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SEISMIC RETROFIT OF AN EXISTING RESIDENTIAL BUILDING IN NEPAL TO FUNCTIONALIZE AS A HOSPITAL USING FERROCEMENT

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Abstract

In many cities in Nepal, urbanization is causing land prices to increase and less spacing being available for constructing new buildings. Therefore, it is increasingly common for residential buildings to be converted to buildings of other usages, such as hospitals or schools. It causes an increase in the seismic weight of the buildings. Also, some usage such as hospital, schools require an even larger design base-shear coefficient as per Nepal Building Code (NBC). However, building usage is often converted without considering and implementing retrofit solutions. For developing countries like Nepal, an economic retrofitting solution is required to motivate them for retrofitting. As an economic retrofit solution, “Ferrocement” seems the best fit in Nepal.

Here in this research, a conceptual case study on the effectiveness of applying Ferrocement retrofit solutions is examined. The case study considers an existing 3-storey residential reinforced concrete frame building with unreinforced masonry infill that survived the 2015 Gorkha earthquake, which is converted to a hospital building. The seismic performance of the building without retrofit was evaluated using Japan Building Disaster Prevention Association (JBDPA), 2001 standard and nonlinear pushover analysis paired with the Capacity Spectrum method. The results show that the building would be safe in Gorkha earthquake and is up to code standards when used as a residential building. However, increasing the building’s mass and changing the usage type without applying any retrofits causes it to fail during the Gorkha earthquake and fall well short of code requirements, highlighting the importance of considering the need for retrofitting when changing usage types.

Three different techniques of retrofit were considered for the hospital building; (i)- application of Ferrocement to masonry walls over the bottom two floors only, (ii) application of Ferrocement to all masonry walls in the building, and (iii) adding additional masonry walls to the ground floor in addition to solution (i). All three solutions were found to be code-compliant using the Capacity Spectrum method. However, the structural performance of solution (iii) was found to be the best in terms of reducing drift and ductility demands, where else solution (ii) was found to be the worst due to deformations all concentrating solely on the ground floor. This indicates that retrofitting the entire building is not necessarily an ideal solution and that careful identification and selection of building components to retrofit would be a more effective option overall.

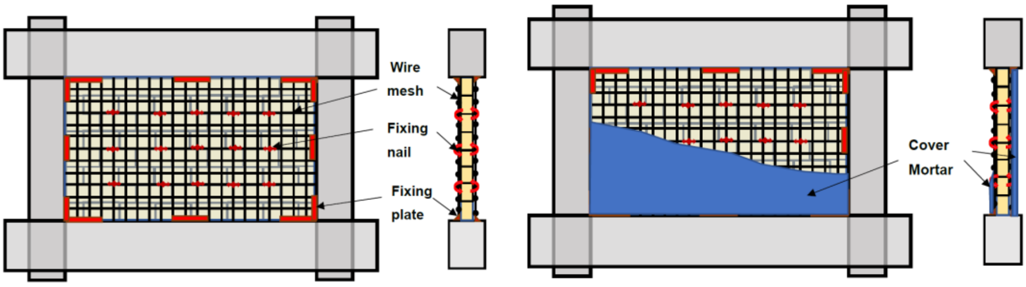
Keywords: Ferro-cement Retrofit, Wire mesh; Infill Masonry; Functionality change, Non-engineered Buildings.

1. Introduction

The topographic structure, frequent tectonic movement make Nepal as seismically prone. Damage caused by past earthquakes was massive. The recent great earthquake on April 25, 2015, claimed lives of 8970 [1] people in Nepal. More than 498,852 residential buildings and 2,656 governmental buildings were collapsed, and 256,697 private houses and 3,622 government buildings were partially damaged. The maximum public buildings which were damaged by the earthquake were non-complying to current building codes as well as those which changes its occupancy from residential to public.

It was found that the collapse of buildings is 95% cause of human death and economic losses from earthquakes. Failures of the buildings are the result of poor construction practice, non- complying building codes, lack of frequent revision of seismic codes, lack of awareness, lack of preparedness and old un-repaired/retrofitted buildings. Therefore, such structures with the low seismic performance required a retrofit. The retrofitting of buildings is feasible if the cost of retrofit is less or equal to 30% for reinforced concrete (RC) structure. So for developing countries like Nepal suitable and economical ways of retrofitting is also another issues. Therefore, ferrocement (FC) lamination retrofitting techniques, which is found to be appropriate techniques for developing countries like Nepal are presented in this study.

