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Seismic Response of Monolithic and Precast RC Building for Site-Specific Conditions

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Abstract

This paper investigates the seismic response of a rigid and flexible RC building by performing nonlinear time history analysis (NLTHA). In the present study, the numerical model of a 5-storey monolithic RC (MRC) and 5-storey precast RC (PRC) buildings are developed in SAP2000. The buildings are assumed to be situated in Assam and a real Silchar site from Assam is considered. For the NLTHA, six spectrum compatible time histories (SCTH) are considered. The first set comprises of 3 SCTH matched to the Indian seismic code design spectra (ISCDS) and the second set comprises of 3 SCTH matched to the site-specific elastic response spectra (SSERS). The NLTHA results show that the roof displacement of the MRC building is less as compared to the PRC building for all the considered cases. However, the response for both the structures for SSERS compatible time histories is more significant as compared to the ISCDS compatible time histories. It is interesting to note that when the energy dissipation in the structure is evaluated for ISCDS compatible time histories, the damage in PRC building is negligible as compared to MRC building. Moreover, for SSERS compatible time histories, the damage in both the buildings are comparable. The results show the importance of site-specific study and its response on the structure behavior.

Keywords: Seismic performance, site-specific spectra, compatible ground motions, precast building, ground response analysis

1. Introduction

The dynamic response of a structure depends on the ground motion which is having a specified spectral acceleration (*Sa*) at a given period. Also, the time history (TH) records used for nonlinear time history analysis (NLTHA) can influence the structural response significantly; hence, selection of the set of appropriate time histories is vital and a topic of great interest. One of the methods of selection of time history is spectrum compatible time history (SCTH) in which the TH's are made compatible with the target hazard spectrum. Indian seismic design code [1] provides response spectra up to 6 sec for three types of soil classes. However, Adhikary and Singh [2] concluded that the site classification of Indian seismic code is qualitative and quite broad and the omission of shear wave velocity places it at a significant disadvantage. They also concluded that the Indian code ignores the amplification of peak ground acceleration (PGA) due to soil. So, as compared to other codes, Indian code spectra results in lower design spectral accelerations on soil sites. To overcome this issue, several researchers have performed ground response analysis individually for the different cities across India and estimated the site amplification factors, response spectra, site coefficients, etc. Some of them include works by Ranjan [3] for Dehradun; Mahajan et al. [4] for Dehradun; Govindaraju and Bhattacharya [5] for Kolkata; Paul and Dey [6] for Silchar; Boominathan et al. [7] for Chennai; Sitharam and Anbazhagan [8] for Bangalore; Raghukanth et al. [9] for Guwahati; Phanikanth et al. [10] for Mumbai; Chandrasekaran et al. [11] for Coimbatore; Shukla and Choudhury [12] for Gujarat ports; Jain and Gupta [13] for Delhi, Dehradun, Kakrapar and Kalpakkam; Jishnu et al. [14] for Kanpur; Sitharam et al. [15] for lucknow; Mandal et al. [16] for Greater Delhi region; Kumar et al. [17] for Guwahati; Naik and Choudhury [18] for Goa; Desai and Choudhury [19] for important sites of Mumbai; Elayaraja et al. [20] for Coonoor and Ooty; Pandey et al. [21] for Uttarakhand; Chatterjee and Choudhury [22] for Kolkata; Chatterjee [23] for Kolkata and many more. Further, Bajaj and Anbazhagan [24] proposed site amplification factors and response spectra for Southern India based on the nonlinear ground response analysis. To classify the soil sites, they used the site categorization of National Earthquake hazards Reduction Program (NEHRP). Further, Kumar and Haldar [25] proposed site coefficients and design response spectra for Guwahati region of India based on the extensive ground response analysis. Recently, Deoda and Adhikary [26] proposed a new site classification scheme and site-specific elastic response spectra (SSERS) for Indian seismic design code. They modified the existing site classification scheme (three soil classes) into five soil classes viz. A, B, C, D and E in line with the other national codes. Also, they proposed the MATLAB [27] tool which gives the site-specific elastic response spectra by providing the site details.

In the present study, the seismic response of a rigid and flexible RC building is assessed by performing NLTHA.

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Here, rigid building refers to monolithic RC (MRC) building and the flexible term refers to precast RC (PRC) building. Both the considered buildings are assumed to be situated in Silchar with the PGA of 0.36 g. A real soil profile data of Silchar site is taken from Paul and Dey [6] with the available dynamic soil properties. Moreover, this site is classified as per the Indian site classification and the site classification given by Deoda and Adhikary [26]. In addition to this, two sets of time TH records are selected in which the first set comprises of 3 SCTH matched to the Indian seismic code design spectra (ISCDS) [1] and the second set comprise of 3 SCTH matched to the SSERS. Further, the NLTHA is performed for both the considered buildings subjected to both the set of ground motion records.

2. Selection of Site

Paul and Dey [6] did the ground response analysis of a deep soil site in Silchar subjected to the 1997 North-East India earthquake. The local soil profile of Silchar is shown in Fig. 1. It is observed that Silchar site is a deep soil site in which the 15 m of clay layer overlies 60 m of sand deposit. The dynamic soil properties (modulus reduction and damping ratio curves) evaluated by Paul and Dey [6] for the considered site is shown in Fig. 2. Before proceeding with the numerical analysis, the Silchar site is validated with the literature results using DEEPSOIL [28] software and the validation is shown in Fig. 3. It can be observed in Fig. 3 that the peak amplification factor is approximately 8 due to high impedance contrast and the numerical result follows a similar trend to the published result [6]. However, there is a shift in the period, which may be attributed due to the sensitivity analysis or the digitization required for data extraction.

