monsoonal climate, it is made even more challenging given limited scientific and practitioner experience of how earthquake damage affects future landslide hazard and risk [13,35]. In this paper we provide a summary of research that has been conducted across the 14 districts identified by the Government of Nepal as those most severely impacted by the 2015 earthquakes. We focus on the district of Sindhupalchok, to consider how landslide hazard and risk have evolved since 2015, and how this risk can or could be reduced. We begin by providing a short review of current scientific understanding of the nature of coseismic (earthquake-triggered) landsliding and how this evolves through the years that follow the initial earthquake shaking. We then describe a program of research that has used satellite imagery to map the evolution of landsliding up until post-monsoon 2019. We summarise the findings of this work to show how landsliding has evolved, and the consequences for this on the risks that people face. We describe how the findings were integrated within the Durable Solutions II project that supported communities at risk from geohazards after the 2015 earthquakes. We distil a series of observations on the nature of post-earthquake landslide hazard and risk and demonstrate where and when landslide risks can be reduced through improved land-use planning, and where and when this becomes more problematic.

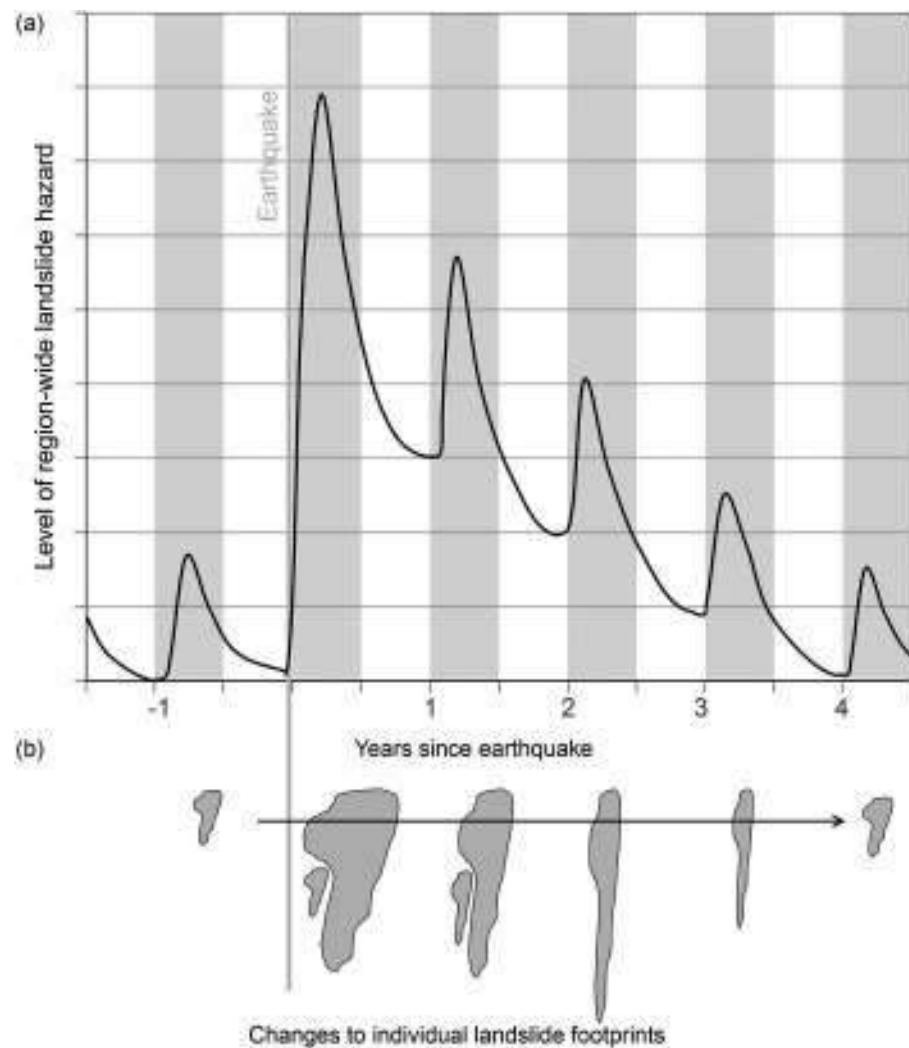


Fig. 3. Conceptual diagram of the evolution of post-seismic landslide hazard, based on understanding gained before the Gorkha earthquake. **(a)** shows years since the earthquake (orange line), and the change in regional landslide hazard through time. Plot shows typical peak in landslide hazard (black line) early in each monsoon season (shown by the blue bars), and how this is anticipated to change as a result of the Gorkha earthquake. **(b)** shows how individual landslide footprints may change through time, from small landslides before the 2015 earthquake, to larger landslides after, and in particular an elongation as landslide debris is remobilised into debris flows in subsequent monsoons. The period over which the return of landsliding to pre-earthquake levels remains poorly understood and is shown only schematically here. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

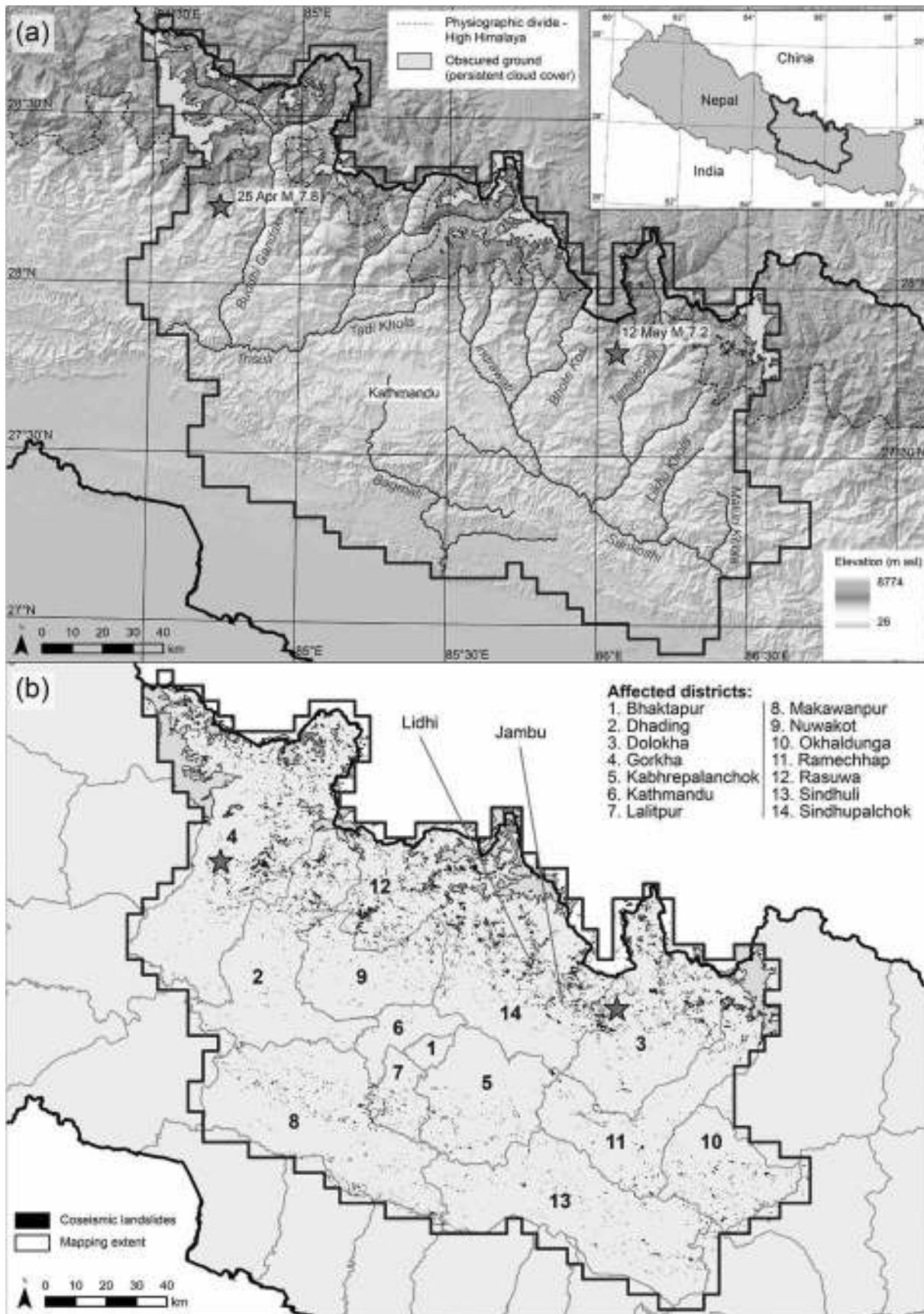
1.1. The nature of coseismic landsliding

Coseismic landslides are the most significant secondary hazard associated with high-magnitude continental earthquakes [13]. Widespread landsliding has been documented after numerous large earthquakes, and such landslide-triggering events are known to result in substantially higher death tolls than earthquakes without landslides [6]. The consequences of coseismic landsliding includes wider disruption to infrastructure [3,5], and the transport of large volumes of sediment into the fluvial network [47]. Much research has focused on the characterization of coseismic landslides, which has led to an improved understanding of their spatial distribution, impact, and style. This insight has been gained from the development of mapped coseismic landslide inventories that describe landslide location and extent [45].

Despite a growing number of studies that have documented coseismic landsliding, far less is known about how landsliding evolves post-earthquake. Examples from recent significant earthquakes, notably the 1999 M_w 7.6 Chi-Chi earthquake in Taiwan and the 2008 M_w 7.9 Wenchuan earthquake in China, reveal a persistence of enhanced landslide rates, and long-term impacts of coseismic hillslope damage, in the years to decades after the shaking (e.g., [9,16,25,35]). This work has started to

document two key landslide processes (Fig. 2). The first is the continued instability, activity and eventual stabilization or exhaustion of landslides that were triggered by the earthquake. The second is the occurrence of new landslides in the months or years after the earthquake, often in response to intense rainfall, but importantly also as a direct result of coseismic damage to the ground. The timescale over which such new landsliding occurs, and remains over and above ‘normal’ conditions, is poorly constrained, mainly because there are only a small number of well-documented examples from a limited range of tectonic and physiographic settings. For example, analysis of suspended sediments in the fluvial network and time series landslide mapping following Chi-Chi suggested a post-seismic reduction in sediment flux [16], with the rate of new landsliding [25] returning back to pre-event levels within approximately six years after the earthquake. Conversely, research on vegetation recovery following landsliding during the 2008 Wenchuan earthquake suggests a more extended and complicated response over periods of decades rather than years (e.g., [52]).

This concept of a landslide ‘recovery time’ is a critical factor in post-seismic landslide hazard assessment as it determines the likely time period over which enhanced landsliding should be expected. However, the interplay and dominance of each of these two forms of landsliding remain poorly documented, and consequently how post-seismic landslides evolve, and the



(caption on next page)

hazard that they pose, is poorly understood (e.g., [41,49]). Nevertheless, previous research has provided several key insights into the nature of coseismic landsliding that are pertinent to understanding the post-seismic landslide hazard and risk, described below.

1.2. The hazards posed by coseismic landslides in the aftermath of an earthquake

The nature of landslides triggered by earthquakes is known to markedly differ from landslides typically triggered by rainfall [13]. This difference is key in identifying the likely location, nature and timing of landslides in the period following an earthquake, and hence the hazard that they pose, as shown in Fig. 2. The main characteristics of relevance include:

- (1) Coseismic landsliding is not uniformly distributed and is typically characterized by the preferential failure of specific parts of the landscape [31]. For example, an asymmetry in the density of landslides on slopes directed towards the seismic source versus those facing in the opposite direction has been previously demonstrated [41]. It follows that future landsliding may follow a similar spatial pattern. Similarly, ridgelines and convexities generate localized amplification of seismic waves [12], triggering many landslides high on valley sides (e.g. [39]). As a result, and particularly in earthquakes which occur during dry soil moisture conditions, much landslide debris released during earthquakes can remain perched high in the landscape, posing a significant potential future hazard.
- (2) Landslides triggered by earthquakes can be very different in mechanism compared to those triggered by rainfall. As a result, these landslides may behave very differently during later rainfall. This was typified in the Gorkha earthquake, where many deep-seated rainfall-triggered landslides that pose perennial disruption in the Middle Hills showed almost no sign of accelerated movement during the earthquake itself (e.g., [4]). Conversely, coseismic landslides typically include shallow failures in regolith or weathered bedrock, rockfall, deeper-seated failures triggered by liquefaction, and spreading due to intense localized shaking ([28]). Critically, coseismic landslides and the debris that they release are very sensitive to rainfall, reducing the post-earthquake intensity-duration threshold for debris-flow triggering [67]. In this context, the degree to which (local) knowledge and lived experience of pre-earthquake landslide hazards remains germane in a post-earthquake setting is poorly understood [1,33].
- (3) It is widely acknowledged that earthquake shaking can generate extensive damage to the ground through cracking (commonly termed *ground cracking* (e.g. [17]), *fissuring* (e.g. [34]) or *lateral spreading* (e.g. [8])), resulting in a net reduction in material strength even in areas that show little or no obvious surface evidence of landsliding. In the aftermath of the Gorkha earthquake, many slopes were observed to have surficial cracks, suggesting a potential incipient landslide. To date, there is very limited research on the degree to which such surface disruption can be taken as an indicator of future risk [28,36], and how such damage influences slope stability and future landslide hazard.

The consequences of these factors for post-seismic landslide hazard are twofold. Firstly, and most importantly, the hazard posed by the reactivation of coseismic landslides can be assessed with some degree of confidence; where coseismic landslides are mapped, the future risks posed by their reactivation and runout can be modelled using established flow-routing algorithms. It is therefore critical to identify, repeatedly map and assess the potential for runout at these locations. At present, however, it is not known if this type of landsliding poses a significant component of the overall hazard faced in the aftermath of an earthquake. If it does, then this type

of assessment could be used to significantly reduce net landslide risk in the years that follow. Secondly, and more challenging, is the assessment of likely locations of new landslides in previously (apparently) stable locations. Key to this is understanding the overlay of earthquake damage and existing landslide susceptibility, to identify how post-seismic landsliding is distributed across the landscape, and, critically, how this evolves through time.

This complexity is simplified in a conceptual model (Fig. 3). The annual concentration of rainfall-triggered landsliding around the start of the monsoon, followed by an asymptotic decay back to background levels as the monsoon recedes, is well-understood. The manner in which this pattern – either regionally across the area impacted the earthquake (Fig. 3a), or locally for an individual hillslope or landslide (Fig. 3b) – responds after the earthquake is largely unknown. Based on previous research, it was anticipated that the reactivation of landslides triggered by the earthquake and new landslides as a result of the damage to the wider landscape would result in exacerbated landsliding in the 2015 monsoon. It was also anticipated that the remobilization of coseismic landslide debris in the monsoon would lead to increased numbers of debris flows [10]. Critically, the period over which these processes are anticipated to persist above ‘average’ (months, years or decades), and the changes in the year-on-year intensity of landsliding, remain unknown. Encompassing this is also a wider social and political context and the consequent human-environment links that aggravate landsliding [37,43]. For example, the post-earthquake period saw massive investment in reconstruction, but also the proliferation of rural road construction that was at least anecdotally associated with the first local elections in 2017 [50]. The key unknown here is, given this wider ongoing change, whether the pre-earthquake landslide conditions might ever be regained.

1.3. Coseismic landsliding associated with the Gorkha earthquake

The Gorkha earthquake initiated ~80 km northwest of Kathmandu, with the rupture propagating east ~140 km along the Main Himalayan Thrust (MHT) [2]. A series of aftershocks followed, including a M_w 7.3 event on 12 May ~75 km east-northeast of Kathmandu close to the border between Sindhupalchok and Dolakha districts. The intense shaking generated by the earthquake triggered extensive landsliding across the full east-west extent of the fault rupture. The density of landslides (the number or area of landslides per unit area) generally increased towards the eastern margin of the rupture [19,27]. Multiple coseismic landslide inventories have been generated since the earthquake (e.g. [18,27,51,46,40,49,30,19]), resulting in a range of estimates of coseismic landslide numbers ranging from <5000 to ~25,000. The number varies based upon the mapping techniques, the satellite imagery, and the choices made in the generation of the inventories (see: [19]). The most spatially detailed assessment using high resolution optical satellite imagery, and therefore probably the most complete inventory to date, was generated by Roback et al. [40], who mapped ~25,000 landslides, covering around ~90 km² and distributed across 28,300 km² of Central and Western Nepal.

1.4. National reconstruction authority, the geohazards assessment and durable solutions II

Following the earthquakes in 2015, and after the recognition of the severity of the landslide impact triggered by the event, the Government of Nepal began an assessment of the landslide hazard and associated risk to feed into the response and reconstructions efforts, termed the Geohazards Assessment. This involved an initial series of field assessments led by the

← Fig. 4. (a) Study area extent in central and western Nepal (purple boundary), covering the area impacted by coseismic landslides associated with the Gorkha earthquake. Stars show the epicentres of the Gorkha earthquake sequence: 25 April M_w 7.8 and 12 May M_w 7.2. Shaded relief elevation map derived from a 30-m ALOS DEM of the study area (Credit: AW3D30 – JAXA). (b) Mapped coseismic landslide inventory, with landslides shown as black polygons. The locations of the Lidhi and Jambu case studies in Sindhupalchok (Fig. 1) are labelled. Modified from Kinney et al. [19]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

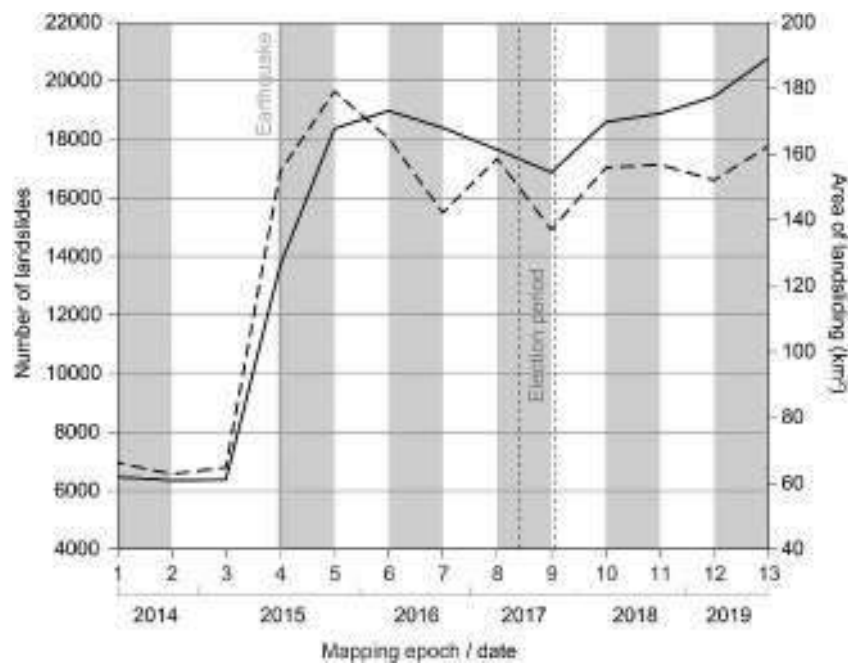


Fig. 5. Changes in mapped landslide numbers and total landslide area between 2014, the Gorkha earthquake in 2015, and post-monsoon 2019. Vertical blue bars show the timing of the monsoon; solid black line is landslide number; dashed black line is landslide area; and, the time of the earthquake (orange line) and the first local elections are indicated by orange and green lines respectively. Modified from Kinney et al. [19]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Department of Mines and Geology, reaching around 130 settlements. The identification of these settlements for the assessment was based on requests made by local government officers, where a potential risk had been recognized. A further round of assessments followed, reaching a further 455 locations across 15 districts, as part of the National Reconstruction Authority (NRA), with support from the UN Office for Project Services (UNOPS) in Kathmandu, which involved around 40 geologists and engineers undertaking detailed site visits. These assessments resulted in a three-tier categorization: Category 1, 'Safer communities / villages where reconstruction can be started any time'; Category 2, 'Communities / villages under the risk of manageable geohazards where reconstruction could be started only after applying suitable countermeasures'; and Category 3, 'Unsafe communities/villages due to the existing state of geohazards which are extremely difficult to control technically as well as financially where reconstruction is not recommended.' The assessment documented the number of households requiring relocation where deemed necessary to reduce the risk to an acceptable level, as well as outlining recommendations for remedial mitigation, and identifying the responsible government agency to take this forward in Category 2 locations. The geohazards assessment was extended in the Durable Solutions program,⁴ led by People In Need, acting as a bridge between government and communities affected by landslides to support fair and voluntary relocation.

Since this initial effort, a larger number of additional sites have been evaluated, and some reassessed, notably where concerns were raised about recent deterioration in a landslides condition. As of July 2020, a total of 1053 sites had been assessed. Of these sites, 40% (419 sites) were Category 1, 30% (320 sites) Category 2, and 30% (314 sites) Category 3, with more than 4000 households recommended for relocation.

While this rapid appraisal was an essential component of the assessment of geohazard risk, it was inevitably a single snapshot in time that did not capture the dynamic changes in landslide hazard. This effort also depended on local recognition and then reporting of sites at risk. This was made all the more challenging by the remote rural expanse of the affected districts, and the competing demands of the post-disaster context. Given the lack of

precedent for assessing the future threat posed by landslide hazards, plus the uncertainties around how ground damage accrued in the earthquake might develop into landsliding, it was challenging for local government, householders, and technical specialists to assess the likely future risks.

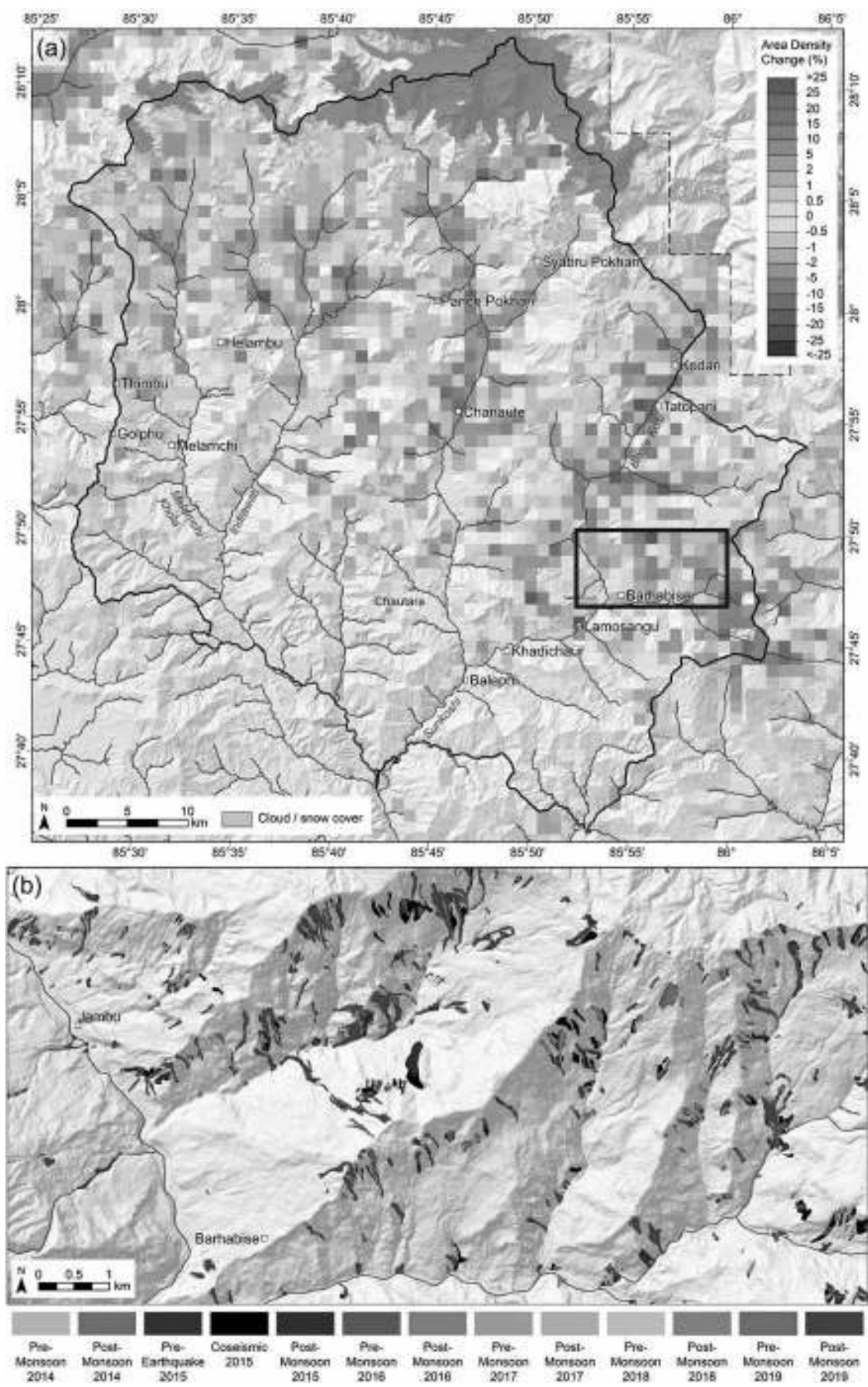
2. Mapping the evolution of coseismic landsliding after the Gorkha earthquake

In order to complement the Geohazards Assessments, and to provide a spatially continuous and updating assessment of landsliding after the Gorkha earthquake, systematic mapping using freely available satellite imagery was developed. The intention was to develop a sustainable and consistent method to generate reliable and repeatable landslide information, with the specific intention of assessing change through time at a scale relevant to individual households. Whilst some mapping efforts (e.g., [40]) have exploited very high-resolution optical imagery allowing very small features (< 5 m) to be identified, the low orbit height of these satellites results in considerable topographic image distortion (up to >100 s of m), particularly in high-relief topography. This makes change detection difficult, because the errors in image rectification far exceed the changes on the ground [48]. We therefore used medium resolution (ca. 10–30 m) optical imagery with minimal distortion to provide a more reliable means of monitoring landslide change.

We manually mapped landslides from freely-available optical satellite imagery (Landsat and Sentinel-2) between 2014 and 2019, with two image periods before and after the monsoon each year and one immediately post-earthquake, yielding 13 mapping epochs. We focused on the 14 districts most affected by the earthquake, which includes around 90% of the landslide-affected area initially mapped by Roback et al. [40] (Fig. 4). Landsat 8 imagery (30 m spatial resolution, pan-sharpened to 15 m) was used for epochs 1–5 (2014–2015), and Sentinel-2 imagery (10 m spatial resolution) from epoch 6 onwards (2016–2018). Landslides were mapped on true colour (R-G-B) and false colour (NIR-R-G) composites using bands 2–3–4–5 for Landsat 8 and 2–3–4–8 for Sentinel-2.

Unlike previous multi-temporal inventories (e.g., Fan et al., 2018; [22,23,26]), we independently mapped the full extent of all landslides visible on imagery from each epoch, reducing any reliance on assumed

⁴ www.durablesolutions.org (accessed: 1.10.20)



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similarity or difference with the previous epochs. A common issue with large-scale multi-temporal landslide inventory analysis over mountain topography is the presence of intermittent cloud, shadow, and snow, which typically limits the area that can be assessed. Automated masking of clouds was undertaken using *Fmask* (Function of mask, v4.0) [38], which was manually checked for accuracy. Areas of persistent cloud or snow totalled 5% of the study area concentrated in the High Himalaya, coincident with areas of minimal population. For ease of comparison, landslides were summarized to areal densities (landslide area per km²) on a 1 km² grid. The full methodology is provided in detail in [19].

3. Results

3.1. Summary of the landslide inventories

The landslide inventory we consider here includes 200,866 mapped landslides across all 13 epochs. Landslide numbers average ~ 6400 for all 3 pre-earthquake epochs, although the location of individual landslides change, but with little notable systematic variability between the characteristics of pre- and post-monsoon inventories (Fig. 5). The Gorkha earthquake (epoch 4) and the monsoon that followed (epoch 5) led to very significant increases in the number of mapped landslides, peaking at 18,978 in pre-monsoon 2016 (epoch 6), declining through post-monsoon 2017 (epoch 9), and increasing in both pre- and post-monsoon 2018 and 2019 (epochs 10–13). Critically, by the end of the study period, there were over 7000 more visible landslides compared to immediately post-earthquake (ca. 13,700), and over 14,000 more than the pre-earthquake inventories (Fig. 5). In this sense, landslide hazard remains significantly higher today than on the day of the earthquake, and so may reflect only the beginnings of a longer-term response to the earthquake [13,19].

Considering the areal density of landsliding, for the majority of epochs, the proportion of grid cells newly affected by landslides relative to the preceding epoch was low (1–2%), with the exception of the earthquake (10%), the 2015 monsoon (5.5%) and pre-monsoon 2018 (3%). The critical conclusion from this is that, at least at this scale of assessment (1 km² grid), by far the majority of changes to landsliding in the aftermath of the earthquake are concentrated near coseismic landslides, rather than in areas that did not experience landslides during the earthquake (Fig. 6a). It follows that knowledge of coseismic landslides, and if and how they evolve, is critical for understanding the majority of landslide risk in the aftermath of the Gorkha earthquake.

Superimposed on top of this preferential concentration of activity near coseismic landslides, about 11% of grid cells in the post-monsoon 2018 epoch were newly affected by landslides since the earthquake (epoch 4), indicating that the spatial pattern of landsliding had altered steadily but progressively since the earthquake. It is therefore important to recognize that the potential for additional new landsliding in previously apparently stable areas is persistent for years after the earthquake, and so better understanding of post-earthquake landslide susceptibility and how cracked and damaged ground develops into landsliding is essential.

3.2. Assessment of landslide risk to households

The sequential mapping of landslides over the period since the Gorkha earthquake shows that a considerable proportion of the overall landslide hazard can be attributed to the reactivation and remobilization of coseismic landslides. Reactivation mostly occurs during intense prolonged rainfall in the monsoon, notably as debris flows [13]. Identifying the likely pathways along which (re)mobilised sediment could travel as debris flows is therefore a crucial aspect of a timely assessment of post-seismic landslide hazard. Given the large number of landslides in the 14 earthquake-affected districts,

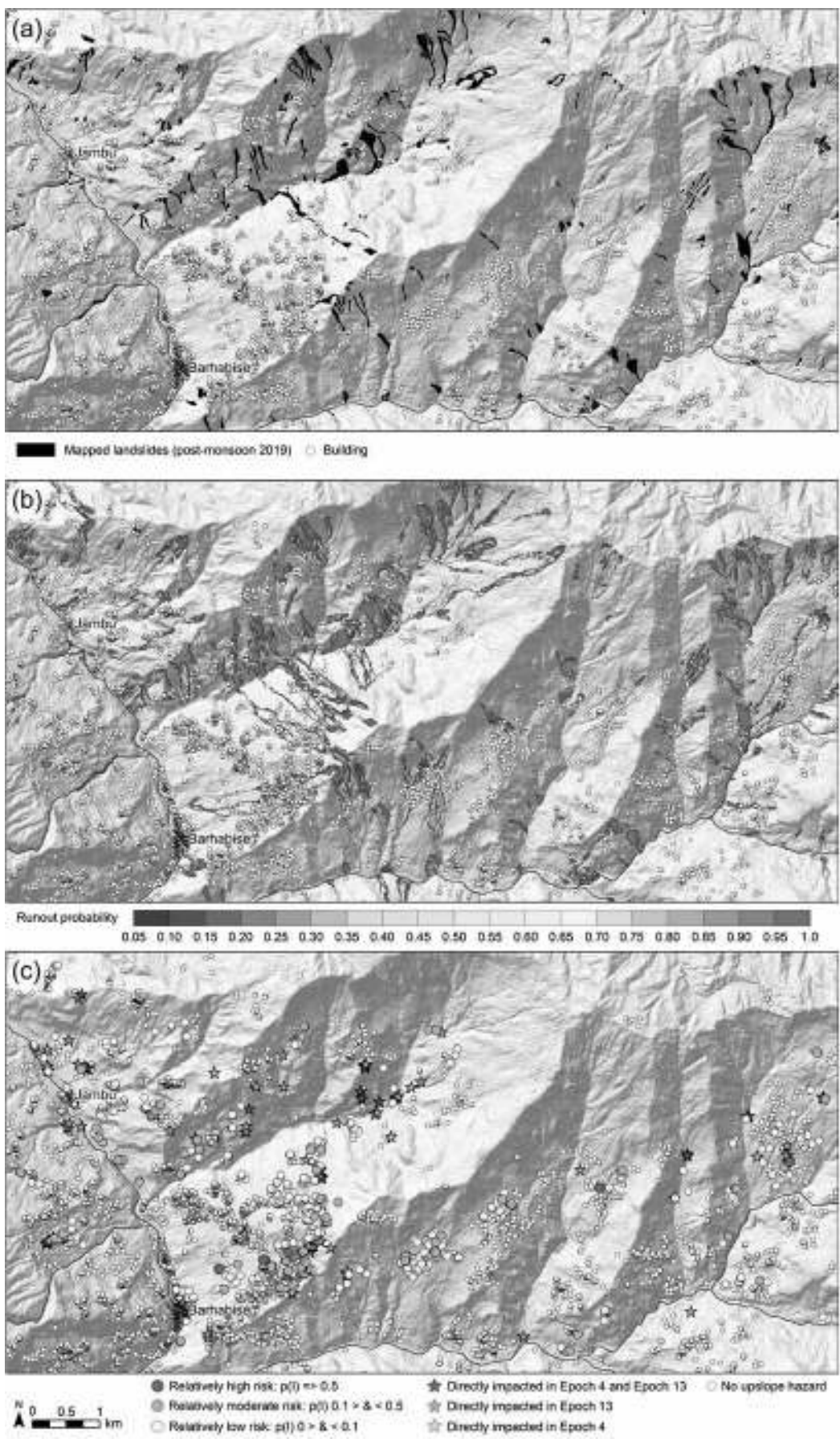
an approach was needed that combined a synoptic regional assessment but also locally relevant detail to those potentially at risk.

The typical approach to assess regional-scale debris flow hazard is to model runoff pathways based on a landslide source dataset. An assumption can be that each landslide scar has the potential to remobilize as a debris flow, and so can be considered a source. To undertake this, we compared the coseismic landslide inventory, with that mapped in November 2019 [19], to analyse the evolution of post-earthquake landslides over this 4.5-year period. We considered a ‘plausible but worst case’ scenario, in which intense localized rainfall triggers highly mobile debris flows, akin to the type of events that resulted in the landslides at Jambu in 2020. To do this, we used Flow-R, a distributed empirical model for regional susceptibility to debris flows [15], to assess the spatial distribution of runoff probabilities across the area impacted by the earthquake. As the path of debris flow runoff is highly sensitive to topography, we used a high-resolution digital elevation model (5 m AW3D), down-sampled to 10 m, as the optimum balance of resolution and noise [15]. This DEM provides improved delineation of the ephemeral hillside channel network, and local topography that may direct or divert flows to or from settlements. The parameterization of Flow-R is described in full in Kinney et al. [20], and was tuned to enhance runoff to be extensive but plausible, providing a conservative modelling strategy.

The output of the modelling was a spatially continuous 10 m raster of relative debris flow probability ranging from 0 to 1 (Fig. 7). This probability surface was then overlain with household locations, collated from the Central Bureau of Statistics and revised with post-earthquake (re)locations mapped in OpenStreetMap. This intersection attributed a risk score to every household and was used to identify hotspots of at-risk buildings and locations where (1) there was a risk not described in the Geohazards Assessment, (2) where the level of relative risk diverged from the Geohazards Assessment, and (3) where risk was increasing through time (Fig. 7). This approach has been validated by cross-checking the locations of those buildings that were affected by landslide runoff in subsequent epochs with the modelled relative risk score, as reported in Kinney et al. [20].

In Sindhupalchok, we mapped 2898 landslides that were triggered by the Gorkha earthquake, representing 21% of the entire inventory. The post-monsoon 2019 inventory contained 4026 landslides, an increase of 39% relative to 2015. Although the area covered by landsliding in Sindhupalchok decreased from 36 km² in 2015 to 30 km² in 2019, this still represented 1.2% of the district. The increase in landslide number between 2015 and 2019 resulted in an increased impact of landsliding over this period. Of all buildings in Sindhupalchok ($n = 100,908$), 299 were directly hit by landslides in the earthquake. By post-monsoon 2019, 538 had been impacted, of which 108 were impacted in both the earthquake and during post-monsoon 2019. In contrast, the modelled landslide runoff risk to buildings decreased between 2015 and 2019, with a total of 3128 buildings potentially at risk following the earthquake, but only 2917 by post-monsoon 2019. Immediately following the earthquake, 84% of these at-risk buildings were in the relatively low risk category (with probability of debris-flow impact, $p(I)$, between 0 and 0.1), with 15% at moderate risk ($p(I)$ of 0.1–0.5) and 1% at high risk ($p(I) > 0.5$). The absolute numbers of buildings at risk decreased in all categories by 2019, but with a slightly higher proportion at relatively low risk (87%) compared with moderate risk (13%) and high risk (<1%) categories. A critical observation is that over this period we observe a significant interchange in individual buildings at risk in 2015 as compared to 2019; around 50% of those at risk after the earthquake were no longer at risk by 2019, but importantly as the landsliding has developed, around 50% of buildings at risk by 2019 were safe in 2015. The total number of buildings that have experienced landslide risk since the earthquake (5355) therefore continues to increase.

← Fig. 6. (a) Map of change in landslide area density at 1 km² resolution between the time of the Gorkha earthquake and post-monsoon 2018, with hot colors indicating an increase in landsliding and cold colors a decrease. Box shows area near Jambu and Barhabise in panel (b). (b) Mapped landslides colored by date for each epoch between 2014 and post-monsoon 2019, for the area around Jambu and Barhabise, Sindhupalchok (see Fig. 4b for wider context). Shaded relief elevation map derived from a 5-m ALOS DEM of the study area (Credit: © NTT DATA, RESTEC/©JAXA).



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4. Discussion

We have presented a summary of the evolution of post-earthquake landslides in the aftermath of the Gorkha earthquakes. This research has shown that the landscape has not recovered as rapidly as implied by studies that focus only on the occurrence of new (additional) landslides in the earthquake aftermath (e.g., [26]), identifying a significant prevalence of hazard and risk from the reactivation of coseismic landslides. Our analysis illustrates that the nature of landslide hazard, and therefore the risk, has significantly changed since 2015. The sequential mapping demonstrates that the location of landslide activity has shifted systematically through time since the earthquake (see also [19]). The implication is that whilst the need to rebuild and reconstruct is pressing, doing so too quickly and in the absence of good data on evolving geohazards can have long-term and potentially devastating impacts on the population, property and livelihoods [33].

