



## 1. Introduction

In highway construction, subgrade conditions are often encountered that do not follow the required technical specifications, including the condition of high plasticity value, small soil shear strength value, and a high potential for swelling and shrinkage of soil [1]. The Bojonegara area of Banten province is an integrated industrial area [2]. This condition makes traffic services on Bojonegara Highway increasingly heavy with traffic conditions so that the road is damaged [3] significantly in the subgrade, which supports road construction. There are many methods of soil improvement in overcoming these conditions, including mechanical, hydraulic, physical & chemical soil improvement as well as the use of waste including palm oil waste for roads in Cibecalah Pandeglang Village [4] to improve the subgrade for Bojonegara highway using waste from one of the steel mills. The largest in Cilegon is steel slag waste, which will be mixed with the subgrade. The utilization of steel slag waste is one of the efforts to recycle waste that is not useful into something more useful. The availability of steel slag waste is very abundant for the Cilegon area because steel factories include PT Krakatau Steel and PT. Posco. Waste from steel factories has not been utilized optimally.

The formulation of the problem in this study looks for the physical properties of the tested soil in the form of grain analysis, grain density, and Atterberg boundaries. So that the type of soil to be tested will be obtained using the unified soil classification system (USCS) method. The process of making soil samples is carried out using subgrade mixed with variations of steel slag 0%, 5%, 10%, 15%, and 20% of the dry weight of the original soil which then the sample will be cured and tested for unconfined compressive strength for 0 days, three days, 14 days and 28 days. Testing of variations in steel slag aims to obtain the best composition obtained while curing is to determine the process of increasing or decreasing the value of unconfined compressive strength in time.

Several studies related to steel slag include [5] discussing the utilization of steel waste with clay in the Lamongan area, which was tested by the California bearing ratio (CBR) test method obtained from testing a mixture of 20% slag. The mixture reduced the original soil index value from 54.4% after being mixed with 20% steel waste to 33.81%, the liquid limit value (LL) of the original soil was 79.76% after being mixed with 20% steel waste to 67.55%. This process can also increase the original plastic limit value in the original soil condition from 25.36% to 33.74% after being mixed with 20% steel waste. The test value of 0.1" CBR on the original soil is 2.27%, increasing after being mixed with 20% of steel waste to 11%. Research [6] discussed the addition of steel slag and fly ash on the value of soil shrinkage and CBR at the optimum condition of 10% mixture where the CBR value of the original soil condition was 6.889%, increased to 8.316%, and decreased the value of soil shrinkage expansion from 5.592% to 0.474%. Research [7] concluded that adding 10% slag cement to organic clay can affect the original soil strength of 4.25% after stabilization. The CBR value increased to 30%.

## 2. Research Methodology

The research was conducted by finding the location of the soil that is not good for the construction on it, collecting materials to be studied, including soil samples, steel slag. Performing physical and mechanical soil testing, mixing soil, water, and steel slag, where the mass of the material remains determined is water based on the optimum water content of the original soil and the soil mass based on the dry weight of the original soil. In contrast, the changed mass is steel slag with various variations based on the dry weight of the original soil. The manufacture of the test material is carried out after measuring the mass of water, soil, and variations in the steel slag mixture, which is compacted by standard compaction testing and making test objects for the Unconfined Compression Test (UCT), which is cured for 0 days, three days, 14 days 28 days. Furthermore, do the UCT test on the day determined based on the Indonesian National Standard (SNI) test.

### 2.1. Research Sites

The research location is on Bojonegara Highway, which is included in the Serang Regency, Banten Province, where the research location can be shown in Figure 1.



Figure 1 . Map of Bojonegara Highway.



