A STUDY ON SEISMIC PERFORMANCE AND RETROFIT APPROACH FOR CURRENT RC BUILDINGS WITH SOFT FIRST STORY IN NEPAL

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ABSTRACT

The soft first story RC buildings proved to be vulnerable in Nepal during the 2015 Gorkha earthquake. The RC buildings in Nepal are constructed with a weak frame, lack of ductile detailing, and brick masonry infill. In the city area, due to the urbanization and lack of land area, the upper story is used as brick masonry, and the first story is used for shopping and parking purpose. This research intended to assess and compare the seismic vulnerabilities of RC buildings with soft story in Nepal namely, (i) building constructed by following NBC 205:1994 i.e. Mandatory Rule of Thumb (MRT) with poor detailing and modified later by adding story (NBC) and (ii) building constructed based on modified MRT of 2010 recommended by DUDBC, with poor detailing and modified later by adding story (NBC+). Seismic performance is evaluated by JBDPA guidelines of seismic evaluation, FEMA-356, NBC 1994, nonlinear static pushover analysis and dynamic analysis by Gorkha Earthquake motion. The results are discussed in terms of story shear, capacity curve, maximum roof displacement, inter story drift and damage pattern. Retrofit by wing wall and shear wall is purposed. The research found that seismic behavior, ductility demand, inter-story drift pattern, of RC building with the soft first story are different from those with analysis of bare frame. The soft first story suffered extreme inter story drift change causing severe damage. Seismic vulnerability of both building before and after retrofit showed NBC+ building performed better than NBC building. Both model buildings sustain Gorkha earthquake motion which reveals the building collapsed during earthquake are of low concrete strength, poor detailing, lack of reinforcement constructed before application of NBC. A combination of RC shear wall and wing wall proved to be effective to eliminate stiffness difference and control excessive inelastic lateral drift keeping the usability of open space in the first story.

Keywords: Soft-first story, Seismic Performance, Retrofit, Wing wall, Shear wall.

1. INTRODUCTION

Reinforced Concrete (RC) building construction has begun from the late 1970s and increased rapidly in the last 3-4 decades in Urban areas of Nepal. The increasing population and scarcity of land have compelled people to construct non-engineered multistory buildings with open space on the first floor for shopping and parking purposes. As infill material is commonly used for the upper story of brick masonry structure, lateral stiffness differences occur between the upper and the first story. Soft story building proved to be very vulnerable and performed poor during 2015 Nepal Earthquake.

Most of the buildings are of owner-driven poorly constructed with inferior masonry quality in light reinforced frames lacking ductile detailing. However, to improve the quality of construction and

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enhance the seismic behaviour of buildings, Nepal Building code (NBC) was implemented from 2003. NBC contains mandatory Rules of Thumb (MRT) that provides the facility for ready-to-use in terms of dimensions and details for structural and non-structural elements for up to three-storey RC, framed, ordinary residential buildings commonly built by owner-builders in Nepal (NBC). Later in 2010, the Department of Urban Development and Building Construction (DUDBC) published an additional recommendation for the construction of Earthquake Safer Buildings in Nepal with the assistance of UNDP (NBC 1994). It is an improved version of MRT in NBC 2003 which specifies the increased minimum size of columns, including the rebar detailing for the three-story building. Hence, people constructed buildings following both MRT of 2003 and 2010 additional recommendation to some extent. However, with urbanisation and increase in the land price, owners tended to add the other story to their existing buildings, which were not initially designed for this condition. This tendency makes the building more vulnerable.

Since Nepal lies in the subduction region of the Eurasian plate and Indian plate, it poses a high risk of an earthquake. During earthquake force, inadequate lateral strength in the first floor of the soft-story building to withstand massive displacement of the building may cause extensive damage or even collapse. Moreover, it is estimated that more than 90% of the buildings, designed and constructed according to old standards, are non-engineered RC frame and owner-built, posing a high risk to life and property. Those structures constructed and modified without considering soft-story effects are under threat of severe damage or collapse during a future earthquake. In this context, understanding the seismic behaviour of the prevalent soft-first story buildings constructed in Nepal and the employment of the strengthening mechanism has become a subject of paramount importance.