In detail, our results show a series of key characteristics vital in any appraisal of landslide hazard in the aftermath of a mountain region earthquake. Coseismic landslide occurrence is a reasonable first-order indicator of where future recurrent post-seismic landsliding will occur. It is critical to recognize that a substantial proportion of overall landslide threat arises from existing landslides in the landscape, and so knowing where these are and how they evolve is vital: it is not appropriate to dismiss existing landslides as 'finished' and of negligible risk. Prior to the earthquake, around 15% of the mapped 1 km² grid cells experienced landsliding, but this number increased to 24% following the earthquake, and then increased again to 29% following the 2015 monsoon [19]. In all years since, this proportion of cells has remained high (28–30%), so the proportion of the landscape at some degree of risk remains high.

Beyond the reactivation of coseismic landslides, nearly 10% of the landscape that did not experience landsliding on the day of the earthquake did so in the period that followed, and this as a proportion of the total increases through time. This demonstrates that the coseismic landsliding pattern should not simply be projected forward to anticipate the evolution of the hazard. It is therefore essential that indicators of future instability and changes to the landscape are monitored. Whilst the ultimate trigger of landsliding in the years that followed the earthquake was most commonly rainfall, our data strongly suggest that the pattern is linked to earthquake damage, such that these events would not have occurred if the earthquake had not happened. This attribution of fundamental cause is critical where access to compensation is reliant on precise definitions that relate specifically to the earthquake itself.

The dominance of debris flows reactivating existent landslides has a significant influence on the nature of hazard, and how this can be managed. For example, debris flows preferentially channelize, most commonly flowing from open slopes into pre-existing concavities and channel networks. Once confined within a channel, the most likely flow path is defined by pre-existing topography. Pre-existing channels therefore represent perhaps the highest risk locations in the post-earthquake landscape. This observation also reflects previously-proposed landslide hazard zonation methods, distilled into 'simple rules' from empirical analysis of the spatial characteristics of landsliding after several large earthquakes (e.g. [32]). Avoiding development in these channels is a key risk reduction measure. Related to this, risk from post-earthquake landsliding can reduce from high to negligible over very small distances (< 10 m), so precise building location matters. Similarly, it has been apparent in forensic investigations of landslide impacts after the Gorkha earthquake that new, often earthquake-resistant houses were commonly poorly located only by a matter of meters, placing them at high landslide risk. The precise positioning of

a house within a plot can therefore hold a considerable influence on exposure to landslide hazards.

Landslide activity has shown little indication of a return to pre-earthquake levels, even after 4.5 years. It is clear that the legacy of the earthquake shaking holds continued influence over enhanced landslide susceptibility. Our data suggest however that a return to pre-earthquake average landslide conditions may not be simple. During this period, and particularly since 2017, we have documented an uptick in landsliding across the area, which visually from satellite imagery and anecdotally from observations on the ground appears associated with the proliferation of rural road construction around the time of the first local elections (Fig. 5). Whilst the direct impacts of rural road construction remain difficult to isolate, extrapolating what appeared to be the beginnings of a recovery in landsliding up until post-monsoon 2017 would imply that the number of landslides in the landscape should be now less than on the day of the earthquake (Fig. 5). However, in the most recent mapping we recorded c. 21,000 landslides, nearly double the coseismic number, implying that the changes to the landscape since the earthquake have had a landslide impact comparable to that of the earthquake itself. This impact is no doubt exaggerated by coseismic damage, whereby standard alignment choices and construction techniques may now be unworkable and unsustainable.

Based upon this effort, we identify several ways in which our assessment could be used in the management of future landsliding. The first is in providing regional-scale but high-resolution data on the evolution of landslides, which is essential for informing ongoing recovery and reconstruction. Further analysis could utilize physically-based modelling of the release, entrainment and transport of landslide debris through the fluvial network (e.g. [7]), feeding into consideration of the full earthquake-triggered hazard chain (e.g., [13]). Second, our landslide mapping can be used to refine regional-scale post-earthquake landslide susceptibility models that consider the whole impact footprint of the event with the detail of individual landslides, in order to improve their ability to anticipate the occurrence of new landslides over and above the capabilities of static models that do not account for seismicity. This type of susceptibility analysis is essential in contexts that lack systematically collated landslide inventories, for prioritizing areas that may face higher potential future risk. The research described here in part demonstrates the value of systematic inventories, and provides a sustainable workflow to underpin this in future. Third, our data provide an assessment of the trajectory of landslide risk for individual landslides which adds considerably to one-off site assessments.

Finally, returning to the tragic events in Jambu and Lidhi in Sindhupalchok during the 2020 monsoon season, we consider the degree to which either of these events might have been avoided or mitigated from the type of mapping and modelling outlined above. The settlement of Jambu was identified as an at-risk location in our modelling of landslide runout (Fig. 7). Landslides had been mapped in the headwaters of the Almo Thado and Kabre Kholas, and the modelling suggested that if these landslides remobilized, then the kholas would likely route the debris flows across the Arniko Highway, as happened in early July. This situation was exacerbated by a series of rural roads traversing the slope above, crossing the kholas, and apparently destabilising the surrounding hillside since the earthquake. Even without this analysis, the location of Jambu on a debris flow fan at the base of pre-existing channels shows its long-term susceptibility to debris flows. Therefore, risk sensitive land-use planning using geospatial information on hazards could be used to identify areas of potential new future landslides and where they may runout. In Jambu, for example, such approaches would identify construction on debris flow fans at the

← Fig. 7. (a) Footprints of mapped landslides in post-monsoon 2019, for the same area as shown in Fig. 6b. White circles show the location of buildings. (b) Modelled landslide runout, showing the predicted debris flow propagation under extreme rainfall, using the 2019 mapped landslides as source areas. The colour scale indicates the relative probability of any location being hit by a debris flow (white – negligible risk; blue – low risk, red – high risk). (c) Individual building relative risk scores extracted from the runout model, with stars indicating a direct impact. Note that the model is able to discriminate between individual houses within a single settlement. Shaded relief elevation map derived from a 5-m ALOS DEM of the study area (Credit: © NTT DATA, RESTEC/©JAXA). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

mouth of steep channels as unacceptable, and therefore have the potential to help reduce exposure to such hazards in this location. Problematically, however, Jambu was one of around 10 comparable at-risk locations along just the adjacent 2 km of the Arniko Highway. Where locations for development are limited, the almost inevitable consequence is building on high risk land.

In the case of Lidhi, whilst the settlement had been identified as a Category 2 location in the NRA Geohazards Assessment with mitigation deemed sufficient to reduce the risk to an acceptable level at the time of the survey, this location was not identified in our mapping analysis. No landslide was visible above the settlement in the satellite imagery, either immediately after the earthquake or in any of the epochs mapped since. This demonstrates firstly the scientific challenge of identifying those areas damaged and at elevated levels of landslide risk across such an extensive area, particularly when the surface expression of such damage (e.g. cracks) is so limited. Secondly, this example highlights the significant value of local knowledge and observations in assessing the potential for landslide risk; observations of cracking are reported to have raised sufficient concerns for the community to relocate each night to reduce their exposure to a potential landslide if it were to occur. Attempts to relocate residents away from Category 3 communities after the Gorkha earthquake (e.g. www.durablesolutions.org) have shown the strength of attachment to place in making such decisions is immensely challenging for communities with long-term ties to land, places of cultural, livelihood and religious significance [33]. It would therefore appear that where a community has a firm conviction to relocate due to a perceived risk, that a technical assessment to affirm their perception or to reassure them of a lower level of risk should be undertaken.

5. Conclusions

Through sequential mapping of the landslides in the area impacted by the Gorkha earthquake, we have described patterns that characterize the spatial and temporal evolution of landslide hazard and risk in the period since the shaking stopped. From this we have distilled a series of observations, and here have considered these in the context of risk faced during the period of the reconstruction. Our key observations are:

- Systematic mapping of landslides in the area impacted by the Gorkha earthquake has demonstrated the value of detailed inventory data to feed into a dynamic assessment of landslide risk. This illustrates the critical value of investing in baseline data on environmental hazards, to understand pre-disaster conditions, but also to provide insight into the likely future trajectory of hazard and risk.
- Our mapping shows that the landslide hazard in the 14 worst-affected districts remains significantly higher than on the day of the earthquake in 2015. Whilst some areas have experienced a degree of stabilization, new areas have experienced landsliding and some continue to develop. Mapping and monitoring these areas is critical for informing risk sensitive land-use planning in coming years. Critically, based upon our data, it should be expected that the levels of landslide risk in these areas will remain elevated for at least several more years.
- The modelling of landslide risk due to debris flows indicates that the household-level landslide risk evolves considerably after the earthquake, with a increasing number of houses having been exposed to landslide hazard at some point since the earthquake. We identify that the most characteristic form of landsliding is a transition to debris flows, which deliver highly mobile material through hillside channels to the fluvial network. These channels represent one of the highest risk areas in the landscape. Locating houses close to these areas is therefore extremely risky, but their identification can be made from either landslide hazard and risk maps as described here, or through adopting basic principles for risk sensitive land-use planning. Critically, these risks are therefore largely avoidable.
- Two landslide disasters from Sindhupalchok in the summer of 2020 show the value of multiple approaches to assessing landslide risk in a

dynamic and largely unprecedented context. What we present here is a large-scale assessment of changing risk that is intended to capture individual household conditions, by adopting a high-resolution mapping and modelling approach, but also to provide a synoptic precis of the evolving risk landscape at federal level. This however must be undertaken in tandem with on the ground, detailed geotechnical site investigations at locations of particular apparent and emerging concern. It is also essential to provide space to feed in and build upon local observations and understandings of landslide hazard and risk across the area impacted by the earthquake.

Author statement

NJR: Conceptualisation, Writing, Reviewing, Editing, Funding Acquisition; **MEK:** Methodology, Writing, Reviewing, Editing; **TR, KJO, ALD:** Writing, Reviewing, Editing; **DSP, RS:** Data Curation, Writing, Reviewing, Editing; **JS, KG, SL, MRD:** Writing - Review & Editing.

Declaration of Competing Interest

None

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Retrofitting of an RC frame building damaged in “April 2015 Gorkha earthquake” in Kathmandu valley

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ABSTRACT

The effect of “April 2015 Gorkha Earthquake” was devastating in terms of loss of life, heritage, buildings and emotions. A residence located at Purano Naikap-13, Kathmandu, built in 2006 was also severely damaged amongst many buildings. The building was a three and half story non-engineered reinforced concrete (RC) building. The main objective of this paper is to show the step-by-step process of retrofitting adopted in this building. After the initial survey and structural analysis in ETABS software, a suitable repairing and restoring of the stability of the structure was done which was followed by an appropriate retrofitting techniques. Concrete jacketing and steel jacketing with epoxy chemical grouts in columns were the two main interventions implemented. Pushover analysis was done to assess performance of the retrofitted building. The building was deemed acceptable; the Life Safety level was not exceeded under design basis earthquakes.

1. Introduction

Nepal lies in an active fault/thrust zone due to the collision of Indian plate with Eurasian tectonic plate which results in frequent occurrences of earthquake. Seismologists suggest that a major earthquake of moment magnitude (M_w) greater than 8 is likely to occur every 50 to 70 years in Nepal [1]. The April 2015 Nepal Earthquake (also known as the Gorkha earthquake) [2] killed 8979 people and injured nearly 22,000 [3]. It occurred at 11:56 Nepal Standard Time (NPT) on 25 April 2015, with a magnitude of 7.8 M_w and a maximum Mercalli Intensity of VIII (Severe) [4]. A major aftershock occurred on 12 May 2015 at 12:50 NST with a magnitude of 7.3 M_w [5]. More than 750,000 structures either damaged or destroyed [6].

Kathmandu is prone to earthquake as it lies in active seismic zone V [7]. The soil type of Kathmandu valley is lacustrine thus having low bearing capacity [8]. Kathmandu valley is assigned to Type E soft soil as per the Nepal National Building Code NBC105: 2020 [9]. The Mw7.8 2015 Gorkha Earthquake caused significant structural and nonstructural damages to the residence building under study. Structural damages included shear hinge formation at the beam-column joint in two of the columns and hairline cracks in beams at first floor. Nonstructural damages included diagonal cracks in internal as well as external walls and falling of parapet walls. The walls at staircase was heavily damaged. Figs. 1 and 2 shows the plan and elevation of the building.

The main purpose of this study was to provide best retrofitting, repair and restoration technique applicable to the building and to improve performance of the building. Retrofitting technique to be adopted should also be economic, time-effective and feasible in terms of materials and manpower. After preliminary damage survey, it seemed necessary to provide immediate supporting and restoring techniques as well as implement proper retrofitting scheme to the structure. The restoring and retrofitting were done in three phases. First phase incorporated temporary supports, repairing and restoring of the damaged components of the structure. Second phase included analysis in ETABS software and selection of proper retrofitting techniques and the third phase included all the construction process such as detail retrofitting of columns, strengthening of beams and repairing of masonry walls.

General description of the building:

Type:	Reinforced Cement Concrete Frame Structure
Building Height:	12 m
Number of stories:	3 and a half
Column Size:	230 mm × 300 mm (All Columns)
Beam Size:	230 mm × 350 mm (All Beams)
Slab Thickness:	115 mm
Type of Foundation:	Isolated Footing

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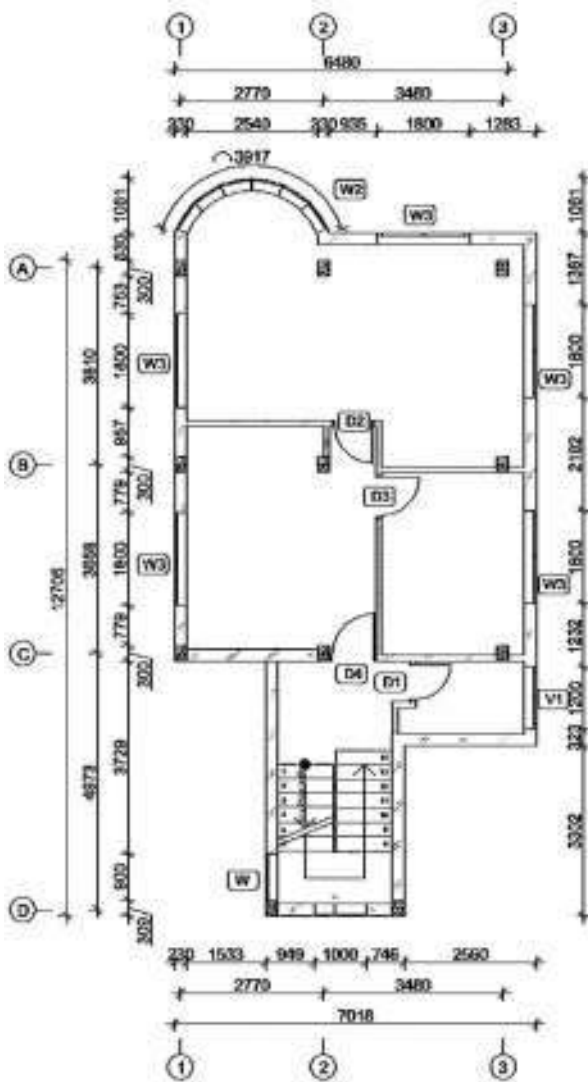


Fig. 1. Plan of the building.

2. Methodology

The main earthquake was followed by hundreds of aftershocks which made the building more vulnerable to damage. The retrofitting process was done in three phases which can be seen in the flowchart (Fig. 3). In the first stage, metal prop supports were provided to secure stability and help to retain the structure from collapse. This process of immediate support assisted in resisting many aftershocks of the earthquake, one being the major aftershock in 12 May 2015.

In the second stage, analytical assessment of the building was done with the help of ETABS software. The required sections and materials for retrofitting were deduced from analysis. After the increment of column size through concrete jacketing and increased area of steel through steel jacketing, pushover analysis was done to obtain the seismic performance level of the building.

3. Damage survey

After the detail survey of the damage extent of the building, it was observed that the column 2A (Fig. 1) failed at the beam-column joint of the first-floor level. The dislocation of column from the beam-column joint could be seen on Fig. 4 with spalling of concrete. Due to lack of proper

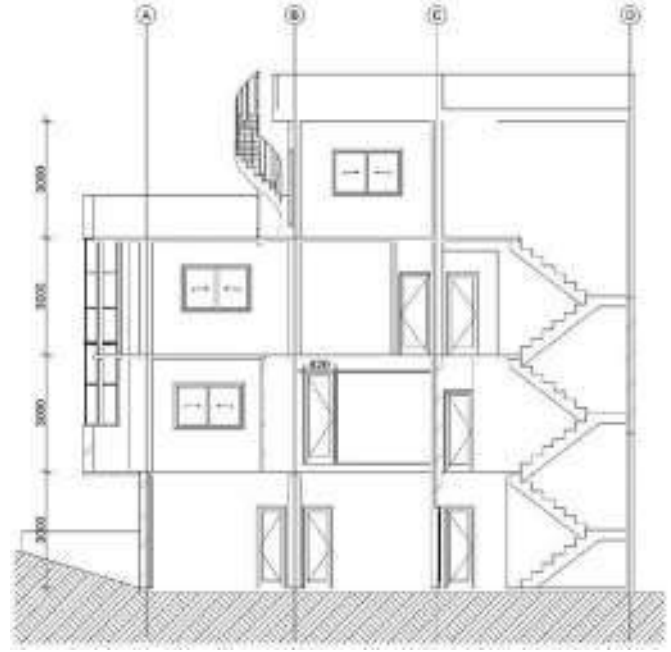


Fig. 2. Elevation of the building.

support at column 2A, vibration could be felt at first floor. Few hairline cracks were visible in column 2B (Fig. 1) and beams of first floor (Fig. 9). Diagonal cracks were also observed in the partition walls (Fig. 5) as well as peripheral wall. Figs. 6 and 7 show the picture of extent of damages to the internal and external walls respectively. Immediate support for stability were required to avoid any further major structural damage.

4. Retrofitting of the structure

Retrofitting is undertaken to enhance the original strength to the current requirement so that the desired protection of lives can be guaranteed as per the existing codes of practice. Retrofitting of a building will involve either component strength enhancement or structural system modification or both. It is expected to improve the overall strength of the building after the retrofitting process is completed. There are many retrofitting and strengthening techniques available for reinforced concrete building such as reinforced concrete jacketing, steel jacketing, addition of concrete shear walls, addition of steel bracing, base isolation, use of Fiber Reinforced Polymer (FRP), use of dampers, etc. which is also provided in the guideline "Seismic Vulnerability for Private and Public Building" published by the Department of Urban Development and Building Construction (DUDBC), Nepal in 2011 [10]. Injection of grouts can be done to fill cracks in structural members which requires special equipment and specially trained personnel which aids in strengthening of existing structure. Retrofitting should be done very carefully without causing negative impact on existing strength of the building. The selected technique must also be economical and the resources should be easily available.

After the detail survey of the building, it was found that the retrofitting was the only way to make the building habitable. The most familiar materials for retrofitting in Nepal are concrete and steel. High technology intervention methods such as FRP wraps, use of dampers etc. are not feasible in residential building due to high material, maintenance and labor cost. Therefore, in this building, retrofitting technique adopted was concrete and steel jacketing of the columns based on demands. Cost estimation of retrofitting and repair from preliminary investigations was found to be NRs.30 lakhs whereas the cost of demolition and construction of new building was estimated to be NRs.90 lakhs. The estimation was done on the basis of the then current market rate of Kathmandu (May 2015) of materials, labors and contractors. The approximate time calculated for retrofitting was 2

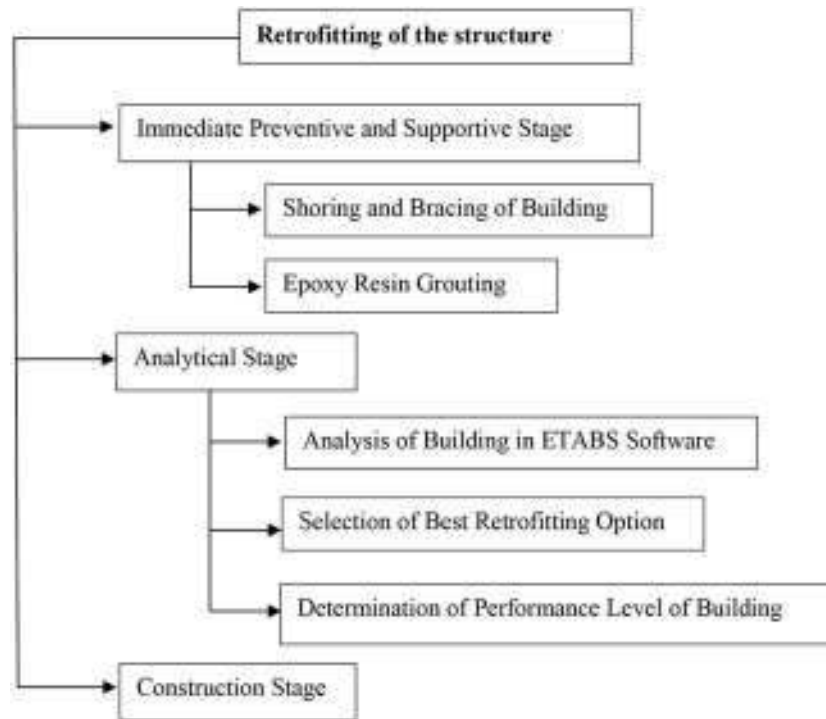


Fig. 3. Flowchart showing retrofitting process of the building.

months whereas for demolition and new construction the projected time was 8 months. Based on the parameters of time and cost, it was concluded that retrofitting, repair and strengthening of the building was the best choice for the building.

The intervention of the building under study was done in three stages namely,

- Immediate Preventive and Supportive Stage,
- Analytical Stage and
- Construction Stage.

5. Immediate preventive and supportive stage

The earthquake load is mainly dependent on the weight of the building and the earthquake force. Therefore, first step taken during this stage was the reduction of seismic weight of the building which included removal of live loads in upper floors. Rooms were marked with levels of risk and evacuation route was assigned. In order to prevent potential damage from the aftershocks, the structure was shored with metallic props (Fig. 10) under the beams and slab of first floor immediately after the first earthquake on 25 April 2015 (Fig. 8). The disintegrated concrete was removed and the area was cleaned at column 2A (Fig. 4). Fresh micro concrete with non-shrinking epoxy resin was injected to fill voids in cracks and



Fig. 4. Shear failure of column.



Fig. 5. Diagonal crack in staircase wall.



Fig. 6. Cracks in wall column interface.



Fig. 8. Epoxy grouting and support at column 2A.

strengthen the weakened columns as seen in Fig. 8. Due to unavailability of construction workers and materials in that situation of frequent aftershocks, these steps were found to be effective to support the structure from further damages during the major aftershock of 12 May 2015 as well.

230 mm thick brick masonry walls with concrete bands were constructed at the exterior as well as interior partition under the beams (Fig. 11) to provide permanent support against dead load of the structure maneuvering the loads from damaged columns. Masonry walls were constructed below the beams leaving space for retrofitting of columns (Fig. 8). Severely damaged walls were removed and reconstructed using rebar and seismic bands at two levels at ground floor while partition walls were restored by reconstructing the partition wall as prior at upper

floors. Walls with minimal hairline cracks were grouted with mix of cement and superplasticizers followed by wire mesh plaster using micro silica. The cracks in beam at first floor (Fig. 9) were injected with epoxy chemical under pressure until no excess chemical could be induced thereby conforming the complete filling of cracks.

6. Analytical stage

6.1. Numerical modelling and analysis

The analysis and design were carried out using finite element software ETABS 2015 to create, modify, analyze, design, and optimize the structural



Fig. 7. Crushing of bricks of external wall.



Fig. 9. Nozzles for epoxy grouting at beam.



Fig. 10. Metallic props under the first-floor slab.

elements in a building model (Fig. 12). The structure design was intended to be based primarily on the National Building Code of practice of India [11,12].

Table 1 shows the seismic parameters adopted for the analysis. Indian Standard code IS1893:2002 [14] was referred for seismic loading. Seismic zone factor was taken as 0.36 for zone V. Importance factor for residential building was considered as 1. The building follows the ductile detailing in accordance with IS 13920:1993, hence response reduction factor was taken as 5. Fig. 13 shows the column layout plan after jacketing.

After the analysis of the building, it was found that column 2A and 2B in Fig. 13 were inadequate in size. Therefore, concrete jacketing was opted for



Fig. 11. Brick wall under the beams.

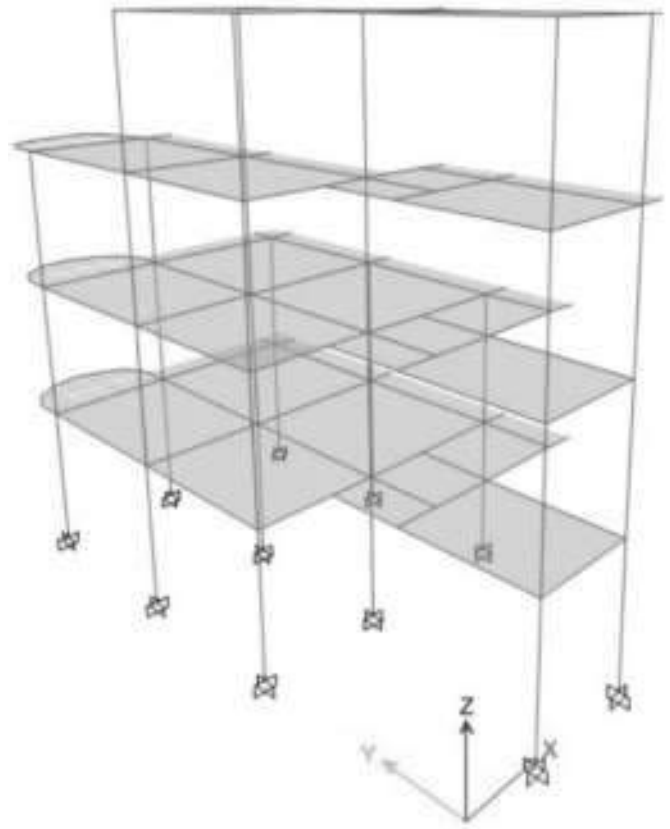


Fig. 12. 3D model in ETABS 2015.

these two columns whereas rest of the columns were deficit in area of steel and were jacketed with steel angles and plates. Table 2 shows the before and after size of the column with jacketing schemes. The required area of concrete and the area of steel for retrofitting purpose were increased by 1.5 times and 1.33 times as per IITK GSDMA guidelines [13,19]. Details of reinforced concrete jacketing and steel jacketing are discussed in Sections 8.2 and 8.3 respectively. Similarly, Table 3 gives the detail of retrofitted columns.

6.2. Pushover analysis

The pushover analysis was done to evaluate the seismic capacity of the structure. It is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. [15].

The purpose of pushover analysis is to evaluate the expected performance of structural systems during earthquake. The performance of a structural system is estimated by its strength and deformation demands, and these demands are compared to available capacities at the performance levels of interest. Fig. 14 shows the plot of performance level of the structure.

Fig. 15 shows the pushover analysis result presenting the sequence of plastic hinge formation and the state of hinge at various levels of the building. The Acceptance Criteria IO (Immediate Occupancy), LS (Life Safety) and CP (Collapse Prevention) is indicated by different colors to indicate the state of the hinge at various stages. Numerical software ETABS

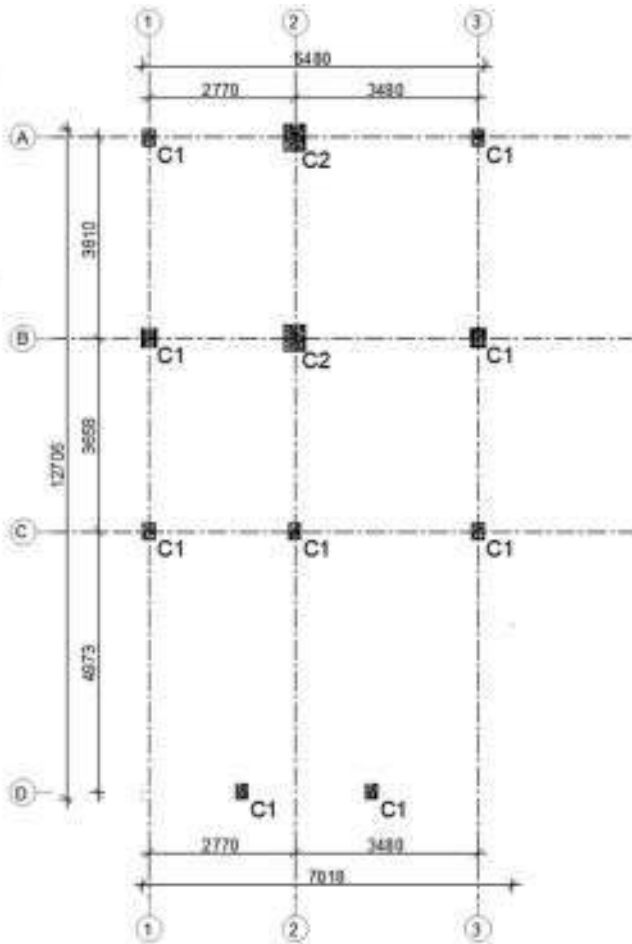


Fig. 13. Plan of the building after retrofitting.

calculates the performance point based on the procedure A given in ATC40 [17]. Procedure A is one of the three procedures A, B, C given in ATC 40.

7. Result

The retrofitting of the building was based on the result of drift, deflection and push over analysis which are briefly described below.

7.1. Inter story drift

The maximum inelastic drift in the building was 0.056 before retrofitting which reduced to 0.022 after retrofitting at level 3 in x-direction. Similarly, in y-direction the inelastic drift changed from 0.036 to 0.016 after retrofitting. The drift reduced by 61% and 53% after retrofitting the columns in x and y direction respectively. Tables 4 and 5 shows the drift at each story in which stiffness of brick infills are ignored. The graph presented in Fig. 16 compares the before and after retrofitting drift in each level.

7.2. Roof deflection

Roof deflection of the building was reduced from 116 to 43.8 mm and 71.2 to 34.1 mm in x & y-direction respectively after providing retrofitting scheme to the structure. The deflection reduced by 62% and 52% after retrofitting the columns in x and y direction respectively. Tables 6 and 7 shows the deflection at each story in which stiffness of brick infills are

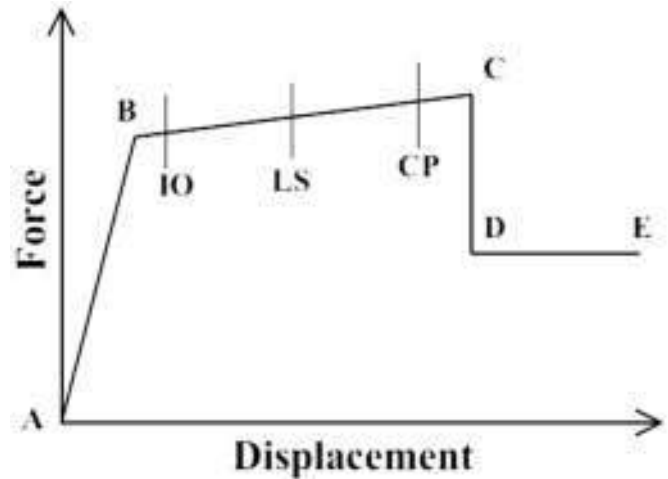


Fig. 14. Typical Flexural Hinge Property, showing IO (Immediate Occupancy), LS (Life Safety), and CP (Collapse Prevention; [16]).

ignored. The graph presented in Fig. 17 compares the before and after retrofitting deflection in each level. Allowable roof deflection of the building was 48 mm as per IS1893:2002 code [14].

7.3. Performance level of the building

Pushover analysis was done to check the performance level of the building before and after the retrofitting analysis. Fig. 18 shows the change in capacity of the building after retrofitting option. The base shear, spectral acceleration and displacement at performance point of the building was 1824.03kN, 0.33 g and 239 mm respectively. If the top story deflection was limited to 240 mm the capacity of the building improved from 720 to 1340 kN after retrofitting which was an increment of 86%.

Table 8 shows that the performance level of the building after retrofitting lies between step 4 and 5. If the displacement of the building at performance level was considered as 239 mm, the total drift of building would be 2%. According to ATC-40 [17], the building lies in the performance level of Life Safety. Fig. 18 shows the comparison of the capacity of the building before and after retrofitting.

8. Construction stage

8.1. Epoxy grouting in beams and columns

The strength of all beams and columns (Fig. 19) was enhanced by pressure grouting with epoxy resin. Epoxy resin were injected through nozzles placed in beams and columns in pressure. The process was controlled and monitored under strict guidelines as per supplying company. The main purpose of the epoxy grouting was to fill all the voids and cracks in the structure. It also establishes a strong bond within the void surface. Due to its non-shrinking properties, it is used for strengthening of structures than the conventional grout of cement, sand and water.

8.2. Reinforced concrete jacketing

Reinforced concrete jacketing for the columns 2A and 2B started from their respective isolated footings. The excavation of soil was done from ground floor to the base of foundation. The tie beams and footings in contact with soil was cleaned and the surface was roughened. The area of column was increased from 230 mm × 230 mm to 430 mm × 500 mm. Four numbers of TMT 16 mm diameter and eight numbers of TMT 12 mm diameter was added to the existing structure (Fig. 20).

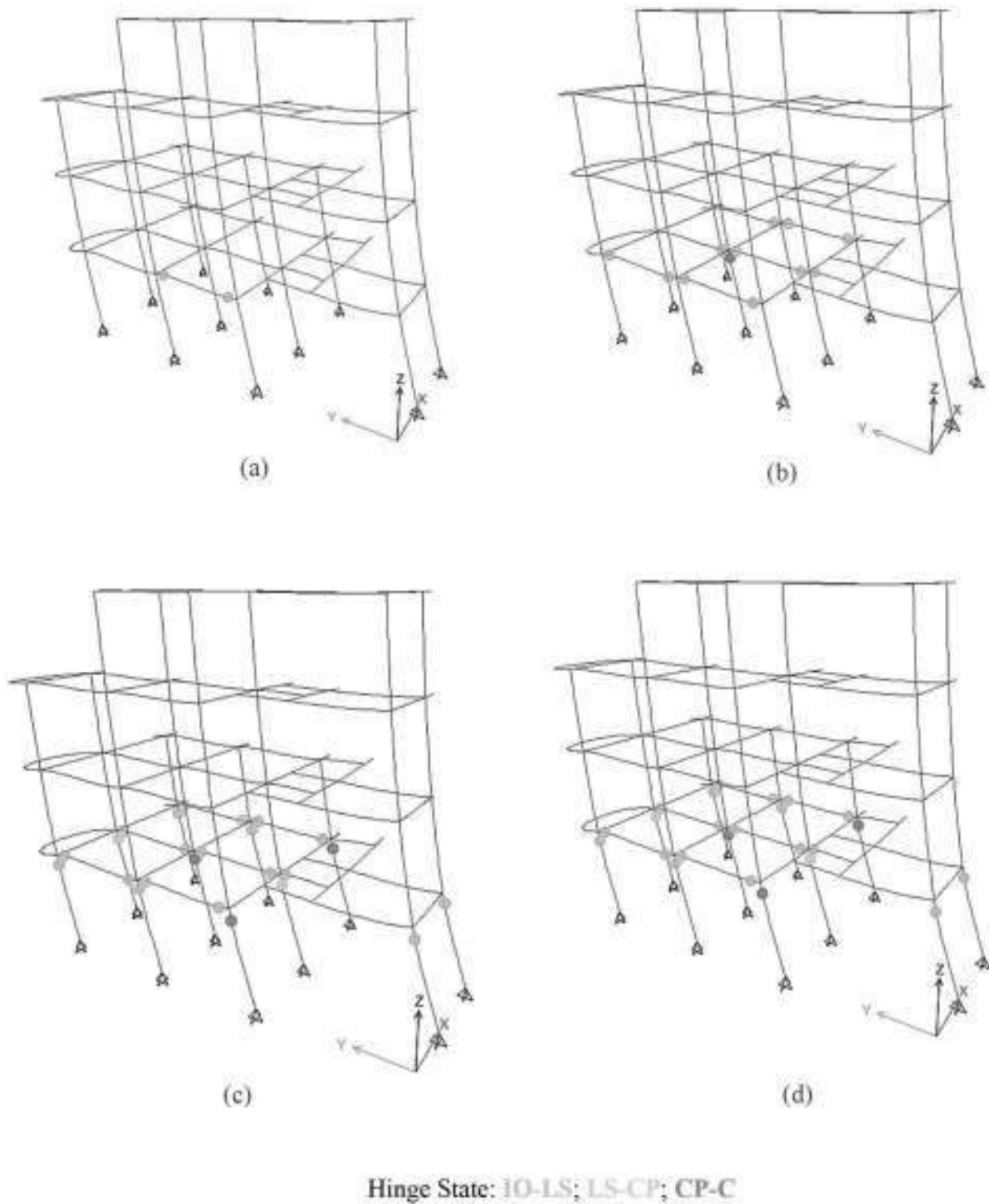
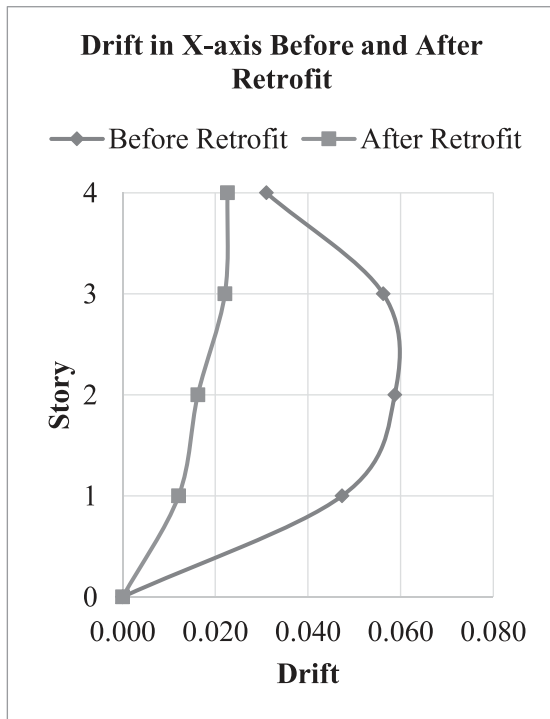


Fig. 15. Hinge states in the structure model at (a) step 4, (b) step 6, (c) step 8 and (d) step 10 during the pushover analysis, with color codes of hinge states.