Figure 2. Steel slag. [17]

### 2.2. Data and Material Collection

The test soil was taken from Bojonegara Highway on disturbed soil, which was taken using a hoe. Steel slag waste is obtained from one of the largest steel processing plants in the city of Cilegon. Slag is obtained from the remains of the steelmaking process in furnaces at very high temperatures. This steel slag waste is in the form of small chunks. The content of steel slag can be seen in Table 1 [8], and the shape of steel slag can be seen in Figure 2. Compounds in steel slag include  $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ , and  $\text{Al}_2\text{O}_3$ , the same as the constituent compounds in cement [9], so that steel slag has properties like cement when mixed with water harden.

### 2.3. Sample Testing

After obtaining the steel slag and completing the subgrade, the subgrade will be subjected to a variety of tests.

#### 2.3.1. Moisture Content

Testing of soil water content ( $w$ ) in the original soil is carried out to determine the value/percentage of water contained in the subgrade where the mass of water contained in the soil ( $m_w$ ) is compared with the dry soil mass ( $m_s$ ). Water content data is needed for determination in the calculation of soil compaction and others [10]. The formula for calculating the water content of a soil is:

$$w = \frac{m_w}{m_s} \times 100 \% \quad (1)$$

**Table 1.** Compounds contained in steel slag.

Compound	Percentage	Compound	Percentage
CaO	26,65 %	TiO	1,22 %
MgO	14,80 %	V <sub>2</sub> O <sub>4</sub>	0,37 %
SiO <sub>2</sub>	12,83 %	Cr	0,19 %
FeO	10,75 %	Pb	0,013 %
Al <sub>2</sub> O <sub>3</sub>	8,75 %	Cd	<0,0001 %
MnO	1,76 %	TiO	1,22 %

#### 2.3.2. Analysis of Granules

Grain size analysis is carried out to determine the grain size contained in the subgrade, where the results of this test can determine whether the type of soil is fine or coarse-grained [11].

#### 2.3.3. Grain Density

Grain density ( $G_s$ ) is the weight of grain volume at ( $\gamma_s$ ) compared to the volume weight of water ( $\gamma_w$ ) at a certain temperature. Grain density has no units [12]. The formula for calculating soil density is:

$$G_s = \frac{\gamma_s}{\gamma_w} \quad (2)$$

#### 2.3.4. Liquid Limit

The liquid limit (LL) of the soil is the state of the soil that will change its properties from a liquid state to a plastic state. This test uses the Cassagrande [13]. The results of this test are used to determine the classification of the soil and soil properties.

#### 2.3.5. Soil Plastic Limit

The plastic limit (PL) is the water content at which a soil condition changes from a plastic condition to a semi-solid condition. The plastic limit is calculated based on the ratio between the weight of water to the dry grain weight of the soil on the test object [14]. Soil Plasticity Index values were obtained after the plastic limit, and liquid limit tests were completed. Soil plasticity index value reduces the liquid limit (LL) with the plastic limit (PL). The formula for soil plasticity index is

$$PI = LL - PL \quad (3)$$

#### 2.3.6. Soil Classification System

The soil classification system is used to determine the type of soil being tested. The soil classification system used is the USCS system (Unified Soil Classification System). The use of this system is because the USCS system can recognize organic and inorganic soil types.

#### 2.3.7. Standard Soil Compaction

Soil compaction testing is carried out to obtain the optimum water content value in the original soil, which will be used as a reference in calculating the material requirements for making test samples. After the material requirements are calculated and prepared, the material is mixed between subgrade, water, and steel slag. Next, the materials were mixed and compacted by the standard compaction method [15]. Tanah yang terdapat dalam cetakan tersebut dicetak sesuai ukuran untuk pengujian UCT dengan ukuran 3" dan diameter 3/2". After making the UCT test material, it was continued by curing the test sample for 0 days, three days, 14 days, and 28 days, followed by unconfined compressive strength testing.

