Analysis of Column and Beam Minimum Reinforcement Requirements on the Building Structure of the Faculty of Psychology, University of Semarang

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ABSTRACT : *In formulating the seismic design criteria for a building at ground level or determining the amplification of the peak earthquake acceleration from the bedrock to the ground for a site, the site must be classified first. Site class assignment must be carried out through field and laboratory soil investigations. Site Class consists of SA (hard rock), SB (rock), SC (medium soil), SE (soft soil) and SF (special soil). SNI 1726: 2019 with various classes of SB, SC, SD and SE sites. From the analysis results, it is found that the variation of soil site classes has an effect on the area of minimum reinforcement requirements, except for the logitudinal reinforcement requirements of the lower support beam for site class variations, the value is fixed. The variation of soil site classes has a significant effect on the area requirements of the longitudinal reinforcement in the column. The largest requirement for column longitudinal reinforcement is Soft Soil Site Class (E) and the smallest requirement is Rock Site Class (B).*

Keywords : earthquake, SNI 1726: 2019, site class, reinforcement, columns, beams

1. Introduction

Indonesia is one of the countries included in earthquake-prone areas in the world. It occupies a very active tectonic zone because the world's three large plates and nine other small plates meet each other in the territory of Indonesia and form complex plate meeting paths. Given the last few years there have been many large earthquakes that have occurred in Indonesia. For example, the Aceh earthquake in 2004, the Yogyakarta earthquake in 2006, the Padang and Bengkulu earthquake in 2007. For this reason, in building construction, it is necessary to plan earthquake-resistant buildings so as not to cause casualties. Buildings in Indonesia must be planned in accordance with SNI 1726: 2019 regulations concerning earthquake resistance planning procedures for building and non-building structures.

Spectrum Response is a plot of a spectrum which is presented in the form of a graph / plot between the vibrating periods of the T structure, against the maximum responses for a certain damping ratio and earthquake load [1]. The response spectrum is influenced by earthquake load, damping ratio, ductility and soil conditions. In SNI 1726: 2019, the design response spectra must be analyzed first.

The classification of a site to provide seismic design criteria in the form of building amplication factors. In formulating the seismic design criteria for a building at ground level or determining the amplification of the peak earthquake acceleration from the bedrock to the ground for a site, the site must be classified first. Site class assignment must be carried out through field and laboratory soil investigations. Site Class consists of SA (hard rock), SB (rock), SC (hard soil), SD (medium soil), SE (soft soil) and SF (special soil) [2]. How big is the influence of soil conditions on the response of the structure when experiencing earthquake loads.

In this study, we want to compare the behavior of the building structure of the Faculty of Psychology, University of Semarang using the SNI 1726: 2019 regulations with variations in the class of SB, SC, SD and SE sites. The problems to be reviewed are:

a. How much is the difference in flexural reinforcement in the building structure if it is subjected to earthquake loads based on SNI 1726: 2019 with variations in site class variations of SB, SC, SD and SE?

b. How much is the difference in shear reinforcement in the building structure if it is subjected to earthquake loads based on SNI 1726: 2019 with variations in site classes SB, SC, SD and SE?

2. LITERATUR REVIEW

A structure can be composed of several elements with different properties or characteristics, the structure can be divided into 4, namely Beam-Column Structure, Trusses Structure (Truss Structure), Frame Structure (Rigid Frame Structure), and Shell Structure (including plate, Shell and Membrane) [2].

The results of the calculation of the earthquake lateral force loading using SNI 03-1726-2012 have a difference of 15.6% from the earthquake loading regulations SNI 03-1726-2002 earthquake, meaning that the lateral force loading of the building is increased from the original calculation, the beam bending reinforcement design uses regulations Earthquake loading SNI 03-1726-2012 obtained a greater number of reinforcement with a difference of 15.7% in the beam support and 22.7% more in the beam field, on the re-planning for the calculation of the beam shear reinforcement design on the pedestal more 13.1 % and the number of beam shear reinforcement in the field is 0.11% more, for the planning of column analysis on column bending using the SNI 03-1726-2012 earthquake loading regulations, it is found that the number of column reinforcement is more than the previous plan, namely with a difference of 17.5%, planning column shear reinforcement experienced a reduction in the shear reinforcement in the supports and fields with a difference of 14.3% from the planning se not yet. So it can be said that the results of the analysis of this study show many increases in terms of reinforcement [3]

From the results of the analysis of the structure of Building T, Faculty of Psychology, University of Semarang using SAP2000 software, the results are as follows: the moment increase in structures designed using SNI 1726-2002 against SNI 1726-2012 is 11.35%; increase in shear forces in structures designed using SNI 1726-2002 against SNI 1726-2012 valued at 5.04%; increase in normal force on structures designed using SNI 1726-2002 against SNI 1726-2012 valued at 34.42%; and the increase in the need for reinforcement in structures designed using SNI 1726-2002 against SNI 1726-2012 valued at 28.46% [4]

The results of the study of the response spectra of the Tarutung City design based on SNI 1726: 2012 show an increase in the value of the spectral acceleration compared to SNI 03-1726-2002. Based on SNI 03-1726-2002 the maximum spectral acceleration value is 0.85 while based on SNI 1726: 2012 the maximum value is 1.0. Buildings in Tarutung City which are built with reference to SNI 1726: 2012 will be safer if they are hit by earthquakes in the future compared to buildings built based on SNI 03-1726-2002. Therefore, in an effort to mitigate the earthquake disaster in Tarutung City, it is necessary to evaluate the houses and buildings built based on SNI-03-1726-2002 [5].

Reviewing the response of the earthquake acceleration spectra on the ground surface which is required as a parameter for determining the earthquake load in the planning of earthquake resistant building structures based on SNI 03-1726-2019, which is a substitute regulation for SNI 1726 2012, where SNI 1726-2019 uses earthquake hazard maps for Indonesia 2010 From the analysis, it was found that the response value of the acceleration spectra, Sa (g) increased even though the amplification factor for the city of Palembang had decreased, especially in moderate (SD) and soft (SE) soil locations. The increase in response spectra in short period design (SDS) for hard, soft and medium soils was 23%, 12%, and 5% respectively, while for the design response spectra for the 1 second period (SD1) was 39%, 49%, and 40%. This indicates that the seismic base shear load in the design of earthquake resistant structures will of course also increase in the structural period, T <= Ts or T> Ts [6].

Budi Rahmad Tangahu, et al (2019) The Special Moment Bearer Frame System generally uses the response modification factor (R) 8 (SNI 1726; 2012), where the structure must behave ductile. For reinforced concrete structures, it will be difficult to detail the reinforcement. Therefore, the variation of response modification factors is carried out to determine their effect on structural deviation, beam moment capacity and beam ductility. The 5-storey building structure was analyzed using response modification factors 4, 5, 6, 7 and 8. For each response modification factor, the deviation of structure, moment capacity and ductility were obtained. The moment capacity and ductility of the beam elements are calculated based on the reinforcement obtained from the design results. The results of the analysis show that the smaller the response modification factor (R), the larger the structural deviation, the greater the moment capacity and the lower the ductility [7].

3. Research Methodology

3.1 Research Methods

The method used in this research is to use a computerized simulation method with SAP 2000 version 14 to get a comparison of the earthquake forces that occur using SNI for Earthquake 03-1726-2019 with variations in the class of sites SB, SC, SD and SE.

