

Proposed Empirical Calculation to Predict Bearing Capacity of Embankment on Reinforced Wooden Stems as Mattress Overlying Soft Soil

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Abstract—Indonesia is an archipelago country that there are about thirty per cent lowlands covered by deposit soft soils or peat soil. Local government has been built road infrastructure, but the soft soil layer has a problem for soil stiffness. Ministry of Public Works has published a guideline for road construction on soft soil of peat soil, which reinforced timber pile. A number of Indonesian researchers have been reported that mattress reinforced timber or bamboo, it can be reduced and distributed loads from the embankment. Those investigation results were performed by trial construction method and laboratory tests on a small scale. Unfortunately, these guidelines and result studies were to work trial construction method for design, and also must be conducted monitored data to the software package to simulate the criteria of design for embankments. In the application of this design, a method is still difficult to handle by Indonesian local. In order to propose an empirical calculation method based on the rule of geotechnics, the application of traditional reinforcement system for foundation soil is placing a certain layer of wooden stems as a mattress on the ground surface. In this proposal, calculations were provided design criterion, which purposed to reinforce and give up floating force and as well as a distribution of loads from an embankment. Therefore, this study was employed the empirical calculations method by applying index soil properties on different site for design. Finally, these calculation results were presented on graphs of correlation between the bearing capacity of foundation soil and the loading pressure distribution. These graphs may guide Indonesian local to design and handle embankment construction on soft ground.

Keywords—empirical calculation; bearing capacity; embankment; wooden stems; mattress; soft soil

I. INTRODUCTION

Indonesia country consisted of thousand islands, there are about thirty percents of the ground covered by deposit soft soil or peat soil. In which, the largest area can be found in the Eastern part of Sumatra, Northern part of Java, Southern part of Kalimantan. In fact, these soft soil layers can be found down depth 30 metres, which characterized by soil index properties of cohesion c_u is less than c_u of 25 kPa. This situation is categorised as a natural problem in Indonesia. A notable example marked ten years ago as a

natural problem of subgrade located in East Halmahera is shown in Figure 1.



Fig. 1. The natural situation of the subgrade in East Halmahera, North Maluku (Photographer Muhajir, Taken on June 30, 2008)

Figure 1 shows that the natural problem of subgrade of track roads in Halmahera island, an example case in East Halmahera. The subgrade gives a low performance of stability for road constructions, it is due to weak stiffness subgrade, which related to the index soil parameters such soil cohesion c_u , internal friction ϕ_s , and bulk density γ_s .

In order to avoid the problem aforementioned, the Ministry of Public Works published guideline how to construct an embankment for a road on soft soil or peat soil. Expecting the road construction using wooden or bamboo stems. These local materials are very popular in Indonesian, it is called *Cerucuk* [1].

The use of *Cerucuk* pile is installed to increase the stiffness of soft ground as subgrade. There are two majors of traditional reinforcement system such as 1) *Cerucuk* pile such wooden stem placed on the soft ground as a mattress, and 2) Wooden pile installed into soft ground as reinforcement. In a practical implementation, the mattress is often constructed by several thicks of the ground surface. However, this construction method recommended designing embankment based on trial data in full - scale, which recorded on vertical deformation to simulate the design

criteria such as stability and deformation using commercial FEM [2].

The application of design that the index of soil properties gives different values, it is regarding the deposit of soil in site. So the design technique cannot be handled by engineer local. This technical design of the traditional reinforcement for embankments on soft ground is still difficult to apply by Indonesian locally.

In order to solve that problem, Indonesian local people are expected to know how to design stability of embankment on mattress overlying soft ground using traditional reinforcement, which involved by local materials such as timber or bamboo. The traditional reinforcement for reinforced soft ground based on a reasonable rule of geotechnics. From these design results, the engineer can be provided with the documents of design construction for a road project in the local government. Therefore, the proposal empirical calculation for determining the stability criterion of an embankment on mattresses such as gravel and local materials for roads that reinforced soft soils using timber as presented below.

II. PROPOSAL METHOD

A. Guideline for Road Embankment on Soft Ground

The construction procedure for constructing an embankment on soft soil or peat soil is sown the traditional reinforcement method [2]. However, the guideline has only explained the procedure of construction without discussed how to design criterions for embankments.

