Seismic Performance of Reinforced Concrete Buildings in Bhutan

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ABSTRACT

Reinforced concrete (RC) frame is one of the most common building structures in Bhutan. While many RC buildings were built in the past and many are still under construction, seismic response of these buildings has not been studied in detail. RC buildings built prior to 1997 were designed only for gravity load and only those built after 1997 were designed for seismic load according to the Indian seismic code IS 1893. Although, Bhutan is located in one of the most active seismic zones in the world, yet a very limited study has been done on the performance of these buildings. This paper presents the numerical investigations carried out to study the performance of three typical RC buildings in the capital city, Thimphu under seismic loadings. The predicted ground motions obtained from Probabilistic Seismic Hazard Analysis (PSHA) at generic soil sites in Thimphu, Bhutan are used as input in the structural response analysis. Non-linear analysis and performance assessment software, Perform 3D is used for the numerical simulations. Soil Structure Interaction (SSI) has been incorporated for different soil sites. The accuracy of the numerical model is calibrated with the test results reported by other researchers. The results of analyses are presented in terms of the inter-storey drift and displacements. The seismic performance of the buildings is assessed under different performance levels based on Vision 2000 document. The effect of incorporating SSI in the analysis is also discussed.

Keywords: Reinforced concrete frame, seismicity, performance level, inter-storey drift, SSI.

1. INTRODUCTION

It is well known that earthquake is one of the most destructive natural disasters. It has claimed many human lives and damaged huge amount of properties. It was reported that more than 50% of the casualties from natural disasters is attributed to earthquakes (Walling and Mohanty, 2009).

Bhutan, a tiny Himalayan country is no exception from the fatalities of earthquakes. Earthquakes of various sizes have occurred in Bhutan inflicting heavy casualties and damages for centuries. The first severe earthquake reported in the literature was 1713 earthquake which was believed to have occurred in the eastern Bhutan near the Indian state of Arunachal Pradesh (Bilham, 2004, Ambraseys and Jackson, 2003). Although the exact time, size and location of the earthquake were not very certain, yet it was reported that the earthquake occurred in the night of spring and inflicted heavy casualties to human lives and their properties (Ambraseys and Jackson, 2003). The most recent earthquake that rocked Bhutan was in 2009 which had a magnitude of 6.1 in Richter scale. This earthquake claimed 13 lives and damaged hundreds of buildings including rural and urban residential houses, schools and monasteries (Joint Report, 2009). For the last seven and half decades, there were 32 earthquakes of engineering significance occurred in Bhutan, the most notable one being 1941 earthquake which had a magnitude of 6.75 (Dorji, 2009). In addition, there were a lot of earthquakes occurred around Bhutan such as 1897 M_w=8.7 Shillong Plateau, 1934 M_w=8.3 Bihar-Nepal border, 1947 M_w=7.7 upper Assam and 1950 M_w=8.6 Arunachal Pradesh earthquakes (Walling and Mohanty, 2009). Figure 1(a) and (b) show the seismic hazard map of Bhutan and earthquakes occurred in and around Bhutan respectively. It can be inferred from these earthquakes that Bhutan indeed is located on one of the most active seismic zones in the world. The high seismicity of the area is due to the subduction of the Indian plate into Eurasian plate which is reported to be moving at an average of 20±3mm per year (Bilham et al., 2001).

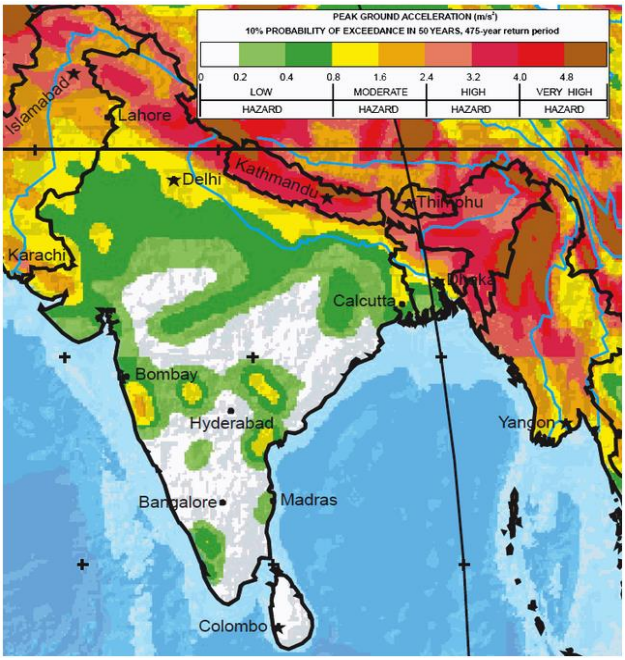

Figure 1. (a) Seismic hazard map of Bhutan (GSHAP, 1992)