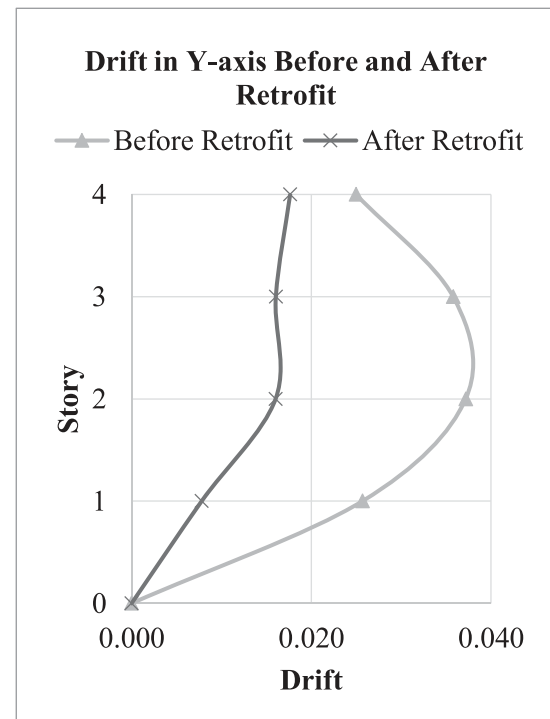
To establish a sound bond between the existing and new concrete, the concrete cover of the original member was scraped with chisel and bonding chemical was coated. For the anchorage of added rebar and the existing structure, holes were drilled to depth of 100 mm in the existing columns, epoxy resin was induced through the holes and 10 mm diameter rebar was inserted at 200 c/c to hook the new reinforcement with the existing

reinforcement (Fig. 21) and the photographs taken at site of same is shown in Fig. 22(a).

To increase the moment capacity of beam column joint, haunch was provided at the joints (Fig. 22b). This technique stiffens beam-column joint and avoid joint shear hinging of RC frame structures, subjected to earthquake imposed lateral loads[18]. RC haunches are more reliable

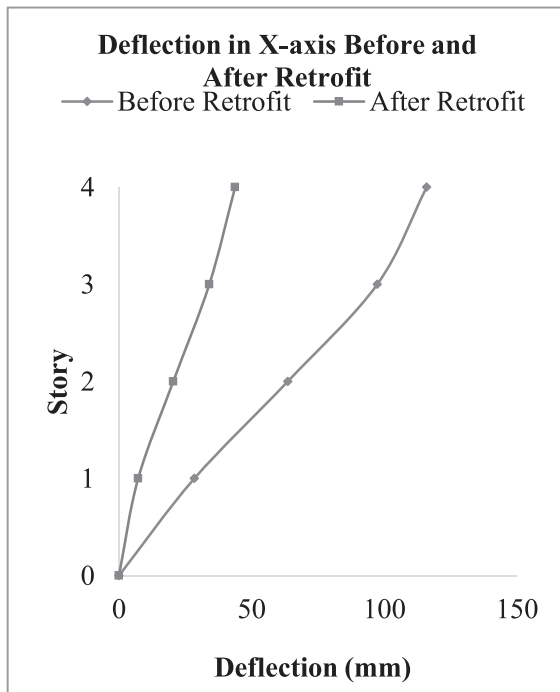


(a)

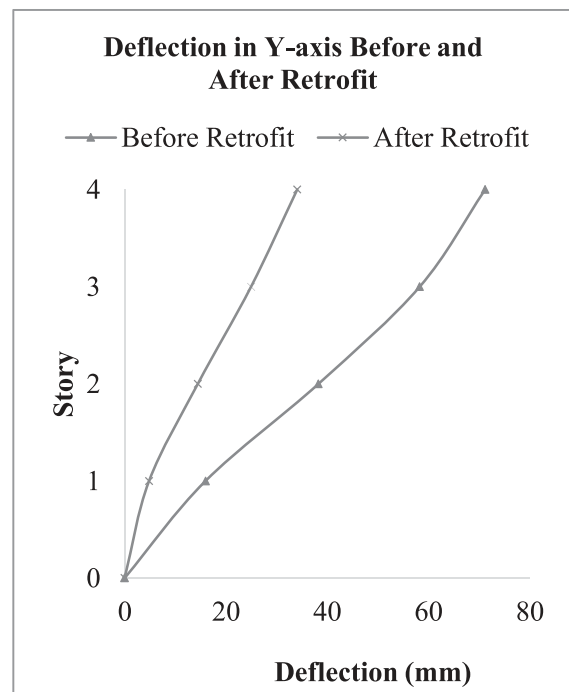


(b)

Fig. 16. Inter-story drift before and after retrofit in x-direction (a) and y-direction (b).



(a)



(b)

Fig. 17. Story-deflection graph before and after retrofitting in x-direction (a) and y-direction (b).

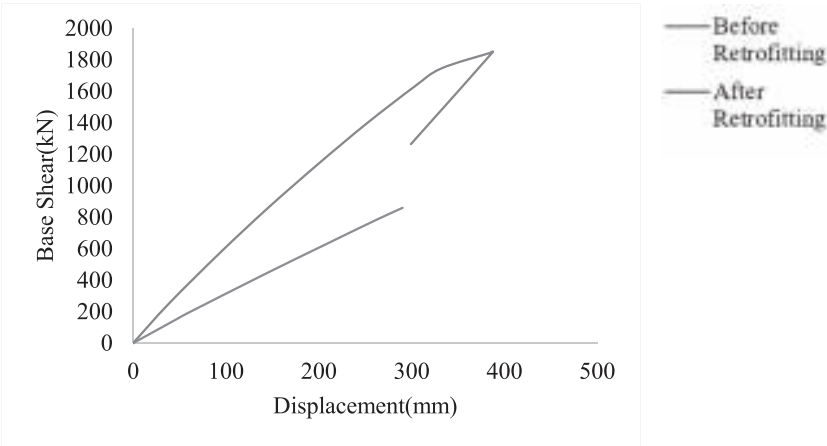


Fig. 18. Base Shear Vs Displacement of the building before and after retrofitting analysis.



Fig. 19. Injecting Epoxy grout in beams (a), (b) and columns (c), (d)



Fig. 20. Installation of base for column jacking.

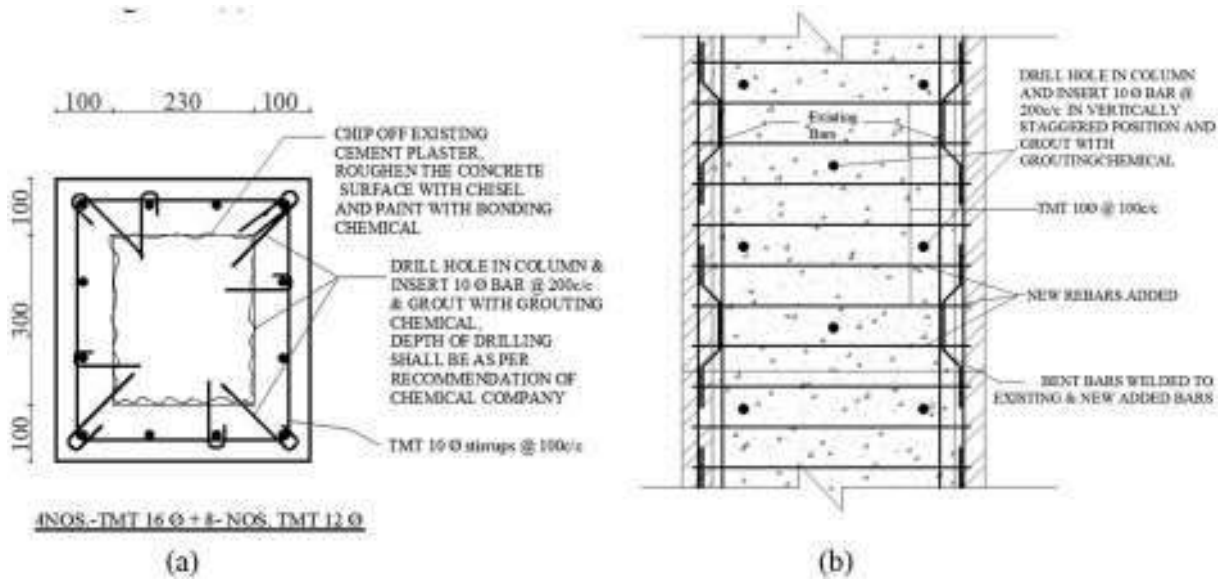


Fig. 21. Retrofitting detail of column (a-typical plan, b-typical section).

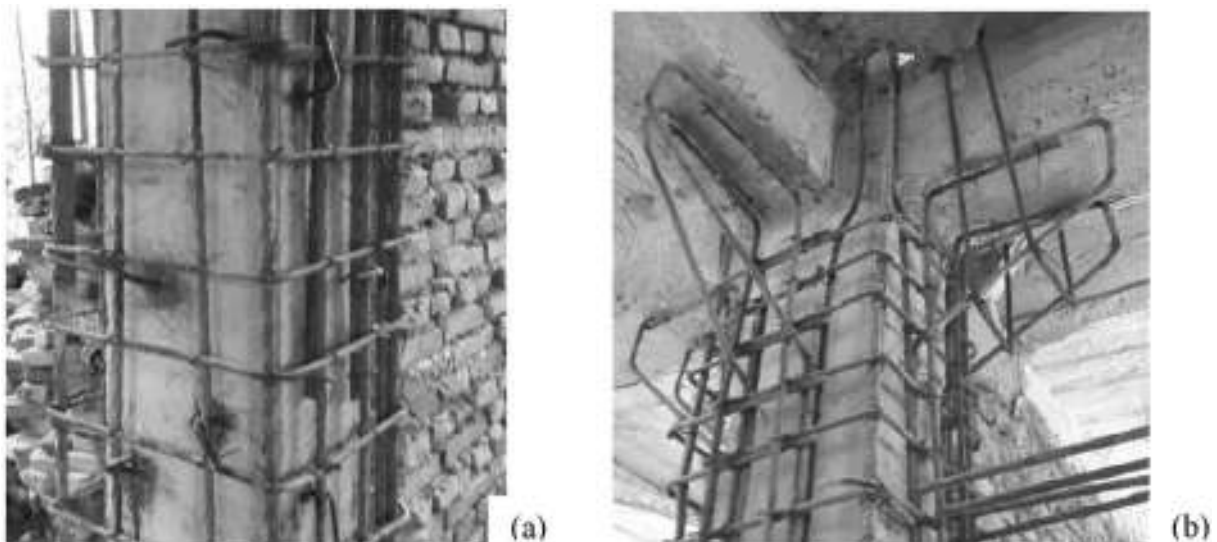


Fig. 22. Rebar installation on the existing column.

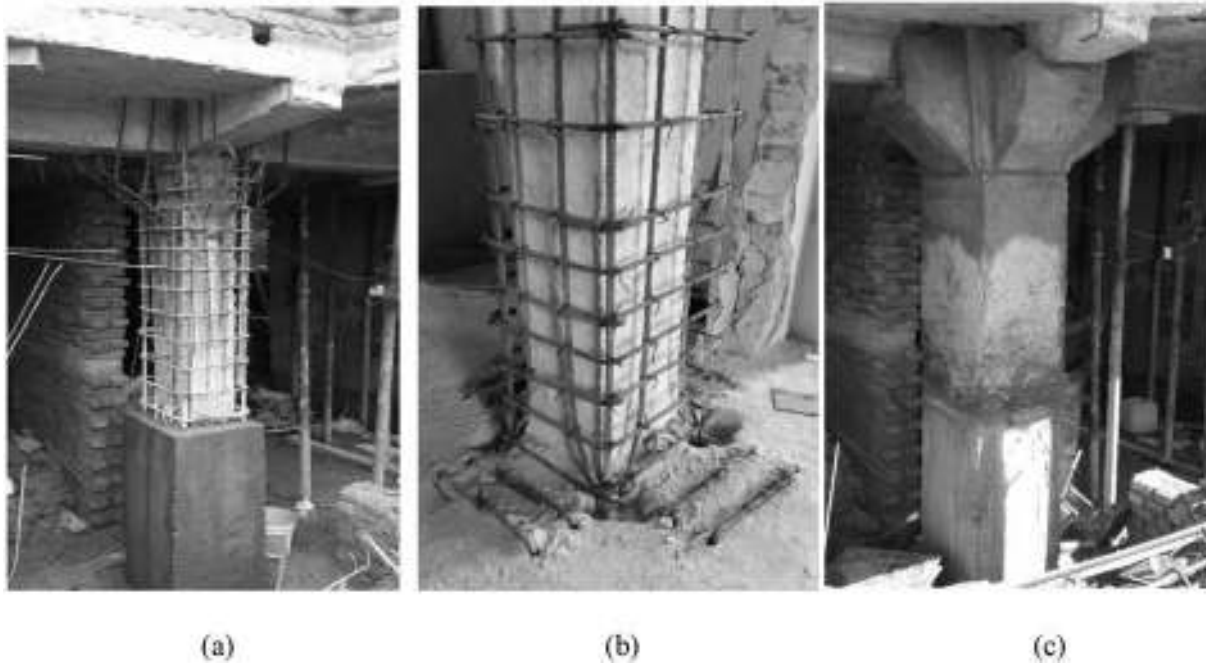


Fig. 23. (a) Haunch rebar connected through floor, (b) Haunch rebar shown in half way done concreting, (c) Concreting of the column).

than steel haunch as the connection of steel haunch in RC frame is subjected to pullout due to anchorage slippage and pullout due to concrete pry-out failure [20]. The haunches provided at top and bottom of the columns in a column beam joint performs better than provided only at the top end connection [21]. In this building, haunches were provided only at the top ends of the column to ensure least disturbance in mobility. The vertical rebar of the haunch was drilled through the floor slab to connect and form a ring at upper floor (Fig. 23b). The concreting of column was done in installments to avoid segregation of concrete. The height of casting ranged from 1 to 1.2 m at a time (Fig. 22a). Proper compaction was done using the needle vibrator. Fig. 22c shows the final product of concrete jacketing in column.

8.3. Steel jacketing of columns

The columns, except 2A and 2B, were steel jacketed using angles and plates. The required area of steel was determined from ETABS analysis. For example, the required area of steel in column C1 was 4078 mm^2 and actual area provided was 1206.84 mm^2 . The deficit steel area (Dst) of steel was 2871.6 mm^2 . This Dst was multiplied by 1.33 to get the final design area of steel which was $1.33 \times 2871.6 (= 3819.22 \text{ mm}^2)$. The Indian Standard Angle (ISA) $75 \text{ mm} \times 75 \text{ mm} \times 8 \text{ mm} (= 4560 \text{ mm}^2)$ was provided in four corners of the column

and Mild Steel (MS) flats $100 \text{ mm} \times 5 \text{ mm}$ was welded transverse to the ISA at 300 mm center to center spacing. For proper bonding with the existing concrete surface and the steel, the surface of concrete was chipped and roughened and bonding chemical (Epoxy) was applied prior to the welding of the steel sections. Fig. 24a is the pictorial representation of application of ISA and MS with existing column. Fig. 24b represents connection of ISA and MS through Hilti bolts. Similarly, at beam column interface, 8 mm thick plates were extended on beams up to 150 mm in each direction to connect it with upper floors base plates. The two plates were connected by 16 mm dia "Hilti" bolts. Fig. 24a and b represents the general plan and elevation of placement of ISA and MS flat plate respectively. Fig. 24c and d represents the plan and elevation of detailing of ISA and MS connection through Hilti bolts in beams and slabs. Fig. 25a and b shows the steel jacket applied to the columns at site.

9. Conclusions and recommendation

The study showed that the damaged building can be restored and strengthened with proper retrofitting design and techniques. There are many inventions regarding the retrofitting techniques in which cost and time of the opted techniques plays a crucial role. In this case, concrete jacketing and steel jacketing with epoxy grout

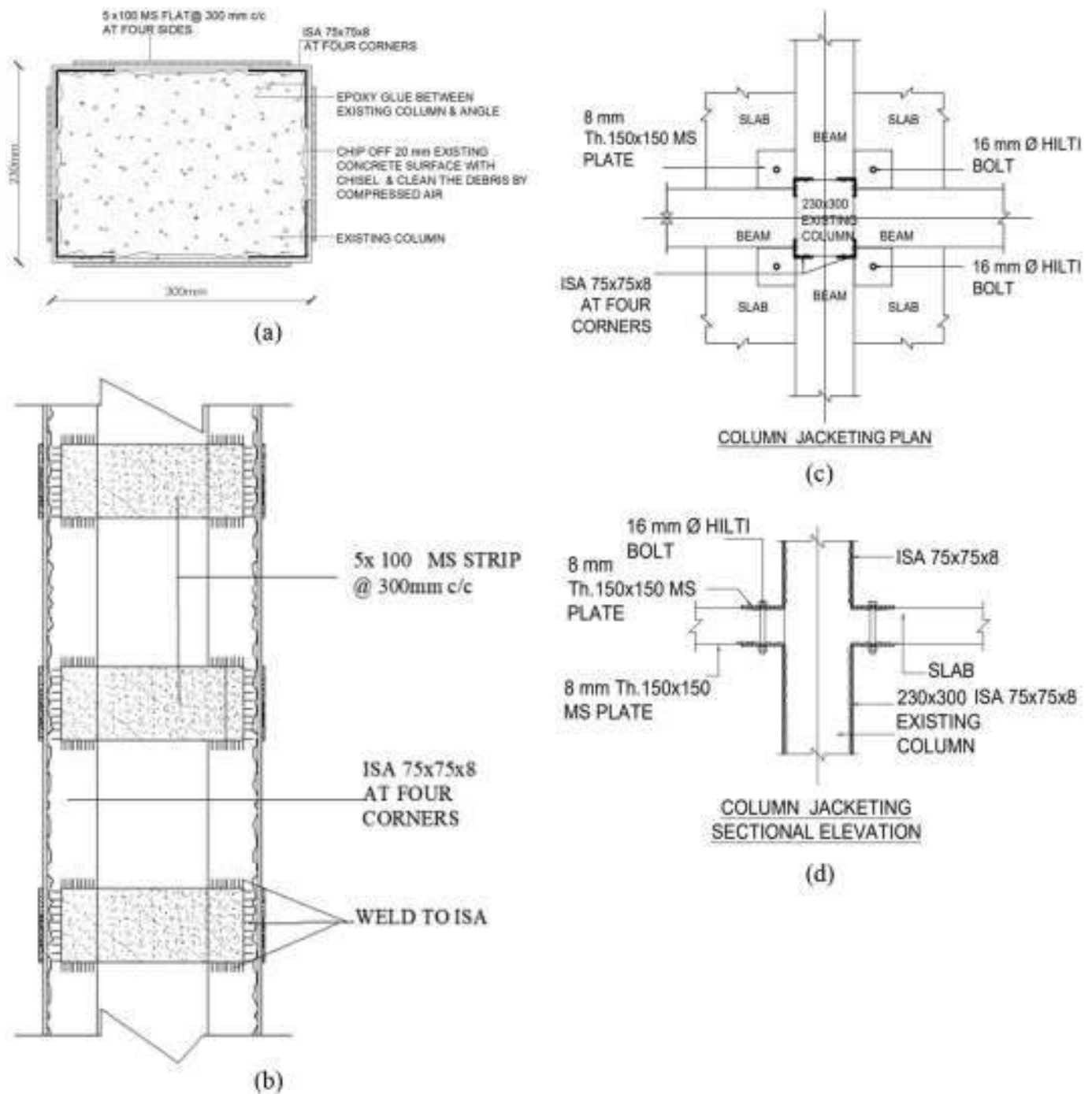


Fig. 24. (a) Detail of steel jacketing plan. (b) Elevation of steel jacketing. (c) Detail of steel jacketing plan. (d) Elevation of steel jacketing.

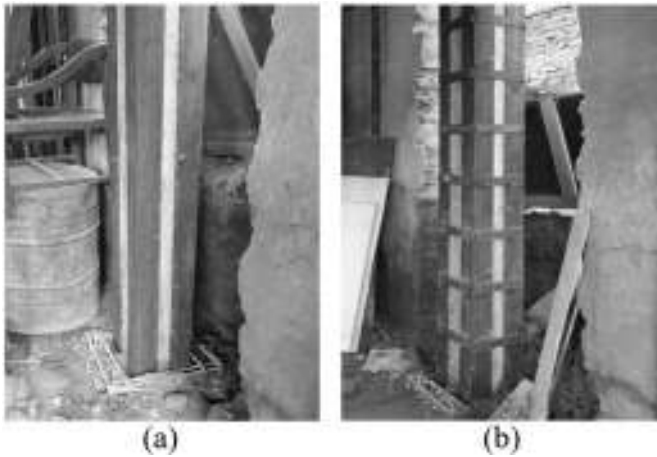


Fig. 25. (a) ISA at four corners of a column. (b) MS placed at interval welded with ISA.

Table 1
Seismic parameter for analysis.

Input parameters	
Seismic zone factor (Z)	0.36
Importance factor (I)	1.0
Soil Type	III
Time Period (τ/y)	0.483 s
Response Reduction Factor (R)	5
Design Seismic Horizontal Coefficient	0.09
Base shear	269.96kN

Table 2
Column size and retrofitting scheme.

Column	Before size (mm $\times$ mm)	After size (mm $\times$ mm)	Retrofitting scheme
C1	230 $\times$ 300	230 $\times$ 300	Steel Jacketing
C2	230 $\times$ 300	430 $\times$ 500	Concrete Jacketing

Table 3
Column size and retrofitting scheme.

Concrete Jacketing Details	4 numbers of TMT 16 mm diameter + 8 numbers of TMT 12 mm diameter
Steel Jacketing Details	Indian Standard Angle (ISA) 75 mm $\times$ 75 mm $\times$ 8 mm at four corners and Mild Steel flat 100 mm $\times$ 5 mm at 300 mm center to center distance

Table 4
Inter-story drift before retrofitting.

Story	Eqx	Eqy
4	0.023	0.018
3	0.022	0.016
2	0.016	0.016
1	0.012	0.008

Table 5
Inter-story drift after retrofitting.

Story	Eqx	Eqy
4	0.031	0.025
3	0.056	0.036
2	0.059	0.037
1	0.047	0.026

Table 6
Deflection before Retrofitting.

Story	Eqx	Eqy
4	116.0	71.2
3	97.4	58.3
2	63.6	38.3
1	28.4	16.0
0	0	0

Table 7
Deflection after Retrofitting.

Story	Eqx	Eqy
4	43.8	34.1
3	34.1	25.0
2	20.5	14.5
1	7.3	4.8
0	0	0

injection was considered due to easier material and manpower availability. Structural analysis performed in ETABS 2015 software displayed significant improvement in inter story drift and deflection of the building after columns were retrofitted as discussed in above sections.

Inter story drift was reduced by 61% and 53% in X-direction and Y-direction respectively. Top story deflection was reduced by 62% in X-direction and 52% in Y-direction respectively.

Static nonlinear push over analysis was used for assessment of capacity of the building which showed significant improvement after retrofitting option was implied. The capacity of the building was increased by 86% from the state of building before retrofitting. The building falls in Life Safety performance level on the basis of final drift after retrofitting.

Retrofitting of the structure improved the overall performance of building. It also minimized the total cost by 66.67% and time of construction by 25% than the demolishing and construction of new building.

Ground floor was formerly used as parking area with light weight partition in peripheral of the building area. The story was open in nature without internal partitions whereas upper floors were used as residential floors with 230 mm brick wall partition and similar partitions in upper floors. The difference in stiffness provided by brick walls in ground floor and upper floors could be the main reason for the damage of the building during earthquake.

The building was analyzed considering one code only i.e. IS1893:2002 [14]. It is suggested to analyze the structure using the Nepal National code NBC105:2020 [9] to evaluate the difference in various aspects in terms of seismic response and performance level. Retrofitting options can also be played with in future studies while comparing the time and cost. The stiffness of brick wall has been ignored in the study but can be taken into consideration in future study.

Table 8

Base shear versus monitored displacement.

Step	Monitored displacement, mm	Base force, kN	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	0.0	0.0	363	0	0	0	0	363	0	0	0	363
1	38.7	251.8	361	2	0	0	0	363	0	0	0	363
2	93.8	574.3	333	30	0	0	0	363	0	0	0	363
3	145.4	858.7	313	50	0	0	0	363	0	0	0	363
4	200.8	1144.7	283	80	0	0	0	361	2	0	0	363
5	252.2	1397.4	272	91	0	0	0	353	8	0	2	363
6	303.4	1630.6	249	114	0	0	0	347	14	0	2	363
7	332.0	1744.5	237	126	0	0	0	339	20	0	4	363
8	383.6	1841.7	229	134	0	0	0	319	34	4	6	363
9	387.7	1849.2	229	132	2	0	0	319	34	4	6	363
10	299.4	1264.6	227	134	2	0	0	319	34	4	6	363

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Regular Article

Construction technology of multi-tiered temples and their rehabilitation after 2015 April Earthquake in Bhaktapur



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ABSTRACT

Kathmandu Valley comprises numerous tiered temples ranging from single to multi-tiered. A 7.6 magnitude earthquake struck Nepal on 25th April 2015, with the epicenter in the Gorkha district at 80 km northwest of Kathmandu and south of the China border. The 2015 Gorkha earthquake and the following aftershocks caused damages to many temples; the damages ranging from minor to few fully collapsed state. This paper focuses on Nepal's tallest temple the Nyatapola, square-shaped in the plan, and the Bhairavnath temple, rectangular-shape in the plan-representing the tiered temples with more than three tiers of the Kathmandu Valley. The paper investigates the employed indigenous construction technology, the condition/ level of damage suffered by case studies during the 2015 earthquake; presents the ongoing rehabilitation/strengthening works introduced following the recommendations of structural, architectural, and conservation experts. The main objectives are to explore indigenous construction technology, evaluate damage scenarios in case studies, and plan rehabilitation approaches aftermath 2015 earthquake. Methodology in the research includes the literature reviews on the construction technology of multi-tiered temples, case studies on presentative cases and the rehabilitation process adopted, key findings for damages, conclude, and provide recommendations. The rehabilitation process consisted of workshops and meetings with related authorities and the formation of a technical committee as per the recommendations of the experts. The team prepares a condition assessment report based upon visual inspections, documentations through on-site measurements, photographs, records of changes, and alterations. Based on condition assessment, the reasons for the damages are analyzed and appropriate rehabilitation/strengthening methods are recommended. The key findings consist of common construction technology of locally available materials like timber, mud, bricks, and stone with reducing wall thickness, and roof towards the top. The geometrical configuration, the inconsistent relative motion of the wall and roof during the earthquake; insufficient joint keys, and lack of regular monitoring maintenance are responsible for the level of damages in the temples.

1. Introduction

The geology of Nepal varies from plain terai lands, hilly areas, and high-altitude mountains. The formation of such geology is the result of the collision of the Indian plate and Eurasian plate towards each other, which is believed to begin about 55 million years ago and form the Himalayas. The collision is still active and this dynamic process gives rise to diverse geological conditions. Nepal also lies on the Himalayan range and boundary between the Indian Plate and the Eurasian Plate. These tectonic plates move beneath the Himalayas along the fault line [18]. Nepal was struck by a 7.6 magnitude earthquake on 25th April 2015, with the epicenter in the Gorkha district at 80 km northwest of Kathmandu and south of the China border, with a focal depth of 15 km. The 2015 Gorkha earthquake was said to be the result of converging tectonic plates; the Indian plate and the overriding Eurasian plate to the north as studied by the different

researches on earthquake. 57 districts were majorly affected with 14 districts severely affected in the Gorkha earthquake as declared by Ministry of Home Affairs/MOHA of Nepal. As listed by the Department of Architecture of Nepal, a total of 743 historical structures were affected by this earthquake among which 133 were totally collapsed, 95 partially collapsed and 515 were partially damaged in Nepal.

The historical and monumental structures of the Kathmandu Valley also encountered substantial damages during this earthquake. Many temples and monuments are partially damaged and a few are completely collapsed. These monuments are in the stage of reconstruction and renovation. Documentation and assessment of these structures from an architectural, structural, and seismic point of view have become an important part to safeguard these structures of heritage value from possible earthquakes in the future. The documentation and conservation of these structures are important to conserve our cultural heritage and keep our identity alive and

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express it to the future generation. This paper focuses on the construction technology of the multi-tiered temples, damages, and rehabilitation of Bhairavanath temple and Nyatapola temple as case studies representing the multi-tiered temples of the Kathmandu Valley, after the damages by the 2015 Gorkha Earthquake.

2. Construction technology of the multi-tiered temples

Nepal is a culturally diversified and rich country in art and architecture. The Kathmandu Valley, in particular, has numerous temples of different styles/types - shikhara, dome, and tiered temples. The tiered temples also vary from single-tiered to five-tiered temples with their distinctive features. All the temples of the Kathmandu Valley constructed in the medieval period are based on the structural system of unreinforced brick masonry in mud mortar and wood. The tiered temples consist of various parts and elements performing structural and decorative functions, and these elements are located at various strategic levels and places. These main components include the masonry walls as the principal structural system, and the wooden posts, wooden beams, joists at floor and roof levels, and cornices connected with different types of joints. These structures are constructed with the indigenous construction technology, materials, and ideas, best available during the time of the construction with the locally available materials and skills.

2.1. Masonry walls

The tiered temples of the Kathmandu Valley are single to multi-tiered. The structural system is based on unreinforced brick masonry and wooden members. Different types of wall systems are shown in Fig. 1. Most of the temples stand on multiple receding plinths which raises the temple above the street level to prevent it from the splash of rainwater, and dampness. Besides, the foundation of the tiered temple is either mat or of sufficiently large width capable of undertaking vertical as well as horizontal loads due to earthquake action [12]. The plinths act as a stiff base resisting strong ground shakings and reduce the displacement amplitude at the plinth surface [9] to the multi-tiered temples. Heavy plinths reduce the shear forces at the foundation level. The wall thickness of the multi-tiered temples is thicker in the lower levels with gradual reduction along with the upper levels. The masonry wall is a sandwiched masonry, with an outer wall made from fired clay bricks, inner walls from stronger rectangular sundried bricks (*ma apa*), and the inner portion filled with rubble stone, mud, and brickbats. The plaster is done only towards the inner face either by mud mortar or yellow clay mortar which gives strength to these units as a whole. The walls are not plastered from outside which makes a weak connection between the walls (See Fig. 2.)

Most of the temples dedicated to Bhimsen and Bhairav are raised in a rectangular base. The Bhimsen temples of Kathmandu, Patan, and Bhaktapur, Bagh Bhairav of Kirtipur is some of the examples of rectangular base temples. Bhairavnath temple is a rectangular-shaped temple (the plan is shown in Fig. 3) dedicated to the god Bhairav, located at Taumadhi Square in Bhaktapur. It has thicker walls in the first three floors up to the first roof and diminishing wall thickness in the upper floors extending to the following roofs with the temple standing on a low plinth only towards the east. A central wall runs from the ground floor to the fifth floor as shown in Fig. 4. The wooden joists and the floor run horizontally resting on the wall plates on the walls on every floor.

The geometrical configuration of the Bhairavath temple is a rectangular base where walls constitute the major part of the structure. The area of walls with respect to each floor plan is shown in Table 1 below;

Bhairavnath temple is a three-tiered temple but with six floors including the mezzanine floor in between two roofs. As shown in Fig. 4 and Table 1, more percentage of walls can be seen 52.33%, 33.17%, and 28.94% respectively in the first three floors; and reduced floor area resting on the deep wooden beams on the lower floors in the third and fourth floor with 50.23% and 21.21% wall coverage and last two floors -fifth and sixth floor covering 67.12% and 15.49% wall. The percentage of the wall is

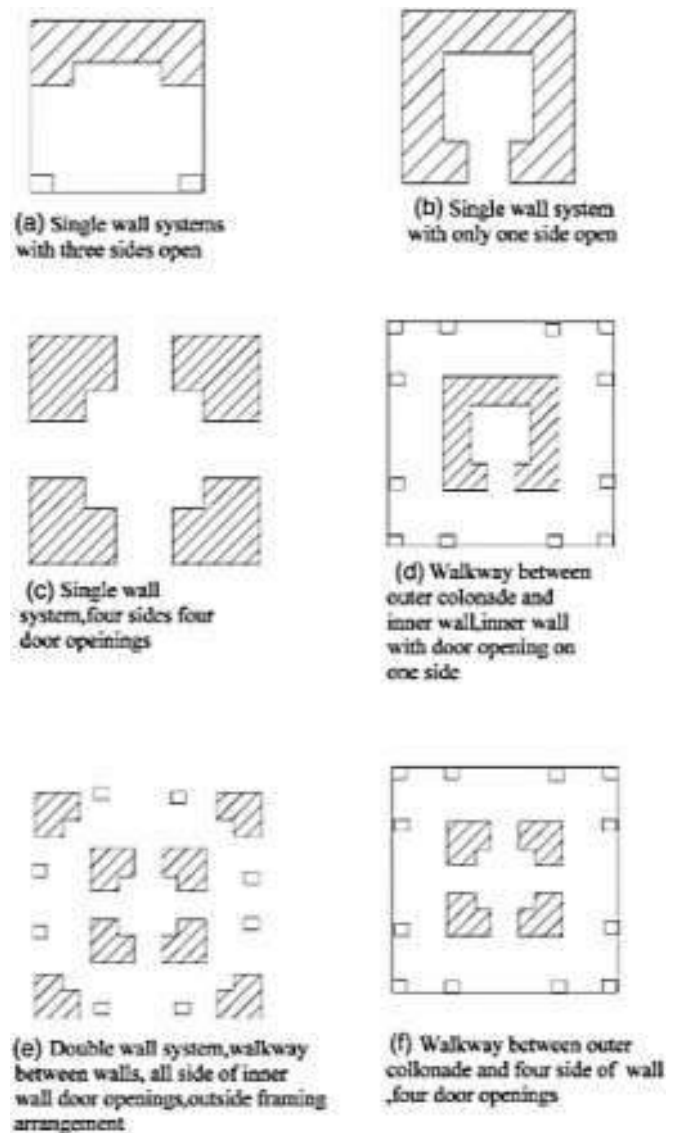


Fig. 1. Wall system of multi-tiered temples of Nepal.
Source: [10].

more in the mezzanine floors where it consists of small latticed windows adjoined to the exterior part only.

Apart from the rectangular-based tiered temples, square-based temples are also prevalent in the Kathmandu Valley. The Maju Dega of Kathmandu, Char Narayan temple, and Kumbheshwor temples of Patan, Nyatapola of Bhaktapur are few prominent examples of square-based temples. Nyatapola temple is dedicated to the tantric goddess Siddhilaxmi, standing on five high plinths that support the overall weight of the superstructure of the temple. It is a temple with a square room that is encircled by a colonnade. The wall thickness varies from 2.67 m on the ground floor to 0.55 mm at the topmost level. From the observations of other such temples and as described in the general concept of such a category temple by [17], the temple contains a core that extends to two floors enclosing cella and the empty compartment above. Around the core, there may or may not be a closed circumambulatory path (*pradakshinapatha*) depending upon the position of the deity in the cella, so that the wall of the core forms the inner wall of the *pradakshinapatha* and in the upper storey forms the outer wall of the temple as shown in Fig. 6. A similar case is in the Nyatapola temple, where the deity of Siddhilaxmi is placed on the northern side with an inner wall of the ground floor- thus forming an outer wall in the upper storey and exterior wall with the colonnade of 270 × 270 mm wooden posts

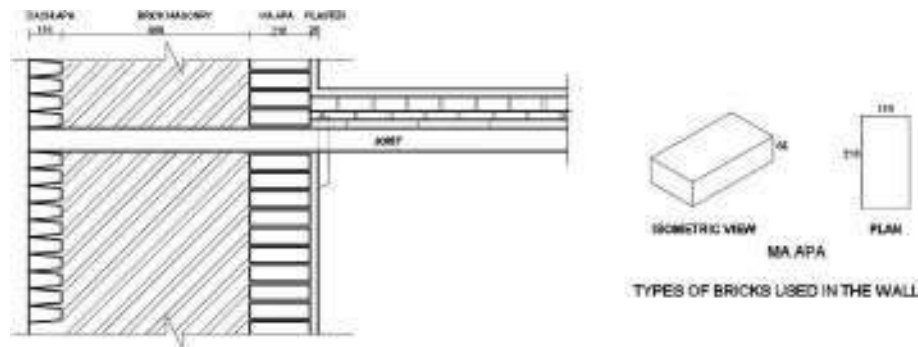


Fig. 2. Wall section showing different types of bricks used.

