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Retrofitting Practices of Stone Masonry Buildings: Cost Comparison and Status in Nepal

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Abstract
Abstract -The study described herein, studies the retrofitting practices of stone masonry buildings in Nepal after the devastating earthquake in April of 2015. While new construction of severely affected buildings after the earthquake has gained pace lately, another facet of reconstruction, i.e., retrofitting of partially damaged house has been sluggish. This has been due to the fact that most of the buildings needing retrofitting are built with stone masonry bonded with mud mortar and methods to retrofit these types of structures are either new to the designers and masons in Nepal, or they are far too expensive than government provided aid for the typical Nepalese homeowner to be put into practice. As such, this study aims to compare retrofitting methods for stone masonry buildings joined with mud mortar under the constraints of cost. The different methods under study include the Strong Back approach, and Splint and Bandage with Jacketing using Galvanized wire, Rears and Wood as the material. To do this, we performeda cost comparison of a typical traditional house for different retrofitting techniques and compared it with the new construction of a similar house. Our results show us that the cost of retrofitting is lowest by Strong Back approach for all three heights from One Story SMM buildings with attic to Two-story and Two Story with attic SMM buildings whereas RC splint and bandage techniques is the most expensive to put into practice .

Keywords: *Earthquake, Reconstruction, Retrofit, Stone Masonry, Cost-Analysis, status*

I. INTRODUCTION

Nepal lies at the zone of the collision between twoactive tectonic plates -the Indian plate in the south and the Eurasian plate in the north, as a result of which large portion of Himalayan Range with the highest peak situated in Nepal. Movement of these plates is ongoing, making the entire regionseismically active. As a result,Nepal has experienced numerous earthquakes,many of which have resulted in human and economic lossesthroughout the past several centuries. The recent catastrophic earthquake - theGorkha Earthquake took place on 25th April 2015, with epicenter in Gorkha and magnitude of Mw 7.8. The destruction was widespread, affecting residential and Government buildings, heritage sites, schools, and health posts, as well astrekking routes andhydropower plants. In the aftermath of the earthquake, the already slow-paced economic growth of the country faced further setback due to the reduction in economic activities.

According to Nepal population and Housing census, 2011[1]out of 54 million houses, approximately 24 million homes in Nepal are low strength masonry in mud mortar. Bricks and adobe are popular in alluvial areas like valleys and plains. In the Himalayan and hilly region, stone is the most prevalent building materials and are commonly bonded with mud mortar. Non-engineered masonry structures are vulnerable to earthquakes, posing the highest risk to their

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inhabitants. However, the replacement of all such types of dwellings is deemed to be unpractical. Thesenon-engineered that do not meet existing seismic safety standard can be either reconstructed or retrofitted to improve their performance during an earthquake. Retrofitting is a process of enhancing the original strength of the building when the evaluation of the building indicates that the present strength is insufficient, and repair or restoration cannot reduce seismic vulnerability to the desired level.

The Gorkha Earthquake originated beneath the hills of Gorkha, thus affecting around 30 neighboring districts, mostly of Hill and Himalayan region. The number of houses collapsed or damaged due to Gorkha Earthquake was congruent to the finding of the census as well as their vulnerability: the majority of collapsed houses were low strength masonry, with stone masonry being most predominant[2]. The higher proportion of collapsed house of low strength masonry is attributed to their predominance as well as their generic higher seismic vulnerability [3], needing further attention/action as these houses are not limited to earthquake-hit districts but common all around the hilly regions of Nepal. In this paper, we focus on retrofitting of SMM houses as these are the most predominant houses needing retrofitting as shown both by census and damage data.

