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IMPROVEMENT OF STRUCTURAL ANALYSIS BY MODIFICATION OF SITE RESPONSE ANALYSIS AND EARTHQUAKE FORCE DIRECTION

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ABSTRACT: The seismic resistance design of buildings in Indonesia is usually performed based on the most recent Indonesian Seismic Code (ISC). Improvement of the ISC will sometimes produce different (increasing or decreasing) earthquake forces for building design. This paper describes the study of building evaluation by conducting a modified Site Response Analysis (SRA) and a modified incoming earthquake force direction. The modified SRA was performed as a result of in-complete soil boring investigation through the bedrock elevation, using 30 m (soil boring investigation) and 50 m (microtremor investigation) soil profile models. The earthquake force towards the building is computed using a pair (East-West/EW and North-South/NS) of ground motion (acceleration time histories) models. Due to the unpredictability of incoming earthquake forces, these models are improved by adjusting the ground motion direction to the building by rotating a pair of ground motions from 0^o to 180^o at 10^o intervals. The time histories were developed according to the Deterministic (DSHA) and Probabilistic (PSHA) Seismic Hazard Analysis. The analysis was performed by evaluating the moment capacity ratio of the building's existing column reinforcement in resisting the earthquake force. The surface time histories and spectrum accelerations computed using the 50 m model is slightly higher (10%) than the same output calculated using the 30 m model. In terms of the moment capacity ratio, the existing column reinforcement of the building is strong enough to resist seismic earthquake scenarios, and the minimum value is observed when the ground motion is rotated by 40^o.

Keywords: Site response analysis; Microtremor; Ground motion; PSHA; DSHA

1. INTRODUCTION

The seismic resistance design of buildings is usually performed by applying a seismic or earthquake force model in terms of spectral acceleration. For design purposes, the Indonesian Seismic Code describes an easier method for preparing the spectrum acceleration design. The spectrum acceleration for building design in Indonesia can be computed using online software (website) facility and is developed based on updated earthquake records collected from all earthquake events in Indonesia.

Seismic resistance design and evaluation can also be performed using surface ground motion in terms of acceleration time histories developed from the accelerometer data of a specific earthquake. To develop surface or design acceleration time histories that can be applied for structural analysis requires the bedrock position or elevation data and all the soil layer data from the bedrock up to the surface elevation. The bedrock position measurements can be carried out utilizing single or array microtremor tests. The soil deposit data can be obtained by conducting soil boring investigations and laboratory measurements.

A soil investigation is commonly carried out when preparing sub surface design requirements. The deepness of the soil investigation data acquisition has a direct correlation with the type of subsurface structure used and the bearing capacity requirements of the foundations. Usually the soil boring investigation has no correlation with the bedrock elevation. For a building located on a soft soil layer having a bedrock elevation more than 100 m, time and money will be needed to prepare soil deposit data, compared to the normal soil boring investigations used for foundation design purposes.

The spectral acceleration data applied to building structure design is usually divided into two directions perpendicular to the building's position (X and Y, or 0^o and 90^o directions). As the building's position relative to the seismic source is unknown, it is difficult to ensure the seismic force direction for building structure design. This paper describes an example of structural analysis calculated using modified acceleration time histories or seismic force directions. The analysis is conducted by first improving the depth of the soil deposit model for SRA by taking a 30 m soil deposit model adapted from a soil boring investigation. The spectral acceleration and the ground motion are then compared to the same analysis using a 50 m soil deposit model developed from microtremor investigation data. The purpose of this analysis is to obtain the differences between the surface ground motion (acceleration time histories) and surface spectrum accelerations computed based on those two models in order to improve them.

The second improvement is conducted by gradually modifying the two perpendicular directions of earthquake forces, EW (East-West) and NS (North-South), time histories from 0^o to 180^o at 10^o intervals relative to the building's position. The purpose of this second improvement is to obtain the minimum moment capacity ratio of the existing column reinforcement and the correlation between the moment capacity ratio and ground motion direction.

2. METHODOLOGY

The modified structural analysis in this research was conducted at the Diponegoro University Semarang (Indonesia) building (40.75 x 16.2 m^2 and 43.2 m height). The building was first open on March 10 2017 and was designed and constructed based on the Indonesian Seismic Code 2012 [1].

2.1 Soil Investigations

Two types of soil investigations were performed in the building area. The soil boring investigation was first performed to design the foundation system to support the upper structure and was conducted down to a 30 m depth. According to the N-SPT data obtained on site, the building was found to be located on medium site class soil/SD [1−3].

