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THE EFFECT OF PLASTIC WASTE AS SOIL STABILIZATION FOR SHALLOW FOUNDATIONS USING DIRECT SHEAR TEST

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ABSTRACT

Expansive clay soil are types of soils that show a significant change in volume once they contact with moisture and structure built on this soil are highly vulnerable due to the swelling and shrinking behavior. Stabilization of soil is required to keep the quality of soil to be used for the foundation work within allowable limits. The material used in this research for soil stabilization is PET plastic because it is one of the most commonly recycled types of plastic. This research aims to determine the classification of soil in Temas village, Batu, East Java based on the USCS classification system and to determine the values of c and ϕ with the addition of plastic size variations of 0,5 cm x 1 cm; 0,75 cm x 1,25 cm; and 1 cm x 1,5 cm at 0,75%; 1,5%; and 2,5%. Soil in Temas villages included in the SP-SC soil type, namely poorly graded sand and clayey sand. From the soil stabilization tests using plastic waste, there is a tendency for improvement. However, the shear angle decreases with increasing percentages of PET waste. The highest shear angle value occurred in stabilization with plastic size 1 cm x 1,5 cm at 0,75%, measuring 49,73°. The highest cohesion value was 0,844 kg/cm^2 obtained from plastic size 0,5 cm x 1 cm at 1,50%. For the allowable load (Q_{all}) with plastic mixture shows significant improvement. The highest allowable occurs in rectangular shape with size of 1 m x 1,5 m. For original soil can only support a maximum load 37,30 tons and the highest allowable load observed in the mixture of original soil + plastic size 1 cm x 1,5 cm at 0,75%, which is 1.382,28 tons. The work carried out are excavation work, sand fill work, lean concrete work, soil mix with plastic waste, compaction work, concrete work, reinforcement work, and formwork with tools used are concrete mixer and manual equipment. The cost estimate for a rectangular foundation is Rp 46.336.177,01.

Keywords : PET plastic; Classification of soil; Soil stabilization; Allowable load; and Cost estimation.

1. INTRODUCTION

Expansive clay soil are types of soils that show a significant change in volume once they contact with moisture. To enhance the mechanical capacity and reduce soil swelling when building on expansive clay soils, the soil needs to be stabilized. However, cost and environmental hazard are always constraints in such situations. So, in order to fulfil the purpose of soil stabilization, there was a need for a more economic and eco-friendlier alternative. Many researchers have studied and developed several soil stabilization techniques to improve the bearing capacity, increasing shear strength, and reducing the swelling properties of the soil. Most of the techniques used involve adding additive materials such as lime, cement, fly ash, etc. Recently, researchers have presented another way to stabilize soil using waste materials, which is plastic waste. Plastic waste one of the big problems facing the world nowadays, especially polyethylene terephthalate (PET). Excessive use of plastic has negative implications for both survival and the environment. Some research on soil stabilization with plastic waste has shown that it can stabilize expansive clay soils. The experimental results of Kassa et al., 2020 showed that the use of plastic could improve the direct shear parameters, the largest value of c and φ was obtained from the 15 x 20 (mm) strip at the 0,5% as 62,67 Kpa and 8,980 which was a 57% and 26% improvement respectively.

2. METODHOLOGY

The method used in this research is an experimental model. Soil samples were collected from the location in Temas village, Batu, East Java and then conducting tests of physical and mechanical properties in Soil Mechanics Laboratory, Civil Engineering Department, State Polytechnic of Malang. The soil samples used in this study include both disturbed and undisturbed soils. The stabilization used in this research is plastic (PET) waste with sizes of 0,5 cm x 1 cm; 0,75 cm x 1,25 cm; and 1 cm x 1,5 cm with percentages at 0,75%; 1,50%; and 2,50%. The test conducted in this research are as follows:

1. Water Content (ASTM D 2216-80)
2. Unit Weight of Soil (ASTM D 2937-83)
3. Specific Gravity (ASTM D 854-33)
4. Atterberg Limits (ASTM D 4318-84)
5. Sieve Analysis (SNI 03-1968-1990)
6. Hydrometer Analysis (ASTM D 422-72)
7. Direct Shear (ASTM D 3080-82)

Then the shear angle (ϕ) and cohesion (c) values used to calculate the bearing capacity of shallow foundations using Terzaghi's theory.