Ferrocement lamination is a technique which is used for strengthening the existing infilled masonry wall by using wire mesh and cement mortar. The wire mesh is impregnated inside the mortar. This technique is very much beneficial for the developing countries because it does not require large budget nor many technical experts. Since this method is simple and uses the locally available materials by utilizing the local labors so it could be the cost-effective methods of retrofitting in the case of developing countries like Nepal. The construction techniques involved in the ferrocement technologies are given below in Fig. 1



(a) Attaching of Ferrocement lamination (b) Finishing by cover mortar

Fig. 1. Schematic diagram of FC lamination on masonry infill.

Thus, in brief the retrofitted ferro wall has the strength contribution from three items, viz bare frames, existing infill brick masonry walls, and added ferrocement walls. The overall strength of the retrofitted ferro wall could be summarized as given below,

2. Outline of building

The selected target building “Chiranjibi Model Hospital” that survived the recent Gorkha EQ is three-story with attic floor RC framed structure. It has a brick masonry infill. The target building constructed before the building code implemented in this area, as a usual trend of construction in Nepal, this building was also built without consulting to engineers and architects. As a result, construction materials, construction methods, design and detailing is not as requirements of the existing code.

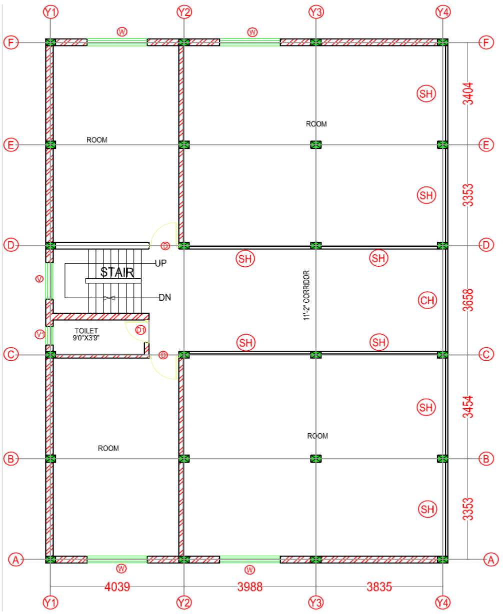


Fig. 2. Typical first-floor plan.

Table 1. Outline of the target building.

1. Geological Information
Soil Class: Type II: Medium
Seismic Zonation Value (Z) NBC:105 =1
2. Structural Information
All floor 2.87m
Columns: All 9" x 12" Main Bar: (4-12mmØ+2-10mmØ) Lateral ties: 8 mm @ 150 mm c/c
Beams: All (230 X 355 mm) with 2-12 Ø (th)+2-12 Ø (ext.) mm top +4-12 Ø mm bottom bars. Hoop 8mm Ø @ 150 mm c/c
Slab: 125mm thick (with 8mm Ø @ 150 mm c/c)
Concrete Grade: M20 (Compressive Strength 20MPa)
Steel Grade: Fe415 (Tensile yield strength 415MPa)
Locally made brick masonry infill having a wall thickness of 230mm and 110 mm.
Load Considered: 14.75 KN/m^2 for first and second floor 8.4 & 7.97 KN/m2 for third and staircase cover floor.
Seismic Demand Index (Is_0) as per NBC 105: 0.48

Initially, the building was a residential building, and later the ownership was transferred to the hospital. The design loads and performance objectives for the hospital buildings and residential buildings are different. Thus, the building requires retrofitting for changing the functionality. The typical floor plan of the building is given in the Fig. 2. The brief information and data related to the building are provided in Table1.

3. Theory and methodology

The selected building evaluated as a bare frame, by using the Japanese Building Disaster Prevention Association (JBDPA) [2], 2001 Standard for first level and second level screening. Then, the building was reevaluated considering existing infill of the structures using the second level procedure of the JBDPA Standard. Based on the deficiency of the structure obtained after considering the infill, the lagging strength to the seismic demand index needed to supply from the retrofitting. As the retrofitting, ferrocement lamination technique introduced. The number of walls required to retrofit by ferrocement (FC) lamination calculated and applied to the structure. The retrofitted building again reevaluated as per JBDPA second level screening. Three different methods of wall retrofitting were selected and evaluated by manual calculation using JBDPA, 2001.

