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BEARING CAPACITY OF SOIL BAGS ON SOFT GROUND REINFORCED BY BAMBOO PILE

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ABSTRACT: North Maluku is one of the archipelago provinces in Indonesia. As reported by the Ministry of Public Works, this province has more than three thousand kilometers of coastline indicated to erosion [1]. The infrastructures and residences along coastal area have been frequently attacked by big waves. To protect the coastal aforementioned from the risk of natural disaster, the local government must construct a robust coastal bank. However, the bearing capacity of the soft ground is very weak for working as a bank. The procedure of the bank construction includes: preparing the construction area, installing bamboo piles, laying geo-bamboo on the piles, placing sandbags as the mattress and constructing selected materials. To make a reasonable way for the design of foundation soil using traditional reinforcement system for a coastal bank, an empirical calculation based on the rule of geotechnics has been discussed. The field CBR method was studied by conducting the full scale of model soil bags on very soft soil reinforced bamboo pile. Finally, the bearing capacity results of foundation soil were compared to the field CBR test for several properties of very soft soil, dimensions of soil bags and bamboo piles.

Keywords: Empirical calculation, Field CBR, bearing capacity, Soil bags, Soft ground, Bamboo pile

1. INTRODUCTION

There are many residences and infrastructure attacked by big waves in lowlands, which are generally covered by a deposit of soft soil. To reduce the impacts of the natural disaster, the local government must build a robust coastal bank on soft soil. However, the criterion on the stability shall be provided to counter the loads from the coastal bank, in which erosion occurs about 3,000 km of 6,000 km of coastal lands [1].

Figure 1 portrays a notable case of coastal land in West Halmahera of North Maluku.

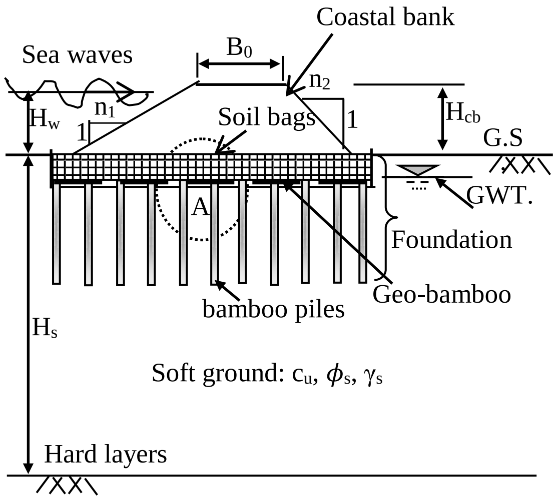
Fig.1 Visualization of erosion land in Halmahera (Photographer Suyuti, May 6th, 2017)

Indonesian local people have a traditional custom for the reinforced soft soil that is by using local materials such as bamboo or timber pile, called *Cerucuk*. The Ministry of Public Works has published a guideline on how to construct an embankment on soft soil or peat soil. The guideline however only explains the general design for road embankment [2, 3] and is mostly recommended to design an embankment by performing a trial construction on site.

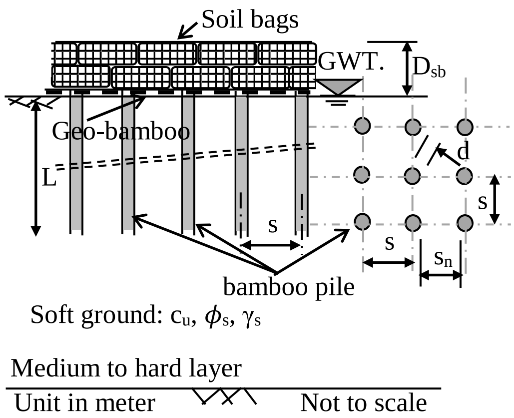
The traditional reinforcement method is frequently implemented for supporting the coastal bank. Ministry of Public Works reported the prototype construction of bank on soft soils to estimate the project cost [4]. In fact, the technical guideline for the coastal bank about the stability criterion is not presented such as for the bearing capacity of soft ground after installing pile.

Concerning on bearing capacity criteria, a certain stiffness soft ground for coastal bank is explained i.e: (i) Preparing the site of construction; (ii) Cutting soil surface for constructing mattress; (iii) Installing bamboo pile into the subsoil; (iv) Laying geo- bamboo on the bamboo piles; (v) Placing soil bags as mattress on the piles; (vi) Constructing selected soil on the mattress; and (vii) Constructing stones for revetment.