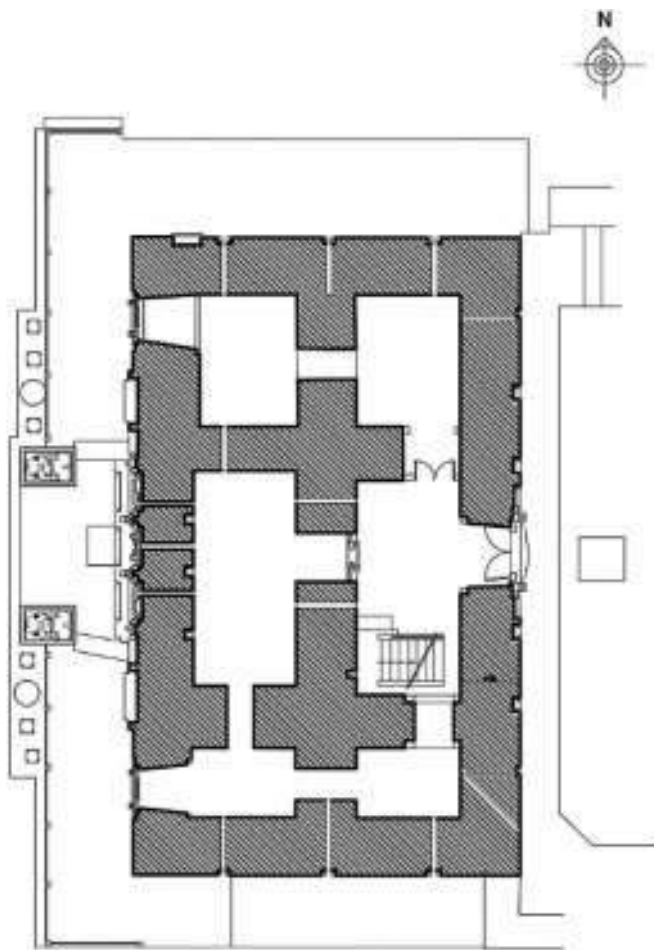


Fig. 3. Ground floor plan of Bhairavnath temple.
Source: (Bhaktapur Reconstruction [5])

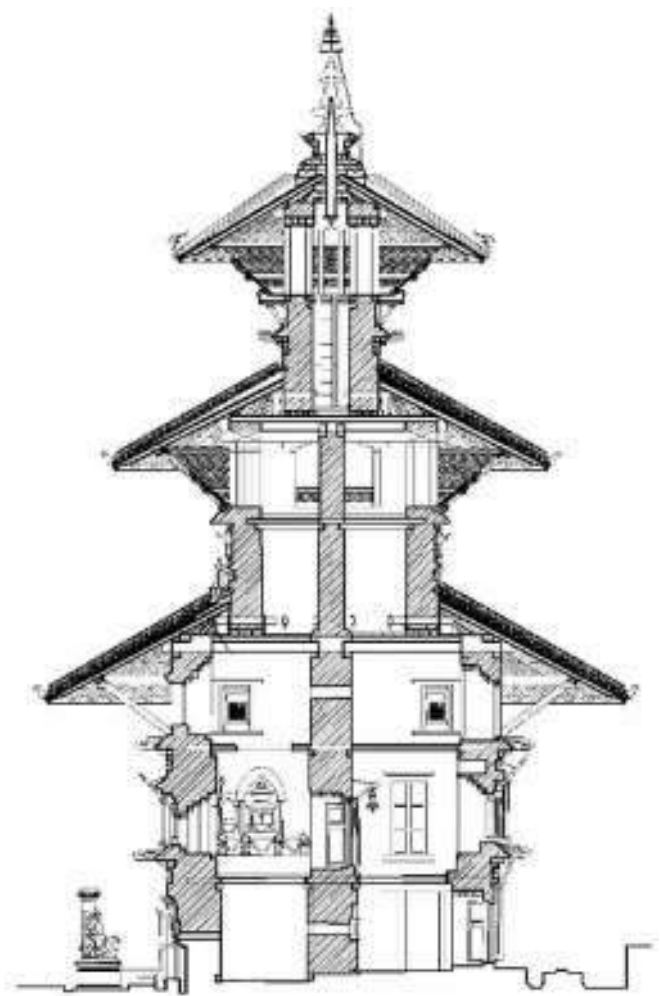


Fig. 4. East- West section of Bhairavnath temple.
Source: (Bhaktapur Reconstruction [5])

(see Fig. 7). The first floor formed by the connection of either side of inner walls by joist can be accessed through the ground floor. There does not exist any flooring in the upper levels which form a void from the first floor to the pinnacle as shown in Fig. 5.

Source: [17]

In the case of the Nyatapola temple also, masonry walls are an integral part of the structure. Table 2 and Fig. 7 elaborate on the system of the masonry structure of the Nyatapola temple with the percentage covered by the wall. The structure of the temple covers 28.56%, 70.99%, 56.03%, 62.77%, 52.62%, and 55.79% respectively in the ground, first, second, third, fourth, and fifth floor respectively while the remaining percentage is covered by

the windows attached only to the exterior face of the wall and void in the center. The central space is a hollow void enclosed by thick walls with reduced thickness in the upper floors.

2.2. Size and proportion

According to different research done by researchers, there are certain design rules and concepts for the construction of the temple. [10] studies the shape, size, and location of the cella generally determine the

Table 1
Masonry wall in Bhairavnath temple.

Floors	Total floor area (sq m)	Total area of wall (sq m)	Wall in %	LxBxH (mXmXm)
Ground floor	96.92	50.72	52.33	12.62 × 7.68 × 2.44
First floor	96.23	31.92	33.17	12.73 × 7.56 × 3.12
Second floor	96.23	27.85	28.94	12.73 × 7.56 × 2.59
Third floor	49.74	24.98	50.23	10.11 × 4.92 × 2.78
Fourth floor	49.74	10.55	21.21	10.11 × 4.92 × 2.44
Fifth floor	16.88	11.33	67.12	7.50 × 2.25 × 2.74
Sixth floor	23.95	3.71	15.49	8.16 × 2.94 × 2.31



Fig. 5. Open floor system in Nyatapola temple.

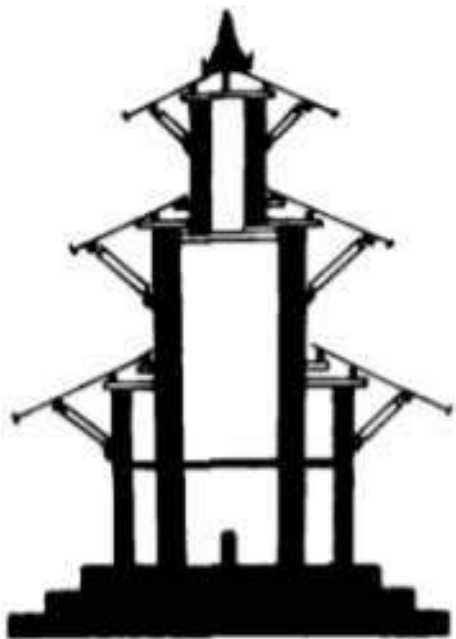


Fig. 6. Schematic section of a three storied temple.

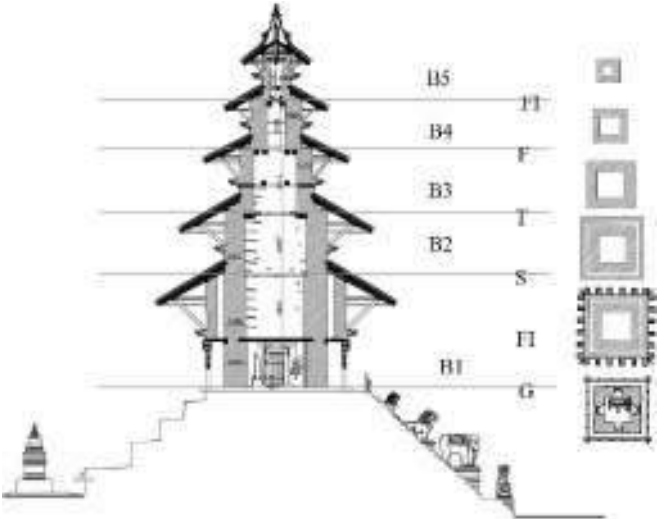


Fig. 7. North- South section of Nyatapola temple.
(Source: Technical committee, Khwopa Engineering College)

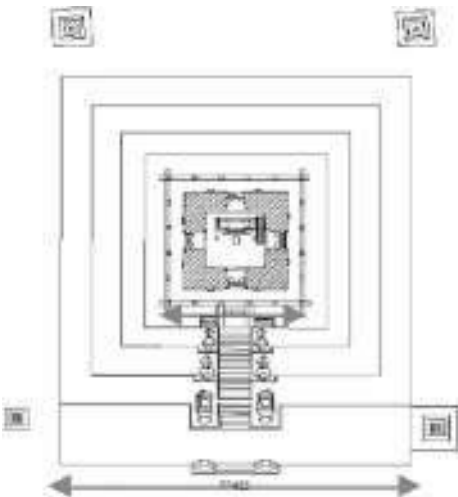


Fig. 8. Ground floor plan of Nyatapola Temple.
(Source: Technical committee, Khwopa Engineering College)

design of the superstructure. In this section, the size, shape, and proportion of the temples will be discussed. Generally, the square-shaped temple has a single pinnacle whereas the rectangular-shaped temple has more than one pinnacle in an odd number to maintain visual balance and symmetry.

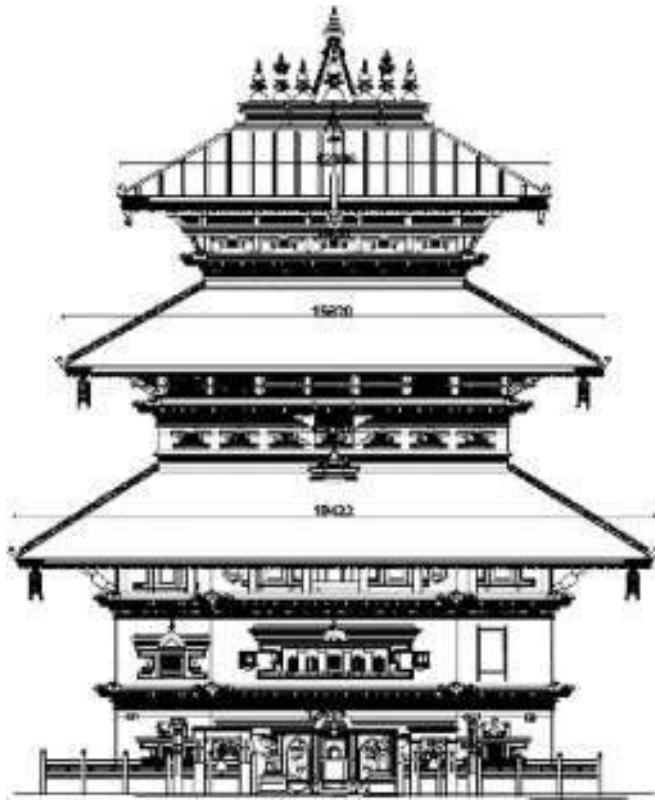


Fig. 9. West elevation of Bhairavnath temple.
Source: (Bhaktapur Reconstruction [5])

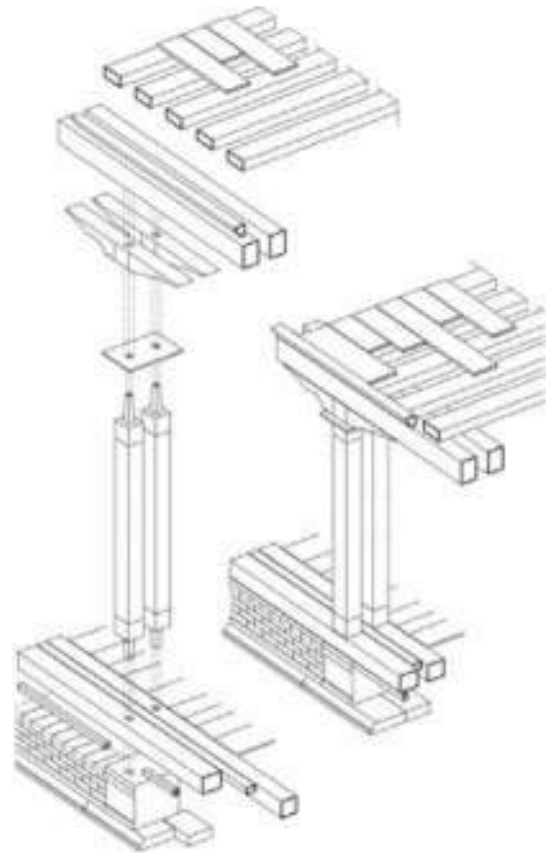


Fig. 10. Beam, post connection.
Source: [4]

The square-shaped plan temple is based on the Vastupurush mandala.¹ The large square of the Vastupurush mandala is divided into 81 smaller squares [16]. Each small square becomes one module for the construction of square-shaped temples. The size of the large square Vastupurush mandala is equal to the width of the colonnade in the case of a square plan temple. The design module for Maju Dega with the three-storied temple, square in the plan is 9 followed by the width of 6 modules in the first storey and 3 modules in the top storey. In this type of temple, the reduction in the size of the successive width of each storey is determined by reducing the width by three modules. The height of the temple should be twice or thrice the width of the temple [6]. The ratio of the width of the temple and the height of the temple from the topmost plinth level to the pinnacle is 1:2 in the case of Maju Dega. Similarly, the design module for the five-storied temple is 15 marked at the base of the temple which is equal to the width of the temple. The reduction in successive wall width of each storey from bottom to top is reduced by 3 modules in a 5:4:3:2:1 ratio.

As mentioned above, the height of the temple should be twice or thrice the width of the temple i.e. 26.9 m which is thrice the width of the temple in the case of Nyatapola. From the measurement, the existing height of the temple is 25.41 m which is nearly equal to the calculated value. The slight error might be errors in past renovations. The width of the colonnade of Nyatapola temple is 8.93 m and the height from the topmost plinth to the pinnacle is 25.41 m which is in the ratio of 1:3. Besides, the width of the bottom plinth is 22.46 m and its ratio with the width of the colonnade is 5:2. The ratio of the bottom roof to the width of the colonnade is 5:3 where the bottom roof sizes 15.60 m [16]. This proportion becomes accurate in other cases of multi-tiered temples like Maju Dega and other temples in Kathmandu valley. Thus, we can see that there is an application of design concepts in the construction of the plinth, the length of the wall, the length of the roof, the height of the temple illustrated in Table 3 and Fig. 7.

¹ Vastupurush mandala is one of such mandalas which forms an integral part of Vaastu shastra- the ancient Hindu canons of architecture and town planning

[15] studies on Baghbhairav temple of Kirtipur (a three-tiered temple with a rectangular-shaped plan) and identified that the three roof sizes (top, middle, and bottom) are proportional to 4:5:6; three core walls (top, middle, and collonade) exhibit 3:4:5 proportionately. Similarly, in the case of the Bhairavnath temple of Bhaktapur, which is geometrically similar to the Baghbhairav temple, the proportion in elevation in the width of the temple can be seen from the measurement. The three roof sizes (top, middle, bottom) are in the proportion of 4:5:6 and three core walls (top, middle, bottom) are in the proportion of 3:4:5 as illustrated in Table 4 and shown in Fig. 17.

2.3. Joinery system

Another peculiar feature of the tiered temple is the use of timber as the construction material. Timbers are used for the structural elements like post (*tham*), beams (*nina*), cornices, joists, rafters, and others with proper joints designated for different purposes like connections of different elements (See Figs. 8 and 9). The different components are assembled using special joints for each element which avoids the fixing devices made from materials other than wood [4]. The wooden joinery is supposed to prevent from seismic loads due to the flexibility of the structure. Different varieties of wood like *Chilaune* (*Schima Wallichii*), *Salla* (*Pinus Roxburghii*), *Utis* (*Alnus nepalensis*), *Sal* (*Shorea Robustus*), etc. are used in the construction works. However, hardwood species like *Sal* and *Chilaune* which are good in strength, termite resistance are suitable for the construction of load-bearing structural elements like beams, columns, bands, and framing of openings. They do not require any particular treatment for protection from termites as well as weathering.

The use of different kinds of joinery systems can be seen in Bhairavnath and Nyatapola temple which are shown in Figs. 10–12. The joinery system

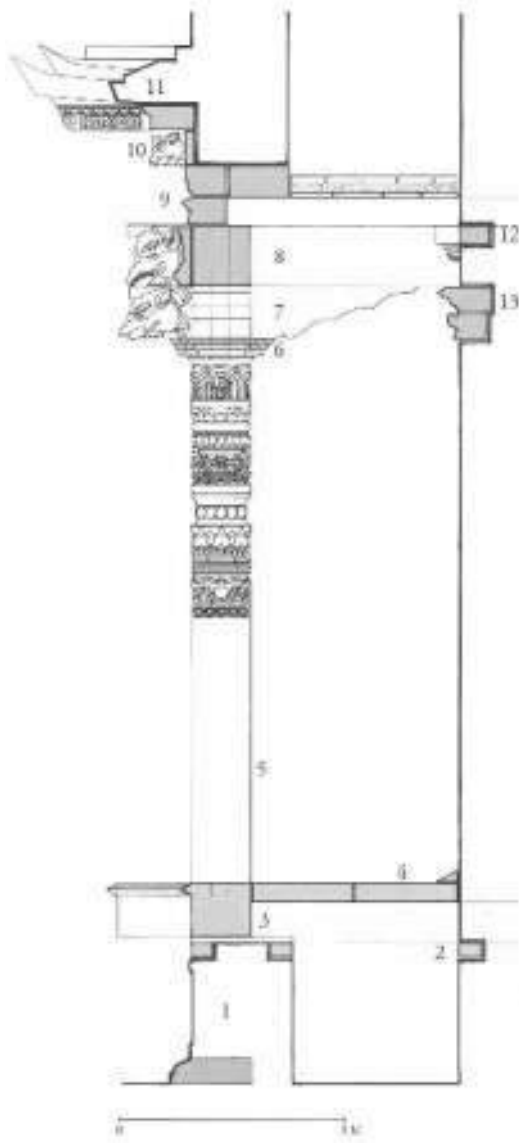


Fig. 11. Wall section details of Nyatapola temple.
Source: ([7] AD)

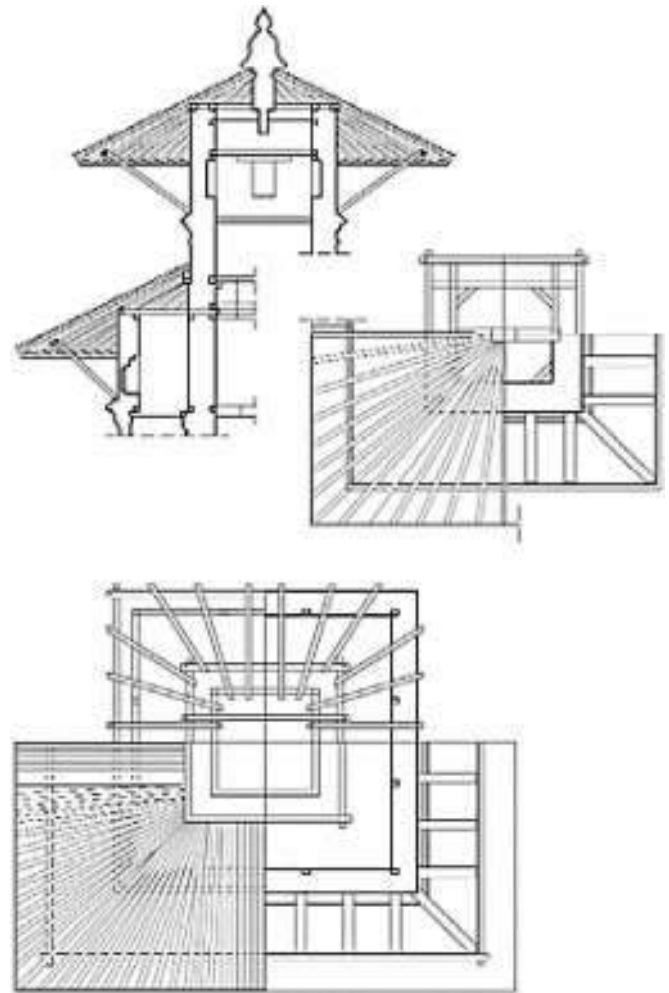


Fig. 13. Roof construction system in Nepal.
Source: [4]

is different for corners, posts, and elongation of eaves board, cornices, and other members. The common joints that are being used in the Newar Construction technology are double notched joint; dovetail joint (*dhukur puchhre san*) used to tie up to inner and outer wall plate; tabling/scrift joint (*chaku san*) used for the ridge, purlin (*challu*), joists, beam joints; dog matching joint (*khicha gachhi san*) for beam joints, tenon and mortise

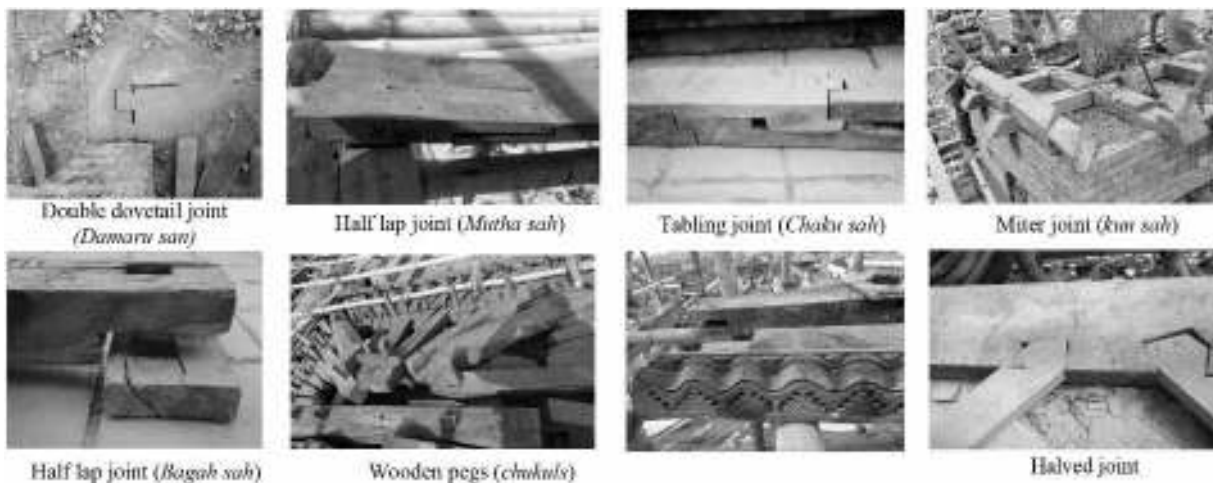


Fig. 12. Different types of joints used in Bhairavnath and Nyatapola temple.

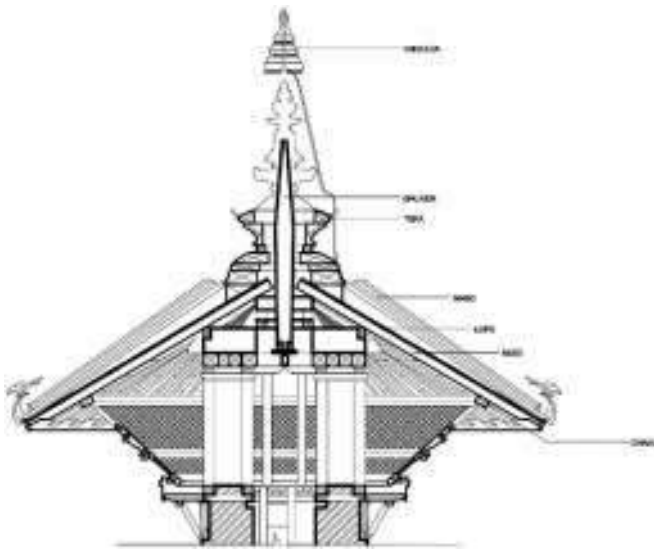


Fig. 14. Roof section of Bhairavnath temple.
Source: (Bhaktapur Reconstruction [5]).

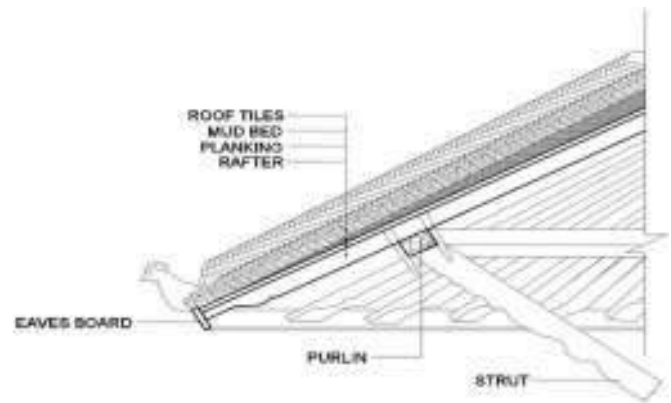


Fig. 16. Roof section details.
Source: (Bhaktapur Reconstruction [5]).



Fig. 15. Laying out jhingati in the roof of Bhairavnath temple.



Fig. 17. Tilting of posts.



Fig. 18. Dislocation of posts.

joints for door and window frames, column base joint for posts, etc. The extensive use of wooden pegs (*chukuls*) can be seen in the Newar construction technology.

2.4. Roof system

The roofing system in the temple gives the tiered temples a distinguishing architectural characteristic with a steep roof pitch and large overhanging eaves supported by rafters. The number of tiers in the temple may vary from a single to many tiers. This paper focuses on the temples of more than two tiers. The role of the roofing system is to protect the

temple from rain and extreme exposure to the sun, which may damage the walls, wooden elements with decay and deterioration. The roof consists of 25 mm thick planking, a thick layer of mud, followed by roof tiles/ *jhingati* on the top over the rafter (see Figs. 13–16). The sloped roofs are supported by fan rafters (as shown in Fig. 13) that start from the corners in a radial arrangement. A dead load of overhanging roofs is supported by the rafters and transferred to wall plates and purlins. Also, inclined struts hold the roof by transferring loads from purlin to the walls but there is no rigid connection between the strut with purlin and the main masonry wall of the temple [13].



Fig. 19. Cracks in first floor.



Fig. 20. Cracks in second floor.

The Bhairavnath temple consists of three-tiers among which the lower two-tiers are laid by jhingati and the topmost roof is mounted by gilded brass sheets in the northern, eastern, and southern side while the western roof is gilded by gold plated sheets as shown in Fig. 14. The top roof system consists of wooden purlins in two layers, on top of the upper layer, the brass and gold-plated sheets are overlapped and fixed on the battens. The overlapping of two sheets prevents the rainwater from penetrating inside the roof and does not let the decay of the wooden members below.



Fig. 21. Decayed posts of ground floor.



Fig. 22. Decayed posts of ground floor.

Similarly, the Nyatapola temple is a five-tiered temple with all five roofs laid by jhingati tiles. The word Nyatapola consists of two words - 'Nyata' meaning five and 'Pola' means roof in *Newar* language which means a monument with five roofs. It is the only temple named after the structure of the temple rather than the deity residing inside [14]. The roof construction in all the temples is done in the same way.

2.5. Structural considerations in the multi-tiered temples

At the time of the period where the concept of construction of multi-tiered temples flourished, there was a lack of formal codes of practices,



Fig. 23. Drainage hole penetrating to ground floor from first floor sanctum room.



Fig. 26. Cracks in the external wall of ground floor.
(Source: (Wood, et al.))

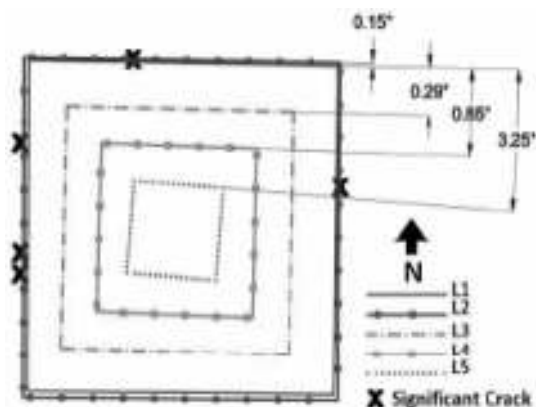


Fig. 24. Torsional drift of the roofs of Nyatapola temple.
(Source: (Wood, et al.))



Fig. 27. Surface cracks in second floor.



Fig. 25. Cracks in internal walls of ground floor.

sophisticated construction materials, and engineers. The materials of construction available at that time were limited to the burnt clay bricks, earth, stone, timber, and some metals. The artisans and craftsmen were the only men power for design and construction to materialize the concept developed based on royal/religious planning. The artisans and craftsmen were trained for traditions from generation to generation and the beginning of the training was learning by mistake. The principal construction



Fig. 28. Damage in the top floor.



Fig. 29. Reconstruction of top floor.



Fig. 30. Replacement of missing parts of windows.

materials were limited to bricks in mud mortar and timber. The unreinforced brick masonry is very weak in tension and hence has limited resistance to earthquakes [8]. The mud mortar used to be the only material for binding the bricks in the masonry. However, the best type of mud mortar used to be produced from the earth from the best location and depth with the raw material. The earth for the mud mortar shall consist of clay content not more than 20% for correct strength and least shrinkage, this part might not be known but they knew that the right kind of earth for the purpose used to be identified from the location from where the earth used to be obtained.

The tiered temples, as well as the prominent types of historical and monumental structures, have the height and span characteristics limited to lower values. For such values, the unreinforced brick masonry in mud mortar was adequate to withstand even the earthquake forces (provided seismic detailing is adopted like seismic bands at strategic locations). The seismic ties in the form of timber ring bands at the floor level, lintel levels are examples of that. The seismic reinforcement in the form of vertical and horizontal ties in the temples and palaces are efficient detailing for earthquake resistant. The floors and roofs are efficiently connected through the joints with the masonry walls with adequate capacity to transfer the earthquake induced lateral loads. The timber joints in the form of wedges (shear



Fig. 31. Replacing the decayed wood by new ones.



Fig. 32. Strengthening of structure in ground floor.

locks) are the endogenous form of connection which facilitate the box form of actions of the masonry walls with floors and roofs.

The gradual reduction of sizes of the structure along the vertical direction of the multi-tiered temples confirms the adoption of the pyramidal theory for the load path of the gravity load. Height and maximum base dimension are the main influencing parameter for time period of the structure. [8] expresses an empirical formula to estimate the natural period of vibration of Nepalese temples in seconds; expressed as $T = 0.0488 \frac{H}{\sqrt{d}}$ where H is the height of the temple, d is the maximum base dimension of the temple in meters and T is the time period. Also, these structures have practically no live load on the top floors. Hence these temples are very rigid with fundamental time period of less than 0.25 s and due to less time period and increasing height of the temple, earthquake impact is very high. Also, lack of vertical structural connections is observed because the upper floors are



Fig. 33. Strengthening of walls in first floor.



Fig. 34. Dismantling of top floor.



Fig. 35. Reconstruction of top floor.



Fig. 36. Placing pinnacles on top roof.

resting on timber floors rather than be rested directly on the wall. Depending upon the calculations from the above empirical formula, the provision of high plinths in the tiered temples like in the Nyatapola temple has saved the temple from seismic forces reducing the amplification of the local soil during earthquakes. This is the reason for the limited damage in the fifth tier of the temple during the Bihar Nepal earthquake of 1934 whereas the Bhairavnath temple with a small plinth height located in the same Taumadhi square temple was collapsed to the ground.

Also, the structural system of the multi-tiered temples can be seen in Section 2 of this paper. The relative motion of the movement of walls and roofs may be inconsistent during the earthquake causing cracks and damages to the walls. Insufficient wall plates, wooden pegs make the structure less stiff making it vulnerable to damages in structure. Apart from seismic ties in the form of ring beams at strategic locations, the smaller sizes of the openings in the brick masonry walls are for reducing the action of the seismic forces. The adoption of the double frames for the door and window openings in the walls is to provide the in-plane shear strength against the seismic forces during the earthquake.

Besides, the damages following the earthquake of 2015 are observed due to the aging of materials, deterioration of the materials of construction, and the lack of proper regular maintenance of the structures apart from the structural and seismic zonings. Due to these reasons, the earthquake-resistant of the structure gets substantially diminished, and hence the damages even leading to the collapse. The brick masonry in mud mortar and timber, subjected to the adverse effect of the environment like dry rot and wet rot, which if not taken care of in time leads to serious damage. This situation can be clarified by the situation of structures like Kasthamandap which was least affected by the Nepal Bihar Earthquake of 1934, a much larger earthquake than the one in 2015, and made the pavilion of Kasthamandap collapsed. In contradiction, the 55 Windowed Palace of Bhaktapur Durbar Square and the Degu Taleju Palace of Patan Durbar Square both were found to be the least damaged in the earthquake of 2015 as these structures were recently renovated. This shows the importance of regular monitoring and maintenance to increase the life span of the building.

3. Damages and the rehabilitation after the earthquake

The earthquake has caused extensive damages to houses, temples, palaces, and other monuments. Many temples and monuments including Vatshala temple, Nyatapola temple, Kedarnath temple, Siddhi Laxmi Temple, Tri Bikram Narayan temple, Fasi Dega, Bhairavnath temple along with other temples in the Kathmandu valley have been partially or totally affected. Bhairavnath and Nyatapola temple of Taumadhi Square of

Table 2
Masonry walls in Nyatapola temple.

Floors	Total floor area (sq m)	Total area of wall (sq m)	Wall in %	LxBxH (mXmXm)
Ground floor	79.46	22.71	28.56	6.65 × 6.66 × 3.103
First floor	74.52	52.90	70.99	9.16 × 9.16 × 3.903
Second floor	52.47	29.40	56.03	6.80 × 6.79 × 4.015
Third floor	24.9	15.63	62.77	4.85 × 4.83 × 4.11
Fourth floor	18.13	9.54	52.62	3.39 × 3.39 × 3.11
Fifth floor	5.18	2.89	55.79	1.87 × 1.83 × 3.26

Table 3
Proportion of Nyatapola temple.

Base	Existing Length (m)	Module design	Actual measurement as per module(m)	Error (m)
B1	8.93	15	–	–
B2	6.80	12	7.14	–0.34
B3	4.85	9	5.36	–0.51
B4	3.37	6	3.57	–0.20
B5	1.87	3	1.78	0.09

Table 4
Proportion of Bhairavnath temple.

Length of roofs (m)		Proportion	Length of three core walls(m)		Proportion
Top	12.38	4	Top	7.50	3
Middle	15.62	5	Middle	10.09	4
Bottom	18.42	6	Bottom	12.61	5

Bhaktapur (case studies of this study) are among the main temples of Bhaktapur, which are partially affected in 2015 Gorkha earthquake. Bhairavnath temple was totally collapsed in the 1934 earthquake and damage to the roof was seen in the earthquake 2015 while the Nyatapola temple was partially destroyed with the collapse of the only top roof in the 1934 earthquake and torsional drift of the top roof in the recent earthquake but still standing strong against many earthquakes in last 319 years. This scenario of damages of both temples in the earthquakes of 1934 and 2015 is important to study the reasons for damages and failures and compare it in two different structural configurations (square and rectangular plan base).

3.1. Damages in Bhairavnath Temple and their causes

The 1934 earthquake caused the total collapse of Bhairavnath temple while the Nyatapola in its close vicinity was only partially damaged with the collapse of the top floor. The 2015 Gorkha earthquake also caused partial damage in the Bhairavnath temple. The latest renovation of Bhairavnath temple was carried out in 1995 by Bhaktapur Municipality where the top floor was renovated and the jhingati roofs of north, east, south was replaced by metal sheets. The damaged and decayed wooden members were replaced by the new ones [2,3]. The Gorkha earthquake has caused damages in the top storey with the falling of masonry walls, inclined windows; displacement of joints, and tilting of posts in the top storey. The upright posts were displaced from their original position and were also in tilted condition.

Apart from the damage on the top floor, different kinds of damages like vertical cracks, diagonal cracks, wall and timber frame separations, disrupted wall plates were seen in the Bhairavnath temple on other floors due to the 2015 Gorkha earthquake. Vertical cracks were caused due to short lintel bands, out-of-plane cracks, lack of thorough bands and horizontal bands; separation of the wall, and timber frames due to local wall settlement [5]. The cracks and damages in the temple are shown in Figs. 17–20.

The ground floor of Bhairavnath temple is more viable to dampness due to fewer openings and lack of air circulation on the floor. Openings are only in the form of small holes locally known as *nasa pwa* (small triangular holes for air circulation). So, the wooden members of the floor are likely to be damaged by dampness causing rotting and decay of timber posts and joists (see Fig. 21–23). Besides, the drainage pipe is lacking due to which the holy water offered in the sanctum on the first floor goes directly through an open hole to the ground floor (see Fig. 23).

Thus, the causes of damages in Bhairavnath temple were observed to be dampness, short lintel band, lack of confinement, and local wall settlements.

3.2. Damages in Nyatapola Temple and their causes

Nyatapola temple was one of the partially damaged temples of Bhaktapur in the Gorkha earthquake. The earthquake and aftershocks have caused much more damage to the top part. The previous record of renovation works was during 1998 by Bhaktapur Municipality where the top roof was renovated and damaged parts of struts, tympanum/struts, door brackets were renewed [7]. That might be one of the reasons the temple has the least damage in the recent Gorkha earthquake. A clockwise torsional drift to a maximum value of 3.25° in the top roof and 0.85° in the second roof from the top, 0.29°, and 0.15° in the third and fourth roof relative to base level as shown in Fig. 24 were observed after the earthquake [20]. With the torsional drift observed on this floor, the masonry wall has been shattered out. The top roof has a very heavy load of mud and tiles. When the intermediate structure is a bit lighter, the top roof is heavier and tends to rotate more.

Based on the visual observations and measurements, mostly diagonal cracks and corner cracks could be seen on the surface of the internal walls on the ground and first floors. External walls of the ground floor have diagonal surface cracks due to stress concentration at openings due to shearing and the northern wall moreover seems the most severely affected one. Minor cracks were observed in the structural walls from the first floor onwards. Simultaneously, subsequent cracks could be seen on the facades of the second and third floors which are mostly due to the resulting action of the out-of-plane bending and compression of the dead load above it. The stress concentration at the openings resulted in the diagonal cracks from the corners of such openings. The use of cement mortar can also be seen in the interior walls of the ground floor which may be another reasons for the cracks observed on the ground floor as the use of cement on the masonry structure increases load. A similar case is on the second floor, the third floor. Significant visible damage in the eastern plinth can also be seen with diagonal cracks greater than 3 cm in width due to ground shaking. Damages in the temple are shown in Figs. 25–28.

Nyatapola temple though being the tallest temple, it has lesser damage in the earthquakes of the previous and the recent one. One of the possible reasons for such damages might be the high plinth on which is standing. It has been built over five plinths in the south and four plinths in the remaining three sides. The temples including Nyatapola temple (with a 9 m high plinth) are supported on massive high solid plinths faired comparatively well during the previous earthquakes and the earthquake of 2015. These plinths resisted strong ground shakings [9] and the damping ratio for the plinth with the greatest height was comparatively lower than those with a lower height. The obtained frequency

of the Nyatapola temple from the HVSR method obtained by [9] shows the plinth is highly stiff which helped to reduce the displacement amplitude at the plinth surface.

4. Rehabilitation procedure in Bhairavnath and Nyatapola Temple

The rehabilitation procedure in both of the case studies follows the same process. Following the damages in the 2015 Gorkha earthquake, different studies were carried out by different institutions. The major stakeholders for the rehabilitation of temples and monuments of Bhaktapur are Bhaktapur Municipality and the Department of Archaeology. The rehabilitation procedure is followed by a series of discussions and workshops by Bhaktapur Municipality on the renovation/reconstruction of the temples among the experts of archaeology, history, architects, structural engineers, administration, security officers, and other experts related to the conservation field. After the discussions in the forum, a technical committee was formed in both cases to study and assess the damages caused by the 2015 Gorkha earthquake. This committee is responsible for preparing a condition assessment report based on visual inspection, on-site measurements, photographs, videos, and also studies the previous changes and alterations in the past. The report is submitted to the concerned authorities who are responsible for the rehabilitation works of the temple. The rehabilitation has been carried out through the users' committee with the participation of locals. As heritages are attached to the sentiments of the locals, their direct or indirect participation was observed through donations of money, materials, and labor. Local craftsmen were involved in woodworks and brickworks in both cases except for the metalworks which were done by the craftsmen from Panauti.

