Government of Nepal
National Reconstruction Authority
Singhadurbar, Kathmandu
Nepal

NRA EXPERIENCE PAPER ON RETROFITTING OF PRIVATE HOUSING POST 2015 GORKHA EARTHQUAKE

ICNR 2021
CONFERENCE
Kathmandu, Nepal

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PREAMBLE

The National Reconstruction Authority (NRA), as a 'Special Purpose Vehicle' (SPV), has been mandated with the coordination and implementation of Nepal's recovery and reconstruction after the devastating Gorkha Earthquake of 2015. Together with a number of partners – Government line agencies, earthquake affected households, donors, Nepal Rastra Bank, commercial banks, and international and local NGOs – the NRA has achieved huge successes, whilst overcoming numerous challenges faced along the way, during its five years' tenure to date. More recently, the Government of Nepal (GoN) extended the NRA's time period for an additional one year.

The NRA intends to capture and document its experiences, learning, and best practices. The NRA has compiled a comprehensive Institutional Memory and continues to expand on this, and, in recent months, as part of the process of ensuring a sustained legacy of its contribution to Nepal's post-disaster history, has published its own 'NRA Experience Paper on Retrofitting of Private Housing'. These initiatives maintain and sustain the dialogue around post-disaster retrofitting, engage all interested parties including both practitioners and academics, show a clear drive towards continued learning and sharing of knowledge, and promote the accumulation and compilation of these into documentary form so that they may play a valuable role – not just for Nepal but for other countries like ours, that suffer from naturally-triggered disasters.

The paper was inspired by reflection and discussion with numerous stakeholders – both in and outside of government – and has been supported equally in its elaboration by these actors. It was also essentially driven due to the NRA's own experience of facing the post-earthquake retrofitting without having such an all-encompassing set of information, guidance, and practices on which it had to base its own intervention; thus, it was felt imperative to provide this for future generations.

We believe that readers of this paper will not just take away ideas, but in addition the knowledge to expand on them and apply the learning that they acquire from this paper. We also trust that through further dissemination in professional networks around the globe we can all benefit from our experiences and learning in Nepal, and be better prepared for facing all future disasters, together. My thanks to you all!

Sushil Gyewali
Chief Executive Officer
National Reconstruction Authority

ACKNOWLEDGEMENTS

This paper is dedicated to all personnel involved, from in the field of academia to the construction industry, as well as administrators and policy makers of the country. This paper provides insight on private housing retrofitting in Nepal.

I would like to express my most profound gratitude to the Department for International Development (DFID) for their support in making this paper possible. I would like to thank the Central Level Project Implementation Unit (Building), together with partner organizations UNOPS, Build Change, UNDP, NSET, CRS and Housing Recovery and Reconstruction Platform (HRRP) – Nepal for their initiation and continuous involvement during the preparation of this paper.

NRA CEO Mr Sushil Gyawali deserves special thanks for encouraging such kinds of papers with tireless energy and commitment. Without his leadership of the NRA over the past five years, this kind of solidarity and smooth operation of activities and knowledge sharing would not have been possible.

A special note of cordial thanks to respected senior experts Dr Hari Ram Parajuli, Prof. Dr Prem Nath Maskey, Prof. Dr Gokarna Bahadhur Motra, Mr Tim Hart and Mr Jitendra Bothara, for their support and suggestions during the discussions on critical issues which were required to finalize this paper.

My sincere thanks to Mr Jhapper Singh Vishwokarma, Mr Bipin K Gautan, Mr Sushant Shrestha, Ms Liva Shrestha, Ms Pragya Pradhan, Dr Ramesh Guragain, Mr Sudin Pradhan and Mr Deepak Saud for their continuous work on preparation of this paper.

I hereby take this opportunity to express my sincere thanks to all personnel involved, both directly and indirectly, for their valuable contribution to the preparation of this paper. I am confident that it will be a valuable resource for all the practitioners of Nepal's reconstruction activities.

Mani Ram Gelal
Secretary
National Reconstruction Authority

FOREWORD

I would sincerely like to congratulate everyone involved in the development of the "NRA Experience Paper on Retrofitting of Private Housing" which has been published by the National Reconstruction Authority. This paper will further support the implementation of retrofitting of vulnerable houses that need seismic retrofitting. This is one of many documents which are prepared as preparatory activities for the International Conference on Nepal's Reconstruction (ICNR-2021). Retrofitting is going to be one of the thematic areas which will be presented in the Conference.

I would like to stress that all the knowledge and experiences achieved during the retrofitting works, including different designs and methods as well as all the feedback and suggestions received from different sources in the last five years of the NRA's existence, have been well presented. The information on the processes adopted during retrofitting programs and their implementation, and the issues and challenges encountered which have been resolved during the course of time, have provided a valuable reference source.

Effort and expertise are required, from both technical personnel and the government sector, to support households to retrofit unsafe structures so that partially damaged houses constructed by different typology can be made safe while remaining budget friendly. This paper represents the amalgamation of each sector's efforts to support the general public to guide households through the retrofit process.

I look forward to seeing the retrofitting implemented across the earthquake-affected districts and all vulnerable houses in the country, and to seeing the impact that it will have. This represents another positive step forward in the construction process, and will support households to retrofit their homes so that they are safe, compliant, and resilient in the face of future disasters. Additionally, I trust that this experience paper will contributes to the building and sharing of knowledge to pave the way forward toward safe housing, and to the consolidation of the NRA's documented legacy for Nepal.

Dr Chandra Bahadur Shrestha
NRA Executive Member & ICNR Convener
National Reconstruction Authority

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INTRODUCTION

In Nepal, there is currently a stock of around 6 million houses across the whole country and 2.5 million houses in the 32 districts affected by the 2015 earthquake. About 800,000 houses are categorized as reconstruction beneficiaries whereas approximately 70,000 are categorized as retrofitting beneficiaries. Analysis suggests that there remain almost 3.5 million houses nationwide and up to 1.1 million houses within earthquake-affected districts that require seismic retrofitting in some form.

Retrofitting is the judicious modification of the strength, stiffness and ductility of structural members or of the structural system to improve the structure's performance in future earthquakes. Retrofitting generally includes increasing the strength or ductility of individual members or introducing new structural elements to significantly increase the lateral force resistance of the structure. There are several approaches and techniques for the retrofitting of existing buildings currently in application all over the world. However, in low strength masonry buildings, especially in stone and mud masonry due to limited implementation examples, repair and retrofitting is viewed as an unfeasible option by our communities. This is why many earthquake-affected house owners have opted towards demolition of their damaged houses for reconstruction rather than retrofitting. In fact, retrofitting presents an ideal means for the conservation of traditional architectural heritage and provides the required space for beneficiaries to maintain their traditional agrarian lifestyle.

Nepal has a long experience of seismic retrofitting. About 300 schools were retrofitted in Nepal before the 2015 earthquake and all of them performed excellently during the Gorkha earthquake. There were cases where a weak brick-in-mud block, retrofitted prior to the earthquake, stood without a crack, whereas in the same premises a reinforced concrete building, which was believed to be relatively strong, collapsed. Those examples and experiences were mainly on brick buildings; there were few examples of retrofitting of stone-in-mud buildings before the earthquake and those that existed were all school buildings. According to data obtained by the Central Bureau of Statistics in Nepal, more than 74% of the buildings damaged in the Gorkha earthquake were of low strength masonry typical in rural Nepal, emphasizing the urgent need for the retrofitting of similar houses across the earthquake region.

Despite more than 18 years of experience of retrofitting preceding the earthquake, very limited guidelines and manuals related to retrofitting were available and the knowledge was held privately among limited organizations and professionals. Retrofitting was not a common practice among masons and engineers compared to new construction practices. This was more evident in rural areas of Nepal for typologies such as stone-in-mud masonry houses.

While retrofitting was undertaken on a relatively small scale when compared to new construction post-2015 earthquake, it was an important intervention that has paved the way for risk reduction and mitigation against future possible disaster. A number of retrofitting resources have been developed by the government and various organizations, and lessons learnt during implementation of retrofit programs have been recorded. These are valuable learnings and the documentation should guide any future implementations of retrofit programs or projects.

Many technical resources like retrofit manuals, innovative retrofitting approaches, mason training guidelines, engineer training guidelines, on-the-job training programs, etc. were produced by implementing partners. Numerous technical and non-technical papers were presented and published on various national as well as international platforms. Non-technical, awareness-generating, sensitizing efforts were carried out, for which many IEC materials (video documentaries, PSAs, etc.) were also developed. It is important that these resources are documented, filed and made readily available for future use.

A list of all the documents collected during the documentation process is available in Annex 1. Digital copies can be accessed through the link provided in the Annex.

Principles and Strategies for Retrofitting

Post-disaster seismic retrofit of housing presents an opportunity not only to ensure safety of the affected population but also to change construction practice permanently so that local builders, engineers, and homeowners build safe houses in the future. Some of the strategies and considerations that were adopted to design or choose an appropriate retrofitting approach are as follows:

- Promotion of appropriate technologies that are technically reliable, economically affordable, locally available, socially acceptable, sustainable and environment friendly.

- Use of detailed housing subsector studies to determine the most cost-effective ways of retrofitting houses using materials and skills that are available through the local private sector.
- Leverage of the knowledge and skills of the technologies used in the region while taking into consideration local sustainability and acceptance.
- Empowerment of homeowners to participate in the design and manage their own construction, with technical assistance.
- Building local knowledge and capacity by working with engineers, architects, builders, universities and government.
- Working with local masons, carpenters and homeowners through on-the-job training programs to build their confidence and their ability to incorporate disaster-resistant building techniques that are culturally accepted and easy to adopt with limited training and education.
- Building confidence of all stakeholders, particularly policymakers through sensitization, demonstration and pilot programs.

Key Elements of a Successful Retrofit Program

- A homeowner-driven retrofit program is most effective when the essential technical, financial, and social components are in place.
- Retrofitting will become more effective only if the technology is locally available, widely known and culturally accepted.
- Homeowners should have been well sensitized to the importance of safety for them to be willing to invest their savings on upgrading the safety of their house, despite the fact that they might not gain additional living space.
- The materials used for retrofitting should be easily available in local markets, and the skills to work with these materials need to be present in the community.
- Demand for safe housing must be created among homeowners through information campaigns and coupling financing with building standards compliance.
- People from different cultures have their own ideas about what a house should be. They will accept structural requirements if their ideas about layout of interior and exterior spaces, orientation to light/wind/view/privacy and security are respected.
- Incentives from the government for retrofitting houses should be in place to motivate the first group of homeowners in the community to retrofit.
- The availability of locally trained human resources like masons and engineers

should be ensured and must be easily accessible to the homeowners; these experts can provide technical guidance and execute the work using local materials and technologies.

- Care needs to be taken that a situation where retrofitting is labelled as a poor person's choice should not arise.

Stakeholders in a Retrofit Program

Invaluable lessons are learnt in the field, both individually and institutionally about constructability and general feasibility of various design solutions. A feedback loop should be put in place such that a continuous learning process exists, constantly improving evaluation, design and construction processes. This can happen if there exists good coordination between different personnel in the system. There are a number of stakeholders involved in post-earthquake housing retrofit. Major stakeholders and their functions are as follows:

Government	Homeowners	Community Groups	Partners
- Develop policies and plans for promoting retrofitting, its enforcements and quality assurance. - Provide incentives to homeowners or community group for retrofitting and also oversee the work of the implementing partner. - Produce or adopt codal guidance or design guidelines for retrofitting. - Review designs, provide permit and conduct inspections to ensure compliance with approved construction documents.	- Lead the process including design, resource management, implementation and maintenance. - Hire trained and certified builders and oversee construction. - Arrange for materials and labour and any additional costs to be incurred in retrofitting.	- Assist in public awareness outreach campaigns. - Provide support, *arma-parma*, to the house owners, supporting retrofitting. - Identify local builders, building materials suppliers and other stakeholders.	- Liaise with community groups and local government to implement awareness building and outreach activities. - Provide technical assistance to homeowners for design, trained masons selection and construction process. - Capacity building of local builders, local engineers and architects on retrofitting. - Support the production of technical resources for retrofitting.

HOUSING TYPOLOGIES TYPICAL TO THE EARTHQUAKE-AFFECTED AREAS OF NEPAL

There are many different housing typologies in different parts of Nepal. Stone masonry in mud mortar buildings is the typology on which most of the retrofitting initiatives have been focused. However, this section enlists only major typologies relevant to the post-disaster reconstruction and retrofitting.

Stone Masonry in Mud Mortar (SMM) Houses

Typical SMM houses are between one and 2.5 storeys in height (two storeys plus attic) with a pitched roof. On plan, they are typically between 8m and 11m in length, and 4–6.0m in breadth. The typical storey height is approximately 2.1m for the ground and first floors, and up to 1.2m for the attic. The walls are at least 450mm thick. Most of these houses do not have cross walls. On the first floor, it is typical for two rooms to be divided by way of plywood partition walls on either side of the staircase. The performance of SMM walls will depend on their geometry (height and thickness), and the quality of masonry. Better quality walls contain a low ratio of mud to stones, more regular sized and shaped stones, and many through stones. In a traditional SMM house, the ground floor is typically used for livestock, the first floor for sleeping, and the attic floor for the kitchen and food storage.

Figure 1: Typical 2.5-storey SMM building
(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

Figure 2: Ground floor room of SMM building
(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

The thick SMM load-bearing walls are typically composed of two faces of placed stone with a rubble filling in the centre of the wall cavity. The timber floor consists of joists supported at one end on the longitudinal SMM walls and at the other end by a central longitudinal timber girder. The joists are normally well embedded into the walls. The timber girder is supported on timber posts and typically embedded into the transverse end walls. Typically, a house has four posts supporting the middle girder – one at each end and two in the middle. These wooden posts occur at each floor in approximately the same location, ultimately supporting the ridge beam of the roof. The transverse wall is usually connected to the floor framing only through this middle girder.

