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The Effect of Use of Bamboo Cerucuk on The Performance of Shallow Foundations on Liquefacted Soils In The Kabonena Area

*Moh.David Rizaldi[1], Sriyati Ramadhani[2], Sukiman Nurdin[3]
[1] *Mahasiswa Pascasarjana Jurusan Teknik Sipil, Universitas Tadulako.*
[2] *Program Studi Teknik Sipil, Fakultas Teknik, Universitas Tadulako.*
[3] *Program Studi Teknik Sipil, Fakultas Teknik, Universitas Tadulako.*

Abstract: *Liquefaction is one of the impacts of earthquakes that causes an increase in pore water pressure, thereby reducing the effective stress and resulting in a loss of soil shear strength. This condition can reduce the bearing capacity and increase the settlement of shallow foundations, especially in saturated sandy soils. This study aims to analyze the characteristics of the soil in the Kabonena sub-district, Palu city, and evaluate the effectiveness of the use of bamboo pits in increasing the bearing capacity and reducing the settlement of shallow foundations in liquefied soil conditions. The research methods include testing soil characteristics in the laboratory, physical modeling using a shaking table, and numerical analysis with Plaxis 3D on several variations of groundwater conditions, both with and without the installation of bamboo pits. The test results show that the study soil is dominated by clayey sand (SC), silty sand (SM), and poorly graded clayey sand (SP-SC), which are coarse-grained soils with high liquefaction potential. The use of bamboo pits has been proven to increase soil stability through reinforcement mechanisms and vertical drainage, thereby improving the performance of shallow foundations. In shaking table testing with a vibration velocity of 10 m/S^2 or 0.9-1.9g, the maximum settlement was reduced from 8.5 cm to 4.7 cm, while the Plaxis 3D simulation results showed a decrease in settlement from 8.31 cm to 4.11 cm after the installation of bamboo pits at ground water level conditions. The findings of this study indicate that bamboo pits are an effective, economical, and environmentally friendly alternative for improving the performance of shallow foundations in liquefaction-prone areas. The results of this study are expected to be a reference in the development of local material-based liquefaction risk mitigation methods for infrastructure development in areas with similar soil characteristics.*
Keywords: Liquefaction, Bamboo Niche, Shallow Foundation, Soil Bearing Capacity, Foundation Settlement, Kabonena, Plaxis 3D.

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I. INTRODUCTION

Indonesia is prone to earthquakes due to its location on the Pacific Ring of Fire. One frequent impact of earthquakes is liquefaction, a condition where fine-grained, water-saturated soil loses its strength and stiffness due to vibrations, thus behaving like a fluid. This phenomenon has the potential to cause structural failure, particularly in shallow foundations that rely heavily on the bearing strength of the underlying soil (Seed & Idriss, 1971).

Various soil improvement methods have been developed to reduce the risk of liquefaction, including the use of prefabricated vertical drains (PVDs), soil compaction, grouting, and stone columns. However, these methods often require high costs, sophisticated technology, and skilled labor (Indraratna & Redana, 1997). Therefore, more economical, easy-to-apply, and environmentally friendly solutions are needed, especially in rural areas.

The Kabonena area in Palu City was chosen as the research location because it was one of the areas severely affected by the liquefaction phenomenon during the earthquake of September 28, 2018. This area has sandy/gravel soil characteristics based on research conducted by (Muh. Rusli et al., 2021). Kabonena was chosen because it is very suitable for testing the effectiveness of bamboo niches in improving the performance of shallow foundations on liquefied soil.

Bamboo, an abundant natural material in Indonesia, has been widely used in various civil engineering applications. One bamboo producer is the Salua village in the Sigi region. Bamboo's strong, lightweight, and flexible mechanical properties make it an attractive alternative for soil stabilization. The use of bamboo indentations, where bamboo is planted vertically into the soil, is considered to increase the soil's bearing capacity and accelerate consolidation (Widodo et al., 2018).

In the context of shallow foundations, the presence of bamboo recesses is believed to help improve foundation performance by increasing the soil's bearing capacity and reducing settlement due to earthquake vibrations. However, specific studies on the effect of bamboo recesses on shallow foundation performance under liquefied soil conditions are still very limited.

