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Strength Evaluation of Reinforced Concrete Structure for Regular Building due to Earthquake Load Based on Different Soil Types

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ABSTRACT Earthquakes are natural events caused by tectonic plate movements and it is unpredictable. Thus, the building design regulation has an important role in ensuring the Earthquake resistant structure. A commonly used method is the response spectrum method. For different soil types, the value of the design spectra may increase or decrease. Therefore this study aims to determine the effect of soil type on the strength of reinforced concrete structures, especially the building behavior and structural internal forces. Analysis results show that the increase of base-shear value of Makassar is about 34% and 103% for medium soil and soft soil condition compared to hard soil. The increase of beam negative moment is about 27% to 39% in soft soil compared to hard soil, while the value is about 8% to 14% in medium soil compared to hard soil. The increase of beam positive moment varies considerably between 8% to 50%. The increasing moment is directly proportional to the required reinforcement area of the beam. Demand capacity ratio of column has also increased about 10% to 35% for medium soil and soft soil compared to hard soil.

KEYWORDS Soil type; Seismic; Reinforced concrete

1 INTRODUCTION

Earthquakes are natural events caused by tectonic plate movements and it is unpredictable (Soelarso, Baehaki and Novtikania, 2016). This phenomenon begins with a clash of plates in the Earth's crust that directly makes the building on the Earth's surface vibrate. This vibration may develop the internal force in the building due to its stiffness to resist vibration. Excessive vibration can cause severe damage and even further the collapse of the building. Therefore, the shock caused by the movement of tectonic plates is one of the main causes of structural damage. Indonesia is an area prone to earthquakes due to its geographical location at the meeting of four major tectonic plates of Eurasia, Indo-Australia, the Pacific and the Philippines (Hasan and Astira, 2013). This results in a high-intensity earthquake in Indonesia.

Thus, the regulation for earthquake-resistant building has a major role in ensuring the building safety. In the last decade, the damage caused by the earthquake has exceeded the predictions of the Indonesian building regulations. Severe building damage has been occurred in Aceh, Yogyakarta, and Padang due to the unpredicted large force earthquake. This is influenced by the increase of peak ground acceleration which is greater than the value in Indonesian code SNI 1726:2002. Therefore there is a need to revise the code from SNI 1726:2002 to SNI 1726:2012 (National Standardization Agency, 2012).

The variation of peak ground acceleration due to the changes in earthquake code resulted in varying seismic load for each region in Indonesia (Cornelis, Bunganaen and Tay, 2014). In addition, the effect of vertical seismic load in SNI 1726:2012 also needs to be included in calculations, in contrast to SNI 1726:2002 which is optional only. The legitimation of SNI 1726:2012 means that all the buildings should be planned by using the new regulations.

The earthquake force is affected by the soil type. The fast movement on the ground due to soil vibration will lead to larger deformation in buildings especially in soft soil cases (Jingga, Suryanita and Yuniarto, 2015). Excessive building deformation will cause even sudden collapse of the building. The higher building will have larger displacement due to larger deformation. The seismic force is the base shear force that acts on the base of the building and will be distributed vertically along the height of the structure as the horizontal story force (Faizah and Widodo, 2013).

Story shear is gained by summing the horizontal story forces. One of the most commonly used methods in

SNI 1726:2012 is the response spectrum method. Generally, in this method, the soil classification is divided into three types. There are hard soil (SC), medium soil (SD) and soft soil (SE). For different soil types, the value of the design spectra may increase or decrease (Arfiadi and Satyarno, 2013). This variation of the design leads to the changes of either the internal force or seismic force distribution values. But the question about the effect of soil types in seismic force has not been fully answered. In addition, the impact on the design of structural strength is also questioned.

Reinforced concrete structure is a commonly used structure in Indonesia construction. The concept of earthquake-resistant building is the structure should not collapse due to strong earthquakes (nominal earthquake) and should have the ability to dissipate the seismic loads (Sudarsana and Yudha, 2014). It is also well-known as the capacity design method. In this method, the structural elements which will yield first should be determined (weak element). These elements will undergo plastification (damage) first in order to anticipate earthquake energy in the structure. Therefore, structural ductility plays an important role.