The second soil investigation was related with the measurement of the predicted bedrock elevation and was performed using single station three-component microtremor at 22 positions surrounding the building position. Fig.1 shows the site plan of the study area, the building position, soil boring position and microtremor test positions. Figs.2 and 3 show the microtremor results analysis in terms of the shear wave velocity profile. As can be seen in these figures the bedrock elevation is predicted at 40 to 50 m below the surface level. This prediction is based on the shear wave velocity (VS) value [1-4].

2.2 Site Response Analysis (SRA)

The SRA is conducted based on two different soil profiles. The first profile is applied using the predicted bedrock elevation (50 m) and the second profile using the 30 m soil deposit model [5-6]. The second model is adjusted in this research due to incomplete data or soil boring investigation from -50 m up to -30 m. The soil boring investigation data was performed until a maximum 30 m depth due to the requirement for the foundation design of the structure and the minimum requirement for site class calculation [1]. Fig.4 shows the first soil profile model (Model-1) using the predicted bedrock elevation. Fig.5 shows the second soil profile model (Model-2). The VS (shear wave velocity) values embedded in these two profiles (0-30 m) are developed using three empirical correlation proposed by [7-9] and the microtremor data. The bedrock position is forecasted at 50 m underneath the surface position.

Fig.1 Study area and building position

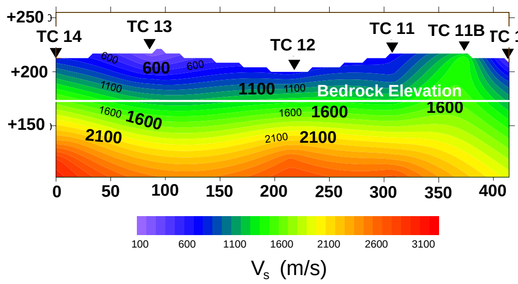

Fig.2 VS Profile of Section 1-1

The SRA is calculated using two different directions of time histories (EW and NS) collected from a 6.52 Mw earthquake event with an epicenter distance of 5.07 km. To perform the SRA, two different response spectral targets are developed in this study based on two different types of seismic hazard analysis: 2500 years return period PSHA (2% probability of exceedance in 50 years) and Deterministic approach (DSHA). The modified ground motions are then recalculated using response spectral matching analysis. Fig. 6 shows the two spectral targets used for spectral matching analysis in order to obtain the modified ground motion at the bedrock elevation. The modified ground motions are used for SRA for obtaining the surface ground motion in terms of acceleration time histories and spectrum acceleration. The PSHA spectral acceleration target was computed based on the new 2017 Seismic Hazard Map of Indonesia [10]. However, the DSHA spectral acceleration target was calculated using three different attenuation functions [11-13].

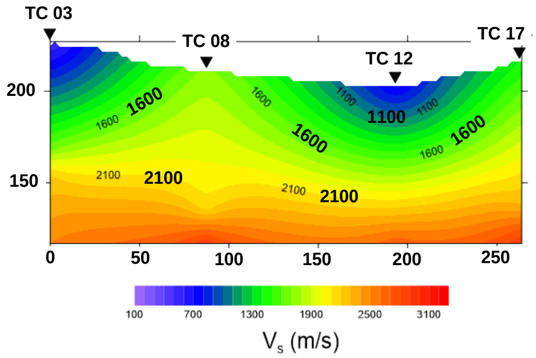

Fig.3 VS Profile of Section 2-2

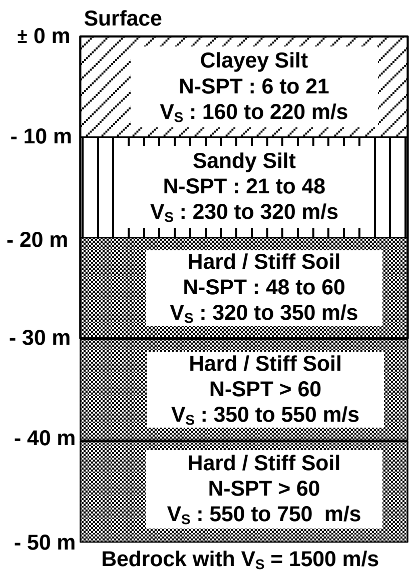

Fig.4 Soil deposit model 50 meter (Model-1)

The two orientations of modified acceleration time histories (EW and NS) developed using the PSHA and DSHA spectral acceleration targets are then used for the SRA using two different soil profile models as shown in Figs. 4 to 8 show the two different adjusted ground motions (EW and NS) computed based on the PSHA and DSHA spectral acceleration targets. As can be seen in those two figures the acceleration time histories computed using PSHA has peak acceleration almost equal to the time histories calculated using DSHA. According to the response spectral matching calculations, the acceleration time histories developed using PSHA is used for SRA.