1. Square foundation

$$q_u = 1{,}3.c.Nc + q.Nq + 0{,}3.\gamma.B.N\gamma \quad (1)$$

2. Circular foundation

$$q_u = 1{,}3.c.Nc + q.Nq + 0{,}3.\gamma.B.N\gamma \quad (2)$$

3. Rectangular foundation

$$q_u = c.Nc.(1+0{,}3.B/L) + q.Nq + 1/2.\gamma.B.N\gamma.(1-0{,}2.B/L) \quad (3)$$

3. RESULT AND DISCUSSION

The following results were obtained in this research:

A. Result of Physical and Mechanical Properties Testing of Original Soil

Based on the study conducted on the original soil in Temas village, Batu, the soil parameters were obtained as shown in

Table. 1 Results of laboratory testing of the original soil

Parameter		Unit	Test Results
Water Content	w	%	41,86
Unit Weight of Soil	γwet	gr/cm^3	1,75
Specific Gravity	Gs	-	2,60
Analysis of Grain Size Distribution	Gravel	%	0,12
	Sand	%	94,05
	Silt	%	2,73
	Clay	%	3,10
Liquid Limit	LL	%	45,80
Plastic Limit	PL	%	24,07
Plasticity Index	IP	%	21,73
Cohesion	c	Kg/cm^2	0,39
Shear Angle	ϕ	°	15,87

Based on the parameters above, the original soil is categorizes as poorly graded sand and clayey sand (SP-SC) in USCS classification method.

B. Shear Strength Parameters of Soil After Stabilization

For the soil sample from Temas village, Batu, stabilized with plastic waste, the shear strength parameters (ϕ) and cohesion (c) were obtained from direct shear testing. The testing involved plastic sizes of 0,5 cm x 1 cm, 0,75 cm x 1,25 cm, and 1 cm x 1,5 cm, with percentages of 0,75%, 1,50%, and 2,50%. The summarized shear strength parameters are shown in the following table.

Table. 2 Summary of shear strength parameter results

Plastic Size	Percentage of Plastic	Shear Strength Parameter	
		Shear Angle (ϕ) deg	cohesion (c) Kg/cm^2
Original Soil		15,87	0,394
0,5 cm x 1 cm	0,75%	41,54	0,404
	1,50%	38,40	0,844
	2,50%	35,24	0,429
0,75 cm x 1,25 cm	0,75%	16,13	0,654
	1,50%	14,59	0,770
	2,50%	38,90	0,287
1 cm x 1,5 cm	0,75%	49,73	0,591
	1,50%	40,46	0,255
	2,50%	29,48	0,356

C. Effect of Plastic Waste Stabilization

This data processing uses linear regression formulas, including the coefficient of determination (R2), to determine the influence of plastic size on shear angle and cohesion values. The coefficient of determination ranges between 0 and 1. A higher R2 value indicates that the selected predictor variables better explain the variability of the response variable.

1. Original soil + plastic waste size 0,5 cm x 1 cm

The influence of plastic size on the values of internal shear strength and cohesion can be observed from the graph below:

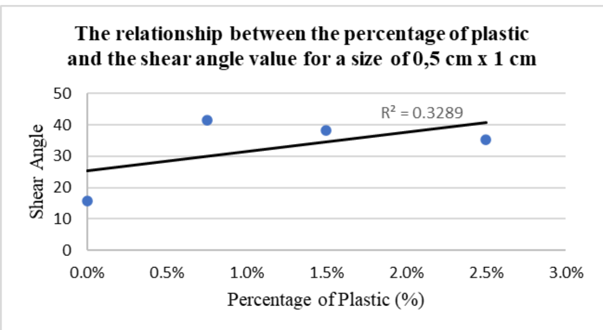

Figure. 1 The relationship between the percentage of plastic and the shear angle values for the size 0,5 cm x 1 cm

Based on the analysis, the obtained R square value is 0,3289. This means that the plastic size variable has an influence of 32,89% on the shear angle value, while the remaining 67,11% is influenced by other variables.

