Analysis of Soil Response to Earthquakes in the City of Makassar Using EERA Software with Walanae Fault Earthquake

A.R. Djamaluddin, A. Arsyad, Hilman Tauhik

Abstract: The response spectrum model for buildings in Makassar is determined by conducting location-specific analysis using a linear quadratic approach of non-linear response techniques. Typical stratigraphy of sedimentary soil in Makassar is collected and categorized as model 1: sand on sand 12 m, and model 2: 10 m clay on clay. The DSHA is carried out by considering two seismic sources that affect the city, involving Walanae Fault Mw 7.53 with a distance of 89.64 km and Makassar Thrust Mw 7.46 with a distance of 149.41 km. Spectral readings were performed where the actual time history obtained from shallow turbid earthquakes with similar seismic characteristics was adjusted according to the target response spectrum obtained from DSHA. A suitable time history is then used as a ground motion input with a PGA target of 0.253 g into the equivalent linear estimate of the nonlinear response using EERA. From the data obtained that seismic pressure on the soil is more related to the depth of soil than the elasticity of the soil. The deeper soil sediments, the greater pressure and strain produced will be propagated. The maximum spectral acceleration of model 1 was found in the range of 1.24 g in the period of 0.21 s to the period of 0.22 s. In model 2 has a smaller spectral acceleration compared to Model 1 which is 0.63 g in the period of 0.68 s.

Keywords: DSHA, Earthquake, EERA software, PGA

I. INTRODUCTION

An earthquake is shaking the earth which is caused by sudden release of energy in the earth result collisions between plates of the earth [1]. The earthquake occurred due to a sudden shift from the soil layer below the earth's surface caused by the movement of the earth's crust / earth's plate [2]. When this shift occurs, vibration occur called seismic waves that lead in all directions inside the earth and spread away from the focus [3]. When this wave reaches the earth's surface, the vibration can be destructive or not. This really depends on the strength of the source and the focal distance of the earthquake, besides that the quality of the building and the quality of the land where the building is standing also greatly affects by the level of earthquake.

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In carrying out earthquake microzonation, several disciplines must be combined in full by conducting several investigations so that the microzonation map will include parameters taken from the results of the multi-disciplinary research [4, 5, 6]. Of all aspects that are owned, the investigation of soil quality is more important than the others, because the earthquake propagates through the soil to the surface inhabited by humans. Indonesia often experienced natural disasters such as volcano eruption and earthquakes [7, 8]. Indonesia is located in the Pacific Ring area and also at a meeting of Eurasia, Indo-Australia, and the Pacific [9, 10]. Makassar city area is included in earthquake zone 4. Makassar city is an economic and education center in the South Sulawesi region. The rapid development of city eventually increases the population in Makassar City. The occurrence of earthquake will give significant damage and impact [11]. Even though geographically, the city area of Makassar is not crossed by a fault that is a source of earthquakes. Therefore, this study analyse the soil response to earthquakes in Makassar City using EERA software with Walanae Fault Earthquake Sources to determine and provide scientific assurance that Makassar city is still habitable in the long term or Makassar city must be arranged restructures according to EERA data analysis [12].

II. METHODOLOGY

The procedure of this study uses the Deterministic Seismic Hazard Analyze (DSHA) method according to Reiter (1990) [13], namely:

1. Identify earthquake sources. The source of the earthquake is determined from the area around the observation point which can affect the observation point.
2. Determine the distance of the earthquake source to the observation point. The distance measured is the closest distance from the source of the earthquake to the observation point.
3. Conduct "Controlling Earthquake" with attenuation equation. The attenuation equation is used to determine the effect of vibrations in the bedrock from the source of the earthquake to the observation point.
4. Determine ground motion parameters. The parameters determined in the form of acceleration after amplification of the type of soil passed to the ground.
5. Input the data obtained into the EERA application program.

The data entered into the program are as follows.

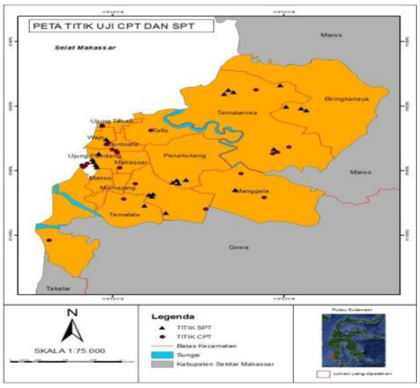
- Earthquake data was obtained from BMKG in Makassar city.
- The data is in the form of an earthquake that occurred in 2015. With earthquake strength of 4.9 SR with location: 5.37 LS -118, 96 BT (at sea, 63 Km Northwest of Takalar-Sulsel) at a depth of 10 Km.
- Soil characteristics at the Panakukang Mall area and UNM PETTARANI Building
- Soil Wave Rate and Speed (Vs), the average value of shear wave velocity used in the program is 194.13 m/s.

