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Probability Liquefaction On Silty Sand Layer On Central Jakarta

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Abstract: Indonesia has a strong earthquake risk. The effects of saturated silty sand liquefaction during earthquakes can be very damaging. Liquefaction is the threats to the safety of structures, and the evaluation of liquefaction potential is essential in locations with silty sand layers. Research was performed at BPJS Branch Office building project in Central Jakarta with 7 floors when conducted the substructure or deep foundation design. This research uses cone penetration test (CPT) data to evaluate the potential and probability of liquefaction. At the same time, this research also predicts the bearing capacity (Q_u) of single pile embedded on silty sand layer at conditions of Non-Liquefaction (NL) and Liquefaction (L) due to an earthquake. The research results showed that silty sand layers were classified as the susceptible layers to the liquefaction potential after plotted of CPT data into the graphic from Robertson & Campanella method [1] and signed by zone A. However, bearing capacity (Q_u) when condition of NL and L was only different around 10 to 11%, it can be considered that the single pile remains stable during occurrence the liquefaction and capable to support the upper structure system. This assumption is also strengthened by the analysis result of probability liquefaction (P[L]) for sand and silty sand layers, the average of (P[L]) based on the maximum earthquake acceleration (PGA) T = 50 years exists in the range < 5 % to 10 % and it can be stated that [P(L)] is very low to low [2] and it can be concluded that the sand and or silty sand layers at study area is hard to category as a liquefiable layer.

Keywords: Liquefaction, CPT test result, probability, central Jakarta

1. Introduction

Jakarta, Indonesia is the capital city of Indonesia. Jakarta is a big city, especially in the Municipality of Central Jakarta has high population growth. The most of layers of soil in the Municipality of Central Jakarta are classified into soft clay soil and has thick larger than 10.0 m which is followed by sand and or silty sand layers. Area of Central Jakarta area is inclined to the natural disasters brought about by the event of frequent earthquakes and its people are consistently in a dangerous situation [3]. One of important issues of the earthquake hazard is liquefaction [4]. During liquefaction occurred, the shear strength of the soil decreases and the ability of soil deposit to hold the load decreases [5]. Liquefaction is one phenomenon that must be anticipated and foreseen at the earliest opportunity on the ground that ought to be predicted and anticipated as soon as possible because the possibility of liquefaction hazard can harm the building structure

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around the Central Jakarta area, especially for the deep foundation embedded in sand and or silty sand layers. The liquefaction potential prediction can be contemplated utilizing three field testing methods, to be specified standard penetration test (SPT), cone penetration test (CPT) and seismic shear measurements [6]. However, some local regulations for the minimum soil investigation required for any classification of small to medium-scale building projects are not very clear [7]. Therefore, this research used only CPT because of simple, quick, and economical tests. From some references, CPT data also provides reliable in situ continuous data (q_c & f_s) of subsurface soil. Lately, improved techniques for the assessment of liquefaction resistance utilizing CPT data are turning out to be ideal on the grounds that CPT can give more standardized and dependable data and more precision to a soft soil layer including loose sand and or silty sand.

This paper aims to focus on analyzing the liquefaction potential of the loose sand and or silty sand layers in Central Jakarta based on CPT data plotted on the Robertson and Campanella graphic [1]. Improved techniques for assessment of liquefaction resistance utilizing CPT data are turning out to be ideal on the grounds that CPT can give more standardized and dependable data and more precision to a soft soil layer including loose sand and or silty sand. In addition, generally CPT data can be potentially to use in determining the other soil parameter using some correlations required for the design of bearing capacity for the deep foundation that uses precast pile concrete (PPC), etc. At the same time, assessment bearing capacity (Q_u) was conducted on a single pile embedded in a layer of silty sand soil during non-liquefaction and liquefaction. An additional analysis was also performed to ensure the susceptibility to liquefaction of the silty sand layers in the study area, it is assessed by the liquefaction probability (P[L]).

