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QUICK ASSESSMENT PROCEDURES FOR TWO STORIES BUILDING BASED ON NUMERICAL SIMULATION RESULTS

Febrin Anas Ismail[1], *Abdul Hakam[1], M Maisaquddus Hape[2], M Sofian Asmirza[3]

[1]Engineering Fac., Andalas University, Indonesia; [2] Civil and Environmental Engineering Fac., Institute Technology of Bandung, Indonesia, [3]Engineering Fac., North Sumatra University, Indonesia

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ABSTRACT: Quick assessment is one of an important step in emergency response following an earthquake. This step is mainly purposed to estimate the financial lost based on the building damage criteria. The result of a quick assessment is also needed to determine whether the damaged building can be repaired and reused or not. There are three damage levels which are classified based on the building conditions after the earthquake. Based on the experience, there is a time constraint in conducting the building assessment. Then a quick-correct method is very important to accomplish the task in the limited time. Base on the series of numerical simulation, the quick assessment procedure is proposed in this study. The structural elements that need to be checked in the quick assessment are including column, beam, plate, and foundation. The numerical result was conducted for some two stories buildings with minimum reinforcement on those structural members. The minimum reinforcement requirements are base on Indonesia code SNI-1736-2012. The critical point of every structural component to be checked, especially columns, is discussed here.

Keywords: Earthquake, Quick assessment, Non-engineered two-story building, Indonesian code

1. INTRODUCTION

West Sumatra is a very earthquake-prone province in Indonesia where great earthquakes have been experienced during the last years in this century. In this province, there are two big geological conditions that become the main source of seismicity. The first source is coming from the subduction boundary in the west part of the province. The subduction boundary takes place at convergent boundaries of tectonic plates of Asian continental and the Indian Ocean Plate on the western side of the West Sumatra province. The second source is the great fault of Sumatra that crosses along the middle of Sumatra Island. This fault called Semangko fault that takes place in the eastern part of the Province. Both seismic sources have caused big earthquakes that resulted in damages in the West Sumatra province.

The first big earthquake that caused many construction damages in West Sumatran Island in this century is the Singkarak earthquake that happened in 2005. This earthquake happened on the Semangko fault at the Singkarak segment. The second big earthquake that includes destructive earthquakes in the West Sumatran Island in this century is the Bengkulu earthquake that happened in 2007. This earthquake also triggered a one-meter tsunami along the south part of West Sumatra province. The Bengkulu earthquake also resulted in liquefaction in several places [1]. Then the Padang earthquake in 2009 which resulted in liquefaction in many places in Padang [2]. In 2010, the Mentawai earthquake occurred on the west-central side of Sumatra Island. This earthquake also caused a destructive tsunami in the Pagai Island, the western part of West Sumatra province. The focus of the last three earthquakes is in the subduction zone. Those earthquakes become the reason for the revising the Indonesian earthquake code [3].

All of the big earthquakes in West Sumatra have resulted in the damage of many civil constructions including two-story structure buildings. During the Padang earthquake in 2009, hundreds of two-story buildings have been damaged. The soil characteristics and the structure design are the main reasons why so many two-story buildings suffer from the earthquake. In this paper, the results of the numerical simulation by taking the intention of soil characteristics and structural strength are discussed. The purpose of this study is for developing quick assessment procedures which is one of an important step in emergency response following a big earthquake. This step is mainly purposed to estimate the financial lost based on the building damage criteria.

The other purpose of quick assessment is also determining the damaged building for reparation and re-occupation. There is three damage level generally introduced in Indonesia for classifying the building conditions after the earthquake. Based on the experience in conducting a quick assessment, there is very important to accomplish the task in a limited time. Even the beam and the plate may be damaged by the earthquake, but the column of the two-story building generally destroyed. Then in this discussion, the column capacity during the design earthquake in Padang becomes the main point.

The study on the building assessment regarding the vulnerability of reinforced concrete buildings against earthquake loads has been done by some researchers [4, 5]. Those works indicate the importance of the building assessment related to the earthquake, especially in seismic prone areas.

Fig.1 Damaged building due to the Padang earthquake in 2009 [6]

2. NUMERICAL SIMULATIONS

It is very necessary to analyze the structure responses together with the soil in the same calculation named soil-structure interaction. This analysis has the main advantage of having near real behavior of the structure related to the underneath soil type of the structures. The modeling of soil structure interaction is done by some researcher [7, 8].

The soil characteristics in the Indonesia earthquake code are categories into six sites. However, for the general building purposes, there are only three categories are adopted, that are hard, medium and soft soil sites. Those three categories are differed based on the average of soil strength in terms either Standard penetration value, Nspt, Shear wave velocity, Vs, or, Soil strength, Su. Those three values are rewritten in Table 1.

