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SEISMIC PROTECTION OF NON-STRUCTURAL ELEMENTS IN RC BUILDINGS

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Abstract

Seismic performance of Non-structural elements (NSEs) is a very crucial aspect in the safety of existing and new buildings. Non-structural elements are mainly free standing simply supported objects present in a structure that do not take part in the load-resistance. It has been observed from the past earthquakes that critical buildings such ass hospitals and fire stations, etc have suffered significant losses in the NSEs after an earthquake, thus hampering their usage post seismic event. During an earthquake, ground accelerations are the input at the base of a structure, which would thus lead to different accelerations at various floor levels and these floor accelerations are the input at the base of these non-structural elements. Hence, the study of floor accelerations is of prime importance to keep their functional requirement intact after a seismic event. This study deals with the development of floor response spectra and the variation of peak floor accelerations (PFA) along the height of RC framed building with varying plan shapes. Special Moment Resisting frame buildings in Seismic Zone V, importance factor of 1.5 in medium stiff soil. All the configurations have been subjected to fourteen recorded near-field ground motions. Linear Time history analysis has been performed in ETABS 2017. From the study of the above configurations, it has been observed that the variation in the Peak floor acceleration along with height is not linear as mentioned by many of the international standards (ASCE7-10, EC 8-2004). No definite trend in the variation of PFA is observed in the study. There is a significant amount of contribution in the higher modes and this contribution is more prominent in the lower stories.

Keywords: Non-structural elements, floor response spectra, near field, FEMAP695.

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1. INTRODUCTION

Nowadays in almost every structure 60-70% of the total construction cost of new buildings in urban India is of the non-structural elements (NSEs). Even if the structure is safe post a seismic event, person's safety may be at risk by the lack of safety in the building's items that directly cater to human needs. Building safety during earthquakes has gotten a lot of attention, but the safety of NSEs has attracted minimal attention. It has been evident from the past earthquakes that there is significant damage to the operational and the architectural equipments of a structure during the earthquake. Generally, in critical structures, functionality of the non-structural elements is at risk due to improper seismic assessment of these elements. Still, there are very few countries that have seismic design provisions for the safety of NSEs against earthquakes. This tells us that lessons are still not learnt worldwide from the losses that have occurred due to NSEs failure during previous seismic events. In most of the countries the losses due to the failure of the buildings and structures is so extreme that NSEs haven't been able to receive the much-needed attention. To satisfy the architectural demands the buildings are more often than not, irregular. The layout and type of structural elements of any building have a significant impact on its reaction. One of the major things affecting the response as a whole is the configuration of the structure. A building subjected to ground motion has the resultant acceleration different at its various floor levels and acceleration at a specific floor level is the input at base of NSEs kept on that floor level just like the ground accelerations due to an earthquake are the input at the base of building as shown in the Fig 1.1. Thus, by this we can conclude that identical NSEs kept on different floor levels experience different acceleration at their base, so the study of output acceleration at various floor levels is very important for the safe design of NSEs. NSEs are basically classified into three categories, namely 1)- Acceleration-sensitive, 2)- Displacement- sensitive 3)-Acceleration-displacement sensitive.

Acceleration sensitive NSEs oscillate during earthquake shaking and if they are not properly localized in a building and if the seismic assessment is not done, then it could lead to its damage which in turn would risk the life of the occupants in the building. Thus, its necessary to study the acceleration response of the buildings for safeguarding the non-structural elements in a structure.

