Bearing capacity of synthetic granular column enclosed reinforcement geogrid on soft soil

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Abstract. The soil reinforcement method using columns has been widely used in some places. Stones or sand and stones are commonly used as fillers for those columns. The availability of natural stones constitutes a major constraint in some areas where there are no coarse aggregates (gravel). This research aims to analyze the use of artificial granular columns using geogrids on soft soil reinforcement. As column fillers, geogrid wrapped synthetic gravel was used. Variations in the shape of the synthetic gravel included a triangular prism, cube, and hexagonal prism. The test tube used was 800 mm in diameter, with a height of 1,400 mm. Column loading was undertaken for each variation in the size of synthetic gravel, plus a combination of the three sizes. The amount of column loading for each variation was 30 kN. Based on results of the loading test, the largest carrying capacity was generated by columns with fillers of synthetic gravel with a hexagonal prism shape and a combination of the three variations.

1. Introduction

Infrastructure development in remote areas, particularly in the eastern part of Indonesia (Papua Province), which aims to break isolation and accelerate economic growth, now the main focus of the Indonesian government. Some regencies in Papua have unique natural conditions. One of them is the Merauke Regency, which lies in the south of Jayapura City (the capital city of Papua Province). In this area, there are no natural coarse aggregates (gravel) at all, making the use of synthetic gravel the most reasonable choice. This research attempts to raise problem-related to use of synthetic gravel as column fillers wrapped with geogrids on soft soil reinforcement. The primary materials in manufacture of synthetic gravel are soft soil mixed with cement and water.

Compression-loaded stone columns may fail through several failure mechanisms. Diameter, length, and distance are parameters that define the type of failure of those stone columns. The research into single stone columns and stone column groups state that a group of stone columns will undergo failure with strain-softening behavior (plastic condition) where it is extremely possible that such failure results from a condition of excessive bulging [1]. The study state that the loading condition of stone columns can be briefly summarized in Figure 1 [2]. The resulting pressure on granular columns or foundations is distributed to the stone columns and soil, depending on the rigidity of the columns. Fail for the following reasons:

- Bulging or a long-curved shape sticking out from a column while bearing load
- Shearing or a shift in short columns whose end gets stuck
- Sinking or failure due to a hit, which occurs in the process of staking of short floating columns
• Bulging in a soft deeper layer or the process of bulge formation on the deeper layers of a column. The research suggests that foundations isolated with a single stone column may.

![Figure 1. Scenarios for several types of stone column loading.](image)

![Figure 2. Failure mechanisms in isolated stone columns [2].](image)

2. Research method and material

The materials used consisted of synthetic gravel, soft soil, and geogrids. Synthetic gravel was made from the main ingredients consisting of a mixture of soft soil, cement, and water, with process and ratio based on an analysis that meets the generally applicable standards. The synthetic gravel produced was molded into three variations, namely: triangle prism, cube, and hexagonal prism, all of which had the same volume. In addition to synthetic gravel, geogrids were used as column casings, with the following specifications: bi-axial woven polyester geogrid with the tensile strength of 40 kN.

![Figure 3. Synthetic gravel with a shape of an (a) triangle prism; (b) cube; (c) hexagonal prism; and (d) bi-axial has woven polyester geogrid.](image)

Soft soil used as loading media and raw materials in the manufacture of synthetic gravel was firstly examined for its physical data (soil properties) [3]. The mixture formula for the manufacture of synthetic gravel, based on analysis results, was comprised of soft soil mixed with cement by 12.5% and water with the ratio of water to cement (w/c) of 3.5 [4]. Synthetic gravel that had been molded was then left to cure for 28 days. The test tub was cylindrical and made of a steel plate with an 800
mm diameter, 1400 mm in height and 12 mm thick, and with proving ring and load dial gauge installed on it for loading. As for the measurement of vertical and horizontal deformation (settlement), a dial gauge was installed.

After the test tub had been installed, the bottom of the test tube was filled with sand and stones of approximately 700 mm thick [5]. Then, above the sand and stones, soft soil that had been prepared was poured, in a dry condition (room temperature) until the height reached ± 600 mm. In the middle of [6]. Casings made of geogrids were prepared with dimensions according to the dimensions of the hole that had been made. The shape of the geogrids that had been made was cylindrical, and they were then inserted into the hole that had been prepared on the test tub. The bottom of the geogrid columns was not covered [7].

The geogrid columns installed on the test tub were then filled with synthetic gravel. The loading test was carried out for each variation, coupled with a loading test with fillers that were comprised of the combination of the three shapes of synthetic gravel. The loading was done using a hydraulic jack with dial gauge reading undertaken every 500 kg (0.5 kN).

**Figure 4. Test tube sketch.**

### 3. Analysis and results

Based on the results of the physical test of the original soil (soil properties) used as loading media, the following results were generated:

The mixture formula for synthetic gravel was comprised of soft soil mixed with cement by 12.5% and water with the ratio of water to cement (w/c) of 3.5. Synthetic gravel that had been molded was then left to cure for 28 days. An unsoaked CBR (California Bearing Ratio) test was undertaken for each variation, with 10, 25, and 56 blows to examine quality of the materials used to make this synthetic gravel. The results of the CBR test on each shape variation can be seen in the following graph.

