REFLECTION ON THE SEISMIC VULNERA-BILITY ASSOCIATED TO COMMON RC BUILDINGS IN NEPAL

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SUMMARY:
The present paper study the evolution of the Nepal Building Code recommendations and its possible influence on the real construction and safety of RC buildings in Nepal. To this, it was designed a representative reinforced concrete building structure (WDS) following the seismic ductile detailing principles and the results were compared with similar buildings detailed with: *i*) Current Construction Practices (CCP) and *ii*) Nepal Building Code (NBC) recommendations. The results obtained for the three structures are analyzed and discussed in terms of beam and column cross sections and reinforcement. From the global comparison of the structures under study it was observed for the CCP structure a low amount of reinforcement in beam and column sections when compared with the WDS structure. For the structure designed according with the 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 comparisons performed also show 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.

Keywords: non engineered construction; RC buildings; Seismic Codes

1. INTRODUCTION

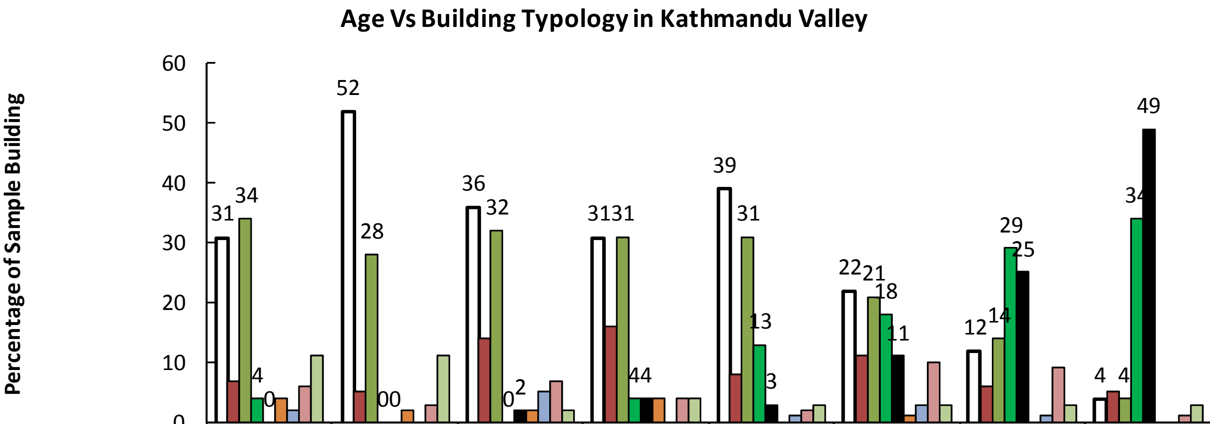
Nepal and the all Himalayan region at the northern border China were formed as a result of the collision of the Indian plate with the Tibetans plate about 50 million years ago. This plate activity continuous which results in subduction of Indian plate below the Tibetan plate, making Nepal and the entire Himalayan region seismically active. Munich Re. Group database pointed out the possibility of devastating earthquakes of intensity IX (MMI) in Kathmandu valley. Historical records shows that the Kathmandu valley had face large earthquakes in the past centuries. Major past earthquakes have occurred in 1255, 1408, 1681, 1803, 1810, 1833, 1866, 1934 and 1988 (Chitrakar and Pandey, 1986).

Among the great earthquakes in the Himalayan arc, the January 15th, 1934, earthquake caused severe damage in Nepal and northern part of India, particularly, the destruction in Kathmandu valley was enormous. The intensity estimated in Kathmandu valley was up to IX in MMI scale. Available data also show that in 1920, there were 66,440 houses in the Kathmandu Valley, and among them 12,397 (about 19%) were completely destroyed, and 25,658 (about 38%) were badly damaged (Rana, 1935). Moreover, the earthquake of August 21st, 1988, with magnitude 6.6 stroked Eastern part of Nepal and killed 721 persons, injured 6553 and damaged 66541 buildings (22695 destroyed and 43846 were severally damaged) (Thapa, 1988). 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, in this paper are analysed the effects of the Nepal Building Code recommendations on the real construction practices and safety. To accomplished this objective three structures, designed and detailed according with: *i*) Current Construction Practices (CCP); *ii*) Nepal Building Code recommendation (NBC); and, *iii*) Well Designed Structures (WDS) were analysed and compared. Moreover, the influence of seismic hazard level on the reinforcement needs of the building structure is analysed by detailing a ductile building structure for a low, medium and high seismic hazard zone.