II. EXPERIMENTAL PROCEDURE

2.1 Research Location

This research was conducted in the Kabonena sub-district, Ulujadi district, Palu City, Central Sulawesi Province. This area was chosen because of its soil characteristics prone to liquefaction, as evidenced by the 2018 Palu earthquake, which caused several areas in Kabonena to experience significant subsidence and landslides.The specific test location was a loose sandy/gravelly soil type, previously identified in research conducted by (Muh. Rusli et al., 2021). The relatively flat area, approximately 400 m2, allowed for the installation of shallow foundations with and without bamboo recesses on a field-scale laboratory test.

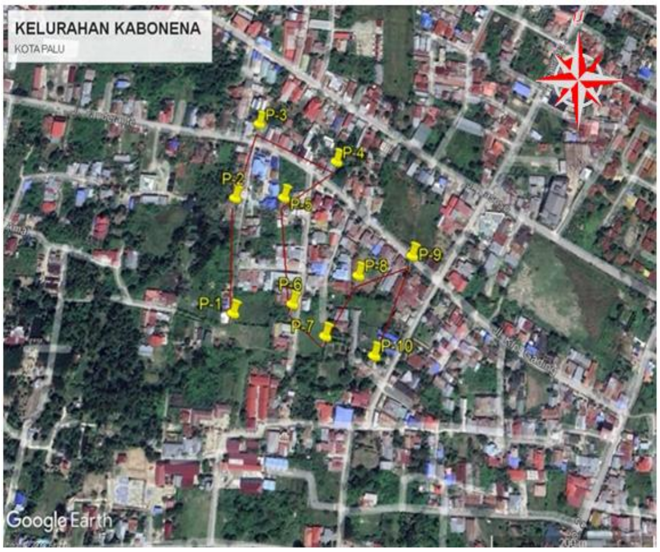

Figure 1. Research Location (Google Earth, 2025)