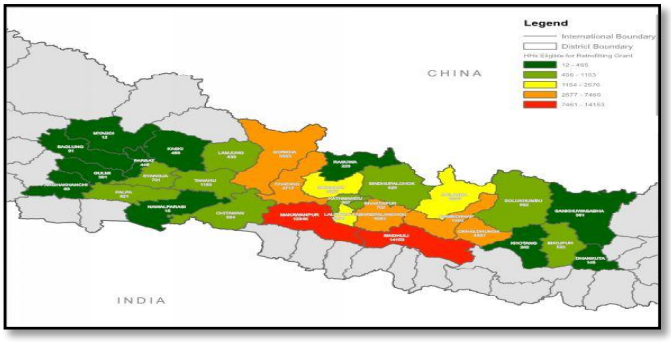

Figure 1 Eligible Houses for Retrofitting Grant in Earthquake affected 32 District. Source : [4]

The reconstruction process was soon started after the quake, followed by the formation of the National Reconstruction Authority (NRA) in August 2015. NRA is the apex body responsible for the reconstruction of Gorkha earthquake-affected private and public buildings from planning, coordinating to financing medium-term and long-term recovery. The survey conducted by NRA categorized the earthquake-affected private houses broadly in two categories based on damage gradeto distribute reconstruction aid.

Damage Grade 0 to Grade 5 was assigned during the survey depending upon the degree of damage of house; Damage grade 0 was assigned for the non-affected house whereas Grade 5 was assigned for the complete collapsed house and Grade1 to 4 in between. By the survey, 816,309 beneficiaries were identified for a complete reconstruction with assigned damage grade 3 to 5, and 69,973 beneficiaries for retrofitting with assigned damage grade 1 to 3 for their houses. Figure 1 shows the distribution of retrofitting beneficiaries across different earthquake-hit districts, with dark green districts having a low number of Beneficiaries and Red marked district having the highest retrofitting demand. The current statistics (September 2019)from Central Level Project Implementation Unit (CLPIU) of NRA show that 492,948 beneficiaries have received the final tranche after complete reconstruction by September 9 while only 27 beneficiaries of retrofitting received last aid after completion till date[4] .

II. RETROFITTING OF SMM BUILDINGS IN NEPAL

A. RETROFITTING IN NEPAL

National Building Code (NBC) of Nepal was first promulgated in 1994, but its implementation was primarily focused on the urban area. Besides, Nepal already had a large stock of non-engineered, semi-engineered building Earlier the Gorkha earthquake, retrofitting was only limited to historical, cultural, and few public buildings. Dharara, a monument of the Kathmandu Valley which was almost collapsed due to the 1934

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Nepal- Bihar Earthquake, was restored afterward. National Society for Earthquake Technology (NSET), a Non-Governmental Organization (NGO) had retrofitted Bhuwaneshwori Lower Secondary School as a pilot project in 1999. Retrofitting of School and other public buildings were extended to other locations but only in limited number. However, the retrofitting required after Gorkha earthquake wason an immense scale. Nepal thus lacked retrofitting technology and human resources for the extensive retrofitting demand.

Various efforts on developing viable retrofit solutions have been carried out on the governmental and non-governmental level. The first step was taken by the Ministry of Urban Development (MOUD) with the help of United Nations Development Program (UNDP) by publishing "Seismic Retrofitting Guidelines of Buildings in Nepal" on 2016 for three dominant construction typologies namely Adobe, RCC and low strength masonry. Also, the NRA has published two ready-to-use manuals, for Masonry and RCC, with technical details to aid the ongoing retrofitting of partially damaged houses.Beside this, different International Non-Governmental Organizations (INGO) and NGOs have also taken the initiative to assist in the retrofitting. Build Change Nepa-an INGO has also developed a unique retrofitting approach for low strength masonry, which is being implemented with governmental approval. NSET under BaliyoGhar projectis carrying out retrofitting for private housing to cater the retrofitting demand. Similarly, UNDP has also carried retrofitting of private houses.

B. RETROFITTING PRACTICES IN NEPAL FOR SMM BUILDINGS

LOAD PATH OF SMM BUILDING

SMM Building is a load-bearing structure with the unreinforced wall as the chief structural element. The gravity load is transferred through the roof/floor to joist/beam frame, which is further passed to the resting wall to the foundation.The lateral force is transferred through the box action of the adjoining wall. Retrofitting is done to improve the load path of existing buildings.

Major current approaches for retrofitting of SMM in Nepal are as follows:

a) Strong Back Approach
b) Splint and Bandage with Jacketing

A. Strong Back Approach

Traditional SMM buildings found in a rural area of Nepal have similar size, configuration, connections, and member sizes. Based on the observed similarities of the SMM buildings, Build Change developed a pre-engineered retrofit design for those buildings[5].

