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Seismic Performance Evaluation of a Multistory RC Building in Padang City

Jafril Tanjung[1,*], *Maidiawati* [2], and *Fajar* Nugroho[2]

[1]Civil Engineering Department, Andalas University, Kampus Limau Manis, Padang, 25163, Indonesia
[2]Civil Engineering Department, Padang Institute of Technology, Jalan Gajah Mada Nanggalo, Padang, 25143, Indonesia

Abstract. Since a long time ago, Padang City has been recognized as one in most-earthquake and tsunami prone city in the world. The successive significant earthquakes that have struck western coast of Sumatra Island from 2004 to 2010 seems to warn the city about its prone condition. The last major Padang-Pariaman earthquake on September 30, 2009, for instance, has caused hundreds of death and lousy damage to thousands of houses and buildings in city. Recently, several new multistory reinforced concrete (RC) buildings have been established in this area. Its include such buildings as government office, mosques, hotels, school and university. The city government plans to use these buildings as vertical evacuation facilities if an earthquake followed by a tsunami hit the city in the near-future. As a consequence, of course, these infrastructures should be well designed and constructed to resist the future earthquakes motion. This paper discusses an evaluation of the seismic performance of an existing multistory RC building in Padang city. The building was a ten-story of hotel RC building located near the coastline of Padang city. A series Pushover and Time History Analyses were conducted to examine the seismic performance of the target R/C building. It uses STructural Earthquake Response Analysis (STERA-3D), a computer software based on the nonlinear finite element method. The Pushover analysis was conducted for maximum drift ratio 1/200 in X and Y directions, respectively. The input ground motion in a maximum acceleration of about 400 gals and 600 gals for 60 seconds' excitation were used for the Time History Analysis. These input ground motions were generated from the recorded ground motion of 2009 Padang-Pariaman earthquake. The result of the analyses suggest that the current target multi-story RC building has outstanding seismic performance. The result is based on the level of damage of the structural components, base shear, inter-story drift, lateral displacement, dynamic responses and the seismic capacity spectrum of the analytical model.

1 Introduction

Padang, a city with a population of more than 900 thousand peoples, has been known as an earthquake and tsunami prone city. It is due to its location which is on the flat terrain and directly facing to the Mentawai segment of Sunda subduction. Since the great Aceh M9.1 earthquake in 2004, Padang city has suffered to successive several significant earthquakes. These significant earthquakes include Nias M8.6 earthquake in 2005, Bengkulu M8.5 and M7.9 earthquakes in 2007, Padang-Pariaman M7.9 earthquake in 2009 and Mentawai M7.8 earthquake in 2010 [1].

The last major earthquake struck the Padang city was the M7.9 Padang-Pariaman earthquake taken place on September 30, 2009 [2-4]. A red-star in Fig.1. shows the epicenter of the earthquake. The earthquake caused more than thousands of deaths and about 140,000 damaged houses and 4,000 other buildings. In Padang city, more than 300 people are dead, and 400 others are in serious injuries. Thousands of houses and several multistory RC buildings were damaged and destroyed. Fortunately, the earthquake was not followed by tsunami [3].

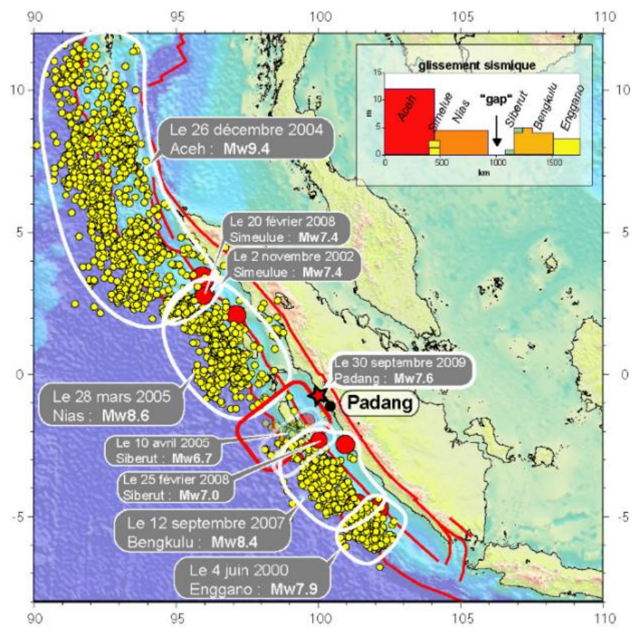


Fig. 1. The West-Sumatra Seismic Crisis [2].