2. Literature Review

2.1 Cone Penetration Test (CPT)

Among the different in situ tests, the cone penetration test (CPT) is considered the most frequently used method for the characterization of the site. CPT is basically advancing a cylindrical rod with a cone tip into the soil and measuring tip resistance (q_c) and sleeve friction (f_s) during penetration. Normally, CPT data were presented graphically for tip resistance (q_c) and total friction (t_f) values. The research uses CPT devices complete with some accessories. CPT device has a maximum compressive capacity was 2.5 tons with bi-conus type and a cross-sectional area unit of 10 cm^2. The friction cone has an area of a blanket of 123 cm^2. All testing procedure was adopted from the standard of ASTM D3441 – 16 [8]. CPT was carried out and data was recorded manually as the information was continuously at penetration intervals of 20 cm depth. CPT investigation was performed up to the maximum soil shear strength reached 250 kg/cm^2 at around a depth of 12.0 meters of hard layers consisting of sand to silty sand at the study area. The (q_c) and (f_s) parameters are used to classify soil strata and to estimate the bearing capacity (Q_u) and deformation characteristics of soils. Some devices can be completed to use cone penetrometers made that it is possible to apply this test for a wide range of geotechnical applications [9].

2.2 Liquefaction Phenomenon

Sandy soil liquefaction is a phenomenon that loses the mechanical resistance of the soil as a result of cyclic (seismic) loads. The loss of soil resistance is indicated by the loss of effective stress between grains of sand or silty sand particles, due to the increase in the value of pore water pressure until it reaches the value of overburden pressure in the soil of fully saturated water in the undrained and or short-term condition based on Seed and Idriss method [10]. Potential liquefaction can be evaluated by CPT data only.

When liquefaction, the frictional strength of the clay soil layer only receives 30% of the total overburden stress, meaning that the friction resistance is corrected up to 30% [11]. The unit skin friction of pile (f_s) at the susceptible layers closes to zero value, this study follows some references, such as [12], [13], etc.

3. Research Method

3.1 Investigation Area

The municipality of Central Jakarta is located in the centre of Jakarta city with Global Positioning System (GPS) coordinates of 6^o 12’ SL and 106^o 50’ EL as shown in Fig. 1. Geographically, the study area is located in Senen District. Senen District consists of 6 villages, there are: Kenari, Paseban, Kramat, Kwitang, Senen, and Bungur. The total area of Senen District is 4.22 km^2. Each village has relatively the same area. Land use in Senen District is dominated by building works and roads. Whereas for industry and guesthouse public buildings are only a small part.

Central Jakarta is one part of Jakarta Bay which was covered of Quartenary deposits with terrestrial deposits intercalation with marine deposits. Marine deposit was characterized by finer clastic, contain remain of shells, fossil, coral, limestone fragments, glauconites, calcareous. The lithofacies variation of Quartenary deposit from the wells indicated lateral and vertical variation change, also on coastline shifting either by transgression or regression [14]. Interaction between those depositional environments produced deposits which have lithofacies variation.

Liquefaction potential is always occurred on silty and sandy saturated soil when they loss the effective stress during earthquake. Jakarta was located in a groundwater basin, known as the Jakarta Groundwater. The basic aquifer system was formed by Miocene impermeable sediments which were also cut outside the southern boundary of the basin [15]. Hydrostratigraphy is a Jakarta groundwater basin divided by 4 zones, such as: Citalang Formation (Zone 1) with permeable lithology; Kaliwungu Formation (Zone 2) with impermeable lithology; Kaliwangu and Genteng Formation with permeable (Zone 3) and impermeable (Zone 4) lithologies. Study site was classified by Citalang Formation of Zone 1 with permeable lithology as part of the aquifer group 1 consisting of alternating sandstone, conglomerate, and claystone layers. From geotechnical data, ground water level (GWL) exists between -5.40 m (CPT-S5) and -6.40 m (CPT-S1).