1.1. Building Construction Trends and Practices in Nepal

Reinforced concrete building construction in Nepal has begun from late 1970s. In the last decades, RC building construction rapidly increase, replacing other construction materials and solutions like adobe, stone and brick masonry in Kathmandu Valley, as well as in other parts of the country (Fig.1). Most of the buildings in the urban areas of Nepal have 2 to 6 storeys, were constructed with light reinforced frames with infill masonry panels, which can present insufficient capacity, can lacked a ductile detailing and were poorly constructed and may have limited durability conditions, due to the existing building practices based on the inferior masonry quality, lean frames, and lack of reinforcement (UNDP/Nepal, 1994).The majority of the buildings constructed in Kathmandu valley were designed by technicians, however in many cases the seismic design was not considered (Shrestha and Dixit, 2008). The Bureau of Crises Prevention and Recovery of the United Nations Development Program ranks Nepal 11th in the World, in terms of earthquake risk, however the total of engineered building construction is less than 10%. In fact, more than 90% of the buildings are considered as non-engineered RC frame and owner built, posing high risk to life and property (Dixit, 2004).



	More than 70 years	60 to 70 years	50 to 60 years	40 to 50 years	30 to 40 years	20 to 30 years	10 to 20 years	within 10 years
Adobe	31	52	36	31	39	22	12	4
Stone	7	5	14	16	8	11	6	5
BM	34	28	32	31	31	21	14	4
BC	4	0	0	4	13	18	29	34
RC	0	0	2	4	3	11	25	49
Stone and Adobe	4	2	2	4	0	1	0	0
Stone and BM	2	0	5	0	1	3	1	
BM and BC	6	3	7	4	2	10	9	1
Others	11	11	2	4	3	3	3	3

Figure 1. Trend of buildings construction (JICA, 2001)

1.2. Failures in RC Building Structures

The history reveals the occurrence of large earthquake every 60-70 years in Nepal (Pandey et al., 1986), and the history of construction practices of RC buildings is only 30-40 years old (UNDP, 1994). From this short history, these structures have very limited or negligible damage experiences in past earthquakes. Due to the lack of information on earthquake damage scenarios in RC buildings, relevant information can only be extracted from surrounding countries which have similar construction trends and practices and seismic hazard. Based on a literature review on the RC building construction trends and practice in India, Pakistan, Indonesia and Turkey, many common points and problems can be identified with the reality in Nepal. Structural deficiencies associated to short column mechanisms, soft and weak storey, beam-column joint capacity and detailing, strong-column weak-beam mechanism, shear reinforcement in RC elements, infill walls, materials quality and ductility are common in RC structures in the surrounding areas (Melo *et al.*, 2011). A brief description of these deficiencies, which may provoke severe damage or failure in buildings is discussed in the following sections.

1.2.1. Short-column effect

Short-column mechanism may occur in a building when the RC frame bay is partially filled with masonry brick walls, leaving wide openings for windows (Rodrigues *et al.*, 2010). In these conditions, large concentration of stresses may occur during an earthquake at the corners of the openings (Vicente et al., 2012). Examples of damages associated to short-column mechanism are shown in Fig. 2.

(a) (b) (c)

Figure 2. Short-column mechanism; (a) Turkey (Dogangun, 2004); (b) Pakistan (Bothara et al., 2008); (c) Indonesia (Ghobarah et al., 2006)

1.2.2. Soft-storey mechanism

In most of the buildings in urban areas, due to commercial and or parking purposes large openings and clear areas are common in lower storeys. The stiffness of building in upper storey increases due to infill masonry. This stiffness change in height may results in soft-storey behaviour, leading in many cases to the building collapse (Varum, 2003). Examples of soft-storey mechanism observed in past earthquakes are presented in Fig. 3.