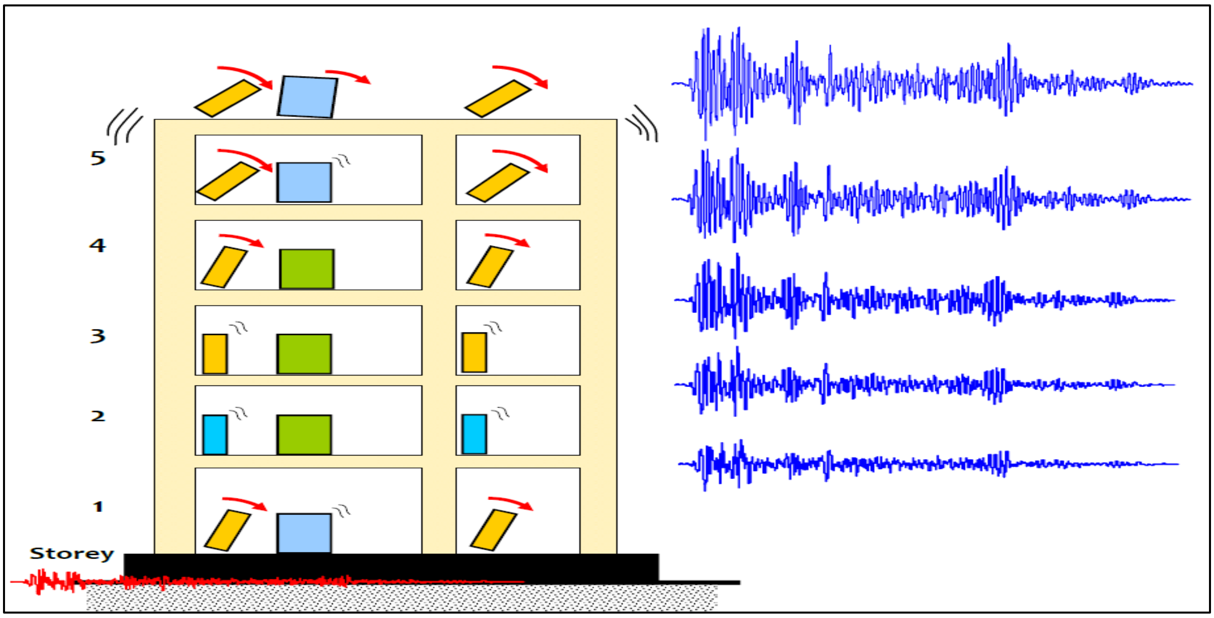

Figure 1. 1 Variation of Floor accelerations in a building (Murty, et al. 2012)

2. Literature Review

Previous earthquakes have shown that there is significant damage to the operational equipments of the structure. In many cases it is noted that there is minimum loss to the structure but the critical equipments have undergone irreparable damage. In USA, the financial losses due to the failure of non-structural components (NSEs) during a seismic event is alone US$2-0-4.5 billion per year over the past three decades (Murty,2012). Equipment failure especially in critical lifeline structures such as hospitals, fire stations can critically affect the performance and also put the life of patients in severe danger in the hospitals. Several prominent hospitals were evacuated during the 1994 Northridge earthquake, not only due to structural damage, but also due to the breakdown of power systems, air-conditioning units, ceilings, and light fixtures. The Saguenay earthquake in 1988 which was one of the strongest events to be recorded within the last 50 years in the eastern North America, caused almost no structural damage but the NSE damage was immense (M. Saatcioglu 2008). It is a fact that maximum injuries, damage to property and financial losses are caused by the damage of the operational and functional components (OFC) in buildings. If in hospital oxygen cylinders topple as happened in 1971 San Fernando earthquake as shown in Fig 2.1 and their pipelines to operation theatres and wards were broken, it could lead to secondary hazards i.e., damage to one element can lead to yet another disaster which would involve the safety of the people's live and the building contents occurred. During the 1971 San Fernando earthquake there was chemical spill in a laboratory which caused huge loss of life. Furthermore, suppose the X-ray machine topples during a seismic event, sensitive parts inside would become useless after the earthquake, and its function to provide the most essential services would be affected, not to mention the human and financial loss that would occur as a result. The seismic fragility of NSEs mounted on hillside buildings was recently exposed by the SIKKIM earthquake, which resulted in considerable damage to hospital equipments thus, halting medical services (Report 2012). In many cases, the financial losses because of the damage of NSEs has even exceeded the cost that would be required to replace the building (EERI, 1984).

