Full-Scale Test of a Causeway Embankment Supported by Raft-Aggregate Column Foundation on Soft Clay Deposit

Tri Harioanto, Lawalenna Samang, St. Hijraini Nur, Arwin

Abstract—Recently, a port development is constructed in Makassar city, South Sulawesi Province, Indonesia. Makassar city is located in lowland area that dominated by soft marine clay deposit. A two kilometers causeway construction was built which is situated on the soft clay layer. In order to investigate the behavior of causeway embankment, a full-scale test was conducted of high embankment built on a soft clay deposit. The embankment with 3.5 m high was supported by two types of reinforcement such as raft and raft-aggregate column foundation. Since the ground was undergoing consolidation due to the preload, the raft and raft-aggregate column foundations were monitored in order to analyze the vertical ground movement by inducing the settlement of the foundation. In this study, two types of foundation (raft and raft-aggregate column) were tested to observe the effectiveness of raft-aggregate column compare to raft foundation in reducing the settlement. The settlement monitored during the construction stage by using the settlement plates, which is located in the center and toe of the embankment. Measurements were taken every day for each embankment construction stage (4 months). In addition, an analytical calculation was conducted in this study to compare the full-scale test result. The result shows that the raft-aggregate column foundation significantly reduces the settlement by 30% compared to the raft foundation. A raft-aggregate column foundation also reduced the time period of each loading stage. The Good agreement of analytical calculation compared to the full-scale test result also found in this study.

Keywords— Full-scale, preloading, raft-aggregate column, soft clay.

I. INTRODUCTION

Development of new port in Makassar city was planned in order to provide a rapid demand and increasing activity of existing port. Makassar new port was constructed with reclamation system that is located in a shallow coastal area. A two kilometers causeway construction was built to connect a newly built port that is situated on the soft marine clay layer to an inland.

Recently, many researchers conducted field observation of full-scale model [1]-[3]. The piled raft has been developed as one of the most economical and effective foundation technique applicable to soft clay, over-consolidated clay and sandy soil [4]-[6]. Normally consolidated clay, this foundation type has been not preferred because of excess settlement, development of negative skin friction and insufficient bearing capacity of group piles. The settlement efficacy of pile-supported embankment is a reliable parameter to assess the overall performance of the rigid inclusion technique [7]. Piled raft model on normally consolidated clay was studied by using numerical analysis. The result showed that the value of safe bearing capacity of piled raft decreased with increasing the ground movement [8]. Application of geosynthetics material for soil reinforcement by using numerical analysis was also studied [9]-[12].

An experiment of full-scale trial embankment of causeway constructed on soft soil reinforced by several reinforcement methods is conducted in this study. The soft clay layer had been loaded with 3.5 m fill for 4 months. This paper describes the detail discussion of the observed behavior from monitoring and observation result. The performance of raft-aggregate column foundation compare to construction of conventional raft reinforcement was investigated.

II. MATERIAL AND METHODS

A. Soil Profile and Material Properties

In order to collect and determine the soil properties, the borehole test was carried out in the full-scale site. The subsoil properties are presented in Table 1. The general soil properties consist of very soft clay up to 5 m from surface. The granular material and hard layer is found in the deeper layer. The engineering properties were obtained by performing index properties and mechanical properties of soft soil. The bore log profile and value of SPT is shown in Fig. 1.

Characteristics of aggregate column material as a composite of gravel-geotextile was determine in this study The Poisson’s Ratio (v) of the composite material was found of 0.4 and the Elastic Moduli (E) is 10.3 MPa.

B. Instrumentation

Full-scale test of trial embankment was constructed of 10 m width and 10 length of each type of reinforcement with 3.5 m
of embankment high. The aggregate column was installed with 3 m length and beneath the embankment a layer of bamboo raft was installed. Typical cross section showing soft soil, aggregate column and bamboo raft is shown schematically in Fig. 2 and Fig. 3. The 0.5 m thick raft was connected to top of the column. A settlement plate instruments was installed on the centre embankment in order to monitor the deformation behaviour. The instrumentation in the subsoil for each type of reinforcement (i.e. raft and raft-aggregate column) was installed prior to the construction of the embankment. During the construction period (4 months), the elastic settlements were observed periodically.

**Table 1**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Indeks properties</td>
<td></td>
</tr>
<tr>
<td>unit weight, (t/m³)</td>
<td>1,689</td>
</tr>
<tr>
<td>plasticity index : I_p (%)</td>
<td>59,5</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td></td>
</tr>
<tr>
<td>unconfined compression strength, q_u (kg/cm²)</td>
<td>0,328</td>
</tr>
<tr>
<td>undrained shear strength, c_u (kg/cm²)</td>
<td>0,164</td>
</tr>
<tr>
<td>effective internal friction angle, $\phi'$ (°)</td>
<td>24,6</td>
</tr>
<tr>
<td>pre-consolidation pressure, p_c (kg/cm²)</td>
<td>1,03</td>
</tr>
<tr>
<td>compression index, C_c</td>
<td>1,09</td>
</tr>
<tr>
<td>void ratio, e_o</td>
<td>2,916</td>
</tr>
<tr>
<td>coefficient of consolidation, C_s (m²/detik)</td>
<td>8,85 x 10^-4</td>
</tr>
</tbody>
</table>