A mattress reinforcement system is often used for soil embankment on soft ground. The road construction on embankment using several reinforcement methods are reported by the Ministry of Public Works [3]. A notable construction method using the mattress as reinforced soft ground its followed the Indonesian guideline before that mattress material of mattress consisted of granular material and timber or bamboo pile. The purpose is to distribute the load's pressure from the embankment and also to avoid embankment fall down into soft ground. Therefore, the geo-synthetic laid on the mattress to reinforce embankment. Meanwhile, the mattress construction purposed also platform for working soils in a site of the project.

The material of mattress may use from local quarry such as soft soil cut and fill, its material should be treated by cement conducting wet mixing in the field. The construction process has followed the guideline above, such as installed timber pile before separate the soil-cement material and compaction reported by the Ministry of Public Works [4]. The reliability performance of road embankment investigated by working trial construction in the field. From the trial data records, the design criterions could be simulated by employing software package. They were reported that embankment on mattress underlying soft soil in depth 7.0 ~ 8.0 m, cohesion c_u of 10 ~ 25 kPa that reinforced timber pile such as diameter d of 10 cm, spacing

s of 60 cm, length L of 4.0 m. In which, the mattress used soft soil from local quarry its stabilized cement for embankment with a height of 3.0 m that resulted in the reduction of vertical deformation to the normal condition is about 29%.

B. The embankment on Mattress Bamboo

Masyhur and Sugent [5] reported that the performance of embankment on soft soil which reinforced by the bamboo mattress and supported bamboo cluster. In which, this idea of reinforcement method is modified from an experiment in a field that the tensile strength of geo-synthetic was the limited tensile capacity to rest the loads from the embankment. This construction method was used for breakwater embankment in Muara Angke Port fish in Jakarta, which also the method is to reinforce soft soil on cohesion very soft down depth 9 m ~ 14 m. The height of construction was measured H of 6.6 m and H of 3.6 m from the seabed, and water low level of respect. The reinforcement system method applied bamboo cluster 6.0 m driven in the soft ground, spacing 1 m and the bamboo mattress placed on the ground surface by five layers.

C. Load Pressure from Embankment

Static loading pressure from embankment should be distributed throughout the bamboo mattress layers on the ground surface. The intensity of load pressure spreading from loads is influenced by modulus elasticity of mattress material. In fact, the effect of mattress construction increases the stability value and to reduce the settlement of embankment.

D. Ultimate Bearing Capacity of Mattress

The ultimate bearing capacity is applied such a large strip footing theory for mattress over soft soil, it was implicitly reported by Taylor [6]. The ultimate bearing capacity can be estimated by approaching general shear failure, but it's depending on index soil properties of the subsoil.

E. Factor of Safety

A fundamental theory that stability design of embankment is performed by the factor of safety F_s , in which the embankment on soft soil with timber pile mattress can be predicted by using empirical calculation method. One scenario failure of an embankment on soft soil reinforced geo-synthetic was defined the bearing capacity of overall it's embankment. The factor of safety is defined by the ratio of allowable bearing capacity to loading pressure of soft ground as subgrade which loaded pressure from an embankment. This design will lead to a balance between cost and safety of construction [7].

Using the factor of safety F_s , the design of embankment is to estimate the allowable height of embankment. A fundamental theory of those parts is provided by an empirical calculation method based on the rule of geotechnics.

In order to present a proposed method by using an empirical calculation method for design stability, the authors present a flowchart of the research method is shown in Figure 2.

F. Design Considerations

Design stability criterion of embankment on soft ground reinforced mattress timber is predicted by using design considerations, such as (i) Assumed that subgrade on homogeneous layer; (ii) Loads from embankment are equally distributed on the ground surface; (iii) The bearing capacity of subgrade is equally provided of its soil self beneath mattress; (iv) Mattress wooden placed beneath the ground surface; (v) Set up that groundwater table (GWT) is level to the ground surface; (vi) The bearing capacity as used large strip footing; (vii) Consider unit weight of wooden stem with soil stabilized cement; (viii) Consider the load of vehicle on mattress wooden.

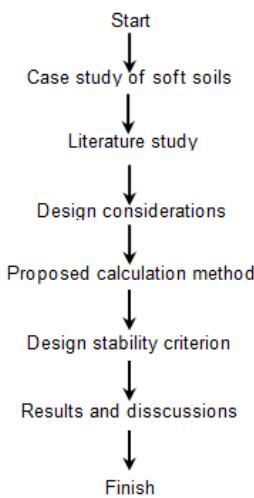


Fig. 2. Flowchart of research method

G. Construction of embankment on the mattress

The mattress wooden constructed on the ground beneath the level of the surface, it is planned by respecting the size and number of the diameter of timber, see Figure 3. For mattress with width 4.0 m, its layer-1 of mattress must be constructed on perpendicular direction to the road. While gaps on both timbers that placed on the ground are covered by soil stabilized cement. Therefore, layer-2 of the mattress is equally constructed on parallel to the road direction parallel.