Based on those values, the numerical simulations are conducted to take the advances of soil-structure interaction methods in which the same structure can be analyzed in three different soils. The soil data for numerical analyses in this study were adopted from those values in the Indonesia Earthquake code (Table 1). The soil modulus parameters for the numerical analysis are calculated based on the following equation:

$$E = G \cdot 2(1+\mu) \quad (1)$$

$$G = \rho \cdot Vs^2 \quad (2)$$

Where G is the shear modulus of soil, ρ is the density and μ is the Poisson's ratio.

Table 1. Site type based on soil characteristic [3]

Site type:	Hard	Medium	Soft
Nspt (blows)	> 50	15 - 50	< 15
Vs (m/s^2)	> 350	175 - 350	<175
Su (kN/m^2)	>100	50-100	< 50

The results of the correlation calculations of the soil mechanic parameters for the numerical analysis are shown in Table 2.

Table 2. Average values of soil parameters

Parameter	Hard	Medium	Soft
Modulus, E (kN/m^2)	563500	265300	90000
Poisson's ratio, μ	0.4	0.3	0.25
qu (kN/m^2)	200	150	80
Density, γ (kN/m^3)	18	16	14

The structural elements of the building in each analysis are designed as reinforced concrete with the minimum reinforcement (Table 3). This applied minimum reinforcement then gives the minimum capacity required for two-story building since the real building may have about the same reinforcement. The typical soil-structure interaction model for numerical simulation are shown in Fig. 2.

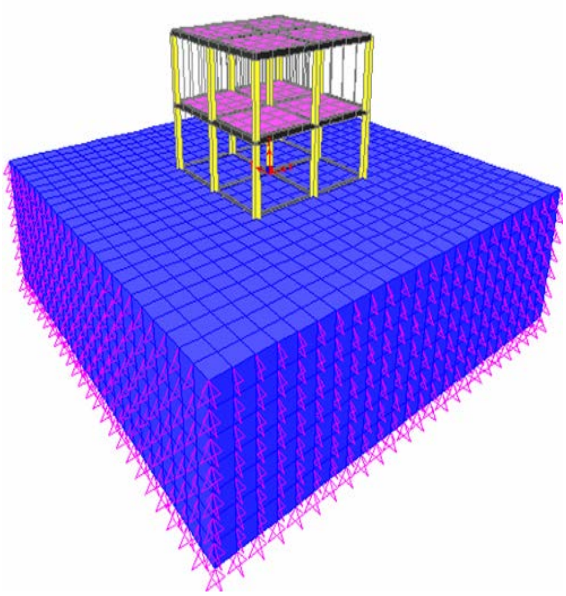


Fig. 2 Typical soil-structure model for analysis

Table 3. Structural element dimensions

Element	Dimension (cm)	Reinforcement (mm)	
		Flexural	Stirrup
Column	30 x 30	4 x D13	ϕ10 - 125
Beam	20 x 30	2 x D13	ϕ10 - 140
Plate	12	ϕ10 - 200	-
Perimeter	20 x 30	2 x D13	ϕ10 - 125

3. ANALYSES AND RESULTS

To investigate the strength of the building against earthquake, finite element models of two-story structure in the three types of ground types are constructed. The geometry of the finite element model shown in Fig. 2 has a height of 3.5m every level and 4.0m between columns. The minimum dimension of the structural element for simulation data was calculated based on the Indonesian code of reinforced concrete for buildings [9].

The applied loads on the models are the self-weight load, live load, and earthquake load. The earthquake load is adopted from the calculation results by the Ministry of Public Service of Indonesia [3] as shown in Fig. 3. The values of Acceleration Spectrum in a unit of g are plotted on Y-axis respect to the period, T in second on X-axis.

The displacement pattern due to the earthquake load is shown in Fig. 4. Meanwhile, the typical internal moment is shown in Fig. 5. The values of displacement and internal forces due to the applied load are given in Table 4.