This computerized simulation is carried out by modeling the 3-dimensional building shape with SAP 2000 version 14 from the building model of the Faculty of Psychology, University of Semarang which will later function as a lecture building, with loading conditions, namely live loads, dead loads, wind loads and earthquake loads. The research stages can be seen in Figure 1.

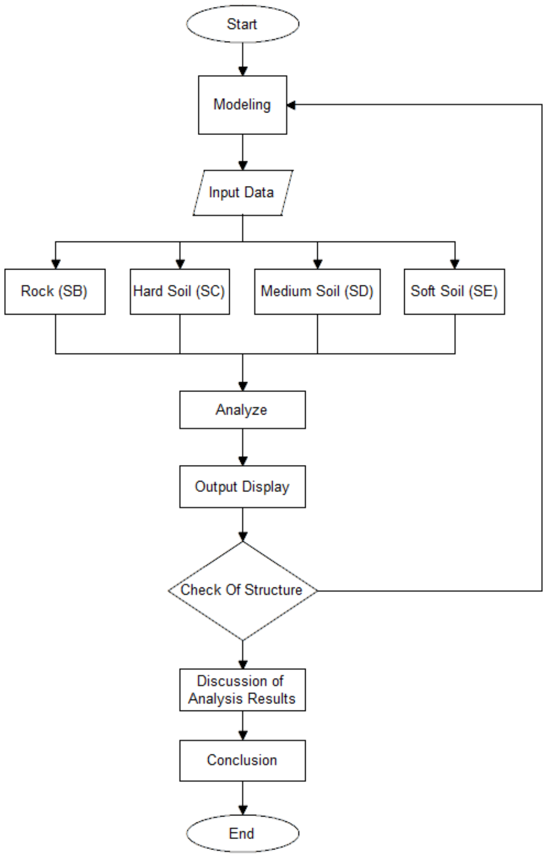


Figure 1 Flow Diagram

3.2 ***Research Design***

In the computational simulation, buildings are modeled using the finite element method, which is a collection of three-dimensional solid elements connected to each other by frames, shells, nodes or joins so that they become unified and monolithic structures like the building model in Figure 2.

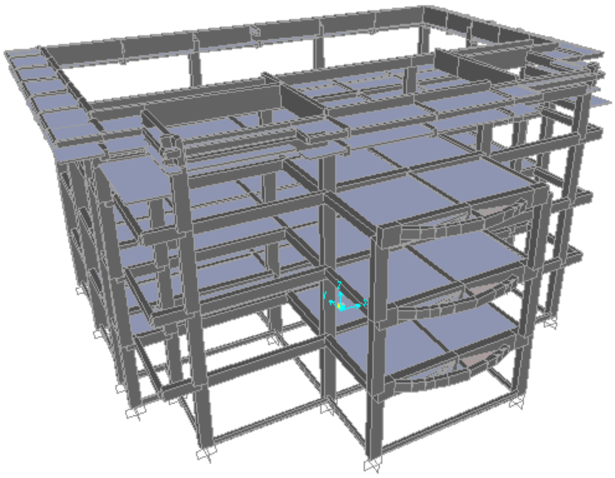


Figure 2 Structure model

3.3 ***Design Criteria***

The building to be analyzed is the building of the Faculty of Psychology, University of Semarang which is located on Jalan Arteri Soekarno-Hatta, Semarang. The building consists of 4 floors (including a roof) which functions as a lecture hall with a building area of 2880 m2. The dimensions of the structure used are the floor slab thickness = 12 cm; Column = 50cm x 50cm; 40cmx80cm Floor Beams; and ring balk = 30 x50 cm. The material used is reinforced concrete with concrete quality fc '= 35 Mpa, reinforcement quality fy = 400 Mpa and fy = 240 Mpa. An example of a floor plan can be seen in Figure 3.

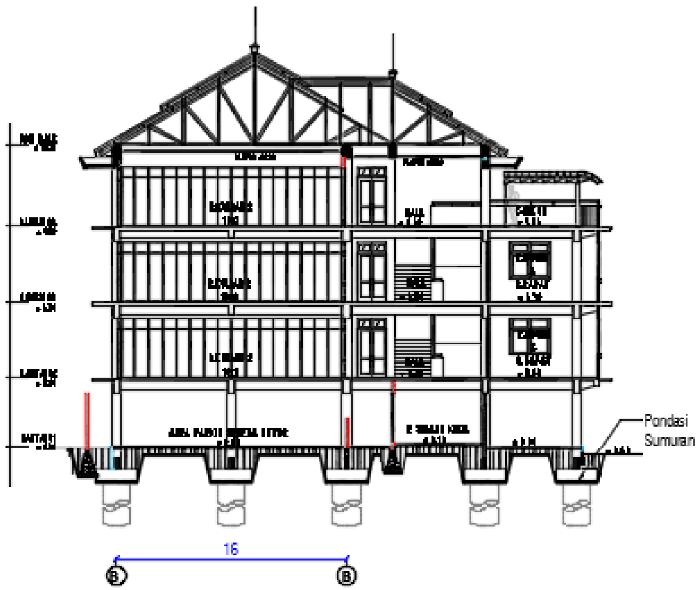


Figure 3 Section Plan

The regulations and standards used as a reference for the analysis of this research are:

a. SNI 1726: 2019, Earthquake Resistance Planning Procedures for Building and Non-Building Structures
b. SNI 2847-2013, Requirements for Structural Concrete for Buildings.
c. ASCE 7 - 10 Minimum Design Loads for Buildings and Other Structures.
d. SNI 1727-2013, Minimum Load for Planning of Buildings and Other Structures.
e. Load Planning Guidelines for PPPURG Houses and Buildings 1987.

4. RESULT AND DISCUSSION

4.1 Stucture System

Structural modeling was carried out using the SAP 2000 (Extended Three Dimensional Analysis of Bulding System) program. Modeling of the 4-story building structure is intended for lecture rooms, the modeling plan can be seen in Figure 4.

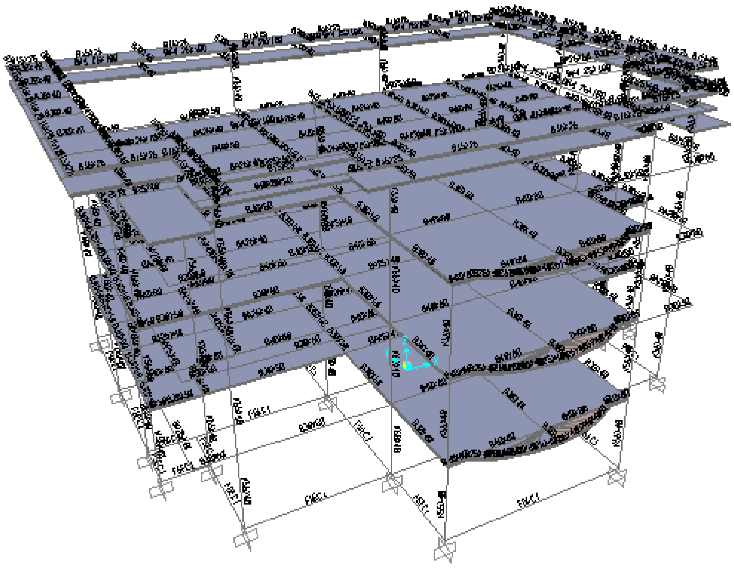


Figure 4 Structure model

*4.2 **Loading Plan***

Reinforced concrete design is based on the limit strength method. The combination of loading and living load reduction factors is based on the standard regulations for earthquake resistance planning procedures for building and non-building structures SNI 1726: 2019. Types of building use, including school buildings and educational facilities, are included in Risk Category IV with earthquake priority factors (Ie) = 1.5.

