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IDENTIFYING SEISMIC RETROFITTING MEASURES FOR COMMON REINFORCED CONCRETE FRAME BUILDINGS IN NEPAL

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ABSTRACT:

Typical Reinforced Concrete (RC) Frame buildings with brick masonry infill are dominantly emerging building typology in the urban areas of Nepal. However, seismic vulnerability of this type of construction, as constructed in Nepal, is presumed very high. To quantify the problem, two prototypes of such buildings, developed based on a survey of the buildings to correctly simulate the building type, were researched. Computer analysis indicated increased seismic risk of such RC buildings of 2 stories and higher, the buildings lack both strength and ductility. The main vulnerability factors are inferior masonry quality, lean frames and above all lack of attention to reinforcement details. As Nepal lies in a very high seismic zone, an immediate attention is imperative to improve the seismic resilience of such buildings. Out of the various available methods, wall jacketing and introduction of shear walls are considered to be the most feasible and economically viable as well as practicable methods though other expensive alternatives are also available. Cost incurred for such interventions is estimated to be 15 to 40 percent of reconstruction.

KEYWORDS:

Non-engineered buildings, frame building structure, masonry infill, seismic retrofit

1. INTRODUCTION

Most losses of lives in past earthquakes in developing countries have occurred due to collapse of buildings. These buildings are generally non-engineered**:** those constructed using informal process in the traditional manner without any or little intervention by engineers. The safety of the non-engineered buildings from the fury of earthquakes is a subject of highest priority in view of the fact that in the moderate to severe seismic zones of the world more than 90% of the population still live and work in such buildings, and that most losses of lives during earthquakes have occurred due to their collapse [1]. The risk to casualty is further increasing due to rising population, poverty, scarcity of modern building materials, viz. cement and steel, lack of awareness and necessary skills and technology, particularly in the developing countries.

The same problems prevail in case of buildings in Nepal. Various studies indicate that more than 60% of the buildings in Kathmandu Valley are unsafe from seismic point of view[2]. Most of the small and residential buildings are built haphazardly with little or no engineering inputs. The main factors creating this situation are lack of knowledge, awareness and poor mechanism of technology dissemination.

In urban areas of Nepal light reinforced concrete frame buildings with masonry infill is becoming dominant method of construction. As a result of urbanization and hike in land price, increase in the height of new buildings is becoming the practice. Most residential buildings are between 2 to 6 stories, some even up to 9 to 10 stories. These buildings, however, are not designed and constructed to meet the seismic requirements. Structural details remain same irrespective of the height of the building. The general trend is to add storey when the owner manages to save enough money for the construction of additional storey, despite the fact that no provision for much later addition would have been made prior to construction of the building. Because of higher height and large occupancy, these buildings are highly vulnerable to earthquake shaking.

Recently mandated building code of Nepal addresses the earthquake resistance of this class of building, but it does not prescribe any suggestion on seismic strengthening of existing buildings, though this typology of construction is estimated to be about 25 % of buildings in urban areas of the country. These structures lack strength and ductility and are deficient in configuration and structural system. The Bhuj earthquake of 26 January 2001 can be considered as an ill-fated event when this class of buildings suffered catastrophic damage causing large scale life and property loss. These buildings need immediate attention and seismic retrofit of such buildings is a pressing need against impending future earthquake in Nepal.

This paper presents an attempt toward quantitative evaluation of seismic vulnerability of this particular type of buildings and proposes practical methods to reduce it. The study is an initiative to address the growing need to evaluate seismic strength of buildings considering the effect of masonry infill walls and produce an overview of some of the retrofitting measures to improve their seismic response. The results, with and without strengthening measures, are compared to estimate the effectiveness of the various intervention options.