3. Indian Seismic Code Design Spectra (ISCDS)

IS 1893 [1] provides response spectra for three soil classes viz. rock/hard soil, medium soil and soft soil. The considered Silchar site has $V_{s,av}$ as 239.06 m/s and fundamental period (T_o) as 1.25 sec. According to the code comparison done by Deoda and Adhikary [26], the soil profile with the above mentioned parameters falls out in type-II (medium) soil of Indian seismic code [1]. Therefore, soil type-II spectra of Indian seismic code (as shown in Fig. 4a) is considered for the further analysis and selection of TH's.

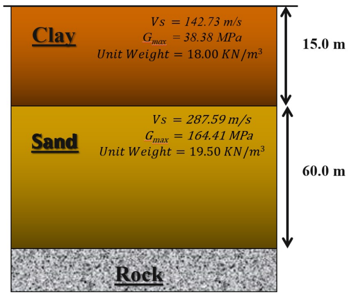
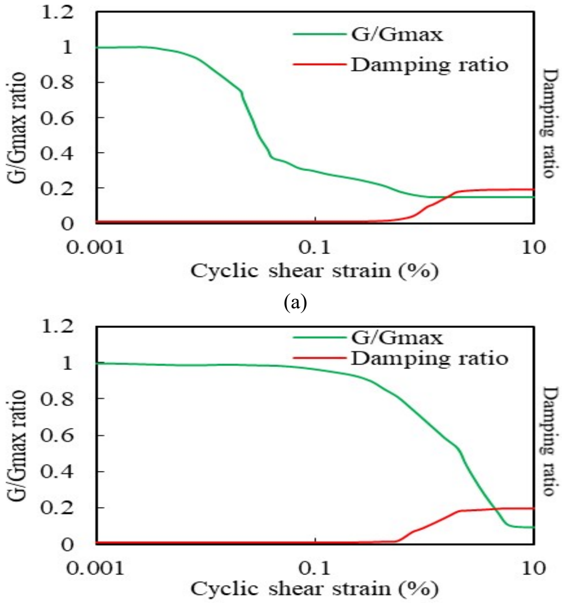


Fig. 1: Soil profile of Silchar site



(a)

(b)

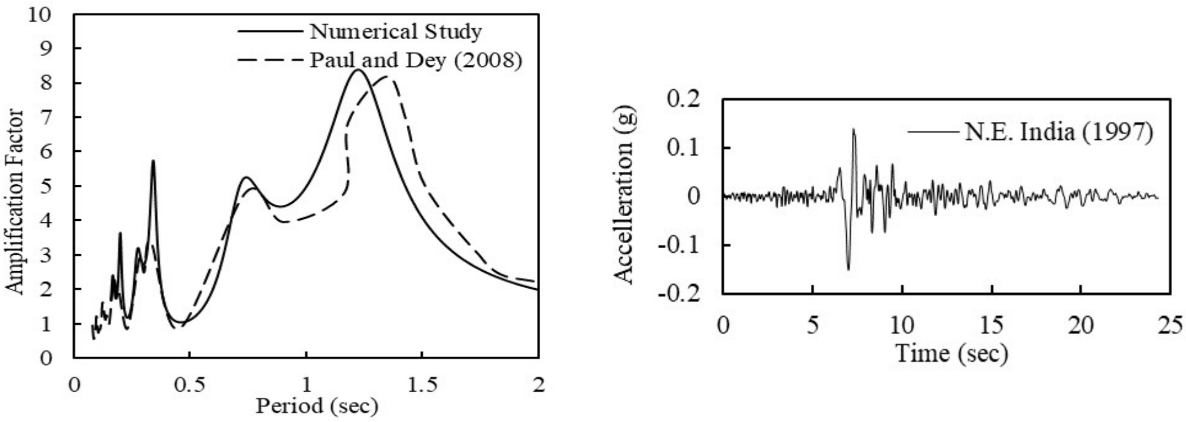
Fig. 2: Dynamic soil properties of Silchar site for (a) Clay and (b) Sand layer

4. Site-Specific Elastic Response Spectra (SSERS)

Deoda and Adhikary [26] did the extensive study on the Indian sites and proposed a new soil classification system (viz. soil classes A, B, C, D and E) for Indian seismic code along with the respective elastic response spectra. Further, they proposed period and intensity-dependent soil amplification factors anchored to two spectral values at 0.2 s and 1.0 s. Additionally, they provided a standalone application tool named 'Site-Specific Elastic Response Spectra' which gives the site-specific response spectra along with the respective amplification factor. Also, it gives an effective period of the site which should not equal to the period of structure in order to avoid resonance. Using this application, the site-specific spectra of Silchar site is evaluated and shown in Fig. 4b. This SSERS is further used for the selection of ground motions