Other structural elements that do not undergo plastification should still behave elastically during strong earthquakes. In SNI 2847-2013 (National Standardization Agency, 2013b) this concept is fully described in the requirements of Special Moment Resisting Frame (SMRF) (Imran and Hendrik, 2010). SMRF has the highest ductility and should be used in earthquake-prone areas. Therefore this study aims to determine the effect of soil type on the strength of reinforced concrete structures, in this case to review the building behavior and the internal forces.

2 RESEARCH METHODS

The function of the building as an office and located in Makassar. The live load value is 240 kg/m^2 based on SNI 1727:2013 (National Standardization Agency, 2013a). Seismic force analysis is based on SNI 1726:2012 while the reinforced concrete analysis is based on SNI 2847:2013. The building is a reinforced concrete structure with a height variation of 5-stories building + roof (h = 19.30 m), 8-stories + roof (h = 30.40 m) and 10-stories + roof (h = 37.80 m).

Each building was analyzed with seismic load for hard soil (SC), medium soil (SD) and soft soil (SE). The lateral system is the Special Moment Resisting Frame (SMRF). Structural plan is typical for entire floors, except for roof (Figure 1). The structural model was analyzed by using ETABS program. The 3D model of the building is illustrated in Figure 2.

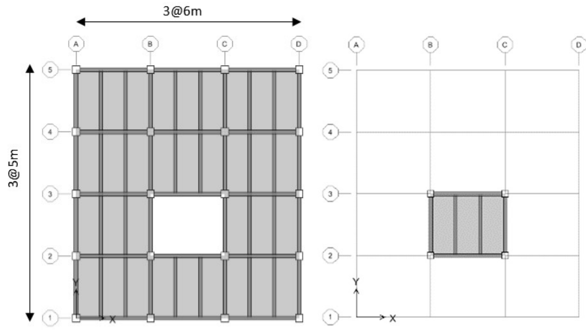

Figure 1. Floor and roof plan.

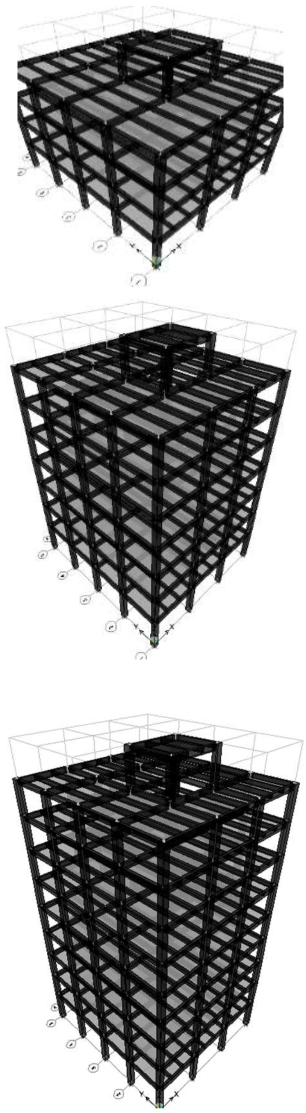

Figure 2. 3D model for 5-stories, 8-stories and 10-stories.

The primary beam dimension is typical for the all structural models. Beam 300 mm x 600 mm is used for 6 m span and 300 mm x 500 mm for 5 m span. The secondary beam dimension is also typically 250 mm x

500 mm. The column dimensions are 500 mm x 500 mm, 550 mm x 550 mm and 600 mm x 600 mm sequentially for the 5-stories, 8-stories and 10-stories model. Slab thickness is typically 120 mm. Concrete strength is f'c = 25 MPa and rebar strength is BJTS40 (fy = 390 MPa). The design response spectrum is illustrated in Figure 3.