The visualization of the proposed coastal bank construction is shown in Figure 2. Where d is the diameter of bamboo; s is the spacing of piles; L is the length pile embedded in soil; D_{sb} and γ_{sb} are the thickness and unit weight of soil bags, respectively; H_{cb} and γ_{cb} are the height and unit weight coastal bank, respectively; H_w is the height of sea level; H_s is the depth of soft ground; n_1 and n_2 are the gradient slope on front and behind sides of bank, respectively; ϕ_s, γ_s, and c_u are the internal friction, the unit weight and the undrained cohesion of soil, respectively; B_0 = width of crest bank; B = width of bank ($B = B_0 + 0.5n_1H_c + 0.5 n_2H_{cb}$); n_1, and n_2 are slope gradient of front side and back side of bank, respectively.



a. Cross section of the coastal bank



b. Detail-A : Traditional reinforcement system

Fig.2 Visualization of coastal bank constructed on the soft ground using traditional reinforcement

2. PROPOSAL METHOD

2.1 The Outline of Proposal Method

To propose a calculation scheme of reinforced soft ground for the coastal bank, the previous dataset investigated in Indonesia is adopted. The outline of the proposed method is expressed in Figure 3.

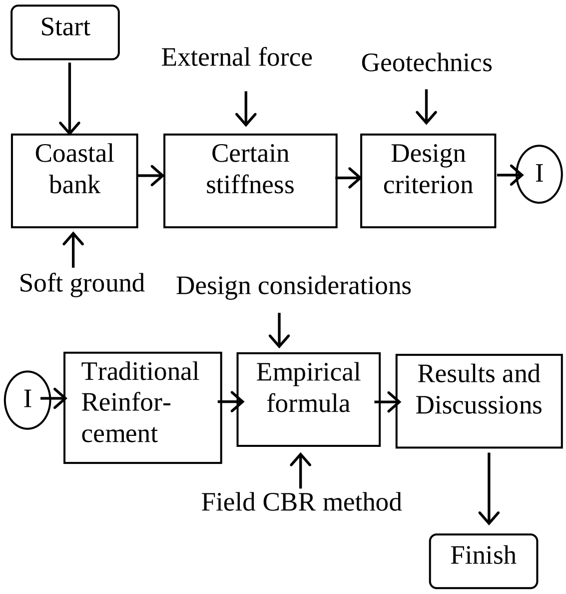


Fig.3 The flow chart of the outline proposal method

3. PROPOSED EMPIRICAL ANALYSES

To propose an empirical calculation for the coastal bank on soil bags overlying soft soil, reinforced by the bamboo pile, there are five failure scenarios for embankment design method of the foundation on very soft soil reinforced by geotextile. One of five failure scenarios is an ultimate bearing capacity model of foundation soil [5, 6]. This construction model for the coastal bank on traditional reinforcement system is shown in Figure 4.

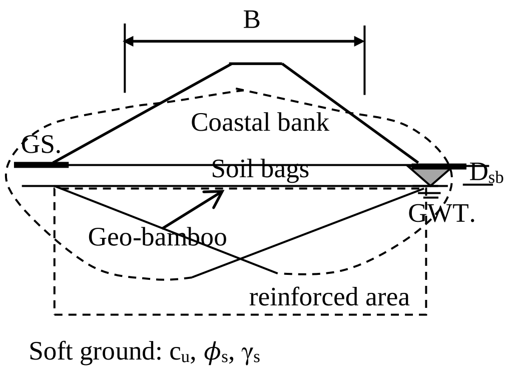


Fig.4. A bearing capacity failure model of foundation soil reinforced by a bamboo pile

3.1 Bearing Capacity of Foundation Soil

The proposed performance of ultimate bearing capacity of foundation soil is proposed by following the construction procedure such as soil-driven bamboo pile and soil bags placed under the ground surface. A simple expression of foundation soil is shown in Figure 5.

