

Behavior of Foundation Subgrade at Maleo PLTG Tanks Based on CPT Data

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Abstract. The stability of a structure is not only determined by the upper structure which directly bears the burden on the structure, but the stability of the lower structure in this case the foundation and capability of the subgrade support all loads to be very important. Good and accurate soil investigations are needed to calculate soil stability. Adequate soil investigations will not cause the estimated carrying capacity to be too low or high of foundation capacity. Design becomes uneconomical and recommendations given cannot be accepted in the worst conditions and even failures. Recently, one PLTG in Gorontalo was built with one operational support facility in the form of an oil tank. Investigation of soil in the oil tank area shows that the dense layer is at a depth of 2.5 meters below the ground level, and a solid layer is at a depth of 16 meters. This study aims to evaluate the behavior of soils on carrying capacity and permissible decreases of 100 mm. The analysis uses the finite-element method by the help of Plaxis. The analogy approach is done by modeling the structure, foundation and soil coating load based on foundation conditions and CPT data. The results of the analysis show that the carrying capacity of rolling and sliding is quite safe. Decrease in foundation subgrade meets the specified criteria so that the foundation soil is stable enough to support static and dynamic loads.

Keywords: Soil Investigation, Foundation, Numerical Analysis, Stability, Settlement.

1. Introduction

Each construction project has problems in planning, as well as construction of foundation on oil tanks. One of the problems faced in the design of oil tank construction is the lack of uniformity in your technical guide lines for the design and design patterns that have been set. Oil tank foundation construction will be more reliable if planning analysis is carried out especially the behavior of sub grade under the foundation.

To use the tank safely and effectively for a long time, we must avoid uneven decreases. Tank pressure is concentrated in the bottom of the tank, especially the first and second layers. To overcome the failure of this part, we have to pay more expensive, so we need inspection and security analysis work [1]. Kumaretal., 2015 said that numerical modeling of pile foundations efficiently static and seismic loading condition sand can be used not only for the validation of statically designed models but also be used to obtain responses from foundation systems in various seismic loading conditions [2].

The purpose of this study was to determine the stability of the foundation based on the carrying capacity of the subgrade, rolling force, shear force and foundation reduction using numerical modeling of static and dynamic loads. This research is expected to provide an overview of the stability analysis of tank foundations based on sondir sound test results (Dutch Cone Penetrometer) for it.

2. Literature Review

a. Loads

The calculated plan load is

- Tank loads (LL and DL), namely live loads, wall plate loads, bases, roofs, main pillars, roof truss, nozzles, stairs and hand rails [3].
- Operation loads (OL) namely oil load after filling the tank.
- Windload (WL) which is the load due to wind pressure based on local wind speed[3].

$$W_L = C_e \cdot C_g \cdot q_s \cdot I_w$$

Where C_e is combined height, exposure and gust factor coefficient as given in Table 16-G (Eksposur C) [3], C_g is pressure coefficient for the structure or portion of structure under construction as given in Table 16-H [3], Q_s is wind stagnation pressure at standard height of 10000 mm as forth in Table 16-F [3], I_w is importance factor as set forth in Table 16-K [3].

- Earthquake load (V) which is the maximum earthquake load [3].

$$V = \frac{2,5 \cdot C_a \cdot I}{R} W$$

Where C_a is seismic coefficient, as set forth in Table 16-Q, I is importance factor given in Table 16-K, R is numerical coefficient representative of the inherent over strength and global ductility capacity of lateral force-resisting systems, as set forth in Table 16-N or 16-P, W is the total seismic dead load defined in Section 1630.1.1.

b. Bearing capacity of soil

Soil carrying capacity is the ability of the soil to with stand building pressure or load safely without causing she are share collap seand excessive reduction. The value of carrying capacity of as oil is based on the characteristics of the subgrade. In this study, shear strength parameters were determined based on the correlation of the CPT test results. Soil consistency can be determined based on the relationship between tip resistance and sticking ratio according to figure 1 (Schmertmann, 1978). Estimate value of the frictionangle in the soil based on the consistency of the soil and the end value q_c according to the following table.

Table 1. Estimated value of ϕ based on soil consistency and value of q_c [4].