Stone Masonry in Cement Mortar Buildings

These are a relatively newer building typology, constructed after cement started becoming available in rural parts of Nepal. Before the earthquake, many public buildings were made of stone in cement mortar, which have also been adopted in construction of the houses. The floor is usually made of reinforced concrete slab but in some cases is made out of timber joists with a plank floor. The roofs are typically two-way slopes and the outlooks are usually similar to the SMM buildings.

Brick Masonry in Mud Mortar Buildings

These are houses typical to old settlements in and around Kathmandu Valley. These comprise load-bearing masonry walls made of bricks with mud mortar. The floor is made of timber joists and wooden planking with mud floor overlay. These houses can be up to four storeys high with typically low storey heights.

Figure 3: Typical brick in mud mortar house
(Photo credit: Build Change)

Brick Masonry in Cement Mortar Buildings

These houses are found in relatively newer settlements in and around Kathmandu Valley. These comprise load-bearing masonry walls made of brick units joined with cement mortar. The floor is usually made of reinforced concrete slab but in some cases is made out of timber joists with a plank floor.

Figure 4: Typical brick in cement mortar house
(Photo credit: Build Change)

Timber Buildings

In some parts of the Siwalik range, a high use of wood is found in building construction. Wooden framed buildings are found to be constructed using traditional methods in Sindhuli, Makwanpur and Okhaldhunga districts. The two types of timber buildings that are common in the areas were retrofitted. These are as follows:

Bare timber frame:

These are unbraced frames which are capable of resisting both vertical and lateral load by the bending of beams and columns. It is a rectilinear assemblage of beams and columns, with rigid connections. Resistance to lateral forces is provided primarily by rigid frame action. These are designed and constructed with enough rigid connections to resist lateral seismic forces. However, the structures that exist in rural Nepal are non-engineered and not designed.

Figure 5: Typical timber frame structure
(Photo credit: Build Change)

Timber frame with masonry walls:

These buildings have a timber frame with masonry infill on the ground floor. The addition of masonry walls increases the structure's stability against lateral loads such as earthquakes and wind load. There are wall types which are dependent upon the construction of masonry. However, the buildings that commonly exist in rural Nepal are non-engineered and not designed.

Figure 6: Typical timber frame structure
(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

Reinforced Concrete (RC) Frame Buildings with Masonry Infill

These buildings have a reinforced concrete beam and columns system. The frames are typically infilled with brick masonry in cement mortar. This typology is very common in urban areas. While damage to RC frame buildings was minimal in the Kathmandu Valley, there was extensive damage to these types of buildings closer to the earthquake epicenter (for example, in Sindhupalchok). The masonry is typically constructed after the frames are erected and most of the time is not connected to the frames.

Figure 7: Typical reinforced concrete frame building with masonry infill
(Photo credit: Build Change)

RETROFITTING APPROACHES

There were various retrofitting approaches implemented by partner organizations during the reconstruction post disaster. Some of the approaches were based on the guidelines and manuals on retrofitting published by the Government, whereas others were based on new approaches developed by the partners with approval from CLPIU/NRA. The approaches that were used are defined in brief below:

Strong Back Approach

The strong back approach is based on the type design approved by the Central Level Project Implementation Unit (CLPIU), Building division, under the National Reconstruction Authority (NRA) of Nepal. A manual aiding the use of the type design has been prepared and can be accessed from the list of resources in Annex 1. This type design can be used by engineers.

The strong back design comprises a system of reinforced concrete strong backs placed at corners and at locations along the length of the wall, connected at floor level by slab strips and a ring beam at the top of the walls, as shown in Figures 8 and 9. Heavy gable walls made of SMM are dismantled and a light CGI or timber gable is provided with good connection to the roof and the ring beam. In addition, improvements to the connections with the existing timber elements are provided with the help of CGI straps.

Technical approach

Strong back:
The function of the strong back is to brace the walls that are out of plane and provide a load path for the out-of-plane wall loads to reach the diaphragms above and below. The corner strong backs help to inter-connect the orthogonal walls, thus preventing corner separation. The strong backs also act as a buttress to break the horizontal span of the wall. The strong back is connected to the walls with the help of through dowels as shown in Figure 11.

Slab strip for diaphragm strengthening:

At the floor levels, a slab strip is provided around the inside perimeter of the wall and across, connecting opposite strong backs. The function of the slab strip is to improve connectivity of all walls to the diaphragms and to each other, creating a box effect, as shown in Figures 13 and 14. The slab strip is also connected to the joists and functions as a chord element at the edge of the diaphragm, thus increasing the diaphragm stiffness and strength. The slab strips aid in distributing the out-of-plane loads to the perpendicular walls.

Ring beam:

A reinforced concrete ring beam is inserted at the top of the walls to provide connectivity and restraint to the walls at the top, and to promote a box effect. The position of the ring beam can be seen in Figure 8. The ring beam in the type design is directly connected, with dowels, to the new strong backs.

Through concrete:

Through concrete is applied all over the walls. The through concrete connects the inner and outer wythes of the thick walls, as shown in Figure 9, preventing delamination and hence increasing the overall out-of-plane capacity of the walls.

Plastering of walls:

The SMM walls are plastered at the exterior and interior face. The plaster, together with the through concrete, contributes to an increase in the capacity of the wall in the in-plane direction. In cases where the wall pier is slender and/or the quality of masonry work is very bad, the wall piers are jacketed with welded wire mesh on both sides.

Improving existing timber connections:

The existing timber connections are generally acceptable for gravity loads but not for wind and lateral loads. So, simple improvements in connections using galvanized iron wires and/or corrugated galvanized iron straps are provided to the roof, as shown in the photo in Figure 15.

Strong back approach construction procedures are well documented in Engineering Manual: Standard Type Design Retrofits for SMM structures.

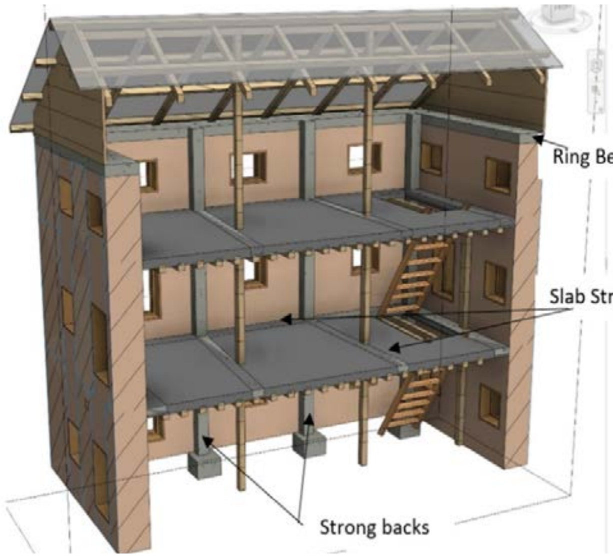


Figure 8: Schematic of strong back approach of retrofitting

(Source: Build Change)

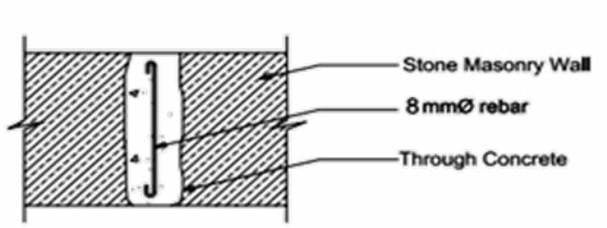


Figure 9: Through concrete in an existing SMM wall
(Source: Build Change)

Figure 10: House retrofitted using the strong back approach
(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

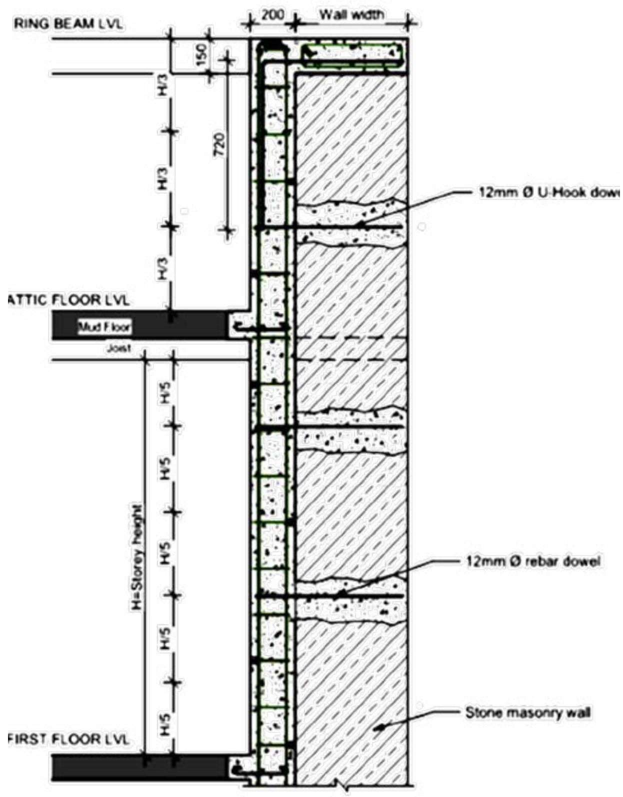


Figure 11: Detail of strong back installation

(Source: Build Change)

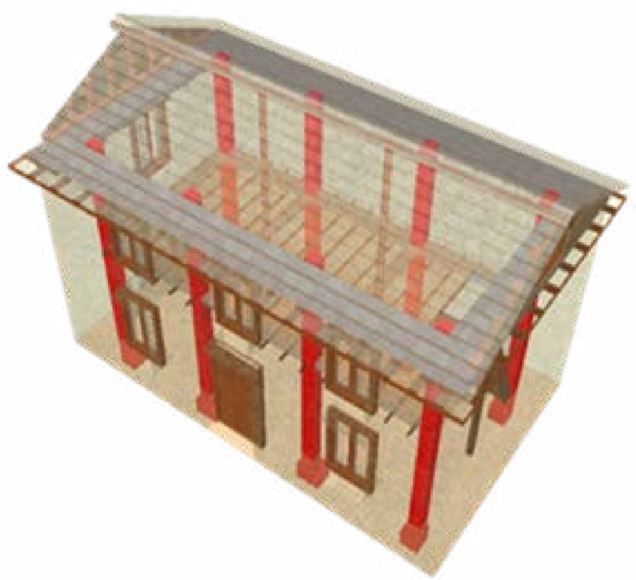


Figure 12: Position of strong backs (indicated in red) in a house
(Source: Build Change)

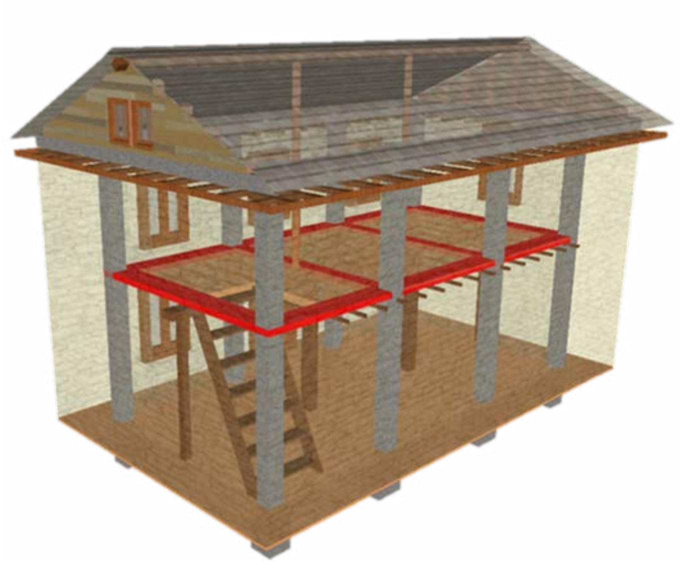


Figure 13: Slab strip (indicated in red) connects the diaphragm to the walls as well as interconnecting the strong backs
(Source: Build Change)

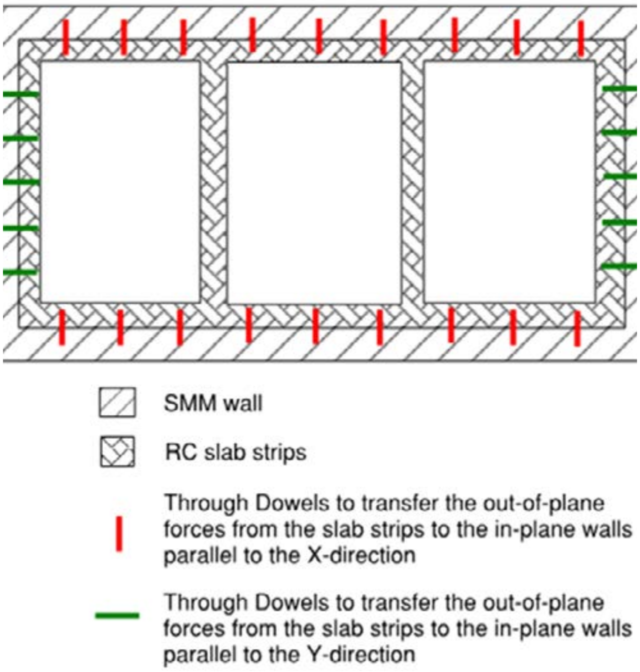


Figure 14: The red and green lines indicate dowels spaced at 600mm that connects the slab strip to the walls
(Source: Build Change)

Figure 15: Improvement of existing timber connection
(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

Cost of strong back retrofitting

Retrofitting approach	Number of storeys	Cost of retrofit (NPR/m2)	Mean liveable floor area (m2)	Total field cost (NPR)
Strong back	1.5	7,000	50	350,000
	2	7,500	50	375,000
	2.5	5,000	110	550,000

Table 1: Cost of strong back retrofit for different number of storeys

Retrofitting approach	No. of houses	Average cost (NPR/m2)
Strong back	225	6,012

Table 2: Strong back average cost of retrofit

GI Welded Wire Mesh Splint and Bandage (with Local Failure Jacketing) Approach

The splint and bandage technique for retrofitting has been in common use in Nepal since the late 1990s. Several hundred schools, private and public buildings had been retrofitted using this approach prior to the 2015 Gorkha earthquake. The method is also based on the designs prescribed in the Repair and Retrofit Manual for Masonry Buildings published by the National Reconstruction Authority in June 2017.