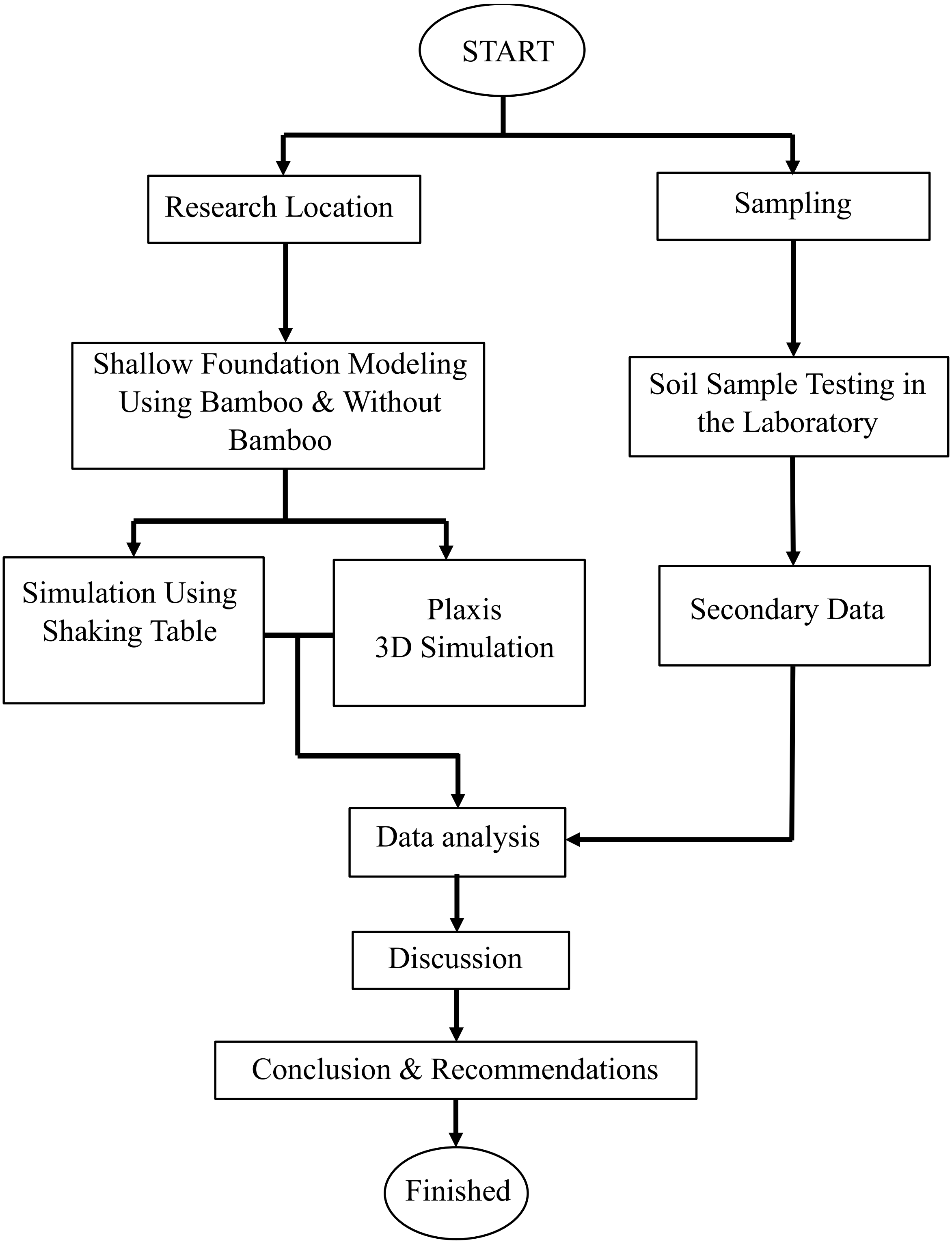

Figure 2. Research Flow Diagram

III. RESULTS AND DISCUSSIONS .

3.1. Soil Characteristic Test Results

A. Sieve Analysis Testing

Based on **Figure 3**, the grain size analysis test results curve according to Tsucida (1970), it was found that at points P-1 to P-10, most samples fell within the red curve, indicating a high potential for liquefaction. Some of the gradation curves fell within the black curve, indicating a potential for liquefaction.To determine the characteristics of the soil under review, the results of the grain size analysis test were combined with the results of the Atterberg limits test. Based on the Unified Soil Classification System (USCS), all samples at the test points were classified as coarse-grained soil. This is because at all test points, less than 50% of the soil passed the 200 sieve. The soil type at points P-1, P-2, P-5, and P-7 was clayey sand (SC). At point P-8, it was silty sand (SM). At point P-6, the soil type was poorly graded clayey sand (SP-SC).

Table 1 Summary of Sieve Analysis Test Results

Sieve Analysis				
	Parameters/Symbols	**Unit**	**Results**	**Sample Code**
Percentage Retained	#200	%	76,33	P-1
Pass Percentage	#200	%	23,67	
Percentage Retained	#200	%	80,87	P-2
Pass Percentage	#200	%	19,13	
Percentage Retained	#200	%	88,83	P-3
Pass Percentage	#200	%	11,17	
Percentage Retained	#200	%	90,18	P-4
Pass Percentage	#200	%	9,82	
Percentage Retained	#200	%	76,17	P-5
Pass Percentage	#200	%	23,83	
Percentage Retained	#200	%	90,56	P-6
Pass Percentage	#200	%	9,44	
Percentage Retained	#200	%	77,38	P-7
Pass Percentage	#200	%	22,62	
Percentage Retained	#200	%	87,05	P-8
Pass Percentage	#200	%	12,95	
Percentage Retained	#200	%	91,68	P-9
Pass Percentage	#200	%	8,32	
Percentage Retained	#200	%	90,68	P-10
Pass Percentage	#200	%	9,32	

B. AtterBerg's Limit

In addition to grain size analysis, Atterberg limits testing can also be used to determine the characteristics of the soil being reviewed and the criteria for soil that has the potential for liquefaction. There are two methods used in analyzing this liquefaction potential using data from the Atterberg limits test results. The first method is using the Modifield Chinese Criteria method. Based on this method, points P-1, P-2, P-5, P-6, P-7 and P-8 are included in the criteria for soil that has the potential for liquefaction because all points show a PL value <35%. The second method is using the method of Seed et al. (2003). Based on this method, points P-1, P-2, P-5, P-6, P-7 and P-8 are included in zone A with the criteria for soil that has a high potential for liquefaction because it has a LL value ≤ 37% and a PI value ≤ 12%. Therefore, all points based on the test samples are concluded to be in zone A with the potential for liquefaction. The summary results regarding the criteria for soil that has the potential for liquefaction at all test points according to several methods can be shown in **Figure 3.**