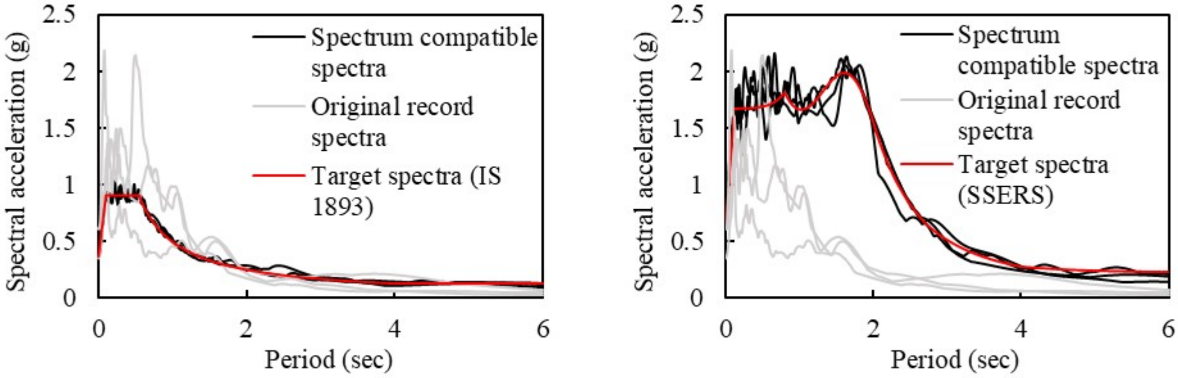
5. Selection of Ground Motions

The selection of time histories for NLTHA is still a topic of great interest. However, various guidelines (viz. EC8, ASCE 7, NZS 1170.5, etc.) are available for the selection of TH to perform NLTHA of structures. The artificial, recorded, or simulated TH's can be used directly or after making them compatible with the target spectra to perform NLTHA. Aiming to the scope of present work, SCTH's are used for further analysis. Initially, three ground motions are selected from Pacific Earthquake Engineering Research Center (PEER) database matching to type-II (medium) soil type response spectra of Indian seismic code. The details of ground motions are given in Table 1. Further, two sets of TH records are obtained using the SEISMOMATCH [29] tool, in which the first set (further referred to as set-1) comprises of 3 SCTH matched to the Indian seismic code design spectra (ISCDS) [1]. The second set (further referred to as set-2) comprises of 3 SCTH matched to the SSERS. The compatible spectra of selected TH's along with the original record spectra are shown in Fig. 4.



(a) (b)

Fig. 3: (a) Validation of amplification factor of Silchar site with the literature results and (b) its corresponding ground motion



(a) (b)

Fig. 4: 5% damped elastic response spectra of both selected and compatible earthquake records along with the target spectra of (a) IS 1893 type-II soil and (b) SSERS of Silchar site

Table 1: Details of selected ground motion records

Sr. No.	Index	RSN	Earthquake Name	Station	Year	Magnitude	$V_{S,30}$ (m/s)	Horizontal Component
1	TH-1, 4	126	Gazli_ USSR	"Karakyr"	1976	6.8	259.59	000
2	TH-2, 5	158	Imperial Valley-06	"Aeropuerto Mexicali"	1979	6.53	259.86	045
3	TH-3, 6	368	Coalinga-01	"Pleasant Valley P.P. - yard"	1983	6.36	257.38	045

6. Selection of Ground Motions

The selection of time histories for NLTHA is still a topic of great interest. However, various guidelines (viz. EC8, ASCE 7, NZS 1170.5, etc.) are available for the selection of TH to perform NLTHA of structures. The artificial, recorded, or simulated TH's can be used directly or after making them compatible with the target spectra to perform NLTHA. Aiming to the scope of present work, SCTH's are used for further analysis. Initially, three ground motions are selected from Pacific Earthquake Engineering Research Center (PEER) database matching to type-II (medium) soil type response spectra of Indian seismic code. The details of ground motions are given in Table 1. Further, two sets of TH records are obtained using the SEISMOMATCH [29] tool, in which the first set (further referred to as set-1) comprises of 3 SCTH matched to the Indian seismic code design spectra (ISCDS) [1]. The second set (further referred to as set-2) comprises of 3 SCTH matched to the SSERS. The compatible spectra of selected TH's along with the original record spectra are shown in Fig. 4.

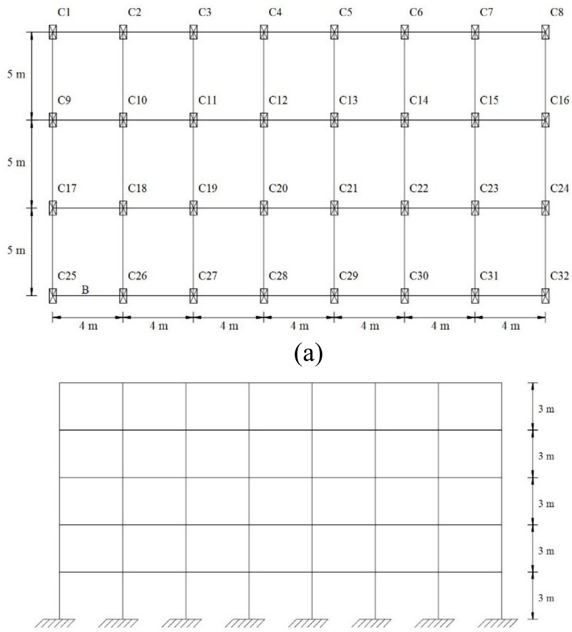
7. Building Specification

Deoda et al. [30] did the seismic analysis of precast and monolithic RC buildings, considering the effect of foundation flexibility. They have considered a total of 6 basic models of the 5-storey building (comprising of rigid and flexible buildings) in their analysis. In the present work, two models viz. Model 1 and Model 6 of Deoda et al. [30] are considered for further analysis. Model 1 (which will further refer to MRC building) is a 5-storey monolithic (rigid) building designed for 0.36 g PGA with a response reduction factor (R) as 5. Model 6 (which will further refer to PRC building) is a 5-storey precast (flexible) building designed for 0.36 g PGA with response reduction factor (R) as 3. The considered building has a rectangular plan dimension of 28 m × 15 m and the plan and elevation of building are shown in Fig. 5. The height of storey is 3 m and is constant for all the floors. Thickness of slab at all the floors is assumed to be 150 mm. The grade of concrete used is M 25 and grade of steel is Fe 415 for both the buildings. Both the buildings are analyzed using the linear dynamic procedure (response spectrum analysis) of Indian seismic code and designed for critical load combination according to the provisions of Indian standards [1,31,32]. Further, NLTHA is performed for both the aforementioned buildings using SAP 2000 [33] software.