Figure 2. 1 Gas cylinders toppling during San Fernando Earthquake (1971) (Rupen and CVR 2012)

3. Objectives and Methodology

Based on the review of limited literature, the objective is to study the effect of various ground motions on building with varying configurations and perform a comparative study of the floor response spectra of these buildings.

The methodology is worked out to achieve the objectives mentioned above and for such purpose bi-directional linear time history analysis is performed on a finite element software package ETABS-2017. Time history analysis is a step-by-step study of a structure's response to a dynamic loading that varies over time. In this method the seismic response of a building is determined using recorded ground motions from a representative earthquake. Time history analysis is based on the appropriate recorded ground motion that is compatible with the design acceleration spectrum for a defined natural period and is carried out using the accepted principles of earthquake structural dynamics (1893 2016). In the present study a set of G+6 buildings with different structural configurations namely moment resisting frames, flat slab buildings, T-shaped buildings, L-shaped buildings, Y-shaped buildings along with a building on sloping ground has been considered. The peak floor acceleration values and the floor response spectra has been noted and developed respectively and compared for all the above cases. To investigate the floor response linear bi-directional time history analysis is performed using the suite of 14 near field recorded ground motions obtained from FEMA P695. Floor response spectrum is an acceleration time history of a particular floor at a particular damping. It shows the greatest acceleration experienced by the NSEs versus their natural time period. It is obtained when number of NSEs with varying natural time periods but having similar damping are subjected to the similar accelerations at that floor. This eliminates the need for each NSE to undergo dynamic analysis.

4. Results and Discussions

The variation in the plan shapes could lead to significant variation in the mode shapes of the structure especially in T-shaped building where in the fundamental mode shape torsion comes along with translation. The peak floor acceleration values are more in L-shaped building as compared to T-shaped building. The maximum values are in the Y-direction as compared to X-direction for both the buildings. The mode shapes for the considered buildings are shown below: -

Mode	T-shaped	L-shaped	Y-shaped
1	X-translation with torsion	X-translation	Torsion
2	Y-translation with torsion	Y-translation	X-translation
3	Torsion	Torsion	Y-translation

Table 4. 1 Mode shapes of T, L and Y-shaped buildings

When there is a lack of symmetry in the plan shape of structures along the sides, certain undesired (diagonal translation and torsional) modes emerge. In typical buildings, the first few modes of oscillation determine the total motion; the fundamental mode (corresponding to the biggest natural period) usually contributes the most, followed by the second mode, third mode, and so on. In the above buildings with irregular plan shapes both T and Y shaped buildings are experiencing torsion in their fundamental mode itself. So, there is high amount of stress concentration which could lead to structural damage and in turn affect the safety of NSEs.