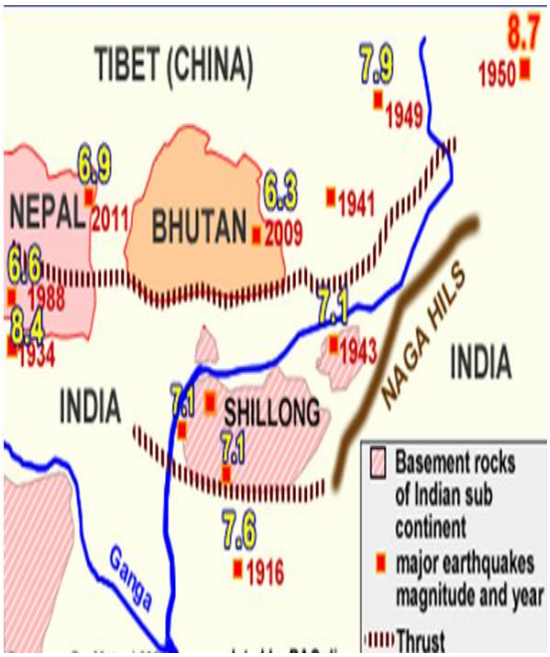

Figure 1. (b) Earthquakes in and around Bhutan (Motegi, 2001)

In spite of being the victim of several past earthquakes, Bhutan is least prepared for the next earthquake. Currently, Bhutan does not have a seismic code of its own and buildings are designed and constructed as per the Indian Seismic code IS1893: 2002. It is assumed that

seismicity of Bhutan is the same as that of north eastern states of India which is designated zone V of the Indian seismic code. Hao and Tashi (2010) studied the applicability of using Indian seismic code to site conditions in Bhutan and expressed some concern for simply following it in Bhutan. They found that while Indian code predicts very similar PGA in Thimphu, the shapes of response spectrum are quite different from that predicted for Thimphu which could result in different structural responses.

Moreover, the use of Indian seismic code has begun only from 1997 in the urban areas. Prior to 1997, all buildings were either built based on some thumb rules or designed only for gravity load. Rural houses were built by the local technicians without seismic features. As a result in the last earthquake in 2009 many rural houses were heavily damaged. Hence, there are thousands of buildings in both rural and urban areas which are potentially vulnerable to earthquakes. Although reinforced concrete (RC) buildings built after 1997 were designed according to the Indian seismic code, yet performance of these buildings has not been properly assessed. Hence, seismic performance assessment of buildings especially in the capital city, Thimphu has become the pressing need of the time. Population of the city is increasing rapidly and so is the risk from earthquakes. It is paramount to know the performance of the buildings beforehand so that mitigation measures can be addressed and be prepared for the future events.

This paper presents the seismic performance assessment carried out for three typical RC buildings in Thimphu using the ground motions predicted at generic soil sites in Thimphu by Hao and Tashi (2010). Nonlinear dynamic analysis and performance assessment software called Perform 3D was employed for the study. Soil structure interaction has been incorporated as per the provision in ASCE 41 (2006) for different soil sites. The performances of the typical buildings in terms of inter storey drift and displacements are predicted for the 475 and 2475 years return period earthquakes and compared with the provision in Vision 2000 document. The effects of soil structure interaction have also been discussed.

2. NUMERICAL ANALYSIS

2.1 Model Calibration

In order that structural responses of the buildings are correctly predicted, dynamic nonlinear analysis has been performed for the four-storey reinforced concrete frame building which was pseudo-dynamically tested at the European Laboratory for Structural Assessment (ELSA). The building was 10mx10m in plan and was designed according to Eurocodes 2 and 8. The test was conducted for both low level (0.12g) and high level (0.45g) ground motions which were artificially generated from the real recorded 1976 Friuli earthquake signal. The test set up of the building is shown in Figure 2(a). The building and test details can be found in Negro et al. (1994), Negro et al. (1996) and Negro and Colombo (1997).

The structural responses predicted numerically are compared with that of test results. Figure 2 (b) shows the comparison of displacements predicted from numerical analysis and that obtained from the test for high level test. As can be seen from the figure, a very good match has been obtained indicating that the numerical model gives reliable predictions of structural responses.

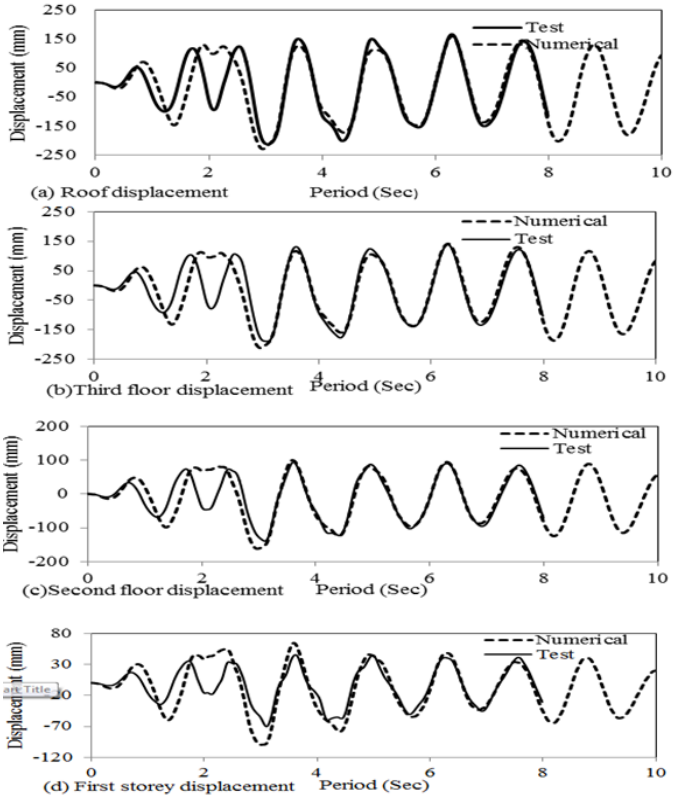

Figure 2(a).Test set of building (Pinto et al. 1994) Figure 2(b). Comparison with test results