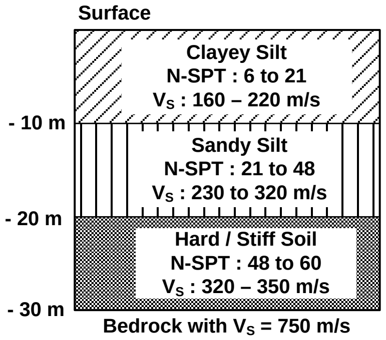

Fig.5 Soil deposit model 30 meter (Model-2)

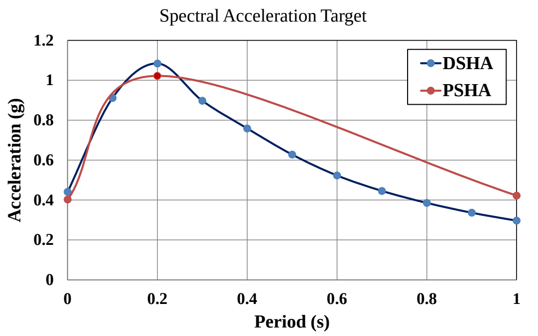

Fig.6 PSHA and DSHA spectral acceleration target

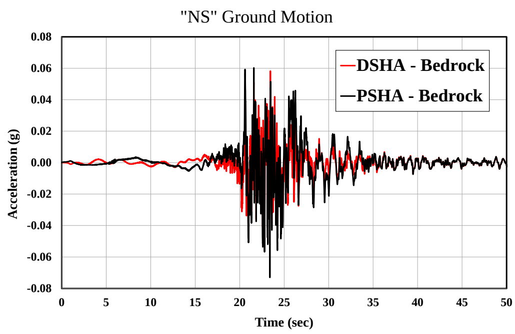

Fig.7 Modified NS direction time histories.

2.3 Structural Analysis

The earthquake forces model used and applied to the structures is based on surface ground motions in two directions, NS and EW obtained from SRA [14 - 17]. The NS direction is perpendicular to the EW direction. Both ground motion directions are then gradually rotated from 0° to 180° at 10° intervals. The existing columns are evaluated to obtain the moment capacity ratio of longitudinal concrete column reinforcement. The moment capacity ratios for all earthquake force directions are then evaluated and compared to obtain the correlation chart between the earthquake force direction and moment capacity ratio. The minimum moment capacity ratio in terms of the force direction can be obtained using this chart. Fig. 9 shows the model of the earthquake directions used for the structural analysis.

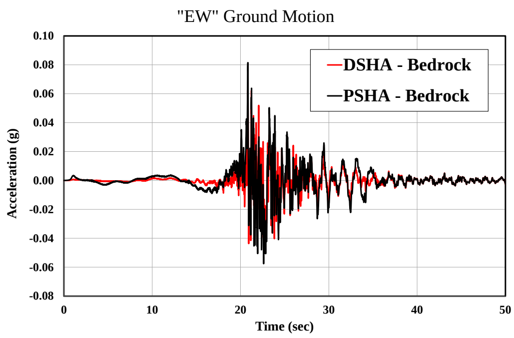

Fig.8 Modified EW direction time histories

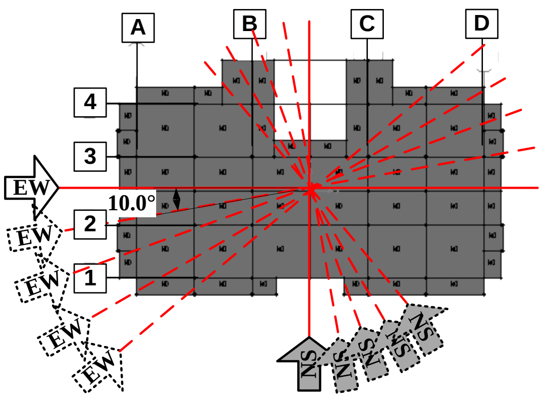

Fig.9 Improvement of earthquake forces directions used for structural analysis

3. RESULT AND DISCUSSIONS

Surface acceleration time histories accommodated and applied in this study were calculated using two soil profile models, Model-1 and Model-2. According to the analysis performed for both models by employing the two different time histories EW and NS directions, the surface acceleration time histories calculated for the two models are almost equal. Fig.10 shows the difference of the NS surface ground motions developed using the two models. As can be seen in Fig.10 the absolute maximum acceleration developed using Model-1 is 0.22 g while the absolute maximum acceleration developed using Model-2 is 0.21g.