The splint and bandage design consists of vertical splints at building corners, at wall intersections and on either side of openings, plus horizontal bandages, at sill, lintel and floor levels. The function of splints is to add in-plane capacity and stiffness to the walls, while bandages provide a box effect to tie all the walls together. The wall areas not covered by the splints and bandages are covered by wire mesh that confines the walls. A plinth beam is inserted, the function of which is to anchor the rebar in the splints, confining reinforcement and connecting it back to the wall foundation. Galvanized iron wire mesh is used for the splints and bandages.

Cement sand plaster is applied on the outside and inside of the walls to cover all the reinforcement. The cement–sand ratio used in splint and bandage design is richer in cement compared to that used in the strong back approach, as the lateral capacity of the system is reliant solely on the mesh and plaster combination. In comparison to approaches where mesh is not used, a higher proportion of cement is required due to the need for a double layer of plastering to ensure proper adhesion with the SMM walls. Other works, such as replacing heavy gables with light, well connected ones and overall improvement in connection of existing timber members, were done similarly, to the strong back approach.

Although there are other options for splint and bandage also mentioned in the Repair and Retrofit Manual, such as reinforced concrete, timber, etc., this document will only consider the use of galvanized iron wire mesh as it was found to be more cost effective, applicable and acceptable at the community level, especially in stone in mud masonry buildings.

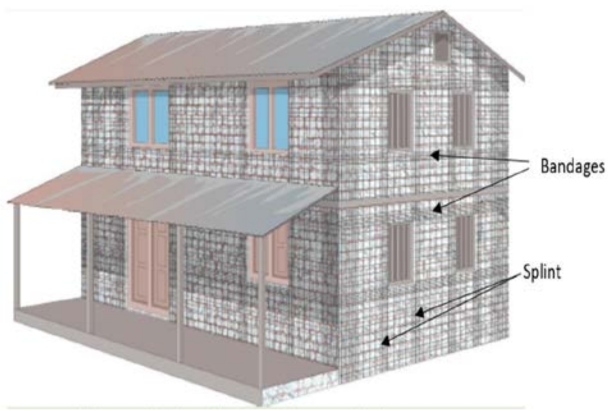


Figure 16: Schematic of splint and bandage approach (Repair and retrofitting manual)

(Source: NRA's Repair and Retrofitting Manual)

Figure 17: Retrofit of a house using splint and bandage approach

(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

Research and development

While the splint and bandage technique has long been in use in Nepal, its research and applicability was limited to rural masonry buildings, especially stone in mud mortar. The huge demand for retrofitting as a result of damages in rural buildings during the 2015 Gorkha earthquake required extensive study of the materials and techniques for retrofitting at a feasible cost.

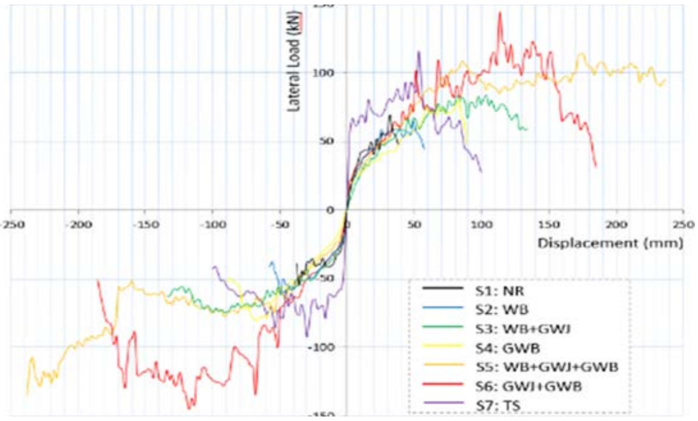


Figure 18: Ultimate load and ultimate lateral displacement obtained from pushover tests conducted in stone masonry walls with various strengthening options
(Source: USAID/NSET, Baliyo Ghar Program)

Figure 18 shows the ultimate load and ultimate lateral displacement obtained from pushover tests conducted in stone masonry walls with various strengthening options.

The P-D curve obtained from pushover tests conducted in stone masonry walls with various strengthening options shows that use of gabion wire mesh as splints, bandages and jacketing (S6) increases the ultimate lateral displacement by 389% compared to the unreinforced stone masonry wall (S1).

Further, shaking table tests were conducted to obtain a better understanding of the level of safety that can be achieved from this type of retrofitting technique. The results gave a lot of confidence, especially as regards the reliability of seismic retrofitting of rural housing. The test was conducted jointly by Beijing Normal University and NSET in China in 2017.

Construction procedure

Key steps for the splint and bandage technology are listed below.

- Scaffolding and Shoring
- Stripping of Plaster
- Architectural Modifications
- Placement of Foundation Tie Beam
- Placement of Splints and Bandages
- Placement of Anchorage
- Providing GI Wire Jacketing for Local Failure Control
- Concreting Foundation Beam
- Plaster and Curing

The construction procedure of splint and bandage technology is presented in the photos below. All these construction procedures are well documented and detailed in the Repair and Retrofit Manual for Mansonry Structures.

Cost of splint and bandage retrofitting

Retrofitting approach	No of houses	Average cost per built up area (NPR/m2)
Splint and bandage	27	7,700
Welded GI wire mesh splint and bandage with local failure GI wire jacketing	60	5,562

Table 3: Splint and bandage average cost of retrofit

Figure 19: Scaffolding and props seen around a stone-mud masonry house undergoing retrofitting in Nuwakot

Figure 20: Trainee masons working on removal of cement plaster and surface preparation of house undergoing retrofitting

Figure 21: Ongoing architectural modification work on construction of wing walls during retrofitting of house in Dolakha

Figure 22: Mason preparing foundation for lateral tie beam below the plinth level for tying up reinforcements

Figure 23: A pair of masons fixing vertical and horizontal strips of welded GI wire mesh as splints and bandages during retrofitting in Dolakha

Figure 24: Anchoring inner and outer mesh of GI wires

Figure 25: Preparing wire mesh using GI wires and anchoring to the wall to prevent local failure in stone masonry building

Figure 26: Concreting of foundation tie beam after completion and anchorage of reinforcements

Figure 27: Plastering of surface after completion of all retrofitting works

(Photo credits for Figure 19–27: USAID/NSET, Baliyo Ghar Program)

Containment Reinforcement Integrated Splint and Bandage Technology

Principles of seismic retrofitting

While developing containment reinforcement (CR) integrated splint and bandage technology for retrofitting, the following elements were critically evaluated for technical and economic feasibility of retrofitting of the unreinforced masonry buildings in mud or without mortar:

- Minimum cost of the intervention
- Minimum downtime
- Minimum intervention
- Minimum discomfort to the building occupants.

General approach for seismic retrofitting

The focus of the seismic retrofitting was the following:

a. Improve building integrity. Stone and brick masonry buildings typically suffer from a lack of integrity. Hence, it is very important to improve the integrity of these buildings to achieve “box effect”. Box effect can be achieved by providing positive connections between the lateral load-resisting elements so the seismic forces can be transmitted to the members that can resist them.

b. Avoid brittle and sudden failure modes. The retrofit should eliminate the possibility of failure of connections or toppling of walls, which are undesirable modes of failure.

c. Increase lateral strength. Improve the lateral strength of building components such as out-of-plane stability of walls and in-plane shear and bending strength of walls.

d. Eliminate sources of weakness. Eliminating features that are sources of weakness, such as a lack of through-stones in walls, leads to delamination or connection between cross walls.

e. Improve uniformity. Asymmetrical plan of masonry buildings and large openings in walls are both sources of stress concentration in certain elements that could lead to premature failure.

f. Reduce building weight. Lighter buildings generally suffer less damage than heavier ones, even though both may have been constructed using similar building materials and techniques.

Technical approach

To meet the general principles of seismic retrofitting following the above discussed approach, the following was recommended for the retrofitting of these buildings:

- Splints and bandages: The technical approach for location, placement, and installation of splint and bandage construction is the same as in the GI welded wire mesh splint and bandage approach.
- Containment mesh: To basket and thereby prevent disintegration of the stone masonry walls, 3mm-diameter galvanized steel wires were provided in both horizontal and vertical directions on both surfaces of the walls. These were tied together by cross links (cross ties) passing through the walls. These cross links also mitigate delamination of stone masonry walls.
- Tying elements together: Elements of floor and roof, such as floor beams and joists, roof beams and rafters, were tied together to improve integrity and floor/roof structure. The floor joists and roof rafters and beams were also tied to the walls. Posts supporting the floor and roof were tied to the floor/roof.
- Floor and roof bracing: Floor and roof bracings made of multiple strands of wires were added to both floor and roof structures to improve their in-plane stiffness. The ends of the bracing were tied to walls.
- Gable walls: Gable walls were either deconstructed and replaced by timber structure clad with timber planks or CGI sheets, or new gable band was provided and then the wall was secured to the roof structure.

Figure 28: Example of CR integrated splint and bandage technology
(Photo credit: UNDP/ Government of India funded Nepal Housing Reconstruction Project in Gorkha)

CR integrated splint and bandage technology is based on IS: 13935 (particularly for splint and bandage). It has been further enhanced through its integration with the containment reinforcement technology developed based on the experimental method approved by the Government of Nepal (Volume II Catalogue: Alternative Technology). This retrofitting technology enhances the seismic performance of the building by using containment reinforcement with splint and bandage, thus increasing its integrity, uniformity, and strength. It has been further enhanced to resist seismic forces.

The following are the key steps for the construction procedure of CR integrated splint and bandage which have been referenced from the scientific paper *Improving seismic safety of existing vernacular buildings - a reality or dream?* (Pradhan et al, 2020):

- Secure "bandages" horizontally on walls
- Secure "splints" vertically at critical junctions of the walls
- Put in place containment reinforcement wires (vertical & horizontal)
- Ensure flexible diaphragms at floor and roof level and ensure connections between wall structure and roof structure

The construction procedure of CR integrated splint and bandage technology is demonstrated in the photos below. All these construction procedures are well documented in the Repair and Retrofit Manual for Mansonry Structures.

Figure 29: Securing the "bandages" horizontally on walls

Figure 30: Securing "splints" vertically at critical junctions of the walls

(Photo credit for Figures 29–32: UNDP/ Government of India funded Nepal Housing Reconstruction Project in Gorkha)

Figure 31: Containment reinforcement wires (vertical & horizontal) put in place

Figure 32: Ensuring flexible diaphragms at floor and roof level and ensuring connections between wall structure and roof structure

Though the retrofitting work was completed in a week, the other elements (bandages, splints, vertical and horizontal wires) were installed in stages. This means the process can be implemented in an incremental manner, spread across a period of time, depending upon availability of funds. These buildings could be further strengthened, if desired, by applying ferro cement plaster to the wall surfaces.

Cost of CR integrated splint and bandage retrofitting

Retrofitting approach	No. of houses	Average Cost (NPR/m2)
CR integrated splint and bandage	30	3,640

Table 4: CR Integrated splint and bandage average cost of retrofit

Retrofitting of Timber Houses

The retrofitting approach taken is to comply with the requirements of the Light Timber and Steel Structures Manual published by the Government of Nepal. This manual was not written with retrofitting in mind, but the concepts prescribed within it could be adopted for the retrofit design scheme. This consists of designing a timber bracing scheme, including the lateral bracing capacity of masonry walls as well, in the case of timber frame houses with masonry walls. In addition, the existing timber connections of the roof and the timber members and the connection between the two floors are improved. The stability of the masonry walls is also ensured, thus preventing failure due to overturning. The retrofitting techniques used for the most prevalent typology of houses are as follow:

Bare timber frame:
Unbraced timber frames with timber plank walls. These are typically two storeys high. During the retrofitting process, the bare frame is converted into braced frames by providing bracings and connection improvements to the timber structure. The bracings are designed to take all the lateral load due to earthquakes.

Timber frame with masonry wall:
These buildings have a timber frame with masonry infill in the ground floor. Retrofitting is done to comply with requirements of Light Timber and Steel Structures Manual published by the GoN. This consists of designing a timber bracing scheme considering the lateral bracing capacity of masonry walls. Also, the existing timber connections of the roof, the timber members and the connection between the two floors are improved. The stability of the masonry wall is ensured, thus preventing overturning.