2.2 Typical Buildings

The construction of RC buildings had begun as early as 1970s in Bhutan (Dorji, 2009). Today, RC structures have replaced almost all the traditional structures such as adobe and stone masonry buildings in the urban areas. Most of the RC buildings in Thimphu are three to seven storeys tall and are mostly rectangular in plan. Ground floor is mainly used for commercial purposes while top floors are used as residential units. In this study, three typical residential RC buildings are considered. They represent the most common RC buildings in Thimphu. They are labelled as '6 storey', '3 storey new' and '3 storey old'. '6 storey' is a typical six storey RC building which was designed and built after the adoption of Indian seismic code in 1997. Six storey RC buildings are very common in the central area of Thimphu where population of the city is concentrated. '3 storey new' is a three storey RC buildings which was also designed and built after the adoption of Indian seismic code. '3 storey old' is a three storey RC building built prior to 1997 when no seismic provisions had been incorporated. Both '3 storey old' and '3 storey new' are common in the central area as well as in the other parts of Thimphu. For comparison, identical building plan with the same

number of beams and columns are considered for '3 storey new' and '3 storey old' buildings. However, they differ in the dimension of RC members and the amount of reinforcement provided. It is to be noted that only the weight of the infill brick masonry wall is considered and their contribution to stiffness and strength are neglected in the analysis. The details of the buildings are shown in Figures 3 and 4 and Tables 1 to 3.

Table 1. Loading details of typical buildings

Parameters	6 storey	3 storey new	3 storey old
Yield strength of rebar, fy N/mm^2	415	415	415
Compressive strength of concrete,fc' N/mm^2	25 for columns, 20 for beams	20	15
Unit weight of reinforced concrete, KN/m^3	25	25	25
Unit weight of bricks, KN/m^3	19.6	19.6	19.6
Superimposed dead load on floors, KN/m^2	1	1	1
Live load on floors, KN/m^2	2	2	2
Lived load on roof, KN/m^2	0.75	0.75	0.75

Table 2. Reinforcement details of 6 storey building

Beam	Dimension (bxD),mm	Reinforcement (Bar dia. in mm)
Floor beams along grid 2& 3	300x450	TB=4-20, BB=2-20+2-16
Floor beams along grid 1	300x450	TB=2-20+2-16, BB=4-16
Floor beams along grid A& D	300x400	TB=2-20+2-16, BB=4-16
Floor beams along grid B& C	300x400	TB=4-20, BB=2-20+2-16
Roof beams along grid 1& 3	300x450	TB=4-16, BB=3-16+1-12
Roof beams along grid 2	300x450	TB=2-20+2-16, BB=4-16
Roof beams along grid A& D	300x400	TB=4-16, BB=3-16+1-12
Roof beams along grid B& C	300x400	TB=4-20, BB=3-20+1-16
Beam stirrups	8@100mmC/C till 2D from either side of column face and 8@150C/C at the centre	
Column		
Column C1	450x450	8-20 + 4-16
Column C2	450x450	12 Nos 20mm dia
Column C3	500x500	4-25+8-20
Column ties	9@90mmC/C throughout	

