2.4 Floor response spectrum

Using Ruaumoko2D program, develop floor response spectrum for 1st floor, 4th floor, 8th floor and 12th floor (Figs. 8-10) by comparing elastic and inelastic analysis results to get a better assessment of the seismic performance of freestanding contents (Vukobratovic 2016). For Kobe, floor response spectral acceleration derived from elastic and inelastic analyses are different at T = 0 where the highest spectral acceleration can be found at 12th floor for elastic analysis while the highest spectral acceleration of inelastic analysis can be seen at 1st floor. Similar to Kobe, elastic floor response spectral acceleration obtained from Imperial Valley is the highest at 1st floor and highest floor response spectral acceleration for inelastic analysis is seen at 12th floor. In contrast, 12th floor response spectral acceleration of Kern County is the highest for both elastic and inelastic analysis. Conclusively, pseudo spectral accelerations of elastic analysis are higher than that of inelastic analysis for all time history records as in Mate (2016).

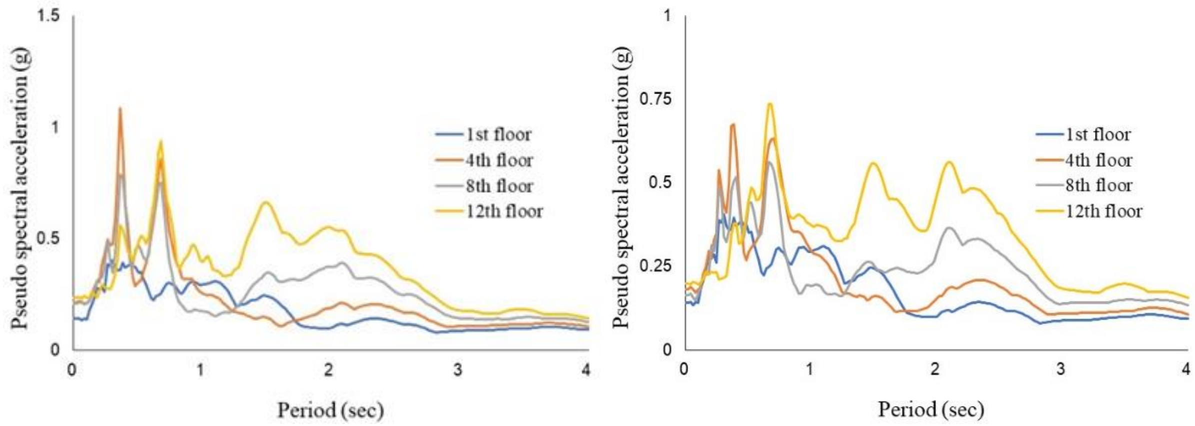


Fig. 8 Elastic and inelastic acceleration floor response spectrum of Kern County

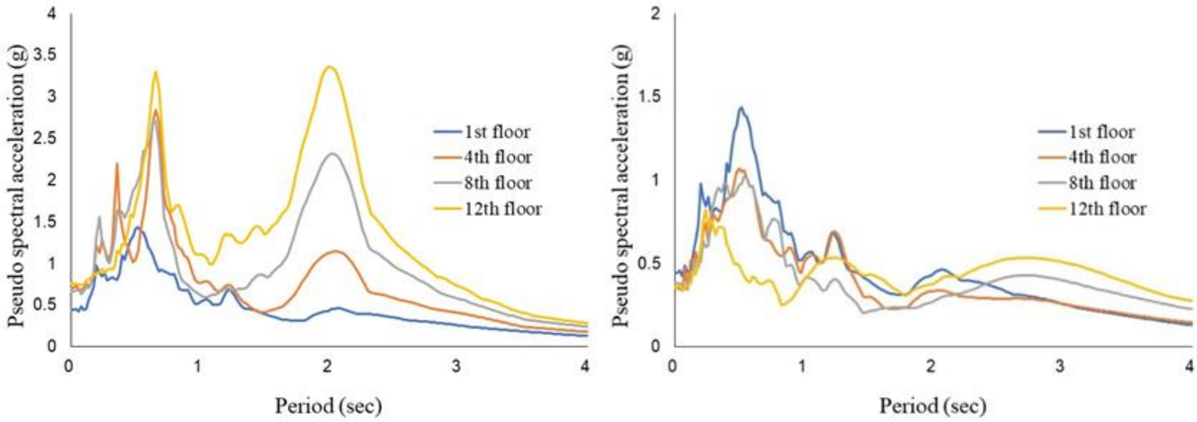


Fig. 9 Elastic and inelastic acceleration floor response spectrum of Imperial Valley

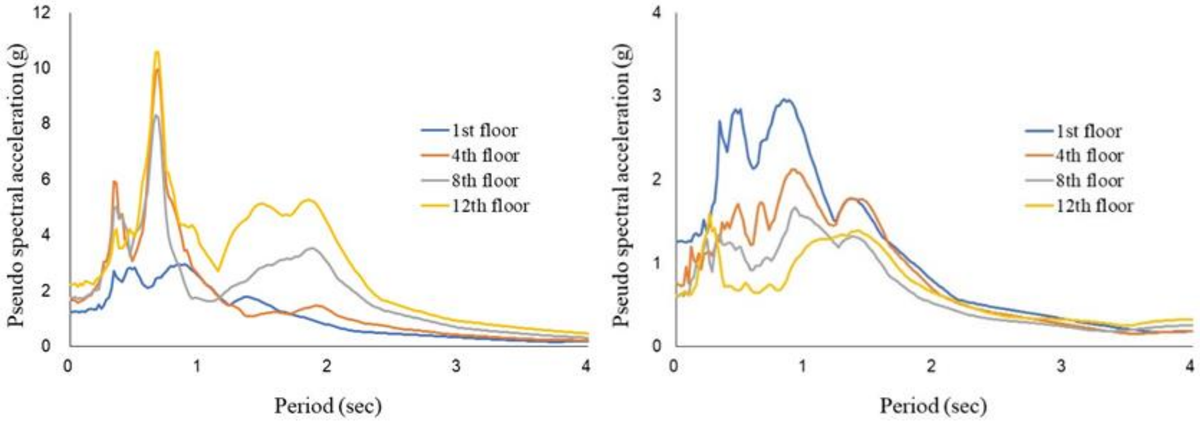
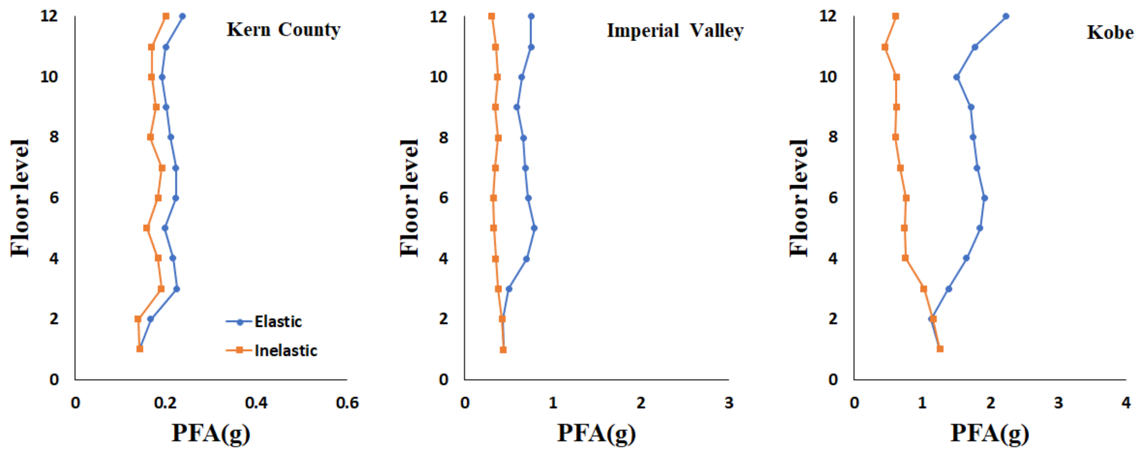