* Corresponding author: jafriltanjung@eng.unand.ac.id

The successive earthquakes mentioned above have ruptured more than 2,000 kilometers long of subduction zone on the western offshore of Sumatra island. Unfortunately, a segment of about 200 kilometers lay on the front of Padang city still holds [2]. Its location is marked in red-box in Fig. 1. Therefore, Padang city may have a significant potential risk to the impact of the near future great earthquake and tsunami.

Figure 2 shows the predicted inundation area in the central area of Padang city [5]. By using the numerical approach, Barrero [6] and Ario [7] have predicted that the flow depth of the tsunami can reach 10-meter high on the coastline of Padang city. The evacuation time to reach safe zone is estimated about 60 minutes. Meanwhile, the tsunami wave reaches the coastline for about 20-30 minutes after the major earthquake [6-8]. In this case, therefore, the vertical evacuation shelters entirely are the best option to reduce the casualties of the future tsunami wave.

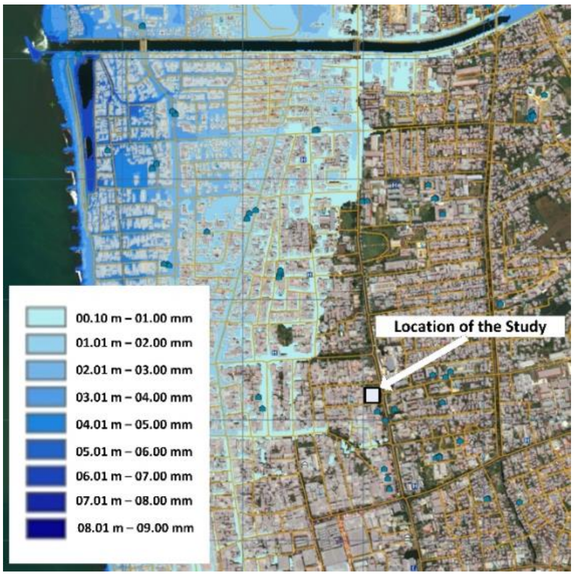
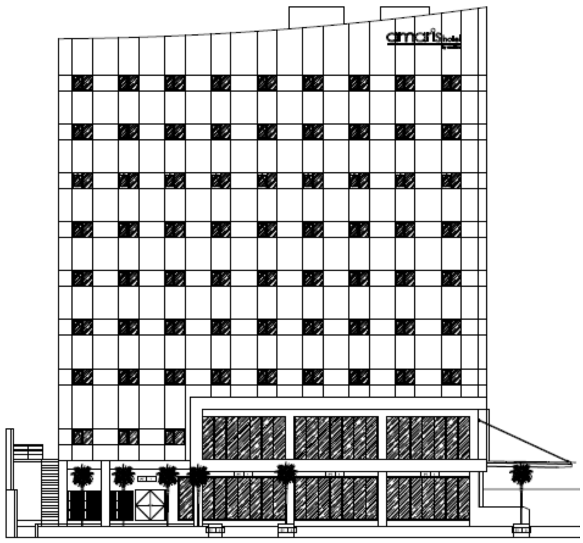


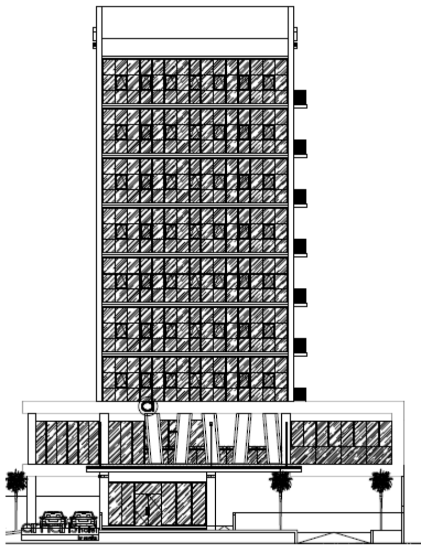
Fig. 2. Predicted Inundation Area [4].

Thus, since the event of 2009 Padang-Pariaman earthquake, several multistory RC buildings have been built in Padang city for government office buildings, mosques, hotels, school, university and other multistory buildings. The government wants to utilize the buildings for vertical evacuation shelters if a great earthquake followed by the tsunami wave hits the city. The structure of these multistory RC buildings should have been well-designed and properly constructed on the basis of the earthquake resistant design structure applying the latest codes for RC buildings.