Figures 4 and 5 show the difference of spectral acceleration for short period (SDS) and 1 second (SD1)

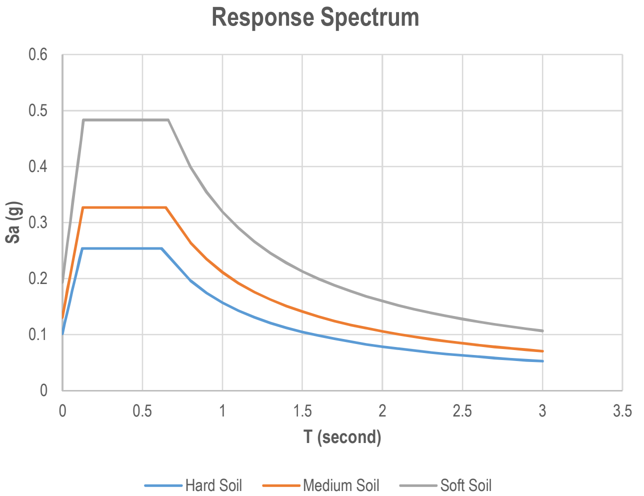

Figure 3. Response spectrum for Makassar with three soil types.

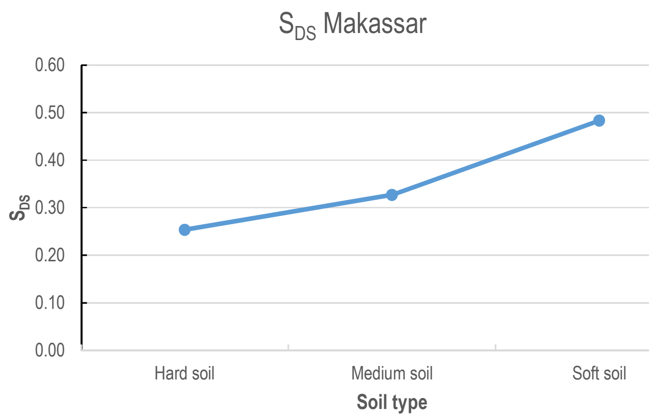

Figure 4. Spectral acceleration for short period.

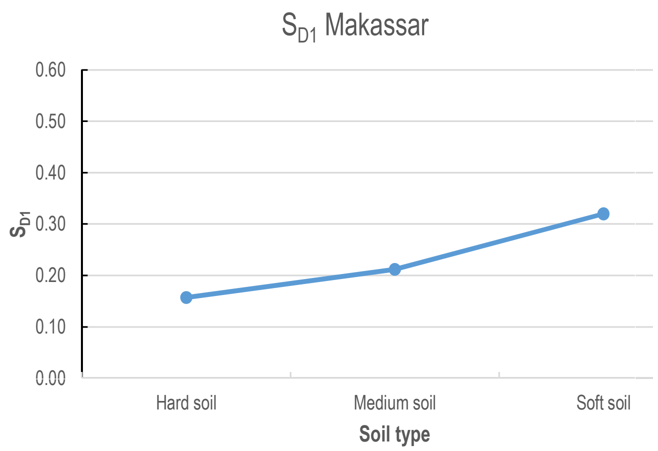

Figure 5. Spectral acceleration for 1 second period.

period for all three soil types. The difference of SDS values for medium and soft soils are 28.92% and 90.58% compared to hard soil. While the difference of SD1 values for medium soil and soft soil are 34.62% and 103.50% compared to hard soil. This difference is quite high, especially when comparing the hard soil to soft soil. It certainly has an impact on the magnitude of the seismic load in the building.

3 RESULTS AND DISCUSSION

Analysis results show that the static base-shear for both X and Y directions are controlled by the minimum value of vibration period so that the value is the same for both directions. The dynamic base-shear should have a minimum value of 85% static base-shear. In this case, the seismic load values for all models need to be scaled back by using the scale factor 0.85 $V_{static}/V_{dynamic}$. The maximum difference of scale factor between soft soil compared to hard soil is 0.28%, 0.90% and 6.78% for 10-stories, 8-stories and 5-stories buildings, while for the medium soil is 0.18%, 0.61% and 4.44% for 10-stories, 8-stories and 5-stories buildings. It can be seen that the smaller difference of the scale factor for different soil types could be found as the increasing of building height (Table 1). Thus the effect of different soil types tends to be insignificant to the dynamic scale factor ($V_{static}/V_{dynamic}$) for higher building. In contrast to lower buildings, soft soil tend to produce larger scale factor compared to hard soil (6.78% for 5-stories buildings).