Description	Relative density, $D_r(\%)$	Cone resistance, q_c (MPa)	ϕ°	Unit weight range (kPa)	
				Dry	Saturated
Very Loose	$D_r < 15$	$< 2,5$	< 30	14	17
Loose	$D_r = 15 - 35$	$2,5 - 5,0$	$30 - 35$	15	18
Med dense	$D_r = 35 - 65$	$5,0 - 10,0$	$35 - 40$	17	20
Dense	$D_r = 65 - 85$	$10,0 - 20,0$	$40 - 45$	19	21
Very dense	$D_r > 85$	$> 20,0$	> 45	21	22

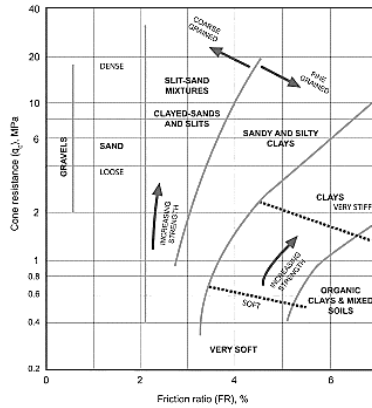


Figure 1. CPT properties, and strength changes for mechanical cones (Schertmann, 1978) [4]

Table 2. Estimated of Young Modulus on type of materials (Gordon, 1978) [4].

Classification	Materials	Young Modulus, E (MPa)
constructions	Rubber	7
	Concrete	20.000
Soils	Soft clays	5
	Stiff clays, loose sands	20
	Dense sands	50
Rocks	Extremely weathered, soft	50
	Distinctly weathered, Soft	200
	Slightly weathered, fresh, hard	50.000

In general, the analysis of the carrying capacity of the land is determined from the ultimate carrying capacity divided by security factors that are appropriate and carried out by an empirical approach to facilitate calculations. The shallow foundation is determined from $D_f \leq B$, where D_f is the depth of foundation, and B are the width or diameter of the foundation [5]. According to Schertmann (1978) the equality of carrying capacity of land permit at the base of the foundation is:

$$q_{all} = \frac{(5 + 0,34q_c)}{SF} \dots\dots\dots(1)$$

$$q_{all} \geq q_R, q_S \dots\dots\dots(2)$$

$$q_R = N_R / A_F + M_O / m_F \dots\dots\dots(3)$$

$$q_S = N_S / A_S \dots\dots\dots(4)$$

where q_{all} is allow able of bearing capacity (kg/cm^2), q_c is cone resistance (kg/cm^2), q_R is maximum soil pressure below ring (kg/cm^2), N_R is vertical load at below ring (kg), A_F is Area of ring foundation (cm^2), M_o is moment due to wind and seismic load ($kg.cm$), m_F is section modulus of ring foundation (cm^3), q_S is maximum soil pressure below soil (kg/cm^2), N_s is vertical load at below soil (kg), A_s is area of soil (cm^2).

According to Reese and O' Neill, 1989 suggested the selection of safety factors (SF) for foundation design taking into account the contro lfactors of work implementation. The range of SF that are often used is around 2-4, and most are used 3.

c. Moment Stability

Pressure oneach side causes the building to tend to rotate on the foot building (M_R), while the vertical pressure on the building and ground pressure, on the other hand, reduces the moment (M_o).The safe factor for rolling (F_o) is 1.5 [3] definedas follows:

$$F_o = \frac{M_R}{M_o} \geq 1,5 \dots\dots\dots(4)$$

Where:

F_o is safe factor for over turning, M_R is moment of resistance against over turning (kN.m), M_o is the moment that caused the over turning (kN.m), 1,5 is safety factor for granular subgrade

d. Shear Stability

The forces that shift the construction will be held back by the weight of the construction and the friction between the soil and the foundation of the foundation. As are factor against. Bowles' minimum foundation base shift,1997 suggested 1.5 [7]. SF for shifting is defined as follows.

$$F_s = \frac{H_R}{H} \geq 1,5 \dots\dots\dots(5)$$

where:

F_s is safe factor for shear on base of foundation, H_R is foundation resistance to shift (kN), H is numbers of horizontal forces (kN), 1,5 is safety factor for granular subgrade

e. Settlement

The problem of decreasing the foundation becomes very importants if there is a settlement in difference between the two adjacent foundation points, this causing angular distortion (δ/L). The total reduction foundation in 5-10 cm and non-uniform decrease is 0.005 L according to table 3.

