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SEISMIC ASSESSMENT OF THREE-STOREY RESIDENTIAL BUILDINGS IN NEPAL

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ABSTRACT

This paper evaluates the seismic performance of existing three-storey residential reinforced concrete (RC) buildings in Nepal. For this, it was designed a representative RC building structure (WDS) and the results were compared with similar buildings detailed with: *i*) Current Construction Practices (CCP); *ii*) Nepal Building Code (NBC) and iii) Modified Nepal Building Code (NBC+) recommendations. The results were analyzed and compared in terms of capacity curve, inter-storey drift and detailing of structures. The overall comparison indicates that CCP structure has a low amount of reinforcement both in beam and column sections when compared with the WDS structure. For the structure designed according with the NBC and NBC+ recommendations, improvements are clear relatively to the CCP structure, but it may be not sufficient for the demands in regions with high seismic hazard. Non-linear analysis shows that CCP and NBC structures experiences lower base shear capacity with higher inter-storey drift demand than other structures. Finally, the influence of seismic zone factor on reinforcement demand of the structure is analysed by designing the same WDS structure for a low, medium and high seismic hazard zone.

Keywords: RC buildings, seismic codes, seismic assessment, storey drift

1 INTRODUCTION

Nepal is located in a Himalayan region which was evolved as a result of the collision between the Indian and Eurasian plates. This collision is still continuous at the rate of 25-30 cm/year which makes Nepal and the entire Himalayan range seismically active. Global seismic hazard map marks Nepal in very high seismic hazard zone IV which has possible shaking of MMI IX or above with 10% probability of exceedence in 50 years (JICA, 2002).

Past earthquake evidence indicates that Nepal had experienced two major earthquake in last century. In 1934 and 1988 of magnitude 8.4 and 6.5 resulted more fatalities and highly affected the building structures in Kathmandu valley. Looking at the urbanization of Kathmandu valley now, if similar earthquake as that of 1934 AD was to occur today, the scenario would be more devastating, and the fatalities would be very high. For that earthquake scenario, Japan International Cooperation Agency (JICA, 2002) estimated up to 59000 houses destroyed, 18000 deaths and 59000 seriously injured [1]. Another study carried out in the frame work of the Kathmandu Valley Earthquake Risk Management Project (KVERMP) estimates a total of 40000 deaths, 95000 injuries and 600000 or more homeless (Dixit, 2001). Based on the lessons from the 1934 and 1988 earthquakes, Nepal took actions for the development and improvement of the Building Codes. The Department of Urban Development and Building Construction developed the Nepal National Building code in

1994, with the assistance of UNDP. Since 2003, the implementation of Nepal National Building Code became mandatory.

In this context, the paper is analysed the effectiveness of the execution of the seismic code in existing construction practices in Nepal. For this four different types of residential buildings (CCP, NBC, NBC+ and WDS) were selected for numerical analysis. It is based on bare frame building modelling with three dimensional models. Finally, the influence of seismic zone factor on reinforcement demand of the structure is analysed by designing the same WDS structure for a low to high seismic hazard zone.

1.1 Building typology identification

The detailed field investigation of the buildings in Kathmandu valley was performed in Kathmandu valley earthquake risk management project (KVERMP, 2002). Based on this study, buildings with similar behavior characteristics, lateral load resisting system and diaphragm were classified as one group. A building with more than one type of lateral force resisting system shall be classified as a mixed system. Building typology and characteristics of each building type is briefly describe as:

- ***Adobe, stone in mud, brick-in-mud:*** *Adobe Buildings:* used sun-dried bricks with mud mortar for structural wall. *Stone in Mud:* used dressed or undressed stones with mud mortar for floor and roof. *Brick in Mud:* used fired bricks in mud mortar.
- ***Brick and Stone in Cement mortar:*** Brick masonry buildings use fired bricks in cement and stone-masonry buildings use dressed or undressed stones with cement mortar.
- ***Non-engineered Reinforced Concrete Moment- Resisting-Frame Buildings:*** These are the buildings with reinforced concrete frames and unreinforced brick masonry infill in cement mortar. The prevalent practice in most urban area of Nepal for the construction of residential and commercial complexes generally falls under this category. These buildings are not structurally designed and supervised by engineers during construction.
- ***Engineered Reinforced Concrete Moment- Resisting-Frame Buildings:*** These buildings consist of a frame assembly of cast-in-situ concrete beams and columns. Floor and roof framings consist of cast-in-situ concrete slabs. Lateral forces are resisted by concrete moment frames that develop their stiffness through monolithic beam-column connections. These are engineered buildings with structural design and construction supervision is made by engineers.
- ***Others:*** Wooden buildings, Mixed buildings like Stone and Adobe, Stone and Brick in Mud, Brick in Mud and Brick in cement etc. are other building type in Kathmandu valley and other part of the country.

