The Effect of Fly Ash-Based Geopolymer Proportion on the Specific Gravity of Mixed Soil

Woelandari Fathonah[1], Rama Indera Kusuma[2], Enden Mina[3], Baehaki[4], Bella Rizka[5]
[1,2,3,4,5]Department of Civil Engineering, Sultan Ageng Tirtayasa University, Indonesia

Article Info

Article history:

Submitted September 2, 2024
Reviewed September 24, 2024
Published October 30, 2024

Keywords:

Soil stabilization, specific gravity, geopolymer, fly ash

ABSTRACT

Road construction planning must consider the characteristics and strength of the soil. This study aims to determine the classification of soil and the effect of fly ash-based geopolymer as an added material on the specific gravity of soil. Specific gravity testing was carried out using a pycnometer to obtain the specific gravity of the soil. The test object used is a soil sample added with geopolymer with fly ash as raw material and an alkaline activator ($Na_2SiO_3$and NaOH). The NaOH concentration is 10 M with a solution ratio of 2.0 (Na_2SiO_3 to NaOH), fly ash content of 20%, and variations in S / L (fly ash to activator) levels of 1/2 and 1/2.5. Based on the research that has been done, the results show that the soil used in the study is included in the organic clay soil with a specific gravity value of 2.49. The effect of fly ash-based geopolymer in this study increases the specific gravity value, with a specific gravity of 2.60 for variation B (80% soil, 20% FA, S/L 1/2) so that the soil falls into the organic clay category and 2.69 for variation C (80% soil, 20% FA, S/L 1/2.5) so that the soil falls into the non-organic clay category.

Available online at http://dx.doi.org/10.36055/fondasi

Corresponding Author:

Woelandari Fathonah,
Department of Civil Engineering,
Sultan Ageng Tirtayasa University,
Jl. Jendral Soedirman Km 3, Banten, 42435, Indonesia.
Email: woelandari@untirta.ac.id

1. INTRODUCTION

Clay soil has a low ability to drain water and high compressibility, causing clay soil to have a low bearing capacity. It could be better for construction work, and soil improvement methods are needed to overcome these problems [1-8]. Soil stabilization should be carried out if the soil in the field is highly compressible or has an unsuitable consistency index, too high permeability, or other objectionable properties that make it unsuitable for a construction project [9-12]. Using soil stabilization materials has become a significant concern in geotechnical engineering. One of the most widely researched materials is fly ash, a by-product of coal combustion. Fly ash converted into geopolymer has excellent potential as an environmentally friendly and economical binder. Fly ash geopolymers can improve the mechanical properties of soil, such as compressive strength and erosion resistance. This study aims to determine the conclusion of various proportions of fly ash geopolymer on the specific gravity of mixed soil. Geopolymer results from polymerization from the synthesis of non-organic materials [13-16]. The main essential ingredients for the manufacture of geopolymer materials are materials that contain a lot of silica and aluminum. Essential solutions such as sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) dissolve Si and Al elements and allow chemical reactions. Si and Al elements are originated in many industrial waste materials, such as fly ash. According to SNI 2460:2014, fly ash is a fine residue resulting from the combustion or dissolution of coal and is transported by hot air flow [17]. According to SNI 03-6414-2002, fly ash is excess from burning coal in the furnace of a steam power plant, which is delicate, round, and pozzolanic. Fly ash is a solid waste produced from burning coal in power plants. Fly ash is a fine-grained mineral residue from pulverized coal combustion in a power plant. If not treated further, fly ash can cause negative impacts on the environment. Coal fly ash can contaminate groundwater with impurities such as arsenic, barium, beryllium, boron, cadmium, conium, thallium, selenium, molybdenum, and mercury [18]. The Indonesian National Standard (SNI 2460:2014), which mainly refers to the requirements of Bina Marga, explains that adding fly ash by 5%-20% to clay soil can increase the bearing strength, plastic limit, and OMC (optimum water content) and reduce MDD (maximum dry density) [19]. Singhi Binod (2015) states that soil with a fly ash-based geopolymer mixture has very high strength [20]. Research by Abdila et al. (2021) shows that the value of free compressive strength (qu) in soil with the addition of fly ash-based geopolymer is 14.398 kg/cm^2 [13]. In research with added materials without geopolymers, the highest increase in free compressive strength value is lower than in other studies using geopolymers. For example, in the research of Rama Indera K., et al [21], with the same length of curing, the optimal qu of soil without the addition of geopolymer material is 2.06 kg/cm^2, and the optimal qu of soil with the addition of 30% fly ash 28 days curing is 2.4 kg/cm^2. In the research conducted by Abdila et al. (2021), where fly ash-based geopolymers were used, the increase was quite significant, although only seven days of curing was carried out. This can be used to determine whether adding geopolymers to subgrade stabilization affects the free compressive strength value produced.