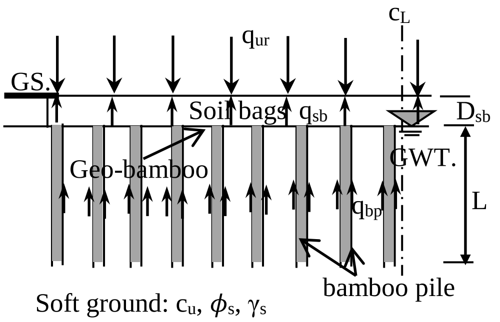


Fig.5 A simple foundation soil reinforced bamboo pile

The ultimate bearing capacity of soil bags overlying soft clay reinforced by geo-bamboo and bamboo piles q_{ur} leads to a simple formula as written by

$$q_{ur} = q_{sb} + q_{gb} + q_{bp} \quad (1)$$

where q_{sb} is bearing capacity of soil bags, q_{qb} is the tensile capacity of geo-bamboo, q_{bp} is the friction capacity of the bamboo pile in soft ground.

3.2. Bearing Capacity of Soil Bags

Figure 5 shows soil bags as a mattress with geo-bamboo placed on the ground surface. The ultimate bearing capacity of soil bags q_{sb} for width strip footing B is written by [7].

$$q_{sb} = \gamma_{sb} D_{sb} N_q + \tfrac{1}{2} B \gamma' N_\gamma \quad (2)$$

where,
γ_{sb} is the unit weight of soil bags.
D_{sb} is the depth of soil bags placed on the ground.
γ' is the effective unit weight of soil ($\gamma' = \gamma_{sat} - \gamma_w$).
γ_{sat} is the saturated unit weight of soil.
γ_w is the unit weight of water.
B is the width of strip footing.
N_q, N_c, N_γ are factors of bearing capacity of soil on its related to the function of $f(\phi_s)$.
ϕ_s is the internal friction of soil.

$$N_q = \exp(\pi \tan\phi) \tan^2(45^o + \phi/2) \quad (3a)$$

$$N_c = (N_q - 1)\cot\phi \quad (3b)$$

$$N_\gamma = 2(N_q + 1)\tan\phi \quad (3c)$$

The bearing capacity of geo-bamboo q_{gb} for large strip footing width B' is not allowed vertical deformation ($q_{gb} \approx 0$) as shown in Figure 6.

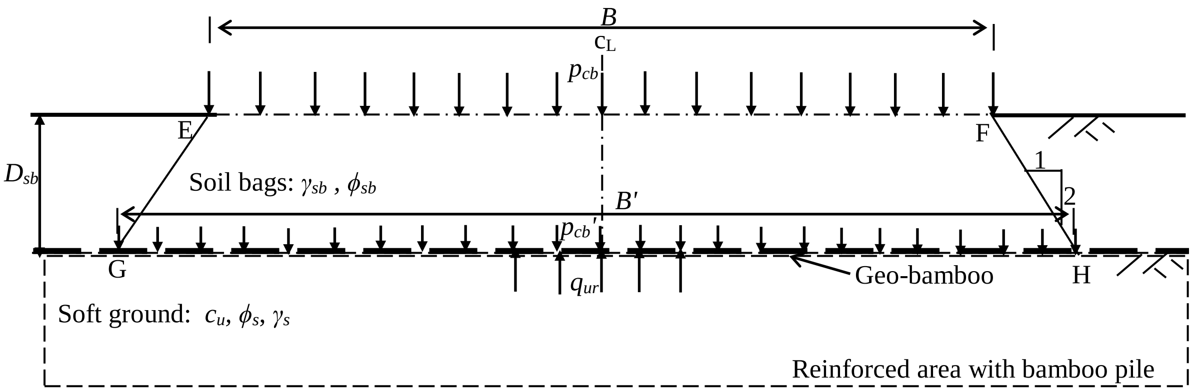


Fig.6 Expressions of soil bags overlying soft ground reinforced by geo-bamboo and bamboo piles

3.3 Bamboo Pile Capacity Driven in Soft Ground

To predict the pile capacity driven in the soft ground, the friction capacity of the pile in clay q_{bp} for the width of footing B' is [8, 9]

$$q_{bp} = \alpha_{bp} \times \left(\frac{B'}{s}\right) c_u \quad (4)$$

$$\alpha_{bp} = \left(\frac{0.5L}{d}\right)^{-0.2} \left(\frac{c_u}{p'_0}\right)^{-0,3} \quad (5)$$

The ratio of the undrained shear strength of soil c_u / p'_0 is [10].

$$c_u / p'_0 = 0.11 + 0.0037 PI(\%) \quad (6)$$

where PI is the plasticity index of soil in the site (unit in percent).
In case, the compression index of soil C_c and the initial void ratio of soil e_0 are available data. Hence, the plasticity index *PI* is defined [11].

$$PI\ (\%) = 102.3\left[\frac{C_c}{(1+e_0)}\right] + 13.34 \quad (7)$$

3.4 Compared Field CBR Data

To determine the bearing capacity of foundation soil q_{ur}, the results data of field CBR test were compared. The field CBR method was measured on the soil bags as the mattress on soft soil reinforced bamboo pile, modeled in a full scale.