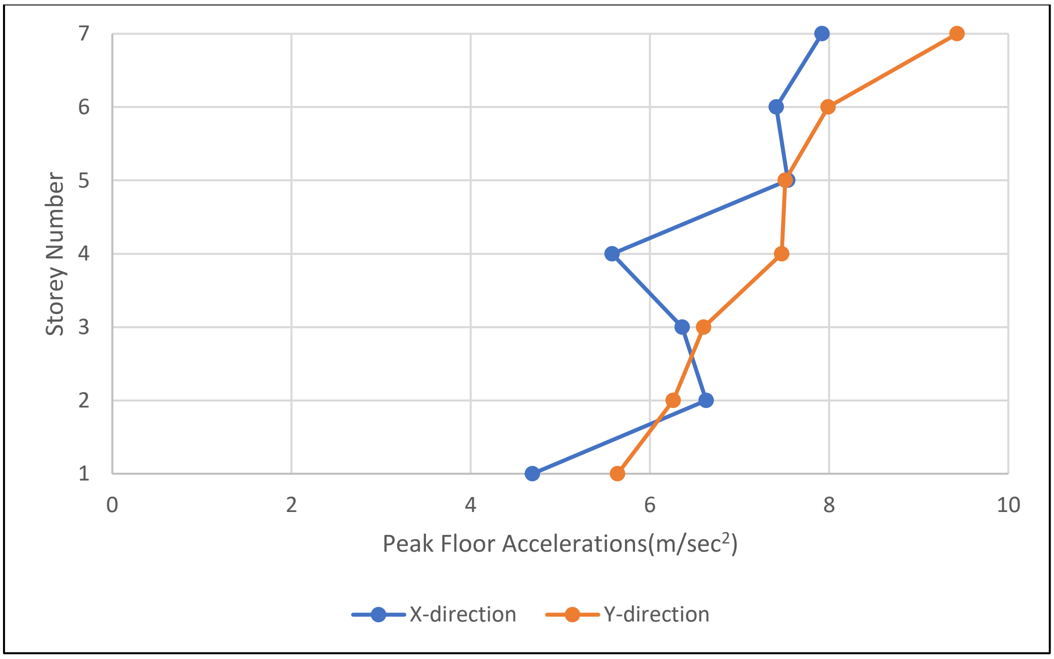

Fig 4. 1 PFA vs Storey No for T shaped building

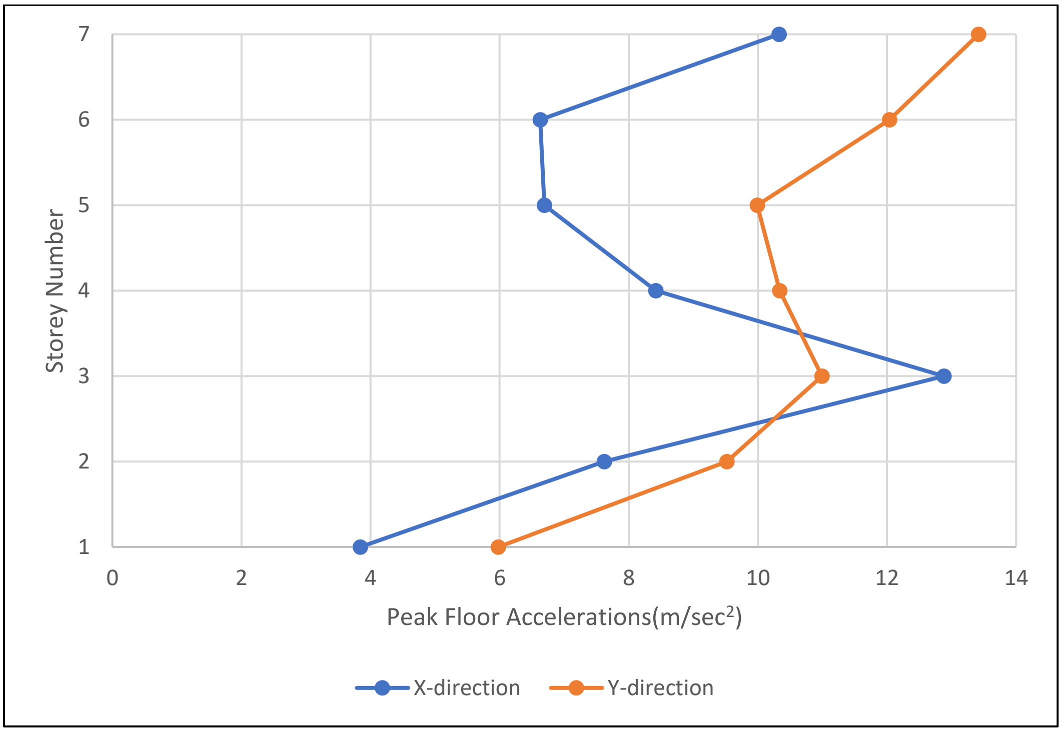

Fig 4. 2 PFA vs Storey No for L shaped building

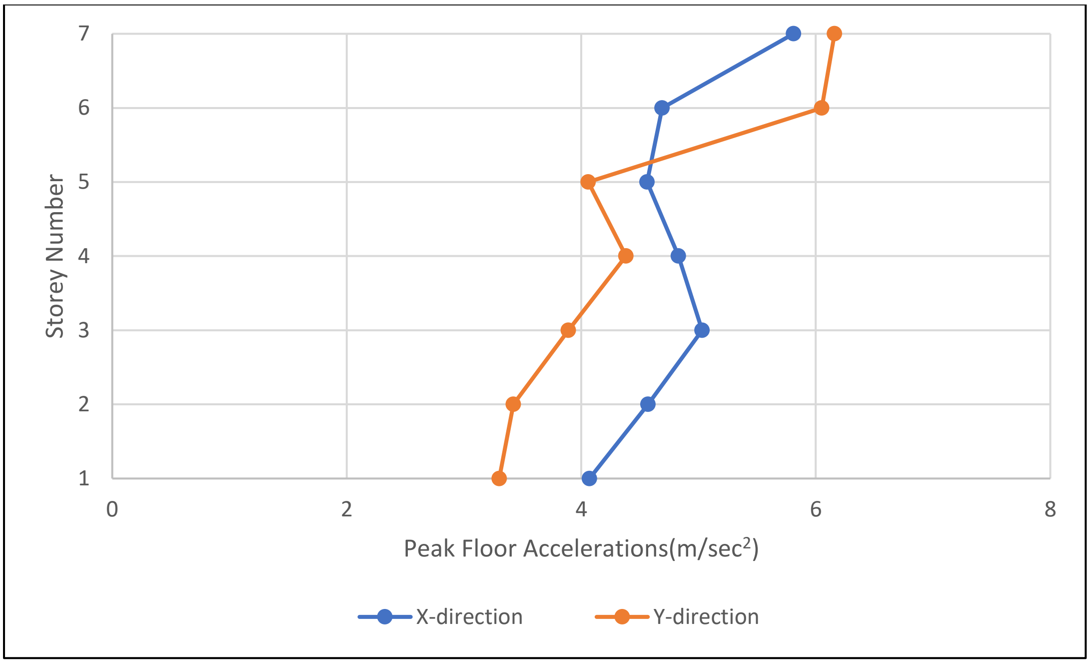

Fig 4. 3 PFA vs Storey No for Y shaped building

The floor response spectra for T, L and Y shaped buildings are shown in the Fig 4.4-Fig 4.6 respectively. It can be observed from the floor response spectra of L-shaped building that the elastic spectral acceleration corresponding to the fundamental time period(T_1) is higher than that for the next two time periods (T_2 and T_3) for the story 7. For story 7 in T-shaped building there is not much of major difference between the elastic spectral acceleration of the first two time periods whereas when comparing the spectral accelerations for both T and L shaped buildings for story 7, T shaped plan experiences more accelerations at the story 7. For the story 5, there is not much of major difference between the floor accelerations for the first two natural periods in L-shaped buildings whereas for T-shaped building the second and the third time periods give more floor accelerations when compared to the fundamental time period. For the story 3 the elastic spectral accelerations are greater for the T-shaped building as compared to L-shaped building. The contribution of higher modes is more prominent in the story 3 and story 1 for L-shaped building as compared to T-shaped building.

