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Soil Reinforcement Model Test Using Timber Pile at Liquefaction Area

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Abstract

Indonesia is a tropical country threatened by many disasters, such as earthquakes and other collateral hazards (liquefaction). Utilization of micro pile on the liquefaction prone areas is quite popular to increase the soil bearing capacity. In this research, Eucalyptus Pellita Timber was used as micro-piles alternatives. This study aims to determine the effect of timber pile addition on soil settlement and the increase in bearing capacity. Some laboratory investigations were conducted, such as timber and soil physical and mechanical characteristics, preloading tests, and seismic load tests by using small-scale shaking table test. The preloading tests were carried out for 40 days, and the settlements were recorded every 24 hours. Subsequently, seismic load tests were conducted on sandy soil with Dr = 40%. The seismic duration was 37 seconds, with PGA = 0.3 g and f = 0.78 Hz. The preloading test results show that Eucalyptus pellita timber piles are able to reduce the settlement by 18%. and from seismic load testing results are able to reduce the settlement by 68% due to earthquake loads with PGA = 0.3g and a frequency of 0.78 Hz on sandy soil with the potential for liquefaction. This is due to the resistance at the tip of the pile and the skin friction on the timber pile. So, from the results of the model test, it shows that the use of Eucalyptus Pelita timber piles can be used as an alternative to handling sandy soils in areas where liquefaction has the potential to occur.

Keywords: Liquefaction; Timber Pile; Eucalyptus Pellita; Soil Reinforcement.

1. Introduction

Micro-piles are defined as small-diameter, drilled piles composed of placed or injected grout with steel reinforcement in the grout's center to resist the bulk of the design load. The central reinforcing element is either a high-strength steel bar or tube embedded in high-pressure grout to improve soil bonding. Micro-piles can be installed on virtually any type of terrain and at any inclination. Micro-piles have been extensively adopted for a variety of applications. They are ideal for use with existing structures because they can be installed in any ground condition with minimal vibration, disturbance, and noise, at any angle, and in areas with limited access and low headroom [1]. The micro-piles are extremely beneficial. Besides increasing the bearing capacity of the soil, micro-piles can also be used as seismic retrofits. The existence of micro-piles directly resists applied loads that mainly through skin friction, and they can also be used as ground reinforcement through the creation of a soil/pile composite structure. Because of that, micro-piles are currently being developed to reduce the risk of soil liquefaction since they can increase soil stiffness and reduce soil movements. If cyclic shear strains are reduced sufficiently, liquefaction should not occur [2–4].

Before numerous studies on micro-piles were conducted, several studies on the use of large-diameter mono-piles were conducted [5, 6]. Some theoretical approaches [7–11] and experimental studies were conducted. It was found that

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the group interaction effect reduced the lateral resistance of group piles relative to the monopile [12]. Several studies on the group-pile foundation as a soil reinforcement are explained as follows:

Gu et al. (2014) conducted a large-scale model test on a 2 × 1 steel pile group subjected to eccentric lateral loading in silts. The test results revealed that the eccentricity of lateral loads had a limited effect on the overall performances of the 2 × 1 pile group, but significantly contributed to the unevenness of the internal forces of the individual piles [13]. Another test on 2 × 1 pile group was presented. Mahmood & Abbas (2019) reported the lateral dynamic response of 2 × 1 alluminium pile groups embedded in dry sand under the influence of vertical loads, which are subjected to lateral two-way cyclic loads. The laboratory tests were done in two types of pile groups, which are circular and square. The result shows the reduction in lateral displacement of the square piles with the presence of vertical loads responding more than circular piles, about 40% [14].

Moreover, the potential of micro-piles for liquefaction remediation was discussed [1]. Centrifuge tests investigating the performance of non-structural inclined micro-piles as a liquefaction remediation method for existing buildings. Centrifuge tests were carried out with and without inclined micro-piles in each soil profile to compare the effectiveness of the micro-piles. From the conclusion of the paper, it may be concluded that the arrangement of non-structural inclined micro-piles did not offer an effective way to reduce the structural damage caused by liquefaction to existing buildings. It was reported that, no detrimental effects were observed, but no consistent improvements occurred either. Some improvements in structural settlement were observed when the earthquake was relatively small and when the depth of free-field liquefaction was above the depth of the base of the uppermost micro-piles. It was suggested to try different configurations of micro-piles, such as a grid formation, since it has been shown to be effective when used under new buildings [15].

Research on micro-piles utilization in Indonesia was mostly carried out by utilizing timber piles. The abundance of sources of timber in Indonesia makes timber-based piles more accessible than other types of micro-piles. Timber is a flexible and versatile raw material that can potentially be used to achieve sustainable construction. To provide concrete evidence, a study on the effectiveness of timber piles to improve the bearing capacity of soft soils was conducted by several researchers.

Harianto et al. conducted research on timber-based raft piles to increase the bearing capacity of soft soil. According to the findings of the research, the bearing capacity of the raft-pile foundation is sufficient to support the load without any excessive settlement. The highest settlement reduction was obtained in the raft-pile foundation, with a percentage reduction of 65% compared to the unreinforced soil. Moreover, there is no significant lateral movement observed beside the foundation [2]. Sandyutama et al. tested a full-scale consolidation test with Galam timber-based pile reinforcement combined with PVD in soft soil. PVD inclusion is meant to accelerate the dissipation of water pressure, so the rate of consolidation could be increased [3]. Another test using Galam timber piles was also studied by Suheriyatna et al. [16]. The tests were comparing three stages of testing: geotextiles reinforcement, geotextiles reinforcement + straight embedded timber pile with length 6 meters and horizontal distance 1 m, and geotextiles reinforcement + inclined timber pile between straight piles with horizontal distances 1,2 m. The diameter of the timber pile is 10 cm, with the degree of inclination 15º. According to the settlement plate observation result, the total settlement of each stage of the test was found to be 1,13 m, 0,54 m, and 0,40 m, respectively. It shows adding timber piles has reduced the total settlement by 52% compared to without the timber piles, and the ratio increased to 65% when inclined timber piles were added. Similar results were also presented by Harianto et al. [17].

As we know, Indonesia is a country threatened by many disasters, such as earthquakes and other collateral hazards (liquefaction). The liquefaction phenomenon in Palu, Central Sulawesi, in 2018 is one of the major disasters that have occurred in Indonesia and caused enormous damage. None of the researchers have discussed the potential use of timber piles as seismic hazard mitigation. Hence, this research aims to determine the effectiveness of timber piles as reinforcement through a seismic scale test using a typical timber pile that is available in Indonesia and many other countries, which is Eucalyptus pellita. In this research, this typical timber pile was tied into groups of three as one pile and arranged at a predetermined distance. It is expected that this modification will bring new insights into soil reinforcement alternatives.