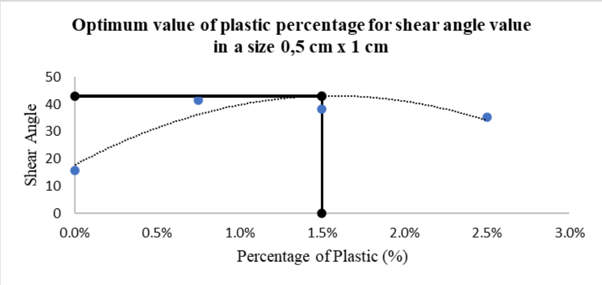

Figure. 2 Optimum value of plastic percentage for shear angle value in a size 0,5 cm x 1 cm

From the graph above, it is observed that the shear angle decreases with increasing percentage of PET waste. The optimum value of plastic percentage occurs at the composition of original soil + 1,50 % plastic waste and get shear angle value at 43°.

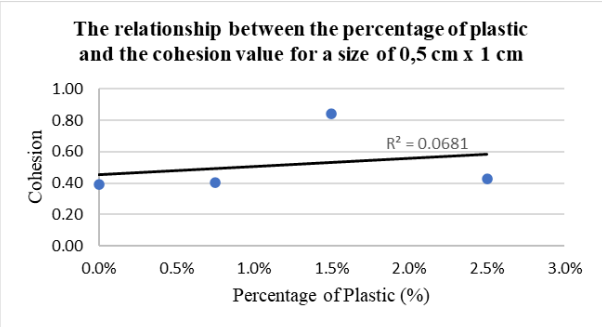

Figure. 3 The relationship between the percentage of plastic and the cohesion values for the size 0,5 cm x 1 cm

Based on the analysis, the obtained R square value is 0,0681 for cohesion, indicating that the plastic size variable influences cohesion by 6,81%, while 93,1% is influenced by other variables.

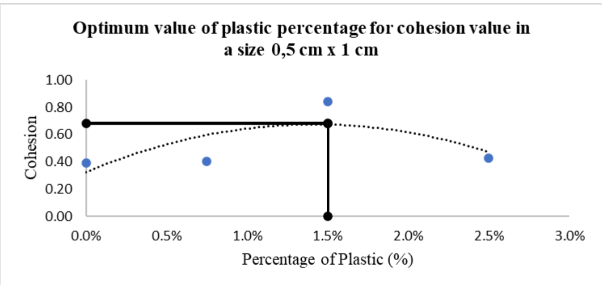

Figure. 4 Optimum value of plastic percentage for cohesion value in a size 0,5 cm x 1 cm

From the graph above, it is observed that the cohesion tends to increase with the addition of plastic waste, but at the composition of original soil + 0,75% plastic waste, the cohesion value of the soil decreases. The optimum value of plastic percentage occurs at the composition of original soil + 1,50 % plastic waste and get cohesion value at 0,68 kg/cm^2.

2. Original soil + plastic waste size 0,75 cm x 1,25 cm

The influence of plastic size on the values of internal shear strength and cohesion can be observed from the graph below:

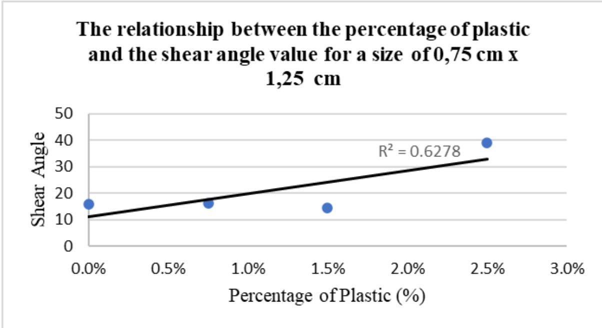

Figure. 5 The relationship between the percentage of plastic and the shear angle values for the size 0,75 cm x 1,25 cm

Based on the analysis, the obtained R square value is 0,6278. This means that the plastic size variable has an influence of 62,78% on the shear angle value, while the remaining 37,22% is influenced by other variables.

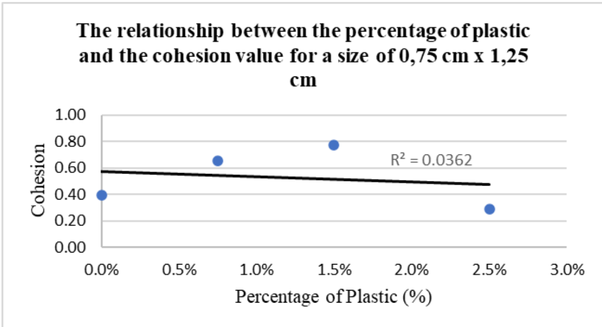

Figure. 6 The relationship between the percentage of plastic and the cohesion values for the size 0,75 cm x 1,25 cm

Based on the analysis, the obtained R square value is 0,0362 for cohesion, indicating that the plastic size variable influences cohesion by 3,62%, while 96,38% is influenced by other variables.

