Seismic Demand Due to the Earthquake Hazard Map 2017 Determination in Indonesia

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Abstract: The Earthquake Hazard Map used in the design of earthquake resistant infrastructure in Indonesia has developed from Earthquake Hazard Map 2010 to 2017. This development affects the improvement of seismicity pattern in several areas in Indonesia, which may lead to the increase of seismic demand. Therefore, it is needed to carry out a study to investigate the condition of seismicity in different cities in Indonesia. This study analyzed a model structure located in 32 cities in Indonesia by referring to the Earthquake Hazard Map 2010 and 2017. The analysis uses a dynamic spectra response method through SAP2000 software to obtain the value of a fundamental period of structure, deflection, and base shear. Based on the analysis, it can be identified that 16 cities increase their seismicity pattern significantly and the highest escalation occurred in Jayapura city of 60%. Meanwhile, the highest base shear value in 2010 is on Palu and changed into Jayapura in 2017. The decrease of seismic conditions also occurred in 16 other cities with the highest decline is in Merauke city of 53%. For particular areas affected by seismicity, further analysis of existing building especially high-risk building is suggested.

1 INTRODUCTION

Ministry of Public Works and Housing (PUPR) in Indonesia released the new Earthquake Hazard Map 2017 (EHM-2017) (PUSGEN, 2017) which is the update of the Earthquake Hazard Map 2010 (EHM-2010) (PU, 2010). The reason for map improvement is because the map has been aged more than five years and it new seismic sources has been identified. In addition, the improvement was also made in order to increase the accuracy estimation of important parameters in the map, as well as the detail of earthquake source using the equation of current earthquake attenuation. This is according to Vipin et al. (2009) statement that earthquake hazard is controlled by three factors, i.e. properties of the source, characteristics of the path, and local site effects. Past earthquake data, characteristics of earthquake sources in the region and attenuation relationships are three important factors that must be considered to assess the hazards of earthquakes

The preparation of EHM-2017 considers the occurrence of major earthquakes in recent years and the identification of earthquake sources such as active faults that appear in various regions in Indonesia. The National Center for Earthquake Study in Indonesia states that the amount of active faults in Indonesia has increased from 81 in 2010 to 295 in 2017 (PUSGEN, 2017). The improvement of seismic hazard in EHM-2017 may affect the earthquake-stricken structural response that may indicate the seismic demand in the structural design. In principle, buildings should be designed to withstand the seismic loads of 2017 safely which is exposed by acceptable deflection and base shear. This case generates a further issue about existing buildings that must be evaluated to determine its performance of seismic loads in 2017 (Imran, 2007). Therefore, it is necessary to investigate structural response in various cities in Indonesia, to identify the seismic demand in each location.

Faizah and Widodo (2013) investigated the previous improvement of EHM that is from 2002 to 2010 and reported that it resulted in changes of seismic demand in 23 cities under review. There was a significant increase in Semarang, Yogyakarta, Kendari, Banda Aceh, and Palu, with the highest escalation in Semarang by 126%. Meanwhile the decline of seismic demand occurred in Bandar Lampung, Palembang, Jakarta, Kupang, Banjarmasin, Samarinda, and Makassar. Similar research was conducted by Arfiadi (2014), by evaluating 22 cities in Indonesia. The results showed

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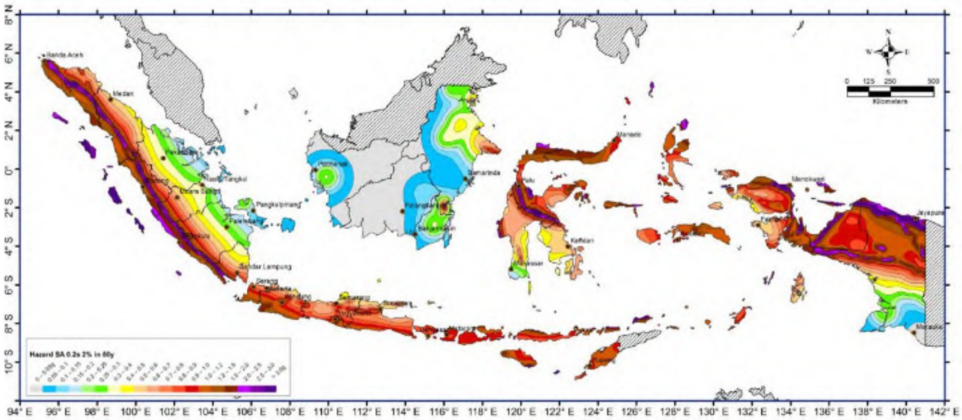


Figure 1: The map of spectral acceleration at short period (SS) with 5% damping ratio in bedrock (SB) for probability exceeded 2% in 50 years (EHM-2017).