The story shear result can be seen in Figure 6. The graph curvature becomes smaller as the soil becomes harder. It is influenced by the smaller base-shear value when the soil become harder so that the distribution of seismic load to each level also decreases. It could be also seen that the percentage difference of building maximum displacement is directly proportional to the base shear of the building (Table 2).

Table 1. Scale factor and base-shear for 10-stories, 8-stories and 5-stories buildings.

Total stories	Soil type	Scale Factor-X		Scale Factor-Y	
	Hard*	2.351	0.00%	2.595	0.00%
10	Medium	2.354	0.14%	2.600	0.18%
	Soft	2.356	0.21%	2.602	0.28%
	Hard*	2.240	0.00%	2.482	0.00%
8	Medium	2.254	0.61%	2.488	0.26%
	Soft	2.260	0.90%	2.491	0.37%
	Hard*	2.789	0.00%	2.824	0.00%
5	Medium	2.913	4.44%	2.950	4.44%
	Soft	2.978	6.78%	3.016	6.78%

*hard soil as reference value for percentage calculation

Table 2. Maximum displacement

Total stories	Soil type	Max X-disp (mm)		Max Y-disp (mm)	
	Hard*	19.80	0.00%	27.72	0.00%
10	Medium	26.65	34.61%	37.31	34.58%
	Soft	40.29	103.48%	56.29	103.03%
	Hard*	15.24	0.00%	21.88	0.00%
8	Medium	20.60	35.17%	29.37	34.21%
	Soft	31.28	105.22%	44.51	103.39%
	Hard*	11.51	0.00%	16.17	0.00%
5	Medium	15.76	36.94%	22.49	39.14%
	Soft	23.78	106.62%	34.67	114.45%

*hard soil as reference value for percentage calculation

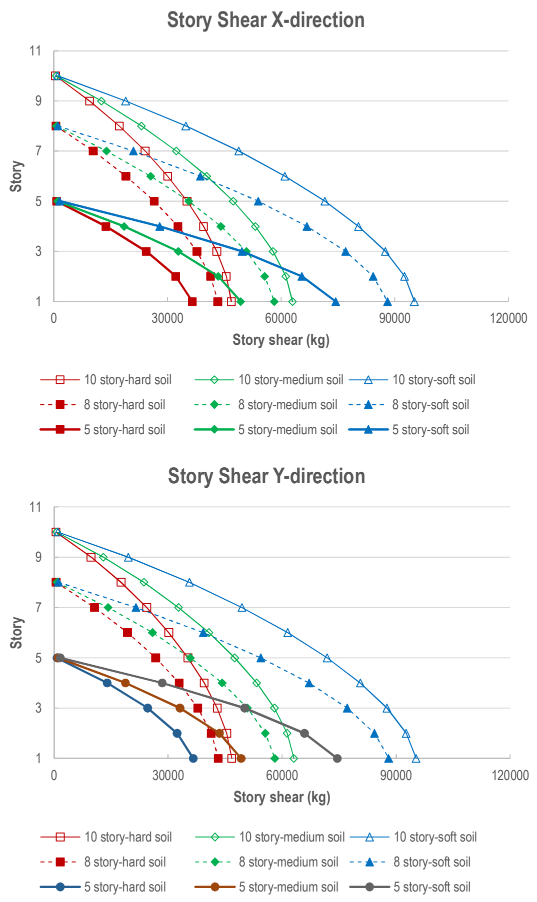

Figure 6. Story shear for X and Y direction.