According to SNI 1964:2008, soil-specific gravity test results can be used to determine the consistency of material behavior and properties. Specific gravity (Gs) is the relation between solid grains' volume weight and water's volume weight at four °C [22]. Because the addition of geopolymers to soil has a reasonably good effect, this material is used as a mixture in the study ‘The Effect of Fly Ash Based Geopolymer Proportions on the Specific Gravity of Mixed Soils’ where there are various tests such as free compressive strength, compaction, moisture content, specific gravity and physical properties of soil which include grain size analysis, liquid limit and plastic limit, in this article will review how the effect of the addition of fly ash based geopolymers on the specific gravity of soil, where the original soil and soil that has been mixed with fly ash based geopolymers are used.

1.1 Soil

From a civil engineering perspective, soil is a relatively loose collection of minerals, organics and sediments that sit on top of bedrock. Carbonates, organics or oxides deposited between soil particles result in relatively weak bonding of soil grains. The spaces between particles can contain water, air or both. Weathering of rocks or other geological procedures that occur near the surface of the bum form soil.. Generally, weathering due to chemical procedures can occur by the effect of oxygen, carbon dioxide, water (especially covering acids or alkalines) and other chemical processes. If the result of weathering is still in its original place, then this soil is called residual soil (residual soil) and if the soil moves, it is called transported soil (transported soil) [22].

1.2 Specific Gravity of Soil

According to SNI 1964:2008, soil-specific gravity test results can be useful to control the consistency of material behavior and properties. Specific gravity (Gs) is the ratio between solid grains' volume weight and water's volume weight at four °C . Typically, the specific gravity of various soils ranges from 2.65 to 2.75. Specific gravity Gs = 2.67 is generally used for cohesionless or granular soils, while for cohesive soils not containing organic matter, Gs ranges from 2.68 to 2.72. The following are the specific gravity values of various soil types [22].

1.3 Stabilization of Soil

Soil stabilization is used to increase the bearing capacity of a soil layer by treating the soil layer [23]. Soil stabilization is an attempt to process soil that aims to improve the achievement of a higher CBR value or magnitude of the original soil or its origin so that it is well used for the bottom layer under construction. Chemical stabilization is soil stabilization by adding a stabilizer (chemical) with special properties to help obtain a more stable soil mass [24]. Some mechanical soil stabilization processes improve grain gradation, compaction, and replacement of the original soil. In comparison, Chemical stabilization is achieved by mixing soil with chemical additives [25].

1.4 Fly Ash

Fly ash is an additive often used as a substitute or mixture of cement to manufacture concrete. It is also popularly used as a soil stabilization additive. Fly ash is the waste from burning coal in the furnace of a steam power plant, which is delicate, round, and pozzolanic [21]. One of the industrial by-products called fly ash is the residue of the coal combustion process in steam power plants. Fly ash is classified as a 'pozzolan' substantial, a silica or aluminous material with cementitious material, such as Portland cement [26].

This material sets while consuming gases and is collected using an electrostatic precipitator. Fly ash particles are generally spherical since the particles are set while suspended in the exhaust gases. The physical properties of fly ash according to ACI Manual of Concrete Practice 1993 Parts 1 226.3R-6 and ASTM C 618 are ϕ 1 micron - ϕ 1 mm in size with a fineness of 70% - 80% passing sieve no. 200 (75 microns). With the addition of water and its fine particle size, the silica oxide confined in fly ash will react chemically with calcium hydroxide and produce a substance with binding capability [9]. Table 1 shows the classification of fly ash based on chemical composition and Table 3 shows the fly ash chemical contents

Table 1. Fly Ash Classification based on Chemical Composition

Description	Class		
	N	F	C
$SiO_2 + Al_2O_3 + Fe_2O_3$, min, %	70	70	50
SO_3, max,%	4	5	5
Water Content, max, %	3	3	3
Lost Incandescent, max, %	10	6	6

(Source: SNI 2640:2014)

Type C fly ash contains CaO above 10%, resulting from burning lignite or sub-bituminous coal (young coal) (Bina Marga, 2015). Class C fly ash is also called high-calcium fly ash due to its high CaO content [9].