8. Results and Discussion

Initially, modal analysis is performed on both the considered building models, and the results are tabulated in Table 2. It is observed that the fundamental period (T_x) of MRC and PRC building is 1.52 sec and 1.87 sec, respectively. The period in the transverse direction (T_y) is 1.39 sec and 1.79 sec for MRC and PRC building, respectively. This increase in the period of PRC building in both the seismic direction shows that the local flexibility in the connections makes the PRC building globally flexible.

Further, nonlinear time history analysis of both the buildings are performed for all the six TH's (as shown in Table 1). The seismic performance of both buildings is evaluated on the basis of lateral displacement and energy dissipation. The lateral displacement time history at the roof of MRC and PRC buildings are shown in Fig. 6 and 7, respectively. It can be observed that the maximum expected displacement at the roof of MRC building due to ISCDS compatible ground motions is found to be in the range of 0.19 – 0.22 m (Fig. 6a). However, due to SSERS compatible ground motions, the peak displacements are 0.83 m, 1.05 m and 1.35 m due to TH-6, TH-4 and TH-5 ground motions, respectively (Fig. 6b). Similar results are observed in the case of seismic response of PRC building. The maximum roof displacement due to ISCDS compatible ground motions is found to be in the range of 0.33 – 0.37 m (Fig. 7a). However, due to SSERS compatible ground motions, the displacements are 1.49 m, 1.65 m and 2.32 m due to TH-6, TH-4 and TH-5 ground motions, respectively (Fig. 7b). The mean lateral displacement at the roof of the MRC building is found to be 0.21 m and 1.08 m for ISCDS and SSERS compatible ground motions, respectively (as shown in Fig. 8a). The mean lateral displacement at the roof of PRC building is found to be 0.34 m and 1.82 m for Indian code and SSERS compatible ground motions, respectively (as shown in Fig. 8b). The expected maximum displacements due to SSERS compatible ground motions at the roof of the PRC building are very large and during which the building gets collapsed. Therefore, the absence of site-specific spectra at special sites results in the conservative design of the structure and predicts less damage.

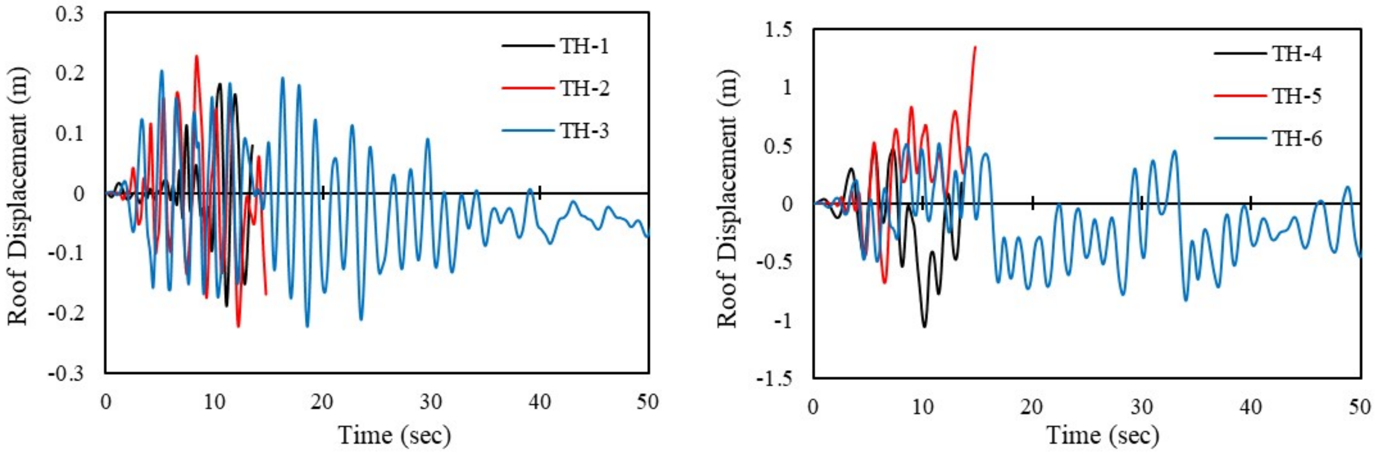


(a)

(b)