2. METHODOLOGY

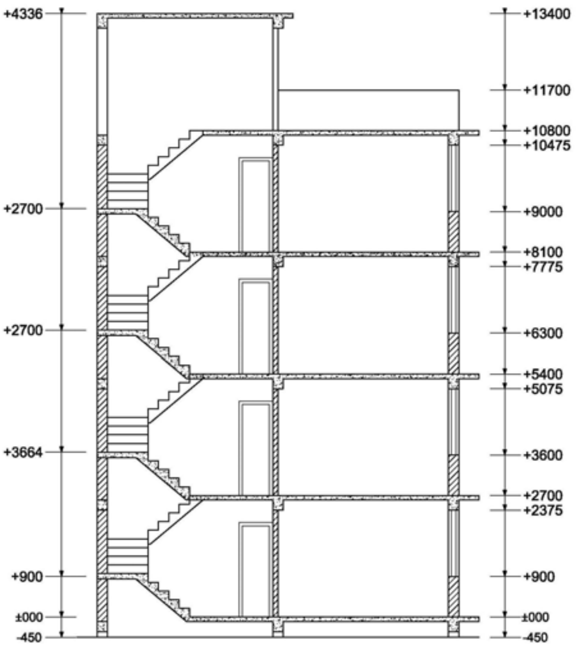
The study methodology included rapid reconnaissance survey followed by detail survey of buildings to correctly simulate the actual building type under consideration. Typical values of material strength used are educated guestimate, as virtually no data exist for such assessment. However, the authors did collect test specimens (i.e. prisms of concrete, brickwork, sub-assemblages etc.) from buildings under demolition in Kathmandu Valley, and subjected these to limited laboratory tests to supplement the assessment work. The Indian seismic code, IS: 1893, 2002 is referred for lateral load calculation[3]. Structural analysis of the selected buildings was performed in ETABS, using data details obtained from survey and experimental works. Finally, the most suitable retrofitting options for possible improvements of seismic performance of the building were identified and costs estimated.

3. CHARACTERISTICS OF TYPICAL BUILDINGS

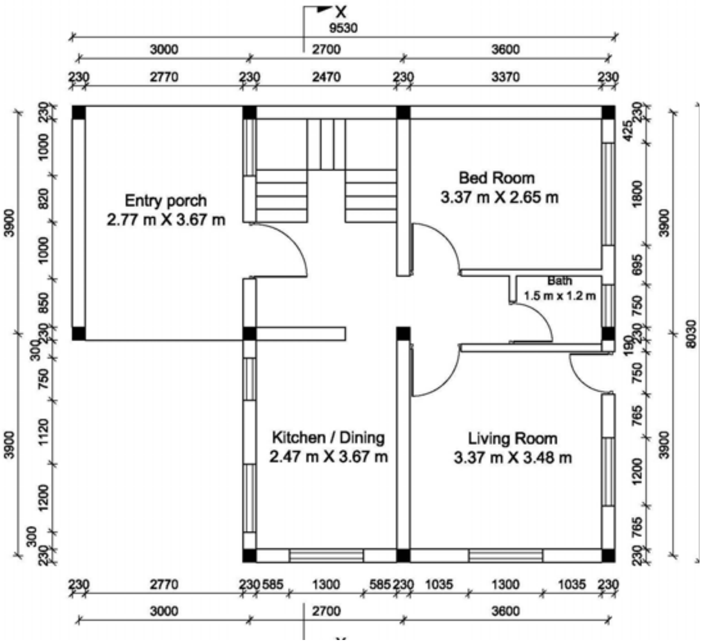
Analysis of survey data on building helped identify prevalent building plans and elevations. Two representative buildings that resemble most of the reinforced concrete non-engineered framed buildings with brick masonry infill in Kathmandu Valley were selected for analysis.