The applicability criteria for the considered type design are as follows:

- The building is a house, with four exterior walls constructed of stone masonry and mud mortar, with wood floor and framing.
- The wall of the building should be true to the plumb line.
- The walls should be at least 450mm thick.
- The building should be rectangular in plan with length to breadth ratio not exceeding 3.
- The longitudinal dimension of the building should not exceed 10.7 m, and the transverse dimension of the building should not exceed 6m.
- The building should not be higher than two stories plus attic with story height and attic height not exceeding 2.1m and 1.2m respectively.
- The opening percentage should be less than or equal to 35% and 25% in the longitudinal wall and transverse wall correspondingly.

Retrofit Elements in Strong Back Approach

The retrofit elements that are introduced to address the deficiencies of damaged SMM buildings are as follows:

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i. Strong Backs

Strong Backs are the vertical elements designed to brace the wall against out-of-plane force and to facilitate connectivity of the walls with diaphragms.Strong backs are connected to each adjacent masonry wall with dowels at two equally spaced points at each floor level. These are reinforced concrete elements located at the corner of the house and at each wall pier.

ii. Slab-Strips

Slab Strips are installed along the inner perimeter of the wall and a cross-connecting intermediate strong back to strengthen the floor diaphragm, thus enhancing the box action by the proper connection between adjoining walls.These are reinforced concrete elements connected to an existing wall with a dowel at a spacing of 600mm that are grouted into the wall.

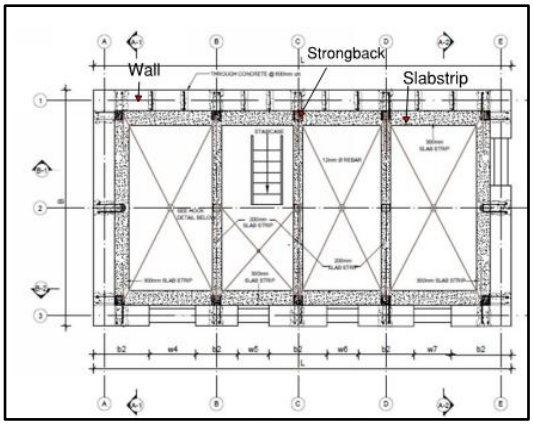

Figure 2 Plan view showing the location of retrofit elements, source : Build Change, Nepal

iii. Through Concrete

Through concrete is provided to bond the inside and the outside wythe of the SMM wall, preventing delamination. The through concrete is approximately 150mm diameter with 12mm diameter rebar placed inside it.

iv. Dowels

The bearing connection between wall and strongbacks, wall, and slab strips, existing vertical post and wall is ensured by providing dowel bars at an equal interval.

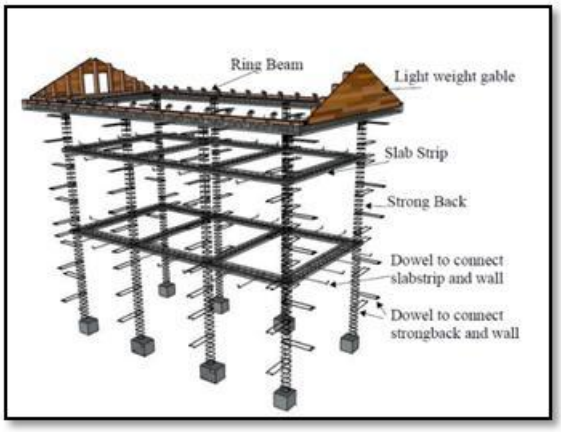

Figure 3 Components in Strong Back Approach. Source: Build Change, Nepal

Ring Beam

Ring beam is added at the top of SMM wall at parapet level connecting the independent longitudinal and transverse wall to promote the box action. The ring beam is reinforced concrete element designed to resist out of plane loads.

v. Wire mesh Overlay

A wire mesh overlay is provided to piers, which are critical in tension due to in-plane flexure. Wire mesh is provided both inside and outside of the wall and is tied at regular intervals. The wiremesh is anchored well at floor level, and the plinth beam is provided at ground level.

vi. Plastering of Walls

The SMM walls are plastered at the exterior and interior face to increase the in-plane capacity of the wall.