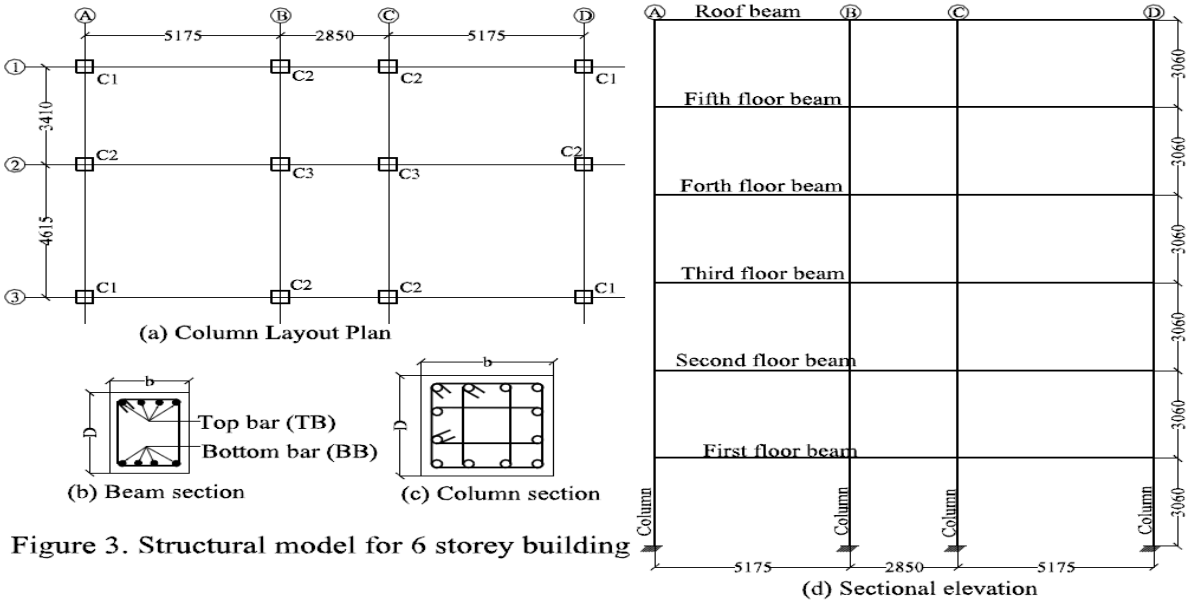

Figure 3. Structural model for 6 storey building

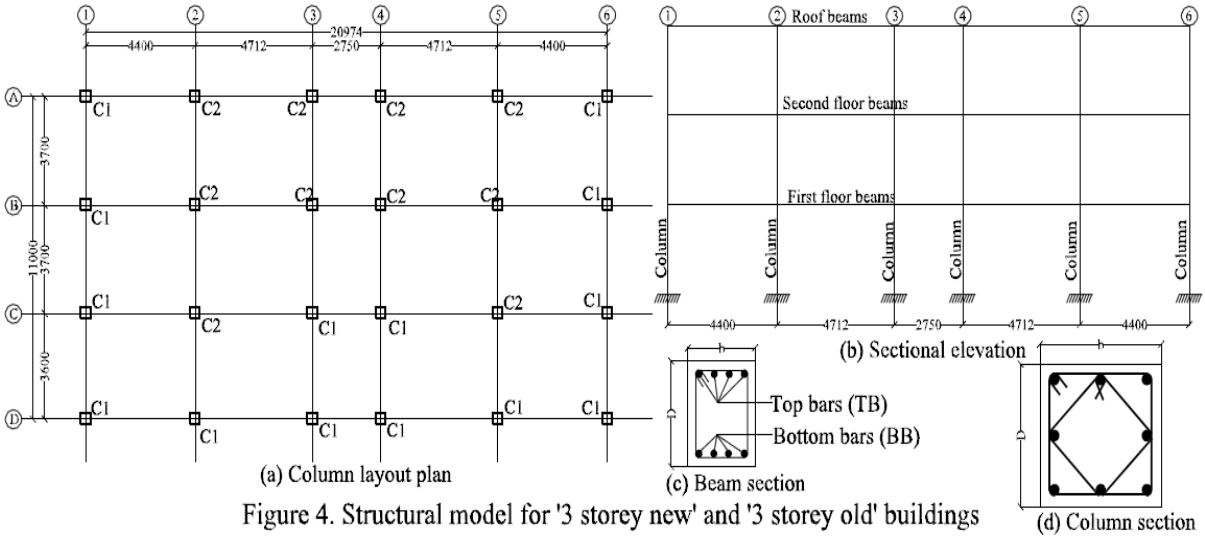

Figure 4. Structural model for '3 storey new' and '3 storey old' buildings

Table 3. Reinforcement details of '3 storey new' and '3 storey old' buildings

	3 storey new		3 storey old	
Beam	Dimension (bxD),mm	Reinforcement (Bar dia. in mm)	Dimension (bxD),mm	Reinforcement (Bar dia. in mm)
Floor beams along grid A,B& C	300x400	TB=4-20, BB=2-20+2-16	250x350	TB=4-12, BB=2-12+2-10
Floor beams along grid D	300x400	TB=2-20+2-16, BB=4-16	250x350	TB=3-12, BB=3-10
Floor beams along grid 1,3,6&4	300x400	TB=4-20, BB=4-16	250x300	TB=2-12+2-10, BB=3-12
Floor beams along grid 2&5	300x400	TB=4-20, BB=2-20+2-16	250x300	TB=4-12, BB=2-12+2-10
Roof beams along grid A& D	300x400	TB=4-16, BB=2-16+2-12	225x300	TB=3-12, BB=3-10
Roof beams along grid B& C	300x400	TB=2-20+2-16, BB=4-16	225x300	TB=2-12+2-10, BB=3-12
Roof beams along grid 1,3,4&6	300x400	TB=4-16, BB=2-16+2-12	225x300	TB=2-12+1-10, BB=3-10
Roof beams along grid 2&5	300x400	TB=2-20+2-16, BB=4-16	225x300	TB=3-12, BB=3-10
Beam stirrups	8@100mmC/C till 2D from either side of column face and 8@150C/C at the centre		6@150mmC/C throughout	
Column				
Column C1	400x400	8 Nos. 20mm dia.	250x250	4 Nos. 16mm dia.
Column C2	400x400	4-25+4-20	250x250	8 Nos. 12mm dia.
Column ties	8@100mmC/C throughout		6@150mmC/C throughout	

2.3 Ground Motions

Hao and Tashi (2010) conducted Probabilistic Seismic Hazard Analysis (PSHA) and predicted the design ground motions at generic soil sites in Thimphu for the return periods of 475 and 2475 years. These ground motions have been used in this study since no other credible ground motions are currently available. PGA values of the ground motions are given in Table 4. Figure 5(a) shows the response spectra for 5% damping and 475 years return period obtained from these ground motions. As shown in this figure, there are two peaks corresponding to near-field and far-field earthquakes which are quite different from that of response spectral shape defined by Indian seismic code. The second peak at long period could lead to resonance with soft soil site and result in much higher response. On the other hand, response spectra defined by Indian Seismic code has no such second peak and would

undermine the response of the structures located on the soft soil sites. The normalised response spectra defined by Indian seismic code for 5% damping is shown in Figure 5(b).