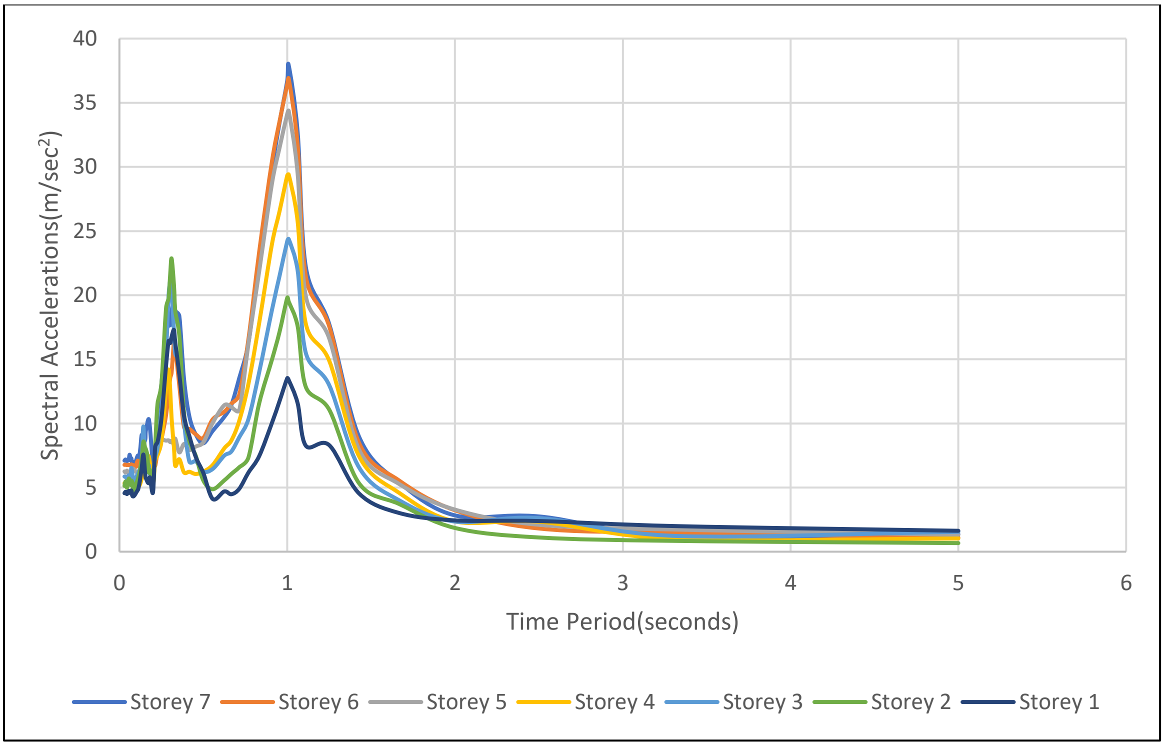

Fig 4. 4 Floor Response Spectra of T shaped Building

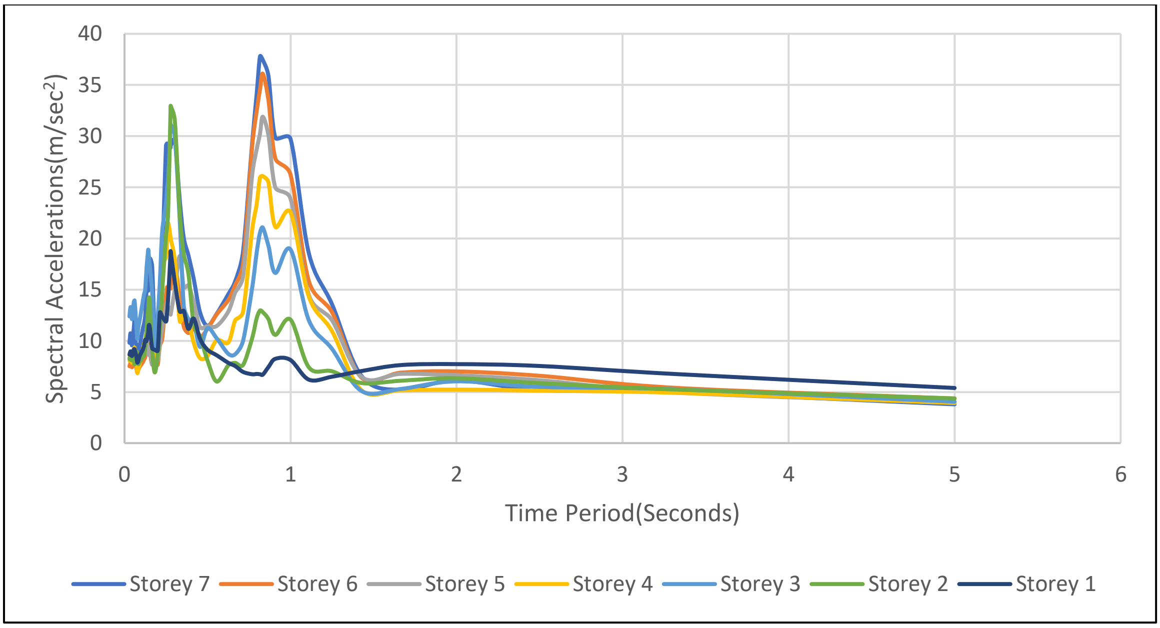

Fig 4. 5 Floor Response Spectra of L shaped Building

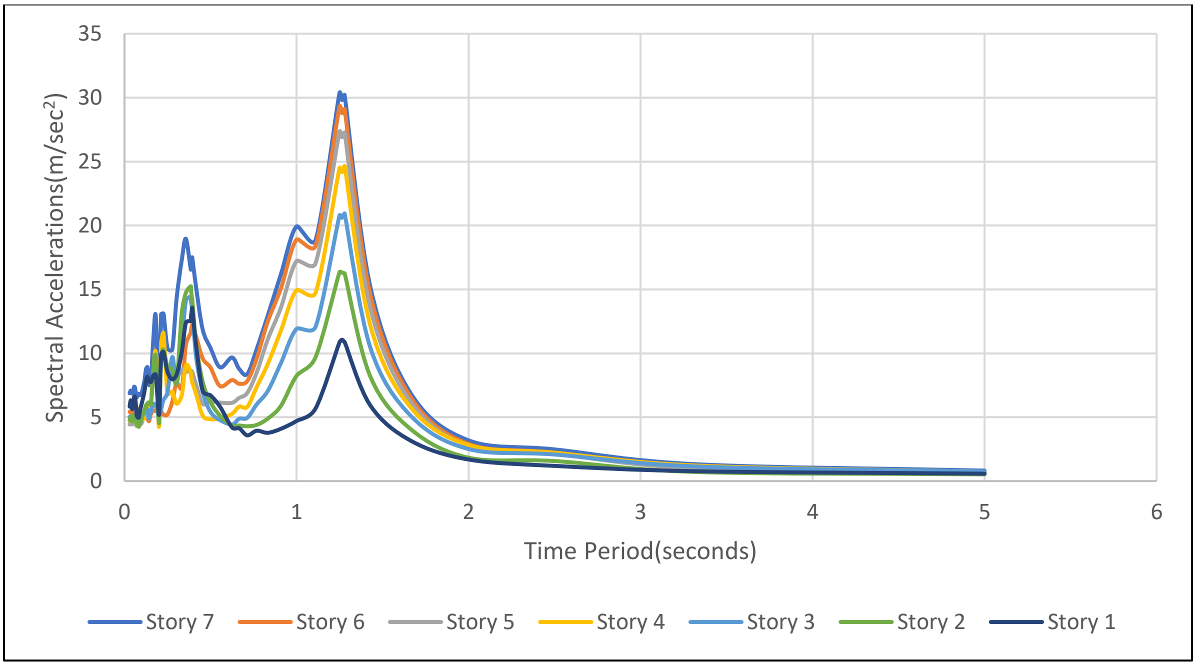

Fig 4. 6 Floor Response Spectra of Y shaped Building

5. CONCLUSIONS

There is no linear variation of Peak floor accelerations along the storey height as mentioned by most of the international standards (ASCE 7-10 n.d., EC-8 2004, FEMA P750 2009). All the configurations under consideration have shown different variations of PFA along the storey height and no common trend in the variation is drawn. Stability charts are generated in this study in the form of floor response spectra and the variation of PFA for different stories. These stability charts are beneficial for studying the overturning and rocking criteria of NSEs and estimating the maximum floor level of a particular NSE to attain stability in the building. It is noted from the floor response spectra of all the configurations considered that there is significant amount of contribution in the higher modes especially in the lower stories which is maybe due to structural deformability and the different ground motion inputs. It is important to note that the NSEs should not be protected only in case of strong earthquakes but also in case of low moderate ones where the vulnerability of the elements with short vibration periods would come into picture and thus can be a danger for them.

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