B. Splint and Bandage Approach with Jacketing

The splint and bandage is another approach to enhance the overall building integrity. Splint and Bandage are provided to prevent global failure while the jacketing is provided to prevent local failure.

Splint

These are vertical reinforced concrete bands located at the position of the highly concentrated internal stresses, i.e. commonly at the corners of the rooms and jambs of openings. Splints are provided both on the exterior and interior wall surfaces and are interconnected with anchorage bar or GI wire at the regular interval.

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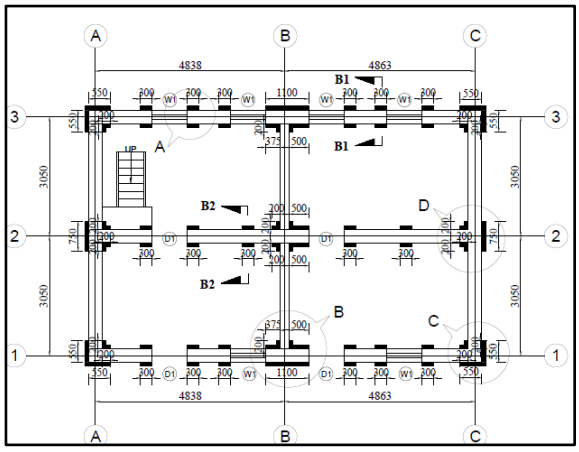

Figure 3 Plan view showing the location of splint Source:NRA

Bandage

These are the horizontal reinforced bands which are placed throughout the length and width of buildings at lintel,floor and/or roof level in a building.Seismic bands hold the walls together and ensure integral box action of an entire building.[6]Bandage are provided on both the exterior and interior wall surfaces and are interconnected with anchorage bar or GI wire at the regular interval.

Jacketing

It consists of covering the wall with a thin layer of welded GI wire mesh, Polypropylene band or rebar mesh interconnected using through-wall anchors to prevent the local failure. The wall is further plastered or micro-concreted.

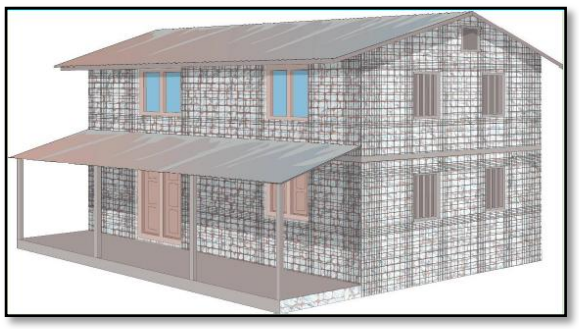

Figure 5 Elevation view showing thelocation of asplint,bandage and jacketing, Source : Build Change, Nepal

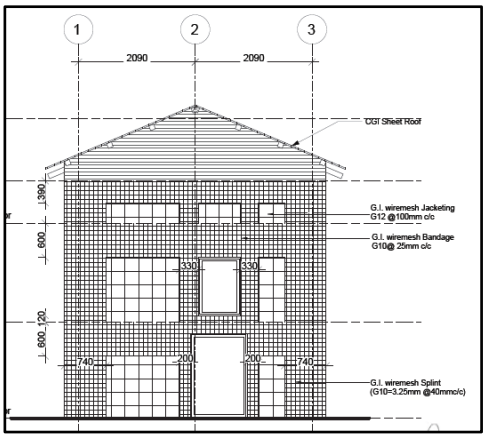

Figure 6 GI wiremesh splint and Bandage,Source:NRA

NRA published prescriptive splint and bandage retrofit designs for all low strength masonry buildings [7] .The applicability criteria for the considered type design are as follows:

i. The plinth area of buildings should be less than or equal to 1000 square feet.
ii. The building should be rectangular in plan with length to width ratio not exceeding 3.
iii. The building should not be higher than two stories plus attic in case of SMM, Brick masonry in mud mortar (BMM), Stone masonry in cement (SMC)/Dry Stone and three stories for BMC with story height not exceeding 3m.
iv. The thickness of the wall should be at least 230 mm and 350 mm for brick and stone masonry, respectively.
v. The unsupported span of the wall should be less than 12 times the thickness of the wall, and else new buttress wall shall be constructed.