1.2 Common structural deficiencies of existing buildings

Majority of the RC buildings in Nepal were designed and constructed without considering adequately seismic provisions, constituting therefore a significant source of risk for the country. Structures should be provided with balanced stiffness, strength and ductility between its members, connections and supports (Bertero, 1997). In reality, most of the structures are potentially seismically vulnerable due to the non-engineered construction (Fig 1-5). Thus, there is a urgent need to investigate the seismic behaviour of existing RC buildings, in order to assess their seismic vulnerability. Researchers (Varum (2003), Bothara (2003), Dogangun

(2004), Ghobaraha et al. (2006)) point out the most common cause of inadequate response of buildings to seismic loadings, which can be summarized as:

- ***Design deficiencies***, such as: insufficient lateral stiffness and strength, horizontal and vertical irregularities, soft-storeys, short columns, weak-column strong-beam mechanism, critical torsional response, not adequate spacing between adjacent structures, etc.
- ***Detailing deficiencies***, such as: insufficient confinement, insufficient and improper anchorage of the longitudinal reinforcement at the joints and footings, inexistence or inadequate beam-column joint reinforcement, lack of adequate amount and detailing of the longitudinal and transverse reinforcement along the beams and columns, inadequate lap-splice in column longitudinal reinforcement, etc.
- ***Construction deficiencies***, such as: poor workmanship, poor quality concrete, construction of the structures not following the design and detailing prescriptions, etc.

Fig. 1 a) No anchorage of beam bars in column b) Beam reinforcement hooking into column reinforcement c) No stirrups in beam-column joint

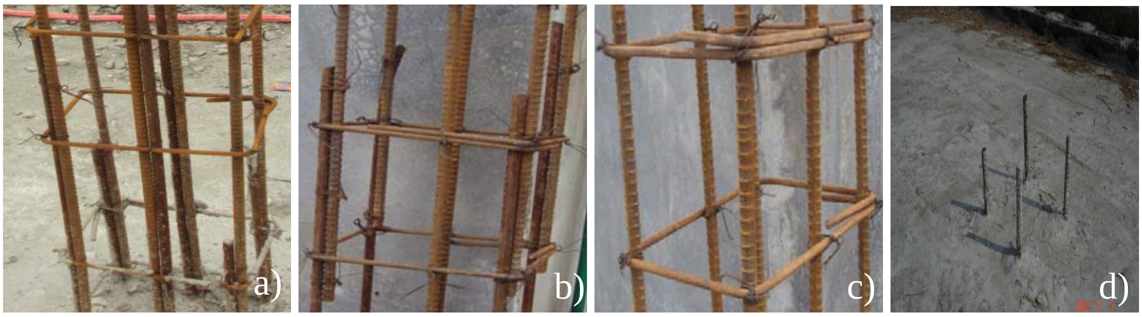


Fig. 2 a) Defective stirrups due to 90^0 bends joint b) Inadequate lap length c) Large spacing of lateral tires in column with 90^0 bend d) Column reinforcement is too short for the continuity of the column

Fig. 3 a) Load path problem due to external wall b)load path problem due to improper beam column connection c) soft storey problems

Fig. 4 a) Column starting from fifth storey b) Missing column in top storey c) Missing beam

Fig. 5 Existing RC building construction practices in Nepal

2 STUDY OF COMMON RC BUILDING CONSTRUCTION PRACTICES

In the present study, field survey was conducted for characterizing the actual designed reinforced concrete (RC) buildings in Nepal . The important data were acquired from construction documents like as built drawing, structural drawings and visual observation during site visit. In some cases, the useful information was taken from interviews with those who were involved in the design and construction of the building or familiar with the contemporary methods of construction (owners/ residents). Sampling was done randomly which represents the nature of design trends and construction practices in different localities. The general information collected during field surveys indicates building dimensions, construction age, structural system, size and detailing of RC elements (beam and columns), inter-storey height, numbers of bays and span lengths, quality of concrete and the type of steels. The site soil condition is taken as medium, clay for all the building structures.

