The effect of soft clay improvement using Prefabricated Vertical Drain (PVD) for rigid pavement structure

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Abstract. Rigid pavement is widely used in subgrade conditions that have low bearing capacity so that it will affect the life of the road plan and rigid pavement performance. Soil improvement that can be done is by using Prefabricated Vertical Drain (PVD). Soil consolidation with plate load test is carried out to get the modulus of subgrade reaction. Modulus of subgrade reaction without PVD is 2179.24 kN/m²/m and with PVD distance of 100 mm is 11311.09 kN/m²/m. The modulus of the verified subgrade reaction without PVD is 22419.21 kN/m²/m and with PVD is 38718.40 kN/m²/m. The thickness of the analyzed plates are respectively of 150 mm, 200 mm, 250 mm, 300 mm, and 350 mm. The position of the vehicle wheel load is in the middle, the end, and the edge. The deflections due to the position at the middle, the end, and the edge loads respectively for the entire plate thickness are reduced by an average value of 31%, 34%, and 33%. Rigid pavement performance based on the modulus of subgrade reaction and deflection caused by MST 10 ton vehicle loads with a 1.2 axis configuration shows that soil improvement using PVD can increase the modulus of subgrade reaction and reduce deflection values.

1. Introduction
The economic development of a region will greatly affect the movement of people, goods, and services that must be supported by improving transportation infrastructure [1]. The construction of new road infrastructure, both rigid and flexible pavement in Indonesia [2], is always developing year by year. Rigid pavement is widely used in subgrade conditions that have low bearing capacity or non-uniform soil [3,4]. The advantage of rigid pavement construction is the nature of stiffness which is able to withstand vehicle wheel loads and spread it to the subgrade efficiently and is able to reduce pavement deformation [4].

However, the rigid pavement built on soft clay soil needs to be analyzed deflections that occur as a result of traffic loads and analysis of the deflection that occurs in soft clay under pavement [5]. If this is ignored there will be a deflection in pavement performance and affect the life of the road plan. This needs to be considered because soft clay soils are soils that have low shear strength, low permeability, low bearing capacity, and high compressibility. Damage that occurs in rigid pavement can be anticipated by carrying out soil improvement. Improvement of soft clay must be carried out before construction begins. Improvements that can be done is to use Prefabricated Vertical Drain (PVD). The effectiveness of the use of PVD as a way to improve soft soil can be seen based on the magnitude of the decrease in consolidation that occurred [6]. Decrease in consolidation can be known based on the properties of compressibility of soft clay, such as the coefficient of consolidation (Cv), compressive index (Cc), and
volume compression coefficient (mv). The objectives of this research are as follows: - obtaining the modulus value of the verified soil reaction based on testing the concrete slab in the laboratory; - obtaining rigid pavement deflection with variations in plate thickness for soil without PVD and with PVD; - knowing the effectiveness of using PVD for the improvement of soft clay soils in terms of performance of rigid pavement based on deflection.

2. Soil improvement

Soil improvement is an effort to soil that has low-quality technical characteristics that are converted into materials suitable for use as construction materials or have better technical characteristics [7,8]. Some methods of soil improvement that can be done are by chemical, mechanical, reinforcing, and hydraulic methods (accelerating consolidation using vertical drain). The objectives of soil improvement are as follows:

- Increasing the carrying capacity, modulus, and shear strength of the soil.
- Reducing compressibility.
- Controlling volume stability (shrinking and swelling).
- Reducing susceptibility to liquidity.
- Improving the quality of materials for construction materials.
- Control permeability and reduce pore water pressure.

2.1. Prefabricated Vertical Drain (PVD)

Prefabricated Vertical Drain (PVD) is a method of repairing soft clay soils replacing the traditional method of using sand drain. PVD is a vertical artificial drainage system that is installed in soft soil layers. PVD is a geosynthetic product that functions as a drainage. The material used is a composite consisting of a core (core) and a filter (filter), as in Figure 1. The function of the filter (filter) is to limit the entry of fine grains of soil that will block the flow of water. While the function of the core (core) is as a way of flowing water vertically and rigidly so as to provide strength to horizontal pressure.

![Figure 1. PVD apperance.](image)

2.2. Principles of soil improvement with PVD

The theory of consolidation due to the flow of pore water in the horizontal direction towards PVD is based on the assumption that PVD has an area of influence of a cylinder with a length equal to the length of the PVD. The purpose of using PVD is to accelerate the process of dissipation of excess water pressure more rapidly horizontally through PVD with the help of preloading loads. PVD provides shorter pore trajectory in the horizontal direction. Porewater that comes out of the soil will cause the soil to compress and the faster the compression process, then the structural cracks due to incomplete compression will be avoided. Preloading system with PVD can be seen in Figure 2.
2.3. Rigid pavement performance analysis

Rigid pavement built on soft soil needs to be analyzed deflections that occur as a result of traffic loads and analysis of the deflection that occurs in soft soil under pavement [5]. Deflection is the vertical surface displacement associated with changes in volume caused by the application of a load [5]. If the subgrade has a bad condition or cannot bear the burden on it, in this case a passing vehicle, the rigid pavement above the ground will experience deflection which if left unchecked will suffer damage and deflection the plan age of the pavement.