2. THEORY AND METHODOLOGY

The prototype 5-story RC building with the soft first story is intended to represent a typical residence with commercial RC building in the urban area of Nepal. The global dimensions of the sample building, story height, number of story's and bays, including span length, concrete quality and steel type typically represent the existing scenario. In this study, the two variations of the typical soft first story moment resistant frame (MRF) with infill masonry are considered. The first type corresponds to a typical 5-story residential cum commercial building with soft first story constructed somehow following MRT, i.e. NBC-205:1994 (called as NBC building) with later adding another story, which makes buildings more vulnerable. Similarly, the second type is also a 5-story building with a soft first story based on a modified version of MRT after recommendation by DUDBC at 2010 (called as NBC+) and modified later by adding stories.

JBDPA guidelines of seismic evaluation is done to clarify the possessed performance of typical soft first-story buildings in Nepal. Nonlinear static pushover analysis is done to understand the structure's capacity by the capacity spectrum method. After evaluating the seismic vulnerability of 5-story buildings with a soft first-story, anti-seismic measures with RC wing wall and the shear wall is proposed and reevaluated to conduct the structure's safety. Nonlinear Time history analysis (NTHA) is performed using the ground motion of Gorkha Earthquake 2015, Nepal to understand the vulnerability of building before and after the earthquake.

Seismic demand index (Iso) is the level of seismic capacity needed for a structure to remain safe against a ground motion or code defined ground motion. For this study, Iso value is taken as 0.6, which is calculated from the design horizontal seismic force coefficient of NBC 105:1994 for the building with importance factor 1.5 to be used even after the earthquake. The building is supposed to be located in zone 1 and medium soil and performance factor of 4 without following ductile detailing. Moreover, for load combination considering earthquake, 25% is increased. Hence the total value becomes the product of basic seismic coefficient in code, i.e. 0.08, importance factor, zone factor and structural performance factor. Demand spectrum is prepared to find the performance point based on the capacity spectrum method.

JBDPA standard for seismic evaluation considers only RC wall. So, for brick masonry infill wall, shear strength of infill panel is taken as 0.2 Mpa from the proposed value from Seki et al. Similarly, for ductility index the proposed value of 1.5 from the Al-Washali et al. is taken.

STERA 3D, the finite element modelling software is used for both nonlinear static and dynamic analysis. Equivalent strut method is used to represent brick infill masonry in modelling. For equivalent strut compressive strength (f'm) is taken from formula proposed by Paulay and Priestley in 1992. The modulus of elasticity of masonry prism is taken from the equation proposed by FEMA.

3. SEISMIC PERFORMACNE OF SOFT FIRST STORY

3.1. Outline of target building

The prototype 5-story RC building with the soft first story is intended to represent a typical residential cum commercial RC building in the urban area of Nepal. It has three-span in both transverse and longitudinal direction. The story height is 2.84 m. The global dimensions of the sample building, story height, number of story's and bays, including span length, concrete quality and steel type typically represent the existing scenario. The buildings have open first floor used for shops and parking areas and brick infill masonry in the upper floor having a thickness of 115 mm in partition and 230 mm in outer side of building. The foundation is isolated footing.

In this study, the two variations of the typical soft first story moment resistant frame (MRF) with infill masonry are considered. The first type corresponds to a conventional soft first story residential cum commercial building construction somehow following the MRT, i.e. NBC-205:1994 (called as NBC building) and later adding story making building more vulnerable. The second type is a 5-story soft first story building based on a modified version of MRT after recommendation by DUDBC at 2010 (called as NBC+).

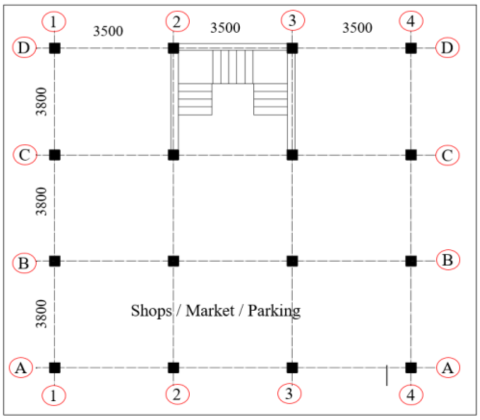

Figure 1. First floor plan.

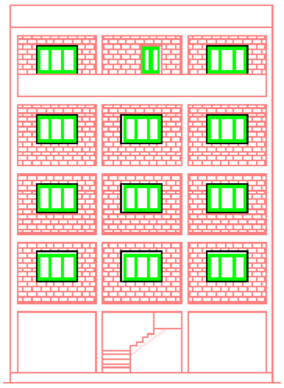

Figure 2. Front elevation.