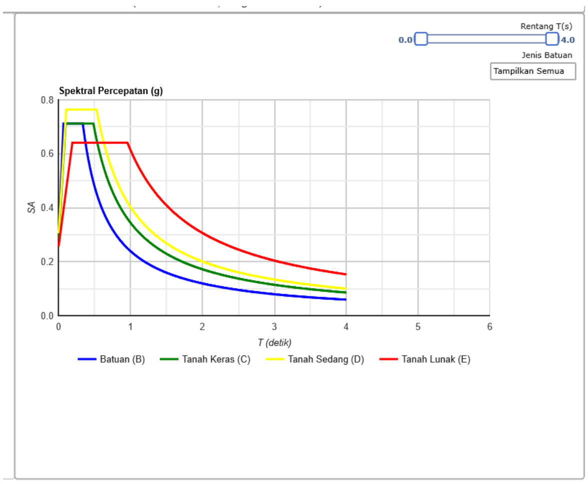


Figure 5 4.2 Loading Plan (Sources: http://puskim.pu.go.id)

The building of the Faculty of Psychology, University of Semarang is located at latitude -6,827 and longitude 110.4519738 by using the http://puskim.pu.go.id/Aplication/desain_spektra_indonesia_2011/ application, the value of the Earthquake Design Response Spectrum is obtained as shown in Figure 5.

From Figure 4, it can be seen that different site classes at the same location have different Earthquake Design Response Spectrum values. The variable value of each Site Class is calculated based on the SNI 1726: 2019 regulations, the calculation results can be seen in Table 1.

Table 1. Variable values of the Site Class

Variables	**Site Class**			
	Soft Soil (SE)	**Medium Soil (SD)**	**Hard Soil (SC)**	**Rock (SB)**
PGA (g)	0,476	0,476	0,476	0,476
S_S (g)	1,068	1,068	1,068	1,068
S_1 (g)	0,358	0,358	0,358	0,358
C_{RS}	0,891	0,891	0,891	0,891
C_{R1}	0,000	0,000	0,000	0,000
F_{PGA}	0,900	1,024	1,000	1,000
F_A	0,900	1,073	1,000	1,000
F_V	2,568	1,684	1,442	1,000
PSA (g)	0,428	0,487	0,476	0,476
S_{MS} (g)	0,962	1,146	1,068	1,068
S_{M1} (g)	0,919	0,603	0,516	0,358
S_{DS} (g)	0,641	0,764	0,712	0,712
S_{D1} (g)	0,613	0,402	0,344	0,239
T_0 (detik)	0,191	0,105	0,097	0,067
T_S (detik)	0,956	0,526	0,483	0,335
Katagori Resiko	IV	IV	IV	IV
Ie	1,500	1,500	1,500	1,500
KDS (SDS)	D	D	D	D
KDS (SD1)	D	D	D	D
KDS	D	D	D	D
Seismic Force Bearing System	Special Moment Reinforced Concrete Frame			
R	8,000			
Ω0	3,000			
Cd	5,500			

The observed minimum reinforcement requirements for beam and column sections can be seen in Figure 6.

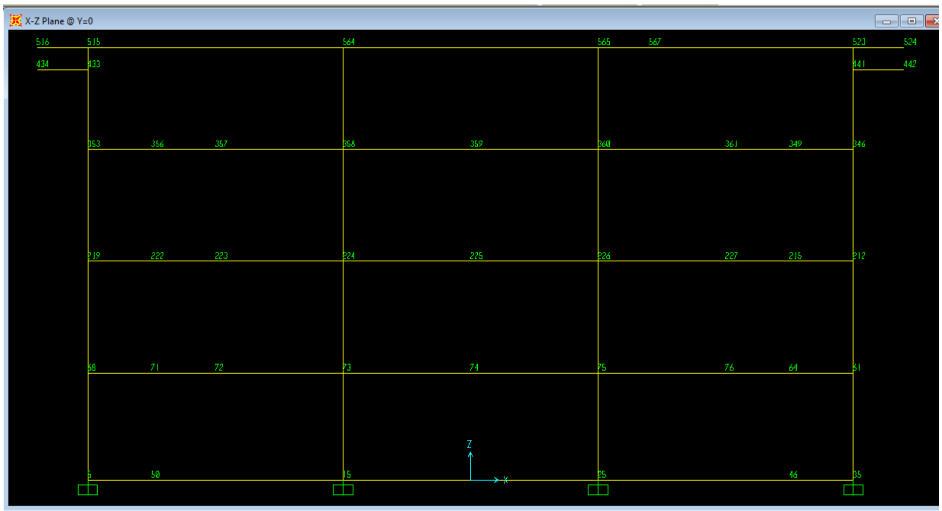
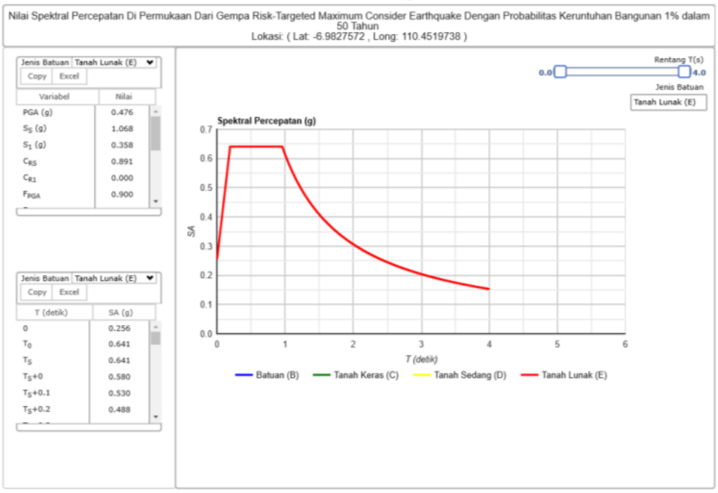


Figure 6 minimum reinforcement requirements for beam and column sections

4.3 *Results of Analysis of Soft Soil Site Class (E)*

Spectum response values for the location of the Faculty of Psychology Building, University of Semarang and the Classroom Soft Soil Sites (E) are shown in Figure 7.



Sources: http://puskim.pu.go.id

Figure 7 Analysis of Soft Soil Site Class

Based on the simulation from SAP version 14 3-dimensional configuration of the building model of the USM Psychology faculty building with Soft Soil Site Class (E), it is obtained longitudinal reinforcement based on the 2019 earthquake SNI with analysis on AS B pieces in the column with dimensions 50 x 50 cm, the reinforcement area is 81,113 cm2 while on the beam with dimensions of 40 x 80 cm on the upper support section, the reinforcement area is obtained as large as 20.222 cm2, and on the lower support section the reinforcement area is obtained 10.267 cm2, while for the longitudinal reinforcement in the lower court section, the reinforcement area is obtained for 13.983 cm2 and for the upper court section obtained reinforcement area of 6,400 cm2. For the minimum area of reinforcement, the results of the analysis of longitudinal reinforcement calculations can be seen in Figure 8.