Table 4. PGA values at generic soil sites in Thimphu

Soil type	PGA value (g)	
	475 years return period	2475 years return period
Rock	0.194	0.337
Shallow stiff soil	0.321	0.486
Soft rock	0.428	0.781
Very soft soil	0.374	0.461

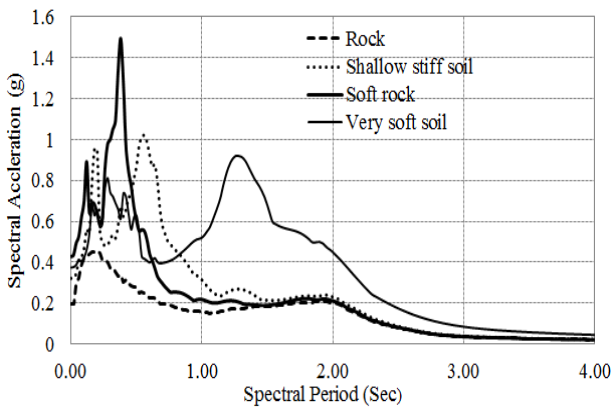

Figure 5(a). Response spectra at generic soil spectra sites in Thimphu

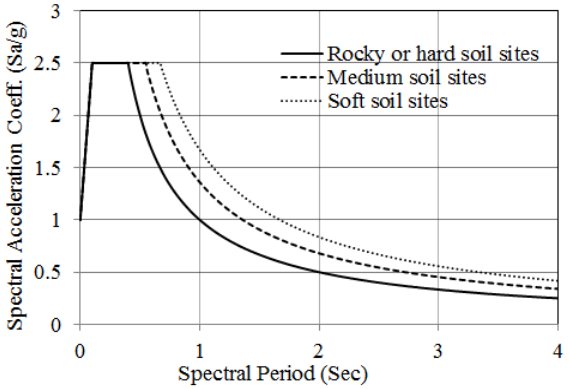

Figure 5(b). Normalised response defined by Indian seismic code

2.4 Response Analysis of Typical Buildings

Nonlinear analyses of the typical buildings are conducted using the ground motions given in Table 4. Modelling parameters such as stiffness, strength and deformation capacity of RC members are calculated as done for the calibrated model. FEMA beam and FEMA column which employs the chord rotation model are respectively used for modelling beams and columns. The force deformation (F-D) relationship as described in ASCE/SEI-41 (2007) and slightly modified in Perform 3D is used for evaluating F-D relationship of the RC members. The general F-D diagram of Perform 3D is shown in Figure 6(a). The main idea of Perform F-D relationship is to capture main points designated by Y, U, L and R which respectively represent yield strength, ultimate strength, ductile limit and residual strength with corresponding deformations. The point X on the plot represents a point which is so large that there is no point in continuing the analysis. The resultant plot is called backbone curve which is defined as the reference F-D relationship that confines the hysteretic response of the component. The F-D relationship of first floor beam for '3 storey new' building is shown in Figure 6(b). The F-D relationships of other members are similarly obtained.

The details of modelling the nonlinear RC members can be found in Panagiotakos and Fardis (2001), Biskinis and Fardis (2010), Elwood and Eberhard (2009), PEER-ATC-71-1 (2010) and ASCE/SEI-41 (2007). Soil structure interaction has been incorporated for shallow stiff

soil, soft rock and very soft soil sites. The stiffness of the respective soil sites have been calculated from the provision in ASCE/SEI-41 (2007) using the typical values of soil properties.

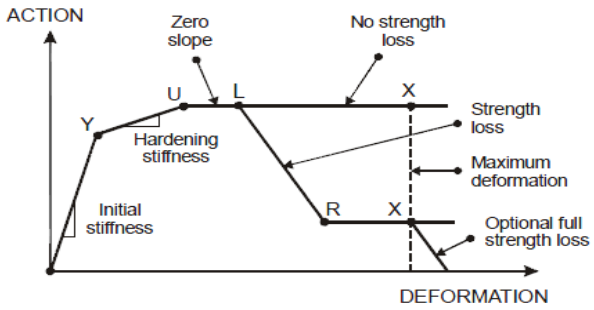

Figure 6(a). General F-D relationship from Perform 3D manual

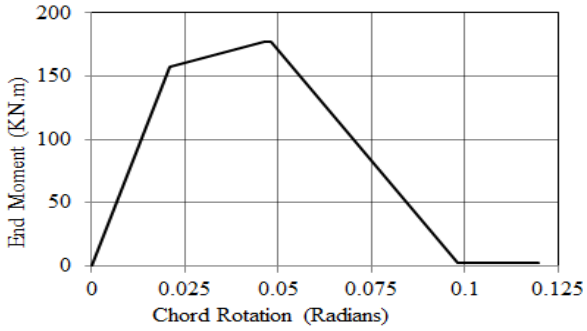

Figure 6(b). F-D relationship of first floor beam for '3 storey new' building

The structural responses of the typical buildings have been evaluated in terms of inter-storey drift and displacement. The inter-storey drift of '6 storey', '3 storey new' and '3 storey old' buildings at the generic soil sites for 475 an 2475 years return periods are respectively shown in Figures 7 and 8. Similarly, displacements of buildings are shown in Figures 9 and 10. The effects of soil structure interaction and performance levels of the buildings as per Vision 2000 document (Committee, 1995) are also shown in the figures. The dotted line indicates the response with fixed support (FS) and the solid line indicates the response with the incorporation of SSI.