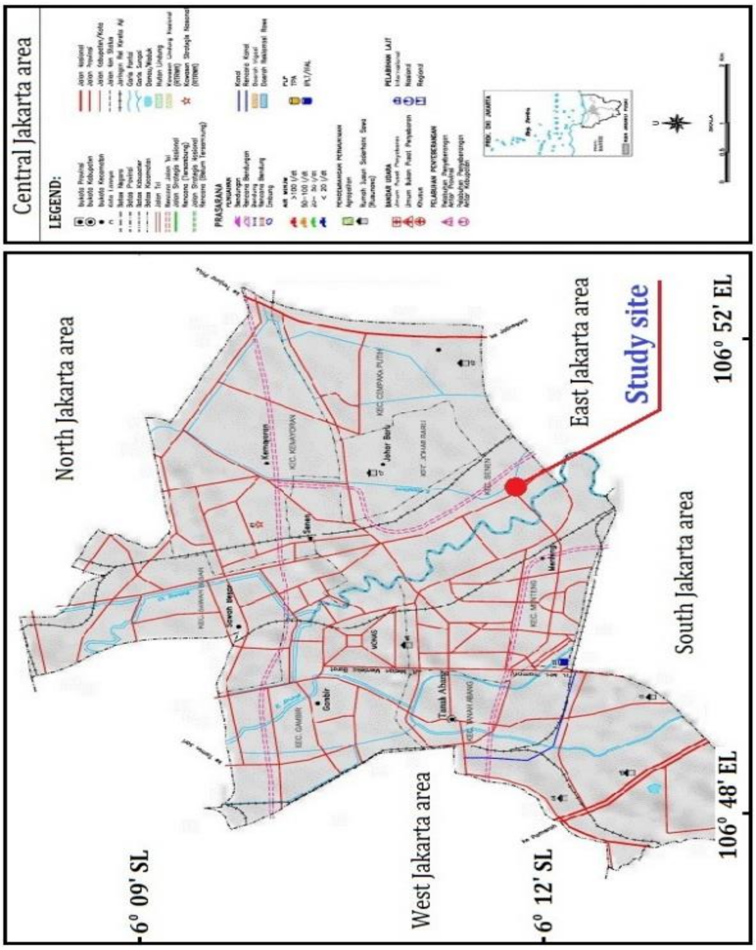

Fig. 1 - Location of study area

3.2 Geotechnical Analysis from CPT Data

3.2.1 Non-Liquefaction (NL) and Liquefaction (L) Potential and Bearing Capacity (Q_u)

CPT results show that the soils in the area are dominantly silty clays of low to medium plasticity, clay and dense to very dense silty sands down to 12.0 m of depth. Because of this project only uses CPT data, some preliminary data around the study area was used as a confirmatory data to validate correlation data in determining ultimate load carrying-capacity or bearing capacity (Q_u) at site study. Furthermore, the earthquake risk is increasing in the region since the last catastrophic earthquake occurred approximately 321 years ago [16], [17], [18], [19]. Finally, the analyses were also to predict probability of liquefaction of silty sand layer at Central Jakarta using CPT data only.

All CPT data samples were taken from study sites planned for the construction of the BPJS building. The layout of cone penetration (CPT) and sample data are shown in Fig. 2. The investigation area is approximately 448 m^2. The figure also includes the CPT and PDA locations as well as the limits of the area under consideration for construction of the BPJS building. This area that would be built the Building of Central Jakarta Service Office of BPJS was an area of old buildings, and it was found a former layer of concrete and building debris filling at near of surface layer. The number of CPT tests is 5 (five) sample points. Typical soil layers are shown in Table 1. The CPT and grain size characteristics data results for identification of potential liquefaction were plotted on Robertson & Campanella [1], [20] graphics as shown in Fig. 3. These results of data plotted indicated that the sand dan silty sand deposits (from S-1 to S-5) were classified as the susceptible layers against the liquefaction potential.

The following methods are used to predict the ultimate load-carrying capacity or bearing capacity (Q_u) of single pile based on CPT data, such as [21]- [28]. Table 2 shows the bearing capacity (Q_u) of single pile during non-liquefaction (NL) and liquefaction (L) conditions.