Table 2 Recap of Atterberg Limits Test Results

Atterberg				
	Parameters/Symbols	**Unit**	**Results**	**Sample Code**
Liquid limit	LL	%	25,67	P-1
Plastic Limit	PL	%	17,81	
Plastic Index	PI	%	7,86	
Liquid limit	LL	%	25,67	P-2
Plastic Limit	PL	%	18,46	
Plastic Index	PI	%	7,21	
Liquid limit	LL	%	-	P-3
Plastic Limit	PL	%	-	
Plastic Index	PI	%	-	
Liquid limit	LL	%	-	P-4

Plastic Limit	PL	%	-	
Plastic Index	PI	%	-	
Liquid limit	LL	%	25,87	P-5
Plastic Limit	PL	%	18,18	
Plastic Index	PI	%	7,69	
Liquid limit	LL	%	27,09	P-6
Plastic Limit	PL	%	21,71	
Plastic Index	PI	%	5,38	
Liquid limit	LL	%	26,50	P-7
Plastic Limit	PL	%	19,91	
Plastic Index	PI	%	6,60	
Liquid limit	LL	%	30,40	P-8
Plastic Limit	PL	%	26,46	
Plastic Index	PI	%	3,94	
Liquid limit	LL	%	-	P-9
Plastic Limit	PL	%	-	
Plastic Index	PI	%	-	
Liquid limit	LL	%	-	P-10
Plastic Limit	**PL**	**%**	**-**	
Plastic Index	**PI**	**%**	**-**	

C. Soil Content Weight

Soil bulk density testing was conducted on 10 soil samples to determine their density characteristics under wet and dry conditions. In Rahmat Hidayat's (2023) research, bulk density was one of the parameters used to describe soil characteristics in the Kabonena sub-district, where liquefaction potential was evaluated.nIn general, the results showed that all samples had relatively close bulk density values, indicating fairly uniform soil conditions across the study sites. Differences in bulk density values between points are thought to be influenced by variations in soil grain composition, natural density, water content, and fine material content at each sampling location. The higher the bulk density, the denser the grain arrangement, resulting in smaller pores and a tendency for the soil to have better compaction. In comparison with the results of the grain analysis according to Tsucida (1970), most samples were dominated by sandy soil with a relatively low fine grain content, so the obtained bulk density values remained within the range commonly found in silty sandy and clayey sandy soils. This condition shows that the soil at the research location has characteristics in the form of relatively dense granular soil, but still has the potential to experience an increase in pore water pressure when it is in a saturated condition and receives earthquake loads.

Table 3 Summary of Soil Bulk Density Test Results

Soil Bulk Weight				
	Parameters/Symbols	**Unit**	**Results**	**Sample Code**
Wet Content Weight	yb	(gr/cm^3)	2,43	P-1
Dry Bulk Weight	yb		2,47	
Wet Content Weight	yb	(gr/cm^3)	2,14	P-2
Dry Bulk Weight	yb		2,20	
Wet Content Weight	yb	(gr/cm^3)	2,47	P-3
Dry Bulk Weight	yb		2,52	
Wet Content Weight	yb	(gr/cm^3)	2,29	P-4
Dry Bulk Weight	yb		2,33	
Wet Content Weight	yb	(gr/cm^3)	2,44	P-5
Dry Bulk Weight	yb		2,49	
Wet Content Weight	yb	(gr/cm^3)	2,40	P-6
Dry Bulk Weight	yb		2,46	
Wet Content Weight	yb	(gr/cm^3)	2,30	P-7
Dry Bulk Weight	yb		2,35	
Wet Content Weight	yb	(gr/cm^3)	2,40	P-8
Dry Bulk Weight	yb		2,42	
Wet Content Weight	yb	(gr/cm^3)	2,27	P-9

Dry Bulk Weight	yb		2,29	
Wet Content Weight	yb	(gr/cm^3)	2,21	P-10
Dry Bulk Weight	yb		2,23	

D. *Swedish Weight Sounding*

The results of the Swedish Weight Sounding test, obtained the largest Nsw value, qa value and qu value for each point located at the last penetration depth with the number of half turns (Na) more than 50 times. The Nsw value, qa value and qu value increased drastically after reaching the number of half turns (Na) to 50 times. If the penetration depth with the number of half turns (Na) is less than 50 times, then the Nsw value, qa value and qu value appear lower when compared to the Nsw value, qa value and qu value when reaching the number of half turns (Na) more than 50 times.