Fig. 10 Elastic and inelastic acceleration floor response spectrum of Kobe

2.5 Peak floor acceleration and velocity

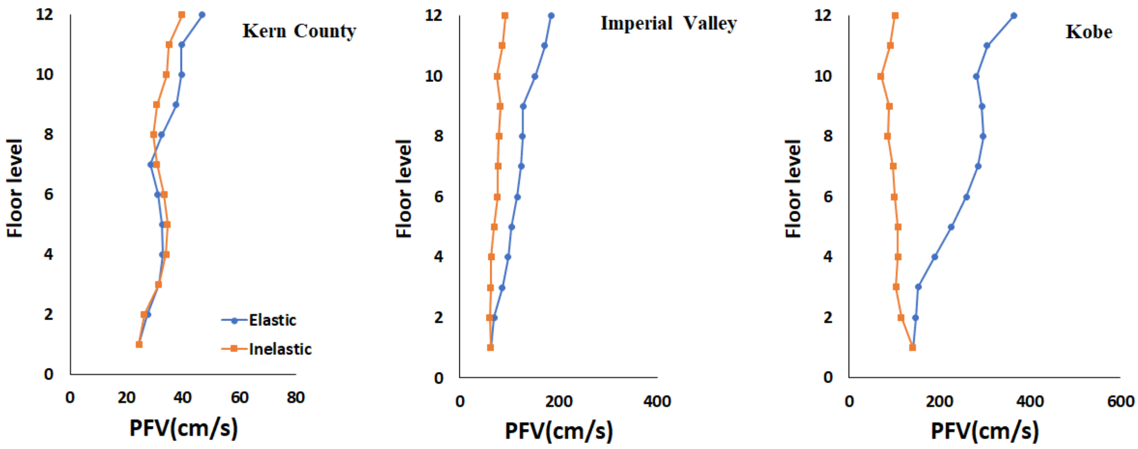
The seismic performance on freestanding contents can be evaluated by geometric parameters of rigid blocks and defined the rigid body motions as sliding, rocking and overturning states. According to Housner (1963), the first investigation of dynamic motion of rigid body, rocking and overturning motion were regarded as assuming no sliding between the base of rigid body and the floor resting on it. Choi (2013) and Lin (2020) stated that peak floor acceleration is the good indicator for describing seismic vulnerability of rigid blocks located at particular floors which lead the excessive damage or even collapse of buildings in some cases.



(a) Kern County (b) Imperial Valley (c) Kobe

Fig. 11 Peak floor acceleration (Elastic and inelastic)

On the other hands, Bommer and Alarcon, J (2006) have studied the researches dealing with seismic vulnerability of buried pipelines and liquefaction assessment which used peak ground velocity (PGV) as a seismic vulnerable indicator of ground strain analysis based on the frequency content measurement. In most cases, PGV was used as damage potential indicator corresponding with intensity and showed that PGV perform well for high intensity cases as compared to PGA.



(a) Kern County (b) Imperial Valley (c) Kobe

Fig. 12 Peak floor velocity (Elastic and inelastic)

To observe the reliable design floor accelerations, the higher modes of vibrations need to be considered (Surana 2019). To develop the stability charts, Ishiyama (1984) is used and investigates the rocking and overturning motions by using the geometric parameters of rigid body and compare it with the different seismic intensity measure (PFA, PFV) obtained from Dynaplot program which is a post-processor for Ruaumoko2D program. Using the input of 3 different time history acceleration records, Dynaplot program outturns peak floor acceleration and peak floor velocity for each node at every floor. The elastic and inelastic analysis results of the ratio of peak floor acceleration and peak floor velocity can be seen in Figs. 11 and 12. The ratio of peak floor accelerations and peak floor velocities obtained from elastic analysis is greater than that obtained from inelastic analysis for all time history records. The highest record of Kobe (2% in 50 years) shows the smallest ratios of peak floor acceleration and peak floor velocity values as compared with Imperial Valley and Kern County since Kobe is high suite obtained from near source record.