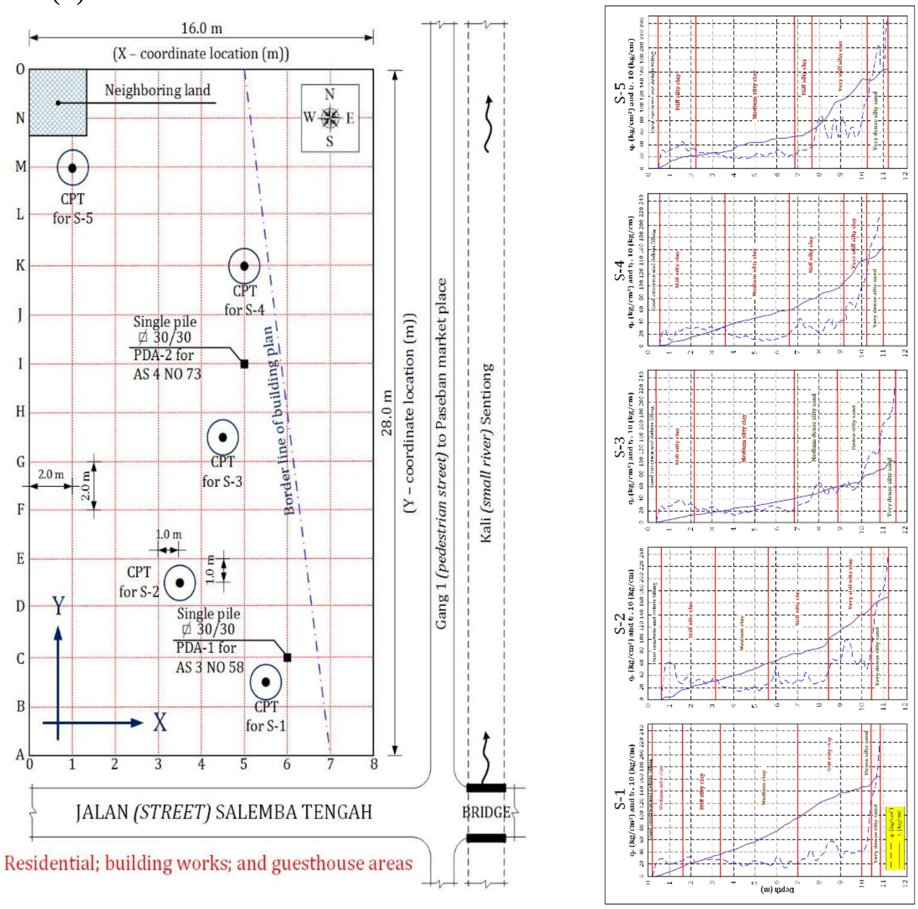

Fig. 2 - Layout of cone penetration test (CPT) and data samples for BPJS building project

Table 1 - Typical of soil layers from CPT data at S-1 and S-2

CPT Point	Depth of soil layer (m)	Average q_c value (kg/cm^2)	Average f_s value (kg/cm^2)	Average f_s/q_c value (kg/cm^2)	Description	Remarks
S-1	0.00 – 0.20	-	-	-	-	Used concrete debris filling
	0.00 – 0.40	27	1.31	4.89	Medium silty clay	
	1.80 – 3.40	32	1.36	4.09	Stiff silty clay	
	3.60 – 7.00	26	1.85	7.48	Medium clay	
	7.20 – 10.00	45	1.91	4.63	Stiff silty clay	
	10.20 – 10.40	106	1.34	1.05	Dense silty sand	
	10.60 – 10.80	210	3.25	1.91	Very dense silty sand	$q_c > 250$ kg/cm^2
S-2	0.00 – 0.60	-	-	-	-	Used concrete debris filling
	0.80 – 3.20	40	1.33	3.64	Stiff silty clay	
	3.40 – 5.60	21	1.30	6.35	Medium clay	
	5.80 – 8.40	36	1.52	4.05	Stiff silty clay	
	8.60 – 10.40	77	2.86	3.89	Very stiff silty clay	
	10.60 – 11.20	197	1.83	1.06	Very dense silty sand	$q_c > 250$ kg/cm^2

3.2.2 Probability of Liquefaction (P[L])

Based on the results of previous research, it can be identified that clean sand is easier to experience an increase in pore water pressure due to cyclic loads than silty sand and clay sand. The results of sieve analysis as shown in Fig. 3 from laboratory works indicate that the effect of fine grains will reduce the tendency of the soil to compact when subjected to vibration. Fine plastic grains also make it difficult for sand grains to slip between particles, and non-plastic fine grains will have no effect on liquefaction. The particle size is associated with the permeable nature of coarse grains will release partial pore water pressure during an earthquake. From the analysis results, it is obtained that the average probability of potential liquefaction based on the maximum earthquake acceleration (PGA) T = 50 years (in the range < 5 % to 10 %) is very low to low [2], [29] as shown in Table 3.