Table 3. Allowable settlement (Sowers, 1962) [7]

Type of movement	Limiting factor	Maximum settlement (cm)
Total settlement	Drainage	15 – 30
	Access	30 – 60
	Probability of nonuniform settlement:	
	Masonry walled structure	2,5 – 5
	Framed structure	5 – 10
Differential movement	Smokestacks, silos, mats	8 – 30
	High continuous brick walls	(0,0005 – 0,001)L
	One-story brick mill building, wall cracking	(0,001 – 0,002)L 0,001L
	Plaster cracking (gypsum)	(0,0025 – 0,004)L

Reinforced-concrete building frame	0,003L
Reinforced-concrete building curtain walls	0,002L
Steel frame, continuous	0,005L
Simple steel frame	

3. Research method

3.1 Soil conditions

At this stage, data collection on soil testing results was carried out on the Maleo PLTG Tank Construction Project in Paguat District, Pohuwatu Regency, Gorontalo Province Indonesia according to the location map in figure 3. Soil testing data in the field with DCPT/Sondir are three points with hard soil depth of $q_c > 150 \text{ kg/cm}^2$ [5] which are $\pm 16\text{m}$. The results of analysis of test data are made in the graphical form. Referring to the 2017 earthquake map of Indonesia with a probability of exceeding 10% in 50 years, this region is in a zone with an earthquake acceleration coefficient of 0.30g.-0.40g. Plaxis analysis by using dynamic loads in the form of time history of earthquakes [8].

3.2 Structure and loading construction

At this stage, the research is carried out by calculating the construction load based on the planning drawing, and earthquake load used in the peak acceleration map in bedrock for a probability exceeding 10% in 50 years [9]. Wind load based on wind velocity by month in Gorontalo Province [10]. The calculated plan load is dead load (DL), Operational Load (OL), windload (WL) and earthquake load (EL). The combination of loading refers to the LRFD without the loading factor coefficient.

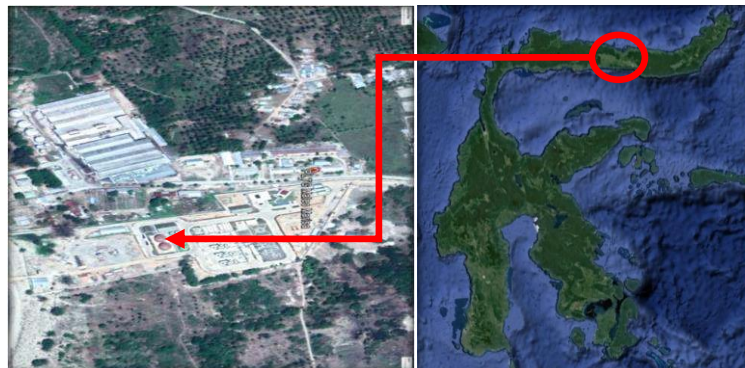


Figure 2. Study location [11].

3.3 Modelling and Analysis of Foundation Stability

At this stage, the calculation of the foundation stability analysis of the carrying capacity of the soil, sliding and rolling is calculated based on a combination of loading and specified safety factors. Furthermore, structure and loading modeling are carried out in Plaxis to analyze the decline that occurs due to the applied load. The earthquake load used in the analysis is 350 cm/s^2 according to figure 7. The research stages are presented in the following figure.