According to the NRA guideline, Splint and Bandage retrofit can be done by four techniques depending upon materials, which are described briefly.

1. Retrofitting using RC splint-bandage

It consists of using reinforced concrete splint and bandage. Splints rebar mesh are located at the corner, T-junction and at the side of openings. Similarly, bandage rebar mesh is located at the sill, lintel and floor level. Micro-

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concrete is done on the splint and bandage location.On the remaining portion, wiremesh jacketing is applied with plastering.

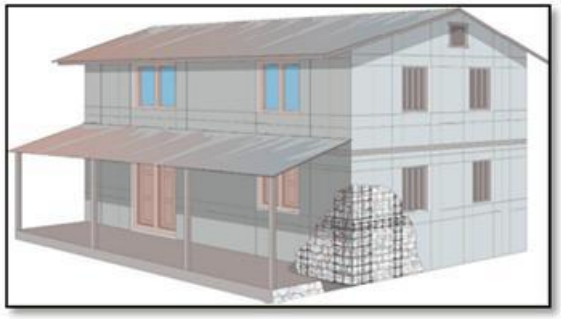

Figure 7Reinforced Concrete Splint and Bandage, Source: NRA

2. Retrofitting using welded GI mesh splint-bandage

It consists of using welded GI mesh splint and bandage Splint and bandage are located as stated earlier. Plastering is done on the splint and bandage location. On the remaining portion, wire mesh jacketing or polypropylene jacketing is applied with plastering.

3. Retrofitting using wooden mesh splint-bandage

The wooden vertical post of size 75mm x 75mm is provided at the corner and sides of the opening- both inside and outside of the wall. A wooden horizontal bandage of size 38mm x 75mm is provided at the lintel level and silllevel.A metal plate is used to connect vertical posts and horizontal band.On the remaining portion,wiremesh jacketing is applied with plastering.

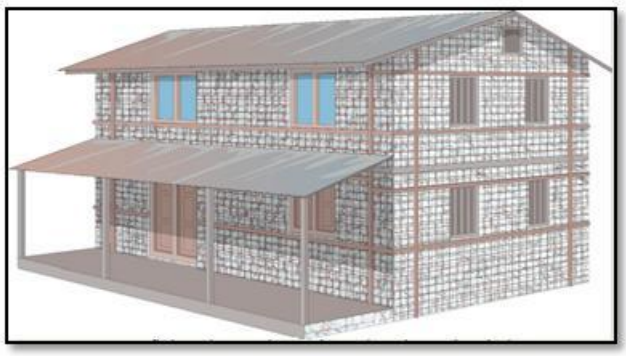

Figure 8 Wooden mesh Splint and Bandage, Source: NRA

JACKETING

Jacketing is the traditional technique used for strengthening of a masonry building. It consists of covering the wall with a thin layer of welded GI wiremesh, Polypropylene band or rebar mesh interconnected using through-wall anchors.The wall is further plastered or micro-concreted.No distinction between stressed and unstressed member/region is the drawback of this method.

In this paper, Jacketing is not considered separately as GI wire mesh G12 is provided along with Splint and Bandage Besides of Jacketing, NRA has suggested following methods to strengthen the diaphragm, which is considered in cost analysis.

i. Wooden plank overlay
ii. Diagonal straps galvanized steel
iii. Concrete overlay
iv. New Reinforced concrete slab

III. COST ANALYSIS

The total cost of retrofitting in each technique is analyzed and break down of cost was done for the significant item. For our study, a typical traditional house, as shown in Figure 9 with floor area 35.25 square meter (7.5m x 4.7 m), is considered. Then the total cost of retrofitting is calculated for a single story plus attic, two-story and two-story plus attic houses.