This paper discusses an analytical study of an evaluation of the seismic performance of an existing multistory RC building. For this purpose, a ten-story RC building built in 2016, Amaris Hotel Padang, was examined. The location of the building is approximately 1.5 kilometer from the coastline (indicated by a filled-white-box in Fig. 2). This building is designed to be used as a vertical evacuation shelter for the people who live nearby the building. Figure 3. shows the technical view of the building. The study uses a computer software based on the nonlinear finite element method, i.e. STructural Earthquake Response Analysis (STERA-3D) which is developed by Prof. Saito from Toyohashi University of Technology, Japan [9, 10]. This analytical study might examine whether or not an RC hotel building is safe enough to be used as a vertical evacuation shelter.



(a) South View

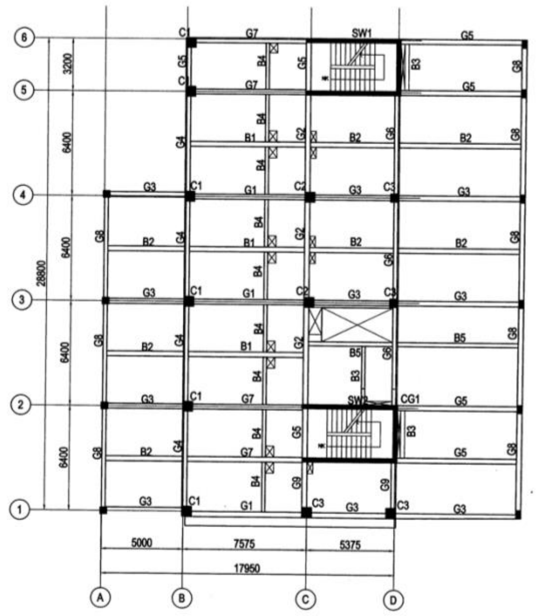


(b) East View

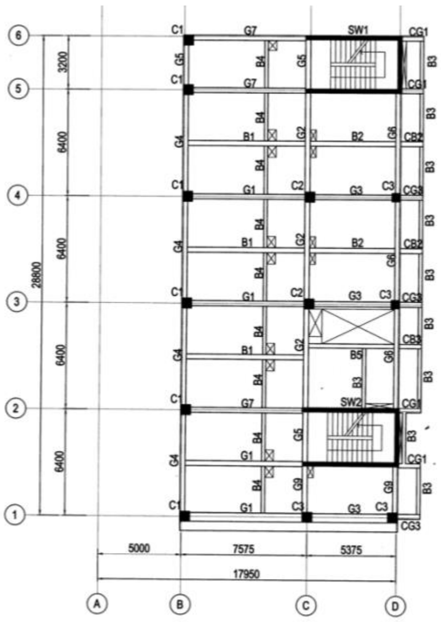
Fig. 3. Technical View of Amaris Hotel Padang.

The STERA 3D is a seismic analysis computer code which is used to evaluate the seismic performance of an RC and steel buildings. The STERA 3D can perform the elastic modal analysis, the nonlinear lateral static pushover analysis, the nonlinear lateral static cyclic analysis and the nonlinear earthquake responses analysis. To make the STERA 3D is user-friendly, the computer code comes with a graphic user interface to create and to analyze the building model and also to show the analysis results in rapidly and efficiently. In STERA 3D, the beam

element is modeled as a line element with nonlinear bending and shear springs, while the column element is modeled by considering the nonlinear interaction between axial force and bending moment. Its interaction is expressed by the nonlinear axial springs for the concrete and nonlinear multi springs for the reinforcements. In the same manner, the wall element is also modeled by the nonlinear spring for the concrete and nonlinear multi springs for the wall reinforcements [9].



(a) Typical Plan for Floor 1-2



(b) Typical Plan for Floor 3-9

Fig. 4. Floor Plans of Amaris Hotel Padang.