Aggregate column (gravel) is covered by geotextile with 0.6 m in diameter and driven to the sub soil up to 3.0 m depth with a spacing 1.8 m by 1.8 m. The 3.5 m of embankment high filled up with selected granular soil. The arrangement of aggregate column is shown in Fig. 4.
III. RESULTS AND DISCUSSION

Settlement observation and measurement of the raft was taken with settlement plate at the center of raft’s surface. The variation of settlements of bamboo raft reinforcement is shown in Fig. 5. Immediate elastic settlement was found during the early stage of construction. The observation results showed that the rate of settlement was low near the surface. Moreover, the settlements tend to increase with increasing the embankment high (approximately 3.5m). The result shows that larger settlement was observed in this type of reinforcement. Initially, small amount of settlement was recorded (0.21 m) with 0.80 m embankment height. Increasing the high of embankment up to 2.0 m show a larger settlement occurred in the soft soil. For the next stage, embankment height increases to 3.2 m, which indicate the settlement about 0.5 m. In the final stage, the final level of embankment was set to 3.5 m. According to monitoring result at the final stage, the settlement was observed around 0.83 m for the 120 days observation in the field. Furthermore, the settlements of the raft consistently increased after reached the final high of embankment.

![Fig. 5 Settlement of the raft with increases of the embankment thickness](image)

According to recorded data for the raft-aggregate column reinforcement, similar settlement behavior with raft reinforcement was found at the lower high of embankment as shown in Fig. 6. Increasing high of embankment (3.0 m) tend to increase the settlement of the subsoil up to 0.55 m. The settlement of raft-aggregate column slightly increased with increasing embankment height. At the final stage of embankment (3.5m height), the amount of settlement observed was 0.64 m in 120 days observation. The rate of increase of settlement with embankment thickness then decreased with further increasing embankment thickness and the settlement of the raft-aggregate column became nearly constant until reaching the final embankment height. However, the time for consolidation taking place is much faster for raft-aggregate column reinforcement system (around 80 days). It is indicated that the presence of raft-aggregate column in the reinforcement system reduces the amount of settlement by 25% compare to the raft reinforcement during the time period of observation (120 days).

General behavior of the settlement of the raft and raft-aggregate column indicated that settlement increases with increasing of embankment height. Settlements of ground depend on the magnitude of the preload, which is approximately 3.5 m.

![Fig. 7 Relationship between embankment height and time](image)

![Fig. 6 Settlement of the raft-aggregate column with increases of the embankment thickness](image)

<table>
<thead>
<tr>
<th>Reinforcement Method</th>
<th>Field Observation (m)</th>
<th>Asaoka (m)</th>
<th>Calculated 1-D/3-D (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raft</td>
<td>0.80</td>
<td>0.73</td>
<td>0.85</td>
</tr>
<tr>
<td>Raft-Aggregate Column</td>
<td>0.64</td>
<td>0.68</td>
<td>0.61</td>
</tr>
</tbody>
</table>

TABLE 2

Comparison of Consolidation Settlement
The observed settlements behavior was further evaluated. Asaoka method [13] and analytical (1-D/3-D Consolidation) methods were also made in order to compare the total consolidation settlement based on observed settlement as shown Table 2. The settlement predicted by Asaoka’s method represented the settlement of the whole stratum (improved and unimproved layers) based on the monitored surface settlement record. The analytical method showed that the amount of settlement lower than the amount of settlement observed in the field. Empirical method showed a higher amount of settlement then field observation. However, both empirical and analytical (calculated) methods were in good agreement with the observed data.

The estimation of degree of consolidation by settlement in embankment construction progress to the soft ground is very important in term of stabilities and economical efficiencies. Fig. 8 shows the predicted degree of consolidation for raft-aggregate column, which is indicated that the primary consolidation (U=90%) of raft-aggregate column system completed around 120 days after construction started. This prediction result has a good agreement with the time of primary consolidation settlement of full-scale test. The acceleration of consolidation settlement due to the presence of granular material column showed that the granular column behaves as a vertical drain. The aggregate column provides a vertical path for the excess pore water pressure to dissipating. Therefore, the raft-aggregate column system has a shorter time to complete the primary consolidation.

IV. CONCLUSION

Two full-scale trial embankments were conducted in development of Makassar new port project site. The field (full-scale) test was conducted in order to study the effect of aggregate column in combination with bamboo raft. The settlement plate was installed in the center of embankment to monitor deformation of embankment. The settlement of raft-aggregate column and raft foundation were 0.64 m and 0.80 m respectively. The performance of raft-aggregate column compared to raft itself showed a reduction of settlement by about 25 % in 120 days observation. Verification of the amount of settlement by conducting empirical method and analytical calculation for each type of reinforcement indicated insignificant difference to the full-scale test results. The rate of settlement of raft-aggregate column foundation is much higher than the raft foundation due to the aggregate column behaved as a vertical path to allow the excess pore water pressure dissipating.

REFERENCES