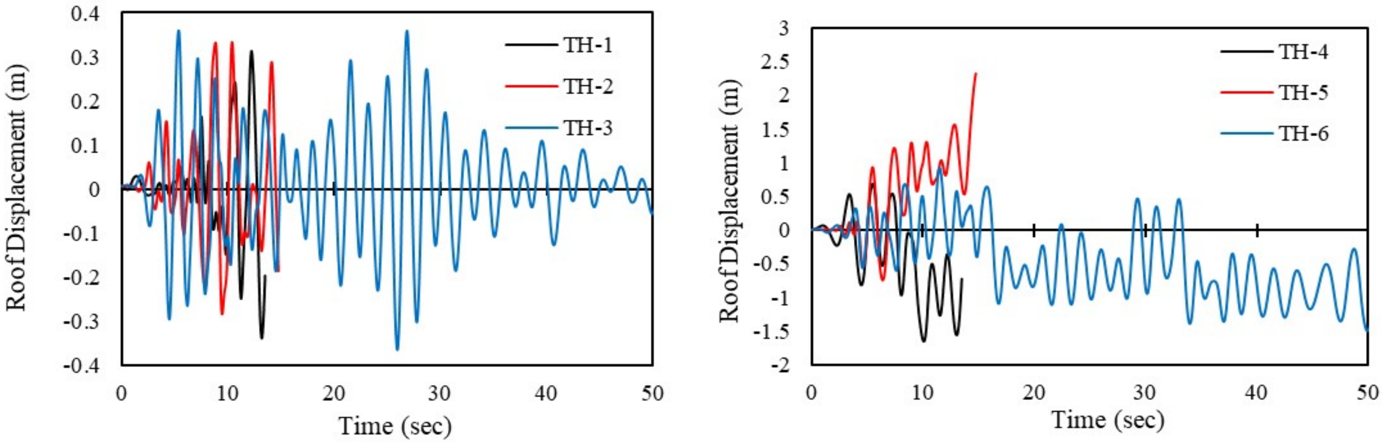
Fig. 5: (a) Plan and (b) elevation of considered 5-storey building

Hysteretic energy is also an indicator of damage in the nonlinear seismic performance of structures. High hysteretic energy will result in severe earthquake damage in the absence of an energy-dissipating device during the inelastic response. The total input energy imparted by all the considered ground motions and their respective energy dissipation by both the buildings are shown in Table 3. Also, the hysteretic envelope (plot of base shear versus roof displacement) is plotted for both the buildings viz. MRC and PRC building and are shown in Fig. 9 and Fig. 10, respectively. From Table 3, it can be observed that the energy dissipation in MRC building is approximately equal to 30% when subjected to ISCDS compatible ground motions; however, the same is greater than 65% when subjected to SSERS compatible ground motions. This shows that the analysis using SSERS compatible ground motions predicts very lesser damage as compared to ISCDS compatible ground motions. This is the case of MRC building which is very common in design practice; moreover, to see the performance of other RC buildings, flexible (precast) building, i.e., PRC building, is also considered. From Table 3, it is observed that ISCDS compatible ground motions don't affect the PRC building and shows negligible damage. One of the reasons is that the main focus in the design of precast RC building is on joint strength. The higher the joint strength higher will be the resistance towards earthquake damage. So that's why the calculated earthquake forces using Indian code spectra are less than the joint strength of PRC building; therefore, it is showing 0% energy dissipation in Table 3. Furthermore, in the case of SSERS compatible ground motions, the energy dissipation is greater than 50% for PRC building. This shows that the site-specific study is important for the seismic performance of structures.



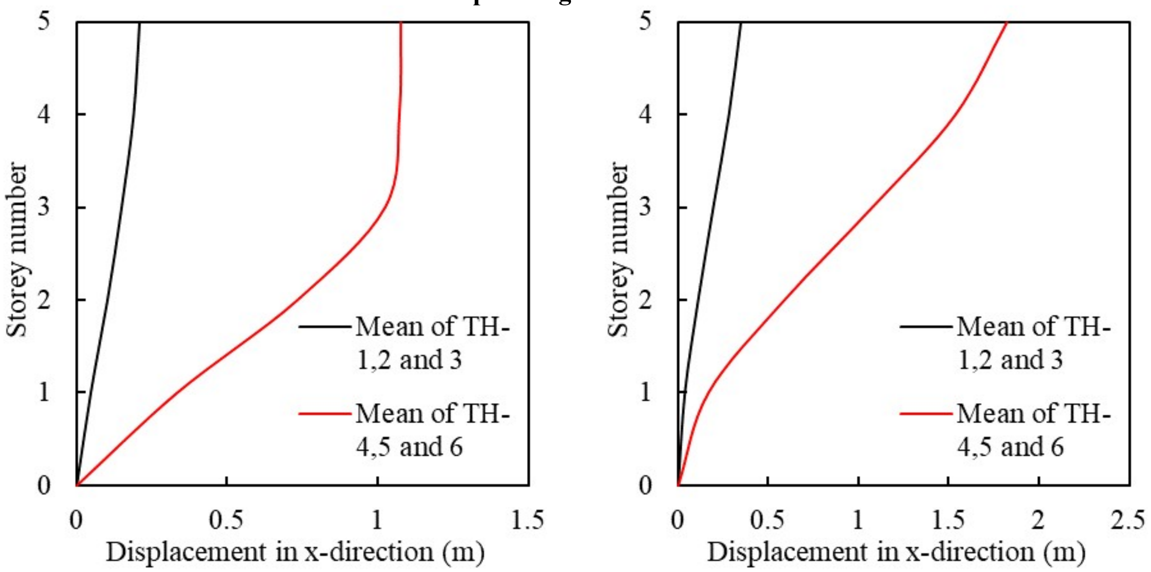
(a) (b)

Fig. 6: Displacement time histories at the roof of MRC building for (a) ISCDS compatible ground motions and (b) SSERS compatible ground motions



(a) (b)

Fig. 7: Displacement time histories at the roof of PRC building for (a) ISCDS compatible ground motions and (b) SSERS compatible ground motions



(a) (b)

Fig. 8: Mean of lateral displacement of both set of ground motions for (a) MRC and (b) PRC building