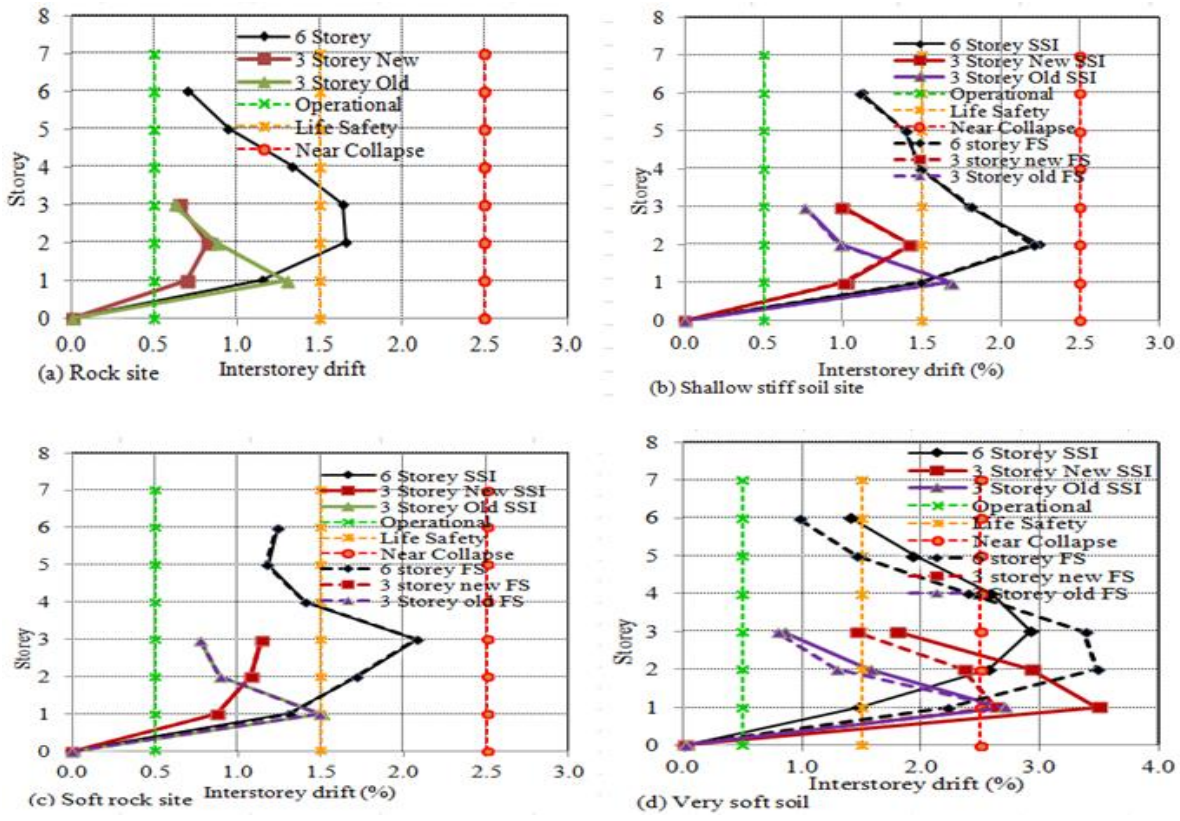

Figure 7. Inter-storey drift, performance levels and effects of SSI for 475 years return period