#### 2.3.8. Unconfined Compression Test (UCT)

Unconfined compressive strength Test is the value of the axial stress at the top condition that the cylindrical test sample can withstand before experiencing shear failure [16]. The value of the unconfined compressive strength,  $q_u$  is obtained from the maximum proving ring dial reading.

$$q_u = \frac{k \times R}{A} \tag{4}$$

Where :

$q_u$  = unconfined compressive strength (kg/cm<sup>2</sup> )

$k$  = proving ring calibration

$R$  = maximum dial reading - initial dial reading

$A$  = cross-sectional area of the soil sample at the time of reading  $R$  (corrected) (yang dikoreksi) (cm<sup>2</sup>).

### 3. Results and Discussion

#### 3.1. Soil Physical Test Results

The results of physical testing of the existing soil on Bojonegara Highway, Serdang consist of water content, analysis of grain size, grain density, plastic limit, liquid limit, and compaction with the following analysis results.

##### 3.1.1. Moisture Content

The initial soil moisture test was 34.17%. Therefore, the amount of water content is from the existing soil conditions on Bojonegara Highway.

##### 3.1.2 Analysis of Grain Size

The results of the analysis of the soil grain size analysis in Figure 3 show that the existing condition of the soil is included in the category of fine-grained soil. Soil that passes Sieve no. 200 is more than 50%. Following the unified soil classification system.

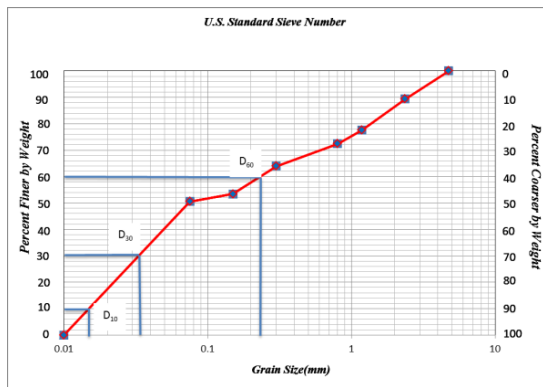


Figure 3. Graph of sieve passing percentage with sieve diameter

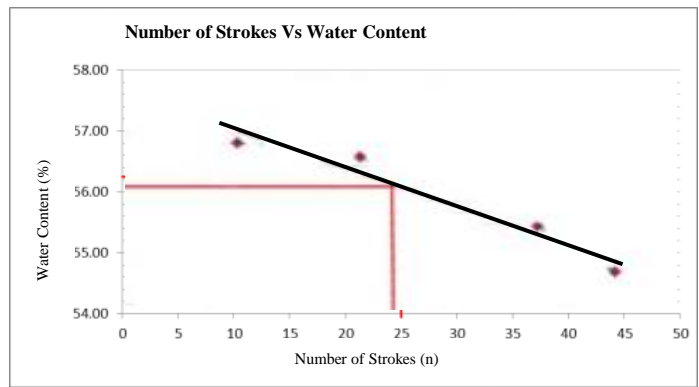


Figure 4. Graph of liquid limit

##### 3.1.3. Grain Density

Testing the specific gravity of the soil on Bojonegara Highway Serang obtained a  $G_s$  value of 2.211. The  $G_s$  value of the soil is not included in any soil type category, so that the soil type cannot be identified based on testing the specific gravity of the soil grains.

##### 3.1.4. Plastic Limit

The results of the liquid limit test on Bojonegara Highway Serang, the plastic limit value (PL) is 33.92%. The result of testing the liquid limit on Bojonegara Highway Serang is that the plastic limit value (PL) is 33.92%.

##### 3.1.5. Liquid Limit

In Figure 4, the liquid limit value on Bojonegara Highway Serang is obtained, namely  $LL = 56.21\%$ . Then the soil is included in the category of high plasticity.