Typical features of building type 1

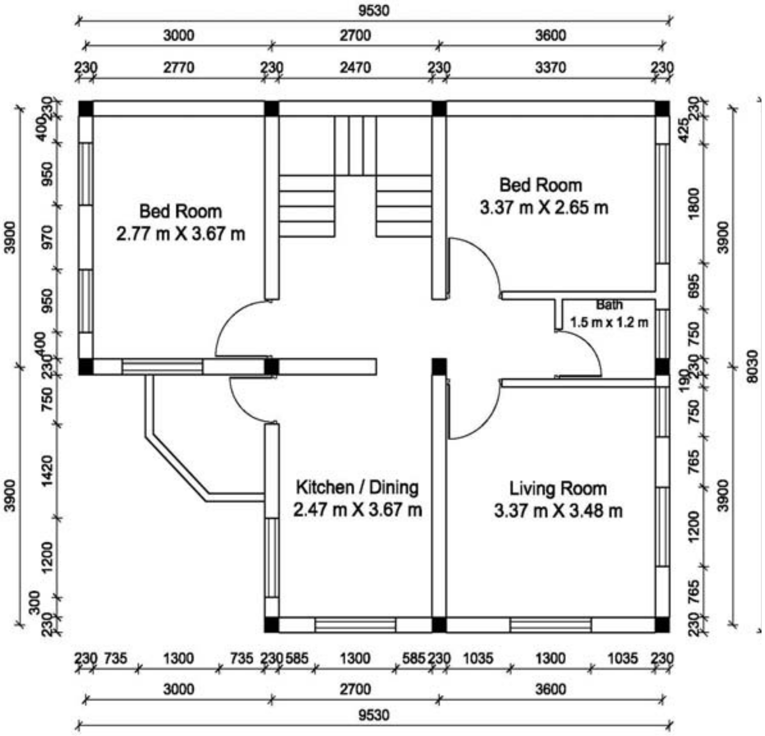
This is a stand-alone detached building with free space around it. All columns are of 230mm X 230mm size with 4 numbers of 12mm diameter reinforcement bars and Beams are 230mm X 325mm, with 4-12 rebars at corners. Floor slabs are reinforced concrete 115mm thick. Grade of concrete and steel for all structural elements are M15 and Fe415 respectively. All the periphery walls and the walls adjacent to staircase are 230mm thick and other internal partition walls are 115mm (half brick) thick. The rear side of the building consists of full brick wall while the remaining three sides have door/window openings. The floor area of the building is 61.0 m^2. Maximum grid spacing is 3.9m.



A Cross Section of Building Type 1



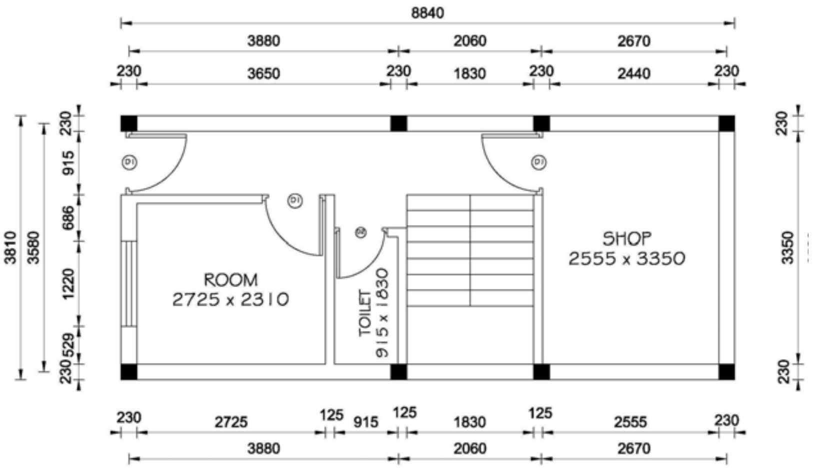
Ground Floor Plan, Type 1 Building



1st, 2nd, 3rd Floor Plan, Type 1 Building

Typical features of building type 2

This is a row building and has a single bay. All columns are 230mm X 230mm size and all beams are 230mm X 325mm depth. Floor slabs are 115mm thick reinforced concrete. Grade of concrete and steel for all structural elements are M15 and Fe415 respectively. The periphery walls are 230mm thick and other internal partition walls are 115mm (half brick) thick. The longitudinal periphery walls on both sides are without openings, while end walls and the internal partition walls have openings for windows and doors. The floor area of the building is 30.0 m^2 and maximum grid spacing is 3.6m.