Fig.11 shows the difference of the EW surface acceleration time histories computed using the 50 m and 30 m soil deposit models. The absolute maximum acceleration developed using Model-1 is 0.18 g and the absolute acceleration developed using Model-2 is 0.16 g. Based on the two different soil profile models developed for the SRA, the maximum surface acceleration for the NS and EW directions is almost equal. Fig. 12 shows the four different surface spectrum accelerations computed using the 50 m and 30 m different SRA models and that the EW and NS spectrum accelerations computed using the Model-1 and Model-2 models are almost equal.

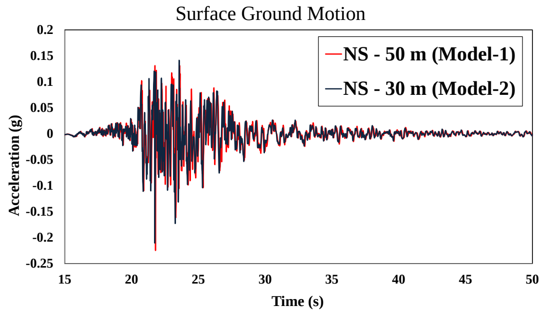

Fig.10 Surface NS direction acceleration time histories calculated using two SRA models

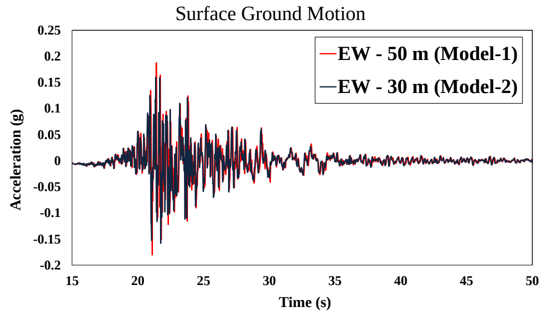

Fig.11 Surface EW direction acceleration time histories calculated using two SRA models

Fig.13 shows the difference of the Peak Ground Acceleration (PGA) profiles computed using the Model-1 and Model-2 SRA models. The PGA values computed based on Model-1 is greater than those calculated using Model-2. All the PGA profiles developed using the two models are almost equal (coincident) with maximum differences of surface PGA is 0.03 g (16%) for the NS and 0.01 g (5%) for the EW. The average surface PGA difference of Model-1 is 10.5% greater than Model-2. Table 1 shows the difference surface PGA output calculated based on the two soil profile models. Based on the analysis for developing surface ground motions using the two models, the 30 m soil profile model (Model-2) can be used as an alternative for developing the surface ground motion. The second soil deposit model (Model-2) used for the SRA is based on the maximum soil boring investigation.

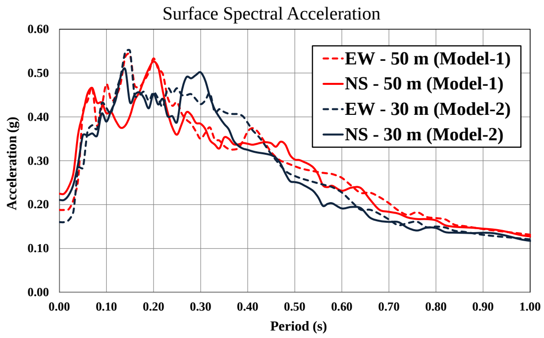

Fig.12 Surface spectral acceleration developed using two SRA models

Table 1 Peak ground acceleration of two models

Model	Elevation. (m)	PGA NS (g)	PGA EW (g)
Model-1	0	0.19	0.22
	50	0.07	0.07
Model-2	0	0.16	0.21
	30	0.07	0.07

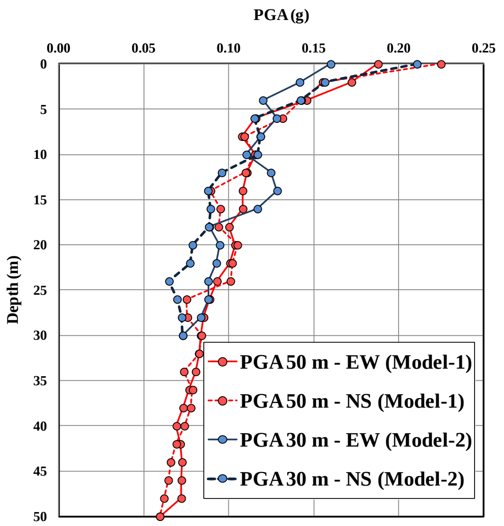

Fig.13 PGA profiles developed using two different models

The surface ground motions, EW and NS, used for structural analysis are two perpendicular ground motion developed based on SRA Model-2. Both ground motions are gradually increased and rotated from 0° through 180° at 10° intervals. The example column elements used for structural analysis have dimensions of 700x700 mm^2 and 700x900 mm^2 and longitudinal reinforcement 32D25 and 48D25 respectively. Fig.14 shows the 700x700 longitudinal and transversal column's reinforcement. Fig.15 shows the 700x900 longitudinal and transversal column's reinforcement.