##### 3.1.6. Plasticity Index

Liquid Limit ( $LL$ ) = 56.21% and Plastic Limit ( $PL$ ) = 33.92%. So the value of Soil Plasticity Index ( $IP$ ) is:

$$PI = LL - PL$$

$$PI = 56.21\% - 33.92\% = 22.29\%$$

Plasticity index ( $IP$ ) obtained 22.29%.  $IP$  value  $> 17\%$ , the soil is classified as clay soil pure, which has high plasticity and is cohesive

#### Unified soil classification system

- The amount of soil that passed sieve no. 200 more than 50%
- Soil liquid limit value is less than 56.21%
- Soil plastic limit value 33.92%

In Figure 5, the soil yield on Bojonegara Highway Serang is classified as OH soil, which is organic clay with high plasticity.

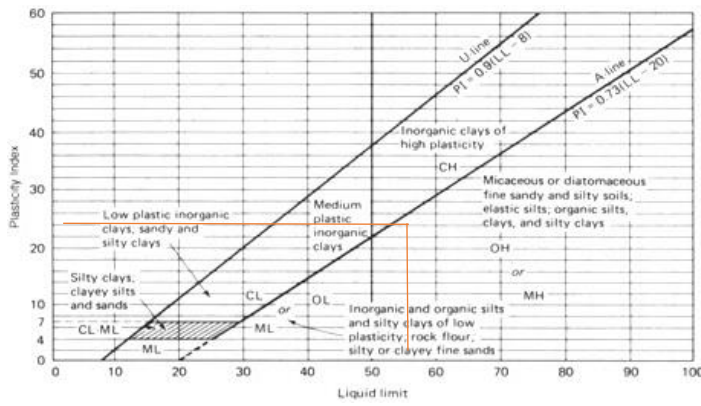


Figure 5. USCS chart for determining soil type

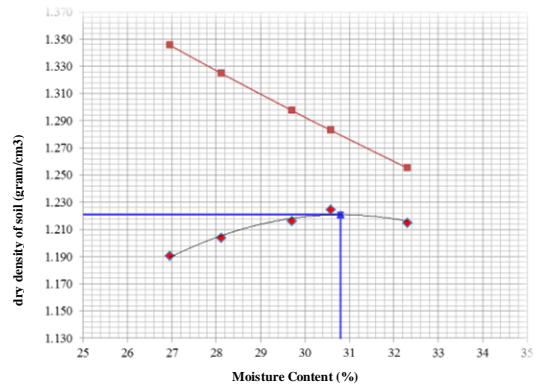


Figure 6. Graph of relationship between dry density of soil with moisture content

3.1.7. Compaction

The compaction test results are then translated into a graph, namely the relationship between the dry density of the soil and the water content. The shape is a parabolic curve. In Figure 6, the maximum dry density value is 1.221 gram/cm<sup>3</sup>, and the optimum water content ( $\omega$  optimum) is 30.80%. All compaction test results are used to calculate the composition of the unconfined compressive strength test specimens with steel slag.

3.2. Soil Stabilization with Steel Slag

The way to obtain an unconfined compressive strength test object is to take a sample from the laboratory soil compaction test to use the maximum dry density and optimum moisture content of the compaction test that has been done previously. The next step is to calculate the need for soil, water, and added steel slag material to make an unconfined compressive strength test of soil specimens for compaction for each mold.

1. Total mass of land requirements

$$\begin{aligned} \text{Mold volume} &= \frac{1}{4} \times \pi \times d^2 \times \text{height} \\ &= \frac{1}{4} \times (3.14) \times (10.16)^2 \times 11.643 \\ &= 943.456 \text{ cm}^3 \end{aligned}$$

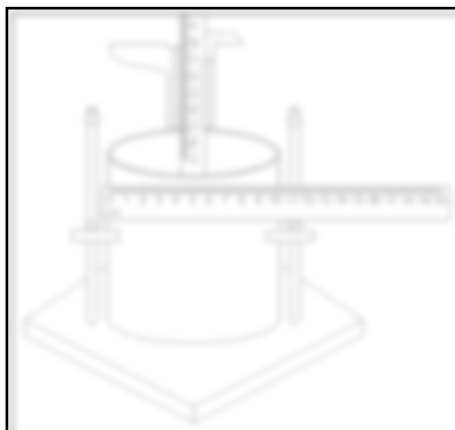


Figure 7. Compaction mold dimension

$$\begin{aligned} \text{Soil mas} &= \text{Volume} \times \text{maximum } \gamma_{dry} \\ &= 1151.96 \text{ gram} \end{aligned}$$