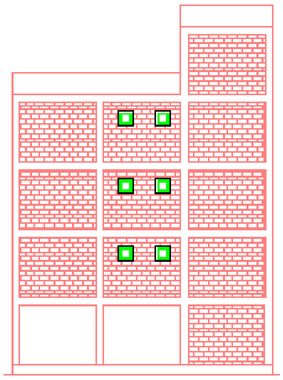

Figure 3. Side elevation.

3.2. Story displacement and inter story drift

Homogenous lateral displacement in every story in bare frame case is observed. Unlike this, in soft first story case, large inelastic deformation is concentrated with subtle inter-story displacement in upper story. The drift at soft first story exceeds the allowable drift limit (1%) as mentioned in NBC 105:1994 and immediate occupancy for FEMA. Thus, soft-story columns are very vulnerable to earthquakes if they do not have adequate ductility and strength to meet the demand. Sudden change of story drift in the soft first story enhances the possibility of forming non-uniform plastic hinge in soft first columns and severe damage or even collapse during earthquakes. However, in the case of bare frames, uniform change of the inter-story drift is observed. However, in the case of bare frames, uniform change of the inter-story drift is observed as in Figures 4 and 5.

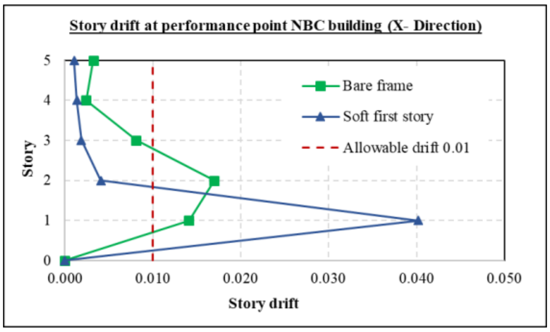

Figure 4. Inter story drift (NBC building).

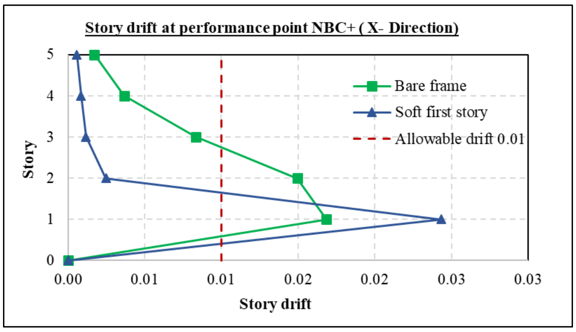

Figure 5. Inter story drift (NBC+ building).

3.3. Damage distribution

Inelastic analysis is vital to know the modes of failure and collapse sequence when any structure's elastic capacity exceeds during earthquake. From the non-linear pushover analysis, the failure mechanism for the structural members in the longitudinal direction of the NBC building at grid D-D for bare frame and at the performance point of the capacity spectrum method for soft first story is shown in Figure 6. In transverse direction also similar damage pattern was observed at performance point. NBC+ building also shows similar damage pattern.

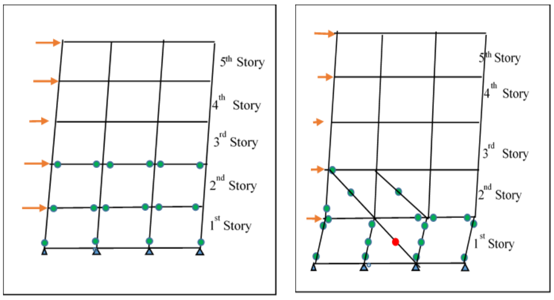

Figure 6. Bare frame case and soft first case for NBC building.

3.4. Seismic evaluation by JBDPA standard

Seismic evaluation by the JBDPA standard 1st level screening for bare frame of both NBC and NBC+ building shows the lack of seismic capacity in all story. In 2nd level screening considering infill wall, NBC building model has a deficiency in earthquake resisting capacity in first, second and third story at the longitudinal direction as in Figure 7. Whereas, NBC + building has only soft first story has inadequate earthquake resisting capacity.