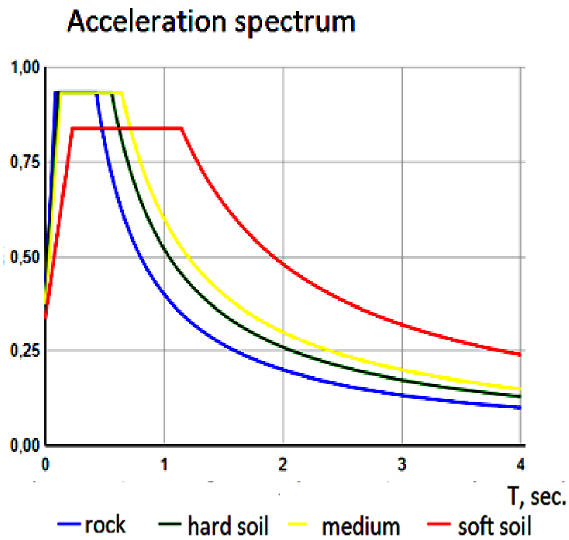


Fig. 3 Earthquake load for numerical analysis

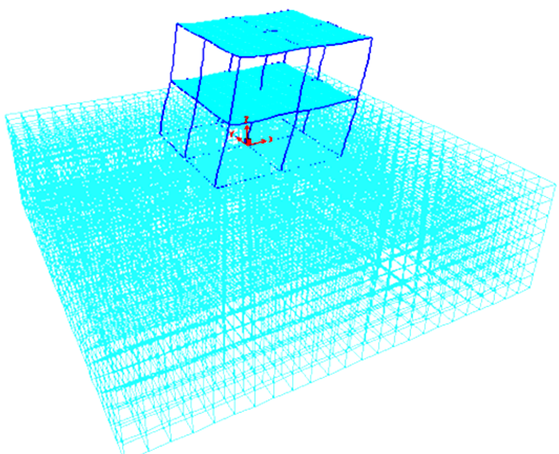


Fig. 4 Typical displacement of the models due to the applied earthquake load.

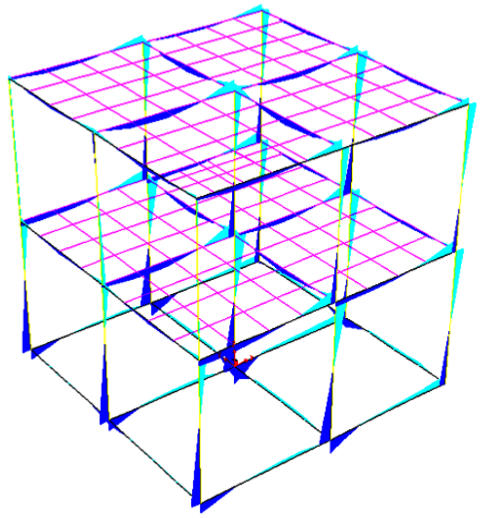


Fig. 5 Typical internal moment due to loads.

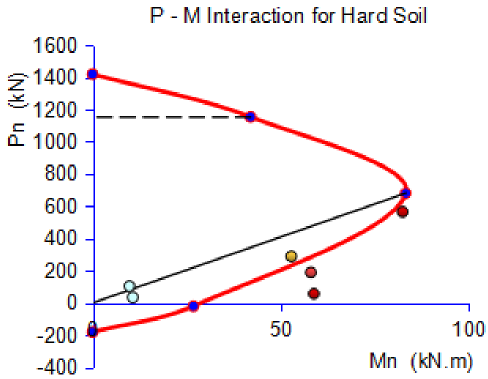
Table 4. Internal forces in column (unit: kN and m)

Column position	Axial (P)	Shear (V)	Moment (M)
Hard soil site			
Edge 2nd storey	-34.97	3.06	-10.68
Edge 1st storey	-57.04	28.76	58.79.
Side 2nd storey	-104.55	-3.45	-9.77
Side 1st storey	-189.04	27.44	58.00
Middle 2nd storey	-289.15	27.78	-52.81
Middle 1st storey	-564.83	45.59	82.36
Medium soil site			
Edge 2nd storey	-36.61	2.08	-9.18
Edge 1st storey	-59.73	29.37	59.18
Side 2nd storey	-104.74	-4.90	-12.61
Side 1st storey	-188.21	29.13	61.32
Middle 2nd storey	-280.95	27.77	-53.05
Middle 1st storey	-549.76	47.08	84.29
Soft soil site			
Edge 2nd storey	-39.90	-.36	-5.69
Edge 1st storey	-67.39	27.20	55.05
Side 2nd storey	-106.25	-8.05	-17.76
Side 1st storey	-192.47	27.61	59.20
Middle 2nd storey	-272.04	25.06	-48.07
Middle 1st storey	-533.16	43.59	77.44

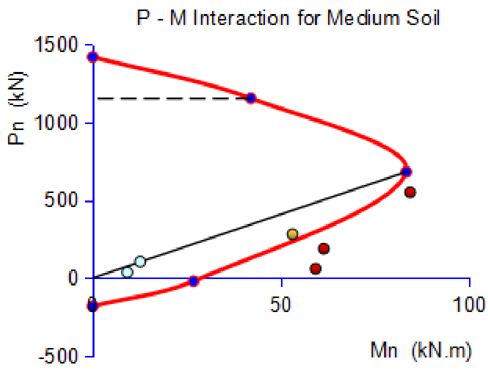
From the numerical results, it can be seen that even though the dimension of the structural element as well as the applied earthquake loads for medium soil site and hard soil site are the same, but the response of the structure give different values. The medium site gives larger internal forces in general. Furthermore, the earthquake load applied to the structure in the soft soil is 10% less than the others. But the responses regarding internal forces give bigger in some points.