Then rounded up to 1152 gram

2. Total mass of water needs

Water content in the existing condition

Existing water content 8.696%

$$\text{Mass of water} = \text{Mass of soil} \times \text{water content} = 100.18 \text{ grams}$$

$$\text{Mass of water} = \text{Mass of soil} \times \text{optimum} = 354.816 \text{ grams}$$

Mass of water for soil stabilization

$$\begin{aligned} \text{Amount of water} &= \text{water} - \text{existing groundwater} \\ &= 254.64 \text{ grams} \end{aligned}$$

3. The amount of mass required for steel slag added

$$\text{Mass of steel slag} = \text{mass of soil} \times \% \text{ of steel slag}$$

4. Mixing all materials for the manufacture of test objects.

$$\text{Test object} = \text{mass of soil} + \text{mass of water} + \text{steel slag.}$$

5. The volume of the unconfined compressive strength test object

Table 2. The composition of the material for making the test object

Variation of added ingredients	Material mass (gram)		
	Soil	Water	Steel slag
Steel slag 0 %	1152	254.64	0
Steel slag 5 %	1152	254.64	57.6
Steel slag 10 %	1152	254.64	115.2
Steel slag 15 %	1152	254.64	172.8
Steel slag 20 %	1152	254.64	230.4

The unconfined compressive strength test specimen was obtained from the compaction test using a mold. Each compaction test resulted in 3 unconfined compressive strength specimens. The calculation of the volume of the molded specimen for the unconfined compressive strength of the soil is  $Mold\ volume = \frac{1}{4} \times \pi \times d^2 \times height = 81.67\ cm^3$

3.2.1. The Results of The Unconfined Compressive Strength Test

In the unconfined compressive strength test, each specimen with variations in the added material of steel slag was subjected to curing (treatment), namely 0, 3, 14, and 28 days, each of which consisted of 3 specimens. The average results of sample testing for the value of unconfined compressive strength with the percentage of steel slag on curing time, the value of qu with variations in the percentage of steel slag added, and curing time are shown in Table 3.

Table 3. The value of qu with curing time to percentage of steel slag

Curing time (Day)	Steel slag (%)	qu (Kg/Cm <sup>2</sup> )	Percentage increase per curing time
0	0	0.92	0.00%
	5	1.25	35.87%
	10	1.27	37.68%
	15	1.37	49.28%
	20	<b>1.72</b>	86.59%
3	0	1.08	0.00%
	5	1.25	15.87%
	10	1.28	18.21%
	15	1.56	43.85%
	20	<b>1.83</b>	69.18%
14	0	1.30	0.00%
	5	1.31	0.90%
	10	1.73	33.20%
	15	1.80	39.00%
	20	<b>1.87</b>	44.14%
28	0	1.57	0.00%
	5	1.71	9.05%
	10	2.04	30.46%
	15	2.37	51.22%
	20	<b>2.40</b>	53.35%

Table 4. The value of qu with the percentage of steel slag on curing time

Curing time (Hari)	Steel slag (%)	qu (kg/cm <sup>2</sup> )	Percentage increase per grade of steel slag
0	0	0.92	0.00%
	3	1.08	17.57%
	14	1.30	40.76%
	28	1.57	70.11%
	0	1.25	0.00%
5	3	1.25	26.67%
	14	1.31	30.93%
	28	1.71	62.93%
	0	1.27	0.00%
	10	3	1.28
14		1.73	36.18%
28		2.04	61.18%
0		1.37	0.00%
15		3	1.56
	14	1.80	31.07%
	28	2.37	72.33%
	0	1.72	0.00%
	20	3	1.83
14		1.87	8.74%
28		2.40	39.81%