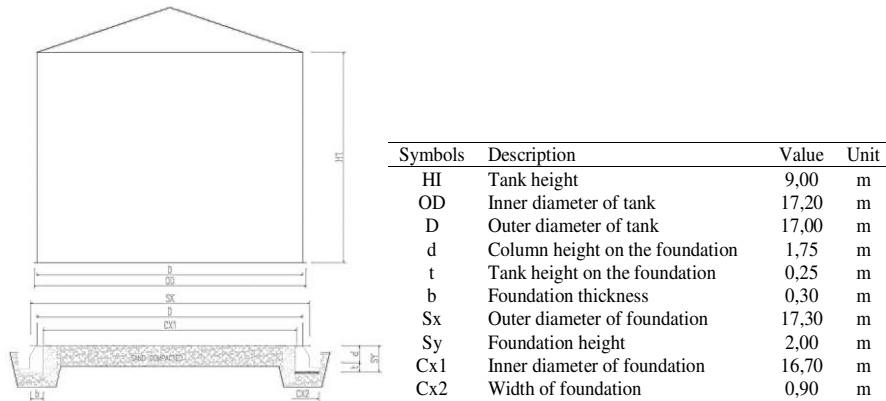


Figure 3. Foundation and tank dimintions [12]

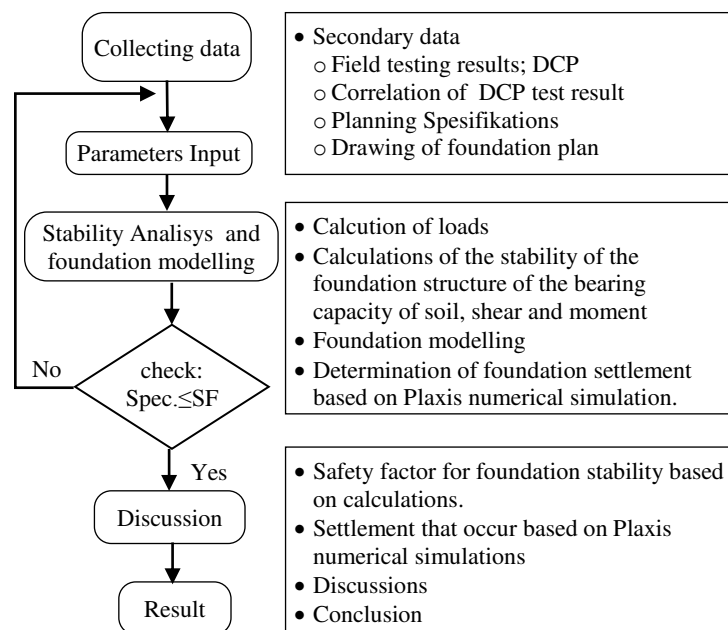


Figure 4. Research flow chart

The foundation of the tank is circular so that finite-element modeling is axisymmetric according to figure 6. Earthquake against the foundation is in the form of inputting time history plaxis the 2D plaxis program.

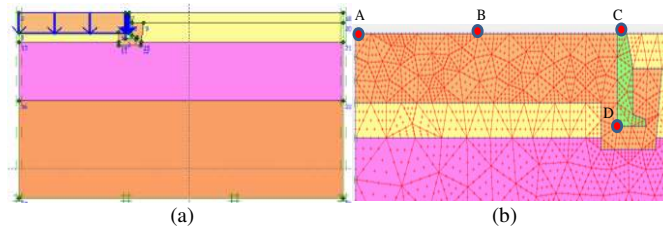


Figure 5. (a) Modeling existing foundation conditions, (b) stress observation and settlement points.

4. Result and discussions

4.1 Soil, steel and concrete properties

From the results of the CPT test, a correlation was made with respect to soil shear strength. As for other materials, can be seen in the following table.

Table 4. Materials data as input

Parameters	Name	Clay	Sand	Deep Sand	Unit
Soil layers (m)		0 - 2	2 - 6	6 - 12	
Material model	-	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb	-
Type of material behaviour	-	Drained	Drained	Drained	-
Soil unit weight above phreatic level	γ_{unsat}	15,5	16,5	17	kN/m ³
Soil unit weight below phreatic level	γ_{sat}	18	20	21	kN/m ³
Permeability in horizontal direction	k_x	0,0001			m/det
Permeability in vertical direction	k_y	0,0001			m/det
Young modulus	E_{ref}	9700	98000	120000	kN/m ²
Poisson's ratio	ν	0,2	0,2	0,2	-
Cohession	c_{ref}	5,5	1	1	kN/m ²
Friction angle	ϕ	24	31	33	°
Dynamic friction angle ($\phi - 2$)°	ϕ_{din}	22	29	31	°
Dilatancy angle	ψ	0	1	3	°
Strength reduction factor inter	R_{inter}	rigid	rigid	0,75	-
Foundation					
Material model	-	Linier Elastic			-
Type of material behaviour	-	Non porous			-
Concrete unit weight	$\gamma_{\text{conc.}}$	24			kN/m ³
Young modulus	E_{ref}	30.000.000			kN/m ²
Poisson's ratio	ν	0,2			-