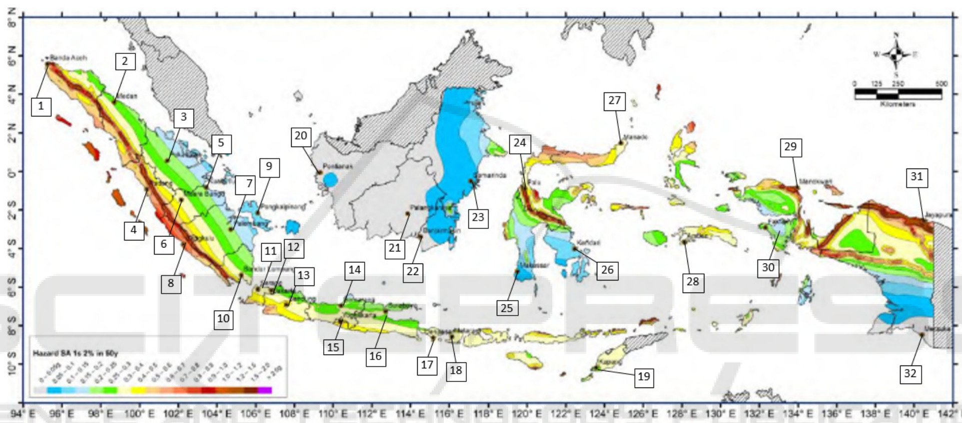


Figure 2: The map of spectral acceleration 1 second period (S_1) with 5% damping ratio in bedrock (SB) for probability exceeded 2% in 50 years (EHM-2017).

that Palu and Semarang have a significant increase of spectral acceleration response both for a short period (SS) and 1 second period (S1). It is also stated that the difference of spectral acceleration response will be greater than that of the soil type is harder.

This study analyzes a structure located in 32 cities in Indonesia by referring to EHM-2010 (PU, 2010) and EHM-2017. From this analysis, it can be identified the base shear value that can indicate the seismic demand in the site. The analysis of seismic demand is very urgent in order to evaluate the performance of existing buildings located in the earthquake prone-area. There are areas which experience an escalation or a decline for the others in term of base shear value. This value must be calculated as a requirement of a seismic load in the design of a structure (ASCE, 2017). Therefore, the escalation of seismic demand after the determination of EHM-2017 generates a problem, especially for the existing building. The paper contributes in developing a new seismic building code especially to assess the structural vulnerability of the existing building.

1.1 Development of the Earthquake Hazard Map (EHM) in Indonesia

Asrurifak (2017) explains that EHM was first created in 1962 and published in the Indonesian Concrete Standard (Peraturan Beton Indonesia/PBI) in 1966, where the Indonesian's territory is without Irian Jaya city. In 1970, EHM was repaired and published in the Indonesian Loading Standard (Peraturan Muatan Indonesia/PMI) by integrating the Irian Jaya city in the Indonesian's territory. After 1970, there were several major earthquakes, including the 1976-Bali Earthquake. It causes PMI-1970 be revised into Indonesian Loading Standard (Peraturan

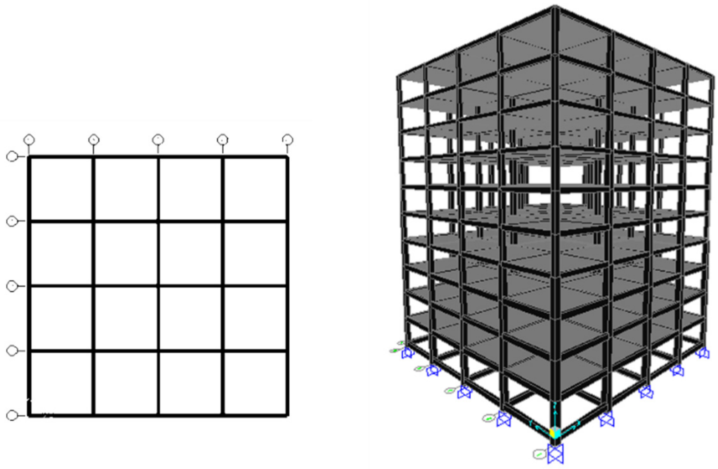


Figure 3: A reinforced concrete frame model.