Eucalyptus pellita plants are one of the forest plants prioritized for development in the industrial plantation forest program. Eucalyptus pellita timber is currently being developed. Research on the quality test of Eucalyptus pellita for the basic properties of timber has been developed by several countries, such as China [18], Brazil [19], and also Indonesia [20–22]. The natural distribution area of Eucalyptus pellita mostly grows in Australia and surrounding islands, including Papua. The abundance of Eucalyptus pellita makes this type of timber expected to be a new construction material that could be the breakthrough in strengthening engineering and soil reinforcement, especially in areas prone to liquefaction.

2. Materials and Method

2.1. Materials

The design and materials used in the research refer to the results of primary and secondary data collection. The results of tests carried out in the laboratory include the physical and mechanical properties of the soil and the material characteristics of timber (Eucalyptus pellita). The test result is needed to determine the type of material used for the scale model planning. The soil samples used in this research were divided into two types. For the preloading test, we used soft clay (CH) from the Turikale sub-district, Maros district. While for the liquefaction test were using sand from the Galesong Beach, Takalar Regency. The timber pile type is Eucalyptus Pellita from Merauke district, South Papua Province, Indonesia (Ulilin district with coordinates 7°14'27.20"S and 140°43'34.59"E). The timber piles with a diameter of 1cm and a length of 35 cm were tied by iron wire into groups of three, as shown in Figure 1.

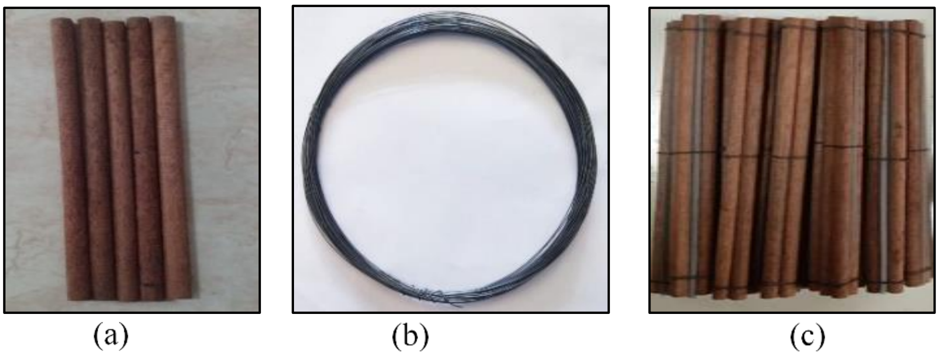


Figure 1. (a). Single timber pile, (b). Iron wire dan (c). Timber pile

2.2. Research Method

Figure 2 demonstrates the research flows for this study. As a preliminary study, a literature review was conducted to determine the materials to be used. The subsequent step was to conduct characteristic tests on materials that will be used in this test, including timber and soil. Then, the preloading tests were obtained to check the tied timber piles effectiveness prior to the seismic loading test.

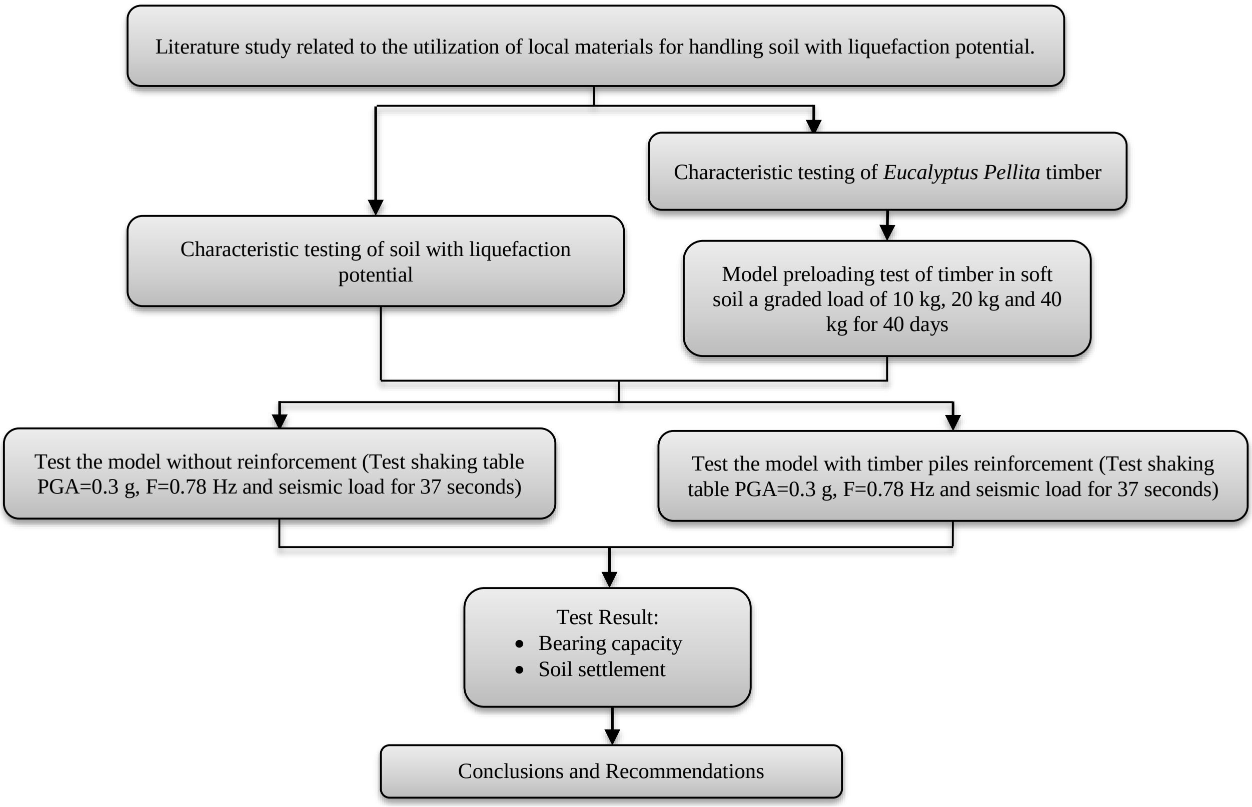


Figure 2. The Flowchart of Research

2.2.1. Preloading Test

The preloading test were carried out by gradually giving the loads (10, 20, 40 kg). The test were conducted in 2 models: soft soil without reinforcement and with timber piles reinforcement. The tied timber piles configuration were set in a rectangular-grid pattern with a distance of 10 cm for each tied timber piles. The surface of the soft soil were covered with woven geotextile and filled with 5 cm loose sand. The load were put on the top of sand layer.