(a) (b) (c) (d)

Figure 3. Soft-storey failure mechanisms: (a) Indonesia (Bothara et al., 2010); (b) Bhuj Earthquake, India (Murthy, 2001); (c) Pakistan; (d) Plastic hinging of columns of an open bottom storey, Indonesia (Bothara et al., 2010)

1.2.3. Beam-column joint failure

Beam-to-column connections can suffer a significant loss of stiffness due to inadequate shear strength and/or anchorage in the connection (Fernandes, 2011). Both of these failure modes are related to inadequate use of confinement reinforcement in the connection, and improper detailing of main reinforcement anchored in, or passing through, the connection. Examples of collapse or severe damage of buildings associated with the inadequate beam-column joint behaviour during earthquake are presented in Fig. 4.

(a) (b) (c)

Figure 4. Failure of beam-column joints: (a) Building collapse due to failure of beam-column joints, Turkey (Sezen et al., 2003); (b) Poor seismic detailing of RC frame members and beam-column joints, India (Murthy, 2001); (c) No stirrups in beam-column joint, Indonesia (Bothara et al., 2010)

1.2.4. Strong-beam weak-column failure mechanism

Strong-beam weak-column failure occurs when strength of beams is greater than the columns. To obtain ductile moment frames and to ensure inelastic demands in the beams, there by localizing damage in the beams, and control the storey drift, the design should privilege the strong-column weak-beam mechanism (Varum, 2003). Many existing RC building frame structures were designed without considering this principle. In recent earthquakes, many RC structures have collapsed or were severely damaged due to the development of the strong-beam weak-column failure mechanism, as shown in the examples of Fig. 5.

(a) (b) (c)

Figure 5. Failure due to strong-beam weak-column mechanism: (a) Pan-caking failure of school-cum-residential building at Chungthang, India (Murthy, 2001); (b) Strong-beams weak-joint and columns, Pakistan; (c) Building collapse due to column failure, Indonesia (Bothara et al., 2010)

1.2.5. Influence of the infill masonry on the seismic behaviour of structural frames

Masonry infill can drastically modify the intended structural response, attracting forces to parts of the structure that have not been designed to resist them (Paulay and Priestley, 1992). Masonry infill panels can increase substantially the global stiffness of the building structure (Rodrigues *et al.*, 2010). The more common failure modes in infill masonry walls are presented in Fig. 6.

(a) (b) (c)

Figure 6. Failure of infill masonry walls: (a) Out-of-plane tilting of masonry infill wall (India); (b) Out-of-plane failure of infill walls in Pakistan (Bothara et al., 2008); (c) Diagonal failure of infill walls separated from columns, Indonesia

1.2.6. Lack of ductile detailing

Many of the failures of building structures in recent earthquakes are due to the lack of adequate ductile detailing. Proper use of steel in reinforced concrete increases the ductility of the structures. Improper detailing may be due to improper anchorages, lack of confining stirrups, steel congestion and deficiency in shear capacity of stirrups, etc. Examples of poor detailing, inadequate transverse reinforcement and inadequate column confinement are presented in Fig. 7.

(a) (b) (c)

Figure 7. Failure due to lack of ductile detailing: (a) non-ductile details for beam-column joints, Bingo Turkey (Sezen et al., 2003); (b) poor detailing, India (Jain & Murthy, 2001); (c) collapsed column (note the absence of stirrups in a column length larger than 700 mm), Pakistan, 2008

1.2.7. Quality of concrete

The majority of building failures in developing countries are associated to low quality materials, like steel, concrete etc., where segregation of concrete and large pebbles/cobbles in the concrete may occurs. Some common examples where failure was observed, associated to low concrete quality are presented in Fig. 8.