6. Control the results of the analysis from the EERA software

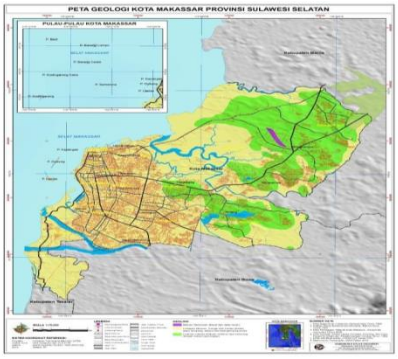
Data Collection

The data used during this study consisted of:

1. Data of earthquake events that occur around Makassar is obtained from the USGS catalogue (United State Geological Survey), namely 0.066°N - 8.037°S and 117°E - 123°E for the period 1924 - 2013.
2. Earthquake history data around Makassar from BMKG. The earthquake points that occurred throughout 2008 - 2013 around the city of Makassar (2.5 LS -6.5 LS and 118.5 BT - 120.5 BT) with a depth of 0 - 700 km and magnitude $3.0 \leq M \leq 6.0$
3. Drill or Sondir data at several points in Makassar City that were tested in 2011 - 2014. (Figure 1 (a))
4. Geological Map of Makassar City (Figure 1 (b))
5. Sources of earthquakes that affect earthquake events around Makassar City.



(a)



(b)

Fig. 1 Map of Makassar City, (a) CPT and SPT data collection points and (b) Geological Map of Makassar City

III. RESULTS AND DISCUSSION

Analysis of DSHA for Makassar City, determine the magnitude of the earthquake around the fault affecting the city of Makassar. Referring to tectonic maps and active faults in Indonesia (Indonesia Earthquake Hazard Map, 2010), as shown in Figure 1 (b) there are 2 faults that affect the earthquake around the city of Makassar, namely Walanae (Fault) and Makassar (Thrust), both information are tabulated in Table 1.These faults can cause earthquakes that have different magnitudes. Determine thedistance of fault to the city of Makassar. At this stage, the distance used is the closest distance between the source of the earthquake and the observation point. This maximum magnitude and fault distance to Makassar City will be used in the empirical predictive equation in the next step.

Table. 1 Maximum Magnitude and Source Distance to observation Point (Indonesia 2010 Earthquake Hazard Map)

No.	Fault	Magnitude	Slip Rate (mm / year)	Distance to Makassar (km)
1	Walanae Fault	7.53	2	89.64
2	Makassar Thrust	7.46	8	149.41

Attenuation equation is chosen to be used in determining the PGA (Peak Ground Acceleration) value. For faults affecting the city of Makassar, several attenuation equations are taken, namely Joyner and Boore (1988), Fukushima and Tanaka (1990).Using these equations and earthquake source data, the results of acceleration of base rock vibration in Makassar City are shown in Table 2.

Table. 2 Base rock acceleration (PGA) in Makassar City based on seismic history

Fault		**Fault Walanae**	**Makassar Thrust**
Magnitude		7.53	7.46
Distance to Makassar (km)		89.64	149.41
Peak Ground Acceleration (gals)	**Joyner and Boore (1988)**	0.0387	0.0258
	Fukushima and Tanaka (1990)	9.76	6.15
Min. PGA (g)		0.0615	
Max. PGA (g)		0.253	
Deterministic Percentile		0.456	

From the attenuation results shown in Table 2, the maximum Peak Ground Acceleration (PGA) value in Makassar is 0.046 g, while the minimum PGA value is

0.01 g. So that 0.046 g is used as the value of ground acceleration to determine the value of Peak Surface Acceleration (PSA) on the ground surface in Makassar City.

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The calculation results are acceleration in bedrock, not amplified due to the influence of local soil types. To find out the acceleration on the ground surface correction is needed based on the influence of the local soil type by using the equation:

PSA = Fa x PGA (1)

Where :

Fa = Amplification Factor

PGA = Maximum earthquake acceleration in bedrock

The Peak Surface Acceleration (PSA) for Makassar City area, especially Panakukang Mall and UNM PETTARANI Building based on the amplification of the type of soil obtained values as in Table 3.

Table. 3 Acceleration of vibrations at ground level after amplification of soil type

Soil Types	PGA (g)	Amplification Factors	PSA
Soft soil	0.253	1.7	0.4301
Medium soil	0.253	1.4	0.3542
Hard soil	0.253	1.2	0.3036

Output Software EERA

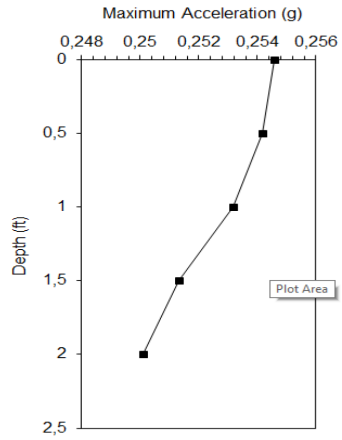
Analysis of site-specific ground responses via an equivalent linear approach from nonlinear response techniques has been carried out. The results show that, in general, ground acceleration at the bedrock level is strengthened by sediment. Soil acceleration increases from 0.253g at the bedrock level, to acceleration in the range from 0.255 g to 0.289 g, at the surface level. The high ground acceleration at the surface level is found in Model 2, while the low acceleration on Model 1. On the average, the acceleration of the ground at the surface level for the three models is 0.272 g.