The loads addition was carried out in 3 stages. The applied loads are given gradually on each stages from 10, 20 and 40 kg, respectively. The loading were increased when the observed settlement has not changed significantly. Settlement monitoring was carried out every day by controlling the dial gauge and ruler mounted on each sample. The settlement was observed every 24 hour during 40 days. This preloading test scheme are presented in Figures 3 and 4.

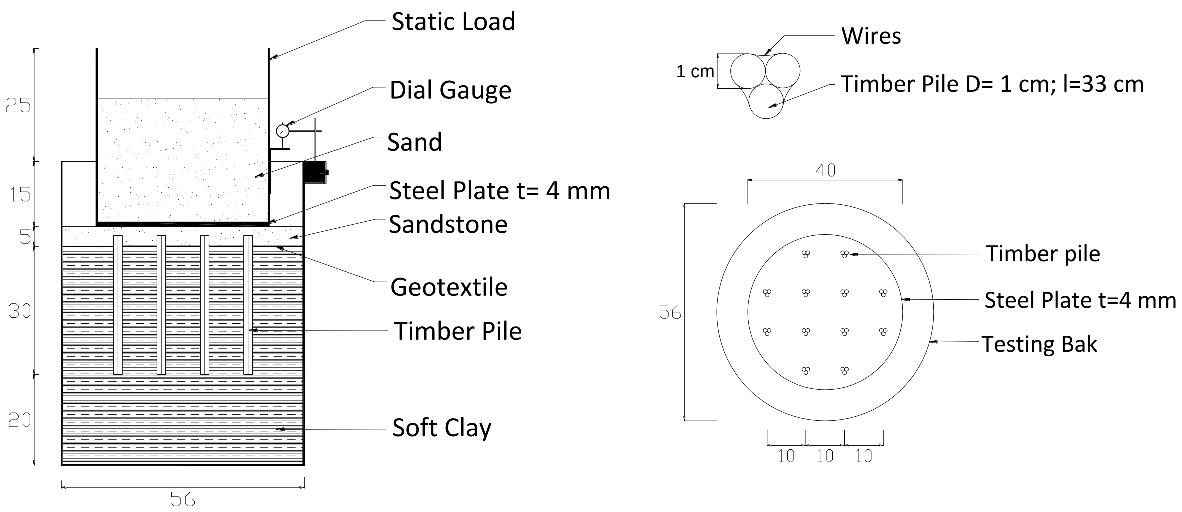


Figure 3. Preloading Test Schemes

Figure 4. Preloading Test Configuration on Laboratory

2.2.2. Seismic Load Test (Shaking Table Test)

The sand used was from Galesong Beach, Takalar Regency. This sand was categorized as having a high potential for liquefaction based on the grain size distribution curves of soils that were vulnerable to liquefaction that were stated in [23, 27]. Selain itu, liquefaction generally occurs in clean, sandy soils with a high degree of saturation and a relative density (Dr) that is less than 50% [24, 25]. Therefore, the relative density (Dr) of the sand in this research was 40%, with a thickness of 50 cm. A steel tub with dimensions of 120 cm × 100 cm × 80 cm was used to configure this shaking table test (Figure 5). Installation of the tied timber was carried out in a rectangular-grid pattern with distances of 10 cm (same as the preloading test). The installation of all the materials is shown in Figure 6.

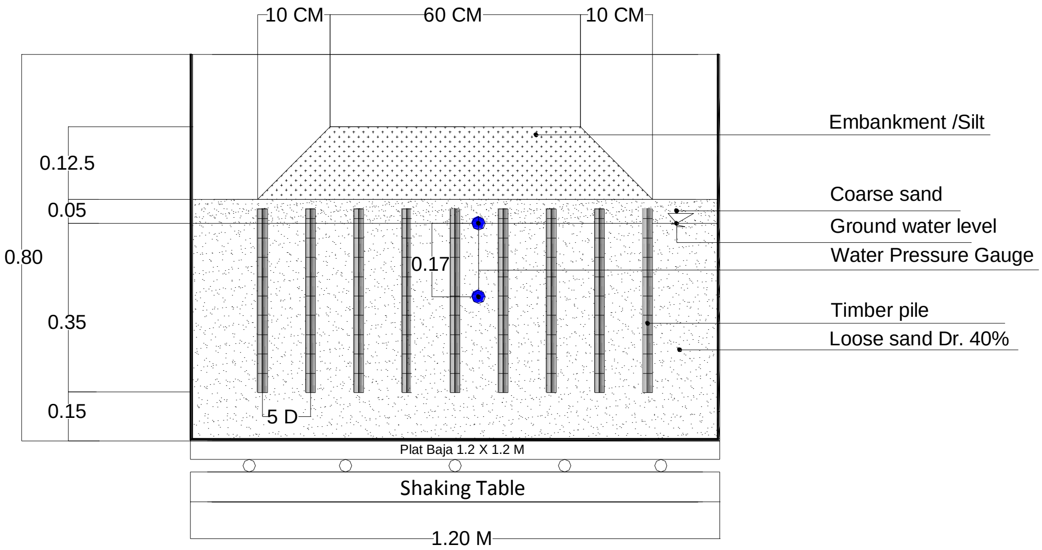


Figure 5. Shaking Table Test Configuration

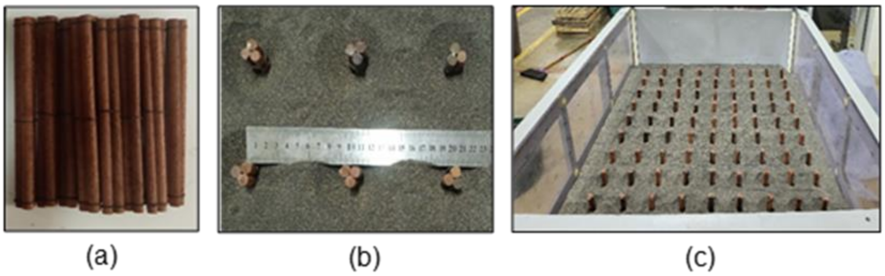


Figure 6. Timber piles (a) tied with wire, (b). installed with d = 10 cm (c). installation pattern

After the installation of the timber piles was completed, it was covered by uniform graded sand material with thickness of 5 cm. On the top of sand, a trapezoid soil embankment which is functioning as a load was placed. The dimensions of the trapezoid embankment were: 1. Lower dimensions of the embankment l = 80 cm, and w = 60 cm, 2. upper dimensions of the embankment are l = 60 cm, w = 40 cm, h = 12.5 cm. This scheme is presented on Figure 7.