Ground Floor Plan, Type 2 Building

4. ANALYTICAL STUDY AND RESULTS

The two representative building were subjected to detailed analysis. Mathematical models were made and analyzed for 2 storey, 3 storey and 4 storey conditions separately, keeping the building plan and elevation the same in each storey. Changes in the number of storey in the building models was done to get in-depth knowledge on patterns of stresses increase in load bearing structural elements and to check the capacity of the building with variable stories. The parameters investigated are the time period, inter-storey drift, base shear and induced element stresses in struts, beams and columns. Stresses induced are compared with their respective permissible values. In this way, critical structural elements that are more likely to fail are identified. It is also able to identify the main cause of failure i.e. whether they fail in shear, tension or in axial compression. With due respect to the induced stresses and the reinforcement provided in beams and columns, lap length require is calculated in each cases. These calculated minimum lap length is compared with the general practice in the actual construction processes. Similarly, anchorage value require in beam column joints in each case is calculated. The cases which exceed the permissible value are strengthened with various intervention measures. Results of the strengthened structure are further compared with the original existing structure and also with their respective permissible values to verify the safety of the structure.
Analytical results have shown axial stress in diagonal strut exceeding the permissible value of 0.4 N/mm^2 for buildings of 2 stories and above. These values range from 0.9 N/mm^2 to 2.0 N/mm^2 for buildings of 2 stories and 4 stories respectively. If each element of the building is to sustain the induced lateral load, maximum value of shear stress in the columns is observed to be 0.32 N/mm^2, 0.44 N/mm^2 and 0.49 N/mm^2, beam anchorage required is 550mm, 750mm, and 1000mm and lap length require for tension column is 350mm, 1100mm and 1730mm for 2 storey, 3 storey and 4 storey buildings respectively. These values of lap length and anchorages are usually not seen in the general practice of construction in the area. Moreover, these values are likely, provided the structural system of the building works together till the ultimate expected lateral load. Most likely, the masonry infill that acts as pin jointed diagonal compressive strut, would start failing prior to subjecting the building a full earthquake force. Beyond the ultimate capacity of compressive strut, the response of the building changes and the actual response of the building become uncertain. As bare frame building analysis results of the same buildings show much worse results in frame elements with much more stress levels, the best option is to take the effect of brick masonry infill. For this, uniform distribution of infill and its subsequent strengthening is imperative. Various intervention options were considered with the purpose to reduce the axial stress in diagonal struts to permissible values. This includes addition of masonry walls at appropriate locations in the alignment of columns, jacketing of selected masonry walls, addition of reinforced concrete walls and replacing

half-brick walls with full-brick walls. These intervention options can bring down the stresses in the building elements within the permissible limits.

Table 1: Comparative Results on Improvement by Different Corrective Measures

Building 1 (2 Storey)					
S.N.	Description	Strut Axial Stress (N/mm^2)	Column Shear Stress (N/mm^2)	Beam Anchorage Required (mm)	Column Lap Required (mm)
1	Existing Building	0.90	0.21	490	335
2	With addition of walls	0.51	0.17	410	300
3	Wall jacketing in first	0.40	0.35	400	200
Building 1 (4 Storey)					
S.N.	Description	Strut Axial Stress	Column Shear	Beam Anchorage	Column Lap
1	Existing Building	1.94	0.45	700	1300
2	Partial Shear walls	0.55	0.16	950	350
3	Full Shear wall	0.39	0.15	350	300
4	Column Jacketting	0.68	0.18	480	
5	Wall Jacketting	0.41	0.30	325	400
Building 2 (2 Storey)					
S.N.	Description	Strut Axial Stress	Column Shear	Beam Anchorage	Column Lap
1	Existing Building	1.0	0.32	540	220
2	Increase thickness along long span and wall jacketing on peripheral walls in the other direction	0.4	0.13	300	All columns in compression
Building 2 (4 Storey)					
S.N.	Description	Strut Axial Stress	Column Shear	Beam Anchorage	Column Lap
1	Existing Building	2.1	0.49	1000	1730
2	Increase thickness along long span and wall jacketing on inner walls in the other direction	0.39	0.13	480	400

5. INTERVENTION OPTIONS SUGGESTED FOR IMPROVING SEISMIC PERFORMANCE

Out of the various available methods, the following alternatives have been identified as practically feasible and economically viable for seismic retrofitting of buildings in the context of Nepal.