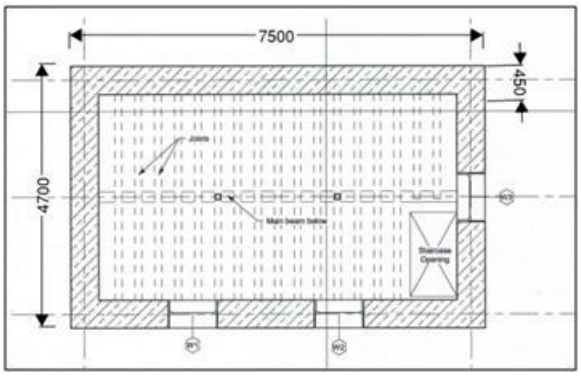

Figure 9 Plan view of typical traditional SMM house

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A. One Story Plus Attic SMM buildings

We estimated the cost of new construction of one plus attic SMM buildings in compliance to current Earthquake Safety guidelines, which need horizontal bands at Plinth, Sill, Lintel, first floor and roof level with additional corner stitches and vertical reinforcement at the corner and near openings.

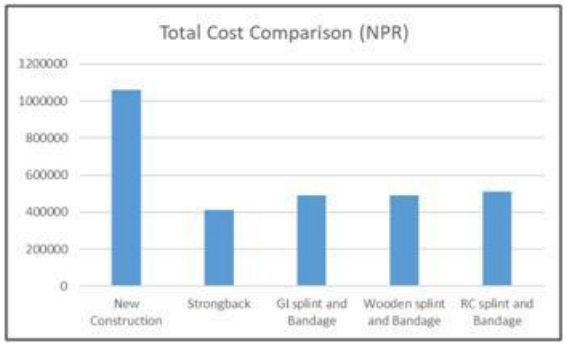

Figure 10 Total Cost Comparisons of retrofitting with New Constructions

The total cost of new construction was estimated to be Nepalese Rupees (NPR) 1,061,464 including contingencies, which was 1400 per square feet.The similar cost estimate was calculated for four techniques of retrofitting and shown in figure 10. Cost of retrofitting by Strong Back approach was calculated to be lowest with NPR 410,157

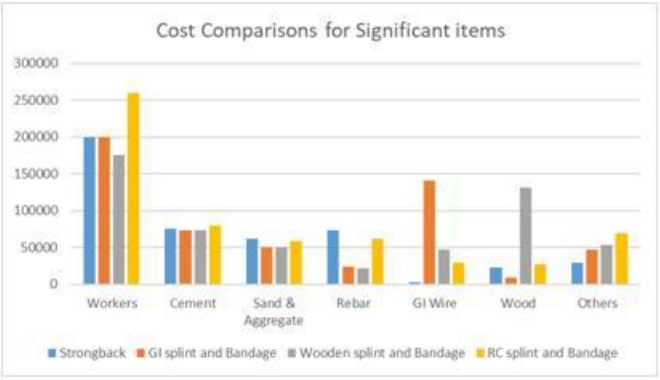

Figure 11.Cost Comparisons of Significant Items in different Retrofitting Techniques for One plus Attic SMM Buildings

. Similarly, the cost of retrofitting by splint and bandage with jacketing was found to be NPR 490,865, 496,301 and 509,989 respectively for GI, Wooden, and RC. Costing per square feet of floor area are NPR 541, 648, 655, and 672, respectively, for Strong back, GI splint and bandage, Wooden splint and bandage, RC Splint and bandage, which is 38.64 %, 46.24 %, 46.76 %, and 47.95 % of the total cost of new construction.RCsplint and bandage is the most expensive retrofitting techniques among four, which is maybe due to the substantial cost for workerscompared to other retrofitting techniques, as shown in Fig 11.

B. Two Story SMM buildings

The similar cost estimate was calculated for four techniques of retrofitting for two-story SMM buildings with the same floor area. However, the cost estimate of new construction was not calculated for two-story buildings as new construction is not allowed for SMM buildings greater than one story plus attic. Cost of retrofitting by Strong Back approach was calculated to be lowest with NPR 464,3652.