The test results in table 3 show that the addition of steel slag affects the compressive strength of the soil. At the percentage of 0% steel slag and 0 days of curing, the value qu was 0.92 kg/cm<sup>2</sup>. The value qu increases with 5% steel slag, which is 1.25 kg/cm<sup>2</sup>. The increase continued to occur with the addition of steel slag, up to 20% steel slag, the value qu is 1.72 kg/cm<sup>2</sup>.

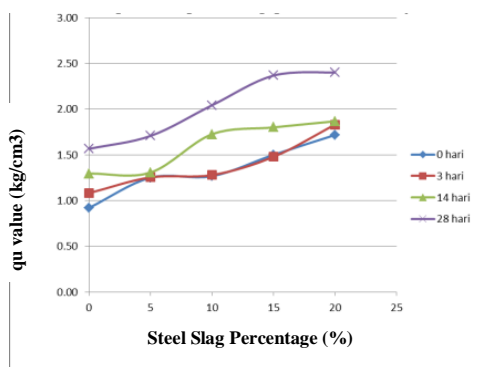


Figure 8. The relationship between the value qu and the percentage of steel slag

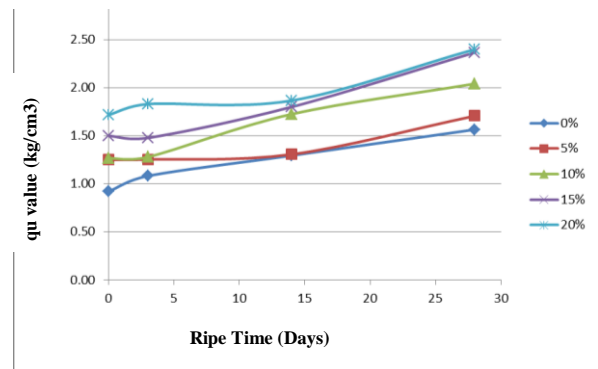


Figure 9. The relationship between the value qu and the percentage of steel slag

Based on the comparison of the graph in Figure 8, the value qu with a curing time of 0 days and three days shows a slight increase. At the 14-day curing time, a more significant increase was seen, and at the 28-day curing time, the value qu became even higher. So it can be concluded that the value qu also increases with the length of curing time. Value of unconfined compressive strength by curing to percentage of steel slag. The results of the comparison can be seen in Table 4 .

Based on the comparison of the graph in Figure 8, the value  $q_u$  with a curing time of 0 days and three days shows a slight increase. At the 14-day curing time, a more significant increase was seen, and at the 28-day curing time, the value  $q_u$  became even higher. So it can be concluded that the value  $q_u$  also increases with the length of curing time. Based on the test results on the length of curing time, it is seen that by giving a longer curing time, the value  $q_u$  increases. For example, in soil with a variation of 20% addition, at 0 days of curing, the value  $q_u$  was 1.72 kg/cm<sup>2</sup>, and then there was an increase with the longer curing time until at 28 days the value  $q_u$  was 2.40 kg/cm<sup>2</sup>.

Based on the comparison of the graph in Figure 9, the value  $q_u$  with the percentage of steel slag 0% and 5% shows very little increase, likewise with the percentage of steel slag 10%, 15%, and 20%. The results of all analyses of the unconfined compressive strength test with added steel slag, with the percentage of steel slag, and the length of curing time affect the value of  $q_u$ . It was proven at 0 days of curing time with 0% steel slag, value  $q_u$  0.92 kg/cm<sup>2</sup>, 5% steel slag value  $q_u$  1.25 kg/cm<sup>2</sup>, up to 20% steel slag value  $q_u$  1.72 kg/cm<sup>2</sup>. At 20% steel slag with curing time of 0 days value  $q_u$  1.72 kg/cm<sup>2</sup>, 3 days curing value  $q_u$  1.83 kg/cm<sup>2</sup>, up to 28 days curing value  $q_u$  2.4 kg/cm<sup>2</sup>.