Differences in base-shear values due to different soil types tend to be almost the same (less than 5%) for all models. This indicates that the difference of building height does not affect the proportion of base-shear values for different soil types. The increase of beam negative moment for B30x60 in soft soil is 28.26%, 27.10% and 28.95% compared to hard soil for 10-stories, 8-stories and 5-stories building respectively (Table 3), while for medium soil is 9.60%, 8.67% and 10.13%. The increase of beam negative moment for B30x50 in soft soil is 36.39%, 34.67% and 38.80% compared to hard soil for 10-stories, 8-stories and 5-stories building respectively, while for medium soil is 12.35%, 11.62% and 13.37% (Table 4). It can be concluded that the increase of beam negative moment is about 27% to 39% in soft soil compared to hard soil, while for medium soil is about 8% to 14%.

Table 3. Ultimate moment and rebar areas B30x60.

Total stories	Soil type	positive/ negative	B30x60 Ultimate moment (t.m)		A_s (mm^2)	
10	Hard*	pos	10.60	0.00%	573	0.00%
		neg	17.62	0.00%	964	0.00%
	Medium	pos	10.60	0.00%	573	0.00%
		neg	19.31	9.60%	1063	10.27%
	Soft	pos	11.45	8.08%	614	7.16%
		neg	22.60	28.26%	1259	30.60%
8	Hard*	pos	10.87	0.00%	581	0.00%
		neg	17.32	0.00%	947	0.00%
	Medium	pos	10.87	0.00%	581	0.00%
		neg	18.82	8.67%	1034	9.19%
	Soft	pos	11.78	8.40%	632	8.78%
		neg	22.01	27.10%	1224	29.25%
5	Hard*	pos	11.24	0.00%	602	0.00%
		neg	18.92	0.00%	1040	0.00%
	Medium	pos	11.56	2.88%	620	2.99%
		neg	20.83	10.13%	1153	10.87%
	Soft	pos	13.10	16.61%	706	17.28%
		neg	24.39	28.95%	1368	31.54%

*hard soil as reference value for percentage calculation

Table 4. Ultimate moment and rebar areas B30x50.

Total stories	Soil type	positive/ negative	B30x50 Ultimate moment (t.m)		A_s (mm^2)	
10	Hard*	pos	6.69	0.00%	477	0.00%
		neg	10.81	0.00%	705	0.00%
	Medium	pos	6.69	0.00%	477	0.00%
		neg	12.15	12.35%	797	13.05%
	Soft	pos	8.19	22.33%	608	27.46%
		neg	14.75	36.39%	981	39.15%
8	Hard*	pos	6.76	0.00%	477	0.00%
		neg	10.86	0.00%	709	0.00%
	Medium	pos	6.76	0.00%	477	0.00%
		neg	12.13	11.62%	796	12.27%
	Soft	pos	7.95	17.58%	601	26.00%
		neg	14.63	34.67%	973	37.24%
5	Hard*	pos	6.86	0.00%	477	0.00%
		neg	11.18	0.00%	730	0.00%
	Medium	pos	6.86	0.00%	478	0.21%
		neg	12.67	13.37%	834	14.25%
	Soft	pos	10.31	50.35%	752	57.65%
		neg	15.52	38.80%	1036	41.92%

*hard soil as reference value for percentage calculation

The increase of beam positive moment for B30x60 in soft soil is 8.08%, 8.40% and 16.61% compared to hard soil for 10-stories, 8-stories and 5-stories building respectively, while for medium soil is 0.00%, 0.00% and

2.88%. The increase of beam positive moment for B30x50 in soft soil is 22.33%, 17.58% and 50.35% compared to hard soil for 10-stories, 8-stories and 5-stories building respectively, while for medium soil does not change. It can be seen that the increasing pattern of the beam negative moment tends to be almost the same (Figure 7), while the increasing pattern of beam positive moment is different, especially for 5-stories building (Figure 8). It is influenced by the difference in seismic scale factor that is quite visible in the 5-stories building, as stated before. As for the negative moment, this difference does not seem to be changing significantly because of the effect of gravity moments at the support area.