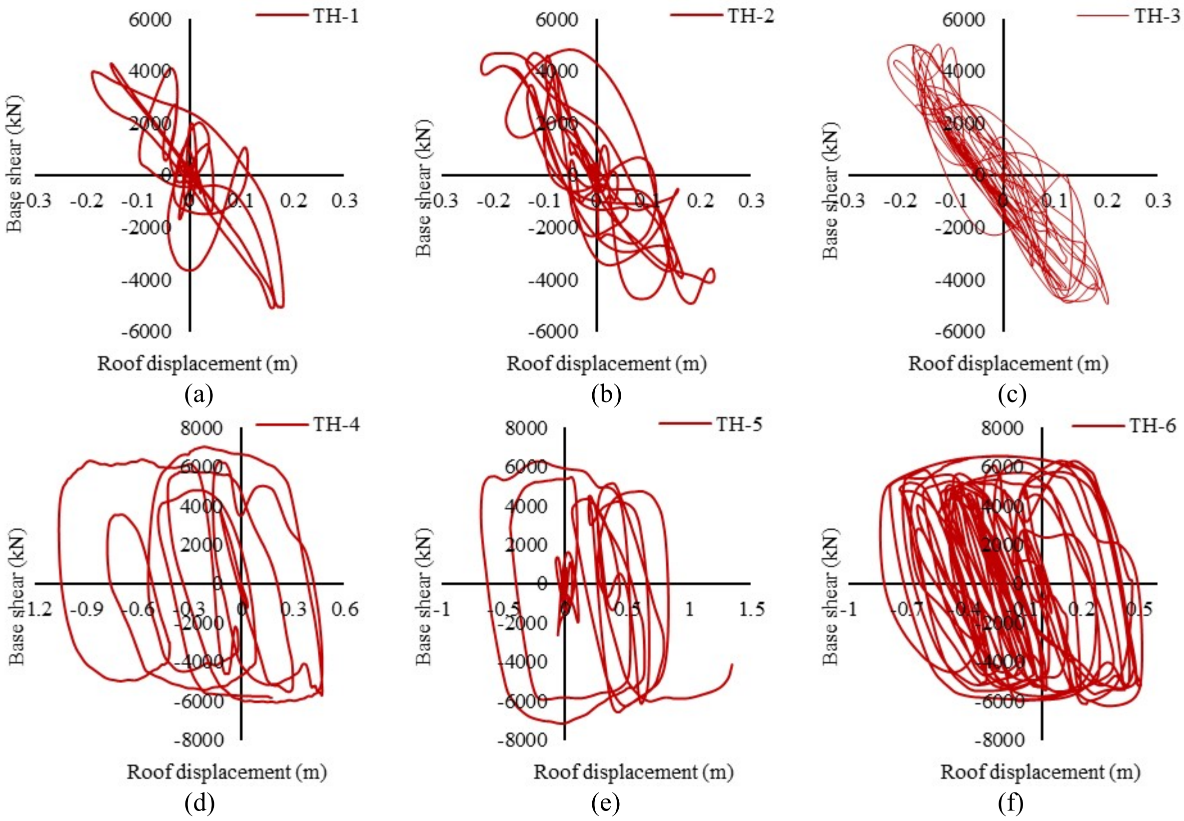


Fig. 9: Hysteretic envelope of MRC building subjected to (a) TH-1, (b) TH-2, (c) TH-3, (d) TH-4, (e) TH-5 and (f) TH-6 ground motions

Table 2: Modal analysis results

Buildings	Period in longitudinal direction (T_x)	Period in transverse direction (T_y)
MRC	1.52	1.39
PRC	1.87	1.79

Table 3: Input energy and energy dissipation of both the buildings subjected to selected ground motions

Sr. No.		Ground Motions	MRC building			Building-2		
			Input Energy (kN-m)	Hysteretic Energy (kN-m)	Plastic Energy Dissipated (%)	Input Energy (kN-m)	Hysteretic Energy (kN-m)	Plastic Energy Dissipated (%)
1	ISCDS compatible (set-1)	TH-1	1249	361	28.90	1385	0	0.00
2		TH-2	1949	580	29.76	1780	3.91	0.22
3		TH-3	3481	1112	31.94	2915	0	0.00
4	SSERS compatible (set-2)	TH-4	28408	19193	67.56	32334	18486	57.17
5		TH-5	29185	20517	70.30	30392	18991	62.49
6		TH-6	65833	48160	73.15	64465	38090	59.09