Following formula are useful for calculating the strength of ferrocement.

1. Required Strength of Ferrocement Wall

   1.1 Required Strength of total ferrocement walls

$$Qfc=Qreq-Qmas-Qc \quad \text{in Newton(N)} \qquad (1)$$

Where,

Qreq: Required total strength (N)

Qmas: Existing total strength of infilled masonry walls (N)

Qc: Existing total strength of infilled masonry walls(N)

1.2 Required Strength of one ferrocement wall

$$Qfc/piece = Qfc/n \tag{2}$$

Where,

n: Total number of ferrocement walls

2. Design of Ferrocement Wall

2.1 Calculate one face required strength of ferrocement wall

$$\Delta fc=Qfc/piece/ns \tag{3}$$

Where,

ns: Number of faces

if one, ns=1

two, ns=2

2.2 Design for one ferrocement face

(i) Required τfc for one face ferrocement wall

$$\tau fc=\Delta\ Qfc/Afc\ \ (\mathrm{MPa}) \tag{4}$$

$$Afc= tfc*lfc \tag{5}$$

Where,

Afc: Area of ferrocement (mm2)

tfc: Thickness of ferrocement (mm)

lfc= length of ferrocement (mm)

(ii) Design of τfc for one ferrocement face

$$\tau fc= Max\ (\ \tau fc1,\ \tau fc2) \tag{6}$$

$$\tau fc1= ffc/20 + 0.5*\rho fc*fcy \tag{7}$$

$$\tau fc2= \rho fc*fcy \tag{8}$$

where,

ffc: Mortar compressive strength (MPa)

ρfc: Steel ratio of wire mesh

$$\rho fc = Afc/(s*tf)*nl \tag{9}$$

where,

Afc: Area of wire mesh steel (mm2)

s: Spacing of wire mesh (mm)

tf: Thickness of ferrocement layer (mm)

nl= Number of wire mesh layer

fcy: Tensile yielding strength of wire mesh (N/mm2)

3. Judgement of Design

3.1 Total strength (Qdes) after design

$$Qdes= \Sigma \tau fc*Af*ns+Qmas+Qc \quad (N) \tag{10}$$

3.2 Judgment

$$\text{If } Qreq \leq Qdes \text{ OK!} \tag{11}$$

In addition to this, the same building evaluated using Nonlinear Static Pushover Analysis (NSPA) method [3], using ETABS 2016 software [4], considering both bare and infill. Finally, the retrofitted building with ferrocement for all three different cases was reevaluated using NSPA. Based on the seismic performance of the various retrofitting plans of the building, the appropriate one was selected.

In addition to this, the target building was evaluated its performance based on three different types of occupancy. Case A: As a residential building (no change in its occupancy) without retrofitting, Case B: a residential building, however it changes its occupancy as hospital building without retrofitting and Case C: a residential building used as hospital building but with retrofitting (as per hospital requirements). The building was evaluated using NSPA using ETABS, and their performance against the recent Gorkha earthquake was studied.

4. Result and discussion

4.1. Results of JBDPA seismic evaluation of existing buildings

From the bare frame analysis of the building except for the fourth floor, none of the stories meets the standard seismic demand index (0.48, as per NBC 105) [5]. However, when infilled of the existing building strength was considered, then the third and fourth story found to be safe. However, the first and second story still could not meet the standard criteria. Therefore, the lagging strength needs to supply by the retrofitting by ferrocements. Fig. 4 illustrates the results of the bare and infilled frame as case 1 and case 2.

4.2. Results of Retrofitting using ferrocement (FC) lamination.

The steps involved in retrofitting using ferrocements given below.

1. The value of Isi,bare-mod. (strength index of bare frame corresponding to ductility index F=1) from the JBDPA analysis is taken from the second level procedure for longitudinal strips and compared to seismic demand index, Is_0.
2. The value obtained (Is0-Isi, bare-mod)/Ø *Wi is the required strength to satisfy by the existing infill and ferrocements. The ductility index F=1 was assumed for infill and ferrocement. where Ø is story modification factor and Wi is floor corresponding i^{th} floor.
3. The value of shear strength by existing infills (Qinfill) considering reduction factor for openings are obtained respectively to observed directions.