1.5 Geopolymer

Geopolymer results from polymerization from the synthesis of non-organic materials [13]. The primary base material for manufacturing this geopolymer material is a material that contains a lot of silica and alumina. Various alkaline activators, such as sodium hydroxide, sodium silicate, and potassium hydroxide, can activate fly ash to produce geopolymers [26]. Essential explanations such as sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) dissolve Si and Al elements and allow chemical responses to transpire. Silica and alumina elements are found in many industrial waste materials, such as fly ash. Sodium silicate serves to hasten the polymerization reaction, while sodium hydroxide reacts with Al and Si elements confined in fly ash to produce strong polymer bonds. In addition to sodium silicate and sodium hydroxide activators, the bond strength of fly ash geopolymers is also inclined by the concentration and ratio of alkaline activators used [27].

Geopolymers comprise solid materials and activator solutions that can replace cement and produce aluminosilicate bonding systems [28]. According to Canakci et al. (2019), aluminosilicate materials are dissolved with an alkaline activator to form reactive silica and alumina. A polycondensation reaction occurs in a highly alkaline environment, causing Si-O-Al rearrangements that give the material high mechanical strength [25]. Geopolymer cement mixed in a material, for example, concrete, will produce a material that has the same mechanical properties as concrete made from Portland cement, where the addition of geopolymers causes the material to have high compressive strength, minimal creep, very low shrinkage or shrinkage and in concrete with geopolymer mixtures more resistant to sulfuric acid [29].

The fine particles of fly ash contribute by filling the empty spaces between the soil particles. This can cause the clay soil to stabilize and raise the compressive strength of the clay soil. Soil chemical elements, including Silicon Dioxide (SiO_2), Aluminum Trioxide (Al_2O_3), Iron Trioxide (Fe_2O_3), and Calcium Oxide (CaO) which are also contained in C-grade fly ash, are tabulated in Table 3. For the geopolymerization process to occur, the primary obligation must be met, and the material used must be rich in silica (Si) and aluminum (Al) minerals [13]. The fly ash used consists of SiO2 and Al_2O_3 minerals with percentages of 41.70% and 21.30%, respectively, making the fly ash suitable for geopolymer raw material.

The essential ingredients of geopolymer are Al and Si. To activate these substances, sodium hydroxide (NaOH) is needed to react with these substances so that the polymer bond becomes solid, and sodium silicate (Na_2SiO_3) is required as a catalyst to accelerate the chemical reaction. Al and Si are contained in soil and fly ash. Where soil and fly ash have mineralogical components [13].

2. METHODS

2.1 Location of Research

This research was conducted on soil samples at Kubang Laban Street, Serang Regency, Banten (-6.002174, 106.085387). The research location is shown in Figure 1.

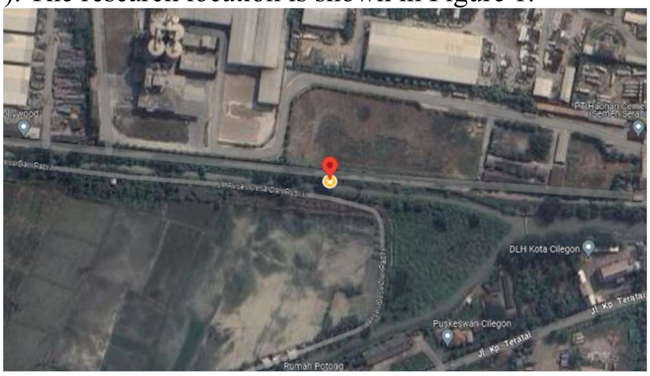

Figure 1. Research Location Map

2.2 Stages of Research

a. Sampling Preparation

The survey is required for soil sampling at the specified location to assess whether the location needs soil stabilization using DCP. testing to determine the CBR. value of the soil at that location. The soil that was taken was disturbed soil. The soil is carried by hoeing and put into sacks. Fly ash raw materials were obtained from P.L.T.U's coal combustion waste source. Banten III, Jl. Ir. Sutami, Loncar Village, Kemiri, Tangerang Regency. The activator used for geopolymer raw materials is a sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) compound that has a Certificate of Analysis (CoA). Soil-specific gravity testing was carried out to determine the classification of soil based on specific gravity with a soil pycnometer on native soil and soil mixed with fly ash-based geopolymers and used in compaction calculations. The test results in the form of data obtained after testing are analyzed based on applicable standards, where the reference used for specific gravity is S.N.I. 1964: 2008.