4.1. Rehabilitation in Bhairavnath Temple

The rehabilitation approaches started on 18th September 2018. It includes the reconstruction of the top floor and the renovation of the damaged parts of the temple. Since the top floor and roof were severely damaged by the earthquake, the dismantling of the top part was first initiated. With the dismantling of the top roof and floor, walls were rebuilt in the mud mortar with the addition of wooden bracing in the vertical timber posts embedded in the walls as shown in Fig. 29 under the experts' advice. Based on some history-related papers, it is mentioned that the carpenters during those times understood the vulnerability of the multi-tiered structures due to earthquake and hence they developed the construction technology through hit and trial methods and provided additional bracings to vertical and horizontal structural members. The carpenters involved in the last rehabilitation were also incorporated to involve during this rehabilitation to use their expertise and further strengthen the temple. This practice was effective in earthquakes and it prevented floors from sliding during the lateral forces. Moreover, the wooden pegs/*chukuls*, which were insufficient in the existing state of the temple, were also added in the reconstruction. The damaged and fallen parts of the inclined windows on the top floor and decayed wooden parts of the pinnacle were replaced by the new ones as shown in Figs. 30 and 31.

In the lower floors where the reconstruction/renovation is not possible, strengthening measures were applied. Strengthening was done in such places by providing timber frames as shown in Figs. 32 and 33. It was done on the ground floor where the decayed portions of the timber posts and in openings of the sacred cella room on the first floor. The cracks of the ground floor, first floor, second floor, third floor, and fifth floor were grouted. A drainage pipe was added from the sanctum to the ground floor to reduce the dampness effect due to the lack of a drainage system. The woodwork, brickwork carvings were done by the local craftsmen of Bhaktapur and metalwork by the craftsmen of Panauti. Also, as the temple is attached to the sentiments of the locals, the missing parts of the pinnacle of the first roof and a gold plated *dhwaja* (descending metal banners) from the base of the pinnacle from the top roof donated from donors are placed in the temple.

4.2. Rehabilitation in Nyatapola Temple

Since the temple was only partially damaged by the earthquake with major damage in the top roof, the rehabilitation started from dismantling and reconstruction of the top roof and floor (suggested by structural and architectural experts as per condition assessment done by the Technical committee of Khwopa Engineering College/ Khwopa College of Engineering). It is still an ongoing project under Bhaktapur Municipality. Dismantling of the top roof showed the decay of the wooden posts inserted in the top floor. They were replaced with the new ones in the ongoing reconstruction of the top floor. Damaged struts and other wooden members were replaced with new ones. Yellow clay with lustrous properties is being used in the masonry walls as the mortar. The cracks in different parts of the temple were grouted. The woodworks, brickworks were done by the local craftsmen of Bhaktapur. The different phases of dismantling, reconstruction is shown in Figs. 34-36 below;

5. Conclusion and Recommendations

The tiered temples in Nepal have their indigenous construction technology built with the locally available materials of that time with reducing roof size and wall thickness on the upper floor. Different elements of the tiered temples have their role to serve for the structural stability as well as the beautification of the temple. Plinths, thick walls, gradual reduction of the size of the structure in the upper structure, joinery system are the major factors that play an important role in the stability and reduce the damages during the seismic activities. In both cases, the top floor has been affected more by the earthquake. The structural reasons like increasing height, the base of the temple (plinths) on which it stands, insufficient wooden pegs, lack of confinement are also responsible for the level of damage during earthquakes in the multi-tiered temples. Besides, the aging of the temple, lack of proper regular maintenance, and deterioration of construction materials are key factors for the damage of the structure. Therefore, it needs regular monitoring and maintenance works for better seismic performance and increasing the lifespan of the structure. Also, the documentation of the existing conditions and study of the possible causes of damages as carried out in the case studies would be useful for records of damage and changes in the temple. The case studies have documented the existing condition of the temples, the damages caused by the earthquake as well as the changes made in previous times, and the present rehabilitation efforts, which is a good effort for the records for future reference. It is recommended to make it a part of every rehabilitation project to document through photographs, videos, sketches, and drawings, and reports. Moreover, the monuments with regular maintenance and monitoring have shown lesser damage to the structure. It is highly recommended to repair and maintain the superstructure as well as the plinth (which is lacking in most cases) periodically as the load of the superstructure is supported by the plinths. The repair of temples is delicate work. Use of skilled and experienced labor should be employed in the rehabilitation works with proper supervision of engineers, architects, and structural experts. Appropriate tests should be conducted to understand the mechanical properties of the timber, mud, mud masonry as well as geological tests to understand the effects of the location and geology of the site on the monument. Detailed seismic performance analysis of the temple should be carried out not only after the disaster but before the disaster so that the level of damage can be predicted.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Regular Article

Communicating to reduce disaster risk through radio in Nepal: A case study of *Milijuli Nepali* and *Kathamaala*

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ABSTRACT

This paper presents findings from a survey (2018) that examined how radio programming supported people in 14 severely affected districts in Nepal following the 2015 Gorkha earthquake. Results showed that regular listeners of the programmes knew more and were more likely to take actions than non-listeners. Nearly two-thirds (62%) of regular listeners reported that they now know about specific government suggested techniques for earthquake resistant foundations and nearly half (45%) reported using these techniques. Logistic regression suggested that regular listeners were more likely to mention taking actions than non-listeners. However, concerns around financial support for reconstruction remained a key issue.

1. Introduction

Nepal is prone to disasters, including earthquakes. The earthquake of 1934 A. D. is the most devastating earthquake (in recorded history) that occurred in the territory of Nepal with casualties of more than 160,00 people including from Nepal and India put together. Other major earthquakes in the region that affected Nepal included the Assam earthquake of 1897, the Kangra earthquake of 1905, and the Assam earthquake of 1950. The 7.6 magnitude Gorkha earthquake that struck Nepal on 25 April 2015 was the most powerful quake to hit the country in over 80 years. The quake was followed by more than 300 aftershocks in the following days. The Post Disaster Needs Assessment estimated the quakes killed nearly 9000 people and injured at least 22,000 [1]. The assessment estimated that eight million people, almost one-third of the population of Nepal, were affected by the earthquake and aftershocks, which destroyed more than 600,000 homes and damaged more than 288,000 in 14 severely affected districts [Fig. 1]. The strongest impact was in remote rural areas

and in Himalayan villages destroyed by avalanches and landslides, making the response extremely challenging.

People are still recovering from the impact on their families, homes, livelihoods, and communities. The National Reconstruction Authority (NRA) founded in 2015 surveyed 1,037,291 houses in the post-disaster phase and recommended 834,911 eligible for private housing reconstruction and retrofitting grants. Only 61% of those (507,623) had been reconstructed as of October 2020 [2]. Information Needs Assessments (INA)¹ identified that barriers to complete reconstruction and retrofitting include cost, a complex grant system,² and lack of familiarity with earthquake-resistant rebuilding practices.

Media and communication can play a key role in this reconstruction process – and in disaster risk reduction strategies in general – by increasing

Abbreviations: ACORAB, Association of Community Radio Broadcasters; BAN, Broadcasting Association of Nepal; BBC, Media Action; NGOs/INGOs, Non-governmental organization/International non-governmental organization; NRA, National Reconstruction Authority, Nepal.

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¹ BBC Media Action worked with 11 partner radio stations across the 14 earthquake affected districts. The partner radio stations conducted community discussions that included Information Needs Assessment (INA) with affected communities. BBC Media Action research team trained and mentored radio stations' staffs in conducting and analysing INA data and disseminating them across all partner stations. See Fig. 8 for an example. A total of 154 community discussions and INAs were conducted between June 2016 and December 2018. Each community discussion was edited into a 15-min radio programme and broadcast on their channel.

² People who were affected by the earthquake were entitled to receive a government grant to help rebuild their homes. This was provided in three tranches and released to people once NRA engineers had completed a six-point check to ensure the correct construction materials, frames and foundations had been used.

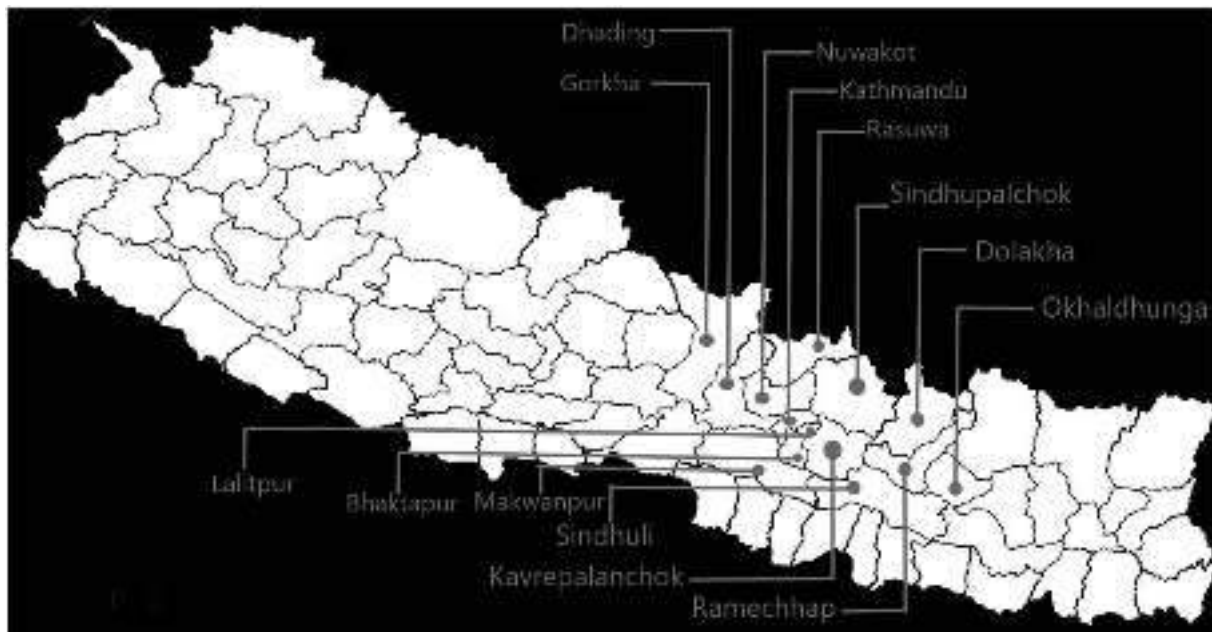


Fig. 1. Fourteen severely affected district of 2015 Gorkha earthquake.

people's understanding of risk, strengthening disaster risk governance, and enhancing disaster preparedness (in this case supporting reconstruction) [10], all of which are priority areas for action under the Sendai Framework.³ Through the exchange of information, advice and opinions between experts and affected populations, people at all levels can make informed decisions and take actions to reduce risk and protect lives and livelihoods. Communicating disaster risk to prompt action can be complex. It requires a sound understanding of people's perceptions [11], concerns and beliefs, their knowledge and practices and the environments in which they live and work. Despite this recognition, there remains a lack of evidence around what works [10].

Media and communication can also play a key role in disaster response by informing and connecting people, prompting discussion and providing psychosocial support [3]. The BBC World Service has a history of using radio to support people directly affected by crises. In 1994 language services ran dedicated programmes for people affected by conflict in the Great Lakes Region and in Afghanistan [3]. Since then, BBC World Service and (since its was established in 1999) BBC Media Action have used radio to respond to disaster and conflict with humanitarian aims [3]. Over the past 10–15 years the humanitarian community has increasingly recognized the importance and need for information to and from people affected [3]. However, these communication initiatives have not been adequately evaluated (or at all in most cases), and there is therefore a lack of systematic learning of what works and what does not [3,10,4].

In light of the lack of impact evaluation of communication to reduce disaster risk and to address humanitarian needs, this evaluative research sought to measure the impact of the two complimentary radio programmes *Milijuli Nepali* and *KathaMaala* on people severely affected by the 2015 Gorkha earthquake in Nepal.

1.1. How BBC Media Action responded in Nepal

Immediately after the earthquake, BBC Media Action launched a Lifeline⁴ radio programme [5], providing humanitarian support on radio

through the BBC Nepali Service and the Association of Community Radio Broadcasters (ACORAB) and the Broadcasting Association of Nepal (BAN), reaching across Nepal including those districts affected by the earthquake. This included information on where to find food, shelter, and water and how people could protect themselves and their loved ones in the immediate aftermath of the disaster [3].

A week later, this Lifeline programme transitioned into a radio magazine⁵ show called *Milijuli Nepali* (Together Nepal), with 15-min episodes broadcast twice a day, six days a week across the entire country as a result of partnerships between the BBC Nepali Service, British Forces Broadcasting Services and 400 other radio stations. This programme reached 12% of Nepalis nationally, reaching a slightly higher population in the earthquake affected districts (14%) [12].⁶ Alongside this factual programme, BBC Media Action also ran a radio drama series titled *KathaMaala* (Garland of Stories). The story followed a milkmaid that went from shelter to shelter sharing information. She retrained as a mason and rebuilds houses in other areas. This drama complimented the factual show by attracting female radio listeners and encouraged female participation in reconstruction process.

From June 2016, the radio programmes began to focus on reconstruction, continued to broadcast nationally on the BBC Nepali Service and Radio Nepal. The programmes also broadcast on 11 local FM radio stations, to provide optimum coverage in in the 14 severely affected districts [Fig. 1].

The programmes aimed to support communities in the earthquake-affected areas of Nepal to live in safer housing and therefore at lower risk of being affected by future earthquakes. To achieve this aim, BBC Media Action set out a theory of Change (ToC) and a clear communication objectives [13] that would increase knowledge on building safer earthquake-resistant houses and motivate affected people and communities to:

³ The Sendai Framework is a 15-year, voluntary, non-binding agreement which recognizes that the State has the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders including local government.

⁴ Lifeline programming is special media programming for communities affected by humanitarian crises. It aims to provide people with timely, relevant and practical information to alleviate their suffering and assist with their recovery. Lifeline programming also aims to give affected people the opportunity to voice their concerns, express their needs, share their stories and hold humanitarian aid providers to account.

⁵ A magazine programme presents a variety of topics in a format that often includes interviews and commentary.

⁶ In December 2015, BBC Media Action conducted a nationally represented survey in 25 districts among 4000 people of Nepal. The main objective of the research was to measure the reach, impact and outcome of BBC Media Action's media programmes in Nepal, focusing mainly on governance and Nepal lifeline earthquake response i.e. *Milijuli Nepali*. Five districts out of those 25 sampled districts were severely affected by the earthquake: Kathmandu, Lalitpur, Sindhupalchowk, Dolakha and Makwanpur. Respondents from affected districts were asked additional questions on *Milijuli Nepali* as well as questions on influence of programme on them. See reference vii for detail methodology of this survey.

- Engage with experts and decision-makers
- Try new building techniques
- Access the government's housing grant schemes
- Take steps to improve their livelihoods and invest in safer rebuilding

The programmes used real-life stories, drama, and advice from experts to provide people with information, role model best practice and highlight the challenges around reconstructing safer homes. The two programmes also aimed to inform and provide examples of alternative livelihoods that people could take up to increase their income to invest in reconstruction and encouraged women to participate more in the livelihood activities and reconstruction processes (such as undertaking mason training).

This research paper shows how BBC Media Action's radio programming supported affected communities and encouraged people to build homes that were more resistant to earthquakes.

2. Methodology

2.1. Research objectives

The main purpose of the study was to assess the impact of the two programmes – *Milijuli Nepali* and *KathaMaala* – on the affected communities. The main objectives of the research were to:

- Measure listenership of and engagement with the two BBC Media Action reconstruction radio programmes: *Milijuli Nepali* and *KathaMaala* in the project target districts
- Understand influence of the programmes on affected people's knowledge around reconstruction issues
- Identify if affected people in the project target districts had taken any action based on the information, they received from the programmes

2.2. Sampling

The research took a quantitative approach with a face-to-face household survey conducted in the 14 severely affected districts in August 2018. The sample size of the survey was 2636. The sample was calculated using the following statistical formula:

$$n = \frac{z^2 \times p(100-p)}{m^2} \times \text{deff} \times \text{nr}$$

Where:

n = required sample size.

z = confidence level at 95% (standard value of 1.96).

p = percent of population who listens to BBC Media Action programme = 12%.

m = margin of error at 15% of p = 1.8.

deff = design effect⁷ = 2.

nr = non response = 5%.

This sample was representative of the population of the 14 districts. A Probability Proportionate to Size (PPS) two stage stratified cluster sampling approach was taken: in the first stage, for each district, urban and rural wards within the district were listed. Municipal wards as per the national census 2011 were used as PSUs (primary sampling units) in both the urban and rural areas in all the districts. In the second stage, to maintain the proportionality of households in each district, a PPS sampling method was used to select PSUs from all selected districts. Fifteen households were randomly selected in each PSU; hence 175 PSUs were selected accounting to the sample size of 2636. One eligible respondent was selected from each household using a Kish Grid. Demographic information on all respondents is shown in Fig. 2.

In addition to this random sample, 400 booster interviews were conducted with purposively selected *Milijuli Nepali* and *KathaMaala* listeners

to provide a robust enough sample size to understand the outcomes of the programmes. This took the total sample to 3036 respondents. The booster sample of 400 people were selected from the same PSUs as the random sample but from different households, and only selected if they had listened to either or both the programmes. The sample was only used in analysis which aimed to examine the impact of programmes on key outcomes such as knowledge, attitudes and practices around reconstruction. Data collection was commissioned to a third-party research agency based in Kathmandu.

2.3. Weighting and analysis

We used SPSS 20 for data analysis. Data (collected through randomly sampled 2636 interviews) was weighted against the 2011 Nepal census proportions to ensure accurate representation of gender, location, and age. Analysis was done in two stages: first, descriptive analysis was undertaken in order to understand the status of people's reconstruction efforts in the 14 districts, people's media consumption, listenership to the programmes and the socio-demographic profile of those listeners e.g. age, gender, education, location etc. Randomly sampled weighted data was used for this first phase analysis to ensure that results were representative of the actual population. Secondly, analysis looked further at the type of engagement audiences had with these two programmes and their influence on key outcomes the project seeks to address such as knowledge and decision making around reconstruction. It used the dataset of 3036 (that included the 400 non-random booster interviews).

To further understand the impact of the programmes on the key outcomes, a range of quantitative analysis methods were undertaken. Inferential analysis and regression modelling were conducted to compare key outcomes i.e. people's knowledge related to reconstruction issues and actions they have taken during reconstructing their houses between those who regularly listen to the programmes and those who did not listen to any of them. Chi-square test was performed along with every cross-tabulation to identify the difference between groups were statistically significant. Only those with significant differences i.e. $p < 0.05$ were reported in this paper. The logistic regression tested the impact of the programmes on audiences while controlling for potential confounding socio-demographic factors in the survey i.e. age, sex, location, region, education, caste and ethnicity, household income, and status with the government private housing grant scheme [6].

3. Results

3.1. Concerns hindering reconstruction

This research sought to understand people's concerns around the reconstruction efforts and the reasons behind them. Respondents reported several issues or concerns affecting or slowing down their effort to reconstruct homes from the beginning of the process. Nearly three quarters (71%) of respondents who were in the process of reconstructing their house or had completed it, mentioned that some of the concerns they had at the beginning of the reconstruction process remained.

One of the main reasons for this slow progress in reconstruction was the lack of financial resources. Of the survey respondents who reported reconstructing their house or having completed it, 89% of them said the main issue affecting progress was the financial obstacle. 85% of them said this concern remained. During the time of the survey, the NRA had been able to complete agreements with 90% of beneficiaries and had disbursed full grants to 41% [6]. However, the total amount given for reconstruction (300,000 Nepali rupees per households) was insufficient to enable completion of reconstruction. Getting a loan from other financial institutions such as banks has always been difficult for affected people and it remained as a concern for some within the survey.

On the other hand, concerns around accessing construction materials and skilled resources such as trained masons or engineers had reduced significantly compared to earlier stages.⁸ For example, one of the major concerns at the early stage of reconstruction was lack of reconstruction

⁷ A design effect (DEFF) is an adjustment made to find a survey sample size, due to a sampling method (e.g. cluster sampling, respondent driven sampling, or stratified sampling) resulting in larger sample sizes (or wider confidence intervals) than you would expect with simple random sampling(SRS). The DEFF tells you the magnitude of these increases. More information on how to calculate design effect can be found here: <https://www.statisticshowto.com/design-effect/>

⁸ The survey asked questions about people's concerns around reconstructions at the early stage reconstruction and their remaining concerns.

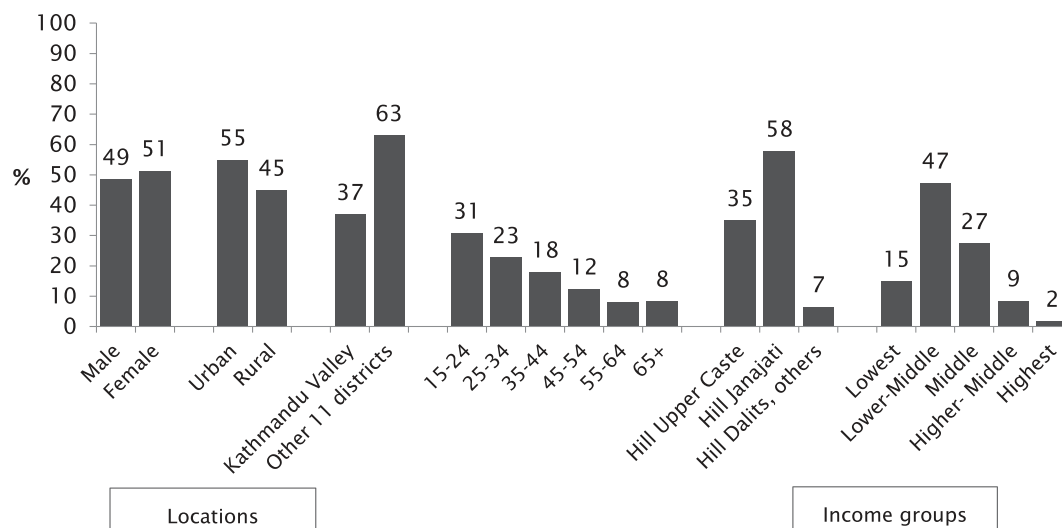


Fig. 2. Demographic Profile of the survey respondents (Base = 2636).

materials (60%) which only 28% of respondents mentioned as a remaining concern. (Fig. 3).

3.2. Information sources on reconstruction

People's remaining concerns may have been affected by the information gap they reported around reconstruction. More than half of the respondents (57%) said that the information they received on reconstruction was not enough to meet their needs. People in their locality were mentioned as a source of information on the reconstruction by the majority of people affected (56%) but only 44% of them said they trust this source a lot. On the other hand, people trusted engineers most (83%) but only 55% mentioned using them as a source of information. Surprisingly, very few respondents mentioned using the two most important stakeholders in the reconstruction process as their sources of information: the government and the NGOs/INGOs, despite the majority of respondents trusting those sources a lot. (Fig. 4).

3.3. Communication through radio

Historically radio has been the dominant media platform in mountainous Nepal. As the topography makes it hard for national frequencies to reach certain parts of the country, particularly Himalayan districts, hundreds of local FM radio stations proliferate. There were an estimated 450 functioning local community and commercial FM radio stations in the

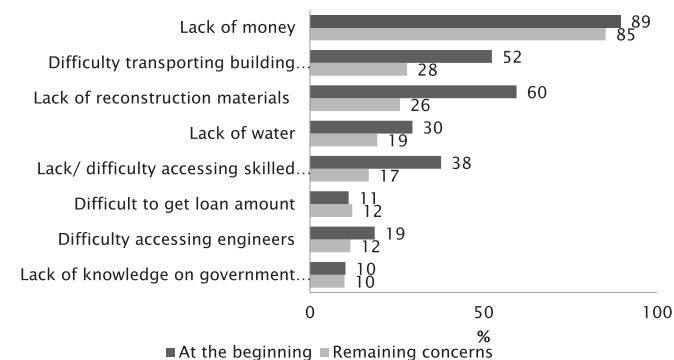


Fig. 3. Main concerns during reconstruction*. Base: All those reported reconstructing houses or had completed (n = 2049), and those reported having remaining concerns (n = 1444).

*Multiple response questions - percentages for both scenarios sum to more than 100 as respondents could identify more than one concern.

country in 2016, covering most of the districts. In the aftermath of the 2015 Gorkha earthquake, when most people in the affected communities lost access to electricity, radio was the only way to communicate lifesaving information to them. It remains an effective way of reaching people with important information. However, access to mobile phone and TV has increased over the past decade [6] and TV has become dominant media platform in many parts of Nepal (Fig. 5).

3.4. Audiences

Milijuli Nepali and *KathaMaala* are two of the most popular radio programmes among those that address reconstruction issues (Table 1). The survey found that 21% of people in the 14 severely affected districts, an estimated 747,257 people listened to either or both *Milijuli Nepali* and/or *KathaMaala* in the previous 12 months from the survey. The overwhelming majority of listeners (70%) listened to at least one of these programmes regularly i.e. at least twice a month.

These two programmes attracted a significant proportion of women and lower caste people in these districts. 46% of the listeners were female, and 50% were from Janajati and Adibasi caste groups. As expected, given the

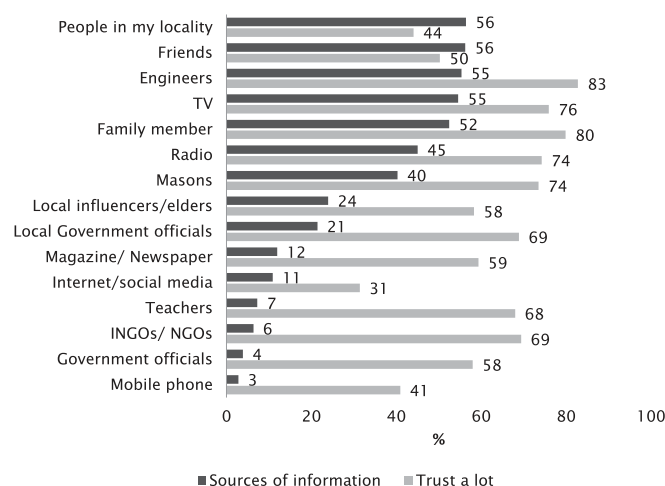


Fig. 4. Sources of information on reconstruction and trust on the sources (Base = 2636)*.

Base: 2636 *Multiple response questions - percentages for both scenarios sum to more than 100.

*Multiple response questions - percentages sum to more than 100.

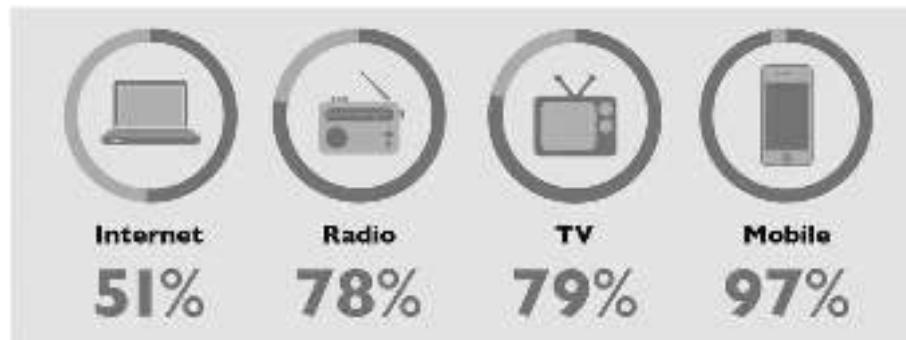


Fig. 5. Media access among earthquake-affected communities (Base = 2636).

Table 1

Media programmes in Nepal that addressed reconstruction issues after 2015 earthquake (Base = 2636).

Programmes address reconstruction issues	Broadcast media platform	Listened in the past 12 months
Baliyo Ghar (Strong House)	TV and radio	29%
Milijuli Nepali & KathaMaala	Radio only	21%
Surakchit Gharbas (Safe Housing)	TV and radio	20%
Mannabta Ko Lagi Hatelmalo (Joining hands for humanity)	Radio only	11%
Bipat Sarokar (Disaster affairs)	Radio only	9%

target audience, the majority of the listeners were from rural areas (59%) and more than three-quarters (78%) were from the districts outside of the Kathmandu Valley. (Fig. 6).

The access to radio varied between different demographic groups. This varied access is one of the influencing factors of varying reach among different groups. Men and people living in rural areas listen to radio more than women and urban dwellers (Fig. 7). The same pattern is reflected in the *Milijuli Nepali* and *KathaMaala* audience profile. Similarly, Hill upper cast and Dalits reported listening to radio more than Janjati and Adivasi (Fig. 7). This is reflected in the audience profile too: 41% hill upper caste respondents reported listening to the programmes as opposed to 35% in the sample, and 9% Dalits listened to the programme as opposed to 7% in the sample.

TV is the most widely accessed form of media in Kathmandu Valley with 98% participants reported having access to TV compared to only 61% of those from outside the valley. Similarly, internet is more accessible in the valley too with 73% compared to 39% from those outside of the valley. Therefore, people living in the Kathmandu valley clearly have other means to access information than radio. Similar patterns have also been observed among audience of similar radio programmes to *Milijuli Nepalai*. For example, listenership of *Surakchit Gharbas* was 47% women and 7% Dalit.

3.5. Radio programmes' influence on knowledge

Nearly all (99%) of respondents recognized the importance of having a safe house, and almost all of them felt it was important in order to save lives in case of a disaster (97%). There were long-term motivations too, such as avoiding financial losses in future and making sure that the house was resistant to future earthquakes. Regular listeners⁹ of *Milijuli Nepali* and *KathaMaala* mentioned these long-term benefits more than those who did not listen to the programmes. 61% of regular listeners mentioned building safe housing is important to ensure the house is earthquake resistant (compared to 49% non-listeners) and 53% said they wanted to avoid financial losses in future (compared to 44% non-listeners). This indicates the programmes perhaps influenced their knowledge around long-term benefits. Results from logistic regression also suggested that the regular listeners

of the programmes were 1.6 times (and 1.3 times) more likely to mention both of these long-term motivational factors compared to those who did not listen to any of the programmes (See Regression 1 & 2 in annex 2). However, people who already believed building safe houses was important and wanted to do so might more likely to listen to a programming about building safe houses.

Affected people in the 14 districts were also aware about different sources of help for reconstruction. More than half of the respondents mentioned engineers (62%) and local authorities (59%), and nearly a half (48%) mentioned masons as people to help with reconstruction work. Regular listeners were more aware of contacting local government and skilled resources (i.e. masons and engineers) for relevant information and advice for their reconstruction work than those did not listen to the programmes (Table 2).

A much smaller proportion of people, both listeners and non-listeners, mentioned I/NGOs as sources of support for reconstruction (Table 2). People generally had very low trust of INGOs following the earthquake and most of the reconstruction activities were managed by local government bodies [7]. Banks were an important part of the grants process but only 10% mentioned them as a place to go for support in reconstruction.

3.5.1. Radio programmes' influences on reconstruction awareness

The survey also measured people's knowledge of the actions they could take to reconstruct their homes. The majority of the respondents (59%) said they were aware of using earthquake resistant techniques endorsed by skilled resources i.e. masons and engineers and using quality construction materials that were available locally (53%). Nearly half (48%) of the respondents said they were aware of the specific techniques to make their houses strong and durable such as using vertical, horizontal, and bracing frames, through stones (locally known as *Kaichi Dunga*) etc. (Table 3). Many of these techniques were included in the NRA-approved earthquake resistant building code and were followed by the trained masons and engineers.

People who had been listening to *Milijuli Nepali* or *KathaMaala*, reported knowing about more actions people should take during reconstruction of their houses compared to those who did not listen to either of the two programmes. For example, 62% of regular listeners reported knowing about specific techniques like vertical, horizontal, and bracing frames, and *Khaichi Dunga* compared to 43% non-listeners of the programmes. (Table 3).

It should be noted, however, that affected people in the study areas have strong financial motivation to learn about and use these techniques in their reconstruction work. To make progress on rebuilding and to receive the second and third tranches of the government's private housing grant, homeowners are required to ensure they follow earthquake resistant building codes. NRA engineers scrutinize six key items while inspecting every stage of the grant process and those include construction materials, frame, foundation etc. Thus, 57% of those who are the beneficiary of the government's grants scheme reported knowing about specific techniques like vertical, horizontal and bracing frames and *Kaichi Dunga* compared to just 33% of those who were not a beneficiary. Nonetheless, results from logistic regression show that whether they were beneficiaries or not, regular listeners of *Milijuli Nepali* or *KathaMaala* were 1.3 times more likely to know

⁹ Those who listened to *Milijuli Nepali* and/or *KathaMaala* at least twice a month.

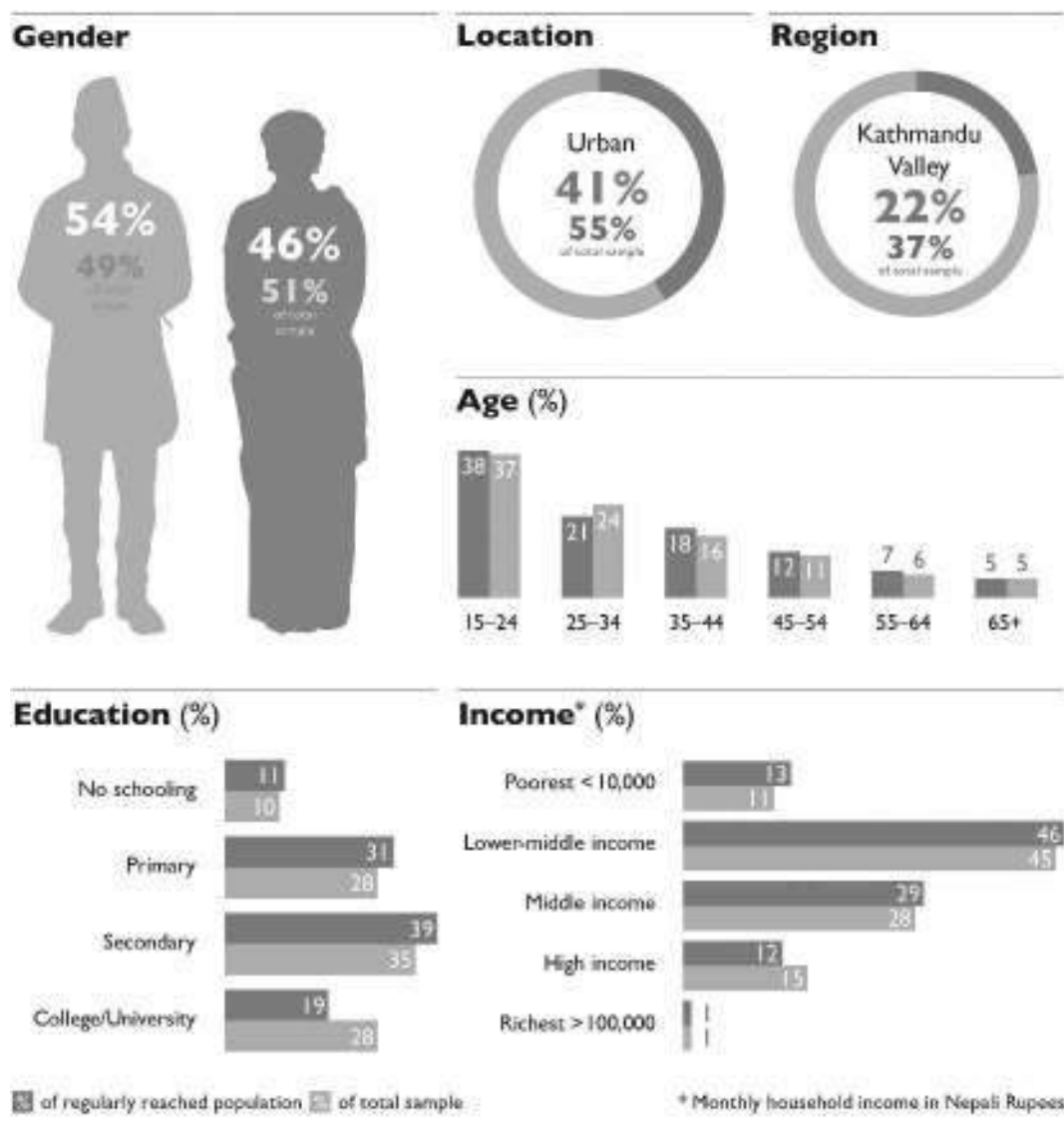


Fig. 6. Demographic profile of BBC Media Action's reconstruction radio programmes' audiences.
Base: Those who listen to Milijuli Nepali or KathaMaala in the 12 months from survey ($n = 560$).

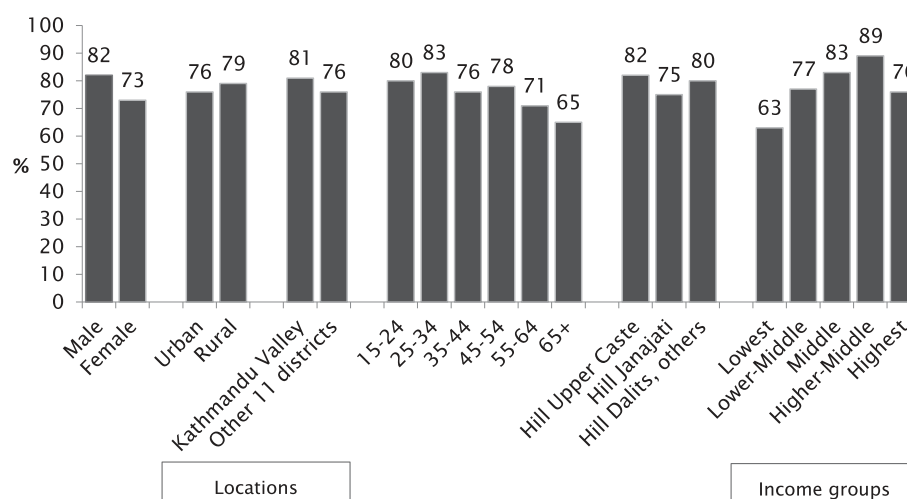


Fig. 7. Demographic profile of radio listeners in affected communities. Base: Those have access to radio ($n = 2044$).

Table 2Sources of help and support on reconstruction (Base = 3036)^a.

Q: Where do you think people can go to get help for rebuilding their houses?	All (%)	Regularly listened to Milijuli Nepali or KathaMaala (%)	Did not listen to Milijuli Nepali and KathaMaala (%)
Engineers	62	69	59
Local authority	59	71	53
Masons	48	55	44
I/NGOs	12	16	10

^a Base included 400 booster sample; Multiple response question – percentage sum to more than 100.

about four or more actions that people could take during reconstruction of their houses than non-listeners (see Regression 3 in Annex 2).