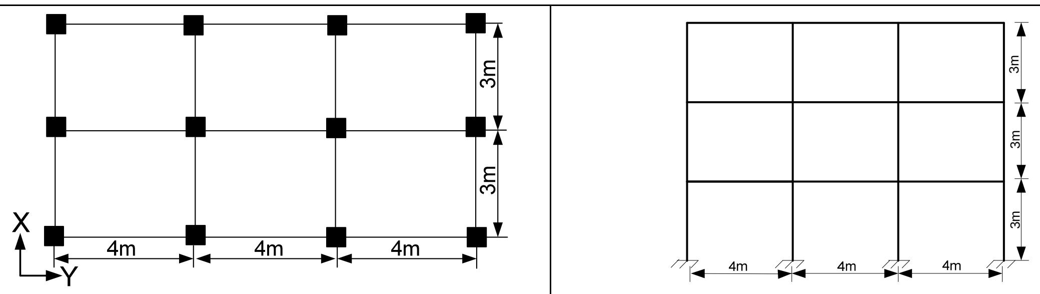
(a) (b) (c)

Figure 8. Failure in buildings with low materials quality: (a) poor quality of concrete, Turkey (Arslan & Korkmaz, 2008); (b) segregation of concrete and large pebbles/cobbles in the concrete, 90º hooks and wide spacing of stirrups, Indonesia, 2010; (c) damage due to poor material quality in beam-column connection, Turkey (Sezen, 2003)

2. DESCRIPTION OF THE CASE-STUDY BUILDING

Recently, a survey was conducted to characterise the actual situation of building construction in different localities of Nepal. The information collected during field surveys includes size and detailing of RC elements (beams and columns), inter-storey height, number of bays and bays' span, year of construction, quality of concrete and type of steel. Actually, in buildings' construction, reinforced concrete framed structure is the most commonly adopted solution all over the country. In RC buildings construction, a technical approach and knowledge is involved in the design of buildings located in the cities centre, but in the surroundings the approach followed is based on experience and common practice.

Based on the data obtained from the field survey, a 3-storey RC structure representative of a typical residential building in urban areas of Nepal was defined and it is presented next. The global dimensions of the prototype building, namely the number of storeys, storey height, bays length, etc., were defined based on the results of a statistical analysis of collected data from a field survey. The plan view and elevation of the prototype building are presented in Fig. 9. In terms of the lateral stiffness and mass distribution, the structure is regular, being symmetric in plan relatively to both two orthogonal horizontal directions. The analysis of the building was performed with two planar models, one for each main direction. The materials properties are assumed to be identical for the three structures studied and throughout each structure' height, as: (a) reinforcing steel yield strength, f_y = 415 MPa; (b) concrete compressive strength, fc' = 20 MPa; (c) live load on roof = 1.5 kN/m^2 (Nil for earthquake); (d) live load on floors = 2.0kN/m^2 (25% for earthquake); (e) roof and floor finishing = 1.0kN/m^2; (f) brick wall on peripheral beams = 230 mm thick; (g) brick wall on internal beams = 115 mm thick; (h) density of reinforced concrete elements = 25 kN/m^3; (i) density of brick masonry (including plaster) = 20 kN/m^3.



(a) Plan of building (b) Frame elevation (Y-Z)

Figure 9. Geometry of the building structure

In this study, the three variations of the moment resistant frame structure defined previously are presented. The first one correspond to moment resisting framed structure designed based on the Indian standard code considering the corresponding seismic provisions, namely the seismic design for ductile detailing. In this study this structure is called Well Designed Structure (WDS). The second framed structure was designed based on the Nepal building code, namely on the Mandatory Rules of Thumb (called NBC design structure). And, the third RC frames structure represents the current construction practices in Nepal (called CCP structure). In the following sections, the particular characteristics of each building structure are described.

2.1. Well Designed Structure

The WDS building 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). The effect of finite size of joint width (e.g., rigid offsets at member ends) is not considered in the analysis. However, the effect of shear deformation is considered. Detailed design of the beams and column section according with the IS13920:1993 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. Slab load is triangular distributed with an angle of 45^0 from the corner of the slab.