The numerical simulations then will be compared to the strength of the structural element to give the idea to built the quick assessment procedure. The results have given the idea to see the soil characteristic in the location of the building during conducting the building assessment in the field soon after the earthquake.

Further, the calculated internal forces are plotted in the column capacity graph to show the better presentation of the load-strength comparison of the column structural elements for each different soil condition. Those load-strength graphs are regarding P-M interaction diagrams and showed in Fig. 6 a, b and c for hard soil, medium soil, and soft soil respectively.

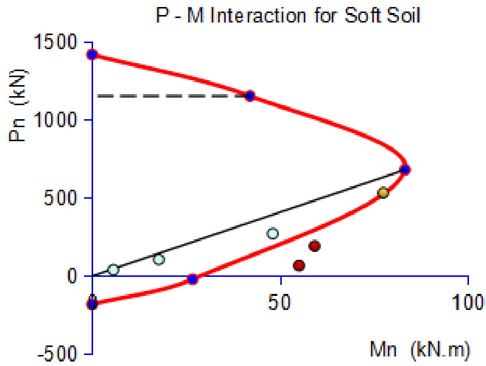


a. Hard Soil



b. Medium soil

The P-M interaction diagrams show that the internal forces in the 1st story for all soil types are out of border the P-M interaction capacity. It indicates that the first story of the buildings on any type of soil failure under an applied seismic load. Meanwhile, the P-M interactions for the second story in the middle columns are on or close to the P-M capacity for all soil types. The application for a quick assessment of these results is that it is very important to do the damage survey on the first level of two story building. But for the upper-level floor, it is necessary to check the damage in the middle columns only but not for side and edge columns.



c. Soft Soil

Fig. 6 Axial and moment diagrams

Fig. 7 A typical first soft story in Padang 2009

Table 5. Shear reinforcement analysis

Hard soil site	
Shear reinforcement	ϕ10 - 150 mm
$V_{u,capacity}$ (kN)	80.36
$V_{u,max}$ (kN)	45.59
$V_{u,capacity} > V_{u,max}$	OK !!
Medium soil site	
Shear reinforcement	ϕ10 - 150 mm
$V_{u,capacity}$ (kN)	80.36
$V_{u,max}$ (kN)	47.08
$V_{u,capacity} > V_{u,max}$	OK !!
Soft soil site	
Shear reinforcement	ϕ10 - 150 mm
$V_{u,capacity}$ (kN)	80.36
$V_{u,max}$ (kN)	43.59
$V_{u,capacity} > V_{u,max}$	OK !!

These results also figure the first soft story phenomena which happened to many building in

Padang during earthquake 2009 (Fig 1 and 7). Based on these results, it is suggested for new two-story buildings must be designed in such a way that the columns in the first story must be stronger than the second story. The second story can be designed for minimum reinforcement according to the Indonesian code, but the first story must be designed at least twice reinforcement of the minimum one.

The internal shear of each structural element was also checked in terms of comparison with the minimum shear capacity. All of the columns can restrain the internal shears since the shear capacity of the minimum stirrup is larger than them as presented in Table 5.

In purpose of build quick assessment tool, it is not so important to check the shear damage of two stories building if the dimension of the columns is larger than it minimum values, that is about 0.85 of their talls.

4. CONCLUSIONS

Padang is the capital city of the West Sumatra is a very earthquake-prone city in Indonesia. The city has experienced many big during the last years in this century. There are two main sources of the earthquake in Padang, first is coming from the subduction boundary in the west part and the second source is the great fault of Sumatra the eastern part. Many big earthquakes have resulted in damages in the West Sumatra province from those sources.

In the purpose of building a quick assessment tool, it is very important to accomplish numerical simulations of typical building structures in the different soil type sites. The analysis of two stories building subjected to Indonesia code earthquake loading in Padang become the main point. The damages of the two-story buildings mainly happen on the first floor due to the less strength of the column on axial and moment interaction.

The numerical results show that for the medium soil site and hard soil site with the same load, give different responses to the structure. Furthermore, for the soft soil with 10% less earthquake load, the responses regarding internal forces give bigger in some points. This work is still under further investigation but results have given the idea to see the differences in soil characteristic during conducting the building assessment due to the earthquake. However, the preliminary results give the idea to check the first floor is very important in quick assessment procedure for building after an earthquake. It is also necessary to check the second floor if the two-story buildings have the internal column.

5. ACKNOWLEDGMENTS

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