Pembebanan Indonesia/PPI) in 1981 which are also published in several standards, such as the Standard of Earthquake Resistant Design-1983 and Standard of Loading Procedures for Indonesian Building-1983. This EHM has revised again to EHM-2002 and published in SNI 03-1726-2002, where Indonesia was divided into six seismic areas. After that, there were several major earthquakes such as the 2004-Aceh Earthquake, 2005-Nias, 2006-Jogja, 2009-Tasik, 2007-Bengkulu, 2009-Padang and 2010-Mentawai in Indonesia, so EHM was revised to the EHM-2010 and published in SNI-1726:2012, SNI-2847:2013, SNI-1729:2014, and SNI-7973: 2013. EHM was finally revised in 2017 which has considered several earthquake events that are not yet to be calculated on the previous map. Besides, there were 214 new faults identified as the latest quake source parameter. The value of spectral acceleration from EHM-2017 at short period (SS) and 1 second period (S1) with 5% damping ratio in bedrock (SB) for probability exceeded 2% in 50 years shown in Figures 1 and 2 (PUSGEN, 2017).

2 RESEARCH METHODOLOGY

The analysis in order to find out the difference of structure response that occurred due to seismic loading in EHM-2010 and 2017 uses the dynamic method of spectra response by SAP2000-3D software. The structure model is a 10-story reinforced concrete frame with four spans of each side which is presented in Figure 3. The specifications of structure model and the column/beam dimensions are shown in Table 1 and Table 2 respectively. The structure model is assumed as an office building located in 32 cities in Indonesia as mentioned in Table 3, including the spectral acceleration value that was observed from EHM-2010 and 2012. Structure response due to the 2010 and 2017 seismic load which includes a fundamental period of structure, deflection, and base shear can be identified from the structure 3D analysis using SAP-2000 software. The result is compared to the structure response 2010 and 2017 to find out its escalation or decline in 32 cities in Indonesia. The response spectra design is also compared between 2010 and 2017 in each city to identify the difference in structure response.

Table 1: Specification of structure model.

Specification	Provisions
Building function	Office
Concrete strength	30 MPa
Modulus of elasticity of concrete	25742 MPa
Reinforcement bar	BJTD 41
Stirrups	BJTD 34
Modulus of Elasticity of steel	2.105 MPa
Typical-height of story	4 m
Wide of spans	4 m

Table 2: Dimension of column/beam (mm).

Level	Side-column		Middle-column		Main Beam	
	b	h	b	h	b	h
1-4	700	700	800	800	350	700
5-7	600	600	700	700	300	600
8-10	500	500	600	600	250	500

b = width ; h = height.

Table 3: Cities and values of S_S and S_1 (sec.).

No.*	City	EHM 2010		EHM 2017	
		S_S	S_1	S_S	S_1
1.	Banda Aceh	1.349	0.642	1.71	0.65
2.	Medan	0.526	0.332	0.58	0.28
3.	Pekanbaru	0.435	0.273	0.35	0.24
4.	Padang	1.398	0.600	1.25	0.52
5.	Kuala Tungkal	0.210	0.170	0.32	0.19
6.	Muara Bungo	0.544	0.310	0.62	0.36
7.	Palembang	0.262	0.164	0.28	0.21
8.	Bengkulu	1.372	0.567	2.15	0.81
9.	Pangkal Pinang	0.057	0.077	0.14	0.11
10.	Bandar Lampung	0.739	0.318	0.77	0.34
11.	Serang	0.784	0,334	0.84	0.36
12.	Jakarta	0.664	0.293	0.72	0.31
13.	Bandung	1.450	0.486	1.20	0.40
14.	Semarang	1.098	0.364	0.73	0.28
15.	Yogyakarta	1.212	0.444	1.32	0.44
16.	Surabaya	0.663	0.274	0.75	0.27
17.	Denpasar	0.977	0.360	0.80	0.31
18.	Mataram	0.960	0.385	0.94	0.34
19.	Kupang	1.113	0.296	0.92	0.26
20.	Pontianak	0.017	0.022	0.17	0.02
21.	Palangkaraya	0.059	0.031	0.04	0.02
22.	Banjarmasin	0.060	0.036	0.08	0.03
23.	Samarinda	0.125	0.089	0.11	0.07
24.	Palu	2.164	0.765	2.42	0.91
25.	Makassar	0.317	0.142	0.22	0.08
26.	Kendari	0.825	0.330	0.64	0.13
27.	Manado	1.035	0.442	0.97	0.35
28.	Ambon	1.380	0.490	0.92	0.30
29.	Manokwari	1.454	0.561	1.65	0.62
30.	Fak-fak	0.518	0.190	0.59	0.24
31.	Jayapura	1.500	0.600	2.81	0.94
32.	Merauke	0.055	0.021	0.02	0.01