4. Now total strength that needs to be satisfied by the ferrocement is obtained as ΔQfc= (Is0-Isi,bare-mod) *Wi/Ø- Qinfill.
5. Various combination of walls is added considering the opening to get the required strength

The flow chart in Fig. 3 shows the procedure involved in retrofit design.

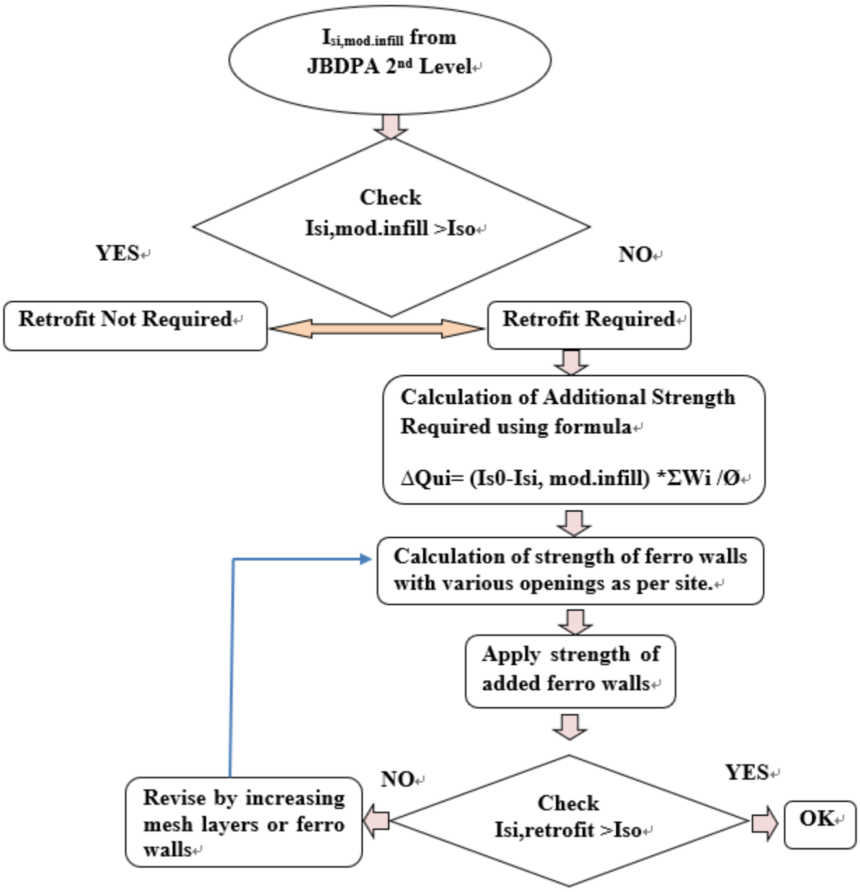


Fig. 3 Flow chart showing ferrocement retrofit technique.

The mortar with the strength of 20MPa and steel wire mesh 0.9mm @ 5.45 mm c/c having 415MPa used for ferro lamination. Fig. 4 shows the results of the evaluation of the existing building (case 1 and 2) and retrofitted buildings (case 3 to 5). Here, case 1 and case 2 are an existing bare frame (BF) and existing building considering infill masonry (BM) respectively. By the same way, for the retrofitted cases; case 3 has the retrofit only in the first floor and second floor without disturbing initial plan (FC2-NW), case 4 is same as case 3 but with additional four masonry wall replacing shutter of grid C and D (FC2-AW) and case 5 is same as case 3, but whole walls of third and fourth floors also retrofitted (FC4-NW). The result of retrofitting shows that the Is value in case of case 5 for the third and fourth floor found to be increased in comparison to that of other it is because of retrofitting in those floors was done only in case 5. The Is value for case 4 in bottom floor found to increase slightly because of strength due to new masonry walls on the bottom floor. Because of having the same strength to that of case 5 for the first and second floor, and some strength to that of third and fourth floor for case 4, the line overlapped and could not be visible.