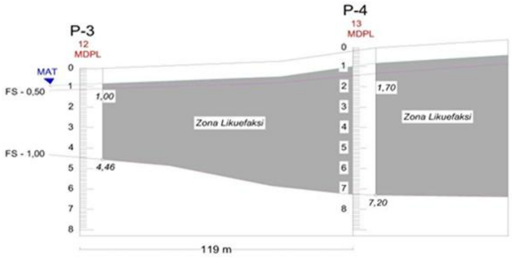

Figure 3. penetration depth with Na at points p-3 and p-4 (Rahmat Hidayat, 2023)

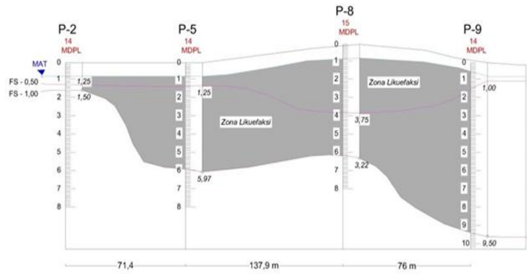

Figure 4. penetration depth with Na at points P-2, P-5, P-8, dan P-9 (Rahmat Hidayat, 2023)

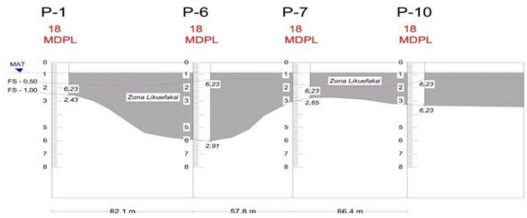

Figure 5. Penetration Depth with Na at Points P-1, P-6, P-7, and P-10 (Rahmat Hidayat, 2023)

3.3 The Effect of Bamboo Niches on Soil Bearing Capacity

A. Test Results Using Bamboo Niches

Calculation Using Bamboo Niche

1. Planning data

   Known :

   Length Of Bamboo : 15 Cm
   Diameter : 1 Cm
   Soil Bulk Density (γ) : 2272 Kg/M^3
   Soil Bulk Density (γsat) : 2375 Kg/M^3
   Cohesion (C) : 0,085
   Friction Angle (Φ) : 30°
   Ground Level (L) : 30 Cm
   PGA Value Of Palu City : 0,9 Pga

2. Calculation Of Soil Bearing Capacity (Qp)

   $Qp = Ap\ (\ cNc + (\ q' + \Delta qE\ )\ Nq\ )$

   - Effevtive Overbudern Pressure :

     $q' = \gamma \times z$
     $= (\ 2375 - 1000\ ) \text{ x } 0.3$
     $= 412{,}5 \text{ kg/m}^2$

   - Earthquake Coefficient (according to Seed and Whitman, 1970)

     $K_h = 0{,}5 \text{ x PGA}$
     $= 0{,}5 \text{ x } 0{,}9$
     $= 0{,}45$

   - Earthquake Stress

$\Delta qE = \gamma \times z \times Kh$
= (2272 – 1000) x 15 x 0,45
= 15336 kg/m^2

- Value Determination Nc And Nq

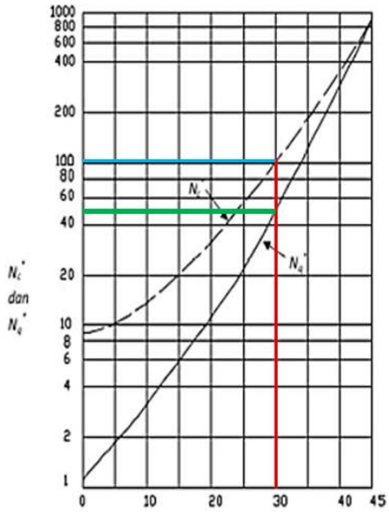

Figure 6. value determination Nc and Nq

Based on **Figure 6** the values of Nc and Nq are :
Nc = 100
Nq = 50

- Cross-Sectional Areas (Ap)
  a x b = 0,1 x 0,1 = 0,01 m^2
  So :
  Qp = Ap (cNc + (q′ + ΔqE) Nq)
  = 0,01 x [0,085 x 100) + (412,5 + 15336) x 50]
  = 7874,335 Kg/m^2