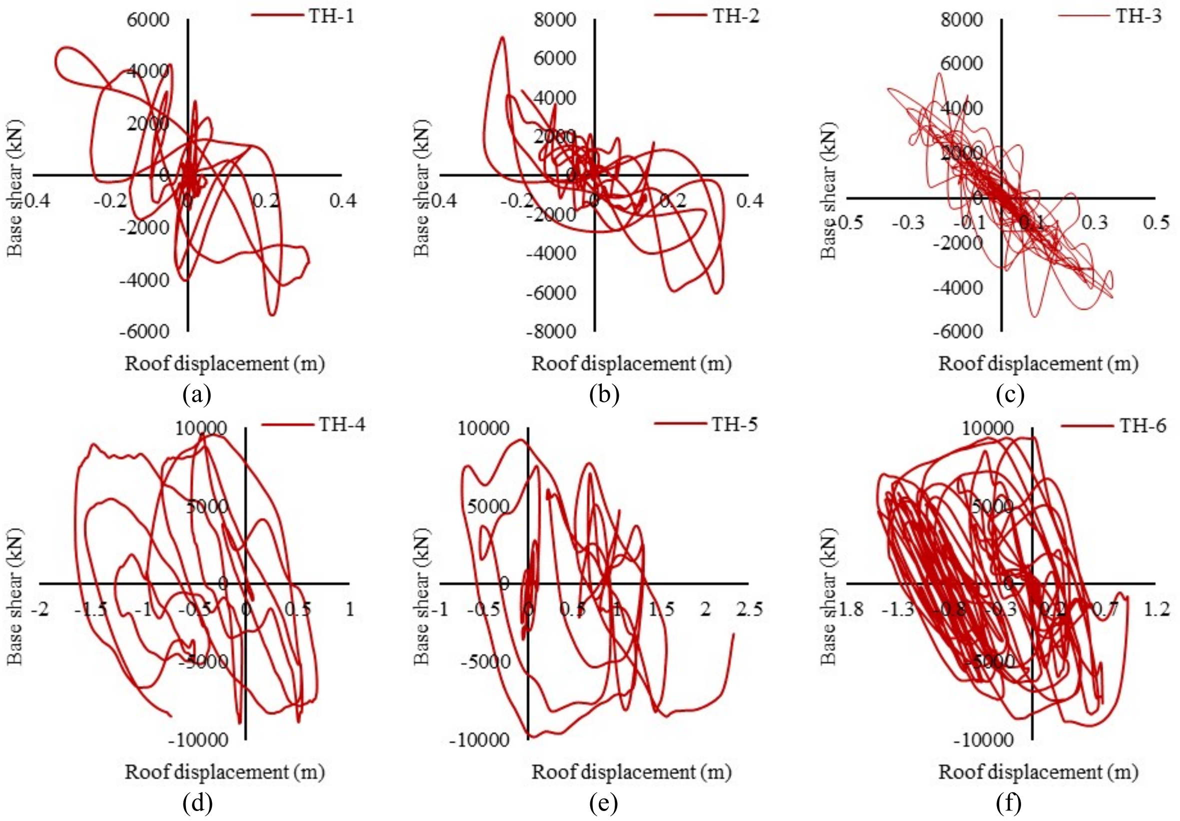


Fig. 10: Hysteretic envelope of PRC building subjected to (a) TH-1, (b) TH-2, (c) TH-3, (d) TH-4, (e) TH-5 and (f) TH-6 ground motions

9. Conclusions

In the present study, the seismic response of a rigid and flexible RC building is assessed by performing NLTHA. Two 5-storey buildings viz. MRC and PRC buildings are considered and the nonlinear results are compared for the ground motions compatible with ISCDS [1] and SSERS [26]. From the modal analysis results, it is observed that the local flexibility in the connection makes the PRC building globally flexible which can be witnessed from the larger period of PRC building as compared to the MRC building. The results of the nonlinear analysis are presented in the form of peak roof lateral displacement time histories of both the buildings and energy dissipation due to earthquakes. It is observed that ground motions compatible with ISCDS predict lesser displacement for both MRC and PRC buildings as compared to SSERS. In SSERS, the consideration of actual site and the dynamic site properties shoot the peak ground acceleration (PGA) and results in larger forces which will propagate in larger displacements. The Indian code spectrum is based on the large earthquake database and is categorized into only three soil classes and the absence of amplification of PGA due to soil results in lesser forces. It is interesting to note that when the energy dissipation in the structure is evaluated for ISCDS compatible time histories, the damage in PRC building is negligible as compared to MRC building. Moreover, for SSERS compatible time histories, the damage in both the buildings are comparable. The results of ground motions compatible with SSERS are found to be realistic as SSERS considers the site period which is used to avoid resonance and also considers the amplification of PGA due to soil. The results show the importance of site-specific study and its response on the structure behavior.

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Disclosures

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References

1. IS 1893(1). *Criteria for Earthquake Resistant Design of Structures*. Bureau of Indian Standards, New Dehli; 2016.

2. Adhikary S, Singh Y. Limitations of Soil Amplification Provisions in the 2002 Indian Seismic

Code. *Journal of Earthquake Engineering* 2012; **16**(1): 1–14. DOI: 10.1080/13632469.2011.594485.

3. Ranjan R. Seismic Response Analysis of Dehradun City, India. Indian Institute of Remote Sensing, National Remote Sensing Agency (NRSA), 2005.

4. Mahajan AK, Slob S, Ranjan R, Sporry R, van Westen CJ. Seismic microzonation of Dehradun City using geophysical and geotechnical characteristics in the upper 30 m of soil column. *Journal of Seismology* 2007; **11**(4): 355–370.

5. Govindaraju L, Bhattacharya S. Site response studies for seismic hazard analysis of Kolkata city. *The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG)*, 2008.

6. Paul S, Dey AK. Dynamic Properties and Ground Response Analysis of Silchar Soil in North-East India. *Indian Geotechnical Journal* 2008; **38**(4): 393–412.

7. Boominathan A, Dodagoudar GR, Suganthi A, Maheswari R. Seismic hazard assessment of Chennai city considering local site effects. *Journal of Earth System Science* 2008; **117**(S2): 853–863. DOI: 10.1007/s12040-008-0072-4.

8. Sitharam TG, Anbazhagan P. Seismic hazard analysis for the Bangalore region. *Natural Hazards* 2007; **40**(2): 261–278. DOI: 10.1007/s11069-006-0012-z.