2.1 Statistical analysis of reinforced concrete buildings in Nepal

The statistical analysis consisted of data from consultancy drawings, municipality drawings, and a field survey of current construction and existing buildings in different localities of Nepal (Chaulagain et al., 2010, 2012; JICA, 2002; NSET, 1999). The information collected during different surveys includes the size and detailing of RC elements (beams and columns), inter-storey height, numbers of bays and dimensions, years of construction, and quality of concrete. The results from the statistical analysis of beams and column sections and the static of survey building structures are presented in Tables 1 to 3.

The maximum (Max.), minimum (Min.), and average (Avg.) sizes of beam elements for the surveyed buildings were 250 × 380, 230 × 230 and 235.95 × 320.38 respectively. The max., avg. and min. amount of reinforcement for the top and bottom of the beam elements were 1.17%, 0.68% and 0.45%, and 0.87%, 0.47% and 0.33% respectively. The maximum covariance is for the top steel reinforcement in beam elements (28.80%) whereas the minimum is for the width of beams (3.93%). Further results from the statistical analysis of beam sections is presented in Table 1.

Table 1 Statistical analysis of beam section

S.N	B (mm)	D (mm)	MoI (mm^4)	Top steel (%)	Bottom steel (%)
Max.	250	380	1143166666.67	1.17	0.87
Min.	230	230	233200833.33	0.45	0.33
Avg.	235.95	308.38	649356441.4	0.68	0.47
Std dev	9.27	59.33	361696187.2	0.20	0.10
CoV	3.93	19.24	55.70	28.80	21.90

The max., min., and avg. sizes of column sections for the surveyed buildings were 300 × 300, 230 × 230 and 240.81 × 245.05 respectively. The max., avg. and min. amount of reinforcement for exterior and interior column sections were 1.95%, 1.18%, and 0.86% and 1.95%, 1.31%, and 0.86% respectively. The maximum covariance is for the moment of inertia of column sections (35%) whereas the minimum is for the width and depth of column elements (13.47% and 14.44%). The detailed results of the statistical analysis on column elements are presented in Table 2.

Table 2 Statistical analysis of column section

S.N	B (mm)	D (mm)	MoI (mm^4)	Ext. col. Steel (%)	Int. col. Steel (%)
Max.	300	300	873350493.12	1.95	1.95
Min.	230	230	233200833.33	0.86	0.86
Avg.	250.81	264.05	423693684.5	1.18	1.31
Std dev	32.44	35.47	209814750.4	0.41	0.42
CoV	12.93	13.43	49.52	34.62	31.92

Furthermore, the max., avg. and min. length of inter-storey height, bay length and bay width of the studied buildings were 3300, 3000 and 2850; 4500, 3950, and 2625; and 4100, 3150 and 2625 respectively. The variations in bay length in the X and Y directions are 12% and 7%, whereas it is only 7% for inter-storey height. The results from the analysis are presented in Table 3.

Table 3 Statistic of survey building structure

S.N	Bays-X Nos.	Bays-Y nos	Avg. C/C in X mm	Avg. C/C in Y mm	Storey Ht. mm
Max.	4	4	4500	4300	3300
Min.	2	2	2017	2625	2850
Avg.	2.72	2.66	3520	3485	3073
Std dev	0.63	0.69	645.92	542.35	135.15
CoV	23.02	26.02	18.35	15.56	4.40

2.2 Description of the case study building structure

The sample 3-storey reinforced concrete building is intended to represent a typical residential RC building in Nepal. The global dimensions of the prototype building, namely storey height, number of storeys, and bay spacing, were based on the statistical analysis of the relevant data. The geometry of the study building structure is presented in Fig. 6. The building has two and three bays of 3m and 4m in the X and Y directions respectively. The inter-storey height is taken as 3m. The material properties are assumed to be identical for the four structures throughout the height of the structure. The material properties and loading on the study building structures are presented in Tables 4 and 5.