- Cutting soil for mattress
- Layering wooden stems on the ground
- Construct embankment

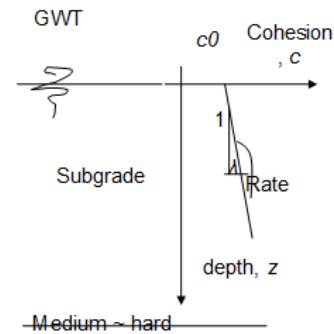


Fig. 3. Cross section of an embankment on mattress timber stems (Suyuti, 2017)

III. PROPOSED EMPIRICAL CALCULATIONS

In order to propose calculation method with empirical equations for determining the stability criterion of an embankment on soft ground reinforced by mattress timber were used flowchart of research as in figure 2. The empirical equation of calculations is used as provided as below.

A. Load Distribution of Embankment

Load from embankment are uniformly distributed as shown in figure 4.

- Load pressure distribution
- the rate of soil cohesion beneath the mattress

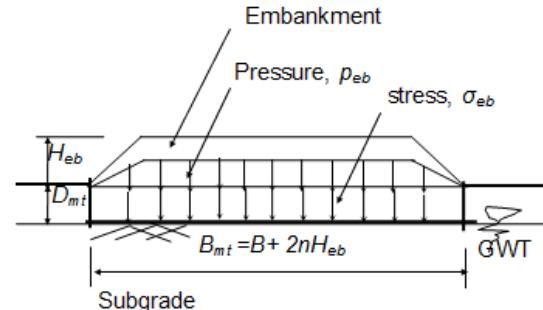


Fig. 4. Load pressure distribution on mattress overlying soft soil with the cohesion of soil increase with depth

Figure 4 shows that total load pressure p_i on the ground surface may predict,

$$p_i = p_{eb} + p_{vi} \quad (1)$$

P_{eb} is the loading pressure from the embankment

$$p_{eb} = \gamma_{eb} \times H_{eb} \quad (2)$$

H_o is the initial on the allowable height of embankment on the soft ground, it is approached by assuming that embankment constructed on the soft soil without mattress [7],

$$H_0 = \frac{q_{ul}}{\gamma_{eb} \times F_{S_0}} \quad (3)$$

q_{ul} is the ultimate bearing capacity of soft soil that is using large footing as constructed for embankments [8].

$$q_{ul} = c_0 N_c + q N_q + \frac{1}{2} B_{mt} \gamma'_{fnd} N_\gamma \quad (4)$$

Where q is the surcharge load of cutting soil.

c_0 is the cohesion of soil at the beneath the mattress.

γ'_{fnd} is the effective unit weight of soil ground ($\gamma'_{fnd} = \gamma_{sat} - \gamma_w$).

γ_{sat} is the unit weight on saturated of soil.

γ_w is the unit weight of water.

B_{mt} is the width of mattress wooden ($B > 4.0\text{m}$).

n is the gradient of the slope of the embankment.

N_q, N_c, N_γ are factors of soil ground respecting the internal friction ϕ , it is written by $f(\phi)$.

$$N_q = \exp(\pi \tan \phi) \times \tan^2 \left(45^\circ + \frac{\phi}{2} \right) \quad (5a)$$

$$N_c = (N_q - 1) \cot \phi \quad (5b)$$

$$N_\gamma = 2(N_q + 1) \tan \phi \quad (5c)$$

c_0 is the cohesion of soil at the beneath mattress, it is defined by [9]

$$c_0 = \frac{q_c}{30} \quad (6)$$

Where q_c is the conus resistance of CPT in a field test.

F_{S_0} is the factor of safety as required for sliding failure method [4].

B. Bearing Capacity of Mattress Wooden

q_{fnd} is the total ultimate bearing capacity of mattress wooden overlying soft soil as foundation soil for embankments [10,11]

$$q_{fnd} = \left\{ F_0 \left(q_{ul} + \frac{\rho B_{mt}}{4} \right) + q_{mt} \right\} \left(\frac{B'}{B_{mt}} \right) \quad (7)$$

F_0 is the correction factor depending on the roughness of footing and ratio $\rho B_{mt}/c_0$.