3. Frictional Bearing Capacity Calculation (Qs)
   Qs = Σp × ΔL × f
   Where :
   - Soil Pressure Coefficient :
     Ko = 1,4 (1 – sinϕ)
     Ko = 1,4 (1 − sin30°)
     Ko = 0,7
   - ΔL = Length Of Bamboo (m)
     = 0,15 m
   - Angle Of Friction Of Soil Pile
     δ′ = 0,8 ϕ
     = 0,8 x 30
     = 24
   - Initial Effective Stress
     $\sigma o' = \frac{1+2\,(1 \sin \phi)}{3}$ x q’
     $= \frac{1+2\,(1 \sin 30)}{3}$ x 412,5
     = 275 Kg/m^2
   - Friction Resistance
     f = Ko × σ_o' × tan δ′
     = 0,7 x 275 x 0,445
     = 81,66 Kg/m^2

   So :
   Qs = Σp × ΔL × f
   = 0,01 x 0,15 x 81,66
   = 0,122 Kg/m^2
4. Ultimate Bearing Capacity (Qu)

Qu = Qp + Qu
= 7874,355 + 0,122
= 7874, 457 Kg/m^2

5. Permit Carrying Capacity (Qall)

Qall = $\frac{Qu}{FS} = \frac{7874,457}{3}$ = 2624,82 Kg/m2

6. Immediate Settelment Calculation

Sc = $\frac{q\ x\ b}{E}(1-\mu 2)Ip$
= $\frac{2624,82\ x\ 0,1}{15000}$ (1 – 0,25^2) x 1,00
= 0,0164 m
= 1,641 cm

Calculation Without Bamboo Niche

Planning Data

1. Known :

foundation width (B)	: 60 cm
foundation depth (Df)	: 60 cm
Soil Bulk Density (γ)	: 2272 kg/m^3
Soil Bulk Density (γsat)	: 2375 kg/m^3
Cohesion (C)	: 0,085
Friction Angle (φ)	: 30°

2. Calculation Of Soil Bearing Capacity (qu)

qu = c x Nc + q x Nq x ½ x γ x B x Nγ

- Value Determination Nc, Nq, and Nγ

Table 3.1 Terzaghi's Bearing Capacity Factors—Eqs. (3.4), (3.5), and (3.6) a From Kumbhojkar (1993)

ϕ'	N_c	N_q	N_γ[a]	ϕ'	N_c	N_q	N_γ[a]
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

[a]From Kumbhojkar (1993)

Figure 7 Table of Nc, Nq, Nγ Values According to Terzaghi (1993)

Based on **Figure 7** with a friction angle value of 30°, the values of Nc, Nq, Nγ are::
Nc = 37,16
Nq = 22,46
Nγ = 19,13

- Value Determinatio q

q = γ x Df
= (2272 – 1000) x 0,6
= 763,2 kg/m2

So :

qu = c x Nc + q x Nq + ½ x γ x B x Nγ

= 0,085 x 37,16 + 763,2 x 22,46 + ½ x 1272 x 0,7 x 19,13
= 24444,64kg/m2

3. Permit Carrying Capacity (qall)

$$\text{Qall} = \frac{Qu}{FS} = \frac{24444{,}64}{3} = 8148{,}21 \text{ Kg/m2}$$

4. Immediate Settelment Calculation

$$\text{Sc} = \frac{q\ x\ b}{E}(1-\mu 2)Ip$$

$$= \frac{8148{,}21\ x\ 0{,}6}{15000}(1-0{,}25^2) \text{ x } 1{,}00$$

= 0,020 m
= 2,037 cm

Based on the calculation results above, the value of the shallow bearing capacity without using bamboo recesses is 8148.21 kg/m2, while the calculation using bamboo recesses produces 2624.82 kg/m2. These results indicate that the value of the foundation bearing capacity without using bamboo recesses is greater than using bamboo recesses. However, the settlement of the foundation using bamboo recesses is smaller, namely 1.641 cm, while in the shallow foundation that does not use bamboo recesses the settlement that occurs is 2.037 cm. This indicates that the main function of bamboo recesses in this assessment is not to increase the bearing capacity of the foundation, but to reduce deformation or settlement of the foundation by increasing soil strength and load redistribution.