Cost of timber retrofitting

Retrofitting approach	No of houses	Average cost (NPR/m2)
Timber	30	4,110
Timber with masonry ground floor	10	4,523

Table 5: Timber house average cost of retrofit

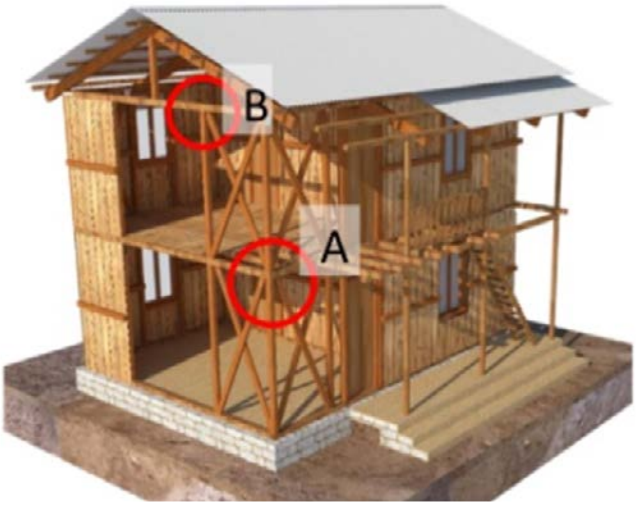


Figure 33: Schematic of timber house retrofit approach

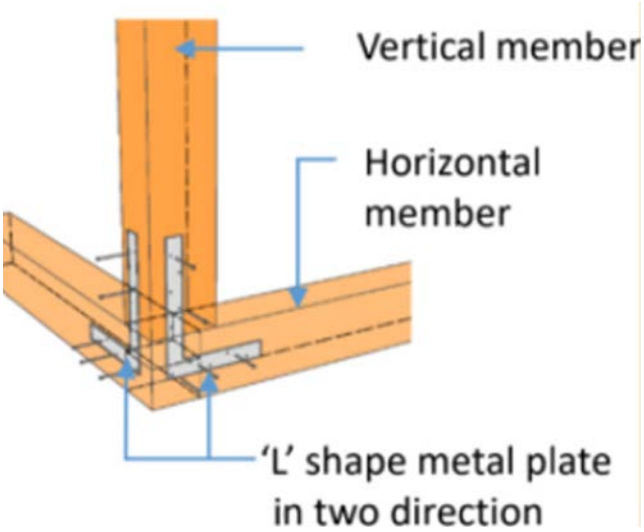


Figure 34: Detail at A: Connection at corners

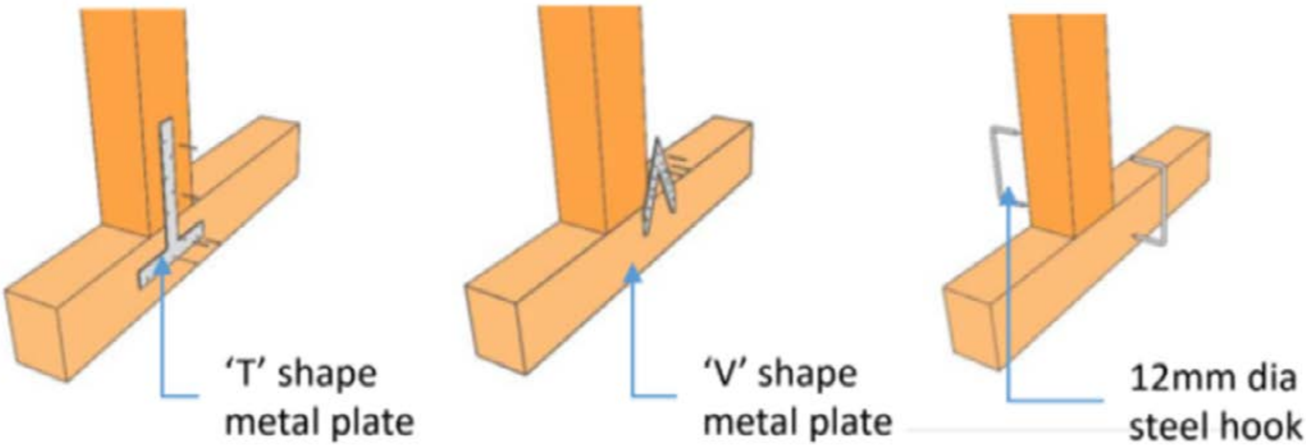


Figure 35: Detail at B: Horizontal and vertical connections at intermediate locations

(Source for Figure 33–35: NRA's Repair and Retrofit Manual for Light Timber/Steel Frame Structures)

DESIGN GUIDELINES AND TECHNICAL MANUALS

DUDBC has published various guidelines and manuals to support the retrofitting process. The manuals range from ones that support engineers for designing retrofits to guidelines that offer quick solutions that even an engineer new to retrofitting can use to offer retrofitting advice and solutions to homeowners post-earthquake. Some of these guidelines are mentioned in brief below:

Seismic Retrofitting Guidelines of Buildings in Nepal

There are a significant number of non-engineered and semi-engineered buildings in Nepal which were built before the code was implemented that are vulnerable to earthquakes and need to be strengthened for withstanding future earthquakes. This vulnerability was exposed in urban and rural areas during the earthquake when a large number of these types of houses were damaged. This document was endorsed by the Government of Nepal in 2016 to provide guidance for engineers to design retrofits. The document consists of three parts covering three major typologies of buildings common to Nepal.

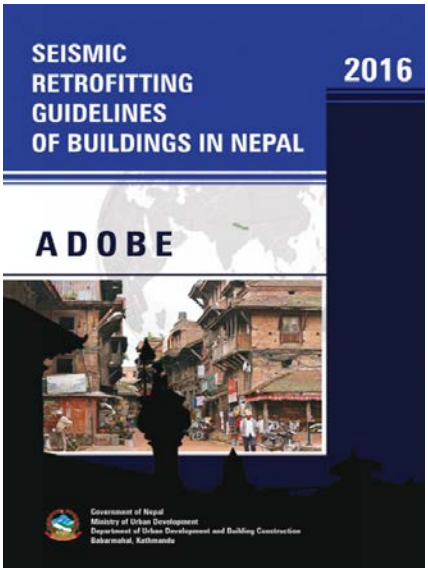


Figure 36: Seismic retrofitting guidelines of buildings in Nepal – Adobe

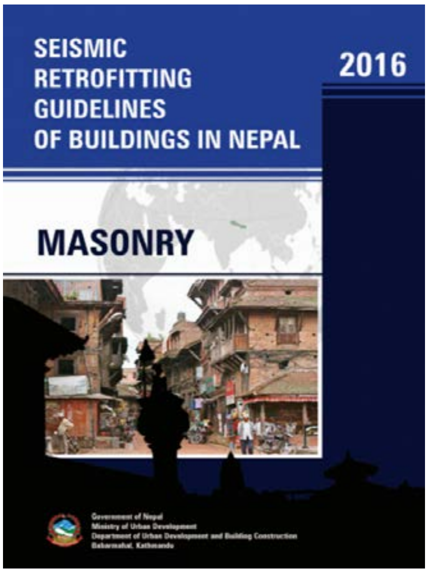


Figure 37: Seismic retrofitting guidelines of buildings in Nepal – Masonry

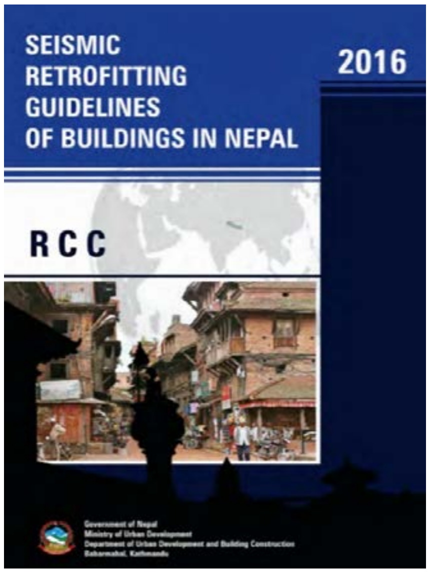


Figure 38: Seismic retrofitting guidelines of buildings in Nepal – RCC

Repair and Retrofitting Manual for Masonry Structures

This manual was published by the NRA to support the minimum interventions work required to carry out the retrofitting of houses categorized as damage grade 2 and damage grade 3 under the GoN reconstruction programme. This manual will support engineers to provide advice and guidance to homeowners for implementation of repair and retrofitting strategies. The document also covers policies for the distribution of tranches including minimum technical criteria that need to be met. The manual can be used for residential houses of a specific size, only and recommends four approaches for retrofitting:

- RC splint-bandage and GI wires in remaining part
- Welded GI wire mesh splint-bandage and GI wire jacketing
- Welded GI wire mesh splint-bandage and PP band jacketing
- Wooden splint-bandage and GI wire jacketing

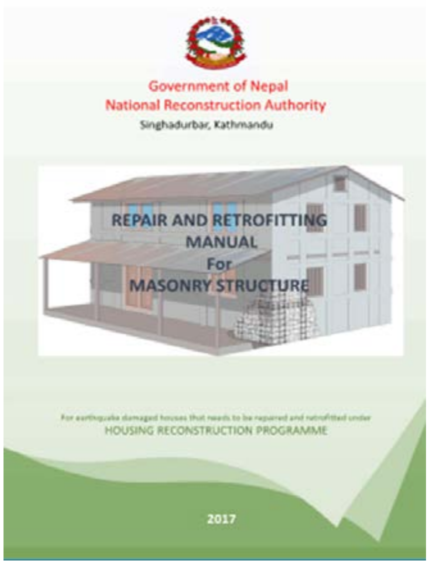


Figure 39: Repair and retrofitting manual for masonry structures

Repair and Retrofitting Manual for RCC Structures

This manual was developed and published by the NRA to aid the Government engineers to evaluate retrofit works and to support them to give necessary advice to the homeowners regarding retrofitting of reinforced cement concrete (RCC) framed structures. Retrofit approaches such as reinforced concrete jacketing methods, use of carbon fiber reinforced plastic jacketing, etc. are mentioned in the manual. As RCC structures are expected to be engineered and are relatively more complex than masonry structures, use of this document has been limited; the manual has, however, been referenced by engineers as useful resource material.

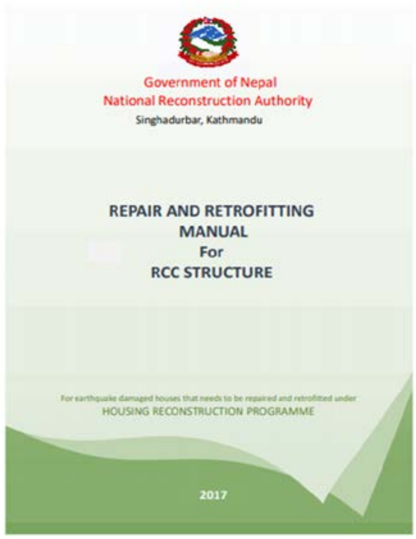


Figure 40: Repair and retrofitting manual for RCC structures

Engineering Manual: Standard Type Design Retrofits of Stone Masonry with Mud Mortar (SMM)

This manual provides the engineering basis, limitations and design of the approved retrofit type design for SMM builds using the strong back approach. The manual clearly communicates the applicability and restrictions of the type design and provides guidance to engineers on how to use and how not to use the type design ready-to-use details.

This manual can be used by relatively young engineers to provide solutions to a wide range of SMM houses where the problem faced comply with the prescribed applicability criteria.

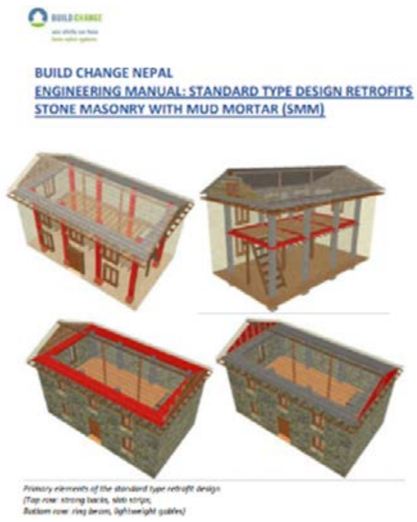


Figure 41: Engineering Manual: Standard type design retrofits of SMM buildings (strong back approach)

Norms for Rate Analysis of Retrofitting Masonry Building

A retrofitting technical working group was formed on 20th December 2019 to support the NRA, CLPIU Building division, to speed up the retrofitting of buildings in earthquake-affected areas through standardization of technical documents, solutions and approaches related to retrofitting. This group consisted of partner organizations, namely, NSET, Build Change, UNDP and HRRP who are actively working in retrofitting in the earthquake-affected districts of Nepal. Norms for Rate Analysis of Retrofitting Masonry Buildings is one of the main documents prepared by the retrofitting technical working group. This document provides basic guidelines of norms for load-bearing masonry structures.

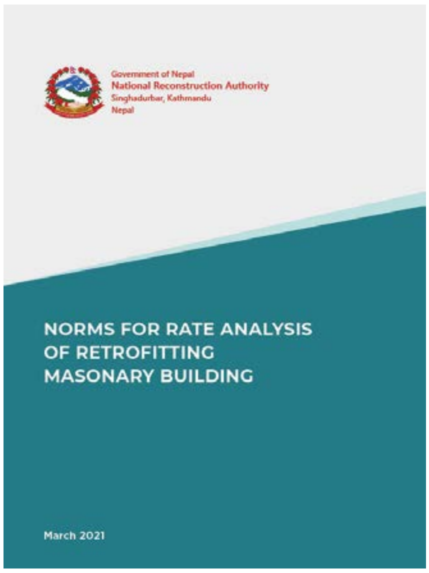


Figure 42: Norms for rate analysis of retrofitting of masonry buildings

This document contains vital information to estimate the bill of quantities of various civil construction works that are unique to retrofitting.