Field CBR data was calculated by following the National Standard of Indonesian Agency, and it is formulated that [12].

For penetration 2.54 mm (0.1 inches), the field CBR was calculated

$$CBR = \frac{p_{measured}}{0.71\, kg/mm^2} \times 100\% \quad (8)$$

For penetration 5.08 mm (0.2 inches), the field CBR was calculated

$$CBR = \frac{p_{measured}}{1.06\, kg/mm^2} \times 100\% \quad (9)$$

where $_{measured}$ was taken from the loading pressure data of field CBR tests.

The procedure of this method is explained as follows:
1. Full-scale test method modeled include: (i) Constructing a masonry tank underground contained with dimension in width X_0 of 2.10 m, length Y_0 of 1.25 m, and depth H_0 of 2.05 m, it is located at Tabona Village of Ternate; (ii) Filling down very soft soil material as subgrade, taken from quarry out site of Gambesi beach, South Ternate; (iii) Installing the pile of bamboo into the subgrade by dimensions of length L of 100 cm, diameter d of 8.07 cm, and spacing s of 3d; (iv) Laying geo-bamboo on top of bamboo pile; (v) Placing soils bags as mattress on the geo-bamboo, which was stabilized soil with cement 5%; and (vi) Construction model of field CBR test method is expressed in Figure 7.

2. Field CBR test method with full scale investigated.
The schematic of the construction of field CBR test 2. Field CBR test method with full scale investigated.
The schematic of the construction of field CBR test method is shown in Figure 8. The set up procedure of field CBR test method worked under frame of still construction on the soil tank such as (i) The frame Profile supported the vertical powered by force of CBR test; (ii) Field CBR test measured based on penetration time; (iii) Field CBR observed during 2 days (2-3 June 2018) as shown in Figure 10; (iv) Field CBR test data followed the Indonesian guideline [12]; (v) Soft ground properties of contained subgrade in the soil tank as listed in Table 1.

a. Bamboo pile installed in very soft soils

b.Geo-bamboo laid on bamboo piles

c. Soil bags placed on the bamboo pile

Fig.7. Modeled full-scale test of field CBR on the soil bags supported bamboo pile

Field CBR test results (CBR, %) may be

compared to the ultimate bearing capacity of soft soil with piles q_{ur} in equations as [13]

$$q_{ur}(kPa) = N \times (CBR - 1.5) \quad (10)$$

Where N is the coefficient of multiply number.