B. Testing Using Shaking Table and Plaxis 3D

Testing using a Shaking table was conducted at a vibration velocity of 9-10 m/s2 or 0.9-1.9g (a very strong earthquake intensity). The soil height for the test was 30 cm, the load used was 5 kg, the bamboo pit length was 15 cm, and five (5) bamboo poles with a diameter of 1 cm were used. Testing using the vibration table and 3D Plaxis was conducted under three (3) conditions.

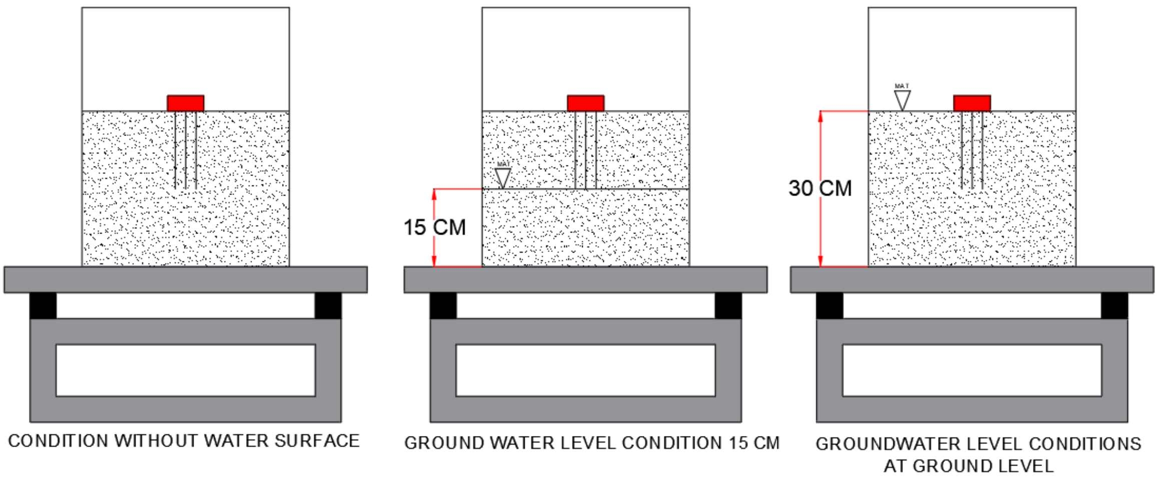

Figure 8. Sketch of test conditions using a vibrating table and Plaxis 3D

Table 4. Recap of the results of lowering the moches bamboo slats using a shaking table and Plaxis 3D

	Without Groundwater Surface + Bamboo	Without Groundwater + Using Bamboo	Groundwater Level 15cm + Without Bamboo	Groundwater Level 15cm + Using Bamboo	Groundwater Level As High As The Ground + Without Using Bamboo	Groundwater Level As High As The Ground + Using Bamboo
Shaking Table	**4 cm**	**1,2 cm**	**4,2 cm**	**1,1 cm**	**8,5 cm**	**4,7 cm**
Plaxis 3D	**4,28 cm**	**1,18 cm**	**4,17 cm**	**1,41 cm**	**8,30 cm**	**4,11 cm**