*refer to Figure 2

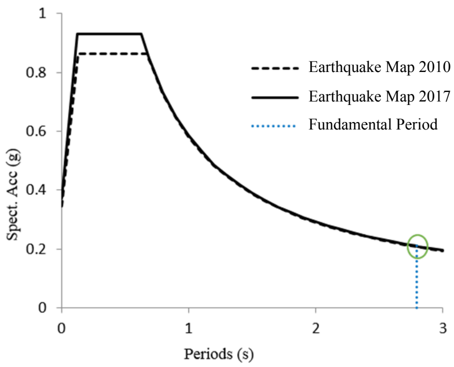
3 RESULTS AND DISCUSSION

The study covers an analysis of the spectra response design and structure response on the structure located in 32 cities in Indonesia due to earthquake loads according to EHM-2010 and 2017.

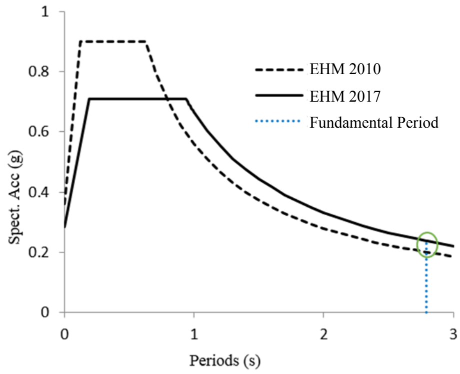
3.1 Response Spectra Design

Based on the spectral acceleration values in Table 3, a spectra response design of 2010 and 2017 is assigned, which has an own characteristic in each city. In this manuscript, some results are given for the sample to be analyzed. Figure 4.a shows Banda Aceh's spectra response design that increases from 2010 to 2017 in all variant structure's period, but the escalation is not fixed. For structures with 0.125 s – 0.69 s of fundamental period, the escalation is significant. Whereas in Jayapura, it is estimated that there is an increase of spectral acceleration for structures with more than 1 second of the fundamental period and decrease for others.

Afriadi (2014) compares the spectra value of 2002 and 2012-according to Indonesian Earthquake Hazard Map and 2012 is higher than 2002. There were 22 cities in Indonesia which was investigated and it is reported that Palu and Semarang city experience a very significant increase of spectral acceleration both short and one-second periods. Cities that have a significant increase in spectral



(a)



(b)

Figure 4: Spectra response design of (a) Banda Aceh and (b) Jayapura.

acceleration due to seismic load 2012 also have a significant increase in the internal force of building. Therefore, with the enactment of the seismic load 2012, it is necessary to evaluate the resistance of the structures, especially for a site which has an increased value of S_{DS} and S_{D1}.

3.2 Fundamental Period

The fundamental period of structure model can be obtained from the analysis, which is 2.79 s. This value can be delineated in the curve of spectra response design (Figure 4) to identify the spectral acceleration due to the earthquake load on the structure. For Banda Aceh (see Figure 4.a), the value of spectral acceleration 2010 and 2017 are 0.208 g and 0.210 g respectively, it means that the value of 2017 is slightly larger than 2010. This value may affect the magnitude of base shear of the structure. This occurrence is different from Jayapura that has a value of base shear 2017 which is significantly greater than 2010, especially for 0.124 s - 0.62 s of the fundamental structure period. Based on Jayapura's spectra response design in Figure 4.b, it can be determined that the value of spectral acceleration 2010 and 2017 are 0.201 g and 0.238 g respectively. There is a significant dissimilarity between both of the values. Based on this result, it can be concluded that the spectral acceleration value depends on the fundamental period of structure and the seismicity pattern of the site, which is in accordance with the statement (Adam et al., 2017; Borzouie et al., 2016; Murthy, 2003) that in a typical city, there are buildings of many different sizes and shapes. One way of categorizing them is by their fundamental natural period (T).