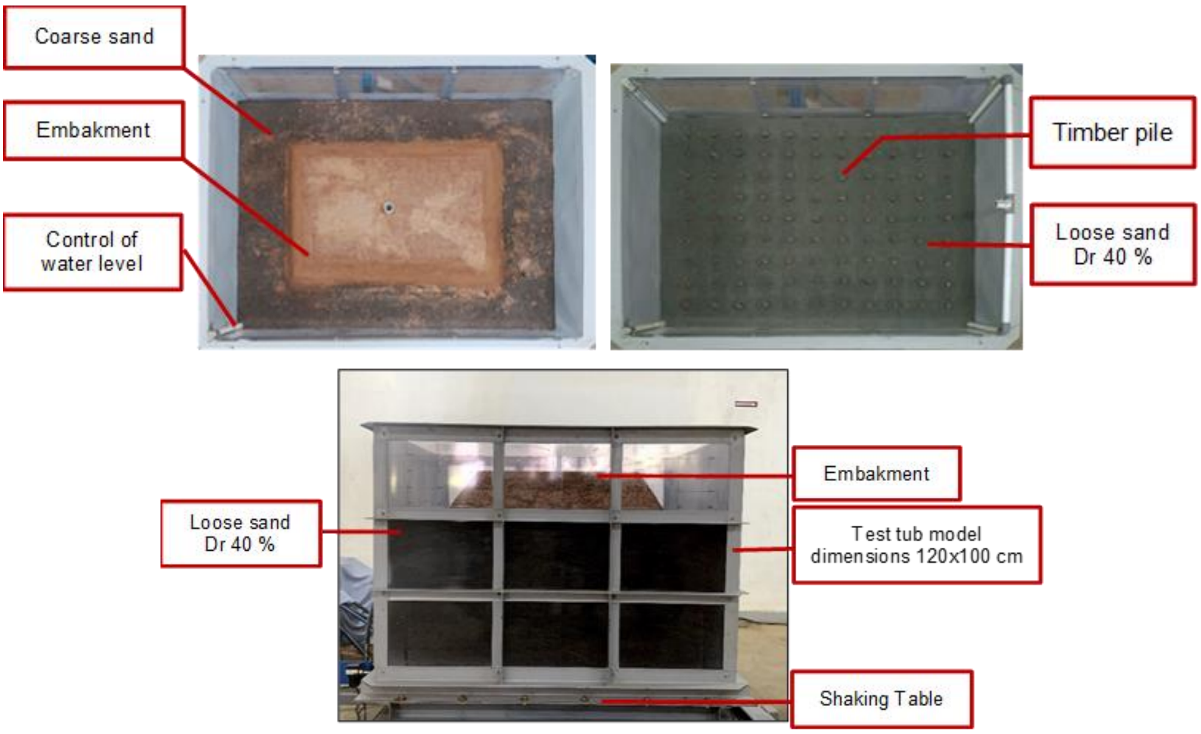


Figure 7. Shaking table test set up

The data parameters were recorded for data analysis. The parameters observed in this test were the changes/improvement of the bearing capacity and the settlement that occurred due to the given seismic loads. The measuring instruments used included the Hand Cone Penetrometer (HCP), elevation grid, scale on the test tub, displacement sensor, and accelerometer.

The seismic load test or shaking table test is conducted on a small-scale model. The test was set at PGA = 0.3g, f = 0.78 Hz with a loading duration of 37 seconds. The accelerometer records taken during testing are attached in Figure 8. The stresses and deformations measured in the experiments do not truly represent the stresses and deformations in the field due to the low confusion pressure and boundary effects in the model study. Therefore, it is very important to apply proper similarity rules to experiments in order to apply the results to actual field conditions. Iai [26] presents the similarity laws for the 1 g model test from the basic definitions of effective stress, strain and constitutive law, overall balance, and mass balance. The geometric scale factor, λ, is defined as a constant of proportionality between the model and prototype geometry. The same proportionality equation is assumed for other parameters such as stress-strain and pore water pressure. For this study, the geometric scale factor, λ, was taken as 10. Therefore, the height of the model wall was maintained at 0.5 m, corresponding to 5 m in the field. The dimensions of the timber pile in the model test were 0.01 m in diameter and 0.35 m in length, corresponding to the field prototype of 0.1 m in diameter and 3.5 m in length.

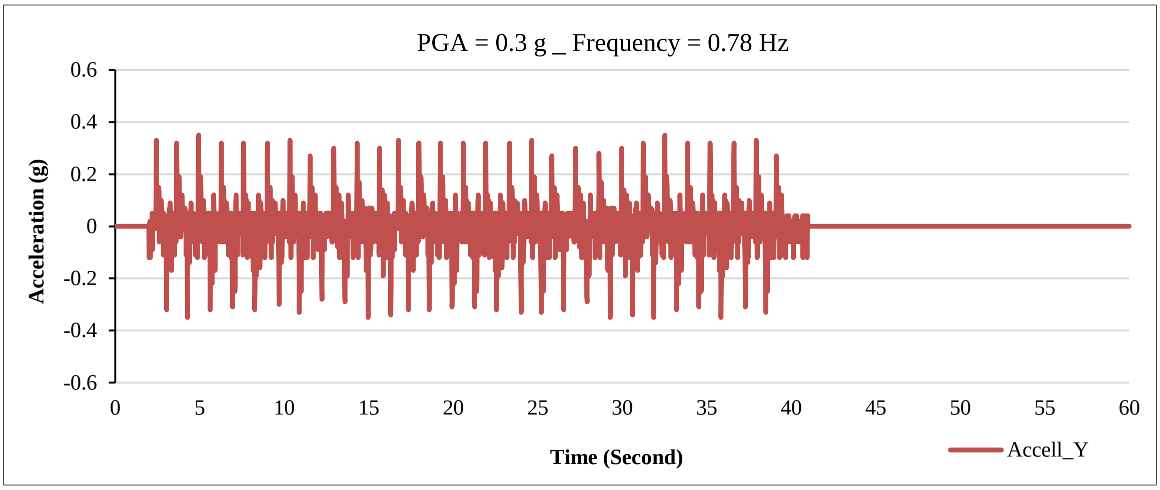


Figure 8. Acceleration graph based on accelerometer record during test

3. Result and Discussion

3.1. Testing The Physical Properties of The Material

Based on the results of mechanical properties test of Eucalyptus pellita timber that has been carried out, Eucalyptus pellita timber is included in the timber group based on the 1979 Indonesian timber construction planning procedures [2]. With a timber specific gravity value of 0.91 and a flexural strength of 118.5 MPa. Therefore, it is included in the timber group I which is classified as a strong category. Based on the this timber class grouping, Eucalyptus pellita timber can be used as a timber pile material according to the technical instructions for timber piles application as foundations issued by the Ministry of Public Works technical guideline, No. 029/T/BM/1999 [27].