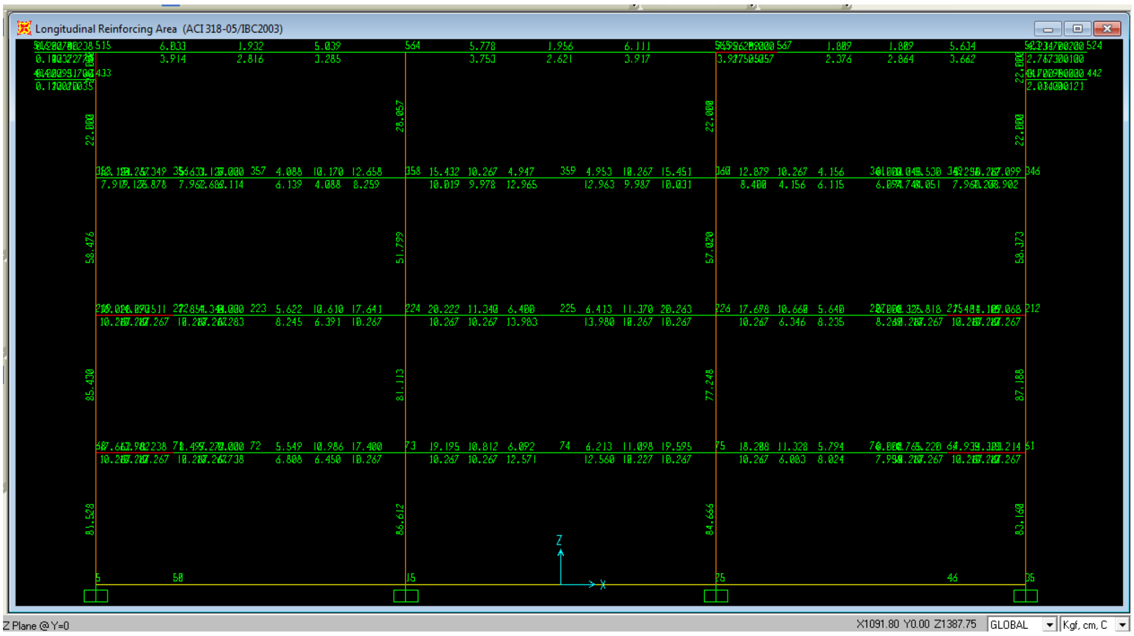


Figure 8 section structure model

Based on the simulation from SAP version 14 3-dimensional configuration of the building model of the USM Psychology faculty building with Soft Soil Site Class (E), it is obtained longitudinal reinforcement based on the 2019 earthquake SNI by analyzing AS B pieces on a column with dimensions 50 x 50 cm, the reinforcement area is 81,113 cm2. while on the beam with dimensions of 40 x 80 cm on the upper support section, the reinforcement area is obtained as large as 20.222 cm2, and on the lower support section the reinforcement area is obtained 10.267 cm2, while for the longitudinal reinforcement in the lower court section, the reinforcement area is obtained for 13.983 cm2 and for the upper court section obtained reinforcement area of 6,400 cm2. For the minimum area of reinforcement, the results of the analysis of longitudinal reinforcement calculations can be seen in Figure 8.

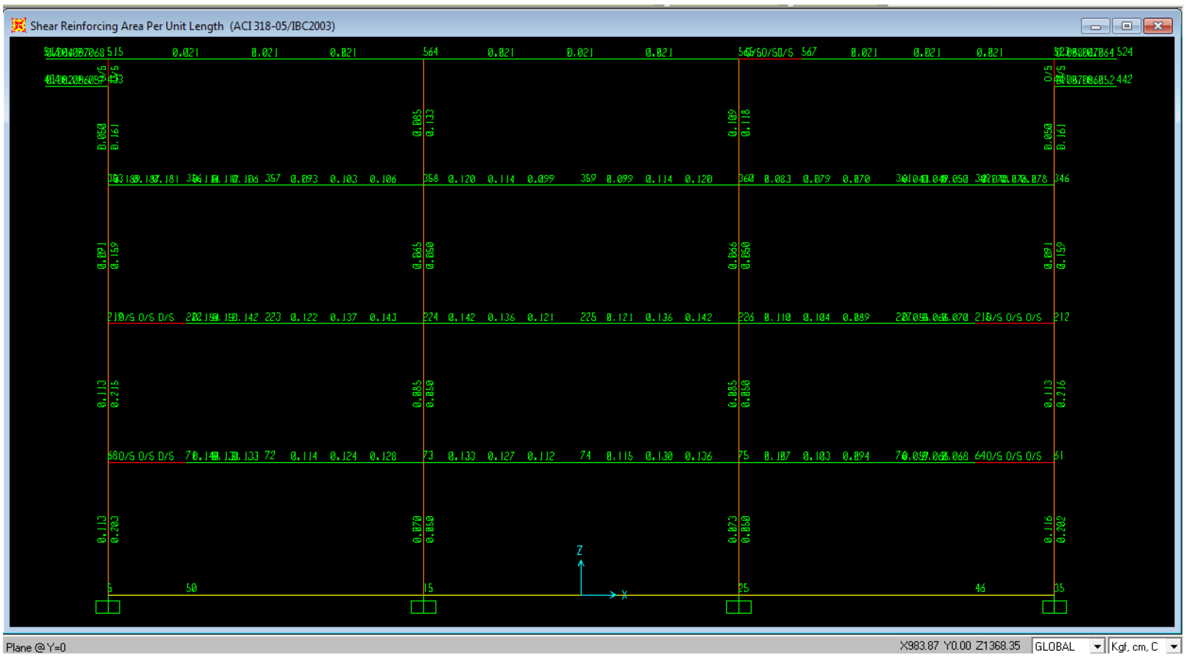


Figure 9 section structure model

4.4 *Result of Analysis of Medium Soil Site Class (D)*

Spectum response values for the location of the Faculty of Psychology Building, University of Semarang and the Medium Soil Site Class (D) are as shown in Figure 10.

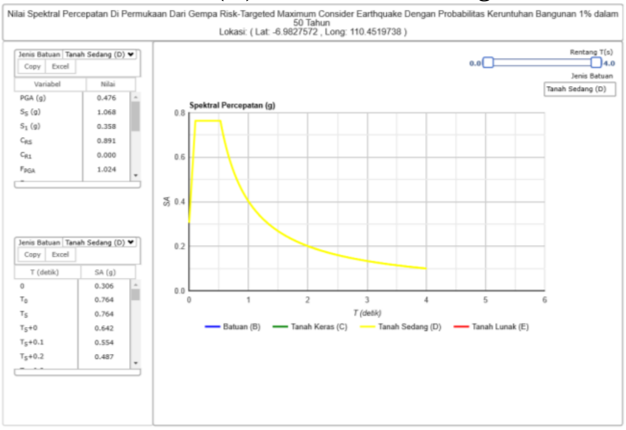


Figure 10. Spectum response values for the location of the Faculty of Psychology Building, University of Semarang (Sources: http://puskim.pu.go.id)

Based on the simulation from SAP version 14 3-dimensional configuration of the building model of the USM Psychology faculty building with Medium Soil Site Class (D), it is obtained longitudinal reinforcement based on the 2019 earthquake SNI with analysis on AS B pieces in a column with dimensions 50 x 50 cm, the reinforcement area is 39.637 cm2. whereas on the beam with dimensions of 40 x 80 cm on the upper support section, the reinforcement area is obtained as large as 19.317 cm2, and on the lower support section the reinforcement area is obtained 10.267 cm2, while for the longitudinal reinforcement in the lower court section the reinforcement area is obtained for 13.983 cm2 and for the upper field obtained reinforcement area of 6,129 cm2. For the minimum area of reinforcement, the results of the analysis of longitudinal reinforcement calculations can be seen in Figure 11.