Retrofitting Options for Building Type 1

Retrofitting Option I: Jacketing of selected walls

Since the building frame is very light as compared the number of storey, the most attractive alternative would be to improve integrity and deformability employing jacketing of the building structure. The following items will be included:

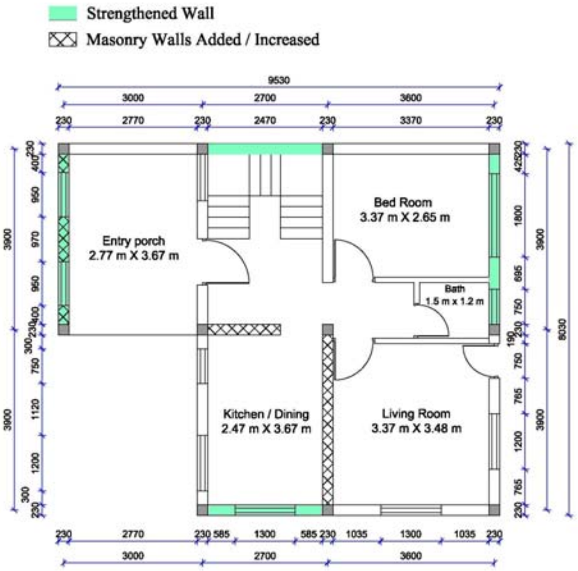
i) Increase strength of existing walls: To improve strength, deformability and reduce risk of disintegration resulting in total collapse of wall of the building, reinforced concrete jacketing of all the selected four walls on the periphery as shown in the figure below could be a good option. In this alternative two steel meshes (welded wire fabric mesh) will be placed on the either side of the wall and connected by steel anchors (each at spacing of 600 mm). A 40 to 50 mm thick cement mortar or micro-concrete layer will then be applied on the two networks thus making two interconnected vertical plates that will augment the wall stability.

ii) Increase area of load bearing walls: Along with the jacketing of these walls, four more masonry (brick in cement) walls are added in ground floor and two walls are added in upper floors to produce symmetricity of wall action which will increase the stiffness of the building.

Retrofitting Option II: Addition of Reinforced concrete shear walls

As the building lacks ductile detailing, which is a key factor for resisting earthquake force, deformation control is of primary concern. Deformation can be significantly reduced if few selected masonry walls are replaced by reinforced concrete shear walls which can be designed to absorb the amount of lateral load that the existing structure is unable to withstand. This option entails:

i) Remove selected brick masonry walls and replace the same with reinforced concrete shear wall and tie with the existing frame structure. This could be the most promising method to reduce the damage due to expected earthquake. This is the better option if newly built reinforced concrete shear walls can be integrated with the corresponding beams and column of existing structure. Analysis result shows that addition of shear walls significantly increase strength and stiffness. Structural response in this case is better than the above mentioned method of wall jacketing. This technique is advised for the buildings of 4 stories and above.



Building Type 1, Retrofitting Option

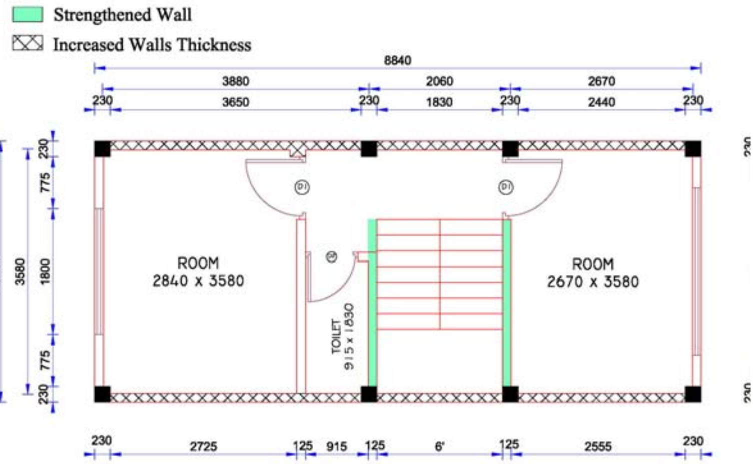
Retrofitting Option for Building Type 2

Retrofitting Option I: Increase thickness of longitudinal brick masonry wall and jacketing of selected transverse walls

The response of the structure is somewhat better in the longitudinal direction than in the transverse direction. As the building is a single- bay structure the strengthening measure should target the weaker walls in transverse direction. The following are suggested.

i) Replace the half-brick wall of 115 mm by full-brick thick (230mm) along the long span from first floor onwards and connect properly with adjacent frames.

ii) Jacketing of selected walls in transverse direction.
This option is viable for the buildings up to 3 stories.