The results of testing the soil characteristics showed that the type of soil used for the preloading model test based on the USCS classification is high plasticity clay (CH) and the classification based on AASHTO is in groups A-7-6. To summarize, the results of characteristic soil testing can be seen in Table 1.

Table 1. The results of testing the characteristics of the preloading test soil

No.	Testing Type	Unit	Testing Result
Characteristics of Physical Properties			
1	Soil Specific Gravity (Gs)	-	2,74
2	Water Content (w)	(%)	72.91
3	Atterberg		
	Shrinkage Limit (SL)	(%)	13.88
	Plastis Limit (PL)	(%)	26.77
	Liquid Limit (LL)	(%)	82.75
	Indeks of Plasticity (IP)	(%)	55.98

	Sieve Analysis and Hydrometer		
4	Gravel	(%)	0.00
	Sand	(%)	7.20
	Silt	(%)	25.50
	Clay	(%)	67.30
5	Permeability	(cm/s)	2.3×10^{-7}
	Classifications		
	USCS		CH
	AASHTO		A-7-6

From the results of sand soil testing, it was found that the beach sand material for Galesong, Takalar Regency, South Sulawesi which, has the potential for liquefaction to occur. This was shown in the grain size distribution curve of soils which are vulnerable to liquefaction [23, 27]. The relative density was calculated based on the loose dry unit weight γd min 1.82 (gr/cm^3) and the dense dry unit weight γd max 2.06 (gr/cm^3). The relative density used in the test model is 40%, so the dry unit weight was 1.91 gr/cm^3. The results of testing soil parameters can be seen in Table 2 and for the grain size distribution curves of soils that are susceptible to liquefaction [23] is shown in Figure 9.

Table 2. Sand / Soil technical data

No.	Types of Inspection	Symbol	Results of Inspection	
	Soil Characteristics Testing			
1	Water Content (w)	wc	18.26	%
2	Specific Gravity (Gs)	GS	3.47	-
	Sieve Analysis Examination			
3	a. Gravel		0.00	%
	b. Sand		99.00	%
	c. Silt		1.00	%
	d. Clay		0.00	%
	Content Weight			
4	Minimum Dry Volume Weight	γ_{dMin}	1.82	gram/cm^3
	Maximum Dry Volume Weight	γ_{dMax}	2.06	gram/cm^3
	Minimum Pore Number	e_{min}	0.86	-
	Maximum Pore Number	e_{max}	0.65	-
5	Potential for Liquefaction		High Potential	

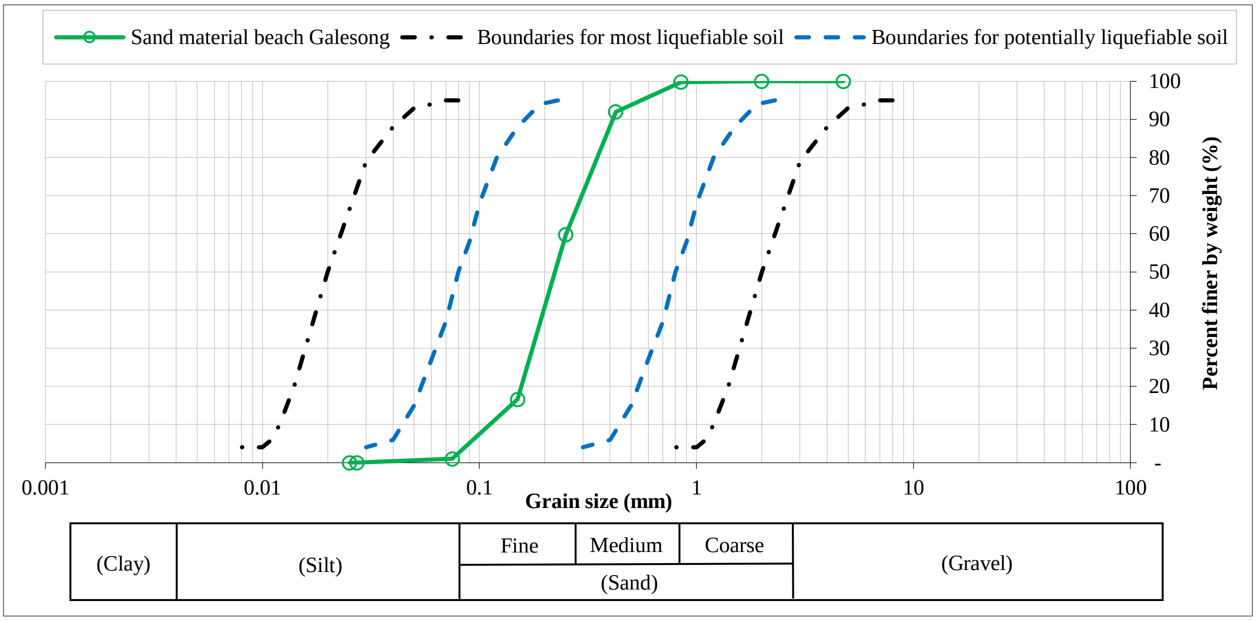


Figure 9. Grain Size Distribution Curve of Soils which are Vulnerable to Liquefaction [23]

3.2. Preloading Test

From the observational data of the preloading test during the test, it was found that the reinforcement of timber piles given to soft clay soils could increase the bearing capacity. This could be seen from the pattern of settlement that occurs due to a given load.

The reinforced soil had a smaller settlement when compared to the unreinforced soil; this was due to the resistance at the top of the timber pile and the shear force on the cover of the timber pile. In the corrugated reinforcement sample, it was able to reduce the settlement to a greater extent when compared to the unreinforced sample. During the loading test for 40 days, it showed that reinforcement using timber piles was able to reduce the settlement by 18%. This can be seen in Figure 10.