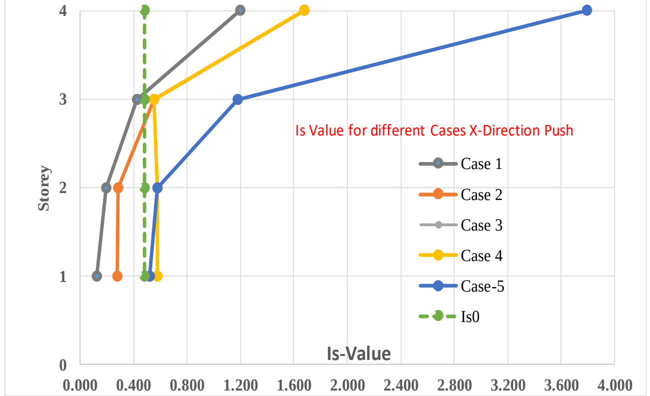


Fig. 4. Is values for various cases of evaluation and retrofitting cases.

4.3. Results of Analytical Modelling

In the analysis, frame elements (beams, columns, and struts) were modeled as line elements by assigning respective cross-sectional properties of frame and masonry struts. The rigid diaphragm applied to the shell elements (slab). The default hinges properties in ETABS 2016 (P-M2-M3) for the column as per Table 10-8, of ASCE 41-13 [6], and flexural hinge properties (as per Table 10-7, of ASCE 41-13, was used) for beam was applied. The hinge length for beam and columns applied at the10% from each end. The hinge properties of the equivalent compressive strut for masonry and retrofitted walls referred as per FEMA 356 [7], table 7-9. It was applied at the mid-section of the struts. The gravity load applied on the model are given above in Table 1, whereas the lateral loads applied on the model are as per NBC 105 distribution pattern.

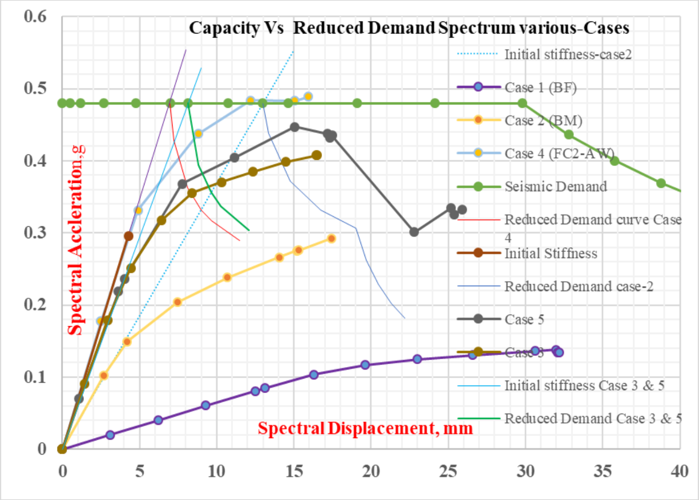


Fig. 5. Performance points for various cases.

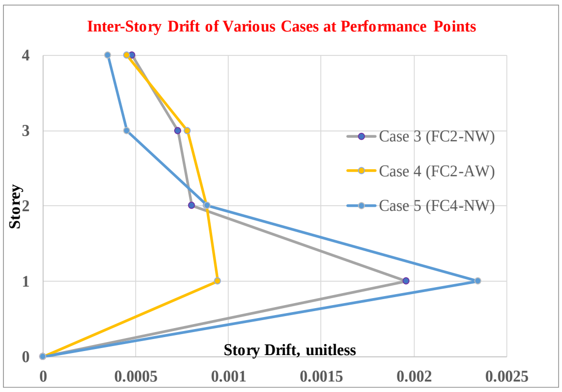


Fig. 6. An inter-story drift of various cases at performance point.

The Fig. 5 shows that at the ultimate state, case 4 has higher strength than that of the other cases. The probable reason is that the addition of walls in the bottom story of case 4 significantly increased the performance of the buildings. Although the story drift given in Fig. 6 shows for all the cases is within the drift limit of 0.4% (which is considered as Immediate Occupancy (IO) for important building in Nepal). However, in the case of case 4, the inter-story drifts (ID) was found to be evenly distributed and least ID values in comparison to other cases. The values of ID for case 3 and case 4 are almost the same for the third and fourth floor because both have no retrofitting in the upper two floors. However, the ID in upper floors in case 5 seems to be lesser because for this case we have retrofitted the upper two floors, that increased the stiffness of the building. As a result, lesser deformation occurred on those floors. In overall, this study found that just by adding four masonry walls could significantly change the structural performance of the building rather than investing a huge amount of money in the name of retrofitting such as case 5. Fig. 7 to 9 the hinge results at the performance point for various cases which was found to be at immediate occupancy state.