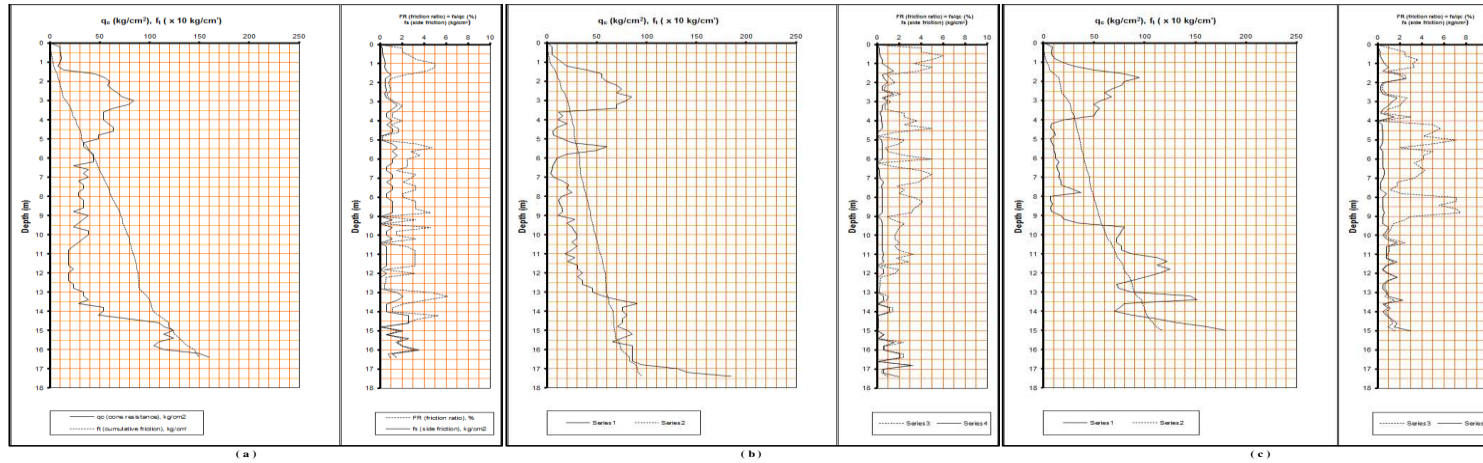


Figure 6. Data from DCP testing results (a) SO-01, (b) SO-02 dan (c) SO-03 [12].

Table 5. Average value of \overline{qc} and \overline{FR}

Depth (m)	SO - 1			SO - 2			SO - 3		
	qc (kg/cm ²)	\overline{qc} (kg/cm ²)	\overline{FR}	qc (kg/cm ²)	\overline{qc} (kg/cm ²)	\overline{FR}	qc (kg/cm ²)	\overline{qc} (kg/cm ²)	\overline{FR}
1,20	8			20			30		
1,40	14			40			50		
1,60	45	36	2,5	55	46	3	80	67	1,5
1,80	55			55			95		
2,00	60			60			80		

Table 6. Wind velocity by month in Gorontalo Province, Pohuwatu Regency in Figures, 2017

Month	Wind Velocity (knot)
January	4.0
February	5.0
March	5.0
April	4.0
May	3.0
June	3.0
July	2.0
August	4.0
September	3.0
October	2.0
November	2.0
December	3.0

[10].

Based on the table above, the maximum wind speed occurs in February and March which is 5 knots or 10 Km/hour.

a. Foundation Stability

Calculation of the stability in this case is allow able bearing capacity (q_{all}) of soil based on soil testing sondir. The average q_c value used in the calculation is 36kg/cm2 with SF=3. In this analysis, the q_{all} factor coefficient is not taken q_{all} account. It calculations according to Schmertmann (1978) areas follows:

$$q_{all} = (5 + 0,34 * 36) / 3 = 5,75 \text{ kg/cm}^2$$

Table 6. Recapitulation of calculation foundation load.