ρ is the rate of increase of the foundation strength with depth [10].

$$\rho = \lambda \gamma'_{fnd} \quad (8)$$

λ is the undrained shear strength ratio [12].

$$\lambda = 0.11 + 0.0037 PI \quad (9)$$

PI is the plasticity index of soil (%).

q_{mt} is the ultimate capacity of mattress wooden

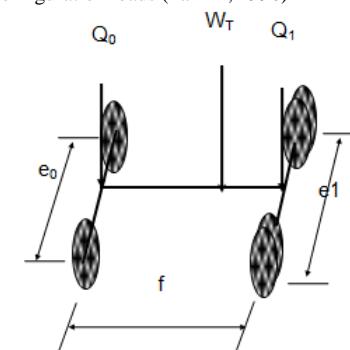
$$q_{mt} = \gamma_{mt} \times D_{mt} N_q \quad (10)$$

Where D_{mt} is the thickness of mattress timber, γ_{mt} is the unit weight of mattress wooden.

C. Statis Pressure Caused by Vehicle

Static loading pressure from vehicle truck contacted on unpaved reported by Fannin [13]. The static loading pressure from vehicle truck worked on the surface of selected soil on the mattress wooden is proposed. The configuration of loading vehicle is shown in Figure 5.

a. Configuration loads (Fannin, 1996)



b. Contact pressure areas

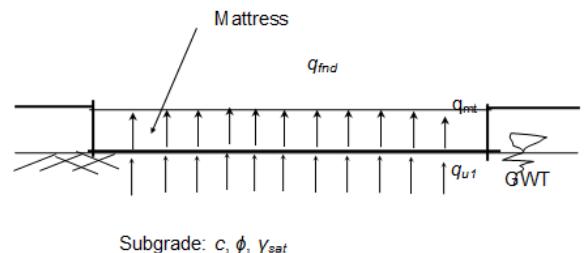
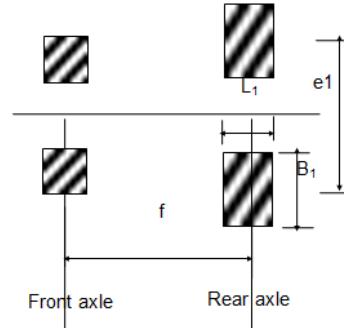


Fig. 5. Geometry of vehicle axle of truck defined on the mattress

Contact area A_c on rear axle loads Q_1 for two wheels are considered by proposing empirical formula [9],

$$A_{cl} = \frac{Q_1}{2p_c} = \frac{0.66W_t}{2p_c} \quad (11)$$

Where p_c is the tire inflation pressure (kPa), W_t is the total weight of the truck.

The empirical equation for contact area equivalent A_{cl} reported by Mulungye [14]. The parameter of contact area equivalent L defined by

$$L = \sqrt{\frac{A_{cl}}{0.522}} \quad (12)$$

In which, the width and length of the contact area for front and rear axles are predicted, respectively.

For width on contact area B_1

$$B_1 = 0.6 L \quad (13)$$

For length on contact area L_1

$$L_1 = 0.87L \quad (14)$$

D. Factor of Safety

The stability criterion of an embankment on the mattress wooden stems considered against the bearing capacity failure model. The factor of safety F_s overlying soft soil may be defined on ratio of the ultimate bearing capacity q_{fnd} of its mattress to static loading pressure due to vehicle truck p_{vt} . It is defined by

$$F_s = \frac{q_{fnd}}{p_{vt}} \quad (15)$$

E. Static Loading Pressure Due to Dual Wheels

The static loading due to dual wheels at the rear axle is considered to evaluate the factor of safety of the mattress wooden. The expression of mechanical performance is shown in Figure 6.

The static loading pressure p_{vt} due to dual wheels of vehicle truck is proposed by

$$p_{vt} = \frac{Q_1}{B' \times L'} \quad (16a)$$

$$B' = e_1 + (B_1 + 2H_{eb} \tan \alpha) \quad (16b)$$

$$L' = L_1 + 2H_{eb} \tan \alpha \quad (16c)$$

Where α is the angle of load spreading within the selected soil; B' , L' is the width and length spreading at the ground surface, respectively [15].