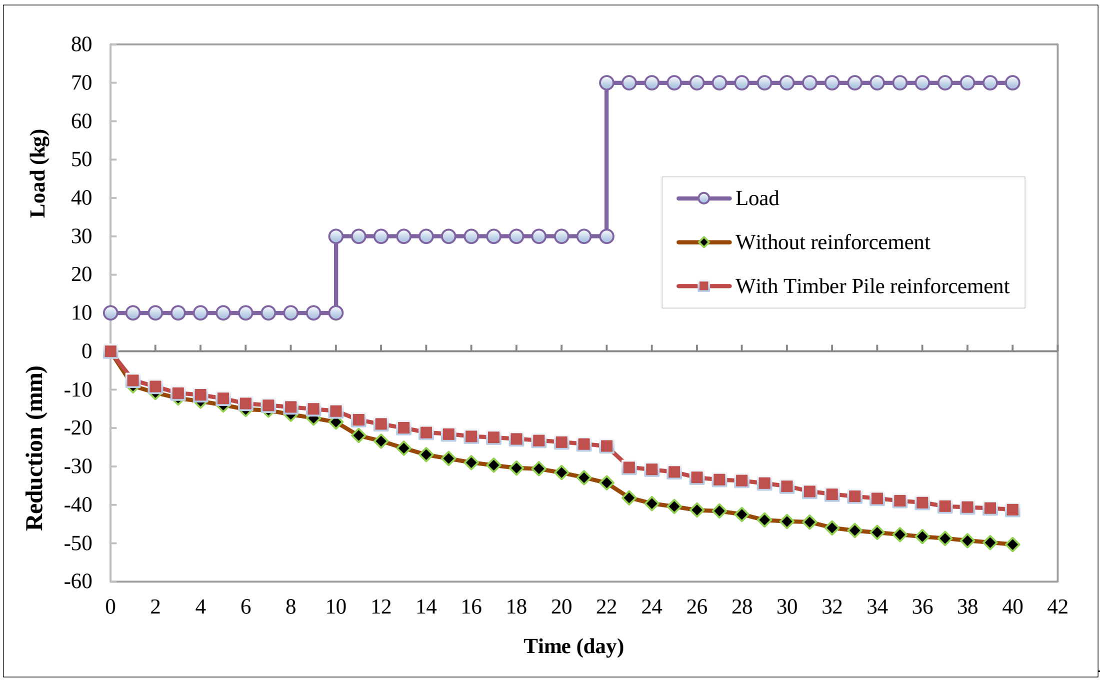


Figure 10. Graph of the relationship between time, load, and reduction

The graph of the comparison of settlement due to load also shows that at the first loading stage, namely 10 kg of reinforcement using a timber pile was able to slow down the settlement rate when compared to without reinforcement. This was due to the installation of timber piles, which resulted in vertical deformation that occurred on the soil given the reinforcement, which was relatively smaller than the unstretched ground. This was due to the pile group's additional load on the subgrade. Load transfer was continued through end resistance and skin resistance to deeper layers, so the test results showed that Eucalyptus timber piles provided a slower settlement time when compared to unreinforced soil.

In addition, the results of the Hand Cone Penetrometer (HCP) test, which was carried out before the preloading test, were 2.93 kg/cm^2 for the 2 models and then experienced an increase after the preloading test was carried out. For the unreinforced test model, the increase in bearing capacity was 4.16 kg/cm^2, and the timber pile reinforcement was 5.87 kg/cm^2. So that the use of Eucalyptus pellita timber could increase the bearing capacity of the soil by 41% compared to the soil without reinforcement. The Hand Cone Penetrometer (HCP) test results can be seen in Table 3 and Figure 11. Comparison diagram of the HCP test results before and after reinforcement. The results align with the research conducted by Suheriyatna et al. [16]. That the use of timber piles was able to increase the bearing capacity of the soil and reduce the settlement due to the load on it.

Table 3. HCP test results before and after the preloading test

Sample	qc (kg/cm^2)		Comparison of qc increase with unreinforced model (%) after preloading
	Before preloading	After preloading	
Without reinforcement	2.93	4.16	0
With timber piles reinforcement	2.93	5.87	41

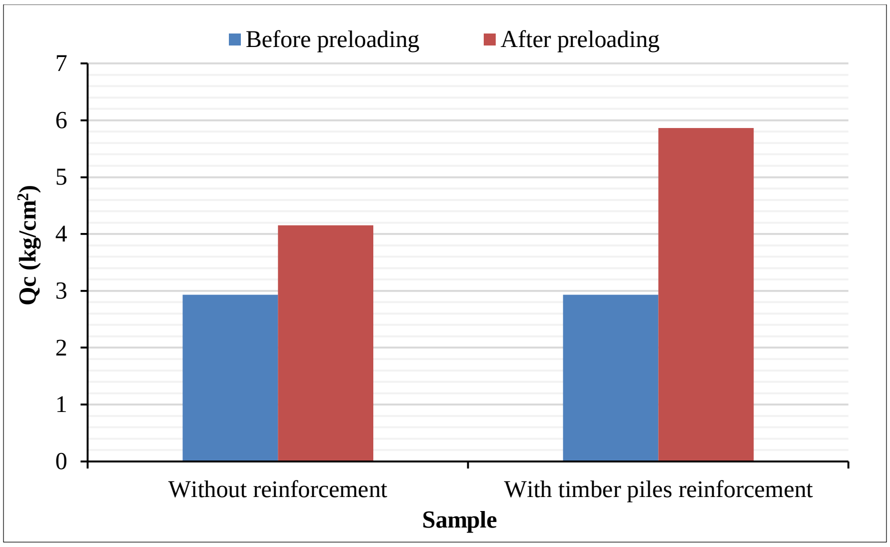


Figure 11. HCP test result diagram before and after preloading test

3.3. Seismic Load Test

From the test results data due to seismic loads with PGA = 0.3 g and a frequency of 0.78 Hz, it was found that the reinforcement of timber piles given to sandy soils that have the liquefaction potential could provide increment of bearing capacity. This could be seen from the settlement that occurs due to the load given, which was smaller compared to the unreinforced soil equal to 2.75 cm or reducing the settlement of 68.04% bearing capacity when receiving seismic loads. The installation of micro pile as a soil reinforcement material has the function of carrying the load indicated by the decrease that occurs in the embankment, this is in accordance with the research of Alsaleh & Shahrour (2009) states that the use of micro pile It also induces a settlement that can have an important effect on the response of the soil - micro pile - structure to earthquakes [28]. Recapitulation of changes in settlement ratio in Table 4 and graph of settlement due to seismic loads Figure 12.

Table 4. Recapitulation changes in the reduction ratio

Model Test	Before	After	X Direction Reduction (cm)	Reduction (%)
Without reinforcement	66.12	57.52	8.61	0.00
With timber piles reinforcement	66.12	63.37	2.75	68.04

Figure 12. Settlement due to seismic loads

Before and after the seismic loading test was carried out with PGA = 0.3 g at a frequency of 0.78 Hz, the Hand Cone Penetrometer (HCP) test was carried out, indicating that the reinforcement of timber beams could provide additional bearing capacity. This test aims to determine the soil's consistency based on the Qc value before and after the seismic load test. From the results of the HCP test, it could be seen that the increase in soil bearing capacity increased significantly in unreinforced soil samples at a depth of 30 cm to 50 cm, while for a depth of 0 to 20 cm, it was relatively small when compared to those using timber piles, this occurred due to the soil decreases. Directly as a result, when receiving seismic loads, while for the reinforcement of timber piles there was the friction of the soil particles against the timber piles so that the compaction process was reduced. This analysis showed that the research was in line with previous research, that when sandy soil liquefies due to seismic loads, relative density will increase, influenced by grain gradation and specific gravity [29]. Yuan et al. [30] stated that the denser soil settlement is smaller than the less compacted soil. The soil without recess reinforcement has a greater settlement than the soil with percutaneous perforation when compared to the unreinforced.