The difference of longitudinal rebar area is directly proportional to the moment (Table 3 and Table 4). Table 5 and 6 shows the converted diameter and rebar amount. It can be seen that the increase in the number of rebar is about 1 to 2 rebars. The stirrup rebar area for shear reinforcing is then calculated based on the used longitudinal rebar using capacity design method (Table 7 and 8). It can be seen that the maximum difference between the stirrup rebar areas is about 15.00% for soft soil compared to hard soil.

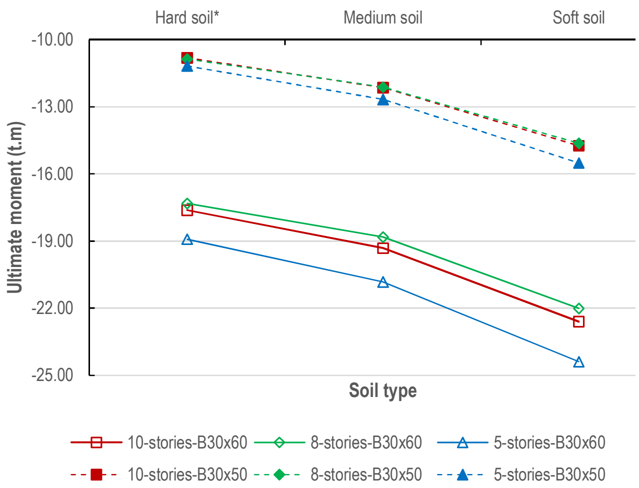

Figure 7. Beam negative moment.

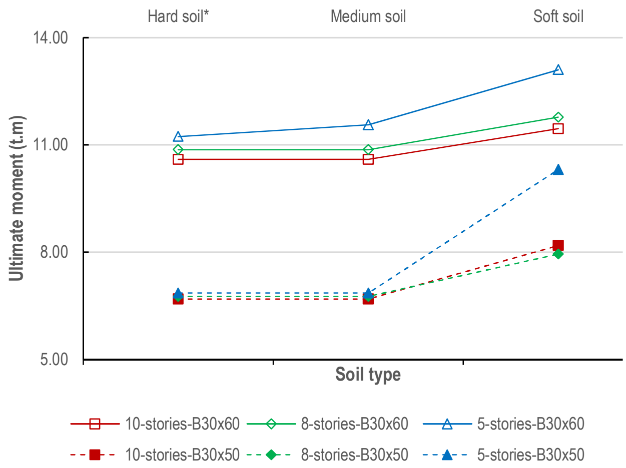

Figure 8. Beam positive moment.

Table 5. The converted diameter and rebar amount B30x60

Total stories	Soil type	pos/neg	B30x60		
			$A_{s\ req}$ (mm^2)	Rebar use	A_s (mm^2)
10	Hard*	positive	573	3D16	603.19
		negative	964	5D16	1005.31
	Medium	positive	573	3D16	603.19
		negative	1063	6D16	1206.37
	Soft	positive	614	4D16	804.25
		negative	1259	7D16	1407.43
8	Hard*	positive	581	3D16	603.19
		negative	947	5D16	1005.31
	Medium	positive	581	3D16	603.19
		negative	1034	6D16	1206.37
	Soft	positive	632	4D16	804.25
		negative	1224	7D16	1407.43
5	Hard*	positive	602	3D16	603.19
		negative	1040	6D16	1206.37
	Medium	positive	620	4D16	804.25
		negative	1153	6D16	1206.37
	Soft	positive	706	4D16	804.25
		negative	1368	7D16	1407.43

*hard soil as reference value for percentage calculation

Table 6. The converted diameter and rebar amount B30x50.

Total stories	Soil type	pos/neg	B30x50		
			$A_{s\ req}$ (mm^2)	Rebar use	A_s (mm^2)
10	Hard*	positive	477	3D16	603.19
		negative	705	4D16	804.25
	Medium	positive	477	3D16	603.19
		negative	797	4D16	804.25
	Soft	positive	608	4D16	804.25
		negative	981	5D16	1005.31
8	Hard*	positive	477	3D16	603.19
		negative	709	4D16	804.25
	Medium	positive	477	3D16	603.19
		negative	796	4D16	804.25
	Soft	positive	601	3D16	603.19
		negative	973	5D16	1005.31
5	Hard*	positive	477	3D16	603.19
		negative	730	4D16	804.25
	Medium	positive	478	3D16	603.19
		negative	834	5D16	1005.31
	Soft	positive	752	4D16	804.25
		negative	1036	6D16	1206.37

*hard soil as reference value for percentage calculation

Table 7. Stirrup rebar area B30x60.