3.3 Base Shear

This study investigated base shear values of structure to predict the magnitude of seismic demand as a requirement of structure design. In addition, the deflection of the structure is also quantified, especially for the location of the base shear decline from 2010 to 2017. Figure 5 shows the comparison of the base shear value of structure between 2010 and 2017 at 32 cities in Indonesia due to the seismic loads according to EHM-2010 and 2017. Jayapura has a peak value of base shear in term 2017 and the highest escalation from 2010 to 2017. The value of Jayapura's base shear-2017 is 4525.5 kN which increases 60.2% from the 2010 value. The escalation of base share value from 2010 to 2017 can be seen in Figure 6. There are 16 cities have increased their base shear value, while the other 16 cities have a decrease in their base shear value.

The result of this study is similar to the result of the research conducted by Faizah and Widodo (2013). However there is a difference in the location that has the peak value of escalation on the base shear. From 2002 to 2012, the peak value of base shear escalation was in Semarang (126%), but from 2012 to 2017, it shifted to Jayapura (60%). Some locations have increased the seismic load design in 2012 but decreased in 2017, conversely. For example is the base shear of Semarang city which experienced a significant increase in 2012 but decrease in 2017. Meanwhile, Bandar Lampung's base shear experienced an increase in 2012, but decrease in 2017. These conditions may not apply equally to various structures because each type of structure may have a different fundamental period that affects its spectral acceleration value. On the other hand, the similar study with variations in structure types like

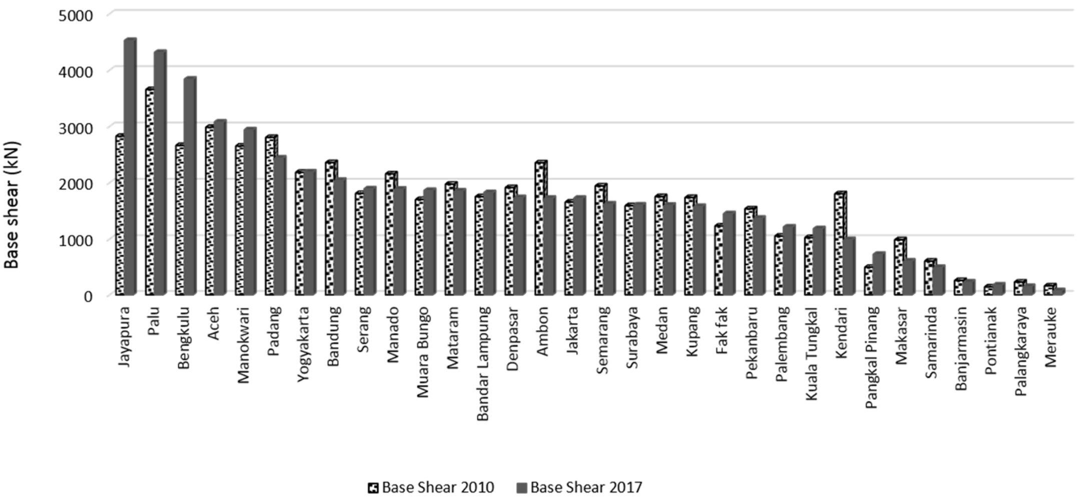


Figure 5: The comparison of base shear value between 2010 and 2017.