Compressive strength test objects are manufactured using variations of native soil (100% soil) and soil with a geopolymer mixture containing fly ash raw materials and alkaline activators (Na_2SiO_3 and NaOH). The NaOH concentration is 10 M, with a solution ratio of 2.0 (Na_2SiO_3 to NaOH), fly ash content of 20%, and variations in S / L (fly ash to activator) levels of 1/2 and 1/2.5. Curing lasts 0, 7, 14, and 28 days. Table 2 shows the sample variations.

Table 2. Sample Variation

Sample Variation	Soil	Fly Ash (S)	S/L	
			S (Fly Ash)	L (AA)
A	100 %	0%	0	0
B	80%	20%	1	2
C	80%	20%	1	2,5

b. Mixing of Testing Materials

Specific gravity testing was conducted using a pycnometer. The original soil test specimens were dried in an oven at (100±5)°C until the weight remained. After drying, the test specimens were sieved using sieves no. 4 and no. 10 and weighed according to the capacity of the pycnometer. Soil mixed with fly ash-based Geopolymer. Before mixing into soil and fly ash, an alkaline activator must first be made by mixing 10M NaOH solution with Na_2SiO_3. The process to create an alkaline activator with Geopolymer is as follows:

1. To make 1000 ml of 10M NaOH, researchers weighed 40 grams of solid NaOH and then put it in a 200 ml measuring cup.
2. Dissolve the solid NaOH with distilled water and wait for it to cool.
3. After cooling, put the NaOH solution into a 1000 ml measuring flask and add distilled water to the 1000 ml limit mark.
4. Transfer the solution immediately into a plastic cap reagent bottle.
5. Settled the solution for one night.
6. After standing the solution, mix the 10M NaOH solution with the Na_2SiO_3 solution, where the Na_2SiO_3/NaOH 10M ratio is 2/1.
7. After mixing well, transfer the solution into a sealed bottle and let it stand for one night. Then, the alkali activator is ready to use as shown in Figure 2.

Figure 2. Alkaline Activator

After making an alkaline activator (geopolymer raw material), test specimens in the form of soil with fly ash-based geopolymer mixture for specific gravity testing. The steps for making specific gravity test specimens of fly ash-based geopolymer mixtures are as follows:

1. Alkaline activator was made with a mixture of NaOH 10M Na_2SiO_3 solution.
2. Soil was mixed with fly ash waste and alkaline activator according to the required variation.
3. Stir the mixture until homogeneous.
4. Then the mixture is placed to harden for less than 1 day.
5. After it hardens, the soil is crushed until it is quite fine.
6. The soil is sieved until it passes sieve no. 4 and no. 10 and weighed according to the capacity of the pycnometer.

c. Specific Gravity Test

The soil's specific gravity was tested using the pycnometer method in accordance with SNI 1964:2008 on 'How to Test the Specific Gravity of Soil.' After the specimens are prepared, the specific gravity test is carried out on the three variations. The work steps carried out for soil-specific gravity testing are as follows [30]:

1. The pycnometer is washed and dried with distilled water. The pycnometer and lid are weighed with an accuracy of 0.01 grams (W1).
2. The test specimen is put into the pycnometer and weighed with the lid with an accuracy of 0.01 grams (W2).
3. Distilled water is added until the pycnometer is filled 2/3. For fine-grained (native soil), the specimen is left for at least 24 hours.
4. The air absorbed in the mixture of soil and water is removed by boiling the contents of the pycnometer carefully for about 10 minutes and the pycnometer is cooled while shaking it once in a while to help accelerate the release of air trapped in it, until it boils evenly.
5. Cool the pycnometer containing the soil and water to room temperature.
6. Add distilled water until complete, put the lid on the pycnometer, clean it and weigh it (W3).
7. Fill the pycnometer with distilled water, dry the outside, and then weigh the pycnometer, including the lid (W4).

d. Data Analysis

Specific gravity data were analyzed to determine changes by adding fly ash geopolymer. Statistical analysis was performed to evaluate the significance of the changes in the particular gravity of soil stabilized with fly ash-based geopolymer additives with a different activator-to-fly ash ratio.

3. RESULTS AND DISCUSSION

The researchers used soil samples from Kubang Laban Street, Serang Regency, Banten (-6.002174, 106.085387). Soil collection was carried out on the soil around the road. The method of sampling soil in the field is by digging the soil on the side of the road approximately 10-20 cm deep from the ground surface. After digging, the soil was taken and put into a sack that had been prepared. Mixing soil with fly ash-based geopolymer and making of Alkali Activator is shown in Figure 3 and Figure 4.