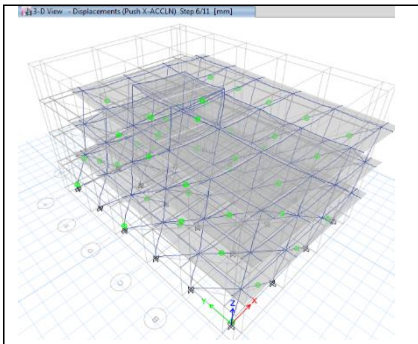


Fig. 7. Hinge Results for Case 3 at performance points.

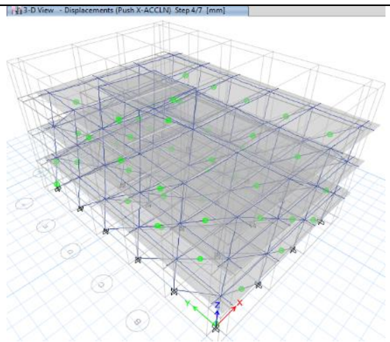


Fig. 8. Hinge Results for Case 4 at performance points.

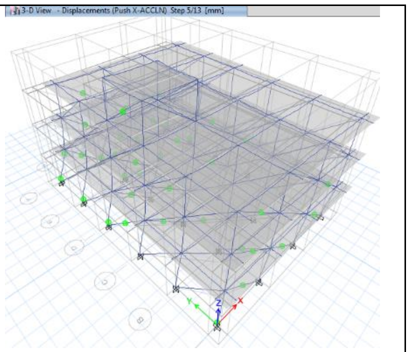


Fig. 9. Hinge Results for Case 5 at performance points.

5. Case study: functionality change

This is the case study, carried out to capture a real scenario (occupancy shifting without taking any strengthening measures for buildings) of Nepal, during the 2015 Gorkha earthquake. Here, as a case study, three different scenarios of a given target building were considered. Case A: If a building is used as a residential building, Case B: If a building of case A is used as a hospital building without retrofitting. (this is the case 2 of the previous section) Case C: If a building of case A is used as a hospital building with retrofitting. (this is the case 4 of the previous section). Fig. 10 shows the 3 different cases of this study.

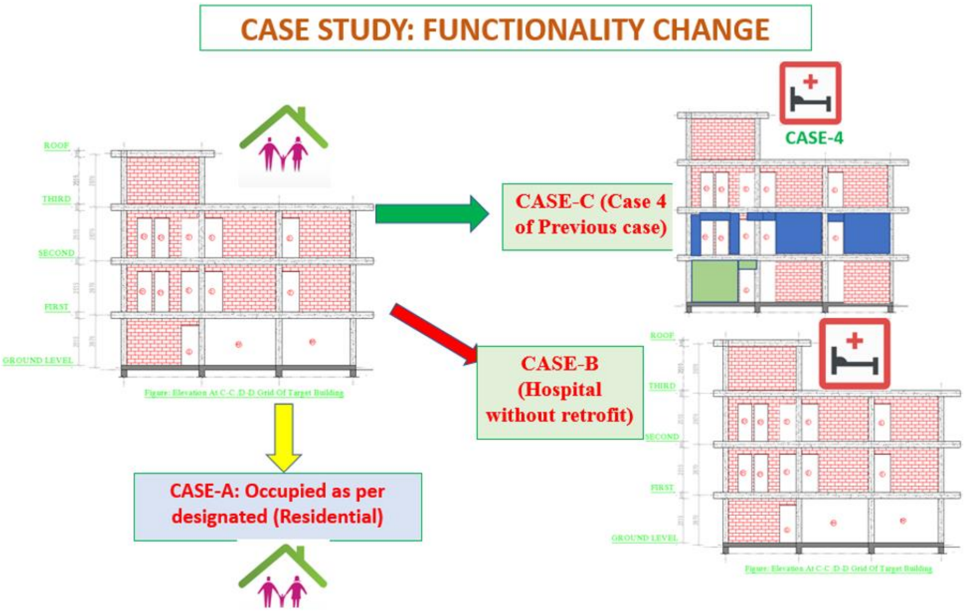


Fig. 10 Different cases considered in case study

The LL for residential and hospital building considered as 2.5 and 4 KN/m2 respectively whereas for the first and second floor the DL for residential and the hospital is 9 and 10.75KN/m2 respectively. The load for the third and fourth floor considered as same being roof floor for both cases. Nonlinear Pushover Analysis was carried out for different cases. The capacity curve of three cases of the building plotted over the demand curve of NBC 105 for hospital and residential buildings as well as the N-S component of the 2015 Gorkha earthquake given in Fig. 11. The demand curve for the 2015 Gorkha earthquake was plotted by using View Wave software [8].