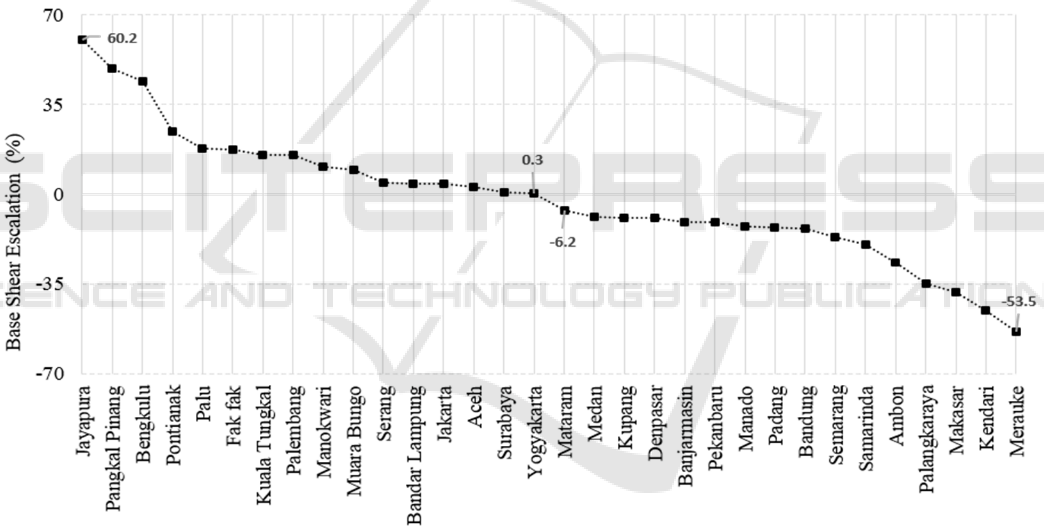


Figure 6: The escalation of base share value from 2010 to 2017.

the number of story and span, type of materials, various fundamental of structures, and etc. is recommended to be done. The development of seismic hazard map is also investigated in various location (Gracia et al., 2018; Unal et al., 2014; Courboulex, 2007).

3.4 Horizontal Deflection

Subsequently, this study reviews the horizontal deflection emerging the structure that experienced an increase base shear in 2017. The horizontal deflection of structures affected by EHM-2017 in 16 cities is presented in Figure 7. Jayapura has the largest horizontal deflection of 0.087 m.

The drift ratio of the structure due to EHM-2017 can be calculated by dividing the deflection with the height of the structure at each level and the results obtained are mentioned in Table 4. The largest of drift ratio in each structure always in 8 stories that are written in bold font. This result is compared to the allowable drift ratio requirement according to Indonesian Earthquake Resistant Structure Design Standard (BSN, 2012). The structure model is an

Table 4: The drift ratio in each story of the structure in 16 cities (mm)

City / no. of story	1	2	3	4	5	6	7	8	9	10
Aceh	0.93	1.40	1.49	1.60	1.81	1.73	1.76	1.88	1.50	0.97
Bandar Lampung	0.55	0.84	0.89	0.96	1.09	1.04	1.06	1.13	0.90	0.58
Bengkulu	1.15	1.74	1.85	1.99	2.25	2.15	2.20	2.34	1.87	1.21
Jayapura	1.35	2.03	2.15	2.31	2.60	2.50	2.55	2.71	2.16	1.41
Pangkal Pinang	0.22	0.35	0.38	0.43	0.49	0.48	0.49	0.51	0.39	0.24
Pontianak	0.05	0.07	0.07	0.08	0.09	0.09	0.09	0.09	0.07	0.05
Palu	1.30	1.96	2.08	2.24	2.53	2.42	2.47	2.63	2.10	1.36
Fak Fak	0.44	0.66	0.70	0.76	0.85	0.82	0.83	0.89	0.71	0.46
Kuala Tungkal	0.36	0.55	0.59	0.64	0.72	0.69	0.70	0.75	0.60	0.38
Palembang	0.37	0.57	0.62	0.69	0.78	0.76	0.77	0.81	0.63	0.39
Manokwari	0.88	1.34	1.42	1.53	1.72	1.65	1.68	1.79	1.43	0.92
Muara Bungo	0.57	0.86	0.92	1.00	1.13	1.07	1.09	1.17	0.93	0.60
Serang	0.57	0.87	0.92	1.00	1.12	1.07	1.09	1.17	0.93	0.60
Jakarta	0.52	0.79	0.84	0.91	1.03	0.98	0.99	1.07	0.85	0.55
Surabaya	0.48	0.73	0.77	0.83	0.94	0.90	0.92	0.98	0.78	0.50
Yogyakarta	0.66	0.99	1.05	1.12	1.27	1.22	1.24	1.32	1.05	0.69