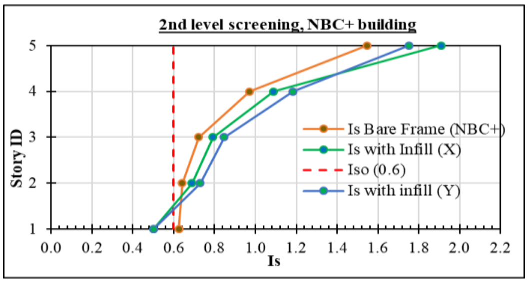

Figure 7. Second level screening (NBC+).

4. RETROFIT

4.1. The retrofit strategy for the soft first story

Many retrofitting mechanisms have been practiced to upgrade the strength and ductility of the vulnerable buildings. Among them, column jacketing is widely used in Nepal in RC building. Whereas bracing, insertion of RC shear walls, steel plate jacketing, structural slit, FRP wrapping and base isolation are popular in other countries. Retrofitting strategies for soft first story is different from the conventional retrofitting of RC buildings. The main goal of soft first story retrofitting is to eliminate the extreme stiffness difference, control excessive story drifts beyond the elastic limit, and increase seismic performance behaviour of structure up to the desired level.

The columns of the study buildings are very slender, which makes retrofitting even more challenging. Using the column jacketing, which is a popular one in Nepal, would not eliminate the extreme stiffness difference. Other retrofitting like FRP jacketing, steel plate jacketing, bracing, base isolation needs high-level technicians and is expensive too. Under such circumstances, the wing wall retrofitting method is time and cost-effective and does not hamper the usage of the soft first story (Nakamura et al.). Moreover, it helps to eliminate stiffness difference, control drift and helps to achieve the desired seismic performance of the building. Retrofitting with only wing wall was not adequate to meet the strength demand, so the addition of shear wall in the proper location was done.

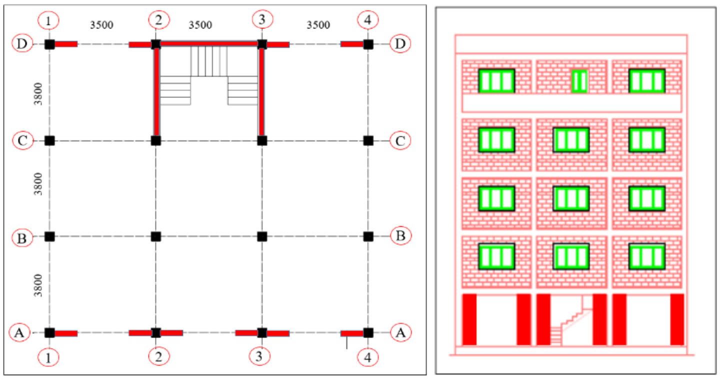

Figure 8. Plan and elevation of retrofitted NBC+ building.

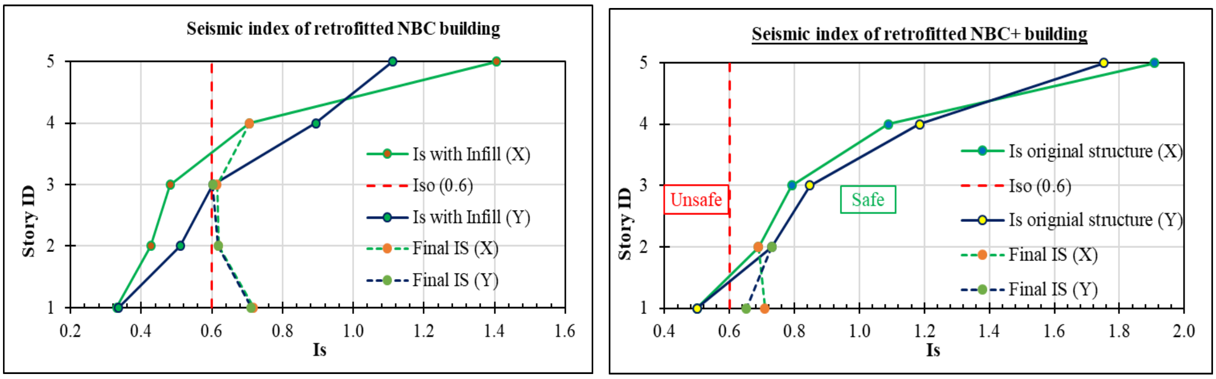

Figure 9. 2nd level screening NBC building and NBC+ building.