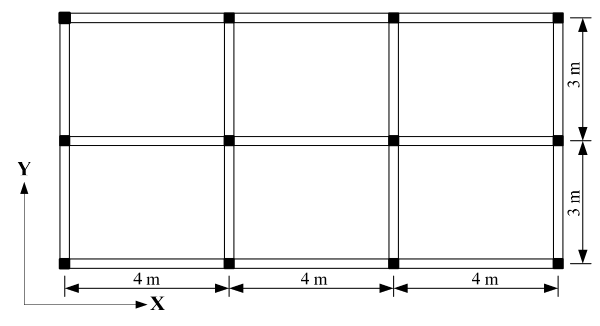
Table 4 Properties of materials used in this research

Materials	Characteristics
Reinforcing steel yield strength, f_y	415 MPa
Concrete compressive strength, f'_c	20 MPa
Brick on peripheral beams	230 mm thick
Brick wall on internal beams	115 mm thick
Density of brick masonry including plaster	20 kN/m^3
Density of reinforced concrete	25 kN/m^3

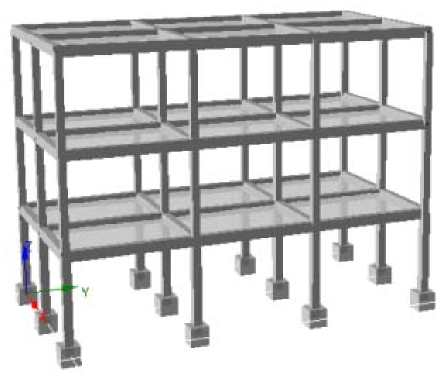
Table 5 Loading for numerical analysis of structure

Loading characteristics	Loading
live load on roof	1.5 kN/m^2
live load on floors	2 kN/m^2
roof and floor finishings	1 kN/m^2

In this study, the four variation of the typical moment resistant frame with same geometrical and material properties were selected for numerical analysis. The first type of building corresponds to moment resisting frames which is designed based on Indian standard code, called WDS structure. The second design type is based on Nepal building code recommendation, called NBC structure. The third type of structure is modified edition of the Nepal building code recommendations, called NBC+ structures. The last type of RC frame design represent the current construction practices in Nepal, called CCP structure. The typical characteristics of each building structure studied is presented in the following sections:



(a) Plan of the building



(b) 3-D model of the building

Fig. 6 Geometry of three-storey reinforced concrete building structure

2.2.1 Well designed structure (WDS)

The WDS building structure was designed based on the Indian standard code, considering seismic design with ductile detailing considering the building located in the seismic zone V and medium soil. Due to low height, regular in plan and elevation seismic analysis is performed using seismic coefficient method (IS 1893-2002). Detailed design of the beams and column section according with the IS 13920:1993 recommendations has been carried out. Dead load considers the self weight of the structural member (beams, columns and slabs) and partition walls according with to IS 875 (Part-I). The Live load considered is also according with IS 875 (Part-II). Load combinations were defined based on IS 456-2000. Moreover, the influence of seismic zone factor on reinforcement demand of the WDS structure for a low, medium and high seismic hazard zone for medium soil will be discussed in section 3.2.

2.2.2 NBC structure

NBC structure was design with the Mandatory Rules of Thumb (MRT) that introduces some requirements 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 201, 1994). The main objective of this document is to replace the non-engineered construction commonly and achieve the minimum seismic safety requirements (NBC 205, 1994). Since 2003, this document became mandatory in Nepal. So, the RC building structures has started to built based on these simplified rules.

2.2.3 NBC+ structure

The Department of Urban Development and Building Construction published in 2010 additional recommendations for the construction of Earthquake Safer Buildings in Nepal with assistance of UNDP (UNDP, 2010). This document is an improvement of the NBC, and specifies the minimum size of columns for buildings up to three stories. Room sizes not more than 4.5 m x 3.0 m, e.g., should have column dimensions of 300 mm x 300 mm or 75 mm more than the beam width. The minimum column reinforcement is also provided. The requirements for beam detailing are the same of those specified in the NBC document. The beam detailing of NBC+ structures presented in this study were defined based on NBC structure.

2.2.4 CCP structure

This type of building represents the current construction practices in Nepal (CPP). The current construction practices of the buildings in Nepal use light RC frames with masonry infill. With urbanization and increases in the land price, owners tended to add an additional storey to their existing building when without making a provision for additional floors prior to construction, without any seismic concern. Due to the increase of the number of storey’s and considering the large occupancy, these buildings can represent a significant risk to in urban areas in the case of earthquake. In fact, the collapse of similar buildings during past earthquakes in neighbouring regions have had showed the catastrophic results and tremendous loss of human lives and damage to property.