Awareness of both male and female masons and using female masons in reconstruction activities was also higher among regular listeners of the programmes. 22% of regular listeners mentioned accessing and using women masons compared to 19% of those who did not listen to these programmes. Logistic regression also showed regular listeners of *Milijuli Nepali* or *KathaMaala* programmes are 1.6 times more likely to know about using women masons compared to those who did not listen to the programmes. (See Regression 4 in Annex 2).

3.6. Radio programmes' influence on action

Milijuli Nepali and *KathaMaala* influenced people's decisions around technical aspects of reconstruction. Among listeners, nearly two thirds of listeners (65%) reported that their decisions around reconstruction were influenced by the programmes. Regular listeners of *Milijuli Nepali* and *KathaMaala* reported taking actions more than non-listeners. For example, 38% reported using construction techniques endorsed by engineers, and 34% used vertical, horizontal, and bracing frames. Other actions they reported taking during their reconstruction work include using skilled resources like masons, and using earthquake resilient techniques advised by them, and taking mason training to change their livelihoods. However, *Milijuli Nepali* and *KathaMaala* regular listeners were more likely to report

taking these actions than those who did not listen to the programmes. For example, 45% of the regular listeners of *Milijuli Nepali* or *KathaMaala* reported following specific techniques like using vertical, horizontal and bracing frames, maintain a safe level (as advised by engineers) of windows and doors and *Kaichi Dunga* in their house reconstruction compared to 28% of non-listeners. (Table 4).

These topics (using locally available materials, trained masons, taking up mason training and following specific earthquake proof techniques like foundations, fortifying the house with lintels and bends, keeping roofs lighter, having the same level of windows and doors etc.) were key issues covered in *Milijuli Nepali* and *KathaMaala*. Since using these earthquake-resistant techniques and advised materials are pre-conditions to progress through the NRA grant process beneficiaries reported taking these actions more than those who were not receiving grants from the government. For example, 45% of those receiving grants reported using vertical, horizontal, and bracing frame, safe level of windows and *Kaichi Dunga* compared to only 9% of those not receiving grants. However, logistic regression found that regular listeners were 1.4 times more likely to report taking six or more specific actions related to reconstruction of their house compared to non-listeners irrespective of whether they were a grant beneficiary or not (See Regression 5 in annex 2).

Almost half of the listeners (49%) reported taking an action or doing things differently after listening to the programmes. This includes using trained masons or female masons along with technical actions. Initially, when BBC Media Action had conducted Information Needs Assessments (INA) together with local partner stations, people raised their concerns that they lacked trust in newly trained masons. Thus, both *Milijuli Nepali* and *KathaMaala* programmes tried to build trust in the masons in various ways, such as by providing information on how trained masons could help, how to identify a trained mason, sharing real life stories of house owners using masons and benefiting from it etc. 14% of listeners reported using a trained mason or a trained female mason after listening to the programmes (Table 5). Regression results also found that regular listeners were 1.3 times more likely to access and use trained masons (including women masons), use semi-skilled masons under direct supervision of trained masons, use techniques and raw materials suggested by masons,

Table 3Knowledge of actions people can take on reconstruction (Base = 3036)^a.

Q: What can, or should people do while reconstructing their houses?	All (%)	Regularly listened to Milijuli Nepali or KathaMaala (%)	Did not listen to Milijuli Nepali and KathaMaala (%)
Used techniques endorsed by engineers	59	64	58
Using or reusing local materials	53	62	50
Following specific techniques such as vertical, horizontal, and bracing frames (Nas), safe level of windows and doors, and <i>Kaichi Dunga</i> etc.	48	62	43
Take mason training	33	36	32
Rotate trained mason (alopalo) for building house	22	25	21
Approached local government for information	20	24	19
Accessed or used trained women masons	20	22	19
Frequently visited or contacted with local authorities	14	17	13

^a Base included 400 booster sample; Multiple response question – percentage sum to more than 100.

Table 4Actions taken while reconstructing houses (Base = 3036)^a.

Q: Which actions did you take while reconstructing your houses?	All (%)	Regularly listened to Milijuli Nepali or KathaMaala (%)	Did not listen to Milijuli Nepali and KathaMaala (%)
Used techniques endorsed by engineers	38	45	34
Bought construction materials from the neighbouring/ local areas	36	39	34
Used or reused local materials	34	44	29
Following specific techniques such as vertical, horizontal, and bracing frames (Nas), safe level of windows and doors, and <i>Kaichi Dunga</i> etc	34	45	28
Took up mason training	11	13	10

^a Base included 400 booster sample; Multiple response question – percentage sum to more than 100.

Table 5

Listeners took action after listening to *Milijuli Nepali* or *KathaMaala*. Base: Those who listen to *Milijuli Nepali* or *KathaMaala* in the 12 months from survey (n = 1060)^a.

Q: What actions have you or your family taken after listening to <i>Milijuli Nepali</i> or <i>KathaMaala</i> ?	<i>Milijuli Nepali</i> or <i>KathaMaala</i> listeners (%)
Used techniques endorsed by engineers	35
Using or reusing local materials	29
Helped each other	27
Used trained masons or women masons	14
Approached for government's financial support i.e. grants	13

^a Base included 400 booster sample.

and take mason training compared to non-listeners (See Regression 6 in Annex 2).

3.7. Programmes' influence on self-efficacy

Listeners reported higher self-efficacy than non-listeners in managing the reconstruction process. People in the 14 districts were generally confident in dealing with issues around reconstruction. Most of the respondents agreed that they knew and felt confident about receiving grants, accessing information and local resources, contributing to a discussion regarding reconstruction and providing technical suggestions. This self-reported confidence was reported more by the regular listeners of *Milijuli Nepali* or *KathaMaala* compared to those who did not listen to the programmes. 94% of regular listeners of the programmes reported feeling confident to go into the process to receive private housing reconstruction grants compared to 80% non-listeners. Similarly, 77% said they could make suggestions to community people on the technical areas of house construction compared to 62% of non-listeners. (Table 6).

3.8. Programmes' influence on changing or adopting livelihood

Neither *Milijuli Nepali* nor *KathaMaala* focused heavily on diversification of livelihoods although there was some focus on encouraging people (especially women) to undertake mason training. For example, in *Milijuli Nepali*, the programme followed stories of a group of masons

who travelled across communities and supported people in rebuilding, and who had trained specifically in this role since the earthquake. The programme also showcased stories of women diversifying their income through selling vegetables or taking a lead role in reconstruction in the absence of male members in the household. In the drama series *KathaMaala*, the central character Maala changed her profession after the earthquake. Maala, who was a milk maid, trained herself as mason and started helping people in rebuilding their houses. Whereas the programmes have had a greater impact on motivating people to take action around specific techniques related to reconstructing their home, they were less successful at motivating people to take up or diversify their livelihood, arguably a more difficult action to take. Nearly one third (32%) of the respondents reported having made a change to their livelihood due to reconstruction. These changes included taking mason training, applying new techniques in agriculture or increasing the number of livestock. Regular listeners of *Milijuli Nepali* or *KathaMaala* reported changing or adopting their livelihood significantly more than those who did not listen to either of these programmes. For example, 14% of regular listeners reported taking up mason training compared to only 7% of non-listeners (Table 7). Thus, the programmes partially met their expectations in encouraging women to take up these livelihood options and many female respondents reported doing so alongside men.

4. Discussion: factors that helped in achieving these results

4.1. Developing and adapting the communication strategy to changing audience needs

Communicating risk is complex. Designing and executing media programmes that prompt people to understand risk and to take decisions and actions accordingly requires a carefully considered communication strategy that reflects a clear understanding of the complexity of people's lives – what spurs them to change the way they do things and what may prevent them from doing so. If communication activities are to prompt people to act, they must be engaging, trustworthy and appeal to the changing needs and specific preferences of the audience. To get these things right, it is important to conduct regular research, collaborate with a wide range of partners, and if producing through local media providers, strengthen

Table 6

Confidence in dealing with issues around reconstruction (Base = 3036)^a

Q: How much do you agree or disagree with the following statements?	Agreed (%)	Regularly listened to <i>Milijuli Nepali</i> or <i>Kathamaala</i> (%)	Did not listen to <i>Milijuli Nepali</i> and <i>Kathamaala</i> (%)
I know all the steps to follow to receive the grants	85	94	81
I feel confident to go into the process to receive the grants	84	94	80
I can access local resources required for safe construction	93	95	92
I can access all the information I require for safe construction	90	95	87
I feel I can contribute in the discussion regarding reconstruction in my community	79	89	73
I can make suggestions on some of the technical areas of house construction to others	67	77	62

^a Base included 400 buster sample; Multiple response question – percentage sum to more than 100.

Table 7

Changes made to livelihoods due to reconstruction (Base = 2660)^a

Q: What changes have you or your family members made to your/their livelihood due to reconstruction?	All (%)	Regularly listened to <i>Milijuli Nepali</i> or <i>Kathamaala</i> (%)	Did not listen to <i>Milijuli Nepali</i> and <i>Kathamaala</i> (%)
	Base: 2660	Base: 2442	
Increased the number of livestock/cattle	9	11	8
Adopted new techniques of agriculture	6	11	4
Started a new business	7	8	6
Changed their job	8	10	6
Took a mason training	9	14	7
Took training to generate more income	5	8	3

^a Base includes those responded to this questions only.



Fig. 8. A graphical presentation of findings from community needs assessments in Dhading districts.

their capacities. Although the programmes launched in an emergency context, BBC Media Action spent considerable time understanding what would help audiences make decisions and act on them. Continuous Information Needs Assessments with the affected communities provided useful insights regarding their changing needs, and the programmes were tailored accordingly. [13].

One year after the earthquakes, as people's needs moved from recovery to reconstruction, so did the focus of the radio programmes. *Milijuli Nepali* began sharing information on how to construct earthquake-resistant housing. As outlined in Fig. 8, affected people had specific barriers to access information on grants and technical issues of rebuilding houses. Access to skilled resources like trained masons and engineers were barriers too. The programme featured experts (i.e. engineers and trained masons) discussing and offering solutions to issues raised by affected people from different communities. It re-visited communities to monitor their progress (Fig. 8).

KathaMaala presented its central character Maala in a new occupation, having trained as a mason. This change not only encouraged people to use trained masons in their house reconstruction but also inspired other women to take up masonry as a profession.

4.2. Delivering creative and entertaining content to hold audiences' attention

Both *Milijuli Nepali* and *KathaMaala* kept audiences at the centre of programming and featured characters and individuals that audiences could identify with.

The magazine show *Milijuli Nepali* travelled to affected areas and brought the voices of local people and communities into the show, alongside experts, to discuss and advise on solutions, issues and concerns raised. The show followed up with communities to ascertain their progress. It included entertaining content such as music and poetry from affected people

[This conversation between presenter of *Milijuli Nepali* and two trained masons demonstrate how the programme used simple language to give technical information about foundation of houses.]

00:00 Mason 1: The walls have been tied together in such a way inside-out, that if there is a tremor, it shakes in its entirety, instead of crumbling.

00:12 Presenter: Because this stone helps to tie the internal and external walls together. This is called ‘*Chhadh*’ in some places. Some called it ‘*Garho Badeko*’.

00:21 Mason 1: Some call it ‘*Karuwa Dhunga*’ or ‘*Paitalish*’.

00:23 Presenter: What happens when we use such techniques?

00:24 Mason 1: If we use this technique, it makes the wall stronger. If you look carefully, you will see that the vertical stones are placed against the horizontal stones, so as to tie up the internal and external walls. When it reaches a certain height, DPC (damp proof concrete) would also help to tie it up. This is basically used for the walls to be stable.

00:36 Presenter: What is the thickness of the wall?

00:38 Mason 1: 18 inches

00:40 Presenter: The stone used here in this 18-inch wall stretches from the internal wall to the external wall.

00:43 Mason 1: Yes! (laughs) It is almost 25 inches (laughs)

00:47 Mason 2: We built the houses by tying up the wall. We call it ‘*Paitalish Dhunga*’. Some called it ‘*Kaichi Dhunga*’. If we use such techniques, then the house will be strong. We have used the techniques in many houses. The houses, where we did not use this technique, now have cracks in them. During the training, we were taught to keep such stones at a distance of every two feet.

Fig. 9. Transcript of a *Milijuli Nepali* episode explaining earthquake-resistant foundation technique locally known as *Kaichi Dunga* or *Paitalish*.

or listeners. These efforts kept the audience engaged over more than four years– the *Milijuli Nepali* audience increased from 15% in 2016 to 20% in 2019 in the severely affected districts [12].

The programmes also attracted listeners from diverse backgrounds: nearly half (46%) of the listeners were women, nearly eight in 10 listeners (78%) were from 11 districts outside of the Kathmandu valley, and nearly six in 10 (59%) were from rural areas and from the caste and ethnic groups not labelled as higher hill castes.

It should be noted that the programme content was informed by formative research partnerships and discussions with civil society, experts, and the Nepali government who were consulted widely when making all programmes.

4.3. Storytelling and role modelling to give people confidence to take action

At the beginning of the reconstruction phase, many people raised concerns in audience needs assessments that they lacked trust in newly trained masons. To address this issue, the drama series *KathaMaala* introduced a mason through its central female character *Maala*, who trained as a mason and encouraged listeners to follow her example to train as well as to seek support from trained masons. *Milijuli Nepali* also discussed the importance of seeking advice and support from skilled masons and engineers when reconstructing houses. The presenter used metaphors to make these technical aspects simple and comprehensible for listeners and helped listeners visualise these techniques. The programme brought stories of people ‘like them’ taking action and trying things that might otherwise seem awkward or difficult. This research found that the programmes helped to build people’s trust in masons. Other research has shown that well-known and trusted figures increased acceptance of information provided on the radio during responses to the Ebola epidemic in West Africa between 2014 and 2016 [8].

The results showed that listeners were more likely to feel confident about applying for government grants compared to non-listeners (94% vs. 80%), and felt they could contribute in discussions regarding safe reconstruction in their communities (89% vs. 73%). Listening to community leaders and experts on the radio, people gained trust in authorities and response teams, and gained confidence in their own individual ability to cope and recover from the crisis [9].

4.4. Using simple and clear language to facilitate understanding of building techniques

Both programmes used language that was easy for the audience to understand, particularly regarding explanations of technical NRA-mandated techniques and other earthquake-resistant techniques (Fig. 9). Some episodes of *Milijuli Nepali* focused on different technical aspects of construction, such as how to create strong foundations, how to strengthen houses with lintels and the importance of keeping roofs lighter. The presenter used metaphors to ensure these technical aspects were easy to understand and helped listeners visualise them. The programme also featured experts and engineers to explain these techniques in precise, yet clear, terms.

Listeners were especially engaged with parts of the programmes that provided technical information on rebuilding their homes. People who were affected by the earthquake were entitled to receive a government grant to help rebuild their homes. This was provided in three tranches and released to people once NRA engineers had completed a six-point check to ensure the correct construction materials, frames and foundations had been used. As discussed above, analysis found that listeners were more likely than non-listeners to know about actions and to take more actions around rebuilding correctly, even when controlling for other factors.

5. Conclusion

This research provides evidence that people in the 14 severely affected districts have benefited from the trusted and relevant information provided in *Milijuli Nepali* and *KathaMaala*. It provides evidence that these two programmes have affected the way people understand earthquake risk in relation to housing and what they do about it.

The programmes have made earthquake affected people aware of where and how to access information and financial support for reconstruction, and informed them about earthquake-resistant building techniques, locally available materials, and skilled service providers, such as masons and engineers. In addition, the programmes have been successful at motivating people to make important decisions related to their reconstruction work and at prompting them to take concrete action that will contribute to risk reduction and building safer housing.

Role modelling good practices through a diverse range of real-life stories and drama and allowing ordinary people to tell their own stories in an engaging way were effective at building knowledge and self-efficacy. Audiences recognized themselves in these stories and identified with the situations. The success of these programmes was also contingent on adapting programming according to people's changing needs at different stages of the reconstruction process.

This paper has brought to light that lack of evaluative data and evidence of impact from similar disaster risk reduction and recovery programmes on the radio has effectively reduced the scope to compare results of this study with others.

However, evidence gathered through a comprehensive review of research papers covering the use or impact of humanitarian radio in several large-scale emergencies has demonstrated that radio programmes were effective at influencing positive behaviours for coping in emergencies. The authors of that review predicted 'no reason to doubt' that radio programmes in emergencies would not create the same positive effect [4]. However, drawing such conclusion based on the robust evaluative results or empirical data may not be possible in the future as Hannides [3] rightly mentioned "evaluations that are considered 'robust'" face multiple practical challenges in a crisis.

Annex 1: Questions asked in the survey

- Do you (or your family) consider yourself affected by the 2015 (2072) earthquake?
- After the earthquake and till now, in what ways did the earthquake affect you?
- How did the government classify your house during the damage assessment?
- What is the status of your house now?
- Are/ were you a beneficiary for the government grant? How many tranches of government grant you have received so far for building your house?
- What were your main concerns at the beginning stages of the reconstruction? Do you still have any of these concerns?
- What are remaining concerns you have related to reconstruction of your home?
- What has been the impact of having to reconstruct or renovate your home?
- What changes have you or your family members made to your livelihoods due to reconstruction?
- Besides the changes mentioned above, are any changes you or your family members made to your livelihoods due to reconstruction?
- What can/ should people do while reconstructing / renovating their house?
- Are there any other ways that people should do while reconstructing their house in terms of using building materials, using different techniques of building house, mason, government information? (What actions can be taken?) Out of these, which action you have done?
- Where do you think people can go to get help for rebuilding their houses?
- How important do you think building safe house is? Why building safe house is important?
- Over the last 1 year, do you think your knowledge on the following have increased, remained same, or decreased?
- What are your main sources of information for reconstruction? How much trust do you have on these sources of information on reconstruction?
- Do you feel you have the information you need to access reconstruction support?
- To what extent does information in the media has influenced your ability to make decision on rebuilding your house?
- Are you aware of any programme on radio and TV about reconstruction?
- Which of these programmes did you listen in the past 12 months? When did you last listened to Milijuli Nepali and Kathamala?
- How often do you listen to Milijuli Nepali, Kathamala and Local discussion programme?
- Has Milijuli Nepali or Kathamaala influenced any decisions you have taken around reconstruction? If Yes, which decisions were influenced?

6. Implications for future media and communication interventions

Develop disaster risk communication strategies based on research and evidence	Conduct early and regular research, work with partners, and adapt programming accordingly. Future programming should continue to not only provide people with trustworthy and relevant information, but encouragement and support through effective role modelling and storytelling – especially reinforcing women's roles in the overall recovery process.
Support to develop livelihoods and to access financial services	DRR programmes for low-income audiences could support people more effectively by including discussion of how to increase their incomes, develop their livelihoods, access financial services, and manage money wisely in order to invest in reconstruction and retrofitting.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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- Have you or your family taken any action/done things differently after listening to Milijuli Nepali or Kathamala, to deal with issues on reconstruction? If Yes, what actions/changes have you/your family made/done?

Annex 2: Tables of logistic regression

Regression modelling was conducted to compare key outcomes i.e. people's knowledge related to reconstruction issues and actions they have taken during reconstructing their houses between those regularly listening to the programmes and those did not listen any of them. The logistic regression tested the impact of the programmes on audiences while controlling for potential confounding socio-demographic factors i.e. age, sex, location, region, education, caste and ethnicity, and household income as well as their beneficiary status with the government private housing grant scheme.

Regression 1: Knowledge of benefit of reconstruction (To avoid financial losses and damage) by regular listeners of Milijuli Nepali and/or KathaMaala.								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
Regular audience	0.243	0.088	7.586	1	0.006	1.275	1.072	1.515
AGE			3.491	5	0.625			
15–24	0.179	0.180	0.996	1	0.318	1.197	0.841	1.702
25–34	0.150	0.159	0.895	1	0.344	1.162	0.851	1.586
35–44	0.258	0.151	2.919	1	0.088	1.294	0.963	1.740
45–54	0.090	0.148	0.366	1	0.545	1.094	0.818	1.462
55–64	0.150	0.153	0.968	1	0.325	1.162	0.861	1.569
RURAL	0.394	0.172	5.219	1	0.022	1.482	1.058	2.077
SEX Male	0.034	0.081	0.179	1	0.672	1.035	0.883	1.213
REGION Kathmandu	0.369	0.190	3.774	1	0.052	1.447	0.997	2.100
EDUCATION			13.042	3	0.005			
No schooling	–0.591	0.169	12.213	1	0.000	0.554	0.397	0.771
Primary-5 years edu	–0.468	0.143	10.631	1	0.001	0.626	0.473	0.830
Secondary-10 years edu	–0.372	0.140	7.093	1	0.008	0.690	0.525	0.907
CASTE			6.134	2	0.047			
Hill upper castes	–0.158	0.159	0.980	1	0.322	0.854	0.625	1.167
Hill Adibasi/Janajati groups	–0.307	0.151	4.158	1	0.041	0.735	0.547	0.988
HOUSEHOLD INCOME			0.415	3	0.937			
Poorest >10,000	0.057	0.180	0.102	1	0.749	1.059	0.745	1.506
Lower-MiddleIncome group 10,000 to 20,000	0.092	0.163	0.319	1	0.572	1.096	0.797	1.509
MiddleIncome group <20,000 to 40,000	0.057	0.172	0.110	1	0.740	1.059	0.756	1.482
Constant	–0.163	0.321	0.259	1	0.611	0.849		

The reference categories for this model are Not reached by Milijuli Nepalis and KathaMaala, Age 65 + , urban, female, other regions, College&Uni education, Hill Dalits, Modeshi & others, and High income group. The model had an Cox & Snell R Square value of 0.019.

Regression 2: Knowledge of benefit of reconstruction (To build durable, strong earthquake resilient house) by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
Regular audience	0.469	0.089	27.520	1	0.000	1.599	1.342	1.905
AGE			4.695	5	0.454			
15–24	–0.345	0.181	3.642	1	0.056	0.708	0.497	1.009
25–34	–0.147	0.159	0.855	1	0.355	0.863	0.632	1.179
35–44	–0.209	0.152	1.899	1	0.168	0.811	0.603	1.092
45–54	–0.235	0.148	2.519	1	0.112	0.790	0.591	1.057
55–64	–0.152	0.153	0.979	1	0.322	0.859	0.636	1.160
RURAL	0.004	0.170	0.001	1	0.982	1.004	0.720	1.400
SEX Male	0.079	0.081	0.946	1	0.331	1.082	0.923	1.270
REGION Kathmandu	0.502	0.190	6.981	1	0.008	1.651	1.138	2.396
EDUCATION			18.384	3	0.000			
No schooling	–0.444	0.170	6.813	1	0.009	0.642	0.460	0.895
Primary-5 years edu	–0.040	0.144	0.079	1	0.779	0.960	0.724	1.274
Secondary-10 years edu	0.105	0.141	0.557	1	0.456	1.111	0.843	1.465
CASTE			1.054	2	0.590			
Hill upper castes	0.156	0.161	0.943	1	0.331	1.169	0.853	1.603
Hill Adibasi/Janajati groups	0.099	0.152	0.423	1	0.516	1.104	0.819	1.488
HOUSEHOLD INCOME			3.282	3	0.350			

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Regression 2: Knowledge of benefit of reconstruction (To build durable, strong earthquake resilient house) by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
Poorest >10,000	− 0.330	0.183	3.241	1	0.072	0.719	0.502	1.030
Lower-MiddleIncome group 10,000 to 20,000	− 0.268	0.167	2.568	1	0.109	0.765	0.552	1.062
MiddleIncome group <20,000 to 40,000	− 0.258	0.176	2.144	1	0.143	0.773	0.547	1.091
Constant	0.287	0.323	0.793	1	0.373	1.333		

The reference categories for this model are Not reached by Milijuli Nepalis and KathaMaala, Age 65 + , urban, female, other regions, College&Uni education, Hill Dalits, Modeshi & others, and High income group. The model had an Cox & Snell R Square value of 0.034.

Regression 3: Knowledge of actions by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
Regular audience of MiliJuli Nepali and/or KathaMaala	0.294	0.090	10.767	1	0.001	1.342	1.126	1.600
AGE			12.985	5	0.024			
15–24	− 0.352	0.185	3.637	1	0.057	0.703	0.490	1.010
25–34	− 0.368	0.164	5.053	1	0.025	0.692	0.502	0.954
35–44	− 0.046	0.154	0.089	1	0.766	0.955	0.706	1.292
45–54	0.032	0.150	0.044	1	0.834	1.032	0.768	1.386
55–64	− 0.110	0.157	0.489	1	0.484	0.896	0.659	1.219
RURAL	− 0.403	0.170	5.615	1	0.018	0.668	0.479	0.933
SEX Male	0.080	0.083	0.924	1	0.336	1.083	0.920	1.275
REGION Kathmandu	− 0.038	0.189	0.041	1	0.839	0.962	0.664	1.394
EDUCATION			17.417	3	0.001			
No schooling	− 0.630	0.173	13.196	1	0.000	0.533	0.379	0.748
Primary-5 years edu	− 0.293	0.145	4.050	1	0.044	0.746	0.561	0.992
Secondary-10 years edu	− 0.084	0.141	0.357	1	0.550	0.919	0.698	1.211
CASTE			11.657	2	0.003			
Hill upper castes	− 0.530	0.161	10.828	1	0.001	0.588	0.429	0.807
Hill Adibasi/Janajati groups	− 0.496	0.152	10.664	1	0.001	0.609	0.452	0.820
HOUSEHOLD INCOME			5.526	3	0.137			
Poorest >10,000	0.289	0.186	2.427	1	0.119	1.336	0.928	1.922
Lower-MiddleIncome group 10,000 to 20,000	0.334	0.168	3.932	1	0.047	1.396	1.004	1.942
MiddleIncome group <20,000 to 40,000	0.159	0.177	0.801	1	0.371	1.172	0.828	1.659
Constant	0.395	0.325	1.477	1	0.224	1.485		

The reference categories for this model are Not reached by Milijuli Nepalis and KathaMaala, Age 65 + , urban, female, other regions, College&Uni education, Hill Dalits, Modeshi & others, and High income group. The model had an Cox & Snell R Square value of 0.025.

Regression 4: Knowledge of accessing and using skilled and trained masons by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
Regular audience of MiliJuli Nepali and/or KathaMaala	0.465	0.138	11.345	1	0.001	1.591	1.214	2.086
AGE			6.095	5	0.297			
15–24	− 0.508	0.313	2.635	1	0.105	0.602	0.326	1.111
25–34	− 0.173	0.266	0.422	1	0.516	0.841	0.499	1.417

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Regression 4: Knowledge of accessing and using skilled and trained masons by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
35–44	0.038	0.248	0.024	1	0.877	1.039	0.640	1.688
45–54	0.049	0.242	0.041	1	0.839	1.050	0.653	1.689
55–64	0.080	0.251	0.101	1	0.750	1.083	0.663	1.771
RURAL	–0.309	0.259	1.417	1	0.234	0.735	0.442	1.221
SEX Male	0.005	0.133	0.001	1	0.971	1.005	0.774	1.305
REGION Kathmandu	0.039	0.288	0.018	1	0.892	1.040	0.592	1.827
EDUCATION			0.895	3	0.827			
No schooling	–0.078	0.273	0.082	1	0.775	0.925	0.541	1.579
Primary-5 years edu	–0.069	0.229	0.092	1	0.762	0.933	0.595	1.462
Secondary-10 years edu	0.090	0.221	0.165	1	0.685	1.094	0.710	1.685
CASTE			11.174	2	0.004			
Hill upper castes	–0.691	0.225	9.409	1	0.002	0.501	0.322	0.779
Hill Adibasi/Janajati groups	–0.680	0.210	10.487	1	0.001	0.507	0.336	0.765
HOUSEHOLD INCOME			5.770	3	0.123			
Poorest >10,000	–0.623	0.272	5.240	1	0.022	0.537	0.315	0.914
Lower-MiddleIncome group 10,000 to 20,000	–0.394	0.233	2.875	1	0.090	0.674	0.427	1.063
MiddleIncome group <20,000 to 40,000	–0.261	0.245	1.139	1	0.286	0.770	0.477	1.244
Constant	–0.976	0.481	4.108	1	0.043	0.377		

The reference categories for this model are Not reached by Milijuli Nepali and KathaMaala, Age 65 + , urban, female, other regions, College&Uni education, Hill Dalits, Modeshi & others, and High income group. The model had an Cox & Snell R Square value of 0.014.

Regression 5: Action taken to reconstruct house by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2789								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
Regular audience of MiliJuli Nepali and/or KathaMaala	0.332	0.106	9.788	1	0.002	1.393	1.132	1.715
AGE			12.602	5	0.027			
15–24	0.040	0.230	0.030	1	0.863	1.041	0.662	1.635
25–34	–0.070	0.208	0.113	1	0.736	0.932	0.620	1.402
35–44	0.032	0.198	0.026	1	0.872	1.033	0.701	1.522
45–54	0.403	0.189	4.546	1	0.033	1.496	1.033	2.166
55–64	0.289	0.198	2.132	1	0.144	1.335	0.906	1.969
RURAL	0.098	0.228	0.183	1	0.668	1.103	0.705	1.724
SEX Male	0.047	0.103	0.207	1	0.649	1.048	0.857	1.282
REGION Kathmandu	–2.682	0.459	34.168	1	0.000	0.068	0.028	0.168
EDUCATION			2.775	3	0.428			
No schooling	–0.347	0.219	2.512	1	0.113	0.707	0.460	1.086
Primary-5 years edu	–0.174	0.185	0.884	1	0.347	0.841	0.585	1.207
Secondary-10 years edu	–0.163	0.181	0.810	1	0.368	0.850	0.596	1.212
CASTE			7.270	2	0.026			
Hill upper castes	–0.330	0.184	3.226	1	0.072	0.719	0.502	1.031
Hill Adibasi/Janajati groups	–0.454	0.173	6.909	1	0.009	0.635	0.453	0.891
HOUSEHOLD INCOME			1.131	3	0.770			
Poorest >10,000	0.181	0.243	0.554	1	0.457	1.198	0.745	1.927
Lower-MiddleIncome group 10,000 to 20,000	0.230	0.224	1.059	1	0.303	1.259	0.812	1.952
MiddleIncome group <20,000 to 40,000	0.208	0.237	0.767	1	0.381	1.231	0.773	1.960
Constant	–1.234	0.417	8.737	1	0.003	0.291		

The reference categories for this model are Not reached by Milijuli Nepali and KathaMaala, Age 65 + , urban, female, other regions, College&Uni education, Hill Dalits, Modeshi & others, and High income group. The model had an Cox & Snell R Square value of 0.054.

Regression 6: Using masons by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
Regularly reached	0.273	0.101	7.283	1	0.007	1.314	1.078	1.602
AGE			8.534	5	0.129			
15–24	–0.118	0.201	0.346	1	0.556	0.889	0.600	1.317
25–34	–0.358	0.174	4.249	1	0.039	0.699	0.497	0.983

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Regression 6: Using masons by regular listeners of Milijuli Nepali and/or KathaMaala								
N = 2791								
Variables	Unstandardized Coefficients		Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
	B	S.E.					Lower	Upper
35–44	– 0.057	0.167	0.114	1	0.735	0.945	0.681	1.312
45–54	– 0.054	0.163	0.108	1	0.742	0.948	0.688	1.305
55–64	0.022	0.169	0.017	1	0.898	1.022	0.733	1.424
RURAL	0.381	0.175	4.742	1	0.029	1.464	1.039	2.063
SEX Male	0.010	0.090	0.012	1	0.913	1.010	0.847	1.204
REGION Kathmandu	– 1.123	0.193	33.914	1	0.000	0.325	0.223	0.475
EDUCATION			8.596	3	0.035			
No schooling	– 0.444	0.186	5.695	1	0.017	0.642	0.446	0.924
Primary-5 years edu	– 0.129	0.159	0.657	1	0.418	0.879	0.643	1.201
Secondary-10 years edu	– 0.116	0.155	0.562	1	0.453	0.890	0.657	1.207
CASTE			0.919	2	0.632			
Hill upper castes	– 0.043	0.181	0.055	1	0.814	0.958	0.672	1.366
Hill Adibasi/Janajati groups	– 0.117	0.171	0.467	1	0.494	0.890	0.637	1.244
HOUSEHOLD INCOME			4.294	3	0.231			
Poorest >10,000	0.258	0.198	1.702	1	0.192	1.294	0.879	1.907
Lower-MiddleIncome group 10,000 to 20,000	0.041	0.177	0.054	1	0.816	1.042	0.736	1.476
MiddleIncome group <20,000 to 40,000	0.159	0.188	0.713	1	0.398	1.172	0.811	1.693
Constant	0.838	0.348	5.804	1	0.016	2.312		

The reference categories for this model are Not reached by Milijuli Nepali and KathaMaala, Age 65 + , urban, female, other regions, College&Uni education, Hill Dalits, Modeshi & others, and High income group. The model had an Cox & Snell R Square value of 0.064.

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Regular Article

Seismic hazard assessment of the Kathmandu Valley and its adjoining region using a segment of the main Himalayan Thrust as a source

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ABSTRACT

An attempt has been made to evaluate seismic hazard in the Kathmandu Valley and its adjoining region. A segment of the Main Himalayan Thrust, which produced the 2015 Gorkha Earthquake is used as an earthquake source. Two rupture models of the source are utilized assigning unequal weight to estimate seismic hazard. The first model considers entire north-south rupture of the source that is similar to the rupture of the 1934 Bihar-Nepal Earthquake (Mw 8.2). The second model considers the northern-half rupture of the source, which is similar to that of the 2015 Gorkha Earthquake (Mw 7.8) and possibly the 1833 Nepal Earthquake (Mw 7.6).

Seismic hazard maps are prepared for 500 and 200 year return periods at engineering rock site condition. A comparison is made between the peak ground acceleration (PGA) of Kathmandu and Nijgadh estimated for 200 year return period with the recorded PGA of the 2015 Gorkha Earthquake in Kathmandu (Kirtipur: a rock site) and empirically estimated PGA of that earthquake in Nijgadh respectively. Kathmandu and Nijgadh are selected for the comparison because Kathmandu falls within the rupture area of the 2015 Gorkha Earthquake and Nijgadh is in the Indogangetic Plain and away from the rupture area of that earthquake. The result shows that the PGA (0.23 g) estimated for Kathmandu for 200 year return period closely agrees with the instrumentally recorded PGA of the 2015 Gorkha Earthquake in Kathmandu (0.25 g). Instrumentally recorded PGA is not available in Nijgadh, which is at about 55 km in the south from Kathmandu. A seismic intensity survey was carried out in Nijgadh and its adjoining region to estimate the intensity of the 2015 Gorkha Earthquake in Nijgadh. The probabilistically estimated PGA (0.1 g) for Nijgadh for 200 year return period is in reasonable agreement with that of the 2015 Gorkha Earthquake (0.07 g) estimated from the seismic intensity (VI on MMI).

1. Introduction

Nepal is situated in the central part of the Himalaya, which is one of the seismically most active zones in the world. Earthquakes in the Himalaya result from the cyclic release of elastic stress accumulating continuously at a rate of about 2 cm a year (e. g. [3,6,25]).

The Main Himalayan Thrust (MHT) is the major source of seismic hazard in Nepal (e. g. [36]). During interseismic period, stress energy accumulates along the Himalaya in the form of straining of the upper part of the crust. This energy is released when the accumulated stress exceeds the rock strength. There are two schools of thought regarding the size of earthquake sources in the Himalaya. One school considers very large earthquakes may occur (e. g. [3,8,27,44,45]) similar to the 2004 Indonesia Earthquake (Mw 9.0). The other school disagrees with the possibility of such large earthquakes and advocates the possibility of earthquakes smaller than Mw 9.0 adopting the major source of seismic hazard (MHT) is segmented into several segments (e. g. [51]; Gahalaut and Arora [21], [11,17,20,24,30,42]). This work is undertaken assuming very large

earthquakes may not occur in the Himalaya because seismicity pattern as well as geomorphic features along and across the Himalaya exhibit lateral variation, which possibly are boundaries of potential earthquake sources.

Nepal has witnessed several mega-quakes, with magnitude above 8, and thousands of smaller earthquakes. The Kathmandu Valley has been reportedly destroyed several times by destructive earthquakes (Table 1) in the past [15]. The 2015 Mw 7.8 Gorkha Earthquake is the most recent destructive event in Nepal, which killed about 8979 (www.drrportal.gov.np) people and injured hundreds of thousands. Small earthquakes (Mw < 4.0) occur every day but they are not strong enough to cause loss of lives and property. Great (Mw ≥ 8.0) as well as major (8.0 > Mw > 7.0) earthquakes occur infrequently but can have a tragic impact on people and society as a whole. Earthquakes cannot be predicted reliably; therefore proper assessment of seismic hazard is important. Such assessment provides information, which is required in construction practices, national level planning, national level policy making, and insurance policies and so on.

Seismic hazard of Nepal has been investigated by several researchers and institutions. The first one of such study was carried out for the Nepal

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Table 1

Historical earthquakes, which reportedly destroyed the Kathmandu Valley and adjoining region [15].

Date	Latitude (N)	Longitude (E)	Magnitude	Intensity (MMI) in Kathmandu
1255	–	–	–	X
1408	–	–	–	X
1681	–	–	–	IX
1810	–	–	–	IX
1833	28°	85°	7	X
1833	27°	85°	7	IX
1833	27°	84°	7	VIII
1866	27.7°	85.3°	7	X
1934	26.5°	86.5°	8.3	IX-X

Table 2

Ground motion parameters (PGA) estimated in previous studies. The PGA values correspond to 500 year return period at engineering rock site condition.

Author	PGA (g)	
	Kathmandu	Nijgadh
NBC-1905 (2020 revision)	0.38	0.4
GSHAP [22]	0.4	0.3
Pandey et al. [35]	0.3	0.1
Thapa and Wang [49]	0.5	0.3
Stevens et al. [46]	0.55	0.4

National Building Code [33]. Similarly, Global Seismic Hazard Assessment Program [22], Department of Mines and Geology and other researchers ([35,46,49] have studied seismic hazard in Nepal. The peak ground accelerations (PGAs) from these studies do not agree among themselves, which range between 0.3 g and 0.55 g in the Kathmandu Valley and between 0.1 and 0.4 in Nijgadh (Table 2).

The differences in the results possibly resulted from different maximum potential magnitude of earthquake sources, recurrence parameters and a little from subsurface geometry of the sources.