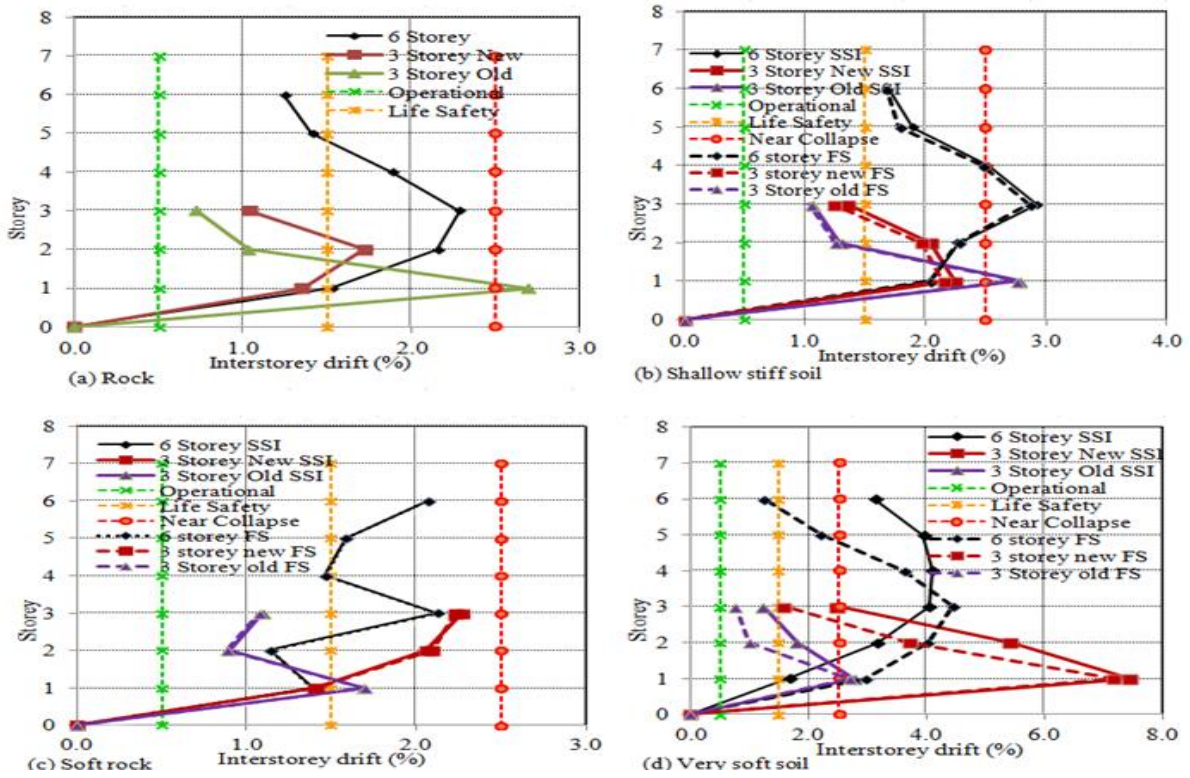

Figure 8. Inter-storey drift, performance levels and effects of SSI for 2475 years return period

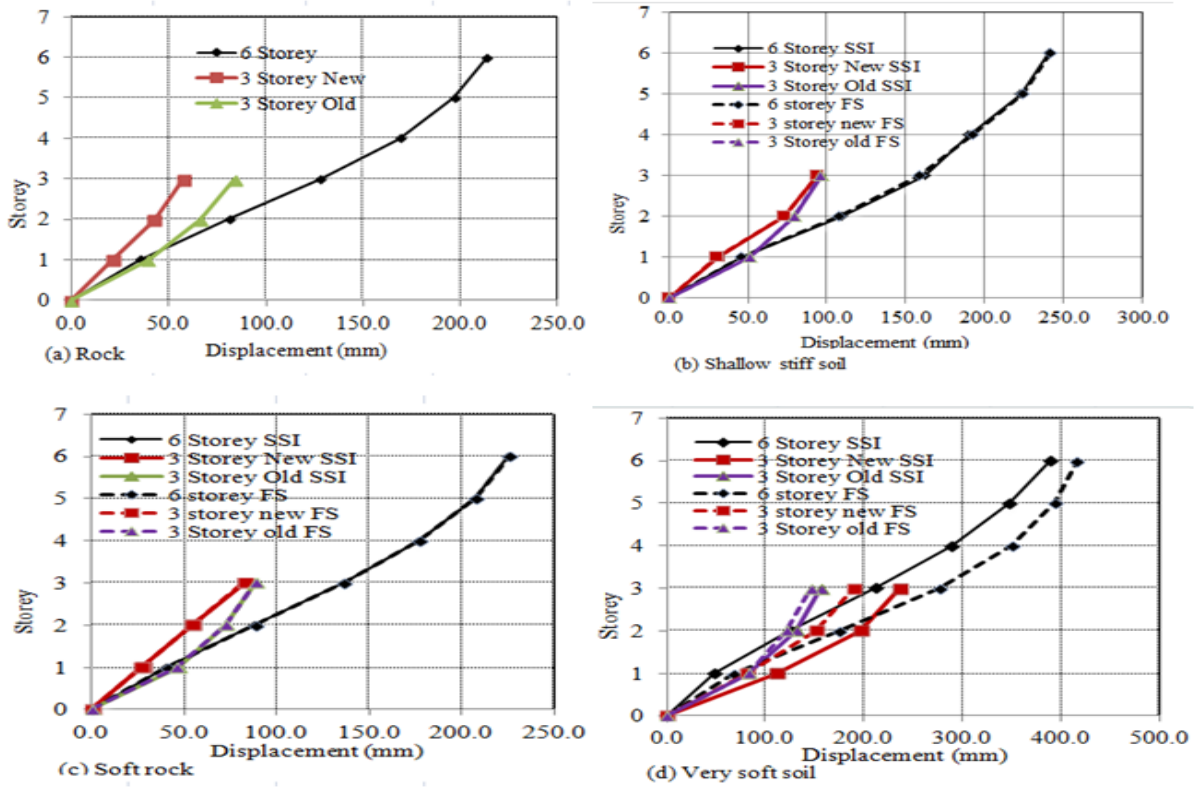

Figure 9. Displacement of typical buildings with effects of SSI for 475 years return period