Building Type 2, Retrofitting Option

Retrofitting Option II: Increase the thickness of longitudinal masonry wall in long span and replace the transverse masonry wall by reinforced concrete shear wall

For buildings of 4 stories and more, it is advised to replace the selected masonry walls as shown in the figure by reinforced concrete shear walls.

i) Increase the half brick wall of 4 ½ inch to full brick thick (9 inch) along the long span from first floor onwards.
ii) Replace the selected masonry walls by reinforced concrete shear walls of suitable thickness in the transverse direction.

6. COST ESTIMATE

Tentative costs of different intervention options for buildings of different stories are listed below.

Table 2: Cost Estimate

S.N.	Description of intervention method	Building storey	Cost per square meter of floor area (US$)
Building type 1			
1	Jacketing of selected walls	2	40
2	Jacketing of selected walls	3	60
3	Jacketing of selected walls	4	76
4	Addition of RCC shear wall	4	90
Building type 2			
1	Increase wall thickness along long span and wall jacketing on peripheral walls in the other direction	2	60
2	Increase wall thickness along long span and wall jacketing on inner walls in the other direction	3	84
3	Increase wall thickness along long span and addition of RCC shear wall in the other direction	4	104

7. CONCLUSIONS

The following conclusions are drawn from the study.

a) The typical buildings which are representatives of the dominant building typologies in urban areas of Nepal do not meet the earthquake-resistant requirements as specified in the National Building code which say “Structures should be able to resist moderate earthquakes without significant damage and structures should be able to resist major earthquakes without collapse”.
b) Seismic risk increases with building height for buildings of storey 2 and more. The buildings lack both in strength and ductility. The risk can be significantly reduced by seismic strengthening of these buildings.
c) It is advisable to adopt wall jacketing for buildings of two to four stories as a strengthening measure to improve the building response in large earthquakes. Similarly, for the buildings of four stories or more, wall jacketing may not suffice; other alternate measures such as addition of reinforced concrete shear walls at appropriate locations should be provided. Out of the various available methods, these methods are the most practically feasible and economically viable options.

d) Cost of strengthening varies with storey height. However, the cost of retrofitting for a particular building differs based on building configuration, its strength, rigidity distribution, redundancy and other social and environmental factors.

8. RECOMMENDATIONS

Considering high seismic vulnerability of existing building stock in urban areas as demonstrated by the analysis, it is obvious to implement strategies of seismic retrofitting of existing buildings in order to avoid future earthquake disasters. Implementation of the retrofitting process straight by the house-owners is apparently difficult under the current situation of house owners, level of awareness, attitude and economic status of most Nepalese people. There are many other factors at play including socio-economic, cultural and environmental. What is required is an integrated effort by the local Government, NGO's and other related organisations to influence public opinion on seismic retrofitting and implement it giving priority to public building and buildings of mass occupancy. To find better and easier acceptance, such measures should be made an integral component of the development plans of the country so that these get appropriately incorporated in the future strategies.

We need to be concerned also about the lack of awareness regarding the availability of simple solutions and their effectiveness in achieving seismic safety as a preventive measure at minimum cost among all the common people. Structural safety can be achieved by adopting appropriate designs and construction details at small extra expenditure which should be within the economic means of people. Nominal retrofitting could prevent life-threatening collapses and bring damages limited to repairable proportions, although these measures may not prevent all damages during moderate or large earthquakes.

To reduce the disastrous effects of earthquakes on building structure, its function and life safety of occupants, the following recommendations are made

a) A time-bound program should be implemented to retrofit vulnerable buildings with incorporation of seismic-resistant measures.
b) Prior to implementing retrofitting process, a detailed assessment of buildings, their structural system and materials should be carried out.
c) Masonry walls are recommended to be braced with reinforced concrete mess or fiber reinforced polymers to prevent non-structural damage during large intensity earthquakes.
d) Uniform distribution of furniture, fixtures, equipment and other non-structural elements should be ensured to achieve even distribution of loads. The non-structural elements (partitions, furniture, equipments etc.) should be fixed properly for restricting their movement to prevent overturning, sliding and impacting during an earthquake.

ACKNOWLEDMENTS

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