2.2. NBC

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. The main objective of this document is to replace the non-engineered construction commonly and achieve the minimum seismic safety requirements. Since 2003, this document became mandatory in Nepal. As so the NBC structure was design according with these simplified rules.

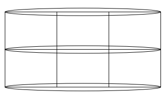
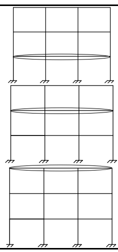
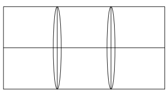
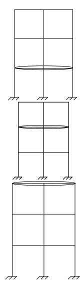
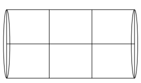
2.3. CCP

A building was also defined to represent the current construction practices in Nepal (CPP). The current construction practices of the buildings in the urban areas of 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.

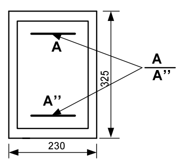
3. RESULTS AND DISCUSSION

The comparison of the obtained results of beam reinforcement quantity for the three structures under study is presented in Table 1. CCP structure has used the same amount of reinforcement for negative and positive bending moment at support as well as at mid- span. The same trend is followed by NBC structure with slightly higher amount of reinforcement. In contrast, and as expected, WDS has used more than twice the reinforcement than CCP and NBC structures.

Table 1. Comparison of beam detailing in study building structure

Plan	Beam elevation	Detailing at support			Detailing at mid-span		
		WDS	NBC	CCP	WDS	NBC	CCP
		$\frac{6\,\phi\,16}{3\,\phi\,16}$	$\frac{2\phi16 + 2\phi12}{2\phi16 + 2\phi12}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,16}{3\,\phi\,16}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{6\,\phi\,16}{3\,\phi\,16}$	$\frac{2\phi16 + 2\phi10}{2\phi16 + 2\phi10}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,16}{3\,\phi\,16}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{3\,\phi\,16}{2\,\phi\,16}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{5\,\phi\,16}{4\,\phi\,16}$	$\frac{3\,\phi\,16}{3\,\phi\,16}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{5\,\phi\,16}{4\,\phi\,16}$	$\frac{2\phi16 + 2\phi12}{2\phi16 + 2\phi12}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{3\,\phi\,16}{2\,\phi\,16}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{5\,\phi\,16}{3\,\phi\,16}$	$\frac{3\,\phi\,16}{3\,\phi\,16}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{5\,\phi\,16}{3\,\phi\,16}$	$\frac{2\phi16 + 1\phi12}{2\phi16 + 1\phi12}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$
		$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{3\,\phi\,12}{3\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,16}{2\,\phi\,16}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$	$\frac{2\,\phi\,12}{2\,\phi\,12}$

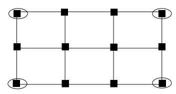
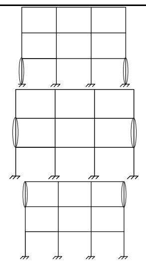
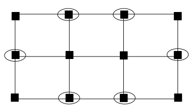
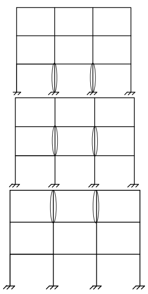
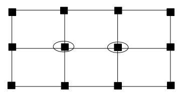
Legend:



Note: width and depth of beams is 230 mm and 325 mm, respectively.

The detailing of WDS, NBC and CCP columns section and detailing of reinforcing steel are presented in Table 2. The study showed that CCP has used same smaller column section with low amount of reinforcement in all storey and locations as compared to NBC and WDS. NBC is the slightly improved form of CCP structures. In contrast, WDS has used highly large section with double amount of reinforcement compared to CCP and NBC structures. The lager section size with maximum amount reinforcement in WDS is due to the joint shear condition with ductile detailing in high seismic zone.