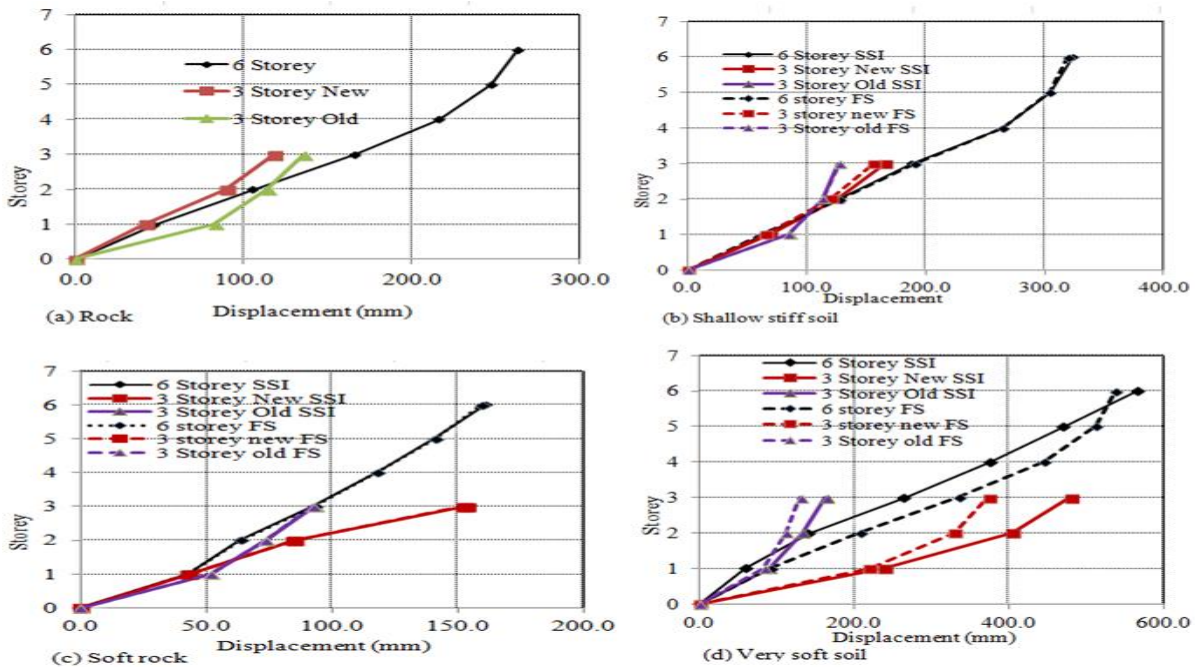

Figure 10. Displacement of typical buildings with effects of SSI for 2475 years return period

2.5 Discussion

From the Figures 7, 8, 9 and 10, it is evident that '6 storey' building, although designed according to Indian Seismic code IS-1893 (2002) is more vulnerable to earthquakes than that of three storey buildings. Even at the rock site and for 475 years return period, the drift demand exceeds the life safety limit and at the very soft soil site, drift demand exceeds near collapse limit indicating total collapse. Similar trend is observed for 2475 years return period although with higher drift demand. This could be due to the fact that either the building was not properly designed for lateral load or that the Indian Seismic code is not adequate enough to be used in Bhutan for the design of medium rise building.

As expected, '3 storey new' building performs better than '3 storey old' building whose drift demand is lower than the life safety limit at rock, shallow stiff soil and soft rock sites for 475 years return period. However, drift demand crosses near collapse limit at the very soft soil site for the same return period. It is interesting to note that '3 storey old' building performs better than '3 storey new' building at the very soft soil site. This is found to be due to the soil resonance wherein the '3 storey new' building period coincided with the site natural period of soil. The irregular drift demand profile observed at the soft rock site is found to be due to the influence of second mode.

As shown in the Figures 7, 8, 9 and 10, soil structure interaction (SSI) has negligible effect at the shallow stiff soil and soft rock sites. However, SSI has pronounced effect at the very soft soil sites. SSI is found to be beneficial to '6 storey' building whereas it is detrimental to the '3 storey old' building and highly detrimental to the '3 storey new' building. As such, the effect of SSI on the response of building is found to be highly dependent on the period of building and the site natural period of the soil.

2.6 Limitation

While every effort has been made in this study to be as practical as possible with respect to the actual buildings at site, stiffness and strength of the masonry walls have been neglected. Only the weight of the masonry wall is considered in this study. The static stiffness of the soil is only considered as per ASCE/SEI-41 (2007), while the soil damping ratio which is integral part of the soil has been neglected. These limitations are part of the author's future course of study.

3. CONCLUSION

Bhutan locates on one of the most active seismic zones in the world. A lot of significant earthquakes have occurred in the past and inflicted heavy casualties to human lives and their properties. Although the seismic risk is certain, Bhutan has no seismic design code of its own. Prior to 1997, all buildings were either built by technicians based on some thumb rules or designed only for gravity load. Post 1997, Indian Seismic code has been followed although its applicability to the site conditions in Bhutan is still in question. The risk is higher in the capital city, Thimphu where population is rapidly increasing. Inspite of all these risk factors, seismic assessment of buildings in Thimphu has not been carried out properly.

This paper presents the seismic performance assessment of three typical RC buildings in Thimphu. A six storey and a three storey buildings, designed and built in accordance with Indian Seismic code IS 1893 and a 3 storey building designed only for gravity load are considered for the study. Performances of these buildings are assessed using predicted ground motions for Thimphu for the return periods of 475 and 2475 years. Influence of soil structure interaction has also been included in the analyses.

From this study, it is found that six storey building is more vulnerable to earthquakes than three storey buildings. The predicted drift demand exceeds the life safety limit even at the rock site for 475 years return period as per Vision 2000 document. Three storey building designed according to Indian Seismic code performs better than the three storey building designed for gravity load alone. Soil structure interaction has limited effect at the shallow stiff soil and soft rock sites, while larger effect is predicted at the very soft soil site. At a very soft soil site, SSI is found to be beneficial to six storey building while it is found to be detrimental to three storey building designed according to Indian Seismic code.

It should be noted that the poor performance of the buildings is at least partially attributed to the relatively weak concrete strength of 20 and 25 MPa being used in the construction in Bhutan. Using stronger construction material and proper design to avoid resonance could greatly improve the performances of the buildings in Bhutan.

4. ACKNOWLEDGEMENT

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