The HCP test was carried out at 4 points in each model test sample, and the location of the test points is shown in Figure 13. And the hand cone penetrometer (HC) test results were made in Table 5. The graph of the relationship between changes in the increase in bearing capacity and depth is shown in Figure 14.

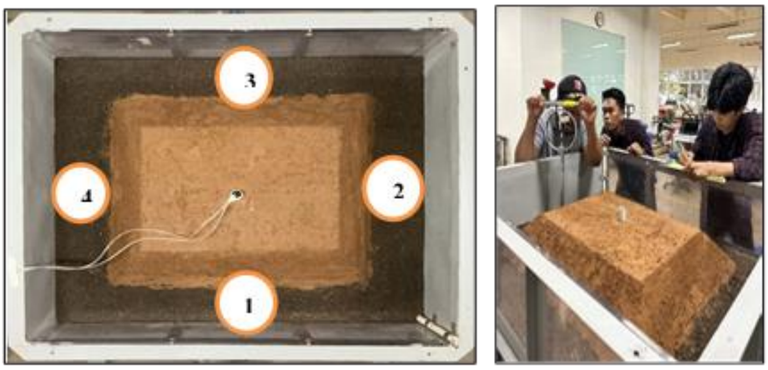


Figure 13. Test point Hand Cone Penetrometer (HCP)

Table 5. Test result of Hand Cone Penetrometer (HCP)

Depth (cm)	Without Reinforcement		With Timber Piles Reinforcement	
	Before	After	Before	After
0	0	0.00	0.00	0.00
10	3.12	13.93	5.50	22.00
20	7.52	36.48	14.67	57.20
30	10.27	82.50	19.80	86.17
40	13.38	100.47	25.48	97.17
50	18.15	109.82	36.30	103.58

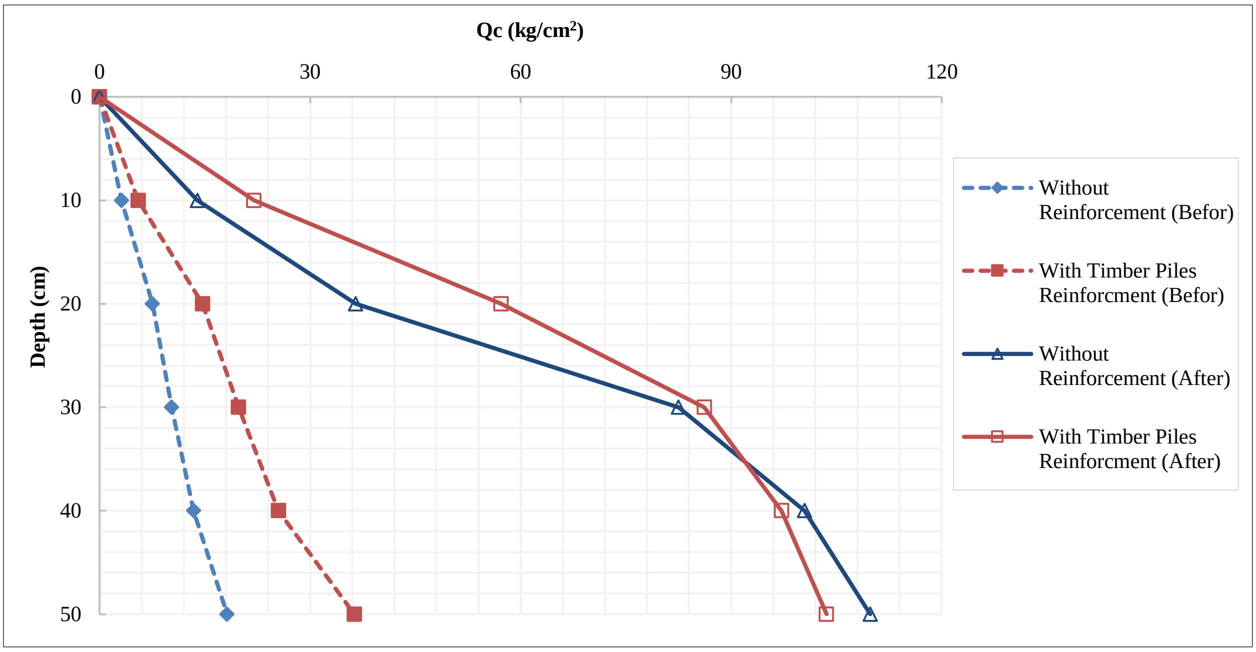
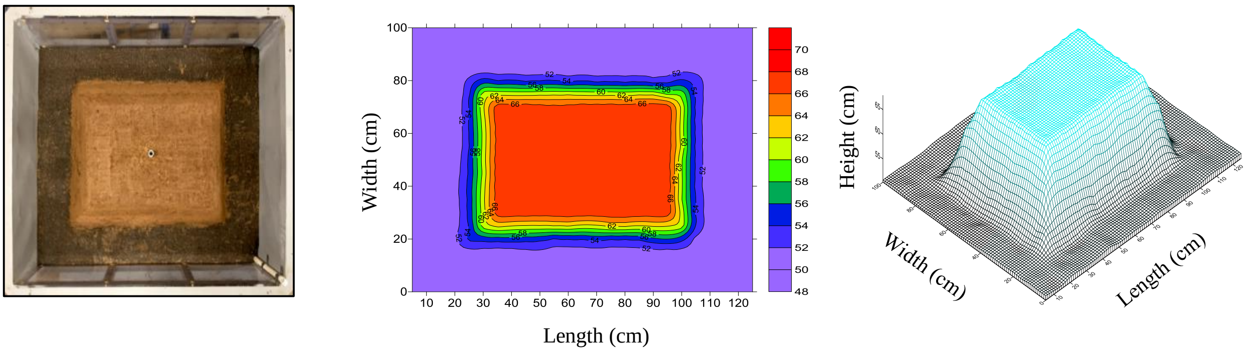
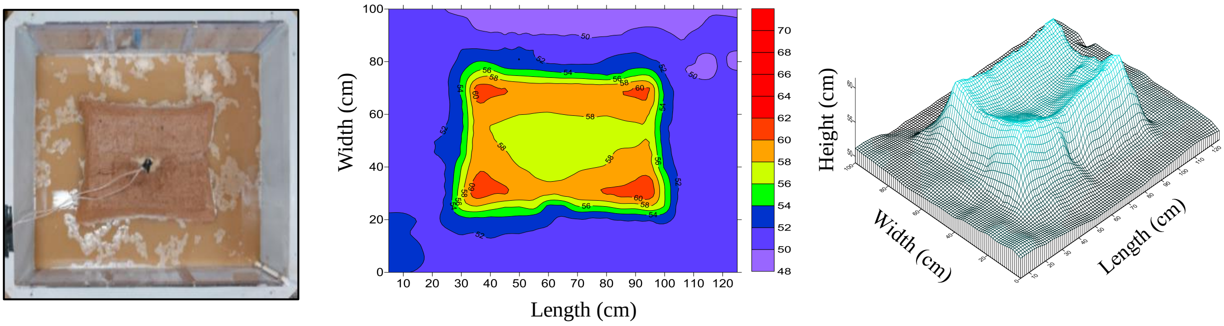