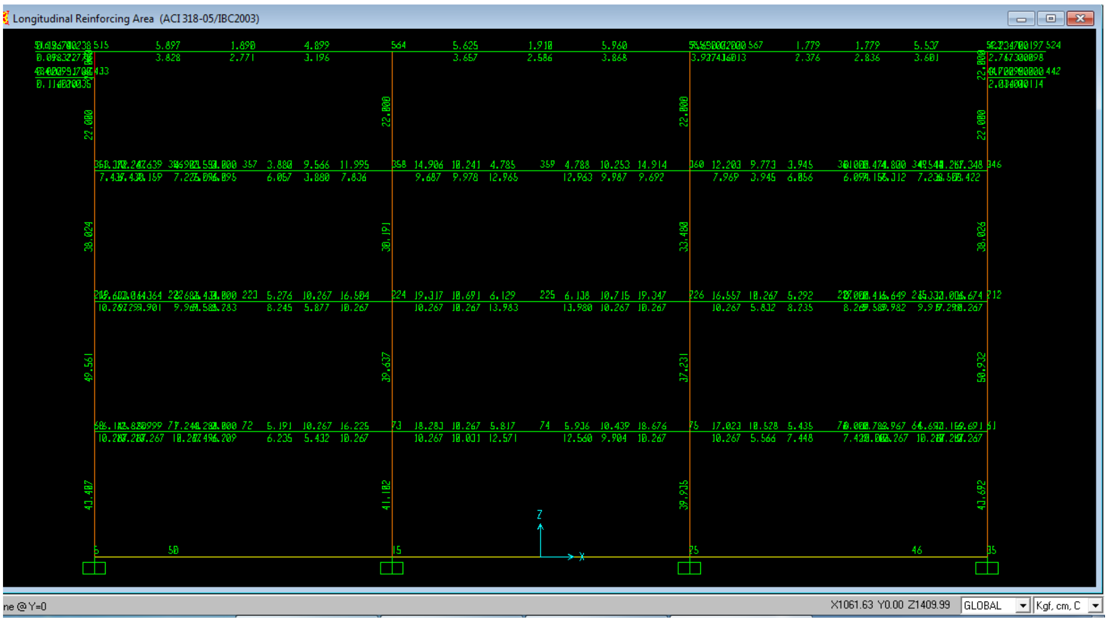


Figure 11. the results of the analysis of longitudinal reinforcement

Based on the simulation from SAP version 14 3-dimensional configuration of the building model of the USM Psychology faculty building with moderate soil site class conditions (D), shear reinforcement is obtained based on the 2019 earthquake SNI with analysis on AS B beam in a column with dimensions 50 x 50 cm, the reinforcement area is obtained 7 , 9 cm2, while on the beam with dimensions of 40 x 80 cm on the support section, the reinforcement area is found to be 13.8 cm2. For the area of reinforcement, the analysis of the calculation of shear reinforcement can be seen in Figure 12.

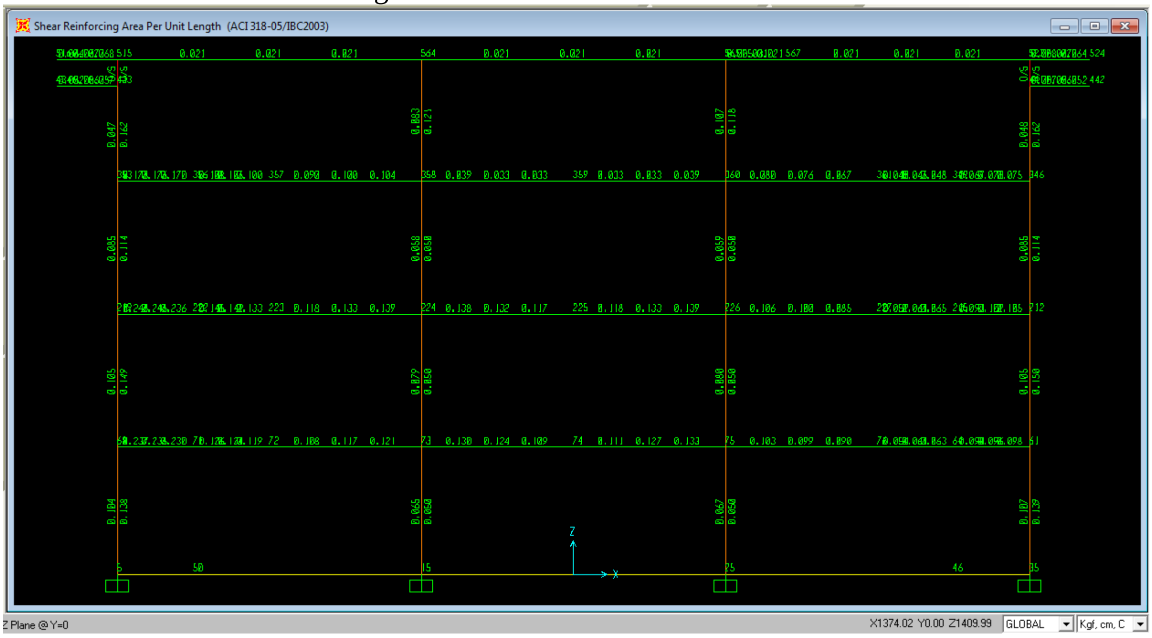


Figure 12 the analysis of the calculation of shear reinforcement

4.5 *Results of Analysis of Hard Soil Site Class (C)*

Spectum response values for the location of the Faculty of Psychology Building, University of Semarang and Classroom Hard Soil Sites (C) are shown in Figure 13.

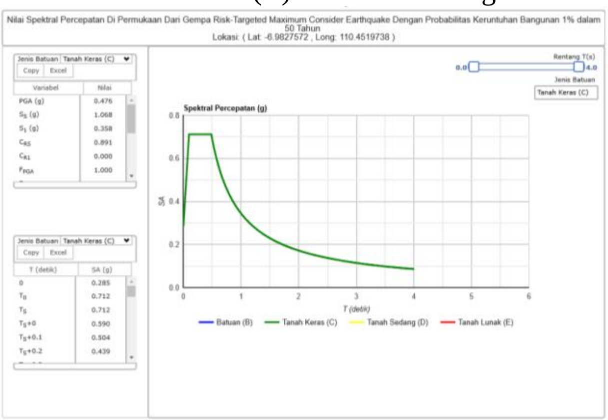


Figure 13. Spectum response values for the location of the Faculty of Psychology Building, University of Semarang and Classroom Hard Soil Sites (Sources: http://puskim.pu.go.id**)**

Based on the simulation from SAP version 14 3-dimensional configuration of the building model of the Faculty of Psychology, University of Semarang with Hard Soil Site Class (C), it is obtained longitudinal reinforcement based on the 2019 earthquake SNI with analysis on AS B pieces in the column with dimensions 50 x 50 cm obtained reinforcement area 27,612 cm2 while on the beam with dimensions of 40 x 80 cm on the upper support section, the reinforcement area is obtained as large as 17,956 cm2, and on the lower support section the reinforcement area is obtained 10,267 cm2, while for the longitudinal reinforcement in the lower court section, the reinforcement area is obtained for 13,983 cm2 and for the field section above, the reinforcement area obtained is 5.718 cm2. For the minimum area of reinforcement, the results of the analysis of longitudinal reinforcement calculations can be seen in Figure 14.