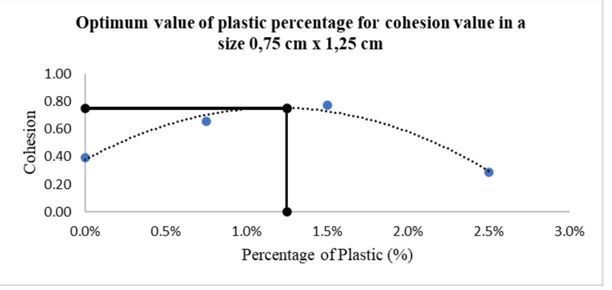

Figure. 7 Optimum value of plastic percentage for cohesion value in a size 0,75 cm x 1,25 cm

From the graph above, it is observed that the cohesion tends to increase with the addition of plastic waste, but at the composition of original soil+ 0,75% plastic waste, the cohesion value of the soil decreases. The optimum value of plastic percentage occurs at the composition of original soil + 1,25 % plastic waste and get cohesion value at 0,75 kg/cm^2.

3. Original soil + plastic waste size 1 cm x 1,5 cm

The influence of plastic size on the values of internal shear strength and cohesion can be observed from the graph below:

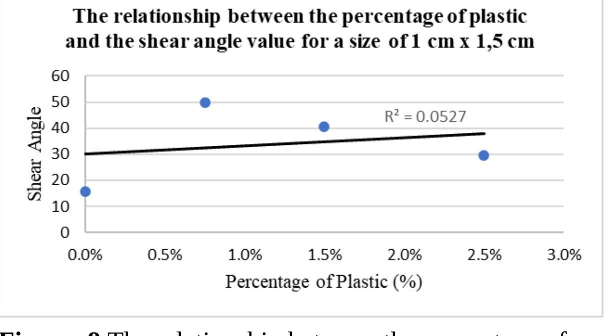

Figure. 8 The relationship between the percentage of plastic and the shear angle values for the size 0,5 cm x 1 cm

Based on the analysis, the obtained R square value is 0,0527. This means that the plastic size variable has an influence of 5,27% on the shear angle value, while the remaining 94,73% is influenced by other variables.

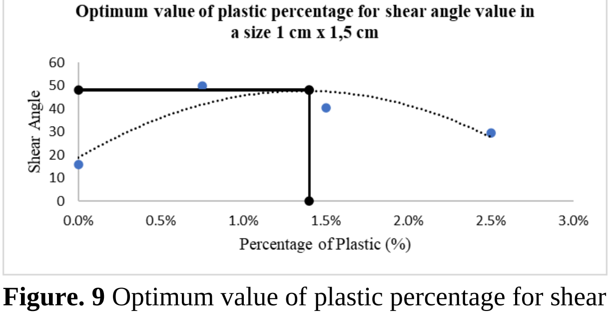

Figure. 9 Optimum value of plastic percentage for shear angle value in a size 1 cm x 1,5 cm

From the graph above, it is observed that the shear angle decreases with increasing percentage of PET waste. The optimum value of plastic percentage occurs at the composition of original soil + 1,40 % plastic waste and get shear angle value at 48°.

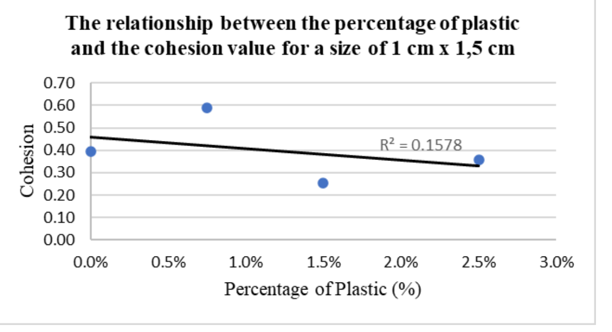

Figure. 10 The relationship between the percentage of plastic and the cohesion values for the size 0,5 cm x 1 cm

Based on the analysis, the obtained R square value is 0,1578 for cohesion, indicating that the plastic size variable influences cohesion by 15,78%, while 84,22% is influenced by other variables.