Table 2. Comparison of column detailing in study building structures

Plan	Column elevation	Cross section of column WDS	NBC	CCP
		8 ϕ16 350x350	4 ϕ 16 270x270	6 ϕ 10 230x230
		8 ϕ16 350x350	4 ϕ 16 230x230	6 ϕ 10 230x230
		8 ϕ16 300x300	4 ϕ 16 230x230	4 ϕ 10 230x230
		8 ϕ16 400x400	4 ϕ 16 270x270	6 ϕ 10 230x230
		8 ϕ16 400x400	4 ϕ 16 230x230	6 ϕ 10 230x230
		8 ϕ16 350x350	4 ϕ 12 230x230	4 ϕ 10 230x230
		8 ϕ16 400x400	8 ϕ 12 270x270	6 ϕ 10 230x230
		8 ϕ16 400x400	8 ϕ 12 230x230	6 ϕ 10 230x230
		8 ϕ16 350x350	4 ϕ 12 230x230	4 ϕ 10 230x230

3.1. Comparison of Reinforcement of Well Designed Structure in Different Seismic Zone

When the issue of earthquake resistant building construction arises, at that time, there is always one question: What are the differences in reinforcement between seismically resistant and non-seismically designed RC building structures? This situation is more remarkable in the developing country like Nepal where there is negligible comparative study conducted in this issue. In this context, the present study explores the reality by comparing the amount of reinforcement in seismically resistant and non-seismically design structure. For this, the same RC building structure is designed for the three seismic 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, similarly zone factor of 0.24 and 0.16 are used in the intensity of VIII and VII respectively. Finally, only the gravity loading condition is considered (dead and live load) to the same RC building structure. Outcomes of final results are summarized and compared in Tables 3,4,5 and 6.

As compared to non-seismically resistant (GLD) structures, structures designed for seismic zone V, IV and III requires 150%, 100%, 25% more beam reinforcement in support. In the mid span, seismic zone V and IV requires 115% and 30% more reinforcement.

Table 3. Comparison of reinforcement in exterior longitudinal beam

IS Zone	Zone factor	Support, -ve (mm^2)	Centre, +ve (mm^2)
V	0.36	1189	509
IV	0.24	991	336
III	0.16	857	309
GLD		635	298

Table 4. Comparison of reinforcement in interior longitudinal beam

IS Zone	Zone factor	Support, -ve (mm^2)	Centre, +ve (mm^2)
V	0.36	1145	478
IV	0.24	940	309
III	0.16	799	286
GLD		553	263

Table 5. Comparison of reinforcement in exterior transverse beam

IS Zone	Zone factor	Support, -ve (mm^2)	Centre, +ve (mm^2)
V	0.36	1014	406
IV	0.24	786	241
III	0.16	286	136
GLD		309	146

Table 6. Comparison of reinforcement in interior transverse beam

IS Zone	Zone factor	Support, -ve (mm^2)	Centre, +ve (mm^2)
V	0.36	1031	400
IV	0.24	779	241
III	0.16	239	116
GLD		263	126

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

4. CONCLUSIONS

The main aim of this study was to evaluate the RC building structures constructed according to current construction trends and practices in Nepal. This research compares a structure idealised as representative of the current construction practice in Nepal, with a structure detailed according to the Nepal Building Code recommendations and with a well designed structure according with the IS 1893-2002 code. Based on the obtained results, the following conclusions are drawn:

- More than 80% of the surveyed buildings correspond to non-engineered constructions.
- Although Nepal Building Code becomes mandatory, limited improvements are observed in many of the buildings, constructed without considering the proper detailing.
- The steel reinforcement detailing used in beams and columns of CCP structure is insufficient for seismically active regions, and may even be inadequate for non-seismically design building.
- The NBC 201 and 205 recommendations requirements in terms of reinforcement in beams and columns are not enough to high seismic demands and can lead to structures with a strong-beam weak-column mechanism behaviour.
- The column sections resulting from a design based on the NBC code are insufficient to withstand the expected earthquake demands. Beam-column joints are not properly detailed.
- Structures designed in seismic zone V have more than two times reinforcement quantities than the non-seismically designed structures.

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