Table 2 - Predicted bearing capacity (Q_u) of single pile in non-liquefaction (NL) and liquefaction (L) conditions for dimension = 30 cm in square shape (Precast Pile Concrete or PPC at a depth of 9.50 to 10.50 m)

CPT	No-Liquefaction (NL)	Liquefaction (L)	Type of soil layer
	Q_u (tons)	Q_u (tons)	
S-1/PDA TEST-NEARBY AS - 3 No. 58	110.9	97.9	Silty sand
S-3 and S-4/PDA TEST-NEARBY AS - 4 No. 73	101.2	101.2	Silty clay
S-3	120.8	106.6	Silty sand
S-4	129.9	129.9	Silty clay
S-5	128.0	128.0	Silty clay

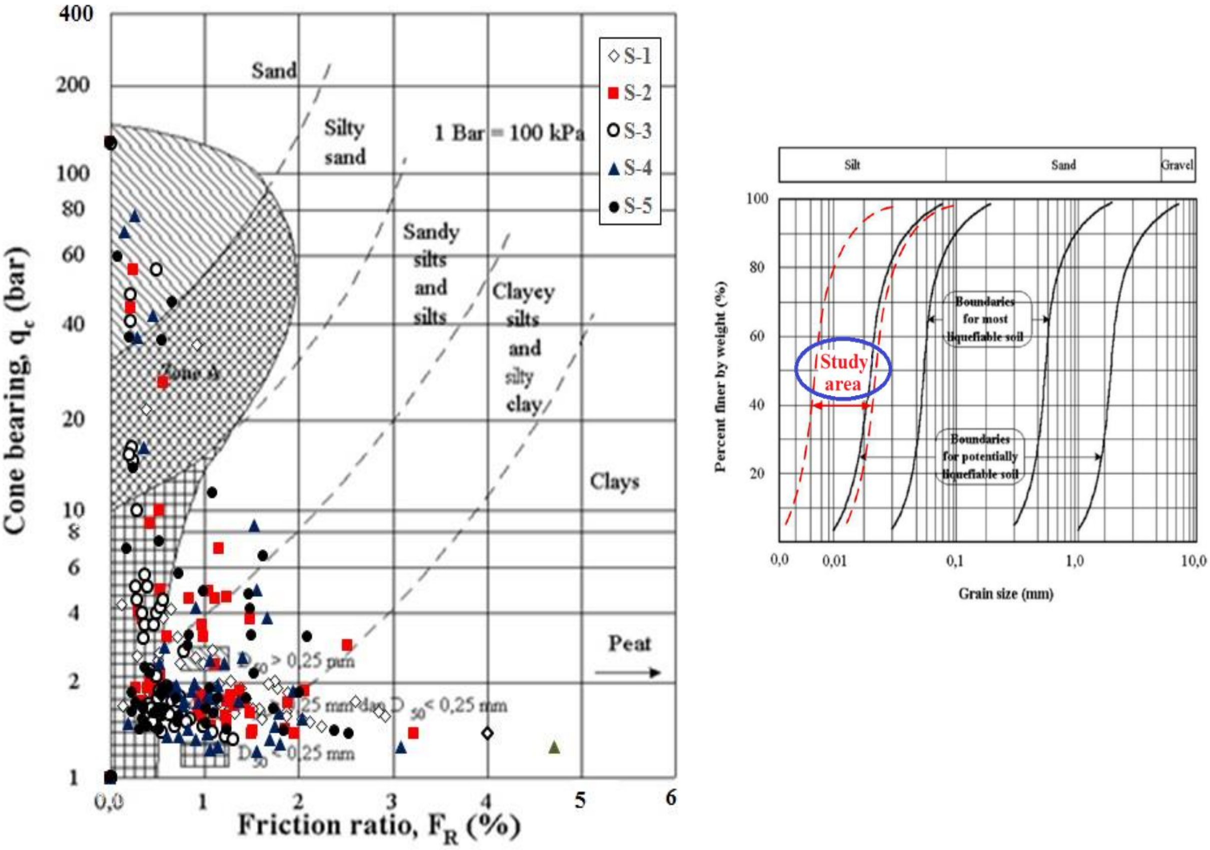

Fig. 3 - Soil classification for identification of potential liquefaction based on CPT and grain size data from some methods [1], [20]