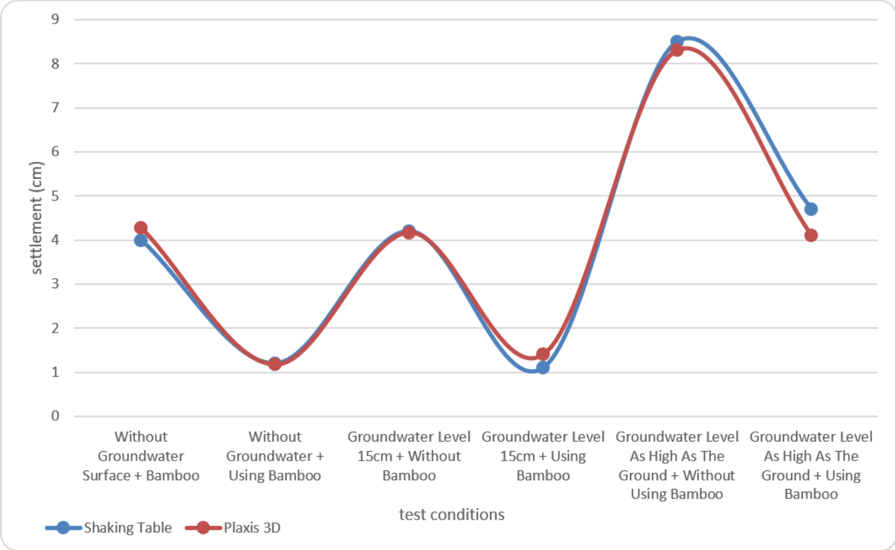

Figure 9. graph of the Settlement of Bamboo

3.4 The Effect of Using Bamboo Niches on Foundation Settlement.

Based on the results of pile foundation model tests on saturated sandy soil simulated by liquefaction using a vibrating table, it was shown that the installation of bamboo piles had a positive effect on reducing foundation settlement. Foundations using bamboo piles showed lower settlement values than those without reinforcement. This indicates that bamboo piles can improve the stability of the soil-foundation system during dynamic loads caused by earthquake vibrations, especially for simple houses.

Mechanically, bamboo piles act as vertical reinforcement elements, increasing soil strength and improving stress distribution beneath the foundation. During vibrations, some of the load is transferred to the bamboo piles through friction between the bamboo surface and the surrounding soil. This interaction provides a composite soil-bamboo system with greater strength than unreinforced soil. As a result, vertical deformation is minimized. This mechanism aligns with the theory that bamboo piles function as mini-piles, helping to resist soil deformation and improve foundation stabilization.

The effectiveness of bamboo recesses in this study was also influenced by several factors, including the number of recesses, bamboo length, bamboo diameter, and installation pattern. The greater the number of bamboos used, the greater the reinforced surface area, thus improving the system's ability to resist deformation. This resulted in less subsidence compared to without reinforcement.

IV. CONCLUSION

The soil characteristics in Kabonena Village are dominated by loose sand to gravelly sand, which has a relatively low density and is prone to liquefaction when subjected to dynamic loads caused by earthquakes. This condition makes the soil susceptible to loss of shear strength, resulting in settlement and foundation damage. Based on the Unified Soil Classification System (USCS) soil classification, the soil types obtained are clayey sand (SC), silty sand (SM), and poorly graded clayey sand (SP-SC). These soils are coarse-grained and susceptible to strength reduction due to increased pore water pressure during earthquake vibrations.

Based on the calculations above, the shallow bearing capacity without using bamboo pits is 9,506.07 kg/m2, while the calculation using bamboo pits yields 2,624.82 kg/m2. These results indicate that the bearing capacity of foundations without using bamboo pits is greater than that using bamboo pits. However, the settlement of the foundation using bamboo recesses was smaller, at 1,641 cm, while the settlement for the shallow foundation without bamboo recesses was 2,773 cm. This indicates that the primary function of the bamboo recesses in this assessment is not to increase the bearing capacity of the foundation, but rather to reduce deformation or settlement by increasing soil strength and redistributing the load.

The use of bamboo recesses has a positive effect on increasing the bearing capacity of shallow foundations on liquefied soil. Bamboo recesses can increase soil stability, improve soil strength, and help better distribute foundation loads, thus making the soil more stable when subjected to dynamic loads from earthquakes. The installation of bamboo recesses has been proven to reduce settlement of shallow foundations due to liquefaction. Based on the results of numerical testing using a vibrating table and 3D Plaixs analysis, the numerical analysis yielded a settlement of 1,641 cm. The soil settlement without bamboo recesses was consistently greater than that with bamboo recesses. In the vibrating table test, the maximum settlement without bamboo reached 8.5 cm, while using bamboo pits reduced to 4.7 cm. The results of the Plaxis 3D simulation also showed a settlement of 8.307 cm to 4.114 cm after using bamboo pits. Thus, bamboo pits are effective as a simple soil improvement method to reduce the impact of liquefaction on shallow foundations. However, it can be seen that under conditions of ground water level, the settlement that occurs using the numerical method compared to the Plaxis 3D method and the vibrating table, the settlement that occurs is significantly different because the vibrating table is able to simulate earthquake conditions and liquefaction directly on the ground. In contrast, the numerical calculations and Plaxis 3D still use certain assumptions so that the effect of increased pore water pressure and loss of soil strength due to liquefaction is not fully described. Therefore, the settlement values of both methods are lower than the results of the test using the vibrating table.

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