Table. 4 Recapitulation Table Results of Seismic Response Sites from Models

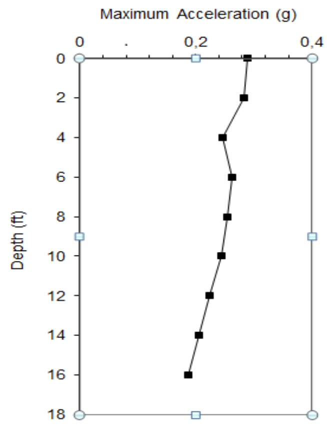
No.	Parameter	Designated sites	
		Model 1	Model 2
1	Maximum acceleration at surface level (g)	0.255	0.289
2	Time of maximum acceleration (sec)	20.36	23.94
3	Mean square frequency (Hz)	1.94	1.29
4	Maximum acceleration at bedrock level (g)	0.253	0.253
5	PGA amplification factor	1.661	2.196
6	Maximum strain (%)	0.0453	1.9283
7	Maximum stress (kPa)	8.6529	24.5179
8	Frequency of maximum amplification (Hz)	18.000	0.800
9	Fundamental frequency of Fourier Spect. (Hz)	1.257324	0.927734
10	Maximum spectral acceleration (g)	0.9178	1.1813
11	Maximum spectral velocity (cm / s)	311.0167	599.0692

Model 1 = UNM PETTARANI, Model 2 = PANAKKUKANG MALL

Table 4 presents a number of soil response characteristics of the model. The high amplification factor can be seen in model 2 with 2,196, while the low amplification factor is in Model 1 with 1,661. The maximum strain in the upper layer during seismic events ranges from 0.0453% (Model 1) to 1.9283% (Model 2). In addition, the maximum pressure spread by seismic events will be produced in the range of 8.65 kPa (Model 1) to 24 kPa (Model 2). The results imply seismic pressure on the soil is more related to the depth of the soil than the elasticity of the soil. Deeper soil sediments, the greater pressure and strain produced will be propagated. Fourier spectra show the basic frequency due to seismic events will be in the range of 0.92 Hz to 1.25 Hz. Figure 2 (a) and (b) show the acceleration of ground response due to seismic waves for Model 1 and Model 2 respectively.



(a) Model 1 = UNM PETTARANI



(b) Model 2 = PANAKKUKANG MALL

Fig. 2 Acceleration of ground response due to seismic waves

Response spectrum analysis is implemented with a critical damping ratio of 5%. The results show a large spectral acceleration on the surface, 0.92 g with a period of 0.58 seconds (Model 1). All models have different response spectral acceleration profiles. Model 2 has a characteristic soil pattern which is denser soft soil. On the other hand, Model 1 is a softer soil profile. This results in a broader spectrum with a peak in Model 1, which is 0.92g at 0.58 s, while Model 2 shows a spectrum that is more focused with a peak of 1.18 g at 0.84 s.

As the seismic wave moves from bedrock to the surface, it moves through sedimentary material with contrast impedance as found in Model 2, Panakukang Building. The impedance becomes much contrasted when seismic waves spread from a layer of low impedance clay to a high impedance muddy sand layer. Seismic waves are then trapped between layers of clay and muddy sand layers, and they begin to echo, causing peak acceleration in the period of 0.68. However, such contrast impedance cannot be found in Model 1 (UNM Building) which is dominated by a layer of low impedance soft clay. That is why the Model in the Panakukang Mall Building only has a focused spectrum with one peak. Low impedance at Panakukang Mall Building is the reason why the spectral acceleration is higher than the UNM Building.

IV. CONCLUSION

The results of the analysis of shear waves from bedrock to surface indicate the surface acceleration (Peak Surface Acceleration / PSA) ranges from 0.4301g to 0.3036g with amplification factors around 1.7 to 1.2.The amplification factor for each soil condition in the review area such as Mall Panakukang and UNM Building is different because of the influence of shear wave velocity (Vs), and the value of the standard penetration test (N) then these two data are used to classify the soil site class based on the Indonesian Earthquake Regulation (SNI 1726-2012). The amplification factor produced for soft soil is 1.7 g, the medium soil is 1.4 g, and hard soil is 1.2 g in accordance with the rules of SNI 1726-2012.

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