3. ISHIYAMA OVERTURNING STABILITY

Ishiyama (1984) analyzed the behavior of the oscillations of rigid blocks through numerous shaking table tests and earthquake excitations and then developed the formulation to assess the rocking and overturning of rigid blocks using geometric parameters B and H which are the horizontal and vertical distance from the center of gravity and overturning edge of freestanding contents as in Fig. 13. In order to develop the stability chart which is an effective tool for representing the safety of freestanding contents is assessed by rocking and overturning conditions of freestanding contents at corresponding floors. The study of Berto (2018) have shown that the response of rigid block is calculated through the formulation of Ishiyama criterion which use two seismic intensity measures: acceleration and velocity respectively when horizontal earthquake acceleration is applied at the base of freestanding contents. The minimum acceleration required to activate the rocking of freestanding contents is calculated by using the Ishiyama overturning criterion $a_{g,c}$ which represents the lower limit of acceleration by geometrical characteristics of freestanding contents as follow:

$$a = \frac{B}{H} g \tag{8}$$

On the other hand, the overturning state of freestanding contents are defined by the lower limit of the maximum velocity which is acquired by equilibrating potential energy of rigid body at rest and kinetic energy released from rotation of rigid block at its base edge. For rectangular and slender freestanding block, the velocity which trigger overturning is equal to:

$$v = 0.4\sqrt{\frac{4gB^2}{3H}} = 14.46\frac{B}{\sqrt{H}}\ (cm/s) \tag{9}$$

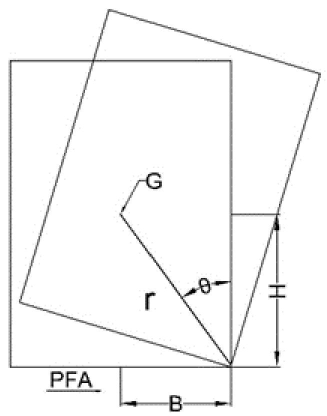


Fig. 13 Geometric parameters of a rectangular rigid block

Various sized of rigid blocks are used to establish overturning stability chart to assess the seismic vulnerability of freestanding elements with respect to B and H as in Fig. 14. According to the study of Pappas (2017), overturning stability chart is developed and shows the rocking limit of freestanding contents calculated by acceleration "a" in blue line. The right portion of acceleration line defines the rocking of freestanding contents but do not start overturning. The minimum velocity "v" required to trigger overturning is defined by orange line which represents the overturning of freestanding contents after excessive rocking. Conclusively, some rigid blocks may be stable without rocking and overturning and also some may rock without overturning but overturned objects may definitely suffer rocking before it.