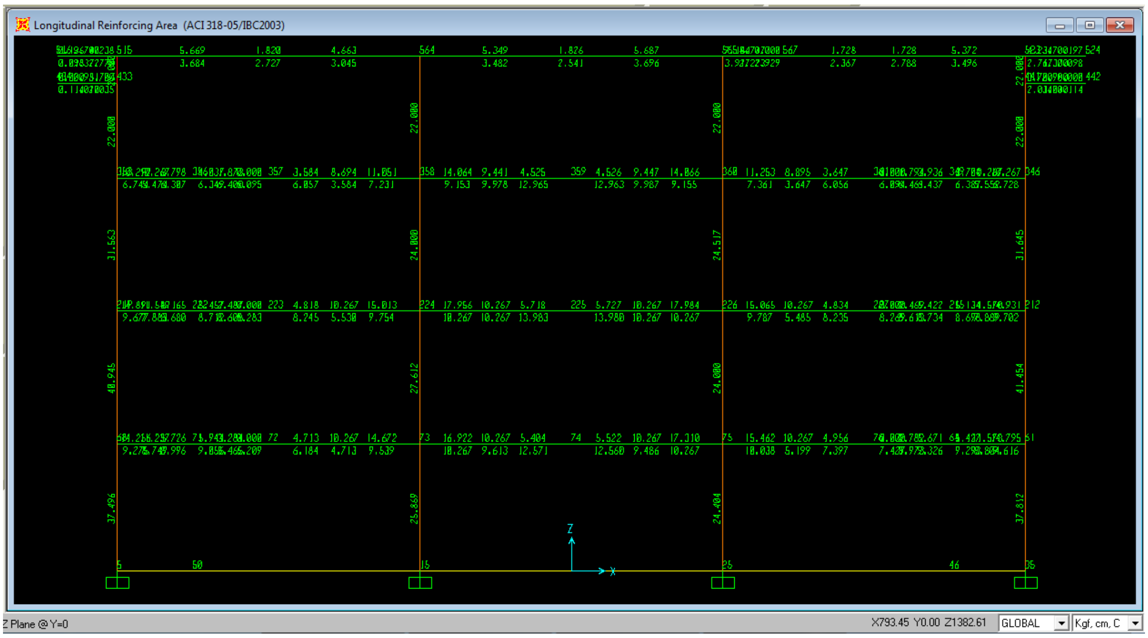


Figure 14 the results of the analysis of longitudinal reinforcement

Based on the simulation from SAP version 14 3-dimensional configuration of the building model of the USM Psychology faculty building with moderate soil site class conditions (D), shear reinforcement is obtained based on the 2019 earthquake SNI with analysis on AS B beam on a column with dimensions of 50 x 50 cm obtained reinforcement area 6 , 8 cm2 while on the beam with dimensions of 40 x 80 cm on the support section, the reinforcement area is obtained as large as 13.4 cm2. For the area of reinforcement, the analysis of the calculation of shear reinforcement can be seen in Figure 15.

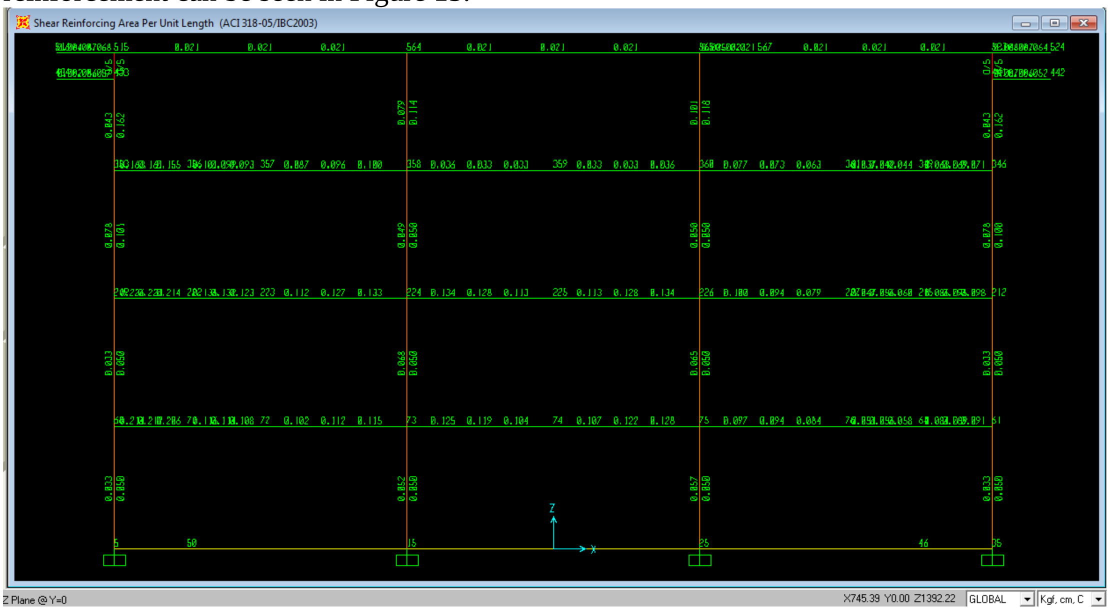


Figure 15 the analysis of shear reinforcement

4.6 *Results of Rock Site Class Analysis (B)*

Spectum response values for the location of the Faculty of Psychology Building, University of Semarang and the Class of Soil Rock Sites (B) are shown in Figure 16.

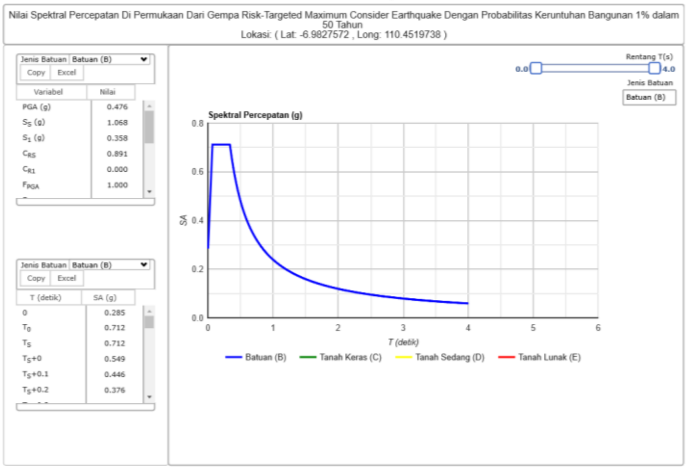


Figure 16 Spectum response values for the location of the Faculty of Psychology Building, University of Semarang and the Class of Soil Rock Sites (Sources: http://puskim.pu.go.id)

Based on the simulation from SAP version 14 3-dimensional configuration of the building model of the USM Psychology faculty building with Rock Site Class (B), it is obtained longitudinal reinforcement based on the 2019 earthquake SNI with analysis on AS B pieces on a column with dimensions of 50 x 50 cm obtained a reinforcement area of 24,000 cm2 while On the beam with dimensions of 40 x 80 cm on the upper part of the support area, the area of the reinforcement is 15.597 cm2, and on the lower part of the support, the area of the reinforcement is 10.123 cm2, while for the longitudinal reinforcement in the lower court the area of the reinforcement is 13,983 cm2 and for the upper field is obtained reinforcement area of 4.998 cm2. For the minimum area of reinforcement, the results of the analysis of longitudinal reinforcement calculations can be seen in Figure 17.