Correction/Exception Manual for Masonry Structure

This manual was published by the NRA to cover the exceptional cases observed in the field, other than those mentioned in Minimum Requirements, plus several correction measures along with step-by-step procedures for mitigation of future issues. This manual can support the engineers to provide advice and guidance to homeowners who have already constructed a house not compliant with the minimum requirements but who would like to implement correction and mitigation strategies. This manual is divided into two sections:

- Exception / Correction
- Mitigation Measures

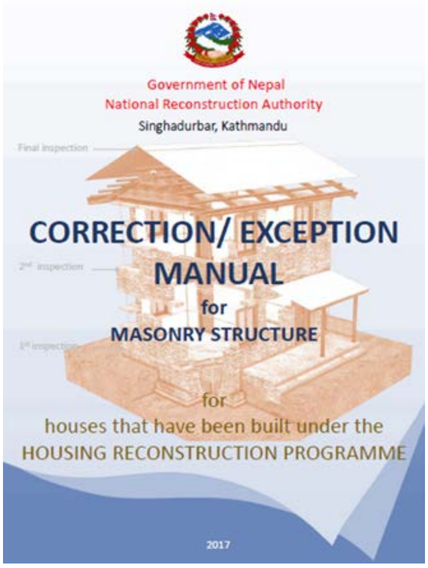


Figure 43: Correction / Exception Manual for Masonry Structure

Light Timber/Steel Frame Structure Manual

This manual was published by the NRA to support, inspect, evaluate and correct light timber and steel frame houses. The manual is based on recognized engineering principles and practices. It consists of simplified calculation and hands-on correction methods. Most of the houses at Siwalik range, Makwanpur, Okhaldhunga and Sindhuli are constructed by traditional methods using wood; this manual will support the engineers to provide advice and guidance to homeowners for implementation of correction strategies. The manual is divided into three sections:

- Theory of Seismic Evaluation
- Technical Specification
- Correction for Existing Buildings

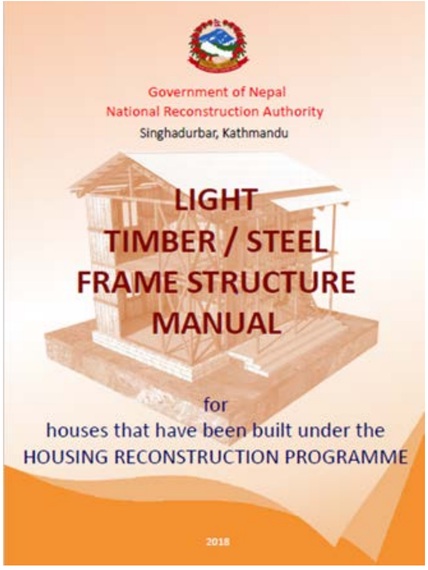


Figure 44: Light Timber/ Steel Frame Structure Manual

PUBLIC OUTREACH, INFORMATION AND AWARENESS

As retrofitting is a new concept that has not yet penetrated the mindset of homeowners and decision makers, a multi-pronged approach is required to develop widespread understanding of the need, the benefits and the methods of retrofitting houses. Public outreach through Information, Education and Communication (IEC) is key to raising awareness of the concepts of retrofitting and thus enabling homeowners, masons and engineers to take informed decisions. Information is key to empowerment. As the process involves various stakeholders such as homeowners, masons, rural municipalities and urban municipalities, engineers, policy makers and other officials, who have different roles and responsibilities and different abilities and capacities to promote retrofitting, their sensitization on retrofitting becomes essential. Hence, the IEC approach needs to consider diversity in terms of end users to produce tailored materials targeted at each group. Various IEC materials in the form of videos, flyers, posters and booklets have been produced by different partners, focusing on different aspects of retrofitting to support the post 2015 earthquake recovery. Various mediums and methods have been chosen to expand the outreach, making the information sharing less technocratic and more inclusive. These IEC materials have been compiled and uploaded onto the drive that can be accessed through Annex 1.

Methods and Media Used

Videos:

Various partners have produced videos capturing multiple aspects of retrofitting. There are fourteen videos prepared to provide conceptual clarity on retrofitting, targeting the general public, technicians and policy makers. These videos mainly focus on what retrofitting is, why there is a need to retrofit, what the benefits of retrofitting are, testimonials from homeowners who have retrofitted their houses, and how to initiate the retrofitting once you decide to retrofit your house. There are also videos focused on building the confidence of stakeholders and homeowners through demonstrations of shock and shake table tests of retrofitted houses, along with experts providing their guidance and explanations on the benefits of retrofitting.

Figure 45: Spreading information on retrofitting though video messaging
(Photo credits: UNOPS, Build Change, BBC Media Action, Baliyo Ghar Program)

Public service announcements:
Short informational videos to give basic information on retrofitting, including explaining what retrofitting is and how it can be done, explaining technical information regarding retrofitting in non-technical and simple ways.

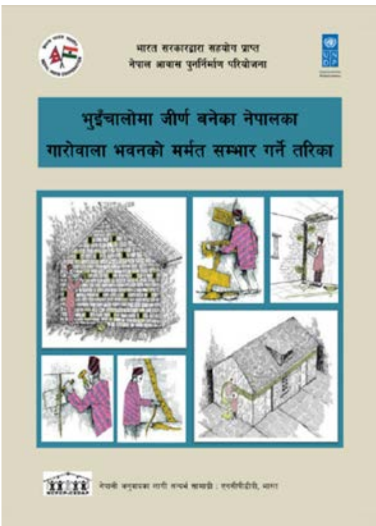


Figure 46: Booklets on repair and restoration

Figure 47: Booklet on 10 points to remember in retrofitting

Posters:

Three different types of posters have been produced for various target groups, raising mass awareness on both technical and financial aspects of retrofitting. The posters targeting homeowners are focused on cost comparison between retrofitted and newly constructed houses and on ten key points to remember when planning to undertake retrofitting. Additionally, a set of 6 posters have been produced for masons and engineers, providing step-by-step guidance on undertaking containment reinforcement integrated splint and bandage technology.

Figure 48: Cost comparison of retrofitting with new construction

Figure 49: Set of 6 posters provide step-by-step guidance on CR integrated splint and bandage technology

Flyers:

Two different flyers have been produced to raise mass awareness of the possibility to strengthen existing or damaged buildings. These aim to sensitize the people to the basic terminology of 'repair, restore and retrofit'.

Figure 50: Flyers for raising awareness on retrofitting

Innovations:

Retrofitting is a new concept, so helping people understand it requires a multi-pronged approach. With this in mind, various radio programs and jingles have also been prepared and broadcasted through local radio stations in the earthquake-affected districts.

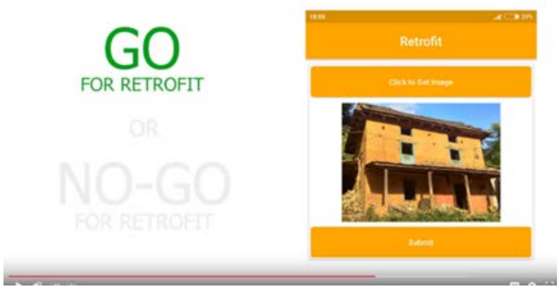


Figure 51: Using Artificial Intelligence to aid retrofitting process

As people in rural villages are more comfortable with visual media than written information, priority has been given to preparing videos that are more interesting, understandable and even sharable using various social media. Likewise, the print materials have also focused on illustrating using visuals.

Videos have been developed to introduce innovations in terms of retrofitting technologies, as well as seismic assessment using artificial intelligence. They provide ideas for strengthening buildings to mitigate pre-existing vulnerabilities.

CAPACITY BUILDING

Different partner organizations developed different training resources for retrofitting based on the varying approaches and requirements. Some of the major training programs that were given to engineers and builders are described in brief in this section:

Builder Training – 50-day OJT for Strong Back Approach

An on-the-job (OTJ) builder trainer's manual and picture guide for strong back retrofitting were developed and subsequently approved by CTEVT. A detailed competencies list required to retrofit a house was also produced. Based on these competencies, an OJT schedule was developed. Engineers and builder trainers delivered training on site for the builders during the construction of model houses. The training included:

- Safety and site management
- Basic construction tasks
- Shoring and scaffolding
- Repair works
- Installation of ring beam, strong backs, timber member splicing, slab strips, through concrete, gable wall
- Connection improvements at the roof, porch and balconies
- Plaster and wall finish

Figure 52: Participant constructing ring beam at ongoing training on strong back
(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

Builder Training – 5-day OJT for CR Integrated Splint and Bandage Approach

A training curriculum for OJT on CR integrated splint and bandage has been developed for training of local masons on retrofitting. It is a 4-day training package plus a refresher day, with both theoretical and practical sessions, providing the opportunity to work on-site on a house covering the major elements and aspects of retrofitting. The training is planned and rolled out based on the step-by-step manual developed to execute the retrofitting on a house as follows:

- First day the masons are provided orientation on repair and retrofitting with overview of the training process. This is followed by practical sessions on dismantling or repairing assessment and mark-ups for placement of splint, bandage and cross links leading to placement of belts and shear anchors
- Second day is mostly practical and focused on placement of splint at corners and openings
- Third day's theoretical session is focused on retrofitting of the roof and flooring elements. Practical sessions are focused on splints at corners and openings, vertical wires, and in-plane diagonal wires for floors
- Fourth day is mostly practical sessions focused on placement of vertical and horizontal wires, and in-plane diagonal wires for securing roofs and roofing elements. Further observations, identified issues and next steps are discussed.

Upon completion of the 4-day training, as formally agreed with the homeowners prior to the training, the same masons continue to work for the next 4 to 5 days to complete the retrofitting of the house, where the homeowner bears the cost of masons and materials. During this whole process, the technical team of the project provides hand-holding support to the masons to complete the retrofitting, helping them to apply their acquired knowledge and skills. Thus, though the training package from the project is only for 4 days, the masons are further engaged until completion of the retrofit of the house, which provides them with the opportunity to understand all elements of retrofitting in a house and develop skills to address any issues. This 4-day mason training regime is followed by a 1-day refresher training session to boost the confidence of the masons and address any issues they have faced while working in the field.

Builder Training – 25-day OJT for Splint and Bandage Approach

This training program is intended to enhance the capacities of existing skilled masons to help in the retrofitting of partially damaged houses in post-quake reconstruction campaigns. Additionally, as part of the training program, a partially damaged house is retrofitted by the trainee masons and is then utilized for local awareness as a demonstration model. Thus, the training serves two purposes: capacity building as well as demonstration.

The training is based on a 25-day curriculum developed following the standards of other on-the-job training curricula developed by CTEVT and endorsed by the NRA.

The major objectives of the training are as follows:

- To enhance the capacity of skilled masons working in the field of housing construction to undertake the retrofitting of partially damaged stone and brick masonry buildings.
- To repair and retrofit partially damaged houses at local level as demonstration models to raise awareness in the local community of the technology and feasibility of retrofitting using locally available human resources and materials.
- To enhance understanding among local communities and stakeholders of methods of increasing the seismic capacity of existing damaged and undamaged buildings, thus driving towards disaster-resilient communities.

Engineer Training – Competency-based OJT for Strong Back Approach and Splint and Bandage Approach

A list of key construction stages were developed for the strong back approach and the splint and bandage approach. Engineers were required to visit any retrofitted house to learn each of the key construction stages. A certificate was provided to the engineer once the engineer completed each of the key construction stages, and a competency test was carried out to determine knowledge gain.

Engineer Training – 4-day OJT for CR Integrated Splint and Bandage Approach

A training curriculum for OJT on CR integrated splint and bandage has been developed for training of engineers. It is a 4-day training package, with both theoretical and practical sessions, providing trainees with the opportunity to work on-site on a house covering the major aspects of retrofitting. The training is guided by a step-by-step field manual prepared specifically for the engineers, which is focused on the fundamentals of retrofitting and field level implementation. This training also includes qualitative seismic assessment of existing buildings, identification of deficiencies, intervention strategies, quality control, adjustments in retrofitting elements, etc.

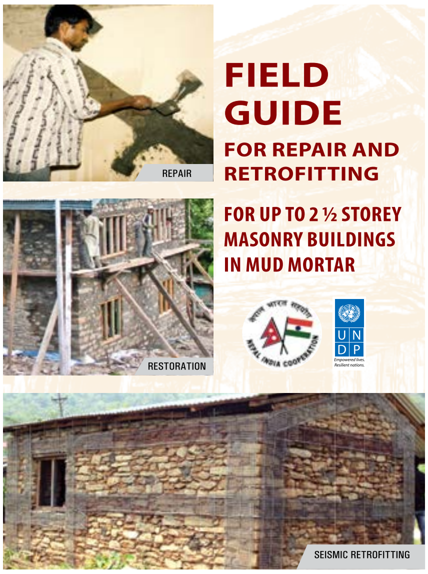


Figure 53: Step-by-step field manual for engineers retrofitting using CR integrated splint and bandage technology (SMM)

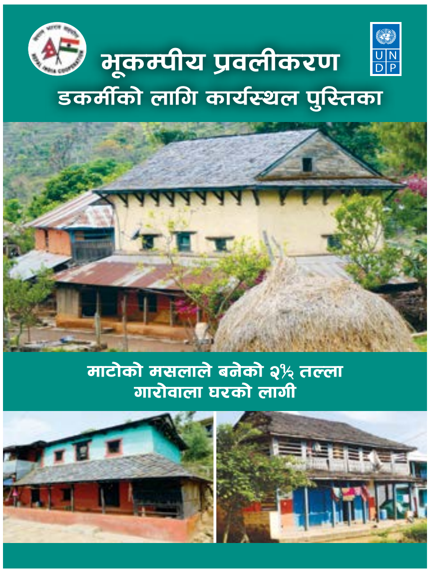


Figure 54: Step-by-step field manual for masons retrofitting using CR integrated splint and bandage technology (SMM)

Figure 55: Field manual for retrofitting of masonry buildings (following GoN approved retrofitting guideline)

Engineer Training – 4-day Classroom Training including Site Visits

A curriculum and training materials targeted at field engineers working on retrofitting was developed and carried out. The training was conducted over 4 days and NRA engineers from 32 districts attended the training. Local district “hubs” were created so that trainees from nearby districts could be grouped together for efficiency, timely delivery and ease of mobilization.