The moment capacity ratio (ϕMn/Mu) is calculated for all element structures. Fig.16 shows the moment capacity ratio of the 700x700 and 700x900 columns. The moment capacity ratios are calculated in terms of the earthquake force directions towards the structure. As can be seen in Fig. 16, the minimum moment capacity ratios for the 700x700 and 700x900 column are observed at earthquake force directions of 40°. The minimum moment capacity ratio for the 700x700 and 700x900 columns are 2.361 and 1.998, respectively. The minimum moment capacity ratios for the 700x700 column are 12.5% to 17.7% smaller than the moment capacity ratios calculated for 0° and 90°, while the minimum moment capacity ratios for the 700x900 are 14.5% to 20.7% smaller than the moment capacity ratios calculated for 0° and 90°.

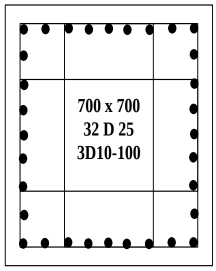

Fig.14 Reinforcement of column 700x700 mm^2

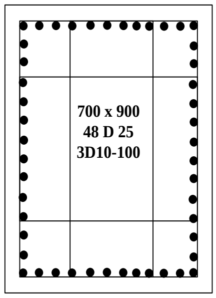

Fig.15 Reinforcement of column 700 x 900 mm^2

Based on the analysis of moment capacity ratio for the 700x700 and 700x900 columns, the existing column size and reinforcements have a minimum moment capacity ratio of 1.998, greater than 1. All the exiting column reinforcements are predicted to be safe enough to resist 6.5 magnitude earthquake forces and a minimum epicenter distance 5 km. Table 2 shows the moment capacity ratio calculated for 0 and 90° (the X and Y directions usually used for building structural design) compared to the minimum moment capacity ratio obtained at the 40° direction of ground motion as can be seen in Fig. 16.

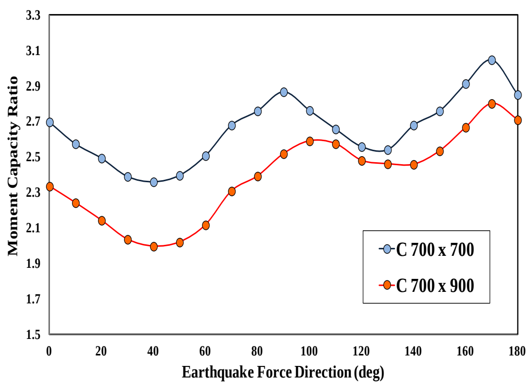

Fig.16 Moment capacity ratio curves in terms of earthquake force directions for column 700x700 and 700x900

Table 2 Moment capacity ratio of column 700x700 and 700x900

Model	Force direction (deg)	ϕMn/Mu	ϕMn/Mu minimum (40 deg)
700 x 700	0	2.698	2.361
	90	2.868	
700 x 900	0	2.336	1.998
	90	2.519	

4. CONCLUSIONS

An improved SRA is conducted in this study for calculating surface ground motion (acceleration time histories). Two different models of soil layer, 50 m and 30 m soil deposit above bedrock elevation are conducted in this study. Surface peak ground acceleration computed using 30 m soil layer model is approximately 10% smaller compared to the 50 m soil layer model.

The modified Site Response (Site Specific) Analysis (SRA) can be implemented or adjusted using a 30 m soil instead of the real soil layer model developed using the real bedrock elevation. The adjusted SRA can be applied where there is in-complete data from the soil boring investigation or when the predicted bedrock elevation is greater than 30 m.

An improved analysis of the incoming earthquake force toward the building position was performed in this study by adjusting the earthquake directions from 0^o to 180^o. In terms of the moment capacity ratio of the column reinforcement, the minimum moment capacity ratio is observed at the 40^o earthquake direction and is reduced to approximately 15% less than the commonly used X and Y (0^o and 90^o) or horizontal structural analysis directions.

5. ACKNOWLEDGEMENT

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