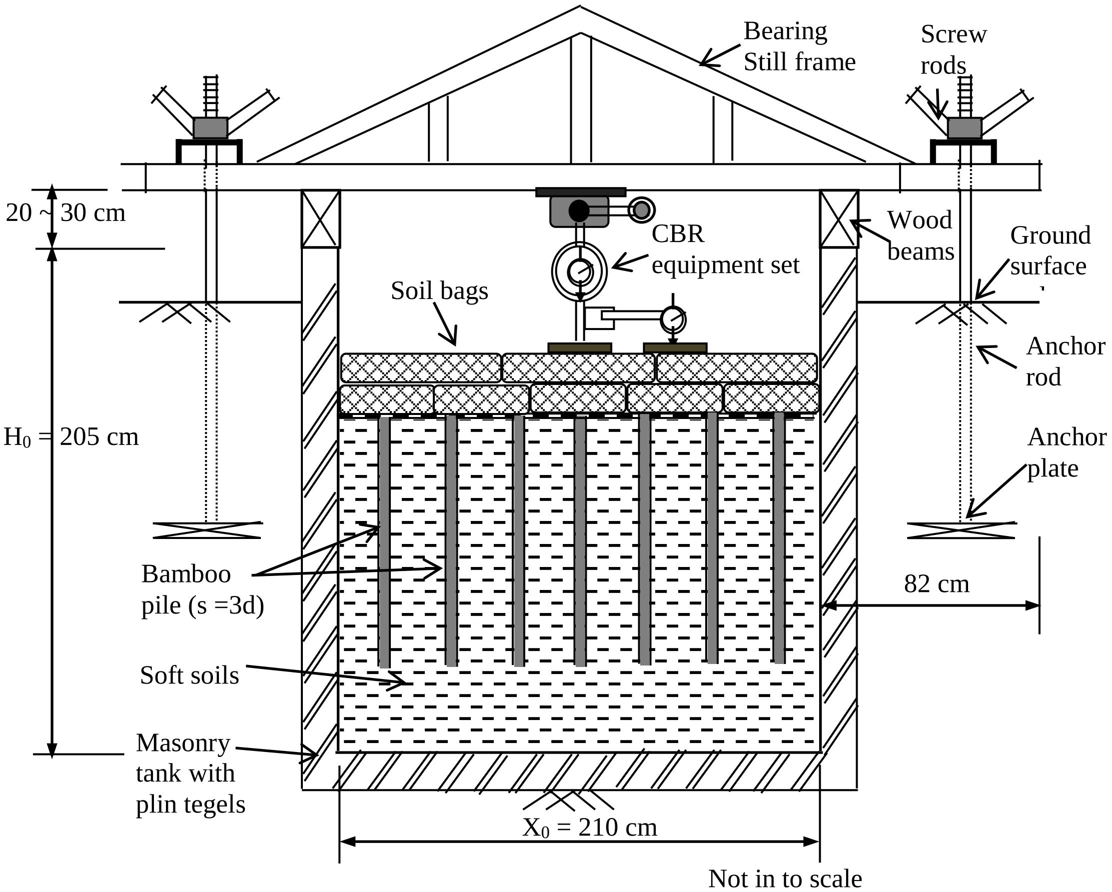


Fig.8. Schematics of field CBR test method for soil bags supported bamboo pile in a very soft soil tank

3.5 Loading Pressure Distribution

Static load pressure distribution PCB' with wide strip footing B' from the coastal bank at the ground surface may be proposed [14]

$$p_{cb}' = p_{cb}\left(\frac{B}{B'}\right) + D_{sb}\gamma_{sb} \quad (11)$$

The load distribution pcb' is required by

$$p_c' \leq q_{ar} \quad (12)$$

The allowable bearing capacity of soil bags $q_{ar'}$ is

$$q_{ar} = \frac{q_{ur}}{Fs} \quad (13)$$

where p_{cb} is the loading pressure of the coastal bank ($p_{cb} = H_{cb} \times \gamma_{cb}$); Fs is the factor of safety [7].

4. RESULTS AND DISCUSSIONS

To apply the proposal of the empirical calculation method for determining the ultimate bearing capacity of soil bags on the soft ground, reinforced by the bamboo pile, it was modeled in the field as shown in Figures of 7, 8 and 9. The soil samples of soft soils were investigated at the Laboratory of Soil Mechanics of Khairun University. It then resulted in the index soil properties as listed in Table 1.

Table 1. Used properties of very soft soil data for observing field CBR method

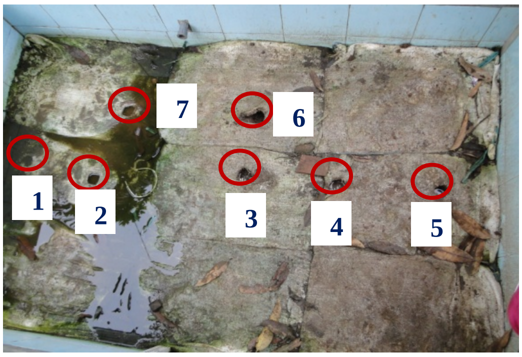
Soil properties	Result
Water content, i_n (%)	102.6
Plasticity Index, PI (%)	7
Unit weight of soil, γ_s (kN/m^3)	14.3
Cohesion, c_u (kPa)	5.0
Internal friction, ϕ_s (^{o})	9.5

Specific weight, G_s (-)	2.08

The soil bags were placed on the bamboo pile installed into the very soft soil with the square pattern as explained above. Therefore, field CBR tests were employed to measure the penetration piston on the mattress as shown in Figure 9.

a. Photo of the still frame as bearing for field CBR

b. Documentation of field CBR test at point-3



c. Lay out of observation of field CBR test for 7 points

Fig.9. Schematic points of observation for field CBR test method in full scale

Figure 9 shows the preparation and observation for the working field CBR test with 7 points. In these points were recorded the penetration of piston for each time reading (in minutes) as in guideline of its field CBR such as 25, 50, 75, 100, 125, 150, 175, 200, 225, 275 and 300.