Figure 56: Practical demonstration at 4-day engineer training

(Photo credit: UNOPS, Build Change, BBC Media Action)

The training covered the following:

- NRA grant distribution process, including the formalities and legalities
- The NRA’s Repair and Retrofitting Manual
- DUDBC’s retrofitting guidelines
- Case studies based on the approved designs
- The innovative tools used in reconstruction
- Strong back and splint and bandage approaches in retrofitting
- Practical training on strong back and splint and bandage technology

The training was based on the approved curriculum from the CLPIU (Building). In addition to the field visits and group discussions, in-class lectures were held with audio-visual materials and PowerPoint slides.

During the training, field visits were conducted as necessary, to demonstrate the techniques learnt in the classroom as well as to give the participants an opportunity to put into practice the techniques learnt. Demonstrations included the retrofitting techniques from the NRA's Repair and Retrofitting Manual and CLPIU-approved strong back design.

A pre-test and post-test evaluation of the participants was conducted to test the knowledge of the participants after the training.

Engineer and Sub-engineer Training – 4-day Training on Inspection of Retrofitting

This training was conducted for engineers and sub-engineers deployed in earthquake-affected areas through the NRA. As these engineers were responsible for the supervision and inspection of retrofitting for quality control as well as grant disbursement, the training focused on theoretical aspects of retrofitting as well as practical aspects, including quality control measures and supervision approaches. Additionally, the participants were also oriented on the inspection criteria and forms developed by the NRA, with a field visit to a retrofit site to demonstrate on field applications of the inspection forms.

Figure 57: Orientation on inspection criteria to engineers at field during practical session

(Photo credit: UNOPS, Build Change, BBC Media Action Consortium)

Engineer Training – 5-day Training on Masonry Retrofit Design

This training was targeted towards engineers and designers with advanced knowledge on engineering and seismic design. The main objective of this training program was to enhance the participants' know-how on seismic performance of masonry buildings and to enable them to perform the structural analysis and retrofit design of load-bearing masonry buildings using the splint and bandage technique. The course was conducted over five days covering the basics for seismic analysis and design of masonry buildings in order to impart the knowledge/concepts on the performance of masonry buildings in earthquakes.

The mode of training was a combination of PowerPoint presentations, practical exercises, group presentations by the participants, discussions and experience sharing. After completion of the training the participants should be able to understand the concept of analysis of retrofit design of masonry buildings.

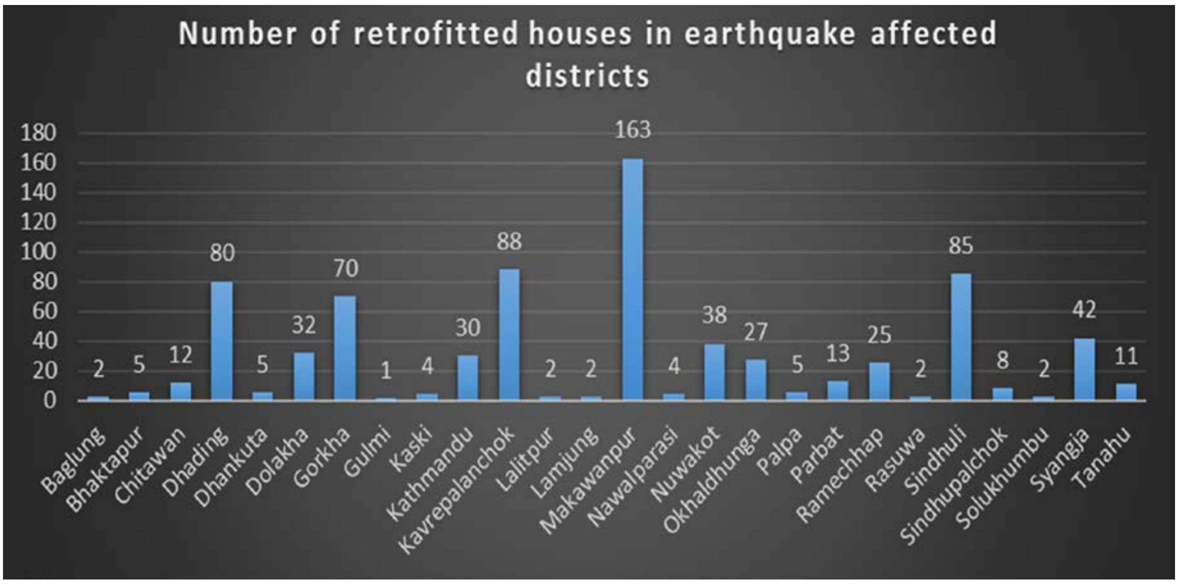
STOCK TAKING

Socio-technical facilitation:

Post-2015 earthquake, a handful of partners have been working on retrofitting, providing socio-technical facilitation with door-to-door and tailored support through mobile technical teams, intensive and comprehensive outreach means using various IEC materials, capacity building of the local government, NRA engineers and particularly local masons through on-the-job training to construct demonstration buildings for extensive sensitization to the need for retrofitting.

Retrofitted houses:

The partners have supported the retrofitting of 758 houses spread across 23 earthquake-affected districts. Of these, concentration of retrofitted houses is highest in Makawanpur, followed by Kavrepalanchok and Sindhuli. See Graph 1.

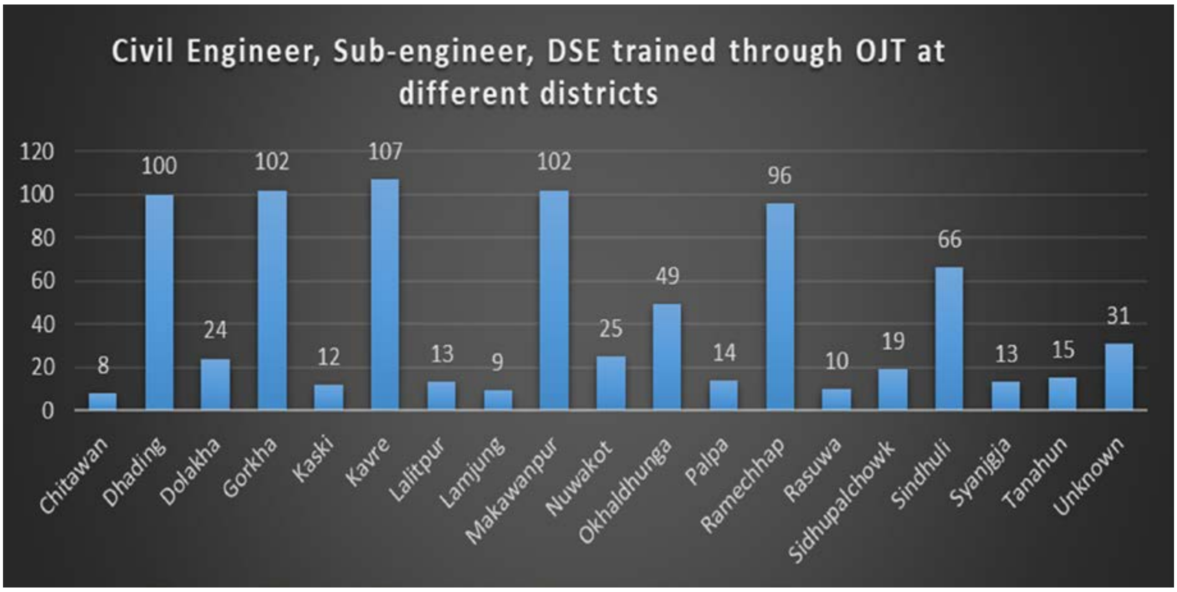


Graph 1: Number of houses retrofitted at different earthquake affected districts

Capacity building:

Various methods and materials have been developed for capacity building of the technical personnel required for retrofitting. These range from engineers and sub-engineers to local masons and artisans. On-the-job training packages were developed, with a combination of practical and theoretical sessions, for the training of the masons, while the engineers were trained through OJT, demonstration and classroom sessions.

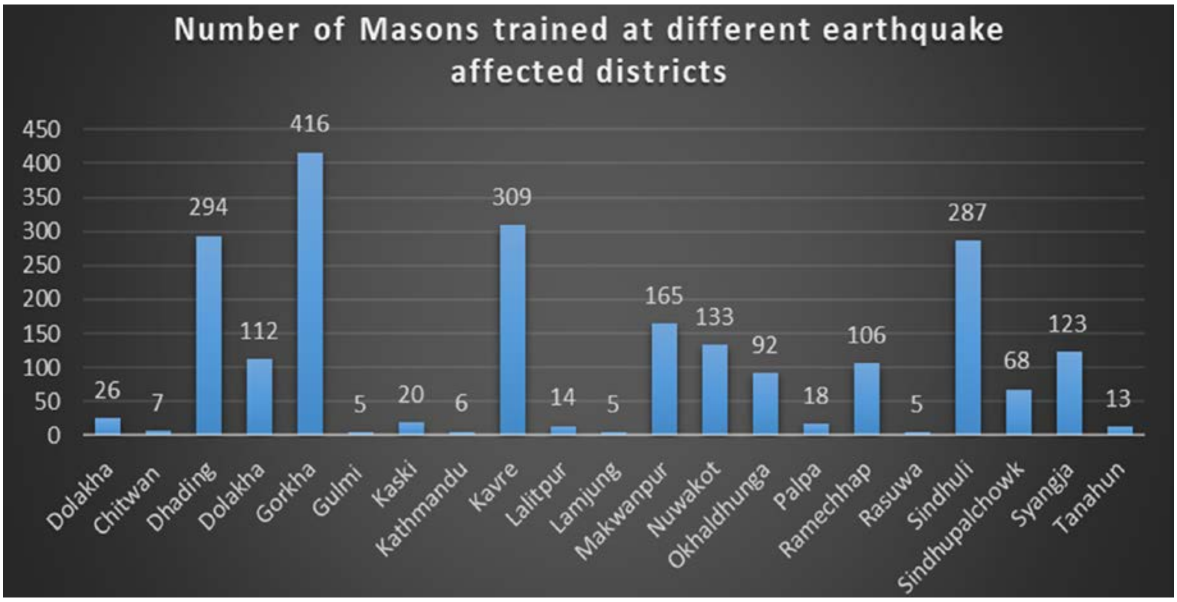
Various partners have trained 815 NRA engineers, other engineers and sub-engineers through OJT. The numbers of engineers trained in Kavre, Makawanpur and Gorkha districts were relatively higher than the other districts, followed by Dhading and Ramechap.



Graph 2: Number of engineers trained in different earthquake-affected districts

Similarly, 1,837 engineers, DSE and sub-engineers were trained in various earthquake-affected districts for four and five days by partner organizations. The training was intended to ensure adequate supply of competent and confident technical personnel to give technical assistance, field supervision, inspection, verification and certification of retrofitted houses. The training incorporates all major retrofitting documents published by the NRA, designs approved by CLPIU (Building) and DUDBC. The training was based on class lectures with audio-visual materials plus field visits.

Likewise, 2,224 masons have been trained in 21 districts by the partners, mostly through on-the-job training on a real site or house. The number of masons trained is highest in Gorkha, followed by Kavre, Dhading and Sindhuli.



Graph 3: Number of masons trained in different earthquake-affected districts

More detailed information on stock taking can be found in the Roster of Trained Human Resources on Retrofitting document.

STUDY ON RETROFITTING IN URBAN AREAS

From among the total number of 70,439 retrofit beneficiaries maintained by HRRP in collaboration with district PIUs, 19,833 beneficiaries are from urban areas. However, the progress on retrofitting is very low and the trend towards transfer to reconstruction beneficiary is high. As of Feb 2021, only 215 houses from rural areas and 194 from urban areas have completed retrofitting. In Kathmandu Valley, a total number of 3,383 beneficiaries are listed as retrofitting beneficiaries but only 30 houses have been completed.