The above mentioned works have considered the complete rupture of the earthquake sources from the MHT. We have a recent evidence of partial rupture of earthquake source (MHT) as demonstrated by the 2015 Gorkha Earthquake [4] and possibly the 1833 North-Kathmandu Earthquake [7]. This study has been undertaken to incorporate earthquakes produced by the partial rupture of MHT in addition to large earthquakes caused by its complete rupture so that the result would be more representative to the real situations.

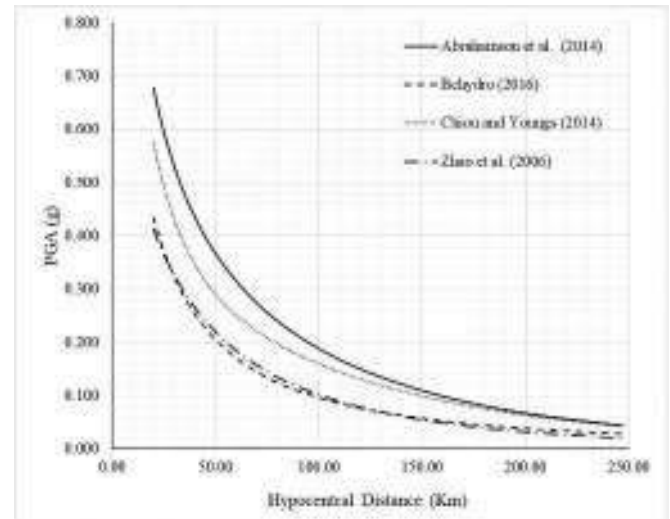


Fig. 2. Attenuation curves of the attenuation relations used in this study. The attenuation curves belong to Mw 8 earthquake at a hypocentral distance of 20 km.

A comparison is made between probabilistically estimated PGA (corresponding to 200 year return period) at engineering rock site condition, in Kathmandu (85.27° E, 27.68° N) and in Nijgadh (85.15° E, 27.18° N), which are separated by a distance of about 55 km. Kathmandu falls within the rupture area of the 2015 Gorkha Earthquake, whereas Nijgadh is away from it. It should be noted that the 1833 Nepal Earthquake and 2015 Gorkha Earthquake are interpreted to have ruptured approximately the same area [4,30], which are separated by 182 years in time.

Geologically, the Kathmandu valley is located in the Midland Zone of the Lesser Himalaya [56], and is bounded by the Mahabharat Lekh in the south and the Shivapuri Lekh in the north. The basement of the Kathmandu basin is interpreted to be a huge nappe (Kathmandu Nappe) formed by thrusting along Mahabharat Thrust (MT), probably the southward extension of the Main Central Thrust (MCT) [47]. It is made up of the Precambrian Bhimphedi Group and Paleozoic Phulchoki Group [47]. The Kathmandu valley is filled in with young fluvio-lacustrine sediments of Pliocene to Quaternary age [54]. The maximum depth to bedrock is more than 500 m at the middle of the basin. Nijgadh is in the northern part of the Indogangetic Plain.

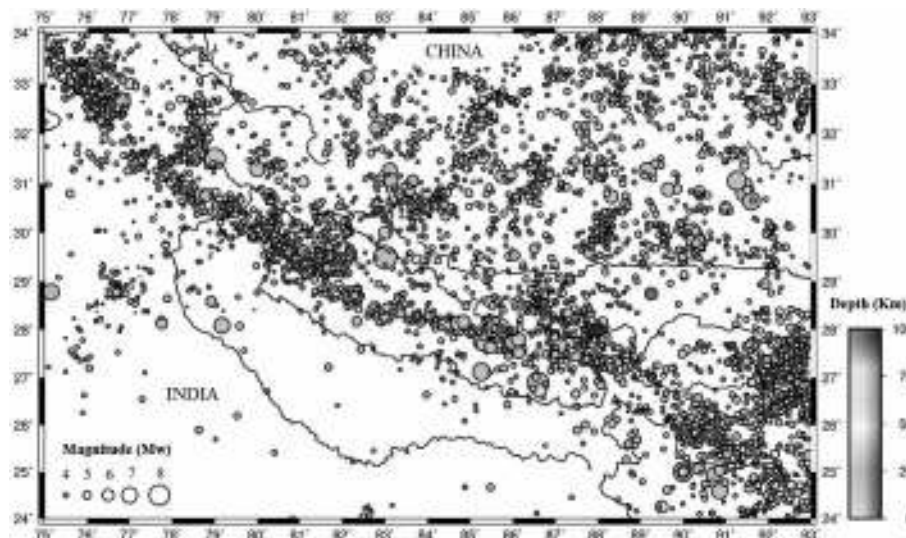


Fig. 1. Epicentral distribution of the earthquake catalogue (Modified from [37]).

Table 3

Characteristics of the attenuation relations utilized in this study. The unit 'g' is acceleration due to gravity (9.8 m/s^2).

Attenuation relation	Tectonic region	Magnitude range (Mw)	Spectral range (s)	Distance range (Km)	Type of distance metric	Unit
Abrahamson et al. [1]	Active-shallow crustal	3–8.5	0–10	0–300	Rrup	g
Chiou and Youngs [14]		3.5–8	0–10	0–300	Rrup	g
Zhao et al. [55]	Subduction	5–8.3	0–5	0–300	Rrup	Cm/s^2
BcHydro [5]		6–8.4	0–10	10–300	Rrup	g

2. Required data and methodology

A magnitude-homogenized earthquake catalogue is required in seismic hazard assessment to identify potential earthquake sources and to derive earthquake recurrence parameters. In this study, we have used the earthquake catalogue prepared by Rajaure & Paudel [37] (Fig. 1). The catalogue contains information of earthquakes (Origin date, origin time, latitude, longitude, depth and magnitude) with magnitudes between Mw 4 and Mw 8.5, since the last 900 years (since 1100 AD).

A locally established attenuation relation, also called ground motion prediction equation (GMPE), is preferred in any seismic hazard assessment, but such a relation is not available to the date for Nepal. There are several attenuation relations established in different types of tectonic regions; however which model fits best the local attenuation conditions is unknown.

Therefore, two attenuation relations Zhao et al. 2006 [55] and [57] (hereafter called BcHydro) [5] from subduction zone and two (Abrahamson et al. [1]) and Chiou and Youngs [14]) from active shallow crustal (reverse) earthquake region (Fig. 2, Table 3) are selected in the present study.

This study utilizes probabilistic technique to evaluate seismic hazard. The technique is based largely on the work by Cornell [16], which estimates the rate of exceedance of some ground motion levels, generally expressed in terms of peak ground acceleration or peak spectral acceleration [29]. It provides a framework in which the uncertainties can be identified, quantified and incorporated to provide a better image of the seismic hazard. The R-CRISIS software developed by [34] was used to estimate PGA at 20 km spacing in the region.

The Main Himalayan Thrust is the major source of seismic hazard in Nepal (e. g. [36,46]), which separates the overriding Eurasian Plate from

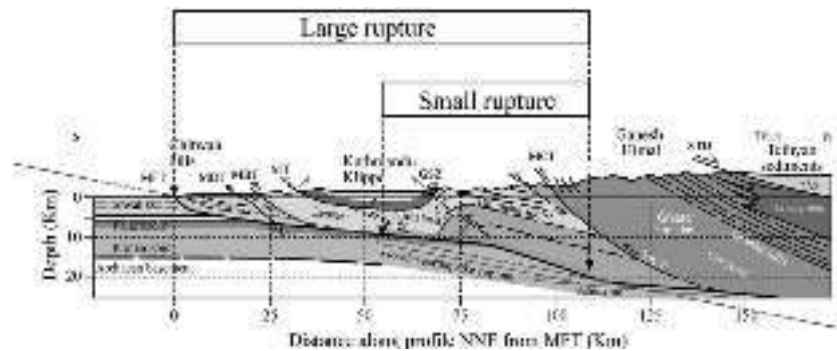


Fig. 3. Schematic cross section across the Himalaya at the longitude of Kathmandu (Redrawn from [19]). The broken blue line represents the sectional view of the simplified geometry of the MHT. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

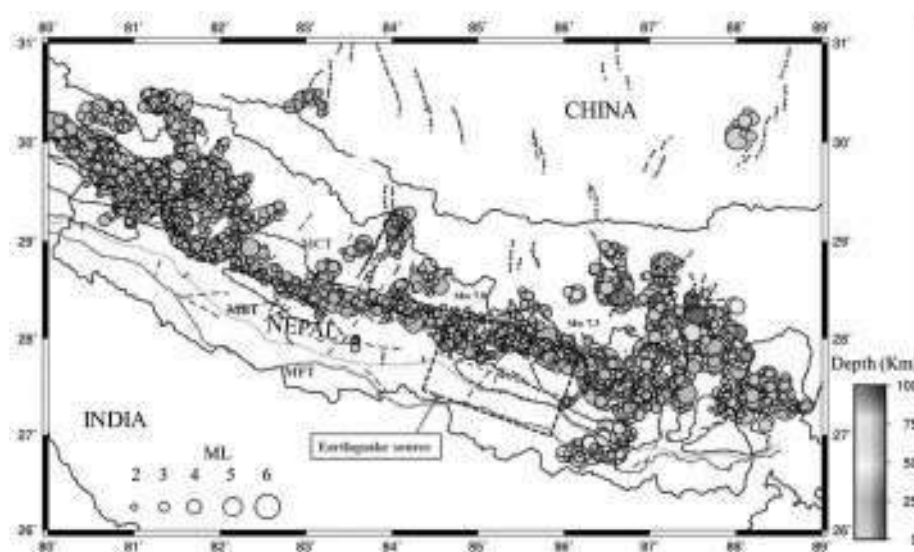


Fig. 4. Surface projection of the earthquake source (broken blue rectangle), the partial rupture of which produced the 2015 Gorkha Earthquake. The red broken line is the southern boundary of the 2015 Gorkha Earthquake rupture. The seismicity depicted is modified from [39]. The MCT, MBT and MFT stand for Main Central Thrust, Main Boundary Thrust and Main Frontal Thrust respectively. The two red stars in the NW and NE corner of the source stand for the location of Mw 7.8 and Mw 7.3 earthquakes which occurred in 2015. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

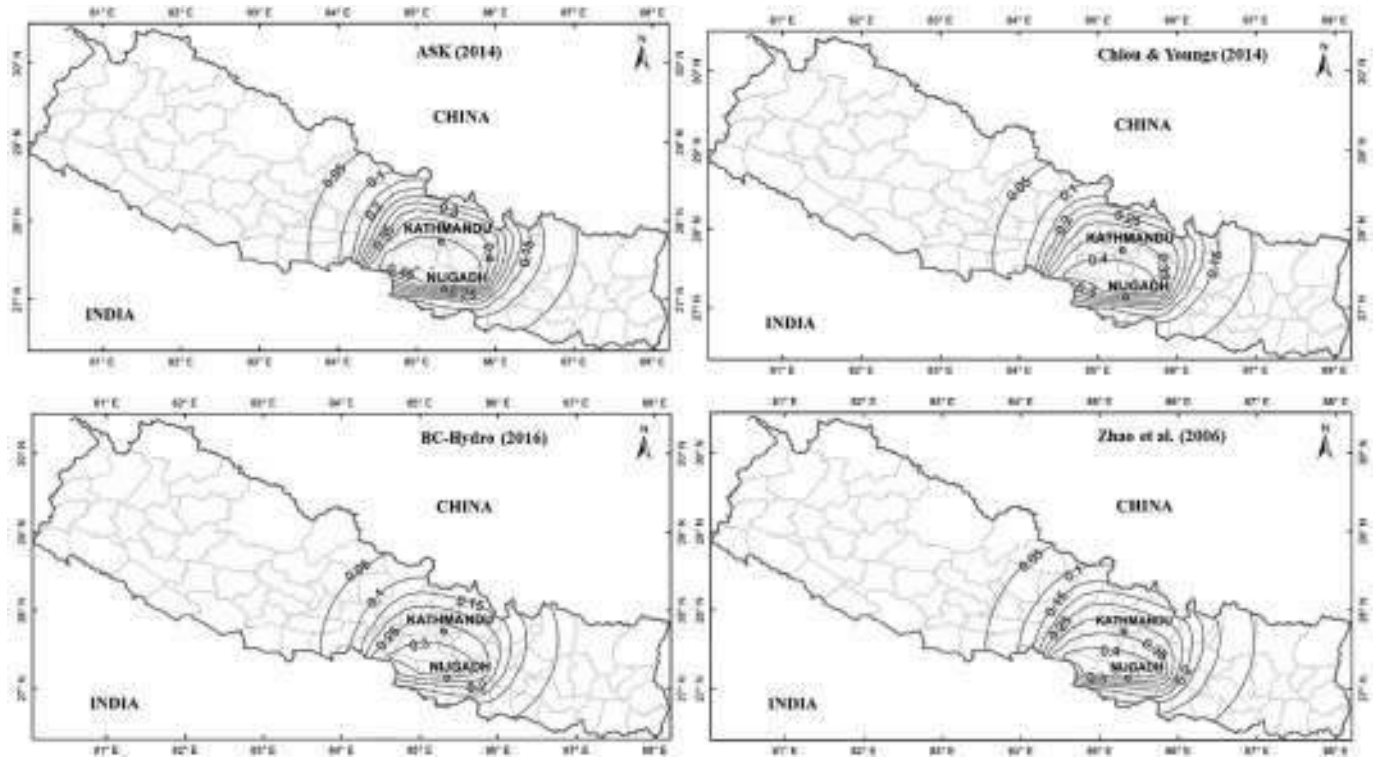


Fig. 5. Seismic hazard in Kathmandu and the adjoining region for 500 year return period. The hazard is estimated for engineering rock site conditions using four different attenuation relations and the large rupture model (Model 1) similar to that of the 1934 Bihar-Nepal earthquake.

the underthrusting Indian Plate [31,32]. A segment of the Main Himalayan Thrust (MHT) (Fig. 3), which comprises the source area of the 2015 Gorkha Earthquake (Fig. 4) has been adopted as a source. The source encompasses a region between the epicentral area of the 2015 Gorkha Earthquake (M_w 7.8) and the 2015 Dolakha Earthquake (M_w 7.3) in the west and east respectively and extends up to the Main Frontal Thrust (MFT) in the south. The source is treated as a three dimensional plane, which emerges to the surface along the MFT, in the south, and dips towards north reaching a depth of about 20 km in the north, beyond which the MHT creeps aseismically (e. g. [10,35,41]).

Two rupture models (Fig. 3) of the adopted earthquake source (Fig. 4) have been envisaged to represent the entire north-south rupture (hereafter called Model 1) similar to that of the 1934 Bihar-Nepal earthquake [40] and that of the 2015 Gorkha Earthquake [4] (hereafter called Model 2). Sapkota et al. [40] claim that they found the rupture of the Bihar-Nepal Earthquake in paleoseismic trenching at Sir Khola in Mahottari District, however Wesnousky et al. [53] do not agree to this claim.

Earthquake recurrence parameters ('a' and 'b' values in Eq. (1)) and the maximum potential magnitude of the source are required in seismic hazard assessment. The 'a' and 'b' values are constants in the Eq. (1), which is called Gutenberg-Richter relation [23].

$$\log(N_M) = a - b * M \quad (1)$$

where N_M is the annual rate of earthquakes having magnitude equal to or larger than magnitude (M). 'a' and 'b' are constants called 'a value' and 'b value' respectively. The factor 'b' describes the relative number of large and small earthquakes. It is important because it is used to quantify seismic activity and seismic hazard. For active tectonic region the 'a' value is about 1 and for volcanic region it is 2.5 (e. g. [28]) or higher. The 'a' value represents the total activity of earthquakes in the region considered.

In this study, we adopted the 'b' value (0.95) estimated by Rajaure and Paudel [37] for Himalayan region. Using this 'b' value, the 'a' value of the source is calculated from the earthquake catalogue using Eq. (2).

This equation can be rearranged as:

$$a = \log(N_M) + b * M \quad (2)$$

Earthquakes smaller than M_w 5.0 do not cause significant damage [26]; therefore it is adopted as a threshold earthquake (M_{min}). The annual recurrence rate (λ) of M_{min} of the source is calculated rearranging Eq. (1) and applying the 'a' and 'b' values to Eq. (3).

$$\lambda = 10^{(a - b * M_{min})} \quad (3)$$

The maximum potential magnitudes of the two rupture models were estimated empirically from the area of the rupture models in Eq. (4) [52]. The area of the large rupture (Model 1) is about 16,000 km^2 and that of the Model 2 is about 8000 km^2 . The maximum potential magnitude of the Model 1 is about M_w 8.1 and that of Model 2 is about M_w 7.8.

$$M_u = 4.33 + 0.95 * \log(A) \quad (\sigma_{M_u} = 0.25) \quad (4)$$

where ' M_u ' is maximum potential magnitude, 'A' is the area of the source in square kilometers and σ_{M_u} is the standard deviation.

The accelerometers operating in the Kathmandu Valley recorded the ground acceleration of the Gorkha Earthquake (e. g. [38,48]). One of the

Table 4

Peak ground acceleration estimated for 500 year and 200 year return period in Kathmandu and Nijgad using entire north-south rupture (Model 1) of the source.

Attenuation relation	PGA (g)			
	Kathmandu		Nijgad	
	500 year	200 year	500 year	200 year
Abrahamson et al. [1]	0.45	0.27	0.46	0.21
Chiou & Youngs [14]	0.37	0.22	0.38	0.2
Zhao et al. [55]	0.33	0.2	0.45	0.23
BcHydro [5]	0.26	0.13	0.3	0.15

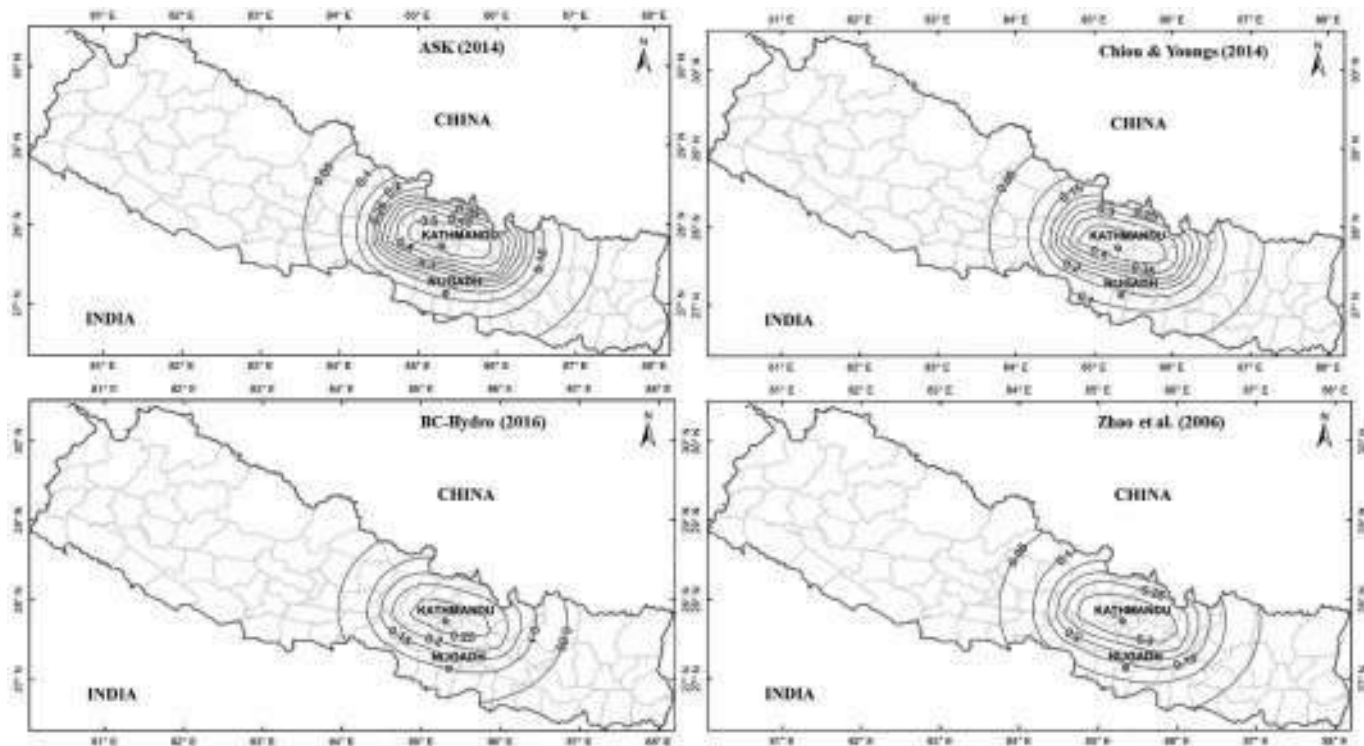


Fig. 6. Seismic hazard in Kathmandu and the adjoining region for 500 year return period. The hazard is estimated for engineering rock site conditions using four different attenuation relations and the small rupture model (Model 2) similar to that of the 2015 Gorkha earthquake.

accelerometers, operating at a rock site in Kirtipur, recorded PGA about 0.25 g [38]. Instrumentally recorded PGA of the Gorkha Earthquake is not available in Nijgadhi, therefore, the observed seismic intensity was converted into PGA using Eq. (5) [50].

$$\text{Log}(A_h) = 0.014 + 0.3 * I_{MM} \quad (IV < I_{MM} < X) \quad (5)$$

where A_h is horizontal PGA in cm/s^2 and I_{MM} is the seismic intensity on Modified Mercalli Intensity (MMI) scale.

3. Result

Seismic hazard assessment has been carried out using two rupture models of the adopted earthquake source (Fig. 4) and four attenuation relations (Fig. 2). When the large rupture (Model 1) was used, the PGA differed negligibly (Fig. 5, Table 4) between Kathmandu and Nijgadhi for Abrahamson et al. [1] and Chiou & Youngs [14] relations, whereas the difference is notable (Table 4, Fig. 5) for BcHydro [5] and Zhao et al. [55] relations. The BcHydro [5] and Zhao et al. [55] relations produce large PGA in the southern part, particularly for 500 year return period.

When the small rupture (Model 2) was used, the PGA dropped significantly towards southern part of Nepal (Fig. 6) on account of the termination of rupture halfway. Table 5 shows the variation of PGA in Kathmandu and Nijgadhi for different attenuation relations. The BcHydro [5] estimates the smallest PGA both in Kathmandu and Nijgadhi, whereas the Abrahamson et al. [1] produces the largest.

When the large rupture (Model 1) is used, the result for 200 year return period may be overestimated, especially in the southern part of Nepal (Table 4). There are reports of frequent strong (Mw 7 to Mw 8) earthquakes felt in the Kathmandu Valley in its written history [10,12,15]. Assuming majority of the destructive earthquakes is similar to the 2015 Gorkha Earthquake (Mw 7.8) and the 1833 Nepal Earthquake (Mw 7.6), in terms of the rupture size (Model 2) and return period, the two rupture models (Model 1 and Model 2) are treated unequally. The small rupture (Model 2) is assigned a weight of 0.65 and the large rupture (Model 1) is assigned 0.35. The second model (Model 2) is assigned a large weight based on the report of

frequent strong earthquakes in the northern part of Nepal (e. g. [10,12,15]), which are not found to be associated with surface ruptures. The result from the combination of unequally weighted two rupture models and equally weighted four different attenuation relations is shown in Fig. 7 and the corresponding PGA for Kathmandu and Nijgadhi are presented in Table 6.

The above results (Table 4, Table 5 and Table 6) show that the PGAs from different attenuation relations do not agree among themselves. Similarly all destructive earthquakes are not associated with complete rupture of the MHT. Therefore, a logic tree (Fig. 8) was applied to incorporate the uncertainties in attenuation models and rupture models to prepare final seismic hazard maps. To accomplish this, the four attenuation relations were equally weighted and the two rupture models were treated unequally. The results are presented in Fig. 9(a) and Fig. 9(b) for 500 year and 200 years return periods respectively. The corresponding PGA in Kathmandu and Nijgadhi are presented in Table 7 for a comparison. The result shows that the PGA (0.23 g) estimated for Kathmandu, for 200 year return period, closely agrees with the instrumentally recorded PGA (0.25 g) during the 2015 Gorkha Earthquake. Similarly, the PGA (0.1 g) estimated for Nijgadhi, for 200 year return period, approximately agrees with the PGA (0.07 g) converted from seismic intensity (VI MMI) of the 2015 Gorkha Earthquake.

Table 5

Peak ground acceleration corresponding to 500 year and 200 year return periods in Kathmandu and Nijgadhi. The PGA values are calculated using the second rupture model (Model 2).

Attenuation relation	PGA (g)			
	Kathmandu		Nijgadhi	
	500 year	200 year	500 year	200 year
Abrahamson et al. [1]	0.51	0.31	0.17	0.1
Chiou & Youngs [14]	0.43	0.26	0.13	0.08
Zhao et al. [55]	0.35	0.21	0.13	0.08
BcHydro [5]	0.27	0.14	0.1	0.06

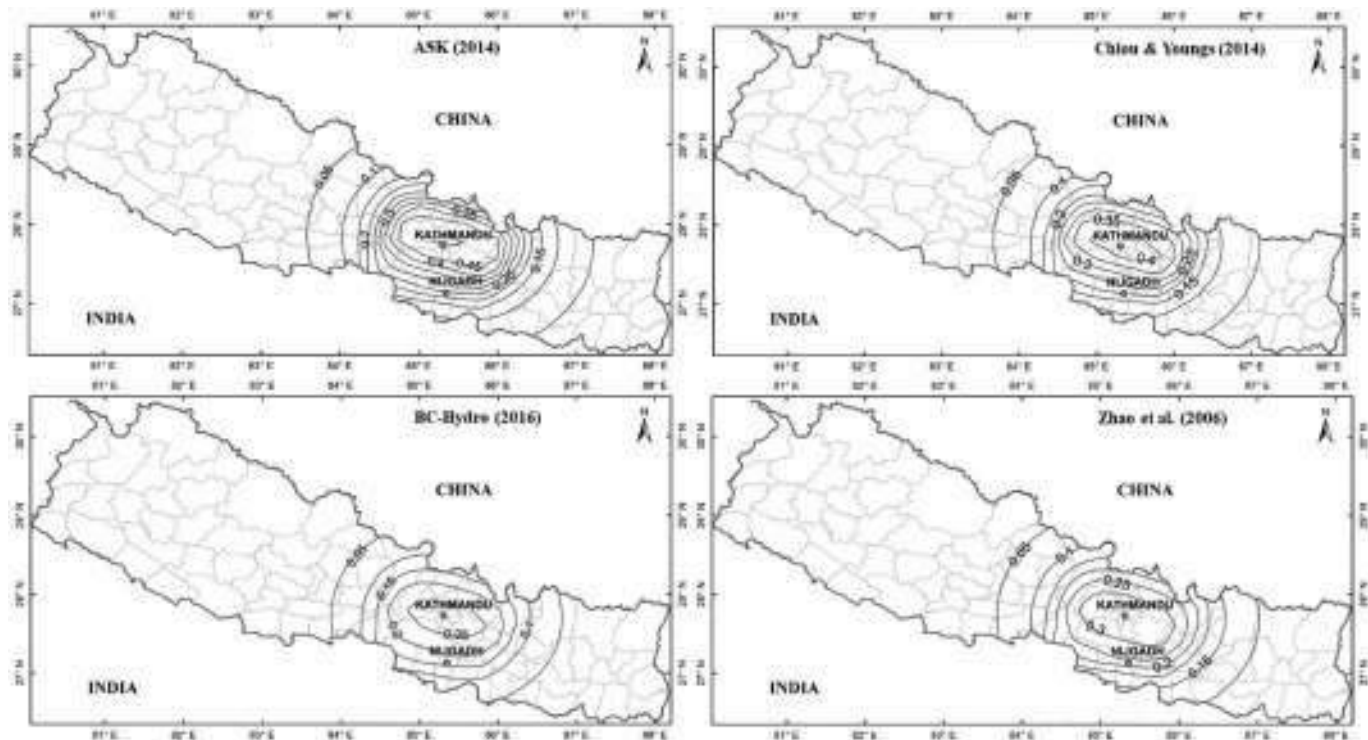


Fig. 7. Seismic hazard in Kathmandu valley and the adjoining region for 500 year return period. The hazard is estimated for engineering rock site conditions using four different attenuation relations and the unequally treated two rupture models.

Table 6

Peak ground acceleration corresponding to 500 year and 200 year return period in Kathmandu and Nijgadhi using the combination of unequally treated rupture models.

Attenuation relation	PGA (g)			
	Kathmandu		Nijgadhi	
	500 year	200 year	500 year	200 year
Abrahamson et al. [1]	0.5	0.31	0.24	0.13
Chiou & Youngs [14]	0.41	0.24	0.2	0.11
Zhao et al. [55]	0.34	0.21	0.23	0.11
BcHydro [5]	0.27	0.14	0.18	0.08

4. Discussion

Most of the previous studies have used area sources (e. g. GSHAP ([22,35], Thapa and Wang [49])), which have not considered the geometry of the MHT. In area sources, all the vertices of the source have same depth. Stevens et al. [46] used the geometry of the MHT and used a very large size earthquake (Mw 9.2) source. However, these works have not considered rupture models of the sources as demonstrated by the 2015 Gorkha Earthquake and the 1934 Bihar-Nepal Earthquake. The present study assumes the MHT is segmented into several pieces so that very large earthquakes (Mw 9.2) may not occur. It has utilized that segment of the MHT as a source, the partial rupture of which produced the 2015 Gorkha Earthquake.

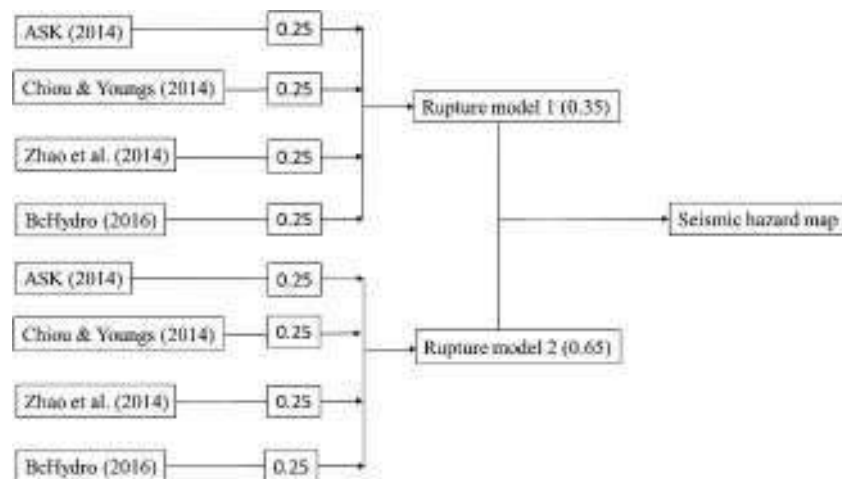


Fig. 8. Logic tree applied in this study. The attenuation relations have equal weight and in contrast the rupture models have unequal.

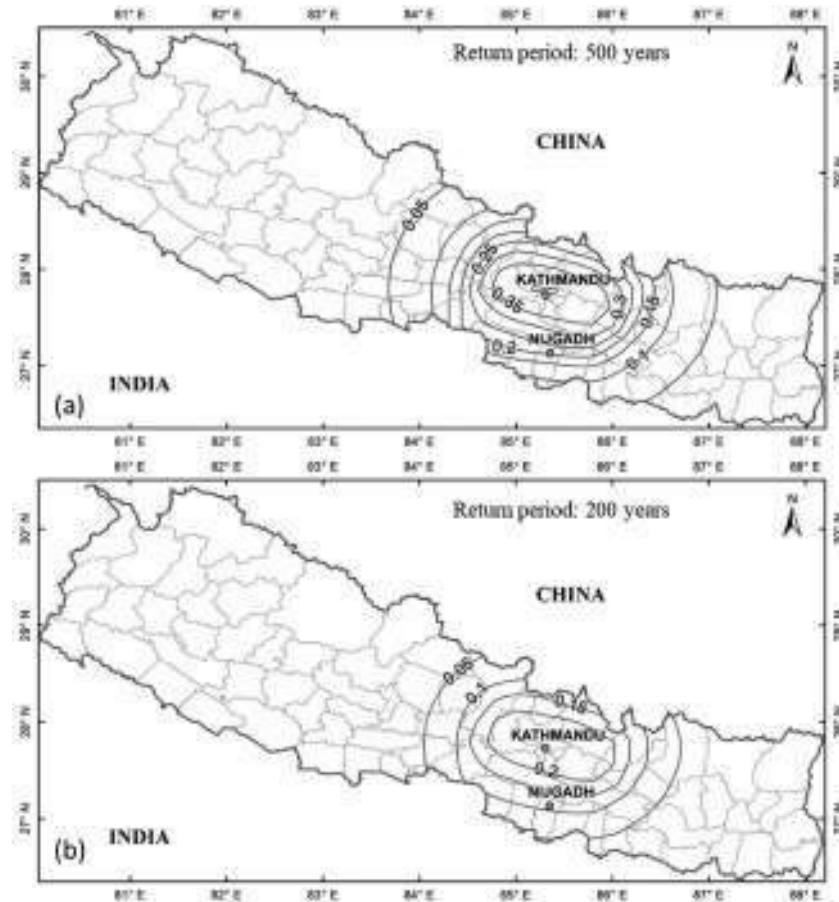


Fig. 9. Seismic hazard maps (a) for 500 year return period and (b) for 200 year return period for engineering rock site conditions.

When the large rupture of the source is applied to the attenuation relations from subduction zone, large PGA appear in the southern margin of the source and comparatively smaller in the northern part, which possibly resulted from the shallow depth of the MHT in the south, whereas the other two relations from active-shallow crustal region do not show significant difference. On the other hand, when the smaller model of rupture is considered, the PGA drops significantly in the south away from the source. The so-far carried out studies have used the full rupture of MHT sources, which properly may not reflect the hazard, when the frequent earthquakes similar to or smaller than the 2015 Gorkha Earthquake (Model 2) occur.

Earthquake recurrence parameters ('a' and 'b' values) are derived from earthquake catalogue which contains two types of data. The first one contains earthquakes which occurred before (1900) the existence of the recording instruments, while the second one is instrumentally recorded (after 1900). The instrumentally recorded data is complemented by pre-instrumental earthquakes from historical documentation and paleoseismic investigation. In comparison to the recurrence period of destructive earthquakes, the record of reliable, instrumentally recorded data is very short.

Table 7

Peak ground acceleration corresponding to 500 year and 200 year return period for Kathmandu Valley and Nijgadh. A logic tree of equally weighted four attenuation relations and differently weighted two rupture models of source was applied.

Attenuation relation	PGA (g)			
	Kathmandu		Nijgadh	
	500 year	200 year	500 year	200 year
Abrahamson et al. [1] + Chiou & Youngs [14] + Zhao et al. [55] + BcHydro [5]	0.4	0.23	0.23	0.1

In this study, the earthquake recurrence parameters estimated from the catalogue available for the short term are assumed not to vary significantly in the long term.

5. Conclusions

The frequent major earthquakes (e. g. 2015 Gorkha and 1833 Nepal earthquakes) are associated with partial rupture of the MHT (Model 2) and occur in the northern part of Nepal. Seismic hazard assessments based only on the large rupture (Model 1) of the MHT may overestimate the hazard, especially, in the southern part of Nepal for smaller return periods (e. g. 200 year). Therefore, the frequent major earthquakes, which are associated with partial rupture (Model 2) of the MHT also, should be considered.

Present result shows that the PGA (0.23 g) for 200 year return period approximately agrees with the instrumentally recorded PGA (0.25 g) in the Kathmandu Valley [38]. The PGA estimated for Nijgadh, for 200 year return period, is about 0.1 g, which is very close to the empirically estimated PGA (0.07 g). The probabilistically estimated PGA is for engineering rock site condition, whereas that estimated from seismic intensity is on surface. Nijgadh falls in the northern part of Terai, which is underlain by more than 30 m thick alluvium (gravel), therefore, the probabilistically estimated PGA on the surface is believed not to vary significantly. This conclusion is based on the result of ground response analysis of a thick sequence of alluvial deposit in Kaligandaki Kobang Hydropower Project (Unpublished report, 2011) and similar subsurface geology in Nijgadh.

The result depicted in the maps is solely from the source considered in this study and does not represent the contribution from other adjoining sources. The present result is valid only for the places within the source region considered and does not represent total hazard from all potential sources.

Further study is required to understand the earthquakes associated with partial rupture of the MHT as evidences of partial rupture are not known from other parts of Nepal. The attenuation relations do not agree among themselves and therefore large variations are observed in the calculated PGA, when the relations are applied independently. A locally derived attenuation model is a must so that the uncertainties associated with the attenuation models could be minimized.

Declaration of competing interest

I hereby confirm that I am the sole author of the paper submitted. Data have been used from [37]. R-Crisis software has been used to calculate the ground motion parameters.

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Regular Article

Inclusion of the poor and vulnerable: Learning from post-earthquake housing reconstruction in Nepal

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ABSTRACT

The poor and vulnerable people are the most affected in any disaster and find recovery extremely challenging. After the 2015 Nepal earthquake, the need for inclusive and targeted policy provisions and socio-technical facilitation was well identified. Nepal's post-earthquake housing reconstruction is world's largest owner driven reconstruction program under which nearly 700,000 houses are being constructed. This paper examines policies, and implementation mechanisms for ensuring social inclusion in this post-earthquake housing reconstruction process in Nepal, specifically examining provisions and delivery mechanisms for finance, land, design and technology for addressing recovery needs of the most vulnerable homeowners in terms of achievements, effectiveness, and challenges of implementation. The paper uses mixed methodology and is informed by the primary survey data of 26,912 homeowners in eight municipalities of the Gorkha district and overall reconstruction data from National Reconstruction Authority and other relevant sources of the Government of Nepal. Data is analysed and interpreted to gain insights on the specific issues of the poor and vulnerable. Top-up grant assistance and subsidized loan scheme have not yet benefited the vulnerable households despite the policy provisions. At the same time, housing reconstruction process in Nepal has helped a significant number of landless households get ownership of homestead land, which is a remarkable achievement. Shift in building typologies needs to be deliberated in context of affordability, sustainability and disaster risk reduction in the future. While policy provisions are the first step for the inclusion of the vulnerable, the desired outcome is difficult and challenging to achieve without enabling environment for their own agency and targeted socio-technical facilitation. Experience of post disaster housing reconstruction in Nepal strengthens our understanding of 'owner driven reconstruction' to make it more inclusive.