3 RESULTS AND DISCUSSION

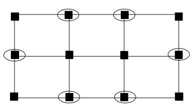
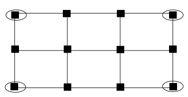
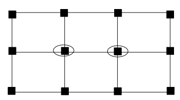
The results obtained from the analyses of the structures are presented in this section. The comparison of beam and columns cross section and its detailing was included in section 3.1. Influence of seismic zone factor on reinforcement demand of the structure was described in section 3.2. Finally, the performance of structures in terms of capacity curve and inter-storey drift was presented in section 3.2.

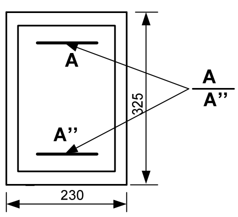
3.1. Comparison of reinforcement for RC elements in study building structures

The comparison of obtained results in beam reinforcement quantity at support and mid-span for the WDS, NBC+, NBC, and CCP structure is presented in Table 6. CCP structure has used the same amount of reinforcement for negative and positive bending moment through out the entire span of the beam which is lowest among other structural types. There is a clear improvements have seen in the beam detailing of NBC and NBC+ structures. In these structures, the amount of support reinforcement is relatively larger than mid-span reinforcement. Moreover, there is a provisions of more reinforcements in first and second storey as compared to top floor beam. In contrast, and as expected, WDS structure demands more reinforcement to withstand design level of ground shaking, which is more than twice the amount required for CCP, NBC and NBC+ structures.

The orientation of columns and its reinforcement in corner, façade and interior columns under study building structure is presented in Table 7. CCP structures have used same column size of 230 by 230 with same amount of reinforcements in all the columns in first and storey. There is some improvements in size and reinforcement amount in corner, façade and interior columns in NBC structures. The bigger size of columns (270 by 270) in first storey and same smaller size of columns (230 by 230) is used in second and third storey of NBC structures. NBC+, the latest upgrading of Nepal building code recommends minimum size of 300 by 300 in all the columns with same amount of reinforcement . In contrast, and as expected, WDS structure demands higher column reinforcements with bigger size to withstand design level of ground shaking, which is more than twice the amount required for CCP, NBC and NBC+ structures.

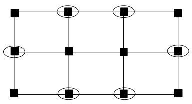
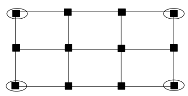
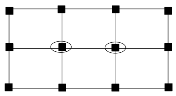
Table 6 Longitudinal reinforcement of beam sections

Column	Storey	Cross section of column			
		WDS	NBC	NBC+	CCP
	First	8 Ø16 350×350	4 Ø 16 270×270	4 Ø 16 300×300	6 Ø 10 230×230
	Second	8 Ø16 350×350	4 Ø 16 230×230	4 Ø 16 300×300	6 Ø 10 230×230
	Third	8 Ø16 300×300	4 Ø 16 230×230	4 Ø 16 300×300	4 Ø 10 230×230
	First	8 Ø16 400×400	4 Ø 16 270×270	4 Ø 16 300×300	6 Ø 10 230×230
	Second	8 Ø16 400×400	4 Ø 16 230×230	4 Ø 16 300×300	6 Ø 10 230×230
	Third	8 Ø16 350×350	4 Ø 12 230×230	4 Ø 16 300×300	4 Ø 10 230×230
	First	8 Ø16 400×400	8 Ø 12 270×270	8 Ø 12 300×300	6 Ø 10 230×230
	Second	8 Ø16 400×400	8 Ø 12 230×230	8 Ø 12 300×300	6 Ø10 230×230
	Third	8 Ø16 350×350	4 Ø 12 230×230	8 Ø 12 300×300	4 Ø 10 230×230



(*beam cross section, dimensions in mm*)

Table 7 Longitudinal reinforcement and dimension of column cross-sections (all dimensions are in mm)

Column	Storey	Cross section of column			
		WDS	NBC	NBC+	CCP
	First	8 Ø16 350×350	4 Ø 16 270×270	4 Ø 16 300×300	6 Ø 10 230×230
	Second	8 Ø16 350×350	4 Ø 16 230×230	4 Ø 16 300×300	6 Ø 10 230×230
	Third	8 Ø16 300×300	4 Ø 16 230×230	4 Ø 16 300×300	4 Ø 10 230×230
	First	8 Ø16 400×400	4 Ø 16 270×270	4 Ø 16 300×300	6 Ø 10 230×230
	Second	8 Ø16 400×400	4 Ø 16 230×230	4 Ø 16 300×300	6 Ø 10 230×230
	Third	8 Ø16 350×350	4 Ø 12 230×230	4 Ø 16 300×300	4 Ø 10 230×230
	First	8 Ø16 400×400	8 Ø 12 270×270	8 Ø 12 300×300	6 Ø 10 230×230
	Second	8 Ø16 400×400	8 Ø 12 230×230	8 Ø 12 300×300	6 Ø10 230×230
	Third	8 Ø16 350×350	4 Ø 12 230×230	8 Ø 12 300×300	4 Ø 10 230×230