Steel slag is a by-product of steel processing, containing lime in the process. Steel slag contains lime which can be used for soil stabilization. While the curing time is the treatment on the test object to be left so that the mixture of test objects consisting of soil, water and steel slag reacts in the binding. The binding reaction process takes time. The longer the curing time, the test object can react better.

### 3.3. Results of Testing the Physical Properties of Soil with Additives

#### 3.3.1. Liquid Limit Test

Testing the liquid limit of the soil on the percentage of steel slag content as shown in Table 5.

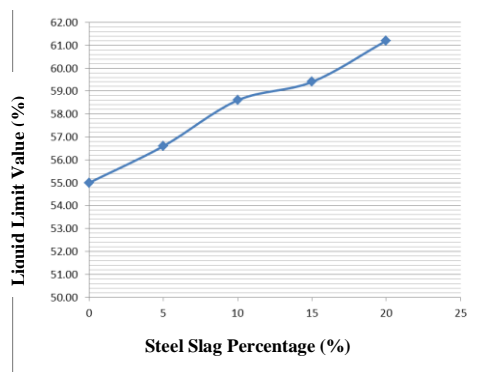


Figure 10. The graph of the relationship between the liquid limit and the percentage of steel slag

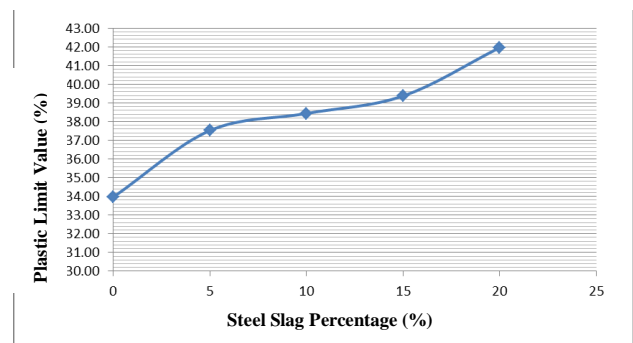


Figure 11. Graph of the relationship between the plastic limit and the percentage of steel slag

Table 5. Liquid limit value to steel slag percentage

Steel slag (%)	Liquid limit (%)
0	55.00
5	56.60
10	58.60
15	59.40
20	61.20

Table 6. Plastic limit value to steel slag percentage

Steel slag (%)	Plastic limit (%)
0	33.92
5	37.52
10	38.44
15	39.37
20	41.96

In Figure 10, the liquid limit value in soil with a mixture of 0% slag is 55%. After being given a mixture of steel slag, it can be seen in the table and graph above that the liquid limit value increases. As in the addition of 5% steel slag, the liquid limit value is 56.60%. The liquid limit value increases as the percentage of steel slag increases until the highest liquid limit value is 61.20% on the addition of 20% steel slag.

#### 3.3.2. Plastic Limit Testing

The plastic liquid limit test on the percentage of steel slag content is as shown in Table 6. Figure 11 shows the plastic limit value for soil with 0% slag mixture is 33.96%. After being given a mixture of steel slag, it can be seen in the table and graph above that the plastic limit value increases. The plastic limit value increases with the increase in the percentage of steel slag until the highest plastic limit value is 41.96%, in addition to 20% steel slag. The results of the soil plasticity index on mixed soils are shown in Table 7. The plasticity index (IP) in mixed soils was obtained from 19.24% to 21.04%. According to the table of plasticity index values and soil types, IP values > 17%, soil with a mixture of steel slag is a pure clay type with high plasticity and is cohesive.