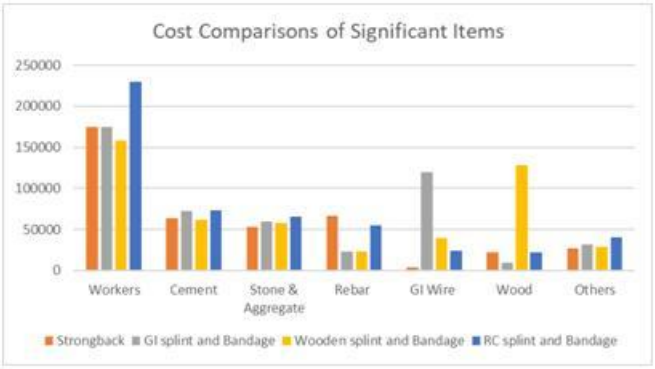

Figure 12 Cost Comparisons of Significant Items in different Retrofitting Techniques for Two Story SMM Buildings

Similarly, the cost of retrofitting by splint and bandage with jacketing was found to be NPR 545,187,551,426 and 585,491 respectively for GI, Wooden, and RC as jacketing materials. Costing per square feet of floor area are NPR 613, 719,728, and 772, respectively, for Strong back, GI splint and bandage, Wooden splint and bandage, RC Splint and bandage.

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RC Splint and Bandage is the most expensive retrofitting techniques among four, which is maybe due to the substantial cost for workers and formworks than other retrofitting techniques, as shown in Fig 12. Despite the high cost of Rebar, Strong Back approach has the least cost.

C. Two Story plus Attic SMM buildings

The cost estimate was repeated for all four techniques of retrofitting for two-story plus Attic SMM buildings. Among all the alternatives, the cost of retrofitting by Strong Back approach was calculated to be lowest with NPR 581,461. Similarly, the cost of retrofitting by splint and bandage with jacketing was found to be NPR 687,645, 663,858 and 702,3768 respectively for GI, Wooden, and RC. Costing per square feet of floor area are NPR 511, 604, 584, and 618, respectively, for Strong back, GI splint and bandage, Wooden splint and bandage, RC Splint and bandage.

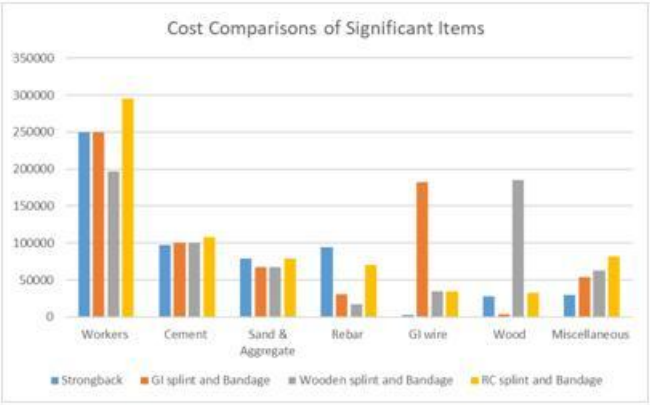

Figure 13Cost Comparisons of Significant Items in Different Retrofitting Techniques for Two plus Attic SMM Buildings

As in previous analysis, RC Splint and Bandage is the most expensive retrofitting techniques. GI and RC splint and Bandage have similar cost but exceed the cost of the Strongback by more than NPR 80,000.

D. Cost Comparison Across Story Height

We compare the total cost of retrofitting a house with the same floor area 35.25 Square meter with different approaches across different story height. Table 1 shows the total cost estimated in NPR along with cost per square feet to ease the comparison.Irrespective of the floor height, Strong back approach has the cheapest cost of retrofitting. It is followed by the GI, wooden,and RC splint and bandage approach. Wooden Splint and Bandage is the most expensive among the four techniques.

For Two Story SMM Building, the cost of retrofitting has increasedfor each technique in terms of floor area. In absolute value, the total cost increases by around NPR 55,000 for three methods other than RC Splint and Bandage. With the highestincrement of cost, NPR 76,502, RC Splint and Bandage is still the most expensive method of retrofitting. Strong Back has the only cost per square around NPR 600, and hence the least expensive techniques for two-story buildings for this floor size. The Cost per square feet is highest for two-story buildings, and this is due to the fact that floor factor two is applied for both one plus attic and two-story buildings.