2 Analytical Model

The structure system of the Amaris Hotel Padang is a dual-system of the RC frame and shear wall structure. The typical floor plans of the structure, as is shown in Fig. 4, while the dimension list of the columns and beams used in this analysis are tabulated in Table 1. The components of RC structure use concrete with a compressive strength of about 25 MPa. The deformed rebar with nominal yield tensile stress of 400 MPa was installed in all of the RC structural components. The structure of the building was analytically modeled in STERA 3D computer codes by using these given floor plans. The final image of the analytical model is shown in Fig. 5. Two types of analysis, i.e. the Pushover and the Time History Analyses, were performed respectively to the model. The Pushover Analysis was conducted for maximum drift ratio 1/200 in X and Y directions, respectively, while for the Time History Analysis, the input ground motions in maximum acceleration about 400 gals and 600 gals for 60 seconds' excitation, were used. The above ground motions were generated from the recorded ground motion of 2009 Padang-Pariaman earthquake as are shown in Fig. 6. The ground motions were recorded by seismograph installed at Singkarak Hydro Electric Power Plant, about 50 kilometers from the epicenter of the earthquake [11]. The analytical study described in this paper follows an analytical matrix as tabulated in Table 2.

Table 1. Dimension List of Structural Components.

Columns		Beams			
Type	Dimension	Type	Dimension	Type	Dimension
C1	600 x 600	G1	300 x 600	B1	300 x 600
C2	600 x 600	G2	300 x 700	B2	300 x 500
C3	500 x 500	G3	300 x 500	B3	200 x 400
		G4	300 x 700	B4	200 x 300
		G5	300 x 500	B5	250 x 500
		G6	300 x 600		
		G7	300 x 600		
		G8	300 x 500		
		G9	300 x 500		

Table 2. The matrix of Analytical Study.

Analytical works	Codes
Pushover Drift Ratio X-1/200	PO-X-1/200
Pushover Drift Ratio Y-1/200	PO-Y-1/200
Time History Analysis Max 400 gals	EQ-0.4G
Time History Analysis Max 600 gals	EQ-0.6G

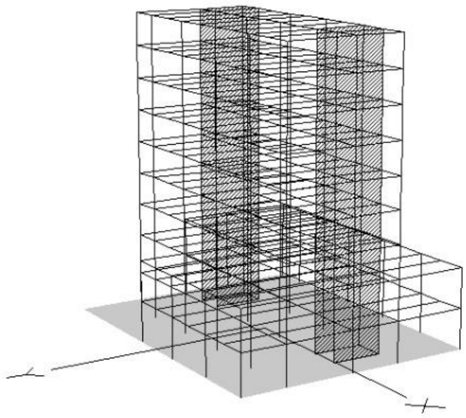


Fig. 5. 3D Analytical Model.

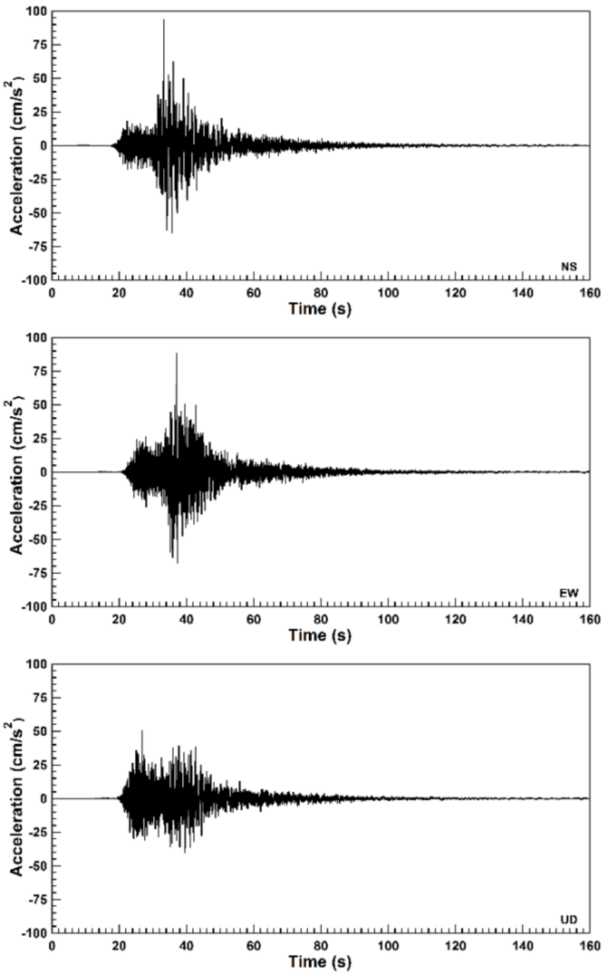
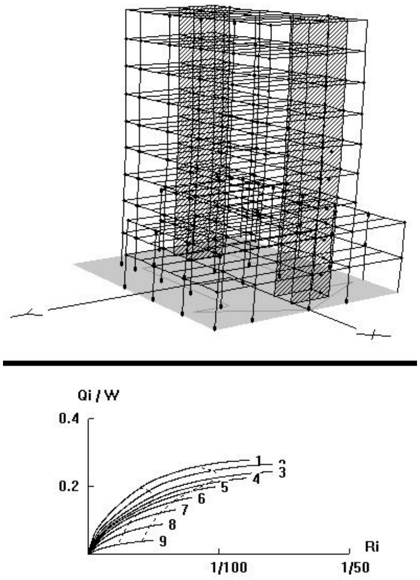