9. Raghukanth STG, Dixit J, Dash SK. Esimation of Site Amplification Factors for Guwahati City. *Proceedings of Indian Geotechnical Conference*, Guntur, India: 2009.

10. Phanikanth VS, Choudhury D, Reddy GR. Equivalent-linear seismic ground response analysis of some typical sites in Mumbai. *Geotechnical and Geological Engineering* 2011; **29**(6): 1109–1126. DOI: 10.1007/s10706-011-9443-8.

11. Chandrasekaran SS, Bharadwaja SG, Bharathi P, Dutt HH. Seismic ground response analysis for a site in Coimbatore. *Proc., ISET Golden Jubilee Symp*, 2012.

12. Shukla J, Choudhury D. Seismic hazard and site-specific ground motion for typical ports of Gujarat. *Natural Hazards* 2012; **60**(2): 541–565. DOI: 10.1007/s11069-011-0042-z.

13. Jain S, Gupta ID. Investigation of commonly used theoretical methods for modelling of soil amplification effects. *ISET Golden Jubilee Symposium Indian Society of Earthquake Technology*, Roorkee: 2012. DOI: 10.13140/RG.2.1.1849.5848.

14. Jishnu R., Naik SP, Patra NR, Malik JN. Ground response analysis of Kanpur soil along Indo-Gangetic Plains. *Soil Dynamics and Earthquake Engineering* 2013; **51**: 47–57. DOI: 10.1016/j.soildyn.2013.04.001.

15. Sitharam TG, Kumar A, Anbazhagan P. Comprehensive Seismic Microzonation of Lucknow City With Detailed Geotechnical and Deep Site Response Studies. *Proceedings of Indian Geotechnical Conference*, Roorkee: 2013.

16. Mandal HS, Khan PK, Shukla AK. Soil responses near Delhi ridge and adjacent regions in Greater Delhi during incidence of a local earthquake. *Natural Hazards* 2014; **70**(1): 93–118. DOI: 10.1007/s11069-012-0098-4.

17. Kumar SS, Dey A, Krishna AM. Equivalent linear and nonlinear ground response analysis of two typical sites at Guwahati city. *Indian Geotechnical Conference*, Kakinada, India: 2014.

18. Naik NP, Choudhury D. Comparative study of seismic ground responses using DEEPSOIL, SHAKE, and D-MOD for soils of Goa, India. *Geo-Congress 2014*, 2014. DOI: 10.1061/9780784413272.107.

19. Desai SS, Choudhury D. Site-specific seismic ground response study for nuclear power plants and ports in Mumbai. *Natural Hazards Review* 2015; **16**(4): 04015002. DOI: 10.1061/(ASCE)NH.1527-6996.0000177.

20. Elayaraja S, Chandrasekaran SS, Ganapathy GP. Evaluation of seismic hazard and potential of earthquake-induced landslides of the Nilgiris, India. *Natural Hazards* 2015; **78**(3): 1997–2015. DOI: 10.1007/s11069-015-1816-5.

21. Pandey B, Jakka RS, Kumar A. Influence of local site conditions on strong ground motion characteristics at Tarai region of Uttarakhand, India. *Natural Hazards* 2016; **81**(2): 1073–1089. DOI: 10.1007/s11069-015-2120-0.

22. Chatterjee K, Choudhury D. Influences of local soil conditions for ground response in Kolkata city during earthquakes. *Proceedings of the National Academy of Sciences, India Section A: Physical Sciences* 2018; **88**(4): 515–528. DOI: 10.1007/s40010-016-0265-1.

23. Chatterjee K. Impact of ground response analysis on seismic behavior and design of piles in Kolkata city. *Indian Geotechnical Journal* 2018; **48**(3): 459–473. DOI: 10.1007/s40098-017-0264-4.

24. Bajaj K, Anbazhagan P. Site Amplification Factors and Acceleration Response Spectra for Shallow Bedrock Sites – Application to Southern India. *Journal of Earthquake Engineering* 2020: 1–21. DOI: 10.1080/13632469.2020.1754308.

25. Kumar A, Haldar S. Design Response Spectra and Site Coefficients for Various Seismic Site Classes of

Guwahati, India, Based on Extensive Ground Response Analyses. *Geotechnical and Geological Engineering* 2020: 1–26. DOI: 10.1007/s10706-020-01434-y.

26. Deoda VR, Adhikary S. A preliminary proposal towards the revision of Indian seismic code considering site classification scheme, amplification factors and response spectra. *Bulletin of Earthquake Engineering* 2020: 1–47.

27. MATLAB R2014a. *The MathWorks, Inc.* Natick, Massachusetts, United States: . DOI: 10.2307/2234838.

28. Hashash YMA, Musgrove MI, Harmon JA, Groholski DR, Phillips CA, Park D. *DEEPSOIL 6.1, User Manual*. 2016.

29. Seismosoft. SeismoMatch: an application capable of adjusting earthquake accelerograms to match a specific target response spectrum 2018.

30. Deoda VR, Adhikary S, Kumar R, Kumbhar OG. New modelling methodology for seismic design of precast structures and performance evaluation considering soil--foundation system. *Arabian Journal for Science and Engineering* 2019; **44**(10): 8305–8324.

31. IS 13920. *Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice*. Bureau of Indian Standards, New Dehli; 2016.

32. IS 456. *Plain and Reinforced Concrete- Code of Practice*. Bureau of Indian Standards, New Dehli; 2000.

33. SAP2000. *Structural analysis program, Ver.14.2.4*. Computers and Structures, Inc., Berkeley, California, USA; 2011.