The observation results of field CBR test of 7 points were obtained. The empirical calculation results were employed to determine the ultimate bearing capacity by using a number of design parameters such as the width of crest bank B_0 of 2.0 m, 4.0 m, 6.0 m, 8.0 m, and 10.0 m; height of coastal bank H_c of 3.0 m; gradients of slope n_1 of 2.0, n_2 of 1.5; soil bags observed by the unit weight γ_{sb} of 20.5 kN/m^3 and thickness D_{sb} of 0.22 m. It was presented by comparing the results of field CBR test method as shown in Figure 10.

The penetration result of 7 points was carried out by observing the loading penetration pressure of both points. The results of the measured field CBR test are summarized in Table 2.

Table 2. Observed field CBR test results

Point of test	Results		Remark
	Pressure (kg/mm^2)	CBR (%)	
1	0.037	5.21	0.1 inch
2	0.055	7.75	0.1 inch
3	0.029	4.62	0.1 inch
	0.054		0.2 inch
4	0.030	4.96	0.1 inch
	0.062		0.2 inch
5	0.027	3.41	0.1 inch
	0.032		0.2 inch
6	0.025	4.05	0.1 inch
	0.049		0.2 inch
7	0.024	4.04	0.1 inch
	0.049		0.2 inch
Average of CBR = 4.86 %			

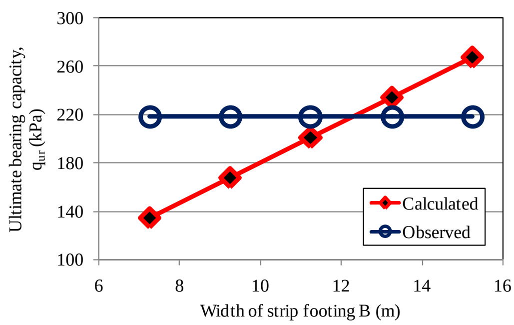


Fig.10. The comparison results between the field CBR tests and the empirical calculation results

Figure 10 shows that the design parameters of crest bank width B_0 of 6.0 m, height of coastal bank H_c of 3.0m; gradients of slope n_1 of 2.0, n_2 of 1.5 were found q_{ur} of 201 kPa, fitted to the average value of field CBR test of 4.86% with N of 65 (where q_{ur} of 218.6 kPa, eq.10) [1].

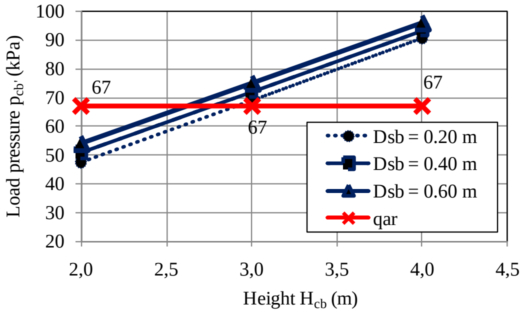
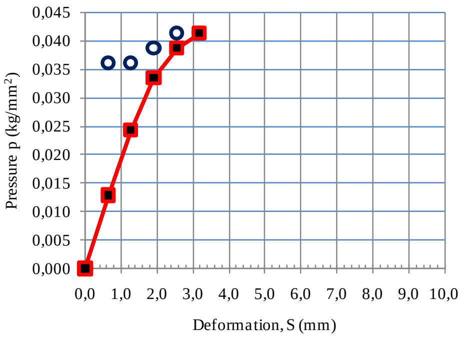
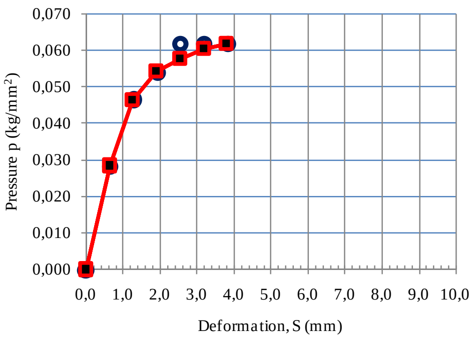