D. Structure of Building

In this area, a single-story house will be constructed with dimensions of 15 m in length, 9 m in width, and a floor height of 3.5 m. Below are the data used for modeling this house:

- Beam = 0,20 x 0,25 m
- Slab = 0,12 m
- Column = 0,30 x 0,30 m

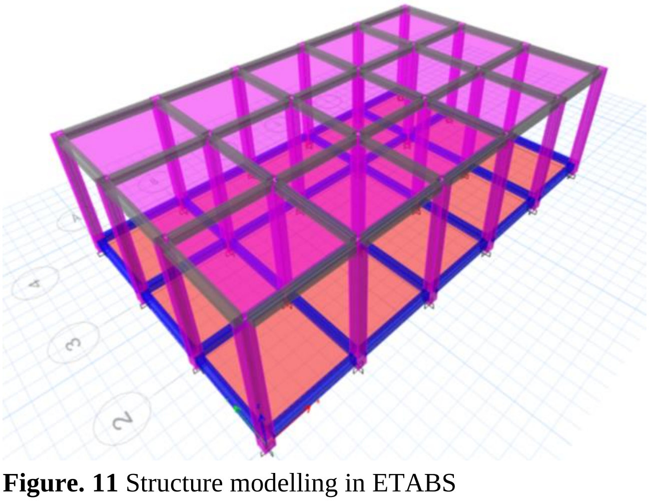

Figure. 11 Structure modelling in ETABS

From the above modeling, the moments and loads transmitted from columns to the foundation are:

Axial Load (Q_v) = 116,74 kN = 11,90 tons
Moment (M_x) = 12,50 kN.m = 1,41 tons.m

Moment (M_y) = 12,58 kN.m = 1,41 tons.m

For each foundation, the calculation of dead loads acting on the shallow foundation can be calculated as follows:

1. Square = (1 x 1 x 0,25) m + (0,3 x 0,3 x 0,75) m
   = 0,32 m^3 x 2400 kg/m^3
   = 762 kg = 0,76 ton
2. Circular = (π x $(0,5)^2$ x 0,25) m + (0,3 x 0,3 x 0,75) m
   = 0,26 m^3 x 2400 kg/m^3
   = 633,43 kg = 0,63 ton
3. Rectangular = (1 x 1,5 x 0,25) m + (0,3 x 0,3 x 0,75) m
   = 0,44 m^3 x 2400 kg/m^3
   = 1.062 kg = 1,06 ton

E. Analysis of Shallow Foundation

From the direct shear test results, shear angle (ϕ) and cohesion (c) parameters are obtained, which will be used for the shallow foundation bearing capacity analysis using the Terzaghi method. In this calculation, it is assumed that the soil experiences general shear failure, and the safety factor is taken as 3. There are 3 types of shallow foundation, namely square foundation with dimension of B = L = 1 m, circular foundation with dimension of B = 1 m, and rectangular foundation with dimension of B = 1 m and L = 1,5 m.

Based on the calculation of shallow foundation bearing capacity, the Q allowable values for original soil and original soil + plastic waste are obtained. The summarized values of Q allowable are shown in the table below:

Table. 3 Recapitulation of Q_{all} values

Plastic Size	Percentage of Plastic	Types of Foundation		
		Square (tons)	Circular (tons)	Rectangular (tons)
Original Soil		26,63	20,82	37,30
0,5 cm x 1 cm	0,75%	313,20	237,84	450,38
	1,50%	337,69	261,49	476,123
	2,50%	142,05	109,43	202,02
0,75 cm x 1,25 cm	0,75%	42,06	32,94	58,68
	1,50%	45,87	35,94	63,90
	2,50%	170,09	129,17	245,60
1 cm x 1,5 cm	0,75%	1.382,28	1.035,97	2.002,04
	1,50%	179,81	135,87	260,91
	2,50%	68,22	52,81	96,71

F. Cost Estimation

Here is the cost estimate analysis for square, circular, and rectangular foundations at 24 points:

Table. 4 Cost estimation for square foundations

Square Foundation						
No	Work Item	unit	volume	unit price	total	sub total
1	Excavation work	m3	61,44	Rp 115.310,97	Rp 7.084.705,95	
2	Sand fill work	m3	1,2	Rp 76.809,10	Rp 92,170.92	
3	Lean concrete work	m3	1,68	Rp 1.251.000,42	Rp 2.101.680,71	
4	Soil mix with plastic waste	m3	0,35	Rp 92.170,92	Rp 32.259,82	
5	Compaction work	m3	0,35	Rp 153.618,21	Rp 53.766,37	
6	Concrete work	m3	6	Rp 1.415.864,42	Rp 8.495.186,54	
7	Reinforcement work	kg	607,31	Rp 17.131,86	Rp 10.404.273,42	
8	Formwork	m2	24	Rp 213.644,45	Rp 5.127.466,82	
TOTAL						Rp 33.391.510,56
PPN 10%						Rp 3.339.151,06
TOTAL + PPN 10%						Rp 36.730.661,62

Table. 5 Cost estimation for circular foundation

Circular Foundation						
No	Work Item	unit	volume	unit price	total	sub total
1	Excavation work	m3	91,27	Rp 115.310,97	Rp 10.524.267,43	
2	Sand fill work	m3	1,2	Rp 76.809,10	Rp 92,170.92	
3	Lean concrete work	m3	1,68	Rp 1.251.000,42	Rp 2.101.680,71	
4	Soil mix with plastic waste	m3	0.27	Rp 92.170,92	Rp 25.323,96	
5	Compaction work	m3	0,27	Rp 153.618,21	Rp 42.206,60	
6	Concrete work	m3	4,71	Rp 1.415.864,42	Rp 6.674.784,42	
7	Reinforcement work	kg	619,95	Rp 17.131,86	Rp 10.620.944,34	
8	Formwork	m2	56,57	Rp 213.644,45	Rp 12.086.171,79	
TOTAL						Rp 42.167.555,18
PPN 10%						Rp 4.216.755,52
TOTAL + PPN 10%						Rp 46.384.310,70

Table. 6 Cost estimation for rectangular foundation

Rectangular Foundation						
No	Work Item	unit	volume	unit price	total	sub total
1	Excavation work	m3	80,64	Rp 115.310,97	Rp 9.298.676,56	
2	Sand fill work	m3	1,2	Rp 76.809,10	Rp 92,170.92	
3	Lean concrete work	m3	1,68	Rp 1.251.000,42	Rp 2.101.680,71	
4	Soil mix with plastic waste	m3	0,53	Rp 92.170,92	Rp 48.389,74	
5	Compaction work	m3	0,53	Rp 153.618,21	Rp 80.649,56	
6	Concrete work	m3	9	Rp 1.415.864,42	Rp 12.742.779,81	
7	Reinforcement work	kg	662,52	Rp 17.131,86	Rp 11.350.116,46	
8	Formwork	m2	30	Rp 213.644,45	Rp 6.409.333,53	
TOTAL						Rp 42.123.797,28
PPN 10%						Rp 4.212.379,73
TOTAL + PPN 10%						Rp 46.336.117,01

4. CONCLUSION

Based on the results of the testing and analysis that carried out in this research, the following are the conclusions drawn from this study:

1. The physical property parameters of the soil indicate that the original soil is classified as poorly graded sand and clayey sand (SP-SC) according to the USCS system.
2. From the soil stabilization tests using plastic waste with sizes of 0,5 cm x 1 cm; 0,75 cm x 1,25 cm; and 1 cm x 1,5 cm at percentage 0,75%; 1,25% dan 2,50%, there is a tendency for improvement. However, the shear angle decreases with increasing percentages of PET waste. The highest shear angle value occurred in stabilization with plastic size1 cm x 1,5 cm at 0,75% percentage, measuring 49,73°. The highest cohesion value was 0,844 kg/cm2 obtained from plastic size 0,5 cm x 1 cm at 1,50% percentage.
3. Based on the values of c dan ϕ obtained from the tests, the allowable load (Q_{all}) with plastic mixtures shows

significant improvement. The highest allowable for original soil can only support a maximum load 37,30 tons in a rectangular shape of 1 m x 1,5 m. and the highest allowable load was observed in the mixture of original soil + plastic size 1 cm x 1,5 cm at 0,75% percentage, with the same foundation shape and dimension, which is 1.382,28 tons.

4. Based on cost analysis, the price for a square foundation is Rp 36.730.661,62. For a circular foundation, it is Rp 46.384,310,70. And for a rectangular foundation, it is Rp 46.336.177,01.

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