Based on the graph presented in the figure above, after left to ripen for 28 days, it can be seen that the unsoaked CBR value of synthetic gravel, for any shapes, with a total of 56 hits, is higher than 20%. This value is already enough to meet the requirement for the conditions of coarse aggregates used as sub-base layers on road pavement work. The more the number of angles synthetic gravel has, the higher its CBR value is.

A load was put on the test tub with vertical (ΔV) and horizontal (ΔH) deformation readings. A load was put on artificial granular geogrid columns, and this was done on each shape variation (triangular prisms, cubes, and hexagonal prisms) plus a combination of the three shapes. For load energy, a hydraulic jack was used, up to 3,000 kg (30 kN), with dial gauge reading undertaken every 500 kg (0.5 kN). Stress on the columns due to loading resulted from the load divided by the plates area of steel, 20
cm in diameter, to reveal the relationship between stress and settlement ($\Delta V$) and horizontal deformation (bulging) taking place on the columns, as illustrated in the graph in the following figure:

![Graph showing the relationship between unsoaked CBR value (%) aged 28 and the number of blows.](image)

**Figure 5.** Relationship between the unsoaked CBR value (%) aged 28 and the number of blows.

Based on the graph above, as a result of loading, it is seen that the resulting settlement ($\Delta V$) is almost directly proportional to the formation of bulging ($\Delta H$). The settlement value will increase in the event of an increase in a load of a column until the collapse point is reached. Synthetic gravel with many angles tends to have smaller deformation. For the modulus of elasticity ($E$) of columns, for each synthetic gravel shape, it can be seen in the following table:

| Type of Soil | AASTHO | USCS |
|--------------|--------|------|
| Triangle prisms | A – 7 - 5 |
| Cubes | CH |
| Hexagonal prisms | |

Based on the table above, it is revealed that the resulting modulus of elasticity of each shape fluctuates considerably. The highest elasticity value is generated by synthetic gravel with more angles (hexagonal prisms) and a combination of gravel shapes.
Figure 6. A graph illustrating the relationship between settlement ($\Delta V$) and stress in columns.

Figure 7. A graph illustrating the relationship between bulging ($\Delta H$) and stress in columns.

Table 2. Modulus of elasticity, based on the shapes of synthetic gravel used as fillers.

| Load (kPa) | Stress (kPa) | Triangle Prism | Cubes | Hexagone Prism | Combination |
|-----------|--------------|----------------|-------|----------------|-------------|
|           |              | Strain (N/mm²) | Strain (N/mm²) | Strain (N/mm²) | Strain (N/mm²) |
| 0.00      | 0.00         | 0.00           | 0.00   | 0.00           | 0.00         |
| 500       | 159.24       | 0.33           | 0.48   | 0.35           | 0.64         | 0.17         | 0.96         | 0.08         | 1.91         |
| 1000      | 318.47       | 0.58           | 0.55   | 0.42           | 0.76         | 0.25         | 1.27         | 0.17         | 1.91         |
| 1500      | 477.71       | 0.75           | 0.64   | 0.67           | 0.72         | 0.58         | 0.82         | 0.42         | 1.15         |
| 2000      | 636.94       | 1.00           | 0.64   | 0.92           | 0.69         | 0.67         | 0.96         | 0.58         | 1.09         |
| 2500      | 796.18       | 1.25           | 0.64   | 1.08           | 0.73         | 1.00         | 0.80         | 0.92         | 0.87         |
| 3000      | 955.41       | 1.58           | 0.60   | 1.42           | 0.67         | 1.33         | 0.72         | 1.17         | 0.82         |

4. Conclusion
Based on the preceding, the following conclusions can be drawn:
- Synthetic gravel used in this research was comprised of soft soil mixed with cement by 12.5% and water with the ratio of water to cement (w/c) of 3.5.
- The smallest vertical deformation value ($\Delta V$), as a result of loading on artificial granular columns, was generated by columns filled with synthetic gravel with a shape of a hexagonal prism (80 mm) and a combination of three gravel shapes (70 mm).
The smallest horizontal deformation value ($\Delta H$), as a result of loading on artificial granular columns, was generated by columns filled with synthetic gravel with a shape of a hexagonal prism (10 mm) and a combination of three gravel shapes (9 mm).

The more angles synthetic gravel has, which is used as fillers for granular columns, the smaller the resulting deformation, including both horizontal deformation ($\Delta H$) and vertical deformation ($\Delta V$), because of inter-locking between the gravel as can be seen if the fillers used are comprised of gravel with a combination of variations in shapes.

With a low deformation value, this synthetic gravel can be used as alternative filler materials for soft soil reinforcement, especially in areas where natural aggregates (gravel) are hard to get even cannot be found at all.

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