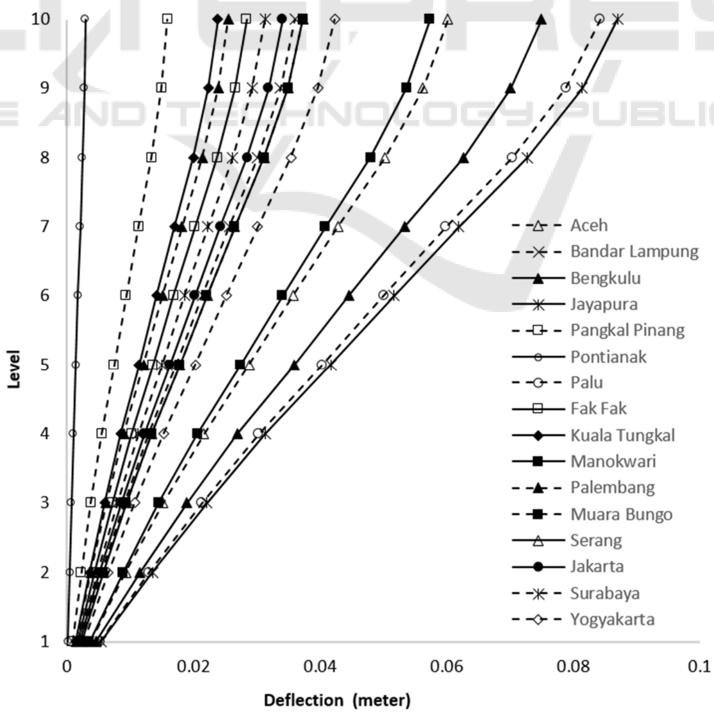


Figure 7: The horizontal deflection of the structure in 16 cities.

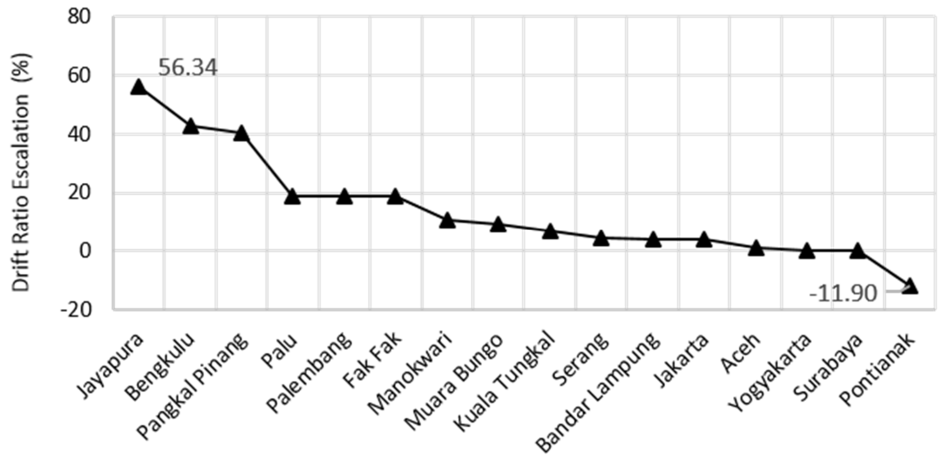


Figure 8: The escalation of structure's drift ratio located in 16 cities in Indonesia.

office building and it is classified as II-risk category. Hence, the drift ratio should not be greater than 0.020 time the high of story. The allowable drift ratio for this structure is 80 mm and the largest of drift ratio is qualify clearly.

Maximum drift ratio of the structure due to EHM 2010 and 2017 are also compared. The escalation of maximum drift ratio due to both of EHM 2010 and 2017 (Figure 8) is not similar to the escalation of base shear value (Figure 6). The structure located in Pontianak increased base shear value by 3% but decreased its maximum drift by -12%. Similar conditions may occur in the other cities. This indicates that the increase in the base shear value is not always proportional to the increase in the drift ratio and cannot be used to predict the building's ability against earthquake. Further study needs to be held to investigate the resistance of various types of buildings located in other cities in Indonesia against earthquakes according to the EHM-2017.

4 CONCLUSION

Seismic demand has been studied in this paper through a dynamic spectra response analysis of the structure model located in 32 cities in Indonesia. It was indicated by the base shear value which was calculated according to EHM-10 and EHM-17. The result showed that there were 16 cities experienced an escalation and degradation for the other city, in term of base shear value. It also found that increase in base shear value from 2010 to 2017 was occurred in Jayapura city by 60%, in term of 2.79 seconds of structure fundamental period. This increase might be different from other structures which have different fundamental periods.

Horizontal deflection was also presented in this study to identify its correlation to base shear value. The analysis concluded that the increase in the base shear value could not be used to predict the building's ability against earthquake. A further study is also suggested in order to investigate the resistance of various types of buildings located in other cities in Indonesia against earthquakes according to the EHM-2017, whether it is in various materials, geometry, located, and function of structures.

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