1. Introduction

Vulnerability may be understood as lack of resilience. Sendai Framework for Disaster Risk Reduction defines resilience as ability to resist, absorb or recover from the effects of hazards [47]. In other words, vulnerability can be defined as sensitivity to stress and shocks due to disasters and lack of abilities to mitigate, respond, cope or recover. Vulnerable people are not just more impacted but are also likely to have more difficulty in recovering to resume pre-disaster functionality as compared to other community members [14]. Vulnerability in disasters is essentially a construct of interactions between socio-economic attributes and geo-physical environment [6,30]. People's ability to cope or recover after a disaster is dependent on a complex set of factors such as physical capacities, caste, class, gender, social network, income, land and other assets, information, legal entitlements, government policies and mechanisms, amongst others. Unequal physical and financial capacities and access to resources can

make certain groups of people more vulnerable than others and can increase social divide and conflict [6,15,26]. Impact on women during a disaster is disproportionately high [13]. Disasters can further worsen the capacities and conditions necessary for coping and recovery and hence result in increasing vulnerabilities [4,22,41].

Inclusion of the poor and vulnerable in post-disaster reconstruction processes has been a challenging issue even in the past, and has seldom been addressed effectively or comprehensively. The 2001 Gujarat earthquake reconstruction policy framework included joint ownership of women in the reconstructed houses. But at the same time, there were no provisions for the land tenure security of the landless [39]. After the South Asian tsunami, the exclusion of *dalits* and *irula* tribals from the rehabilitation in Tamil Nadu, India indicated inadequacy of the policy framework [23]. Policies after the 2005 Kashmir earthquake in Pakistan included the land assistance only for households who were living on hazardous locations and required relocation [46]. The policy did not include other landless poor existing

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due to the socio-economic inequities. After the hurricane Katrina in 2005, policy framework ignored the poor renters dependent on public housing [19]. Review of many such past experiences shows that the reconstruction policies were either uninformed and oblivious of the socio-economic inequities, or inadequate to address such structural issues for ensuring inclusive and equitable reconstruction and recovery.

Nepal is highly prone to multiple natural hazards and falls under high risk seismic zone of Himalayas. The 2015 Nepal Earthquake affected 31 districts of which 14 were severely affected. While 8790 persons died and 22,300 were injured, over 500,000 houses collapsed or were severely damaged [32]. Post Disaster Need Assessment (PDNA) by Government of Nepal highlighted the significant impact of earthquake on the poor and vulnerable accentuated by pre-existing inequities due to geography, income, and gender. Nearly 700,000 persons were estimated to have been pushed below poverty line. The loss of housing could further amplify the shock pushing people below poverty line for extended periods [32]. Taking cognizance of the critical needs of the earthquake-affected people, Government of Nepal (GoN) created a new entity in the form of National Reconstruction Authority (NRA) through a Statutory Act of the Parliament. Subsequently, the government brought out policies for providing financial assistance, materials, skills, technology, and land. It established regulatory and implementation mechanisms for inclusive and resilient reconstruction and recovery.

Reconstruction of more than 700,000 houses after the 2015 Nepal earthquake is the largest owner driven housing reconstruction program globally. In the Gujarat earthquake (2001), the South Asian tsunami (2004), the Kashmir earthquake (2005) or any other disaster, owner driven reconstruction had not been undertaken at this scale [3,29,31]. Confronted by extremely difficult mountainous terrain with very limited access to road networks to reach to the homeowners and lack of institutional and financial capacities, Nepal faced unprecedented challenges in implementation of such a large recovery programme. Concurrently, Nepal adopted the new Constitution and made a complex political transition towards new federal system of governance. Facing the formidable task of strengthening the nascent administrative layers at sub-national and local levels, Nepal undertook substantive devolution of power to municipalities with the mandate of playing a direct role in disaster recovery.

With this backdrop, this paper delves into the key research question of effectiveness of the reconstruction policies, implementation modalities and challenges pertinent to the poor and vulnerable particularly in terms of access to financial support, homestead land and guidance on safer technology for housing reconstruction.

2. Data and methodology

This paper is based on mixed method approach. It draws upon information and data collected from primary and various secondary sources during the course of socio-technical facilitation of housing reconstruction by UNDP. As the paper is focussed on issues specific to the poor and vulnerable in context of effectiveness of reconstruction policies, it analyses data and information available at national level for all the affected districts while diving deeper into specific data of the Gorkha district where primary surveys were undertaken.

Primary data sources include i) homeowner surveys undertaken during last three years in six rural municipalities and two urban municipalities of the Gorkha district - the epicentre of the 2015 earthquake, ii) community meetings, and iii) case studies. The municipalities of the Gorkha district included in this study are Arughat, Ajirkot, Dharche, Gandaki, Gorkha, Palungtar, Shahidlakhan and Siranchowk. The surveys covered each of 26,912 homeowners being supported by UNDP with funding from Government of India through the census process. The homeowner surveys were conducted using a mobile application linked to Reconstruction Information Management System (RIMS) developed by UNDP for the purpose of socio-technical facilitation and monitoring progress of housing reconstruction. This primary data survey is a large dataset covering demographic and socio-economic details of the household, administrative and technical aspects of damage assessment, participation agreement, tranche

disbursement, construction progress, certification and completion. Depending on the stage of construction, each individual homeowners was surveyed between 1 and 6 times in past three years as the construction progressed. This database from the census surveys has been regularly checked for discrepancies and validated. The data interpretations have been confirmed through meetings with the community, ward members and municipalities, that were conducted during the same period for discussions on issues, challenges and progress of reconstruction work.

In addition to the above-mentioned survey data, reports and publications from NRA and National Planning Commission (NPC) have also been used to understand formulation of various policies and analyse the progress in reconstruction. Central Bureau of Statistics (CBS) survey reports, design and technology catalogues by Department of Urban Development and Building Construction (DUDBC) and information from Nepal Rastra Bank (NRB) were also referred.

Literature review was also conducted to understand the socio-economic conditions and issues, land and housing rights and the vulnerability, specifically on Nepal so as to situate the discussion in relevant, but broader, context of vulnerability reduction and disaster resilience.

Data analysis undertaken is essentially on interpretation of data related to disbursement of housing grant assistance, reconstruction progress, cost of construction, and other aspects related to land, technology and administrative facilitation, to derive insights particularly focussed on the poor and vulnerable. The information from the primary field surveys is used in conjunction with the secondary source information to highlight the specific issues. Wherever possible data was segregated for the vulnerable and other households. The progress and outcomes of housing reconstruction were examined from the perspective of policy provisions and their intent. The insights gleaned were verified through discussions and field meetings with the community and other local stakeholders.

3. Results and discussions

3.1. Vulnerable households: A brief profile

While occurrence of hazards is a natural phenomenon, the coping capacities depend, to a great extent, on the socio-economic conditions and environment variables within a community [7]. It, therefore, is important to understand the key socio-economic attributes that identify the vulnerable in Nepal. Besides being a low-income country, Nepal also ranks low (147) in the Human Development Index [45].

Poverty levels are high in Nepal with 25.2% of population below poverty line [12]. While the districtwide data shows that approximately 20.4% population is below poverty line in the Gorkha district, in some municipalities such as Dharche in the Gorkha district, it is as high as 72%. Such high poverty levels have also resulted in a high rate of outmigration. CBS estimates gross migration rate to be about 11.3% - primarily for seeking employment [9]. However, the proportion of the out-migration is much higher in Gorkha as indicated by about 32% absentee homeowners there [10]. The 2016 National Demographic and Health Survey [50] showed that nearly 47% of households had at least one person out-migrated in the past 10 years.

25.7% of the total households in Nepal are women headed [8]. However, gender inequality remains high with Nepal ranking a low 102 in Gender Development Index [48]. At least, 2.2% of the total population in Nepal has some type of disability with a higher concentration in the mountains and rural areas and amongst people with lower literacy [9].

With more than 120 ethnic groups, the vulnerability of households also increases due to social exclusion and caste and gender discrimination [2]. The *dalits* (a term used to identify the communities discriminated or excluded in traditional system of the caste hierarchy) and *janjatis* (tribal/ indigenous communities) are 13.6% and 36% of the total population respectively [9].

Exclusion from land ownership is another key indicator of vulnerability [6]. About 25% of Nepal's population is landless or near landless [49]. Landlessness amongst the *dalits* and *janjatis* is much higher as compared

to the other castes of social hierarchy. Nearly 50% of the *dalits* in Nepal do not have land ownership certificates [5].

The profile of 26,902 households surveyed who reconstructed their houses is important to understand their vulnerabilities and socio-economic status. The marginal occupational conditions of the poor and vulnerable are indicated in Table 1. As compared to others, vulnerable households were nearly 50% less involved in occupations like shops and businesses, government or private jobs. Unemployment in vulnerable households is more than double as compared to other households.

The social asymmetries and discrimination are well identified causes of the vulnerability [22,24,25]. *Dalits*, *janjatis* and female-headed households are comparatively poor having low literacy, marginal social status, negligible political participation, unfavourable work conditions, and high debt burden [21,38]. These conditions hamper mobilization of active local collaborations essential for recovery and thus cause exclusion of the *dalits*, and *janjatis* [27]. The vulnerable households are not a uniform but intricately and unevenly layered group particularly when two or three different vulnerabilities exist together.

3.2. Policy framework for housing reconstruction

Nepal adopted 'owner driven reconstruction' framework for the housing reconstruction. Owner driven reconstruction in the context of developing countries has been proved to be the most effective in terms of its achievements of satisfaction and disaster risk reduction [18]. Nepal's policy framework is quite fascinating and progressive in many ways. Noting concerns of the vulnerable identified in PDNA, strategic objectives of PDRF included specific points to guide policy formulation.

The GoN policy framework was based on a uniform approach to support and implement with universal coverage irrespective of funding sources [33]. Initially GoN committed to provide assistance of NRs 200,000 ($\approx$ \$2000) in three tranches which was later increased to NRs 300,000 ($\approx$ \$3000) to each houseowner whose house had fully collapsed or was damaged beyond repair. These tranches were provided at the stages of i) participation agreement with NRA ($\approx$ \$500), ii) completion of plinth level construction ($\approx$ \$1500), and iii) roof level ($\approx$ \$1000) through bank transfer. Certification by NRA engineers indicating compliance with technical norms and building codes was made mandatory at the time of the release of second and third tranches and finally after completion (to issue completion certificate). NRA prepared a two-volume catalogue of sample designs to communicate the approved standards and technologies [16,17]. The design and technologies included in the catalogue were vetted by a technical committee of experts constituted by the DUDBC, NRA also formulated a scheme to provide loan up to NRs 200,000 ($\approx$ \$2000) at 2% annual interest rate through the commercial banks.

Post disaster recovery is seldom equal and depends largely on extent of access to resources allowing financially able citizens to recover faster [37]. To address the needs of the vulnerable households such as single women, people with disabilities, children at risk and senior citizens, an additional grant assistance of NRs 50,000 ($\approx$ \$500) was designed as top-up on NRs 300,000 ($\approx$ \$3000) grant assistance. This was included in the financial

assistance package for the most vulnerable at a later stage of implementation. PDRF also identified adoption and expansion of social protection particularly cash transfer or cash-for-work schemes as a means to support the poor and vulnerable groups [33]. However, no such policy provisions were instituted or implemented.

Ownership of homestead land was a prerequisite for receiving housing reconstruction assistance from the NRA. Though landlessness was not included criteria of vulnerability, separate policy provisions for providing land entitlement to landless were made. These include three options - i) land regularisation at the same location where houseowner was residing, ii) provision of land at alternative location (minimum 6 *anna* i.e. 2052 sq.ft. or iii) additional grant assistance of NRs 200,000 ($\approx$ \$2000) to purchase a new plot of land.

Similarly, a policy was also adopted to provide financial assistance of NRs 100,000 ($\approx$ \$1000) towards retrofitting of the partially damaged but repairable houses. PDRF also articulated intention of meaningful participation of women, vulnerable and marginalised groups through community-based organisations. However, no specific guidelines or operating procedures were developed and implemented.

3.3. Identifying the earthquake affected vulnerable households

The 2015 Nepal earthquake damaged 1,053,033 houses in 31 districts. The extent of damage is indicated in the following Table 2.

Based on the detailed damage assessment of more than 1.0 million houses, 782,695 households were supported for house reconstruction, which turned out to be 28% higher than the number estimated in PDNA. PDNA also identified the need for a special assistance package for the vulnerable households to ensure they were not left behind [32]. The vulnerable households were identified through analysis of data from the socio-economic survey conducted concurrently with the damage assessment undertaken by the CBS. NRA considered gender, age, and disability for identification of the vulnerable. Similarly, orphan children needed protection and were also included in the list of the vulnerable. Landless were identified through a separate process and a separate policy provision to support their access to land was formulated. It is a limitation of the policy perspective that the defining criteria for the vulnerable households does not consider explicitly the structural inequities and deep-rooted social discrimination due to class and caste hierarchies. Similarly, the awareness of gender issues is very little amongst the community [43]. Therefore, it becomes further challenging to identify the vulnerable as they have weak agency to articulate and influence. While the criteria to identify the vulnerable adopted by NRA may not be comprehensive, these were specific enough to identify significant number of vulnerable households. With detailed operational guidelines for identifying the eligible vulnerable out of 782,695 houseowners for the top-up housing assistance, only a small number of 18,505 households (2.4%) were finally designated as vulnerable (Table 3).

A review of social demographic indicators based on census 2011 [9], there seems to be likelihood that many vulnerable may have been left

Table 1
Occupational profile of houseowners surveyed in eight municipalities of Gorkha district.

Primary Occupation	Vulnerable HHs		Other HHs	
	Number	%	Number	%
Agriculture	6280	78.1	14,256	75.6
Artisans	323	4	442	2.3
Shops and small business	236	2.9	1065	5.6
Govt. Job	258	3.2	1448	7.7
Private job	78	1	415	2.2
Other	211	2.6	491	2.5
Unemployed	653	8.1	756	4
Total	8039	100	18,873	100

Source: Primary data collected by UNDP, Nepal.

Table 2
Extent of damage to the houses.

Damage Grade*	% of damaged houses
G1: Negligible to slight damage (No structural damage, slight non-structural damage)	9.7
G2: Moderate damage (Slight structural damage, moderate non-structural damage)	13.5
G3: Substantial damage to heavy damage (moderate structural damage, heavy non-structural damage)	19.4
G4: Very heavy damage (heavy structural damage, very heavy non-structural damage)	24
G5: Destruction (very heavy structural damage)	33.4

Source: Household registration for housing reconstruction survey, 2016–17, CBS.

* refer [20].

Table 3
Vulnerable houseowners identified by NRA.

Vulnerability Type	No. of houseowners
Orphan children (below 16 yr)	91
Single women	9024
Old aged (above 70)	9147
Persons with disability	243
Total	18,505

Source: Household registration for housing reconstruction survey, 2016–17, CBS.

out. In six rural municipalities and two urban municipalities of the Gorkha district, where UNDP is providing socio-technical support to 26,912 houseowners for housing reconstruction, NRA identified and approved 695 houseowners as vulnerable. However, the municipalities identified 1115 houseowners as vulnerable using the same criteria that was used by NRA. However, only 100 households were found to be common between the NRA and the municipality lists. At the same time, using broader criteria to include left out vulnerable groups such as *dalits*, landless and chronically ill patients also, UNDP identified 8062 houseowners as vulnerable for its socio-technical facilitation support. The lists of vulnerable by the various agencies identified different houseowners albeit using the same criteria. Despite having clear and specific criteria for identification of the vulnerable households, these disparities in terms of coverage and inclusion are indicative of the implementation challenges due to lack of voice and influence of the vulnerable.

3.4. Status of housing reconstruction by the vulnerable

According to NRA, by the end of May 2020, reconstruction of 64% of total houses in 14 most affected district had been completed and another 23% were under construction. By this period, more than 74% of houseowners had received the third tranche [35].

Timeline study (Fig. 1) in the Gorkha district shows that the vulnerable households were slower in reconstruction of their houses as compared to the others. With targeted socio-technical support, the gap between completion rate by the vulnerable and non-vulnerable households has narrowed.

Generally, the vulnerable houseowners took much longer to complete the construction. A reconstruction timeline based on an interview with a vulnerable household from the Gorkha municipality was drawn up. It spanned 5-year long period, for completing the house construction (Fig. 2).

Once construction stage was completed, it took 2–4 months for the tranches to be received by the houseowners. Such delays for the poor and vulnerable were difficult as they had little capacity to pursue with the government and the banks or continue with their own resources. This resulted

in repeated halts in construction. Due to the halts, even the continuation of same team of artisans and timely restart was difficult. Progressing from one construction stage to another, required the vulnerable houseowners to cross many barriers related to the availability of the financial resources, land, design and technology. These aspects of house construction have been discussed below.

3.5. Access of the vulnerable to financial assistance

The most common obstacle for the reconstruction was the gap in funds required for house construction. Nearly 30% of damaged houses continued to be used after the earthquake with or without repairs as of April 2017 [11]. Only 8.4% of the houseowners in 8 municipalities of the Gorkha district where survey was undertaken were able to construct within the financial assistance provided by NRA (Table 4).

NRA grant assistance was received as per the progress of the construction. 80% of the vulnerable households identified by NRA have received NRs 300,000 ($\approx$ \$3000) in three tranches completing the house construction.

Table 5 shows more vulnerable houseowners are still in intermediate stages of first and second tranches as compared to the other houseowners as of 30 June 2020. Proportion of vulnerable houseowners (11%) still at first tranche stage (i.e. yet to begin the construction) was almost double as compared with the other non-vulnerable houseowners (6%). And more of non-vulnerable houseowners (88%) have received all the three tranches as compared to the vulnerable houseowners (80%). This data shows clearly that vulnerable houseowners lag behind and are slower to start and complete the construction. Most interestingly, the above data shows that the vulnerable have not yet received top-up grant assistance of additional NRs 50,000 ($\approx$ \$500). Though the identification of vulnerable houseowners is debatable on aspects of inadequacy of criteria, coverage and accuracy, none of the 18,505 vulnerable houseowners identified by NRA were able to receive top-up grant assistance of \$500 so far. This policy provision for the vulnerable to provide additional grant of \$500 on top of the housing assistance grant of \$3000 has clearly not been effectively implemented.

Market survey conducted over the last 5 years indicated significant increase in construction cost. Daily wages of unskilled labour had increased by two thirds i.e. from \$6 per day in 2015 to \$10 per day in 2019. Similarly, the costs of building material such as bricks, cement, steel, had gone up by 20% to 30% in the last five years. The inflation in material and labour costs led to requirement of more funds to complete the construction of the houses. The situation was further exacerbated by the exclusion of the vulnerable from the traditional communal labour exchange system [27]. All these factors resulted in making house reconstruction costs unaffordable for the poor and vulnerable.

NRA had also drawn up a policy of subsidized credit through commercial banks to the affected houseowners to support reconstruction of their house. There were two schemes: i) an interest-subsidized loan up to NRs 1,500,000 ($\approx$ \$15,000) in other than Kathmandu valley and NRs 2,500,000 ($\approx$ \$25,000) in the Kathmandu valley at an interest rate of 2% per annum was to be made available, and ii) an interest-free loan up to NRs300,000 ($\approx$ \$3000) could be availed on the basis of collective collateral [34]. However, these schemes failed to take off due to lack of willingness from the banks and were withdrawn in August 2018 [34,44]. NRA replaced the earlier schemes with a new scheme of loan up to NRs300,000 ($\approx$ \$3000) with repayment period of 5 years on the condition of property collateral. The new scheme made loans available with 5% subsidy on the interest. Implemented since 2018, only 200 houseowners had been able to receive this loan totalling about NRs. 58,630,000 ($\approx$ \$586,300). The various schemes for loans altogether benefited only 1592 houseowners by April 2020 [36].

In the Gorkha district, households borrowing from informal sources tripled to 52% within the first two years after the earthquake, with higher debt levels in remote locations [42]. In the Gorkha district, a staggering 68.8% of the surveyed houseowners had borrowed money from the local

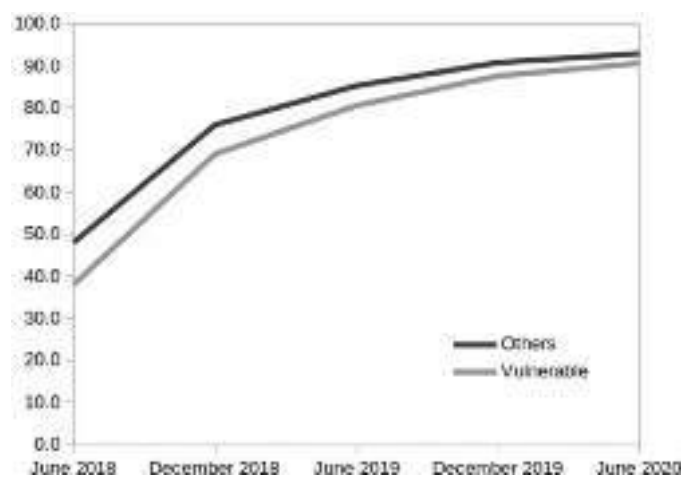


Fig. 1. Timeline of housing reconstruction in Gorkha district (June 2018–June 2020). Source: Primary data collected by UNDP, Nepal

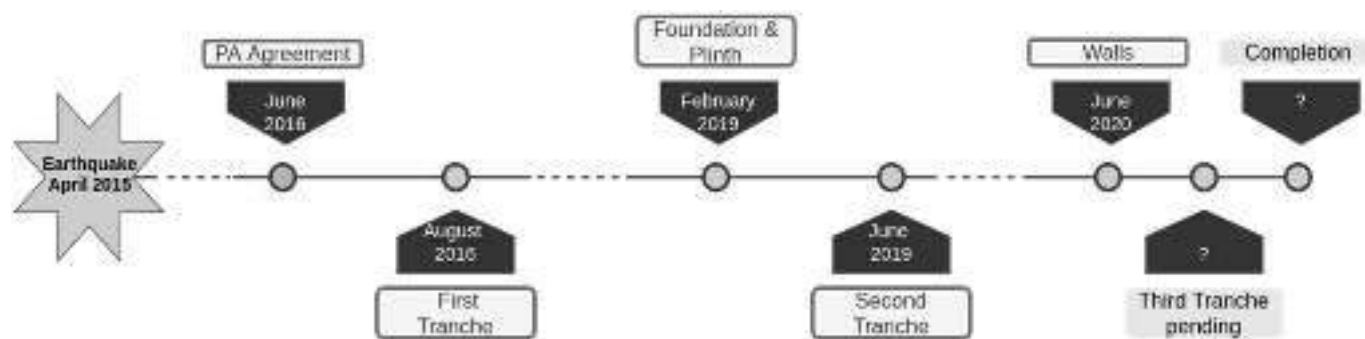


Fig. 2. Timeline of house construction for a vulnerable household in the Gorkha district.

Table 4

House Reconstruction Costs in 8 municipalities of the Gorkha district.

Reconstruction costs of the house	% of houses
Less than \$3000	8.4
Between \$3000 to \$6000	50.7
Between \$6000 to \$9000	21.4
More than \$9000	19.5

Source: Primary data collected by UNDP, Nepal.

Table 5

Status of housing grant assistance to vulnerable homeowners in 8 municipalities of Gorkha district.

Housing Grant Assistance Received	% of households	
	Other than vulnerable homeowners in Gorkha district	Vulnerable homeowners in Gorkha district covered by UNDP facilitation
Only 1st tranche (\$500)	6	11
Both 1st and 2nd tranches (total \$500 + \$1500)	6	9
All three tranche (total \$500 + \$1500 + \$1000)	88	80
Top-up tranche (additional \$500)	0	0

Source: compiled from the data shared by GMALI, GoN and primary data by UNDP Nepal as on 30 June 2020.

moneylenders at 24 to 36% annually compounding rate of interest [40]. Increase in such forms of borrowing during the post-earthquake reconstruction is also resulting in mortgage and sale of assets [28].

Due to unaffordable costs of house construction, a large number of homeowners have been forced to build much smaller houses inadequate for their real needs. Table 6 shows the size of houses constructed by the homeowners.

To enable the vulnerable homeowners with required finance, some innovative approaches were adopted by a few municipalities in the Gorkha district. Arughat, Sahidlakhan and Gandaki municipalities set up *ghoomti kosh* (revolving fund). Through this fund, the municipalities provided interest-free loan of \$500 – \$1000 to the vulnerable homeowners on the

Table 6

Size of the houses reconstructed in 8 municipalities of Gorkha district.

Size of the houses reconstructed	% of houses
One-room house	28.6
Two rooms house	47.9
House with 3–4 rooms	19.1
Houses with more than 4 rooms	4.4

Source: Primary data collected by UNDP, Nepal.

condition of repayment when the next tranche was released. Fifty-nine households had been supported so far through this revolving fund modality in these three rural municipalities with total assistance of NRs 450,000 ($\approx$ \$45,000). A similar concept was also adopted by some municipalities in other districts, for example Chautara Sangachowgadhi in Sindhupalchowk. In Palungtar, the municipality assisted with the supply of essential building materials for the vulnerable families whose housing reconstruction was stuck due to financial constraints. Though this approach has been implemented by municipalities at a limited scale, it provides a viable and evidence-based policy input for enabling vulnerable homeowners to reconstruct their house.

3.6. Access of the vulnerable to homestead land

With more than 25% of the population being landless, unequal distribution of land has been one of the key political issue in Nepal for decades [49]. One of the most significant aspects of Nepal's housing reconstruction and recovery has been the acknowledgement of vulnerability of landless and formulation of policies to address the same. By making the first amendment to working procedures of housing grant distribution, provisions were made to include the option of either regularisation of existing land, or provision of alternative land or additional grant for the purchase of land. The policy for land assistance has benefited 11,551 landless owners in all earthquake affected districts of Nepal so far as shown below in Table 7. However, as the awareness of gender inequality is generally low amongst the people, this aspect of ownership of houses does not find much articulation by the affected households including women or in the policy framework.

Multiple steps through which landless had to navigate for this entitlement involved initial application along with citizenship documents and proofs of residence, affidavits by the neighbours (*muchulka*), verification of landlessness and recommendation by the ward committee, further verification by Grant Management and Local Infrastructure (GMALI), recommendation by Central Level Project Implementation Unit (CLPIU) at NRA and finally, decision by the NRA Executive Committee. To ensure that the grant assistance for land was not used for any other purpose, this amount was released directly to the seller by GMALI based on the agreement between the landless homeowner and the seller. Land registration fees were also waived on the recommendation of GMALI. However, collecting all the documents at each step of verification, approval, land measurement,

Table 7

Status of approval of land assistance for the landless.

Approval of land assistance	Homeowners (no.)
In-situ land regularisation	10,287
Additional grant assistance for land purchase	535
Allocation of alternative public land	105
Land procured by the owners on their own	236
Approved but land yet to be facilitated	367
Built on public land without awaiting approval	21
Total	11,551

Source: Update Report of Durable Solutions as of 30 June 2020.

and registration was a long and complex process making it extremely difficult for the vulnerable households with little resources they had. Looking at geographic constraints of households, each visit to district headquarters where GMALI, land registration office, District Coordination Committee are located involved significant time, effort and cost. Despite such difficulties, significant number of landless households (11,551) have received land ownership, which indicates need, priority and effectiveness of the policy framework. Setting up of Land Rights and Recommendations Committee at the district level to decide upon land registration was an empowering provision for the municipalities and effective for addressing this issue.

3.7. Access of the vulnerable to design and technology

For the communities in Nepal, the house is not merely an engineering product, but it is a result of the socio-cultural and economic processes in interaction with local climate and environmental resources. While discussing the access of the poor and vulnerable households to design and technology, there is need to examine both dimensions – the engineering as well as the socio-economic. An approach towards design and technology in Nepal is an example of implementing stricter building norms with the changed perception of seismic risks by the engineers. *Prima facie* observations show that the engineers' preference is biased towards 'modern' industrial materials such as cement, steel, etc. Traditional materials such as stone and mud, and construction systems had limited adoption primarily due to engineers' limited knowledge and a lack of confidence in these materials and systems besides a lack of established engineering methods to design of houses using these materials.

Design and technology have been of significant focus for the post-earthquake reconstruction in Nepal and were seen as a panacea for disaster risk reduction. PDNA identified maximum damage in low-strength masonry houses [32]. DUDBC prepared two volumes of the building design catalogues that became the basis for house reconstruction in all the earthquake affected areas [16,17]. Compliance with these designs and technologies was mandatory for receiving the instalments of financial assistance offered to the homeowners. Unlike other South Asian experiences, Nepal's approach included both traditional and modern materials and technologies. Though conceptually, the need to include traditional building typologies was understood, insistence was made to use only what could be vetted through the engineering models to meet safety standards of Nepal Building Codes (NBC). While the basis of stipulated norms remains a matter of debate, the design catalogues offered little flexibility for customising the designs as per the needs of the household, climate, site, functions or owner's affordability. When using reinforced cement concrete (RCC) and cement-based construction system, technical guidelines were made available to allow modifications in designs to suit people's own preference and needs. However, traditional technologies were limited to be used only with pre-approved plans in volume 2 of the design catalogue. For any modifications in design when constructing with traditional technologies, structural analysis was made mandatory [17]. In practice, any modification to the designs in the catalogues was considered non-compliance if not supported by structural analysis. For many of the alternative designs prescribed in the catalogues, inspection norms were never developed and therefore, severely limited their use for reconstruction. This approach resulted in a shift in the building typologies for construction of houses. Table 8 based on the data collected from eight municipalities provides an understanding on this shift and Table 9 explains the typologies adopted by the vulnerable.

Table 8
Changes in housing typologies in eight municipalities of Gorkha district.

Building Typologies	Prevalence % (urban)		Prevalence % (rural)	
	Pre-earthquake	Post Reconstruction	Pre-earthquake	Post Reconstruction
Low strength masonry	76	11	95	41
Cement based load bearing	15	72	4	48
RCC frame structure	9	17	1	11

Source: Primary data collected by UNDP, Nepal.

As evident from the data, the reconstruction programme led to a significant change in housing typologies in the earthquake affected areas - from stone and mud-based construction to cement and steel-based construction (Tables 8 and 9). Proportion of low strength masonry houses reduced drastically. From 76% in pre earthquake situation to only 11% in post-earthquake reconstruction in urban areas. Similarly, in rural areas the proportion of low strength masonry went down from 95% to 41%. Cement based building typologies saw very significant rise. In urban areas, these typologies increased from 15% to 72% and in rural areas the increase was from 4% to 48%. Discussion with the homeowners and community representatives revealed two factors that influenced this process - i) orientation of engineers who guided and certified for grant assistance, and ii) lack of clarity in compliance norms for traditional or alternative construction systems. The other factors such as limited number of approved designs using traditional materials, perceived safety of modern buildings and notion of progress in the communities. This shift in typologies has completely changed the architectural milieu in earthquake affected areas leaving them bereft of the rich cultural heritage that the traditional construction technologies resulted in. This raises issues about how desirable the change is in terms of hazard resistance, socio-cultural aspects and environmental sustainability. An increasing proportion of cement-based load bearing and RCC frame houses could be an indication of improved hazard resistance of new houses. But this is a particularly complex issue. On one hand one would tend to assume the improved performance of houses during hazards with compliance to the building norms, on the other, there is a likelihood of greater risk if the quality compromises were made due to cost constraints, lack of timely technical guidance and unfamiliarity with technologies. However, more detailed studies may be required to know the extent of hazard resistance achieved in the newly constructed houses. Sustainability of the shift in the building typologies, particularly in the context of the poor and vulnerable and likelihood of negative socio-cultural and environmental impacts. Further to this, issues of extensions, modifications and maintenance might ultimately lead to mixed and hybrid structures compromising hazard resistance in absence of appropriate technical advice and affordability.

3.8. Access of the vulnerable to administrative and facilitative mechanisms

Housing is not merely a product but also a process involving access and delivery of finance, materials, land, design, technology, information, and skills. Such a process needs navigation through each stage of damage assessment, participation agreement, banking, land procurement, approval for building design, building permit, compliance to construction norms, inspection and certification, completion report, and grievance redressal. These processes were complex and exhausting for the earthquake affected vulnerable homeowners.

The process of damage assessment, the first and foundational step for housing reconstruction, was too complex and earthquake affected communities remained uninformed about the classification and basis for eligibility for housing grant assistance. There were repeated appeals for grievance redressal by the people, and multiple rounds of verification and resurvey process were undertaken.

Municipalities have lacked capacities to ensure compliance to the building codes through the permit process and that had resulted in poor quality housing stock in past [1,25]. The building permit process at the municipality level would have ensured compliance with the building bye laws in

Table 9
Adoption of different typologies by the vulnerable in eight municipalities of Gorkha district.

Building Typologies	Prevalence % (urban)		Prevalence % (rural)	
	Vulnerable households	Other affected households	Vulnerable households	Other affected households
Low strength masonry	13	9	44	34
Cement based load bearing	73	72	45	55
RCC frame structure	14	19	11	11

Source: Primary data collected by UNDP, Nepal.

accordance with the development plans. Post-earthquake, many urban municipalities made it mandatory for the homeowners to get approval of the building plans. However, the limited availability of engineering services there resulted in either unauthorised construction or a significant expense of hiring private consultants. This was particularly challenging for the poor and vulnerable. Field studies in Gorkha municipality indicated that the costs for engineering services to obtain building permit from the municipality were between NRs5,000 ($\approx$ \$50) for a load bearing house to NRs25,000 ($\approx$ \$250) for RCC frame house. A quick estimate shows that services offered by Gorkha and Palungtar municipality with assistance from UNDP helped nearly 2600 homeowners (Table 10) so far with saving of approximately \$270,000 to the homeowners while ensuring authorised construction as per the municipal bye laws. Nearly 25% of total households assisted through these services were the vulnerable. A few building permits were rejected due to issues of lack of right of way, inadequate documents or unclear land titles. Many homeowners who had constructed the house without building permit also needed to be facilitated for rectification and approval. These needed to be resolved on case to case basis. However, such services have been limited and a large number of vulnerable families in other urban municipalities have to make significant expense to obtain building approval.

One of the most challenging aspect of the administrative processes for the vulnerable has been technical guidance during construction and subsequent certification of stage completion. Lack of information and advice at the time of construction resulted in rejection unless rectified as per the feedback of the engineer. The modality of feedback after the construction was a problem for the vulnerable homeowners who had to spend significant costs on rectification [42]. Two separate mechanisms were needed for providing on-site technical advice and certification after each construction stage to avoid conflict of interest and improve effectiveness of the process. However, the NRA continued to rely only on one engineer deputed at the ward level to fulfil both the tasks. At the same time, homeowners depended on the petty contractors or the head masons to follow the technical norms who were not so aware. Largely, the owners remained responsible to ensure compliance of technical norms in their houses without adequate information and technical inputs from the government. This gap was fulfilled by other supporting agencies to some extent in the limited geographic area of their presence. This could be one of the major cause of observed poor construction quality compromising hazard resistance of the newly constructed houses to any hazard in the future.

4. Conclusions

Nepal's post-earthquake housing reconstruction offers many lessons relevant not only to Nepal but globally, particularly on the inclusion of the

poor and vulnerable. Recognising the complex interaction of context, needs, capacities, and challenges during the process of reconstruction improves our understanding of owner-driven reconstruction.

Nepal's reconstruction and recovery policies and implementation mechanisms evolved slowly and were refined and expanded as housing reconstruction progressed and the needs and challenges became more evident. Specific provisions for additional financial assistance to the vulnerable and securing land ownership for the landless along with the use of instruments vested with municipal governments were the hallmark of the 'owner driven reconstruction framework' in Nepal. However, the policy formulation, though essential, is only a first step for enabling recovery process of the poor and vulnerable. It has to be followed with instituting of mechanisms and modalities that are people-friendly and convivial so that the vulnerable households can access their entitlements in timely manner without barriers. Certain implementation mechanisms particularly for damage categorisation, identification of vulnerable families, disbursement of top-up grant assistance and subsidized loans could not be as effective as envisaged and hence, inclusion of the vulnerable though well-intended in the policy framework remained limited.

Identification of the poor and vulnerable was not easy and simplistic criteria were inadequate given the multi-dimensional complexities of socio-economic factors. The weak agency of the poor and vulnerable makes them silent and therefore, invisible. The policy formulation needs to be refined through more in-depth understanding of the myriad forms of the socio-economic vulnerability allowing the invisible to become visible.

Access to the housing finance remained another difficult issue in the reconstruction process. Due to partial financial assistance from the NRA and failure of the subsidized bank loan schemes, many poor households not only constructed much smaller houses than they had before, but also had to borrow money from informal sources at highly exploitative interest rates. There is a risk that the increased debt burden on the poor and vulnerable households can perpetuate deeply entrenched power dynamics of social hierarchies further diminishing their agency.

The security of tenure for the landless through ownership of the homestead land was an unprecedented and remarkable inclusion in the policy framework and its implementation. Though fulfilling land entitlement is a complex process, strengthening of local governments through the devolution of power made this process feasible and effective. However, this policy intervention has also been a missed opportunity to further the cause of social justice in terms of ensuring an equal land entitlement to be held jointly by the women.

It is also amply evident that there has been a major shift in housing typologies in earthquake-affected districts from stone and mud-based masonry to cement based construction. Though more evidence is still required, it is likely that potential hazard performance of new houses may have improved. However, the control of the design process which traditionally had been rooted within the communities through artisanal practices has been shifted to the domain of engineering experts. This has made the communities, artisans in particular, passive recipient of information on hazard resistant design and technology. This also poses a challenge to the sustainability of disaster risk reduction efforts, if the communities lose control over their own construction processes in name of social welfare and safety. Socio-technical facilitation of the vulnerable homeowners, wherever available, helped the poor and vulnerable in mandatory administrative and technical compliances. But it is important to recognise that the design and

Table 10
Building permission for house reconstruction in Gorkha and Palungtar upto July 6, 2020.

Building Permission Process	Gorkha	Palungtar
Total applicant homeowners	1173	1493
Applicant for new construction	427	763
Applicants for as built approval	720	717
Building approvals obtained	804	705
Building approvals rejected or cancelled	26	13

Source: Primary data collected by UNDP, Nepal.

technologies have to be perceived within the framework of community empowerment and not merely seen through the engineering perspective. Without an empowerment perspective, the process would violate the basic tenets of 'owner driven reconstruction'.

For effective and inclusive post-disaster reconstruction, mere identification of the mechanics and procedures of implementation is not enough. Policies and implementation mechanisms need to be formulated with the understanding of pre-existing forms of socio-economic marginalization in order to address those barriers. The poor and vulnerable are better enabled to access their entitlements when the governance shifts from upper echelons of the government to the local governments. The key to their more equitable and effective inclusion is likely to be the transformation of development planning and governance processes enabling the praxis of the communities to influence and lead their own recovery process.

Declaration of Competing Interest

None.

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