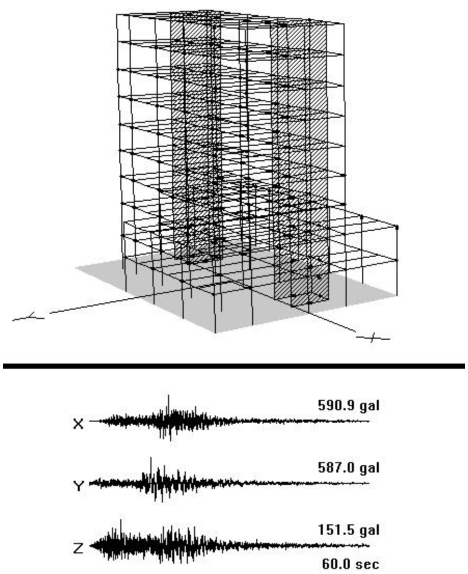
Fig. 6. Ground motions of 2009 Padang-Pariaman Earthquake.

3 Analytical Results and Discussion

Figure 7 shows the examples of the post-images of the analytical model of Amaris Hotel building, which is analyzed by STERA 3D computer code, i.e. for the pushover and the time history analyses, respectively. In STERA 3D, the damages on the structural components of the RC building is defined by the ductility of its structural components (U). If the ductility (U) in a range of one to five denotes its structural components experience light to moderate damage, while if ductility (U) higher than five it indicates severe damage. Table 3. shows the recapitulation of the damage of the structural components of the analytical RC building model in term of the percentage of the ductility of its structural components relative to a total number of the structural components. In all results of analytical cases (analysis), there are no structural components undergo severe damage. The damage of structural components is the only experience in light and moderate damages, and most of them are located on the beams.



(a) Pushover Analysis.



(b) Time History Analysis.

Fig. 7. Post-analysis Image of Structure.

Table 3. Damaged of the Structure Components.

Pushover				
	Column		Beam	
	1>U>5	U>5	1>U>5	U>5
PO-X-1/200	-	-	29%	-
PO-Y-1/200	3%	-	14%	-
Earthquake Motion				
	Column		Beam	
	1>U>5	U>5	1>U>5	U>5
EQ-0.4G	-	-	18%	-
EQ-0.6G	2%	-	40%	-

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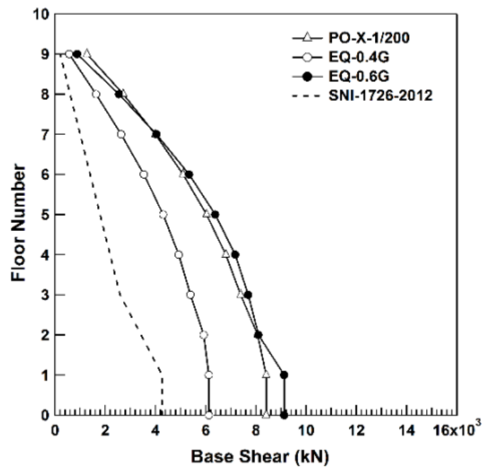
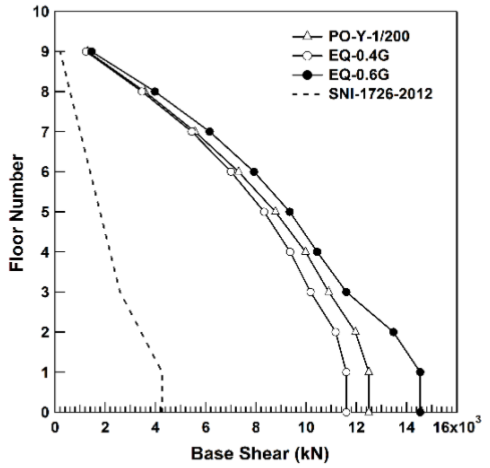