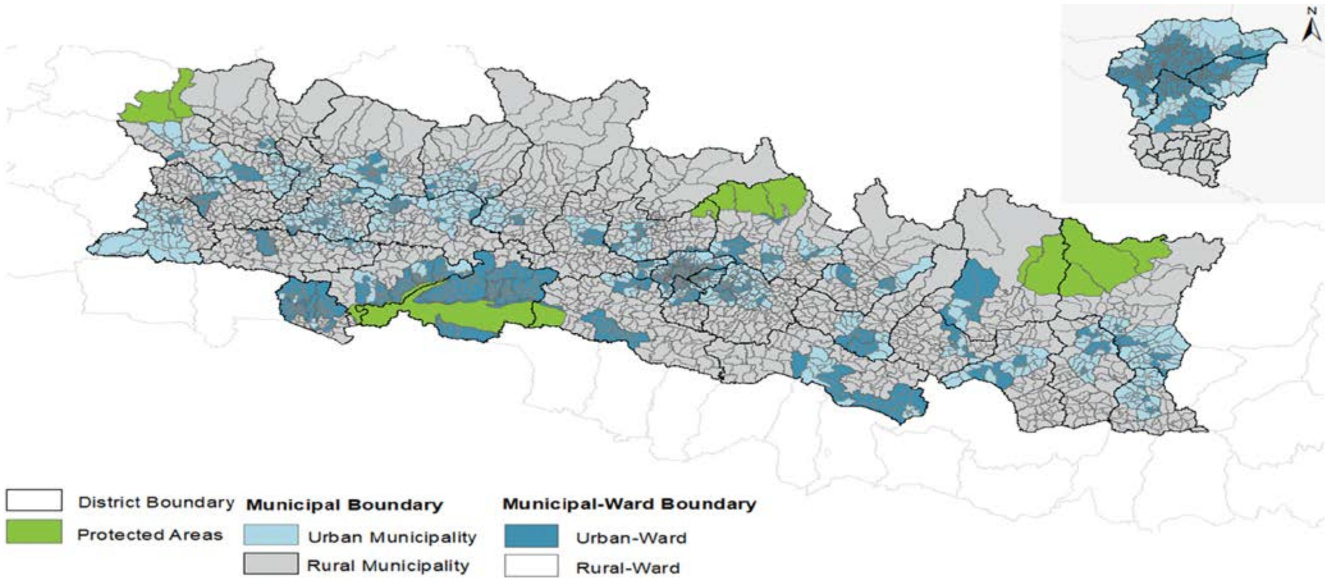


Figure 58: Map showing urban and rural wards. Inset: Urban wards concentration in Kathmandu Valley

(Source: HRRP/CRS)

Urban status	Eligible	Enrolled	Completed	Remaining	Remaining %
Rural	43,408	32,692	215	43,193	99.50%
Urban	27,031	19,833	194	26,837	99.28%

Table 6: Progress of retrofitting in rural and urban locations

Qualitative and Quantitative Analysis

The Urban Recovery Technical Working Group (UR-TWG), with core members HRRP, CRS, Lumanti and NSET, and with support from the NRA and CLPIU Building, conducted a qualitative and quantitative assessment from January to August 2020, on the identification, prioritization and analysis of urban housing recovery issues.

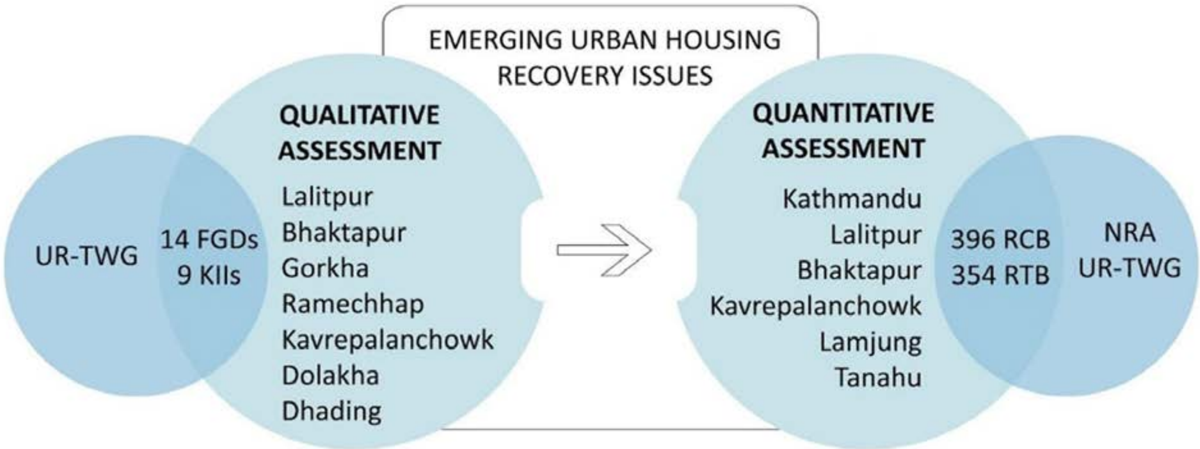


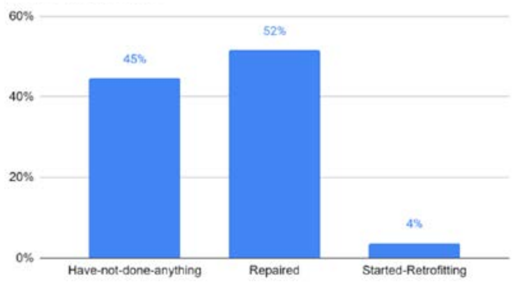
Figure 59: Development of qualitative and quantitative assessments with UR-TWG, NRA & CLPIU

(Source: HRRP/CRS)

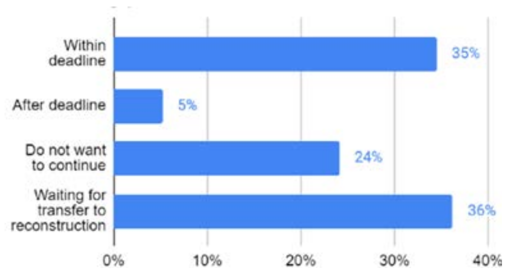
Quantitative findings (n= 818, RCB samples = 473, RTB samples = 345):

Out of the homeowners enrolled in retrofitting schemes, more than half have repaired their houses and not actually retrofitted, 45% have not begun and 4% have started retrofitting. It has been found that 38% of homeowners are aware of the difference between repairing and retrofitting, while the remaining 62% do not know the difference.

About 24% do not want to continue with the retrofitting, and 36% are awaiting transfer of their enrollment from retrofitting to reconstruction.

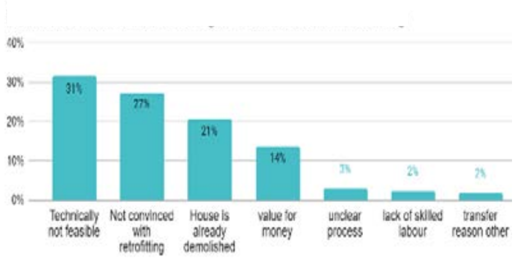


Graph 4: Retrofitting status



Graph 5: Retrofitting plan of homeowners

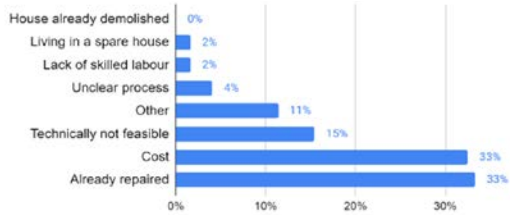
The main reasons for homeowners to transfer to reconstruction are that it is technically not possible to retrofit their houses (31%), they are not convinced by the technique (27%), their houses have already been demolished (21%) or they do not think retrofitting provides value for money (14%).



Graph 6: Reasons for transferring to reconstruction from retrofitting

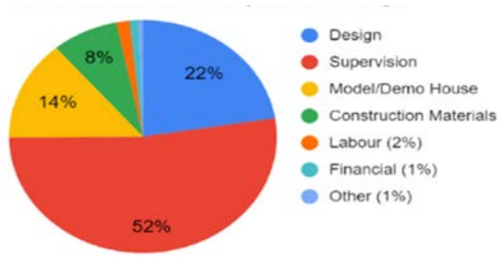
62% of homeowners not wanting to retrofit their homes when it is technically feasible for them to do so is significant. This proves the need for greater advocacy from the government stakeholders and organizations working on retrofitting.

The biggest reasons for homeowners to discontinue retrofitting were high cost (33%), the houses have been repaired instead of retrofitted (33%) or it is technically not feasible to retrofit (15%).



Graph 7: Reasons to discontinue retrofitting

The survey found that 37% of retrofitting homeowners have received technical assistance, and 63% are still to receive assistance. About 52% of assistance received has been in the form of site supervision, 22% design supervision, while 14% have seen demo houses. There has been little support in the form of materials, labour and finance.



Graph 8: Assistance received by homeowners

Qualitative findings (14 focus group discussions, 9 key informant interviews):

SN	Categories	Issues
1	Cost	• Cost is high depending on housing typology and other factors such as structural damage, house size and more. • In urban areas, RCC buildings are dominant and the retrofitting cost of RCC structure may be higher as compared to other structures.
2	Technical manpower	• There is a huge lack of skilled masons and technical expertise on retrofitting. • There are limited structural engineers to analyze and design unique retrofit solutions. • There is a lack of appropriate and timely training and guidelines.
3	Awareness	• There is confusion between, 'retrofit, and repair' among beneficiaries. • There is no separate socio-technical assistance for retrofitting. • There is a lack of willingness among beneficiaries as they are not certain about the technology. • There is a lack of usage of locally available materials.
4	Complexity	• In core areas of Kathmandu such as Sankhu, Indrachowk, etc., load-bearing structures in mud of more than 3 storeys have been listed for retrofitting; this seems unfeasible. • Retrofitting of adjoined buildings is more complex and at times technically unfeasible. • There is no provision for multiple grants for multiple ownership, so many homeowners have not been able to retrofit their houses.
5	Compliance	• Traditional building must be compliant with building code, byelaws of the municipality and of the Department of Archeology. • Several homeowners are willing to demolish and reconstruct a modern house.

CHALLENGES AND LEARNINGS ON RETRO-FITTING

Retrofitting is a new concept for many rural communities. Although retrofitting of public buildings had been done in significant numbers before the earthquake, retrofitting had never been done in any scale in rural houses before the Nepal Gorkha earthquake. Even after the earthquake there were only a handful of organizations involved in retrofitting work. The major challenges that exist in implementing retrofitting programs and in moving retrofitting forward are as listed below:

Lack of awareness of future risk and need of retrofitting:
Due to limited understanding of the potential future earthquake risk, retrofitting is not being prioritized by homeowners and even local leaders, who should otherwise be providing incentives for undertaking forward retrofitting. Retrofitting requires resources, hence without financial assistance or incentives in the initial phase, it is difficult for homeowners to decide to invest their limited money on increasing safety rather than fulfilling other needs. This is especially true when their investment does not give them any additional living space.

Desire of retrofitting beneficiaries to transfer to reconstruction:
There are many reasons behind the desire of retrofitting beneficiaries to transfer to reconstruction. One of the pertinent reasons is the difference between amounts of money provided for retrofitting vs reconstruction, i.e. homeowners receive NPR 100,000 for retrofitting as compared to NPR 300,000 for rebuilding a new house. It is a grant-driven reaction rather than a decision based on the risk. As a result, many beneficiaries are willing to transfer to reconstruction, not realizing that they will end up spending more on a much smaller house. It is also important to note that the unit cost of retrofitting is rather small, amounting to up to 25–30% of new construction. However, existing houses are usually large. Hence the total cost of preserving the traditional house and making it earthquake resilient is more than the allocated assistance of NPR 100,000.

Limited public exposure to retrofitting, making replication difficult:
Retrofitting is a new and evolving concept and there are limited buildings that are retrofitted, making it difficult for the beneficiaries to visualize the entire process. Unlike

reconstruction or new sites, the amount of ongoing retrofitting locations is very few in number, particularly where the impact of the 2015 earthquake has been less. Even in areas impacted by the earthquake, people have lost confidence in stone masonry building and with new RC technology introduced, it is difficult to convince them of the possibility of retrofitting their damaged masonry buildings. Additionally, there was a misconception amongst homeowners and even technicians that retrofitting stone in mud mortar houses was technically difficult or even impossible.

Lack of access to finance:

While there were limited provisions for access to finance for homeowners undertaking reconstruction, such kinds of provisions were not made for retrofitting. Hence, even though the cost of retrofitting a traditional house is more than 3–4 times that of the grant amount, due to lack of access to finance, the homeowners were not encouraged or incentivized in the form of soft loans, similar to those available in the reconstruction category.

Lack of viable technologies:

There is a lack of adequate research on low-strength or non-engineered buildings in Nepal. Hence the retrofitting solutions are still evolving and not matured like the technical norms for new construction. There is a long way to go before we will have developed approaches, and guidelines for all technologies (row houses, dry stone masonry). Implementation considerations will include sparse settlement, difficulty in access, displacement of local materials and skill, lack of confidence in retrofitting and lack of skilled human resources. Inherent weakness of masonry buildings to meet National Building Code requirements with minimal intervention and at affordable cost is challenging. Building codes are prepared for modern and strong materials and attempts are then made to fit the standards into the vernacular structures, which makes the technical solution not viable or affordable.

Lack of adequate quality materials:

Retrofitting of masonry buildings using GI wire mesh splint and bandage technique following the NRA Repair and Retrofit Manual is a plausible technique. However, wire meshes are not locally produced, and are not stocked by hardware vendors in large quantities. One such instance was seen in the immediate aftermath of the COVID-19 lockdown, where local producers in Birgunj were not able to provide the required products due to a lack of raw materials. Although the issue was eventually resolved through direct market facilitation, a shortage of quality material could be foreseen if a large number of retrofit beneficiaries plan to retrofit their house. A market link and bridging the supply-demand gap is an area that needs to be addressed to support retrofitting at larger scale and on people's own initiative.

Lack of personnel/construction workforce to cater to retrofitting needs:
Retrofitting is a technical process that requires discretion, and calculated decisions are taken while designing and implementing. The design and implementation process requires skilled workforce who have prior experience of the process. There is a lack of skilled human resources like engineers and masons who have knowledge of retrofitting, thus making it difficult for homeowners to undertake retrofitting even if they are willing to. Building confidence among engineers and stakeholders is critical; this will come from hands-on experience.

Very few reconstruction implementing partners interested in including retrofitting in their agenda:
Where there were hundreds of organizations working on helping people reconstruct their houses, only a handful of them had retrofitting in their agenda. The consequence of this is that there are uncountable resources for new construction but very limited technical and non-technical resources for retrofitting. Awareness materials and resources at the local level were limited to the efforts of only this handful of organizations.

WAY FORWARD

There are a number of initiatives that need to be undertaken by various public, private and academic institutions for establishing retrofitting in the Nepalese context:

Introduce incremental retrofitting approach:

Retrofitting of the entire house in one go could be burdensome to a majority of homeowners. Partial and incremental retrofitting could offer a tailored solution. This approach addresses basic vulnerability ensuring life safety. The steps to improve seismic resilience are spread over a period of time, based on the resource availability of the homeowners.