According to Yanto, in calculating the deflection of a plate located above the ground [5], the plate is considered as a straight beam supported by elastic media throughout its spans as shown in Figure 3.

The beam is burdened by vertical forces which will cause the beam to sag down. Soil as an elastic medium will give a reaction force that is spread on the surface of the soil. Deflection analysis in rigid pavement was developed based on the assumption that was first developed by Winkler in 1867 [7], that the reaction force of each point would be proportional to the deflection at that point.

The method used in this research is experimental testing in the laboratory and numerical analysis with the finite element method. Experimental testing in the laboratory produces primary data obtained directly. Whereas numerical analysis with finite element method was carried out with the help of ETABS 2016 software. Tests carried out in the laboratory are testing soil samples consisting of index properties and engineering properties (oedometer and rowe cell consolidation test), plate load tests, and concrete plate loading tests for soils without PVD and soils with PVD.

The consolidation test is carried out using 2 (two) tools with the aim of finding out which test results are closest to the conditions in the field are reviewed based on the decline that occurred. Plate load tests were carried out to obtain the modulus of soil reaction (k) as the spring footing input in the finite element analysis method using ETABS 2016 software.

3. Material type of soil in the site

The soil used in this study is soft clay. The soil used in this study was taken using the undisturbed and disturbed methods. Uninterrupted soil samples are used to determine index properties and engineering
properties. Whereas disturbed soil samples are used for soft soil modelling for experimental testing in the laboratory.

4. Testing of soil samples in the laboratory
Soil sample testing was carried out at the Soil Mechanics Laboratory of Bandung State Polytechnic. The test consists of testing index properties and engineering properties.

| Types of Soil Testing          | Standard                  |
|-------------------------------|---------------------------|
| Index Properties:             |                           |
| Moisture content              | ASTM D 2216-98            |
| Specific gravity              | ASTM D 854-02             |
| Weight content                | ASTM C 29                 |
| Atterberg limit               | ASTM D 4318               |
| Grain size analysis           | ASTM D 421-58             |
| Engineering Properties:       |                           |
| Consolidation with Oedometer  | ASTM D-2435-11            |
| Consolidation with Rowe cell  | BS 1377 : Part 6          |

Results and discussion
Index properties testing consists of testing the moisture content, specific gravity, weight content, atterberg limit, and grain size analysis. While the engineering properties test is a consolidation test using an Oedometer [9] and Rowe cell [9,10]. The output obtained from the results of testing soil samples in the laboratory are soil parameters as a basis for the analysis conducted. The tests are carried out in accordance with the standards and can be seen in Table 1.

4.1. Soil experimental testing
Experimental scale testing of models in the laboratory using a steel box measuring 2000 mm x 1000 mm x 1000 mm divided by 2, the front and one side using transparent acrylic. All parts of the box side joints are coated with silicon to prevent water seepage from the box. This steel box is made rigid so that no deformation occurs during the test. The test box used in this study can be seen in Figure 4.

The soil material used in the model scale experimental reduction test, according to Widojoko [8], uses dried and filtered soil using sieve no. 4. Then measured the value of the original water content. Stages of making the soil layer need to be mixed with water in accordance with the water content in the field.

4.2. Plate load test
Plate load tests were carried out based on AASHTO T 222-81 (2004) using plates with a diameter of 12 inches (304.8 mm). Tests carried out by loading in stages using the OPT hydraulic pump with a
manometer with a capacity of 60 kg / cm². A drop gauge reading from the dial gauge is carried out for each pressure.

Loading is done in stages. The loading stages given on the plate load test can be seen in Table 2.

| Stage of Loads | Pressure (kN/m²) |
|----------------|-----------------|
| 1              | 6.58            |
| 2              | 13.16           |
| 3              | 19.74           |
| 4              | 26.32           |
| 5              | 32.90           |
| 6              | 39.48           |
| 7              | 46.06           |
| 8              | 52.64           |
| 9              | 59.22           |
| 10             | 65.80           |
| 11             | 72.39           |
| 12             | 78.97           |
| 13             | 85.55           |
| 14             | 92.13           |
| 15             | 98.71           |

4.3. Modulus of soil reaction

The modulus value of the soil reaction (k) suggested by AASHTO T 222-81 (2004) is based on p = 10 psi = 69 kN / m² which determines a certain deflection. The deflection was obtained from the results of plate load tests without PVD and with PVD. The equation used to calculate the coefficient of modulus of the soil reaction (k) can be seen in equation 1

$$k = \frac{69}{\delta}$$  \hspace{1cm} (1)

where,
- k : modulus of soil reaction (kN / m² / m)
- p : load per unit area on the plate (kN / m²)
- δ : deflection (m)

Whereas according to FEMA 356 the modulus of the soil reaction can be calculated using an equation. Modulus of soil reaction in concrete construction located above the soil surface is divided into 3 directions, namely x, y, and z directions which can be seen in Figure 5.

