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

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ABSTRACT

Because of urbanization, the land price becomes high, and the space in the core cities of Nepal are not available for constructing new facilities. Therefore, the trend of converting residential buildings to public buildings is increasing. Here in this study, the existing non-engineered building that survived the 2015 Nepal Gorkha earthquake that intended to shift its occupancy from residential to the hospital was evaluated. The building was assessed considering the infilled and bare frame and reevaluated the ferrocement retrofitted building using JBDPA, 2001 and Nonlinear Pushover Analysis. Three different techniques of the retrofit were considered (1-partial retrofit, 2-whole wall retrofit, and 3-partial retrofit with some non-retrofitted additional walls). The structural performance of the third types of retrofitting techniques was found to be best. To elaborate on the necessity of retrofit for changing the functionality. Three different cases for the same target building were considered, using Nonlinear Pushover Analysis. Case: A as a residential building without retrofit, Case B as a hospital building without retrofit (that depicts the current scenario of Nepal), and Case C as a hospital building with a retrofit. The recent 2015 earthquake and NBC 105 demand curves used for this study. Case A found to be safe in the 2015 Gorkha earthquake and satisfied code provision, whereas case B could not satisfy any of the demand, and case C satisfied both. The result of analysis could capture the real field scenario of Gorkha earthquakes. Many buildings of case B types collapsed during the earthquake. However, Case C type building remain safer after the quake. The result of the case study implies that many existing non-engineered buildings by the recent earthquake are in a vulnerable state and needs a retrofit. In the same way, this thesis identifies the retrofitting is urgent need before switching the occupancy of the buildings.

Keywords: FC-Retrofit, 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 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.

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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 (Debashish et al. (2018)) are presented in this study.

2. DATA

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.

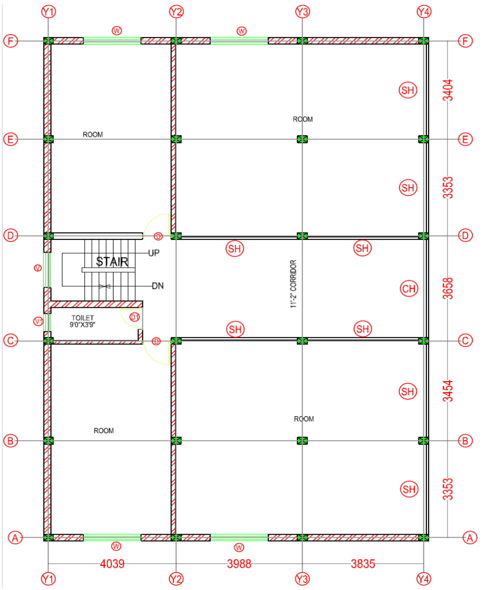

Figure 1. Typical first-floor plan.

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 mmØ @ 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/m2 for first and second floor 8.4 & 7.97 KN/m2 for third and staircase cover floor.
Seismic Demand Index (Is0) 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 below in the figure1. The brief information and data related to the building are provided below in Table1.

3. THEORY AND METHODOLOGY

The selected building evaluated as a bare frame, by using the Japanese Building Disaster Prevention Association (JBDPA), 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.

In addition to this, the same building evaluated using Nonlinear Static Pushover Analysis (NSPA) method, using ETABS 2016 software, 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. RESULTS 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). 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. Figure 2 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. (corresponding to ductility index F=1) from the JBDPA analysis is taken from the second level procedure for longitudinal strips and compared to Is0.
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.
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 mortar with the strength of 20MPa and steel wire mesh 0.9mm @ 5.45 mm c/c having 415MPa used for ferro lamination. The figure below 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.

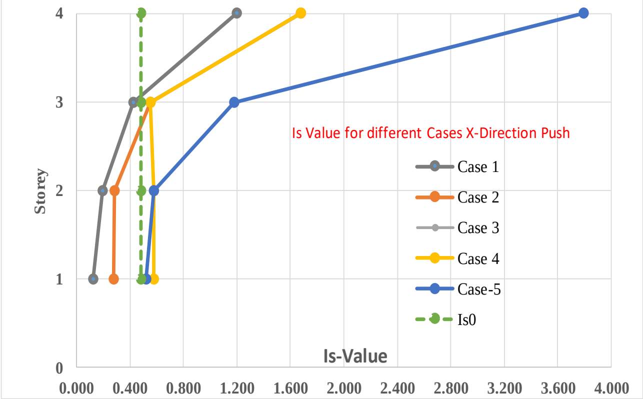

Figure 2. Is values for various cases of evaluation and retrofitting cases.

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, 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, 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.

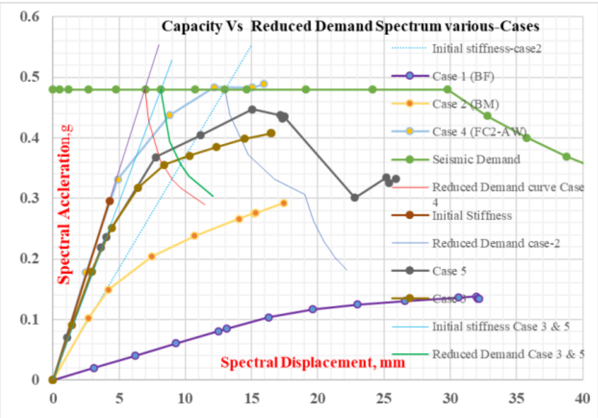

Figure 3. Performance points for various cases.