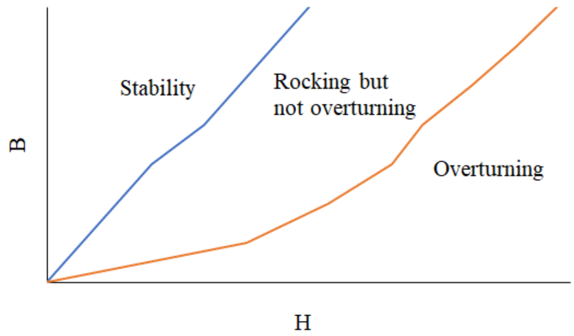


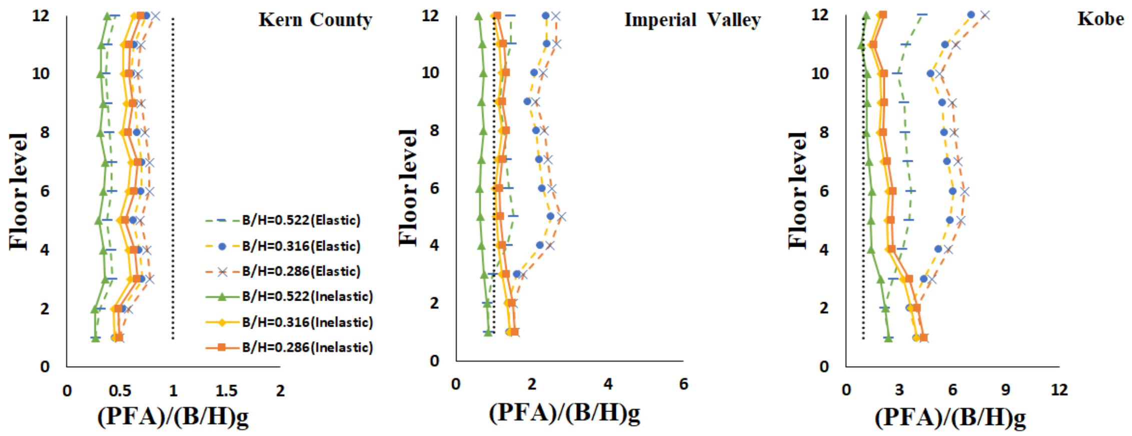
Fig. 14 Ishiyama overturning stability chart for freestanding contents

4. ASSESSMENT RESULTS

The assessment of rocking vulnerability of rigid blocks is effectively evaluated by slenderness ratio of that blocks as in terms of acceleration which induces the rocking state (Ramos 2021). In this paper, the rocking state of freestanding contents at different floors is defined by comparing the lower limit of accelerations computed by Ishiyama criterion in terms of geometric parameters of objects and horizontal peak floor accelerations which excite the base of objects to trigger the rocking. The sizes used for rocking and overturning assessment are taken by considering the common sizes of bookshelves from libraries and then approximately taken as the same B (30cm) with different H as 57.5cm, 95cm and 105cm for rocking and overturning assessment in this study.

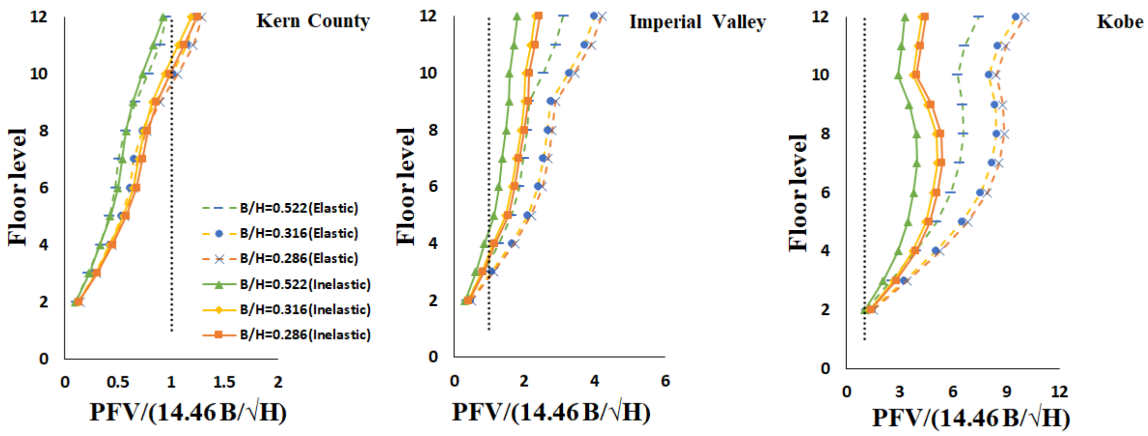
The main concept of this research is comparing seismic demand and seismic capacity to evaluate the rocking state of sample rigid block by comparing the peak accelerations of 1st to 12th floor as seismic demand. Concerning the stability of a freestanding contents, the ratio of PFA should be less than the slenderness ratio derived from Eq. (8). When the critical value of peak floor acceleration divided by (B/H) is equal to or greater than 1, it states that the object initiates rocking. Regarding with the ratio of peak floor acceleration and (B/H)g, it is easy to assess the preliminary rocking state of different freestanding contents and then determine the overturning of freestanding contents with respect to peak floor velocities at different floor levels (Berto 2020).