Figure 5. Direction of modulus of soil reaction.
5. Discussion and data analysis

5.1. Index properties of soil

The index properties testing consisted of testing the moisture content, specific gravity, weight content, atterberg limit, and grain size analysis. The soil used in this study had a water content of 63%, according to Terzaghi [7] the soil was included in the type of soft clay.

| Parameter                  | Value       |
|----------------------------|-------------|
| Moisture content, $\omega$ | 63%         |
| Specific gravity, GS       | 2.49        |
| Weight content             | 1.62 gram/cm$^3$ |
| Liquid Limit, LL           | 72.00%      |
| Plastic Limit, PL          | 35.57%      |
| Plasticity Index, PI       | 36.43%      |
| Grain size analysis        |             |
| Clay                       | 88.16%      |
| Silt                       | 7.56%       |
| Sand                       | 4.28%       |
| Gravel                     | 0.00%       |

The density of the soil is 2.49 and the weight is 1.62 gram / cm$^3$. The soil liquid limit value is 72% and the plasticity limit is 35.57%, and the plasticity index value is 36.43%, according to Burmister (1949) the soil has high plasticity. Grain size analysis test results obtained percentage of clay 88.16%, silt 7.56%, and 4.28% sand. Based on grain size analysis, soils can be classified into groups A-7-5 (41) according to the AASHTO (American Association of State Highway and Transporting Official) and CH groups (non-organic clays with high plasticity) according to USCS (Unified Soil Classification System). The recapitulation of the test results is in Table 3.

5.2. Engineering properties of soil

The engineering properties test consisted of consolidation testing using an oedometer and rowe cell. Tests carried out on 3 (three) samples, hereinafter referred to as sample 1, sample 2, and sample 3 for oedometer consolidation and sample A, sample B, and sample C for rowe cell consolidation. The value of the compactness index ($C_c$) can be seen in Table 4.

| Samples      | $C_c$ |
|--------------|-------|
| Oedometer 1  | 0.465 |
| Oedometer 2  | 0.498 |
| Oedometer 3  | 0.399 |
| Average      | 0.454 |
| Rowe Cell A  | 0.126 |
| Rowe Cell B  | 0.106 |
| Rowe Cell C  | 0.120 |

5.3. Results of experimental model testing

The experimental tests carried out consisted of plate load tests and concrete plate tests. Plate load tests were carried out to obtain modulus values of soil reactions without PVD and with PVD distances of 100 mm and 150 mm as well as data for analysis of selected soil consolidation parameters. While testing concrete slabs measuring 700 mm x 100 mm x 30 mm was carried out to obtain deflection values for each load position, namely the middle, the edge and the edge.
5.4. Plate load test results
The plate load test results are illustrated by a graph between pressure and deflection which can be seen in Figure 6. The modulus of the soil reaction is obtained from the plate load test results and is calculated using Equation 1.

![Plate load test results graph]

5.5. Concrete testing results
Concrete compressive strength test results for conditions without PVD obtained compressive strength values of 23.42 MPa, based on SKSNI T-15-1991 concrete modulus of elasticity value of 22.743.72 MPa. As for the concrete compressive strength test results for conditions with PVD obtained compressive strength values of 24.31 MPa and modulus of elasticity of 23.089,84 MPa.

6. Conclusion
Some conclusions obtained from the research conducted are as follows:

- Recommended consolidation testing for soft clay soils is using Oedometer and Rowe cell tools.
- Modulus of reaction of soil without PVD 2179.24 kN / m² / m, soil with PVD distance of 100 mm 11311.09 kN / m² / m, and soil with PVD distance of 150 mm 4980.94 kN / m² / m.
- Modulus of reaction of soil without PVD verified $k_z = 22419.21$ kN / m² / m and $k_z = 38718.40$ kN / m² / m for soils with PVD.
- Value of rigid pavement deflection with variations in plate thickness with the position of the middle and edge loads meet the maximum deflection requirements of 0.800 mm. While the position of the tip load does not meet the maximum deflection requirements.
- Soil improvement using PVD can increase the modulus of the soil reaction and reduce the deflection that occurs. The reduction in deflection values for middle load, tip load and edge load are 31%, 34%, and 33%, respectively.

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