### 3.3.3. Soil Specific Gravity Test

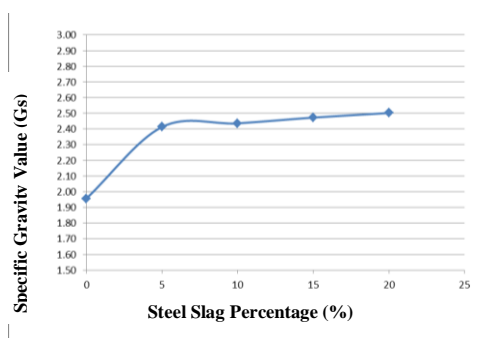
Testing the specific gravity of the soil against the percentage of steel slag content as shown in Table 8. The test results above show that the addition of the percentage of steel slag can increase the value of the specific gravity of the soil, this is because the specific gravity of the steel slag is significant and affects the specific gravity of the soil with a mixture of added materials as shown in Figure 6.

**Table 7.** Plastic limit value to steel slag percentage

Steel slag	Liquid limit (%)	Plastic limit (%)	Plasticity index
0%	55.00	33.96	21.04 %
5%	56.60	37.52	19.08 %
10%	58.60	38.44	20.16 %
15%	59.40	39.37	20.03 %
20%	61.20	41.96	19.24 %

**Table 8.** Specific gravity value (Gs) to percentage of steel slag

Steel slag (%)	Gs
0	2.101
5	2.41
10	2.44
15	2.47
20	2.50



**Figure 12.** Graph of the relationship of specific gravity to the percentage of steel slag

Figure 12 shows the value of specific gravity (Gs) of soil on soil with a 0% steel slag mixture of 1.96. In testing the specific gravity of the soil with a mixture of 5% steel slag to 2.41. Then the Gs value increases with the increase in the percentage of steel slag until the maximum Gs value is in the soil with a mixture of 20% steel slag. Finally, the Gs value becomes 2.50. These findings show that the value of the specific gravity of the steel slag is larger than the value of the specific gravity of the soil, resulting in a rise in the value of the specific gravity of the test sample every time the percentage of steel slag increases. As the value of Gs increases, the weight of the soil will increase.

## 4. Conclusions

From the results of physical and mechanical testing of soil at the Soil Mechanics Laboratory, Faculty of Engineering, University of Sultan Ageng Tirtayasa on the subgrade of Bojonegara Highway Serang, several conclusions were obtained, namely, in testing the physical properties of the existing soil, the soil at that location has an atterberg limit value, namely LL = 56.21% and PL = 33.92%. The Gs value of the existing soil is 2.211, and the results of the grain analysis test include fine-grained soil. According to the USCS classification system, the soil is classified as CH, an inorganic clay with high plasticity. The compressive strength test obtained several results, namely soil mixed with 0% steel slag and curing 0 days, the value of  $q_u = 0.92 \text{ kg/cm}^2$  was obtained. The value of  $q_u$  increases with increasing curing time. The value of  $q_u$  in soil mixed with 0% steel slag with a curing time of 28 days is  $1.72 \text{ kg/cm}^2$ . The percentage increase in the value of  $q_u$  is 86.96%. The value of  $q_u$  also increases with the increase in the percentage of steel slag mixture. The value of  $q_u$  in a mixture of soil and 0% steel slag with a curing time of 28 days is  $1.57 \text{ kg/cm}^2$ . Then in a mixture of 20% steel slag and 28 days of curing, the value of  $q_u$  is  $2.40 \text{ kg/cm}^2$ , and the percentage increase in the value of  $q_u$  is 52.87%. With steel slag material in soil stabilization research on Bojonegara Highway Serang, the value of  $q_u$  increases with increasing steel slag content and curing time. The lowest  $q_u$  value was in a mixed soil of 0% steel slag with a curing time of 0 days, and the highest  $q_u$  value was in a mixed soil of 20% steel slag with a curing time of 28 days.

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