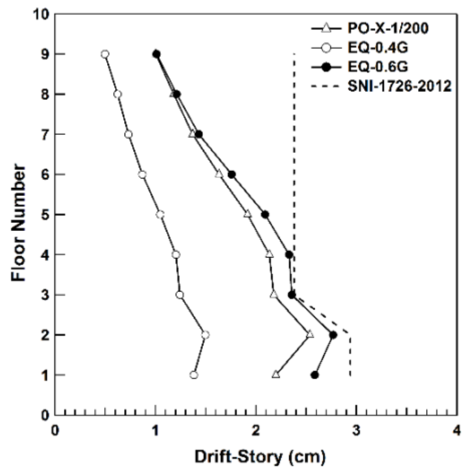
(a) X-Direction



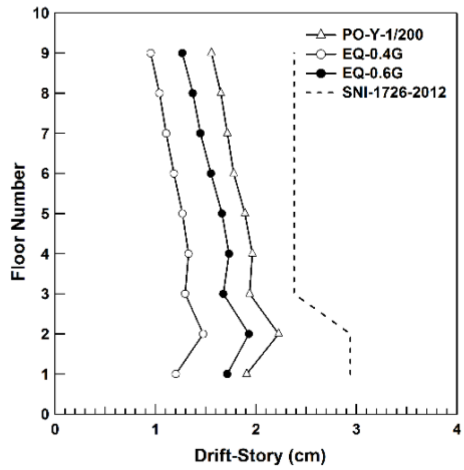
(b) Y-Direction

Fig. 8. Comparison of the Base Shear.

Comparison of the base shear of the analytical models is shown in Fig. 8. The result is then also compared to the requirement base shear design following Indonesia RC building code SNI-1726-2012 [12]. The comparisons are given in X and Y directions. Noting that, for time history analysis, the NS and EW directions are presented in X and Y directions, respectively. The minimum requirement of the base shear design was evaluated based on seismic site parameters where RC building was constructed, i.e. soil specification is the medium soil; the maximum spectral response acceleration at short periods S_S is 1,35; the maximum spectral acceleration at a period of 1 second S_1 is 0,599; the acceleration-based site coefficient F_a is 1,0; the velocity-based site coefficient F_v is 1,3; the maximum spectral acceleration at short periods adjusted for site class S_{MS} is 1,35; the maximum spectral acceleration at a 1 second period adjusted for site class S_{M1} is 0,779; the design spectral response acceleration at short periods S_{DS} is 0,9; and the design spectral response acceleration at a period of 1 second S_{D1} is 0,519. The importance factor I is 1,0, and response modification coefficient R is 8. These analytical results show that the presence of the shear walls seems to have given a significant contribution to increase the base shear, especially in Y-direction.



(a) X-Direction

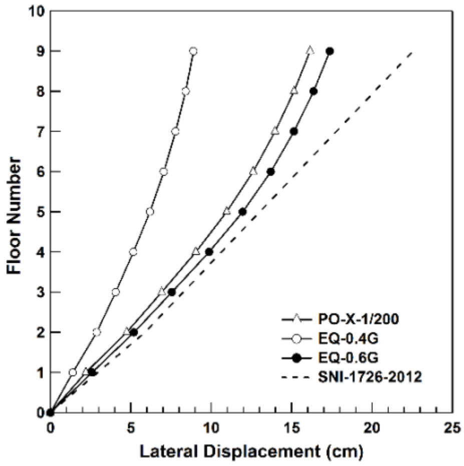


(b) Y-Direction

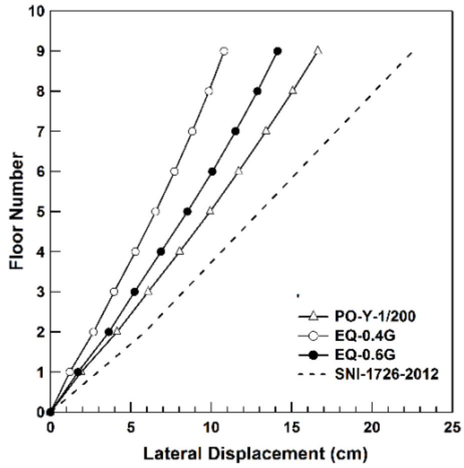
Fig. 9. Comparison of the Inter-Story Drift.