As in Figs. 15 and 16, free standing elements do not rock under the excitation of Kern County (low suite) for both elastic and inelastic analyses by looking at the ratio of PFA by (B/H)g which is less than 1 but observe that the larger slenderness ratio of 0.316 and 0.522 for both elastic and inelastic case is greater than 1 for overturning chart of Kern County for upper floor levels. Similarly, the slenderness ratio of 0.522 for Imperial Valley (medium suite) do not show rocking but overturn except for lower floor levels of inelastic analysis. Contrastingly, free standing elements rock and overturn for all slenderness ratio of Kobe (high suite) and it shows the realistic motions of rigid blocks among three earthquake excitations. Conclusively, it can be commented that Ishiyama criteria for rocking and overturning is not trustworthy for the reason of seeing the results which shows the overturning of objects without rocking. It is due to the Eq. (8) and (9) which define the acceleration and velocity necessary to trigger rocking and overturning. According to those equations, rocking state influences the slenderness ratio of freestanding elements but overturning state govern B section which is twice as much as H in Eq. (9). The unrelatable relation of those equations lead to unreasonable motions of rigid blocks and seismic response under corresponding earthquake excitations.



(a) Kern County (b) Imperial Valley (c) Kobe

Fig. 15 Rocking assessment chart (Elastic and inelastic)



(a) Kern County (b) Imperial Valley (c) Kobe

Fig. 16 Overturning assessment chart (Elastic and inelastic)

5. CONCLUSIONS

In this paper, seismic vulnerability of freestanding contents is investigated by determining the efficiency of peak floor acceleration (PFA) and peak floor velocity (PFV) as seismic intensity measures and then assess the seismic performance of freestanding contents using their geometric parameters. For this study, 12-story two bay span reinforced concrete building is used to analyze the elastic and inelastic responses of structure under three different intensity levels of earthquake accelerations: Kern County, Imperial Valley and Kobe. Rayleigh or proportional damping and lumped mass matrix are considered for analysis options of Ruaumoko2D program (Carr 2007). By using the output analysis data of Ruaumoko2D program, Dynaplot program plots the floor response spectrum of three time acceleration histories at 1st, 4th, 8th and 12th floor respectively. The pseudo spectral accelerations at 0 second period is taken as peak ground acceleration of each floor and determined the rocking and overturning state of freestanding contents at each floor. Among the different methodologies for assessing the rocking and overturning of freestanding contents, Ishiyama criterion is the most conservative method which is not sensitive to the shape of response spectrum and slenderness ratio. Define the rocking and overturning of freestanding contents by Ishiyama (1984) criterion which describe as geometric parameters (B, H) and compare the rocking and overturning state of different B/H ratios by peak floor accelerations obtained from Dynaplot at each node of particular floors. Same as rocking assessment, peak floor velocity of each floor is derived from Dynaplot program and then build the overturning stability chart which is the primarily assessment of seismic vulnerability of freestanding contents. Overturning stability chart is an effective tool which describe the seismic capacity and compare with seismic demand to let know the proper B and H of freestanding contents to withstand the different earthquake excitations and also represent the stabilize location for valuable contents in a building. On the basis of the results, Ishiyama criteria for rocking and overturning shows the incomprehensible results which have different influence on each criterion and the results are not dependable due to the comparison of charts,

In the future steps of this research, the relatable criteria for rocking and overturning which is closer to the practical motions of rigid blocks will be considered to acquire trustworthy assessments of rigid block motions.

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