3.2. Influence of seismic zone factor on reinforcement demand of the structure

The differences in beam reinforcement demand between seismically resistant and non-seismically designed reinforced concrete structure was considered through linear analysis of the structure. For this, the same WDS structure is designed for the three seismic hazard zone ranges from low to high seismicity. The zone factor of 0.36 is used in the region which is liable to shaking intensity of IX and higher (seismic zone V), similarly zone factor of 0.24 and 0.16 are used in the intensity of VIII (seismic zone IV) and VII (seismic zone III) respectively (IS 1893-2002). Finally, the results of WDS structure designed for three seismic zone is compared with the structure designed for gravity loading condition. The comparison of results are tabulated in Tables 8 to 11.

In longitudinal beam, building structures designed for seismic zone V, IV and III demand more than 2, 1.5 and 1.25 times reinforcement as compared to gravity load design structure (GLD). In transverse beam, structure designed for seismic zone III and gravity load demand same amount of reinforcement. The amount of reinforcement is more than 3.5 and 2.5 times in seismic zone V and IV. The overall reinforcement demand is maximum in longitudinal beam. However, the reinforcement demand ratio of WDS to GLD structure is maximum in transverse beam. In all cases the differences is minimum in mid-span beam. Exterior longitudinal and transverse beam have more reinforcement demand as compared to internal one, it is due to the thickness of periphery infill wall (thickness of external wall is double the internal one).

Table 8 Comparison of reinforcement in exterior longitudinal beam

IS Zone	Zone factor	Support, -ve (%)	Centre, +ve (%)
V	0.36	1.59	0.68
IV	0.24	1.33	0.45
III	0.16	1.15	0.41
GLD		0.85	0.40

Table 9 Comparison of reinforcement in interior longitudinal beam

IS Zone	Zone factor	Support, -ve (%)	Centre, +ve (%)
V	0.36	1.53	0.64
IV	0.24	1.26	0.41
III	0.16	1.07	0.38
GLD		0.74	0.35

Table 10 Comparison of reinforcement in exterior transverse beam

IS Zone	Zone factor	Support, -ve (%)	Centre, +ve (%)
V	0.36	1.39	0.54
IV	0.24	1.05	0.32
III	0.16	0.44	0.18
GLD		0.41	0.20

Table 11 Comparison of reinforcement in interior transverse beam

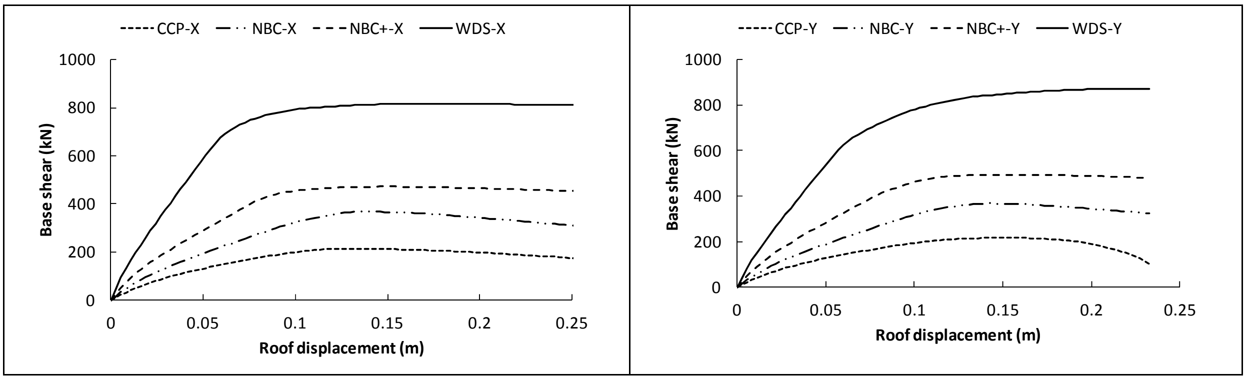
IS Zone	Zone factor	Support, -ve (%)	Centre, +ve (%)
V	0.36	1.38	0.54
IV	0.24	1.04	0.32
III	0.16	0.36	0.16
GLD		0.35	0.17