The analytical results for the inter-story drift and the lateral displacement along the height of the analytical model are given in Fig. 9 and Fig. 10, respectively. In the case of the structure in dual system RC frame and shear wall, according to SNI-1726-2012 [12], the inter-story drift is limited to 0,7% of the inter-floor height. For the time history analysis, one of the results (shown in Fig. 11.) is the responses of the structure in term of lateral displacement at the top of the building in the X and Y direction, respectively.

Figure 12. shows the performance points of the target RC building, i.e. 26,30 cm, 338 gals for X direction and 18,20 cm, 485 gals for Y direction, respectively. These performance points were obtained by superimposing the elastic demand spectrum on the seismic capacity curve in Acceleration Displacement Response Spectrum format. The capacity spectrum curves in Fig. 12 shows the superior of the seismic capacity of the RC building in the Y direction, compared to the X direction, due to existing of the shear walls. These curves also show the ability of the structural components of the RC building undergoes to the inelastic deformation, i.e. when passing the elastic limit.

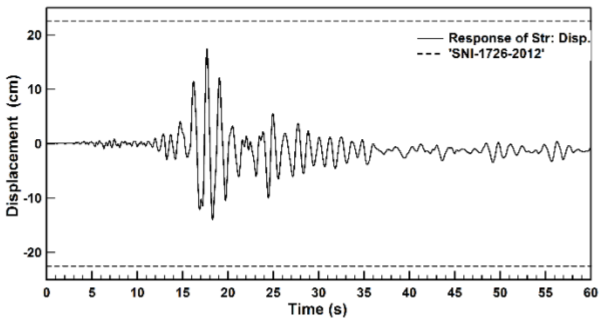


(a) X-Direction

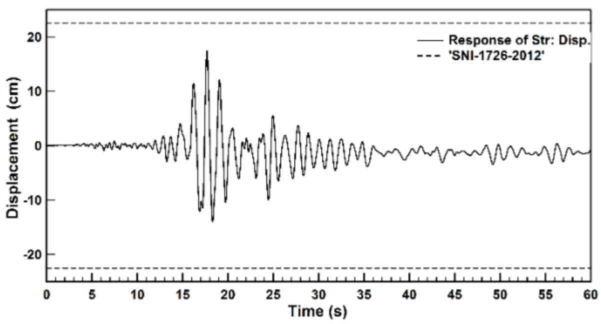


(b) Y-Direction

Fig. 10. Comparison of the Lateral Displacement.



(a) X-Direction



(a) Y-Direction

Fig. 11. The response of Structure: Disp. at top of Building.

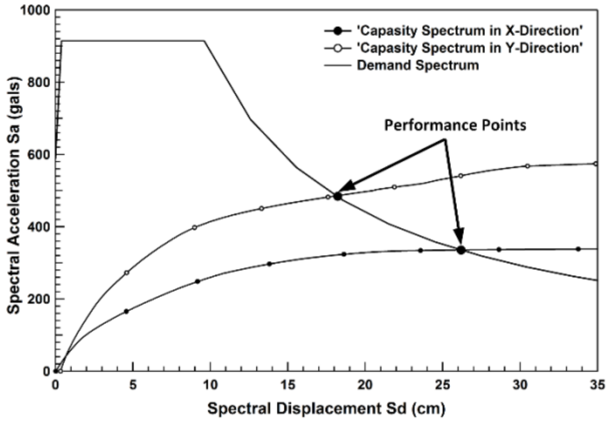


Fig. 12. Seismic Capacity Spectrum.

4 Conclusion

This paper has discussed an analytical study evaluating the seismic performance of the multistory RC hotel building employing STERA 3D computer codes. The study conducted to the ten-story Amaris Hotel Padang performed both Pushover and Time History Analyses. It used the generated ground motions from 2009 Padang-Pariaman earthquake for in time history analysis. Based on the damage level of the structural components, base shear, inter-story drift, lateral displacement, dynamic responses and the seismic capacity spectrum of the analytical model, it appears that the target multi-story RC building has an outstanding seismic performance. This multistory RC building, therefore, could be recommended as a vertical evacuation shelter in Padang city.

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