4. Results

Earthquake potential of the building structure was predicted by SNI [29], and for soil foundation layers that were susceptible to liquefaction phenomena was measured by CPT data. The results of probability liquefaction shown in Table 3 classified very low to low although the soil layers classified by zone A shows susceptible to liquefaction (Fig. 3). The zone A is loose sand and or silty sand with $D_{50} > 0.25$ mm, with q_c values between 30 and 150 kg/cm^2 and FR values < 1%. All points in zone (A) were not as much as previously predicted, thus it can be stated that these soil foundations at study site were not susceptible to liquefaction or dominantly soil layers were not classified by Zone A. Bearing capacity (Q_u) on Table 2 for under non-liquefaction (NL) and liquefaction (L) conditions was only different around 10 to 11% or considered as very small values at sand and silty sand layers.

Table 3 - Probability liquefaction based on some criterions [2], [29]

Depth (m)	S – 1	S – 2	S – 3	S – 4	S – 5
	Probability of Liquefaction Potential				
0 – 3	No	No	No	No	No
3 – 4	No	No	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)
4 – 5	No	No	No	No ($t_h < t_{av}$)	No ($\tau_h < \tau_{av}$)
5 – 6	No	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)
6 – 7	No	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)
7 – 8	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)
8 – 9	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)
9 – 10	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)
10 – 11	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)
11 – 12	No	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)	No ($\tau_h < \tau_{av}$)

Note:

1. Condition of ($\tau_h < \tau_{av}$) indicates no liquefaction potential, although the shear strength due to the earthquake is stronger than the shear strength based on CPT data
2. Condition of ($\tau_h < \tau_{av}$) indicates that there is no liquefaction potential, the shear strength due to the earthquake is smaller than the shear strength based on CPT data
3. Generally, the top layer at the site is clay to silty clay to an average depth of 5.0 to 9.0 m, the clay layer has cohesion and the liquefaction probability level is very low and liquefaction is probably not going to occur.
4. At the bottom of the lower layer of clay - silt clay is a layer of sand to silt sand from a depth of 9.0 to 12.0 m followed by a very dense / hard sand layer, this layer is relatively susceptible to liquefaction, but gradations of sand grains that exist in locations vary from fine to coarse or very little within zone A or outside the zone of potential liquefaction, so the probability is "very low" with the probability of liquefaction (P [L]) ranging between 5 and 10% for liquefaction, except for vibration during the process of pile installation.

5. Conclusion

From analysis carried out for building relates with the non-liquefaction and liquefaction of sand and or silty sand layers based on CPT and the results present the conclusions as follows:

- Evaluation results of liquefaction potential based on the data the CPT test since the soil layers classified by zone A (where they indicate that these layers susceptible to liquefaction), however, the probability of the liquefaction to be occurred in this building area are very low to low [2]. It means that the single pile is remain stable during earthquake even embedded at sand and or silty sand layers and although bearing capacity (Q_u) was calculated by cone tip resistance (q_t) using safety factor (SF) of 3.0 and friction (f_s) applying (SF) of 5.0 at conditions of static loading and liquefaction for a single pile design in Indonesia. As well as the reference [22] that suggested an upper limit of 150 TSF (15 MPa) for the unit tip bearing capacity (q_t) for loose sand or silty sand.
- Investigation of detailed geotechnical studies in the building areas are important before building construction is carried out to reduce the risk of threat of the soil subsidence due to liquefaction, as well as direction in spatial planning in central Jakarta. Detail study for sand and or silty sand layers at study area is still required to make a decision of liquefaction potential during earthquake. Geotechnical investigation for deep foundation design has to use combination between cone penetration test (CPT) and standard penetration test (SPT) including of laboratory soil investigation for one point in the field with a depth exceeding 30 meters. Physical and mechanical properties; and dynamic characteristics of different soil layers have to be carefully combined in terms of liquefaction 'susceptibility', especially against corresponding to pile foundation system when is used for seismic analysis purposes.

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