Figure 14. Graph of the relationship between changes in the increase in bearing capacity to depth due to seismic loads

Settlement changes that occurred in the model test without reinforcement are shown in Figure 15. Meanwhile, changes in a settlement that occurred in the timber piles reinforcement model test are shown in Figure 16.

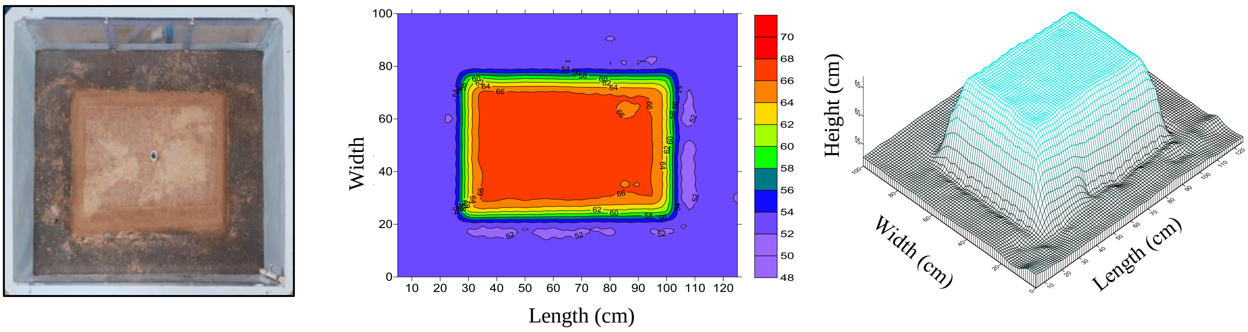


(a) Elevation contour before testing

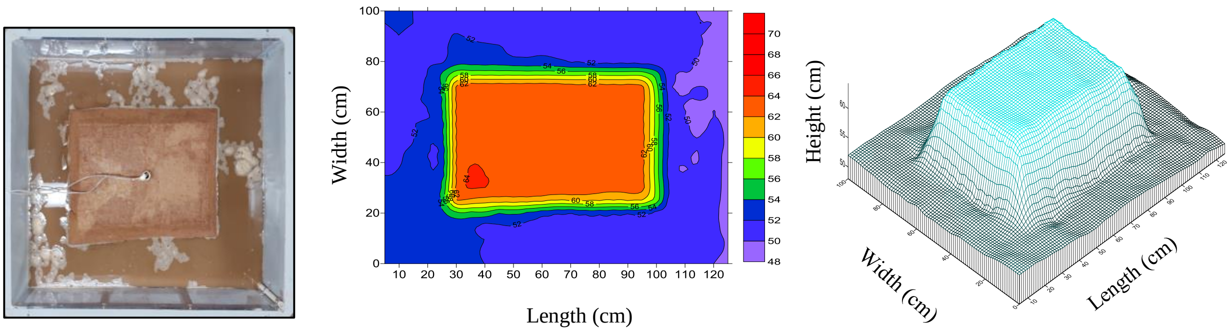


(b) Elevation contour after testing

Figure 15. Appearance of the unreinforced model test condition



(a) Condition before testing



(b) Condition after testing

Figure 16. The test conditions for the timber piles reinforcement model

The results of the model test analysis carried out from the preloading test and seismic load testing with PGA = 0.3 g at a frequency of 0.78 Hz showed that the reinforcement of timber piles could provide improvement on bearing capacity and was able to reduce settlements when compared to without reinforcement. So that, it verifies the effectiveness of using timber beams as a soil reinforcement material in liquefaction-prone areas.

4. Conclusion

This research experimentally evaluated the effect of using Eucalyptus pellita timber piles as reinforcement material on sandy soils with liquefaction potential. Based on the results of the testing of the mechanical properties of Eucalyptus pellita timber that has been carried out, Eucalyptus pellita timber can be used as a timber pile material in accordance with the technical instructions for the implementation of timber pile foundations issued by the Ministry of Public Works technical guidelines (1999), No.029/T/BM/1999. The results of preloading tests on soft soils showed that the timber pile was able to increase the bearing capacity of the soil and reduce the settlement by 18%, while testing due to seismic loads with PGA = 0.3 g, frequency 0.81 Hz on sand soils found that reinforcement of the timber pile given to sand soils with liquefaction potential can provide additional bearing capacity and can reduce the settlement by 68%. This is due to the resistance at the tip of the timber pile and the skin friction of the timber. So the model test results show that the reinforcement test with the reinforcement of the timber pile can increase the bearing capacity of soft soil and soil with liquefaction potential.

Our testing and analysis in this research are still limited to small-scale modeling so that the results achieved are sufficient as a parameter for the mechanical ability of the Eucalyptus pellita timber pile reinforcement model test on potential liquefaction soils. Some suggestions can be made for improvement, such as conducting further research related to the use of reinforcement of Timber pile, as well as measuring changes in vibration acceleration on the surface with a larger scale, complex and also need to conduct a test of the reinforcement model of Timber pile with several kinds of installation patterns and relative density (Dr) and comparing their performances.

5. Declarations

5.1. Author Contributions

Conceptualization, S. and T.H.; methodology, S.; software, S.; validation, T.H., A.B.M., and A.A.; formal analysis, S.; investigation, S.; resources, S.; data curation, S.; writing—original draft preparation, S.; writing—review and editing, S.; visualization, S.; supervision, T.H., A.B.M., and A.A.; project administration, S.; funding acquisition, S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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