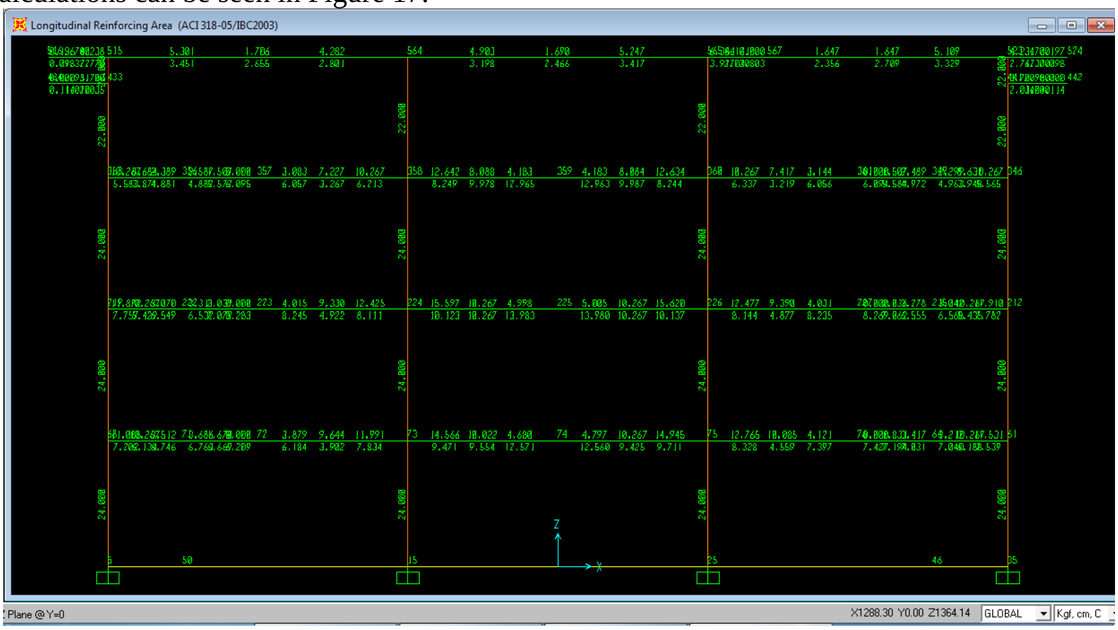


Figure 17 the results of the analysis of longitudinal reinforcement

Based on the simulation from SAP version 14 3 dimensional configuration of the building model of the USM Psychology faculty building with the condition of Rock Site Class (B), the shear reinforcement is obtained based on the 2019 earthquake SNI with analysis on AS B beam on a column with dimensions of 50 x 50 cm obtained reinforcement area 4, 3 cm2, while on a beam with dimensions of 40 x 80 cm on the pedestal, the reinforcement area is 4.6 cm2. For the area of reinforcement, the analysis of the calculation of shear reinforcement can be seen in Figure 18.

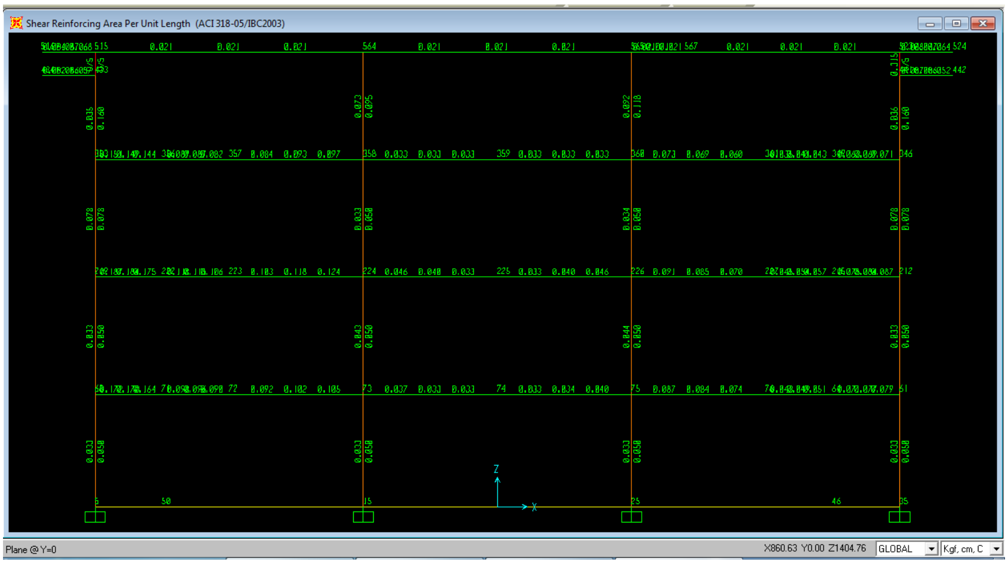


Figure 18 the analysis of the calculation of shear reinforcement

4.7 Results of Comparison of Minimum Reinforcement Requirements of Soil Site Class Variations

From the results of the analysis using SAP 2000, the comparison of the minimum reinforcement requirements with variations in the class of soil sites in Figure 19 is:

a) The minimum reinforcement requirements for the longitudinal column reinforcement for rock site classes against other site classes are increasing. The increase is 15.05% for the hard soil site class; 65.15% for medium soil site class and 237.97% for soft soil site class.

b) The minimum reinforcement requirements for the longitudinal beam reinforcement on the top supports for rock site classes against other site classes are slightly increased. The increase is 15.12% for the hard soil site class; 23.85% for medium soil site class and 29.65% for soft soil site class.

c) The minimum reinforcement requirements for longitudinal beam reinforcement on the lower supports for rock site classes against other site classes are slightly increased. The increase was for hard, medium and soft soil sites by 1.4%.

d) The minimum reinforcement requirements for longitudinal beam reinforcement in the lower court for rock site classes against other site classes did not increase (0.0%).

e) The minimum reinforcement requirements for the longitudinal beam reinforcement in the upper pitch for rock site classes to other site classes are slightly increased. The increase was 14.41% for the hard soil site class; 22.63% for medium soil site class and 28.05% for soft soil site class.

f) The minimum reinforcement requirements for beam shear reinforcement on the supports for rock site classes against other site classes are increasing. The increase was 191.3% for the hard ground class; 200% for medium soil site class and 208.7% for soft soil site class.

g) Minimum reinforcement requirements for beam shear reinforcement in columns for rock site classes to other site classes have increased. The increase was 58.14% for the hard soil site class; 83.72% for medium soil site class and 97.67% for soft soil site class.