Two-story and attic SMM buildings can be retrofitted with the least cost by Strong Back approach. Cost of retrofitting per square feet is lowest among all the alternatives with NPR 511.The highest cost is NPR 618 per square feet floor area, for RC Splint and Bandage. Despite the highest rate of increment of cost for retrofitting from One Story plus attic to Two stories plus attic using Strong Back Approach with 42%, the total cost of retrofitting was still lowest for the approach.

IV. RETROFITTING STATUS

Retrofitting has significant social and economic advantages, which provides spacious room in a shorter duration. It also protects vernacular architecture, which has high cultural value and assets for a country, where tourism is an integral part of the national economy.However, the number of people willing for retrofitting is less than expected.

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Cost comparison of different Retrofitting methods for a floor area of 35.25 square meter									
Retrofitting Approach		Strong Back		GI Splint		Wooden Splint		RC Splint	
Story	Floor Factor	Total Cost (NPR)	Cost per Square Feet	Total Cost (NPR)	Cost per Square Feet	Total Cost (NPR)	Cost per Square Feet	Total Cost (NPR)	Cost per Square Feet
One Story Plus Attic	2	410157	NPR 541	490865	NPR 648	496301	NPR 655	508989	NPR 672
Two Story	2	464652	NPR 613	545187	NPR 719	551426	NPR 728	585491	NPR 772
Two Story Plus Attic	3	581461	NPR 511	687645	NPR 604	663858	NPR 584	702768	NPR 618

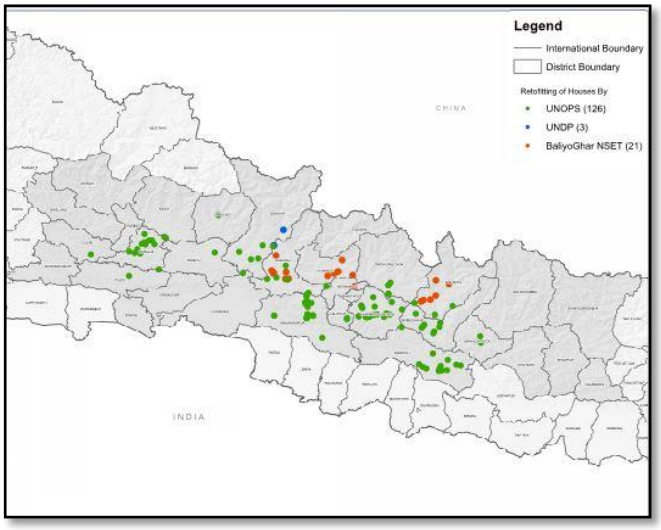

Figure 14 Location of Retrofitted houses in 32 earthquakes affected district, August 2019

Figure 14 shows the current status of ongoing and completed retrofitting as of August 2019. In total, only 150 houses are being retrofitted, which is not even 1 % of the total houses to be retrofitted. Another dimension of the problem is that retrofitting is ongoing only in that location where initiative is taken by organization.

Table 1 Cost Comparison of different Retrofitting methods for traditional houses with a floor area of 35.25 square meter *Some reasons are summarized as follows:*

1. Recently Introduced Technology.

As discussed earlier, retrofitting is only being widespread after two years of Gorkha Earthquake. People are skeptical about retrofitting techniques. The awareness-buildingprogram is vital as we have a similar case with reconstruction earlier. Reconstruction was slow in the first two years but has taken a pace with effort from NRA, Local Government body, NGOs and INGOs.

2. Insufficient financial support from the government

The government only support to NPR one lakh for retrofitting beneficiaries, which seems inadequate even for buying materials. The latest meetings of stakeholders also have highlighted the need for increasing aid amount by 100 % reinforcing the ideas of insufficient Financial Support.

3. Remote Location.

Most of the retrofitting sites are in a remote location. Thus, logistics cost is higher, which makes the already financially deprived people more challenging to arrange materials.

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