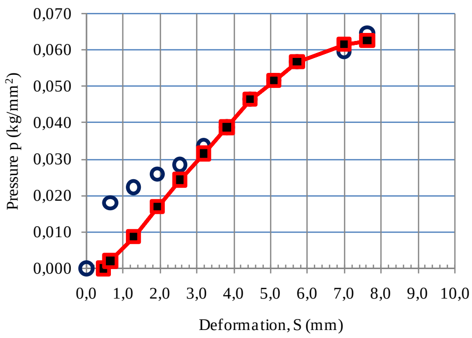
Fig.11. Correlation $p_{cb'}$ versus capacity q_{ar}



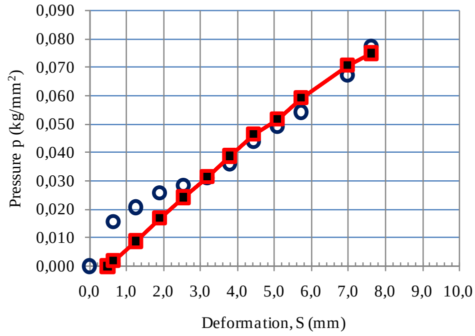
a. Observed field CBR of point-1



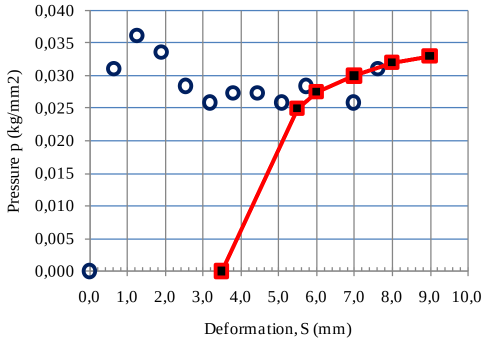
b. Observed field CBR of point-2



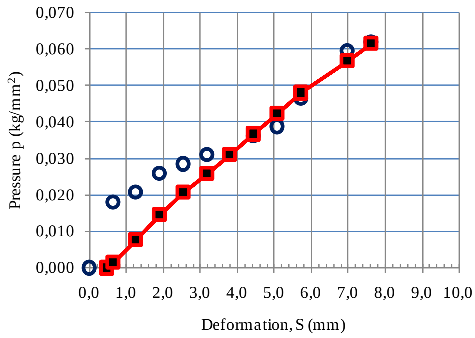
c. Observed field CBR of point-3



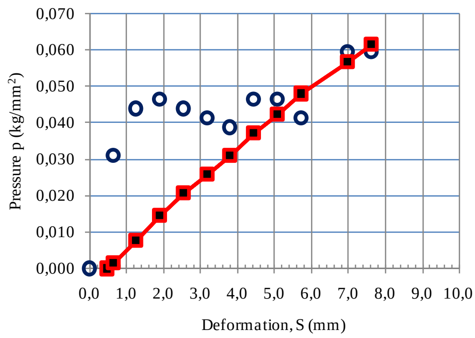
d. Observed field CBR of point-4



e. Observed field CBR of point-5



f. Observed field CBR of point-6



g. Observed field CBR of point-7

Fig.12. Plotting data and calculation values of field CBR

Figure 11 shows that for the design parameters of crest bank width B of 11.25 m, height of coastal bank H_c varied H_c of 2.0 m, 3.0 m, 4.0 m, and the thickness of soil bags D_{sb} was also varied D_{sb} of 0.2 m, 0.4 m, 0.6 m as well as applied Fs of 3.0.

Figure 12 shows the observation results of penetration in full – scale tests.

5. CONCLUSIONS

There are significantly increasing the bearing capacity of very soft soil as subgrade. The average value of field CBR tests for soil bags stabilized cement on very soft soil reinforced by bamboo pile were obtained CBR of 4.86%, it is quite close to the minimum standard of CBR for subgrade as required in Indonesian guideline.

The predicted calculation results of the allowable bearing capacity of soil bags stabilized cement on very soft soil reinforced by bamboo pile as proposed in full-scale. It is appropriated to the field CBR tests data for coastal banks, which loaded by acting pressure of its self-weight with the height H_{cb} less than 2.50 m and the depth of soil bags D_{sb} of 0.40 m ~ 0.60 m.

6. ACKNOWLEDGMENTS

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