Load	Remarks	Vertical (kg)		Horizontal (kg)	Moment (kg.cm)
		Below Ring (N _R)	Below Soil (N _S)	H	Mo
DL	Equip Erecting	128.430,06	-	-	-
	W _O	56.045,16	1.546.037,05	-	-
OL	L _L	6.675,884	-	-	-
	W _O + L _L	62.721,04	1.546.037,05	-	-
Ww	Wind Load	3.244,21	-	10.788,073	4.854.632,866
EL	V	87.024,25	-	355.909,849	160.159.431,895

Table 7. Calculation of soil bearing capacity.

Loads combination	$q \text{ (kg/cm}^2\text{)}$					Result (q_s and $q_R < q_{All}$)
	N_R/A_F	M_O/m_F	q_R	q_S	q_{All}	
DL	0,802	0,000	0,802	0,000	5,75	safe
DL + OL	1,151	0,000	1,151	0,71	5,75	safe
DL + Ww + OL	1,184	0,152	1,336	0,706	5,75	safe
DL + EL + OL	1,695	3,136	4,830	0,706	5,75	safe
DL - EL + OL	0,608	-3,136	-2,527	0,706	5,75	safe
DL + EL	1,345	3,136	4,480	0,000	5,75	safe
DL - EL	0,258	-3,136	-2,877	0,000	5,75	safe

b. Safety factor and Settlement foundation.

From Table 8 above, it can be seen the value of safety a factor used by 3. It is indicated that the foundation stability shows the foundation allowable stress is not exceeded so that the foundation is quite stable. This is due to a fairly wide foundation, so that the stress that occurs is relatively small. The results of the plaxis analysis show that the maximum stress that occurs at the base of the foundation is 1,05 Kg/cm².

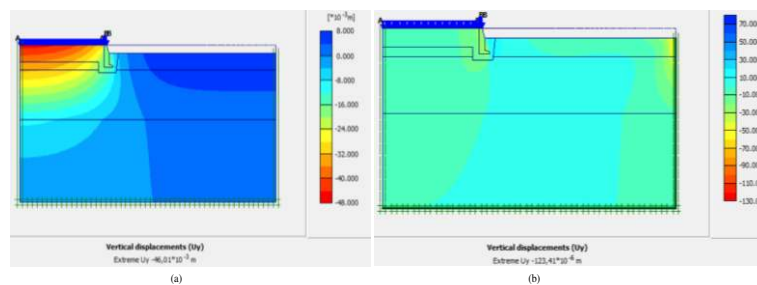


Figure 7. Settlement that occur (a) due to axial loads, (b) due to axial and earthquake loads.

Based on plaxis analysis, it shows that the total settlement that occurred during the earthquake with an acceleration of 350 cm/s^2 was 0.024 cm . There are 4 points reviewed, namely at the bottom of the tank (point A, B, C) and the foundation base (point D) as shown in figure 10. In this analysis, the load combination does not use a load factor, but in the calculation control using the recommended safe factor. This is more efficient in accordance with the load that works and there is no excessive loading.

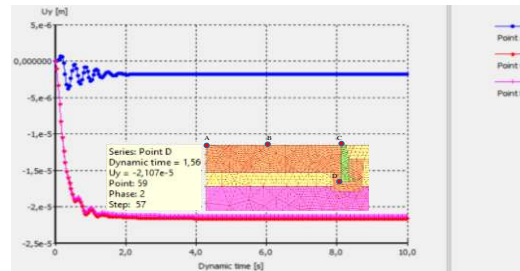


Figure 8. Vertical displacement-time curves at the base due to earthquake loads.

5. Conclusion

Complete and accurate soil investigation is needed for planning the foundation structure. Soil bearing capacity, shear stress, moment and settlement that occur assuming the foundation within the recommended tolerance limit. In general, the foundation used in this analysis is quite suitable in carrying the load plan both statically and dynamically.

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