Total stories	Soil type	B30x60		
		Stirrup used	A_{vs}/s (mm²/mm)	
10	Hard*	2D10-115	1.37	0.00%
	Medium	2D10-110	1.43	4.55%
	Soft	2D10-100	1.57	15.00%
8	Hard*	2D10-115	1.37	0.00%
	Medium	2D10-110	1.43	4.55%
	Soft	2D10-100	1.57	15.00%
5	Hard*	2D10-110	1.43	0.00%
	Medium	2D10-105	1.50	4.76%
	Soft	2D10-100	1.57	10.00%

*hard soil as reference value for percentage calculation

Table 8. Stirrup rebar area B30x50.

Total stories	Soil type	B30x50		
		Stirrup used	A_{vs}/s (mm²/mm)	
10	Hard*	2D10-110	1.43	0.00%
	Medium	2D10-110	1.43	0.00%
	Soft	2D10-100	1.57	10.00%
8	Hard*	2D10-110	1.43	0.00%
	Medium	2D10-110	1.43	0.00%
	Soft	2D10-105	1.50	4.76%
5	Hard*	2D10-110	1.43	0.00%
	Medium	2D10-105	1.50	4.76%
	Soft	2D10-100	1.57	10.00%

*hard soil as reference value for percentage calculation

Table 9 shows the demand capacity ratio (D/C) of column based on the Strong Column Weak Beam (SCWB) concept.

Table 9. Demand capacity ratio of column (Strong Column Weak Beam).

Total stories	Soil type	Column dimension (mm x mm)	1.2 ΣM_{beam} (t.m)	ΣM_{col} (t.m)	D/C ratio	
10	Hard*	600 x 600 (16D19)	34.14	82.20	0.42	0.00%
	Medium		38.05	82.20	0.46	11.46%
	Soft		45.98	82.20	0.56	34.69%
8	Hard*	550 x 550 (12D19)	34.14	64.20	0.53	0.00%
	Medium		38.05	64.20	0.59	11.46%
	Soft		45.98	64.20	0.72	34.69%
5	Hard*	500 x 500 (12D16)	38.05	59.00	0.64	0.00%
	Medium		42.18	59.00	0.71	10.85%
	Soft		45.98	59.00	0.78	20.85%

*hard soil as reference value for percentage calculation

It can be seen that the D/C ratio of the column for medium soil and soft soil increase about 11.46% and 34.69% compared to hard soil. Both values are the same for the 10-stories and 8-stories buildings because the used longitudinal rebar is the same. As for the 5-storey building D/C ratio increase by 10.85% and 20.85% respectively for medium soil and soft soil compared to hard soil.

4 CONCLUSIONS

The effect of different soil types tends to be insignificant to the dynamic scale factor ($V_{static}/V_{dynamic}$) for higher building. In contrast to lower buildings, soft soil tend to produce larger scale factor compared to hard soil. The increase of base-shear for Makassar city is about 34% and 103% for medium and soft soil compared to hard soil. The maximum displacement of building is correlated with the base-shear. The difference in building height does not affect the proportion of base-shear values for different soil types. The increase of beam negative moment is about 27% to 39% in soft soil compared to hard soil, while for medium soil is about 8% to 14%. The increasing pattern of beam positive moment is quite different (about 8% to 50%), especially for 5-stories building. The difference of longitudinal rebar area is directly proportional to the moment. The difference of stirrup rebar area is about 5% to 15.00% for medium and soft soil compared to hard soil. Demand capacity ratio of column increase about 10% to 35% for medium and soft soil compared to hard soil.

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