Figure 3. Soil mixture with fly ash based geopolymer

Figure 4. Preparation of Alkaline Activator (NaOH and Sodium Silicate)

The soil-specific gravity test was conducted to determine the effect of fly ash-based geopolymer proportion on soil-specific gravity. This value can also show the soil category based on specific gravity and can be used in compaction data analysis. The test used a pycnometer on the original soil and mixture variation. The author conducted specific gravity testing at the Civil Engineering Laboratory of UNTIRTA. Specific gravity testing is shown in Figure 5.

Figure 5. Specific Gravity Testing

3.1 Specific Gravity Test Result

The test results show that the specific gravity of the original soil (variation A) is 2.49, which categorizes it as organic clay. After adding fly ash-based geopolymer, the particular gravity of soil in variation B (80% soil, 20% fly ash, S/L 1/2) was 2.60, categorized as organic clay. Furthermore, the specific gravity of soil in variation C (80% soil, 20% fly ash, S/L 1/2.5) was 2.69, categorized as non-organic clay. The specific gravity test results are shown in Table 3 and Figure 6.

Table 3. Soil Specific Gravity Test Result

Variation	Specific Gravity	Classification
Var. A Soil 100%	2,49	Organic Clay
Var. B Soil 80%, FA 20%, S/L 1/2	2,60	Organic Clay
Var. C Soil 80%, FA 20%, S/L 1/2,5	2,69	Non-Organic Clay

Table 4. Percentage Increase in Specific Gravity of Mixed Soil

Mixture Variation		Specific Gravity	Percentage (%)
Var. A	Soil 100%	2,49	0,00
Var. B	Soil 80%, Fly Ash 20%, S/L 1/2	2,60	4,58
Var. C	Soil 80%, Fly Ash 20%, S/L 1/25	2,69	8,26

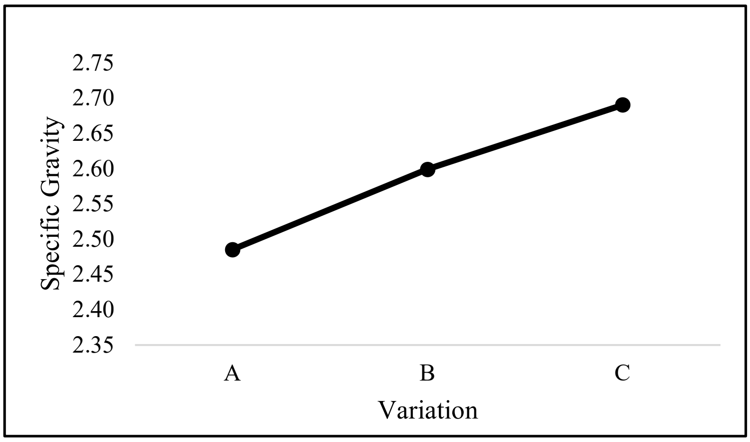

Figure 6. Graph of Specific Gravity of Soil in Each Variation

Table 3 and Figure 6 shows that the addition of fly ash-based geopolymer proportion to the soil increased the specific gravity value significantly; at S/L 1/2, an increase of 4.58% was obtained, and at S/L 1/2.5, a rise of 8.26% was obtained. This increase indicates that changes in the S/L ratio affect the effectiveness of the geopolymerization reaction, with the higher S/L ratio in variation C producing a denser and more compact structure, thus increasing the specific gravity of the mixed soil. These results emphasize the importance of adjusting mix proportions and mixing conditions to achieve optimum soil properties in geotechnical applications. The addition of fly ash geopolymer significantly affected the specific gravity of the mixed soil. As the proportion of fly ash geopolymer increases, there is a change in specific gravity. At a particular proportion, fly ash geopolymer fills the space between soil particles more effectively, thus increasing the specific gravity of soil.

4. CONCLUSION

This study successfully showed that the proportion of fly ash geopolymer and the S/L ratio have a substantial effect on the specific gravity of mixed soil. Variation B, with a specific gravity of 2.60, belongs to the organic clay category, while variation C, with a specific gravity of 2.69, belongs to the non-organic clay category. This indicates that proper control of the geopolymer composition and mixing conditions is critical in achieving the required soil properties for geotechnical applications.

5. ACKNOWLEDGMENT

We sincerely thank the Faculty of Engineering, Sultan Ageng Tirtayasa University, for their support through the 2024 internal grant.

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