Note: *support, -ve and centre +ve stand for the amount of reinforcement required for negative moments at support and positive moment in centre.*

3.3. Capacity curves of the study buildings

The capacity curves are evaluated for representative building structures in roof displacement for X and Y direction of seismic loading. Capacity curve and corresponding inter-storey drift of study building structures are presented in Fig. 7. Based on capacity curves and inter-storey drift profiles, the main conclusions are summarized as follows:

- The shear strength capacity and tangent stiffness of WDS are nearly two, three and four times the values obtained with the NBC+, NBC and CCP structures.
- The code recommendation procedure NBC presents a poor performance in terms of strength, tangent stiffness and deformation as compared with WDS. In fact, the NBC structures present a quite similar performance as CCP structures. In particular NBC design conducts the building model to present a soft-storey mechanism in the second storey, due to the change in the column size between first and second storey, non-recommended for earthquake prone areas.
- The NBC+ building structure has shown a better performance in maximum shear capacity as compared with CCP and NBC structures.



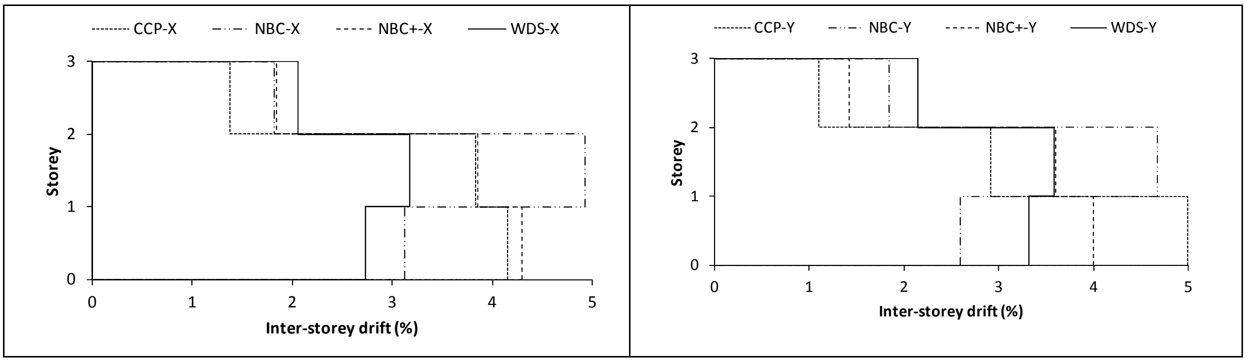


Fig. 7 Capacity curve and corresponding inter-storey drift of study building structures for X and Y direction of loadings.

4 CONCLUSION

This paper evaluates the seismic performance of existing three-storey residential reinforced concrete (RC) buildings in Nepal. For this four different types of residential buildings (CCP, NBC, NBC+ and WDS) were selected for analysis. For the structure designed according with the NBC and NBC+ recommendations, improvements are clear relatively to the CCP structure, but it may be not sufficient for the demands in regions with medium/high seismic hazard. Furthermore, the comparisons performed shows that the structures designed for high and medium seismic hazard demands (WDS) presents approximately double reinforcement in beams when compared to the structures in low seismic zones. The additional results are summarized as:

- From the global comparison of the structures under study it was observed for the CCP structure a low amount of reinforcement both in beam and column sections.
- For the structure designed according with the NBC and NBC+ recommendations, improvements are clear relatively to the CCP structure, but it may be not sufficient for the demands in regions with medium/high seismic hazard.
- The structures designed for high and medium seismic hazard zone demands the double reinforcement in beams when compared to the structures in low seismic zones.
- The shear strength capacity and tangent stiffness of WDS are nearly two, three and four times the values obtained with the NBC+, NBC and CCP structures.
- The code recommendation procedure NBC presents a poor performance in terms of strength, tangent stiffness and deformation as compared with WDS. In fact, the NBC structures present a quite similar performance as CCP structures. In particular NBC design conducts the building model to present a soft-storey mechanism in the second storey, due to the change in the column size between first and second storey
- The NBC+ building structure have shown a better shear capacity as compared with CCP and NBC structures.

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