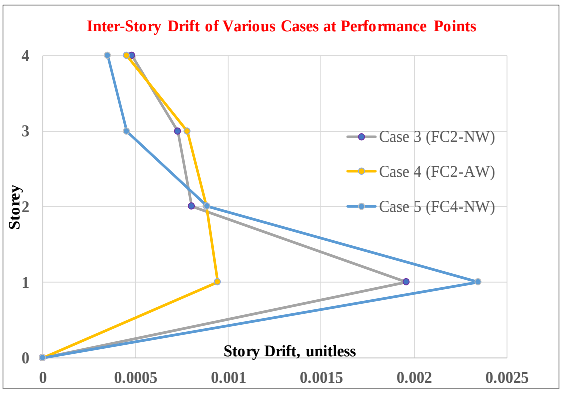

Figure 4. An inter-story drift of various cases at performance point.

The figure above 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 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. Figure 5 to 7 the hinge results at the performance point for various cases which was found to be at immediate occupancy state.

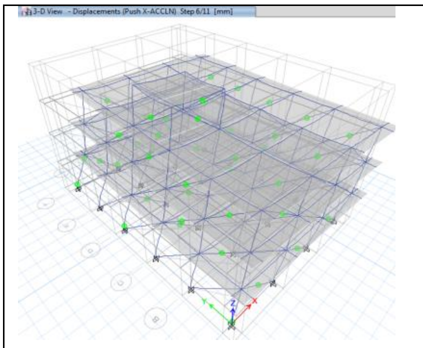

Figure 5. Hinge Results for Case 3 at performance points.

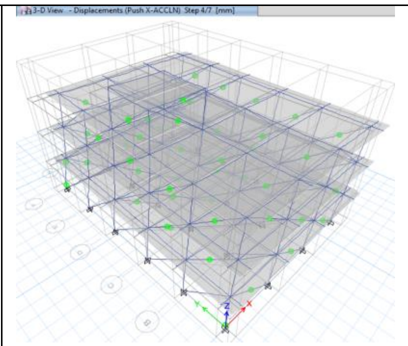

Figure 6. Hinge Results for Case 4 at performance points.

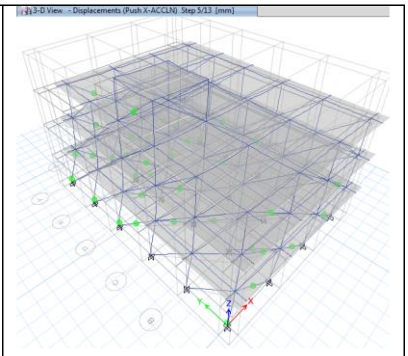

Figure 7. Hinge Results for Case 5 at performance points.

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). 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 Figure 8. The demand curve for the 2015 Gorkha earthquake was plotted by using View Wave software.

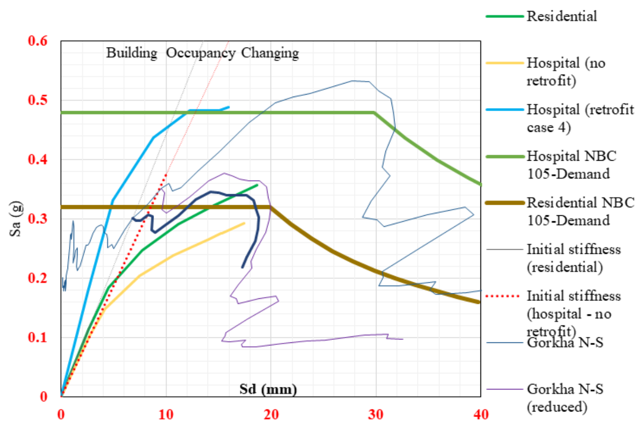

Figure 8. Capacity curve versus NBC & Gorkha earthquake 2015 demand curve for case A, B, and C.

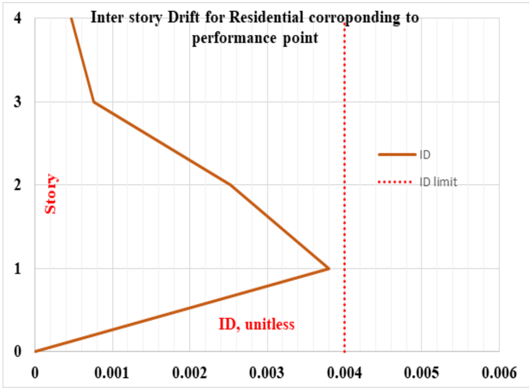

Figure 9. ID for residential building (case A) corresponding to performance Point.

The Figure 8 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 above Figure 9. 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. CONCLUSION

The presence of infill could not ignore. It plays a significant role in strengths and stiffness; therefore, to identify the actual behaviors of the building, it is most to consider the infill. 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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