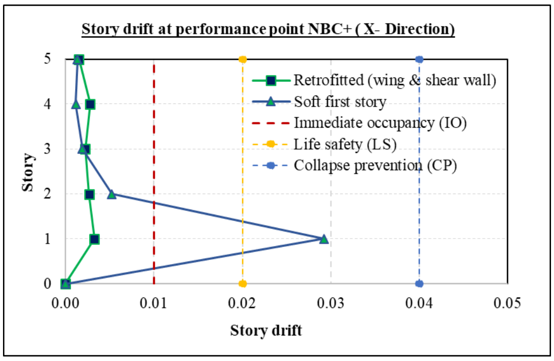

Figure 10. Inter story drift (NBC+).

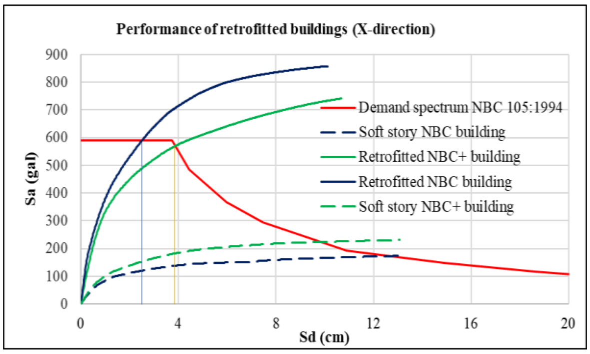

Figure 11. Performance of retrofitted buildings.

In retrofitting of NBC+ building only first story need retrofit whereas NBC building first second and third story in the longitudinal direction and first and second story in the transverse direction need a retrofit. The retrofit by wing wall and shear is easy to apply, provides more inner spaces. The building gives better performance after conducting nonlinear static and dynamic analysis and recommended by this study. In Figure 8 the retrofitting plan for first story of NBC+ building is shown. In Figure 9, seismic index before (original Is) and after retrofit (Final Is) are presented. Is after retrofit are within allowable limit. Improvement in capacity of spectral acceleration of both NBC and NBC+ model building after retrofit is shown in Figure 11 which ensures the structural safety. The inter story drift after retrofit of NBC+ building is presented in Figure 10 which ensures the within the range of immediate occupancy of FEMA and drift limit of NBC 105.

4.2. Dynamic response history analysis by Gorkha earthquake 2015

Dynamic response time history analysis (DRTHA) by the input of 2015 Gorkha Earthquake strong ground motion recorded by DMG is conducted using STERA 3D software, a finite element method based software to check inter-story drift and damage pattern. The story drift of NBC and NBC+ building is reduced significantly after retrofitting, which are within the immediate occupancy of FEMA and drift criteria of NBC. Though both NBC and NBC+ building does not have an adequate seismic capacity from JBDPA evaluation, in DRTHA of Gorkha the building are safe within life safety.

Both NBC and NBC+ building show moderate masonry crack and some moderate hinges in beam and columns before retrofit whereas after retrofit no hinge formation occurred.

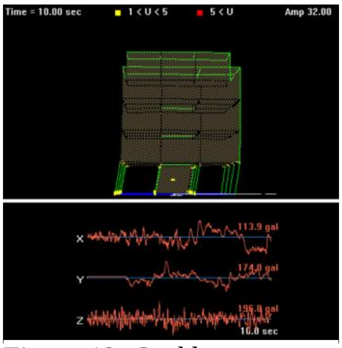

Figure 12. Gorkha earthquake motion on NBC.

5. CONCLUSIONS AND RECOMMENDATIONS

The bare frame model of NBC and NBC+ building shows uniform story displacement. The soft first story model of both NBC and NBC+ building after nonlinear static and dynamic evaluation, a sudden increase in displacement in the soft first story is observed. This abrupt change of inter-story drift due to stiffness difference is the leading causes of soft-story damage. NBC+ model building show better performance than NBC model building in terms of roof displacement, inter-story drift and maximum shear capacity. By retrofitting with a combination of shear wall and wing wall eliminates the stiffness difference and control excessive without altering the occupancy use of the first floor. Both NBC and NBC+ model building in this study survives with the moderate hinge in soft first story after time history analysis of Gorkha earthquake 2015. The soft first story RC building collapsed during the 2015 Gorkha earthquake were weak building constructed haphazardly adding multiple stories with low-strength concrete in the structural members with inadequate longitudinal and shear reinforcement and poor detailing.

Soil structure interaction is not incorporated in this research. It could be incorporated in future research. Investigation of masonry unit can be done to find exact shear and ductility index of brick masonry.

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