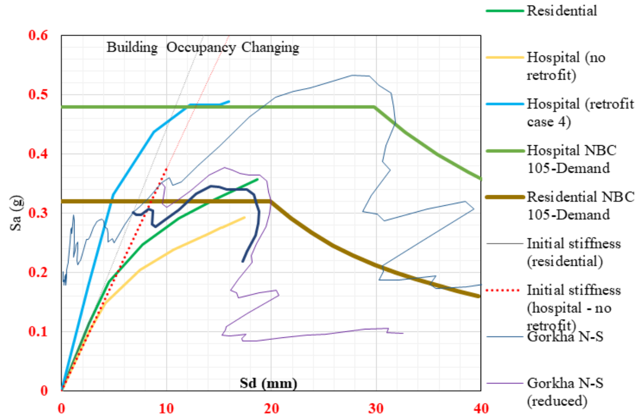


Fig.11 Capacity curve versus NBC & Gorkha earthquake 2015 demand curve for case A, B, and C.

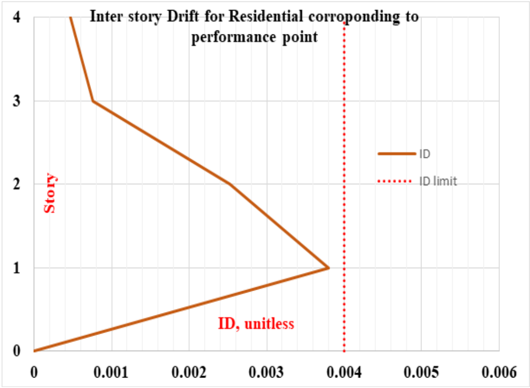


Fig. 12 ID for residential building (case A) corresponding to performance Point.

The Fig. 11 shows that the building which was occupied as a residential building without being retrofit, had a performance point of (Sd, Sg); (16.5, 0.34g) values and corresponding story drift is given in Fig. 12. The corresponding base shear and displacement for this point is 1603.03 KN corresponding to performance point. The maximum drift corresponding to this point is 0.38%, which is a bit smaller than ID limit 0.4% and this implies that building remains safe during the 2015 Gorkha earthquake. The building seems just satisfying the NBC provision for residential buildings. However, there are many other existing buildings which have poor construction detailing in comparison to this building. It implies that although the buildings that remain safe during the 2015 Gorkha earthquake are required to retrofit for satisfying the present NBC demand. However, if the building was used without retrofitting as a hospital building, then, in that case, the importance factor of the building is considered as 1.5 because the demand index must be increased by 1.5 times. Because of the increase in building seismic weight due to the change in occupancy load, the capacity of (Sa,g) decreased. Because of this, the building could neither satisfy the 2015 Gorkha earthquake demand nor requirements of hospital buildings as per NBC 105. This building will collapse if the same scale earthquake as the 2015 Gorkha earthquake occurs.

However, if we can do a retrofit for the buildings as per the intended occupancy to satisfy the NBC provision, the building could be safer. The retrofitted building was found to fulfill the 2015 Gorkha earthquake demand almost linearly within the elastic region without any damage. The building also found to satisfy the hospital demand as per codal provision. Therefore, a retrofit is an urgent need for changing the occupancy of the buildings.

6. Conclusions

Since the presence of infill plays a significant role in strengths and stiffness the contributions of the infill wall were studied. The strength and stiffness found to be increased significantly, from bare to infill and infill to ferro laminated structures. From the analytical results, it was found that the performance of the buildings in case 4 was better. It was because of the additional four masonry walls on the first floor. These walls increased the performance of the building significantly. From this, we can conclude that the performance of the building will not increase only by retrofitting in uneconomic ways as in the case of 5. Thus, the judgment of the retrofitting plan is significant, so that cost-effective work could be achieved. The vulnerability (seismic demand) of the building increases as the occupancy converted from residential to the public. Therefore, the building which is intending to shift their functionality must be retrofitted. The ferrocement techniques found to be suitable techniques in developing countries like Nepal.

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