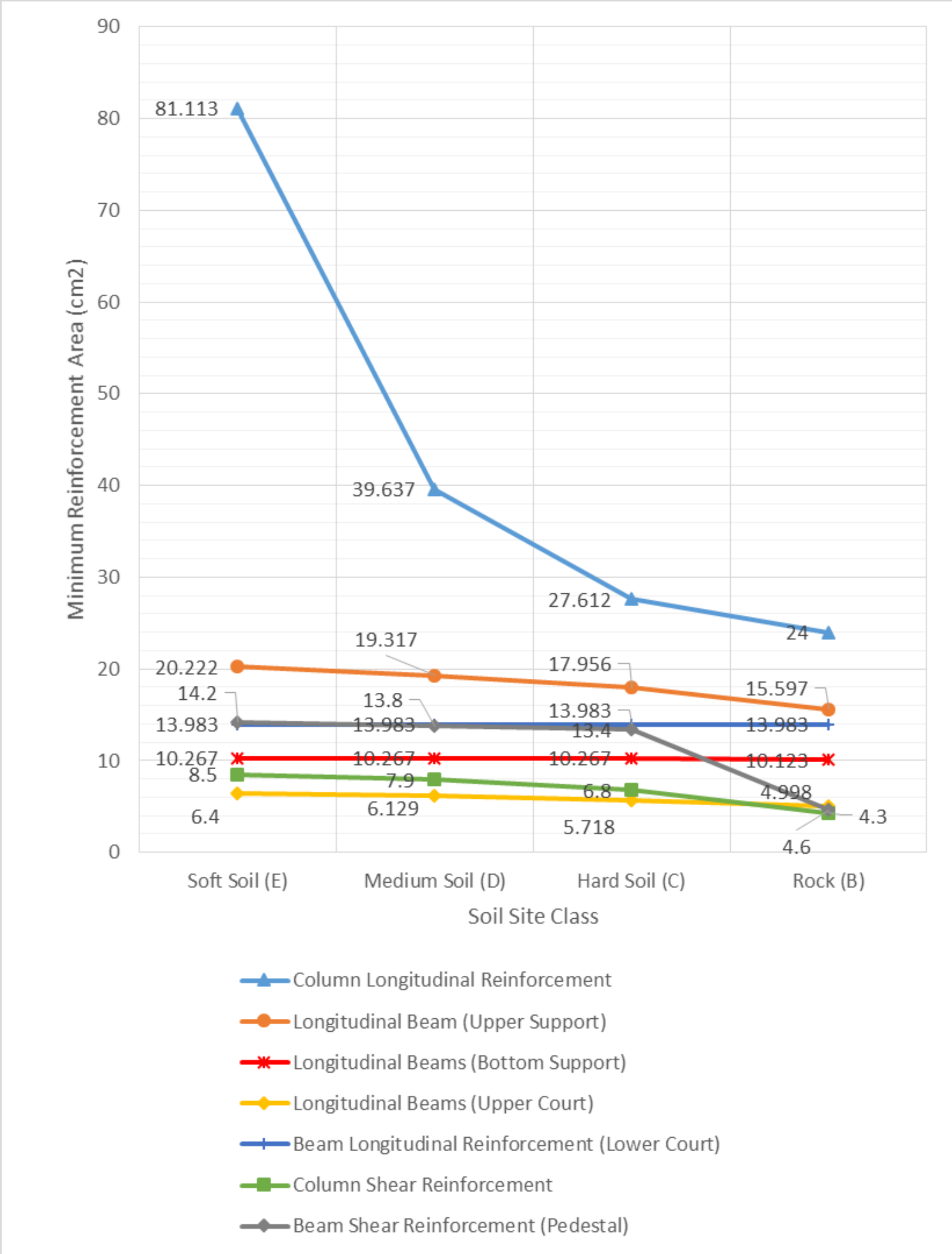


Figure 19. the comparison of the minimum reinforcement requirements with variations in the class of soil sites

5. Conclusion

From the results of the analysis using SAP2000 on the building of the Faculty of Psychology, University of Semarang, with variations in the class of soil sites that affect the area of minimum reinforcement requirements, except for the logitudinal reinforcement needs of the lower support beam for variations in the soil site class, the value is fixed. Soil site class variations have a significant effect on the area requirements of longitudinal reinforcement in the column. The largest requirement for column longitudinal reinforcement is Soft Soil Site Class (E) and the smallest requirement is Rock Site Class (B).

REFERENCES

[1] Widodo Prawirodikromo, *Analisis Dinamika Struktur*, (Yogyakarta: Cetakan I, Pustaka Pelajar, 2017).

[2] Badan Standarisasi Nasional, SNI 1726:2019 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung (Jakarta: Badan Standarisasi Nasional, 2019).

[3] Achmad Hambali, *Perbandingan Perencanaan Struktur Tahan Gempa berdasarkan SNI 03-1726-2002 dan SNI01726:2012*, Tugas Akhir, Universitas Muhammadiyah Yogyakarta, Yogyakarta, 2016.

[4] Bambang Purnijanto, Mukti Wiwoho, Ngudi Hari Crista, *Perbandingan Analisis Struktur Gedung Fakultas Psikologi USM (Empat Lantai Gedung T) Menggunakan SNI Gempa 03-1726-2002 dengan SNI Gempa 03-1726-2012, Teknika, 9(2)*, 2015, 12-22.

[5] Meassa Monikha Sari, *Studi Perbandingan Respon Spektra Kota Taruntung Berdasarkan SNI 03-1726-2002 dan SNI 1726:2013 untuk Evaluasi Pelaksanaan Bangunan Tahan Gempa*, Konferensi Nasional Teknik Sipil 7, Surakarta, 2013, 277-284.

[6] Sari Farlianti, Sapta, Perhitungan Respon Spektra Percepatan Gempa Kota Palembang Berdasarkan SNI 1726:2019 Sebagai Revisi Terhadap SNI 1726:2012, Teknika:Jurnal Ilmiah, 6(2), 2020, 167-177.

[7] Budi R T, Kasmat S N, Mirzan G, *Analisis Pengaruh Faktor Modifikasi Respon SRMK Struktur Gedung Beton Bertulang Pada Balok Katagori Desain Seismik D*, Jurnal Teknik, 17 (1), 2019, 57-65.

[8] Anonim, Desain Spektra Indonesia, http://puskim.pu.go.id/Aplikasi/desain_spektra_indonesia_2011/

[9] Indarto, H, *Buku Ajar Mekanika Getaran dan Rekayasa Gempa* (Semarang: Universitas Diponegoro 2005).

[10] Badan Standarisasi Nasional, *SNI 1726:2012 Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung* (Jakarta: Badan Standarisasi Nasional, 2012).

[11] Badan Standarisasi Nasional, SNI 2847:2013 Persyaratan Beton Struktural untuk Bangunan Gedung (Jakarta: Badan Standarisasi Nasional, 2013).

[12] Dipohusodo, I, Struktur Beton Bertulang (Jakarta: Gramedia, 2002).

[13] Ngudi Hari Crista, Trias Widorini, Belajar Mandiri Membuat Struktur Rumah Dua Lantai dengan SAP 2000 (Yogyakarta: Andi, 2018).