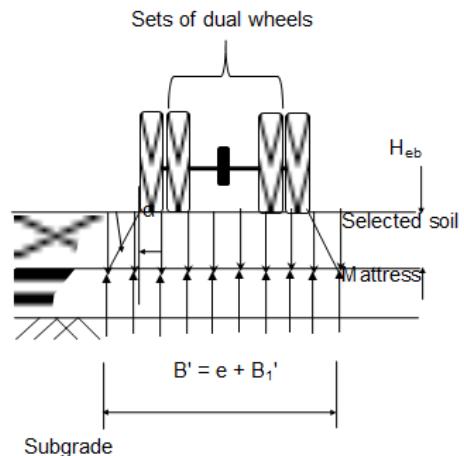


Fig. 6. Schematics of mechanical geotechnics of supporting selected soil (embankment) on mattress wooden stems

IV. RESULTS AND DISCUSSIONS

Design parameters were applied such as soft soils (subgrade) with cohesion c_0 of 10 kPa, internal friction ϕ of 3 degs, unit weight of saturated soil γ_{sat} of 15 kN/m³ ($\gamma' = 5.19$ kN/m³). The mattress wooden constructed diameter d of 12 cm with 3, 5 and 7 layers, width B_{mt} of 5.50 meters. The embankment used ini 21 k γ_{eb} of 21 kN/m³ and slope n of 2. The factor of safety applied F_{s0} of 1.5 [3].

The bearing capacity factors resulted in N_c of 5.86 and N_q of 1.18, N_y of 0.24. The height of embankment on soft soil is listed table 1.

TABLE I. PREDICTED HEIGHT OF EMBANKMENTS

Mattress D _{mt} (m)	Capacity q _{ul} (kPa)	Height H ₀ (m)
0.36	69.08	2.19
0.60	73.79	2.34
0.84	78.49	2.49

The total load pressure from the vehicle truck and embankment are determined by using parameters as shown in table 2. Design parameters such as tire inflation pressure p_c of 620 kPa and some loads on the rear axle varied Q_1 of 52.8 kN (80 kN), 36.3 kN (55 kN) and 19.8 kN (30 kN). The load pressures p_t are shown in Figure 7 [13].

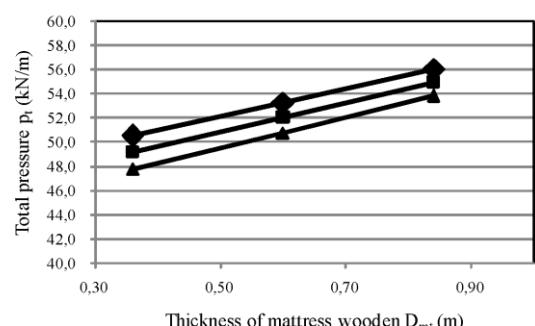


Fig. 7. Graph correlation between a mattress and load pressure

Figure 7 shows that the total load pressure on mattress increased in proportional to thickness of mattress for index properties of soft soils.

Using design parameters for design stability such as plasticity index PI, the bulk density of wooden γ_{mt} of 1.1 kN/m³. It is obtained F_0 of 1.11, 1.13, 1.15 for PI of 7%, 27% and 40% respectively. The design criterion which required a factor of safety against the ultimate bearing capacity of a mattress as foundation soil for embankments is shown in Figure 8.

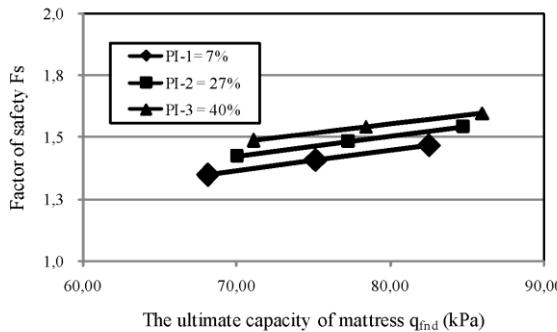


Fig. 8. Graph correlation between an ultimate capacity of mattress q_{fnd} and factor of safety F_s Fig.8.

V. CONCLUSIONS

The simulation results using empirical calculations that varied the thickness of mattress D_{mt} , a width of road embankment B_{mt} , plasticity index PI and a total weight of vehicle truck W_T . The design criterion of a factor of safety F_s for mattress wooden is sufficient with F_s more 1.50 for the thickness of mattress 0.60 m ~ 0.84 m and W_T of 30 kN ~ 55 kN.

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