Diffuse technology through demonstration in public buildings:

Public facilities and government buildings can be used to lead the public towards acceptance of the retrofitting technology. Selecting municipal buildings, health centres, schools or other public buildings and retrofitting them will pave the way for broader acceptance.

Select of appropriate techniques and materials:

The retrofitting technologies have to be tested and vetted by experts, while the technology should be easily adaptable, replicable and economically viable. There have been several studies on the retrofitting of masonry buildings using various techniques and materials. It was learnt that the selection of appropriate techniques and materials based on building typology, the cost of materials and transportation and the beneficiary's economic status are all determining factors for successful implementation of retrofitting. This situation requires case-specific recommendation from the public sector and targeted awareness schemes for the general public.

Undertake discourse on compliance with “Building code”:

A discourse, followed by a logical decision, is required around whether retrofitting techniques must strengthen buildings to a desired performance level or whether they must comply with the “current code”. It has been recognized that the inability to meet current code should not be a barrier to retrofitting. Even developed countries have been meeting partial strength targets (about 50%) of the new construction building through retrofitting.

Undertake a comprehensive awareness campaign:

In Nepal, where priority is on fulfilling basic necessities, it is a challenge to convince people to retrofit their houses when they may not see any short-term benefit. The public sector has to communicate the urgency of retrofitting to the vulnerable households through appropriate modes of communication. The retrofitting should be practical, affordable and understandable. It should have flexibility by way of staggered investment and an incremental building approach. Hence, integrated and comprehensive social awareness campaigns are recommended through orientation programs, video demonstrations, and door-to-door campaigns. Engagement of the local governments in this process is indispensable.

Initiate financial incentive for retrofitting:

Poor access to finance has been realized as a major barrier for effective propagation of retrofitting technology. After assessing effectiveness of the housing credit, the Nepal Rasta Bank may consider introducing a loan provision for retrofitting. On the other hand, the Ministry of Urban Development (MoUD) may consider amalgamating retrofitting technology with the “People Housing Program”. Amalgamation of other similar housing programs with retrofitting interventions can be considered.

Facilitate the formation of a guild of locally trained masons:

Both engineers and locally trained masons who received on-the-job training (OJT) have demonstrated enhanced levels of delivery. A guild of such masons would be instrumental to propagate the technology with a limited backstop of engineers.

Improve supply chain and assure quality of construction materials:

The supply of appropriate materials and tools for retrofitting needs to be addressed by working with construction material suppliers. A functional supply chain needs to be established for such materials. In conjunction with the awareness drive, which will generate demand, a sustainable and affordable supply chain needs to be facilitated in coordination with building material suppliers. A mechanism for ensuring material quality should be established.

Initiate formal provisions:

The NRA needs to take forward three formal arrangements:

1. Integration of retrofitting in engineering course curricula
2. Initiation of dialogue for incorporating retrofitting into building code
3. Accreditation of trained masons

In the absence of these interrelated provisions, other attempts become vacuous. The Department of Urban Development & Building Construction (DUDBC) has to take the baton from the NRA and carry on.

Plan for retrofitting for urban building typologies:

While the focus of the NRA-promoted guidelines is on retrofitting of rural building typologies, DUDBC in conjunction with the research institutes needs also to deliberate on urban row housing typologies, which is yet to be fully researched.

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5. GoN National Reconstruction Authority. (2018) “Light Timber/Steel Frame Structure Manual”
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ANNEXES

Annex 1: List of Retrofit Resources Available for Public Use

A collection of retrofit resources are available digitally in the following link:

https://drive.google.com/drive/folders/0ANBjKIKKdlbwUk9PVA

The list of documents available for public use is as follows:

Document Title	Organization	Type of Document	Description	Who can use it
Baldam Bahadur Pulami, Resident – Tinpatan, Sindhuli	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Mr. Bal Bahadur Lama, Resident – Khadadevi, Ramechhap	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Balasari Rai, Municipal Council Member, Siddhicharan, Okhaldhunga	UNOPS	Case Study	Municipal Member's experience on retrofitting their house	Anyone
Bir Bahadur Thapa, Ward Chair – Siranchowk, Gorkha	UNOPS	Case Study	Ward Chair's experience on retrofitting their house	Anyone
Dil Maya B.K., Mason – Syangja	UNOPS	Case Study	Mason's experience on retrofitting their house	Anyone
Hasta Tamang, Resident – Ramechhap	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone

Document Title	Organization	Type of Document	Description	Who can use it
Janak Bahadur Bishwokarma, Resident – Okhaldhunga	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Jogmaya Tamang, Mason – Kavre	UNOPS	Case Study	Mason's experience on retrofitting their house	Anyone
Kamal Kant Regmi, Resident – Syangja	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Kiranman Bal – Makwanpur	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Krishna Kumar Khatri – Dolakha	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Mithu Maya Lama	UNOPS	Case Study	Builder's experience on retrofitting their house	Anyone
Sanilal Adhikari – Sindhuli	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Teknath Baral – Pokhara	UNOPS	Case Study	Homeowner's experience on retrofitting their house	Anyone
Benefits of retrofitting	UNOPS	IEC Materials	Video showing the benefits of retrofitting	Anyone
How retrofitting is done?	UNOPS	IEC Materials	Video showing how retrofitting is done	Anyone
What is retrofitting?	UNOPS	IEC Materials	Video showing what retrofitting is	Anyone
Whom to meet to retrofit the house	UNOPS	IEC Materials	Video showing how to initiate retrofitting process	Anyone
Why retrofitting?	UNOPS	IEC Materials	Video showing benefits of retrofitting	Anyone

Document Title	Organization	Type of Document	Description	Who can use it
Shyam Bahaur Lama – Bhimphedi	UNOPS	IEC Materials	Video showing benefits of retrofitting	Anyone
Call for Code – Artificial Intelligence for Retrofitting	UNOPS	IEC Materials	Video showing how Artificial Intelligence can be used for retrofitting design and drawing	Anyone
Retrofitting Short Film – Kavre	UNOPS	IEC Materials	Video showing benefits of retrofitting	Anyone
Retrofitting awareness video	UNOPS	IEC Materials	Video showing benefits of retrofitting	Anyone
Splint and Bandage retrofitting video	UNOPS	IEC Materials	Video showing benefits of retrofitting	Anyone
Usha didi retrofitting awareness video	UNOPS	IEC Materials	Video showing benefits of retrofitting	Anyone
Typical strong back retrofit design	UNOPS	Retrofit Technical Documents	Retrofit design drawings for a house with strong back technology	Engineer
Typical splint and bandage retrofit design	UNOPS	Retrofit Technical Documents	Retrofit design drawings for a house with splint and bandage technology	Engineer
Typical timber house retrofit design	UNOPS	Retrofit Technical Documents	Retrofit design drawings for a timber house	Engineer
Typical timber house with masonry ground floor retrofit design	UNOPS	Retrofit Technical Documents	Retrofit design drawings for a timber house with masonry skirt	Engineer
Typical open front house retrofit design	UNOPS	Retrofit Technical Documents	Retrofit design drawings for an open front SMM house	Engineer

Document Title	Organization	Type of Document	Description	Who can use it
Typical dry stone retrofit design	UNOPS	Retrofit Technical Documents	Retrofit design drawings for a dry stone masonry stone house	Engineer
Rural house retrofitting training for Builders	UNOPS	Retrofit Technical Documents	On-the-job training manual for builders on SMM house retrofitting using strong back approach	Builder trainers/ engineers
SMM house retrofitting Manual using strong back approach	UNOPS	Retrofit Technical Documents	Manual for designing retrofit for SMM houses using strong back approach	Engineer
Picture guide for retrofitting an SMM house with strong back approach	UNOPS	Retrofit Technical Documents	Pictorial guide showing construction steps for retrofitting SMM houses with strong back approach	Builders, engineers
Seismic-resistant construction and retrofit of dry stone masonry houses	Build Change	Retrofit Technical Documents	Technical paper of retrofitting of dry stone masonry houses	Engineers
Non-linear analysis of traditional SMM houses in Nepal before and after retrofitting	Build Change	Retrofit Technical Documents	Technical paper on non-linear analysis of SMM houses	Engineers
Calibrating a constitutive non-linear material model for SMM walls in Nepal	Build Change	Retrofit Technical Documents	Technical paper on establishing non-linear material model for SMM walls	Engineers

Document Title	Organization	Type of Document	Description	Who can use it
Seismic retrofitting of traditional SMM houses in rural Nepal	Build Change	Retrofit Technical Documents	Technical paper on seismic retrofitting of SMM houses	Engineers
Comparison of retrofitting approaches in Nepal	Build Change	Retrofit Technical Documents	Study comparing strong back approach and splint and bandage approach for retrofitting SMM houses	Engineers
Repair and restoration awareness flyer	UNDP	IEC Materials	Public awareness on repair and restoration	Anyone
Retrofitting awareness flyer	UNDP	IEC Materials	Public awareness on retrofitting	Anyone
Field guide for repair and retrofitting for engineers	UNDP	Retrofit Technical Documents	Visual technical guideline for repair and retrofitting for the engineers	Engineers
Mason's field guide for seismic retrofitting	UNDP	Retrofit Technical Documents	Visual technical guideline for repair and retrofitting for masons	Masons
Repair and Restoration Booklet	UNDP	IEC Materials	Guideline for repair and restoration of damaged house	Anyone
Posters on retrofitting for public awareness	UNDP	IEC Materials	Set of 6 posters on step by step retrofitting of SMM house	Masons and Engineers
Towards safer life	UNDP	IEC Materials	Video on awareness on retrofitting	Anyone
Retrofitting brings safety – seeing is believing	UNDP	IEC Materials	Video on awareness on retrofitting – shock table demonstration	Anyone
Case story: Restoring ancestral home	UNDP	Case Study	Homeowner's experience of retrofitting	Anyone

Document Title	Organization	Type of Document	Description	Who can use it
Case story: Mason training bringing hope	UNDP	Case Study	Mason's experience of training on retrofitting	Anyone
CR integrated splint and bandage technology	UNDP	Retrofit Technical Documents	Drawings and pictures of 2.5 storey house retrofitting using CR integrated splint and bandage	Engineers
Step-by-step 3D of CR integrated splint and bandage	UNDP	Retrofit Technical Documents	3D step by step snapshot of 2 storey house retrofitting using CR integrated splink and bandage	Engineers and masons
Splint and bandage_1 storey	UNDP	Retrofit Technical Documents	Drawings of 1 storey house retrofitting using splint and bandage	Engineers
Improving seismic safety of existing vernacular buildings	UNDP	Retrofit Technical Documents	Scientific paper – publication – incremental approach in retrofitting	Engineers
Case Stories_Retrofitting_house owner, LG, masons	NSET	Case Study	Compilation of 4 case stories	Anyone
Handbook_Retrofit 10 Key Points	NSET	IEC Materials	10 key points to remember for retrofitting	Anyone
10 key points for retrofitting	NSET	IEC Materials	Poster for public awareness	Anyone
Retrofitting cost comparison	NSET	IEC Materials	Poster for public awareness on cost of retrofitting	Anyone
Orientation on Retrofitting_Video	NSET	IEC Materials	Video on public awareness – retrofitting	Anyone
Way forward in retrofitting	NSET	Lessons Learnt	Challenges and major learnings – notes	Policy makers

Document Title	Organization	Type of Document	Description	Who can use it
Retrofit Mason Training 25 days Curricula	NSET	Retrofit Technical Documents	Training curriculum for Masons for retrofitting using splint and bandage construction	Trainers
Retrofit Engineers Training 4 days Curricula	NSET	Retrofit Technical Documents	Training curriculum for Engineers for retrofitting using splint and bandage approach	Engineers/ Trainers
Experiences on Retrofitting of Low Strength Masonry Buildings by Different Retrofitting Techniques in Nepal	NSET	Conference Paper	Case study of retrofitting in Nepal presented during 15th WCEE, Lisboa (2012)	
Exploration of different retrofitting options for RC frame buildings in Kathmandu	NSET	Symposium Paper	Case study of retrofitting in Nepal presented during USMCA, Kathmandu (2015)	
In-plane cyclic tests of seismic retrofits of rubble-stone masonry walls	NSET in collaboration with Beijing Normal University	Journal Article	Bulletin of Earthquake Engineering (2017)	

Document Title	Organization	Type of Document	Description	Who can use it
Shake table tests on the two-storey dry-joint stone masonry structures reinforced with timber laces and steel wires	NSET in collaboration with Beijing Normal University	Journal Article	Bulletin of Earthquake Engineering (2018)	
Laboratory experimental test on low strength stone masonry buildings of Nepal to understand their seismic behaviour	NSET	Symposium Paper	Earthquake Safety Day Symposium (2018)	
Increasing the lateral capacity of dry joint flat-stone masonry structures using inexpensive retrofitting techniques	NSET in collaboration with Beijing Normal University	Journal Article	Bulletin of Earthquake Engineering (2019)	
Experimental investigation of low cost steel wire mesh retrofit for stone masonry in mud mortar	NSET in collaboration with University of Bristol	Conference Paper	17th World Conference on Earthquake Engineering, Sendai (2020)	

Document Title	Organization	Type of Document	Description	Who can use it
A case study on retrofitting of stone masonry in mud Buildings in post gorkha earthquake reconstruction	NSET	Conference Paper	17th World Conference on Earthquake Engineering, Sendai (2020)	
Efforts and impacts of socio-technical assistance for retrofitting in post-earthquake reconstruction in Nepal	NSET	Conference Paper	17th World Conference on Earthquake Engineering, Sendai (2020)	

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