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Probabilistic of in Situ Seismic Soil Liquefaction Potential Based on CPT-Data in Central Jakarta, Indonesia

Putera Agung Maha Agung[1]*, Ramlan Sultan[2], Muhammad Idris[2], Agus Tugas Sudjianto[3], Mustaffa Anjang Ahmad[4], Muhammad Fathur Rouf Hasan[1,5]

[1]Department of Civil Engineering
Politeknik Negeri Jakarta, Depok, 16425, INDONESIA

[2]Department of Civil Engineering,
Politeknik Negeri Ujung Pandang, Makassar, 90245, INDONESIA

[3]Department of Civil Engineering,
Widyagama University, Malang, 65142, INDONESIA

[4]Department of Civil Engineering,
Universiti Tun Hussein Onn Malaysia, Johor, 86400, MALAYSIA

[5]Department of Physics,
Brawijaya University, Malang, 65145, INDONESIA

*Corresponding Author

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Abstract: Jakarta City located at the northern part of Java Island has a potential liquefaction since there are many soil layers as a qualified as liquefaction susceptible, such as: silty sand and sand. The effects of liquefaction occurrence on saturated silty sand and sand during earthquakes can have potential to damage structure. A case history using CPT-data randomly taken from Central Jakarta region was compiled and back analyzed to investigated probability of liquefaction. The present study focuses on the probabilistic evaluation of liquefaction potential of this region, considering silty sand and sand layers related to CPT soundings. Silty sand was found as a thin layer or a lens between silty clay, silt and clay which was classified as a soft soil layer, and the sand layer is mostly found as a hard bottom layer. Normalization of tip CPT resistance (qc) corrected by an effective overburden stress was not only used to thick layer of silty sand and sand, but also it was applied to determine liquefaction potential existed as the "thin" layers. The silty sand and sand layers have a probability of liquefaction (PL) between 5 to 50% for magnitudes and distances of 500 years with PGA less than 0.42 gal.

Keywords: Liquefaction, silty sand, sand, CPT, probability

1. Introduction

Liquefaction is a complementary event after the occurrence of an earthquake hazard, especially if the location affected by the earthquake has a liquefiable soil layer, such as saturated silty sand and sand as a cohesionless soil. In many cases of liquefaction occurrence from the literature, the most of shear strength of liquefiable layers especially for saturated silty sand and or sand will close to zero and pore water pressure will increase exceeding total overburden

**Corresponding author: putera.agungmagung@sipil.pnj.ac.id*

stress during ground shaking or other repeated of rapid loading. High excess pore water pressure of cohesionless soil will eliminate effective overburden stress surrounding the liquefiable layer and finally a whole of soil layer will follow to collapse. After ground shaking due to earthquakes, it usually demonstrated several damaging on infrastructures. Several researchers have been tried to understand and characterize the liquefaction phenomenon since the first time evaluating or triggering event of cyclic liquefaction potential of soils during earthquakes. Various models were established during the last few decades based on simplified until geostatistical analyses or combination analyses for estimating the liquefaction potential with the shortage and advantage during application. Recently, probabilistic, and deterministic approaches for liquefaction analysis by the simplified method using safety factors, and statistical method involved geospatial analysis, so that there are many the liquefaction potential mapping created by some researcher (Frankel et al. 2002; Holzer et al. 2005; Agung & Mustaffa, 2014; National Agency for Disaster Countermeasure, 2015; Tint et al. 2018).

CPT-based liquefaction was developed by several researchers in the past. Recently, improved techniques for assessment of liquefaction resistance utilizing CPT data are turning out to be ideal on the ground. CPT data quality assessment after case histories were more standardized included screening; adjustments, and corrections. Normalization of CPT data associated with tip resistance (q_c); sleeve (f_s); and or friction ratio (R_F) measurement were corrected by the effective vertical stress for each layer. Hereinafter, this paper aims to focus on probabilistic analysis of potential liquefaction of the silty sand layers on Central Jakarta based on in situ test of the CPT. The present study will involve evaluation geostatistical of liquefaction potential considering the effect effective overburden stress and thin layer at Central Jakarta region using a purposed method developed by Cetin et al. 2004 and Moss et al. 2006.

2. Methodology

Silty sand and sand were considered as a liquefiable soil layer by several researchers. Five (5) CPT data was taken randomly from Central of Jakarta City region with the coordinate of 6° 12' SL and 106° 50' EL (Fig. 1). CPT-data identified that fill material of 1.0 to 1.5 m thick was placed on the original ground surface and followed by medium to stiff silty clay, medium clay, dense to very dense silty sand on bed rock. CPT results exhibited 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. The main goal in this study was to analyze the probability of liquefaction of silty sand soils using CPT – data (Fig. 2). The silty sand and sand layers have a susceptibility potential to liquefaction hazard after rapid strong motion or repeated ground shaking. Susceptible layers were classified as silty sand and sand after all CPT data plotted on the graphic of Robertson, 1985. Soft soil included silty clay or clayey silt, silt, and clay layers, etc could be catergorized as not susceptibility layers. Typical of liquefiable soil layers were suitable with alluvial deposits geologically which was studied by several researchers (Listyono et al. 2016). Based on some provided geology and geotechnic map in previous study, bay of Jakarta was covered of quartenary deposits with terrestrial deposits intercalation with marine deposits consisted of silty sand and sand.

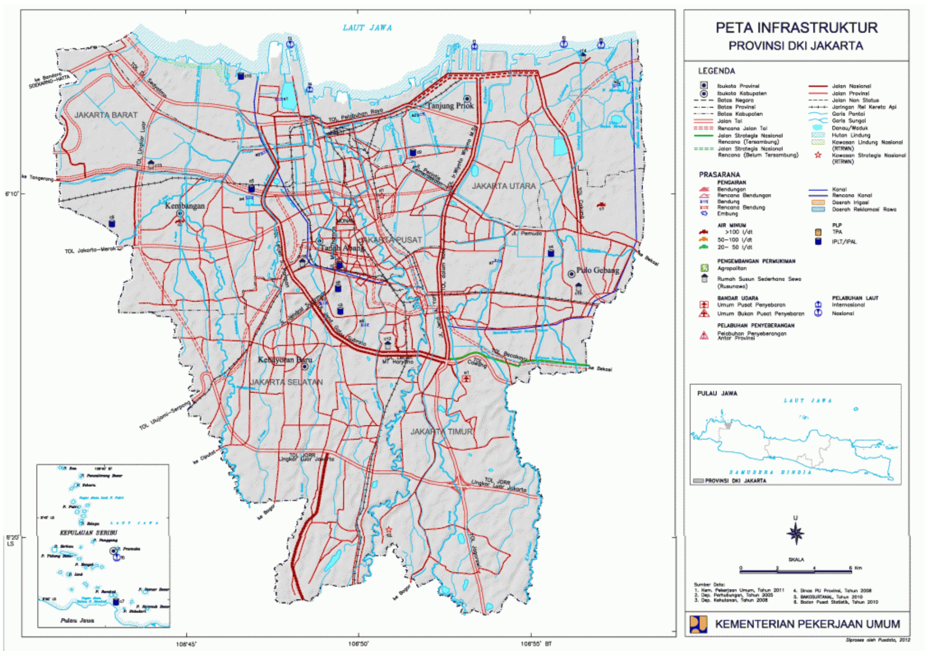

Fig. 1 - Location of study site (Ministry of Public Works, 2012)

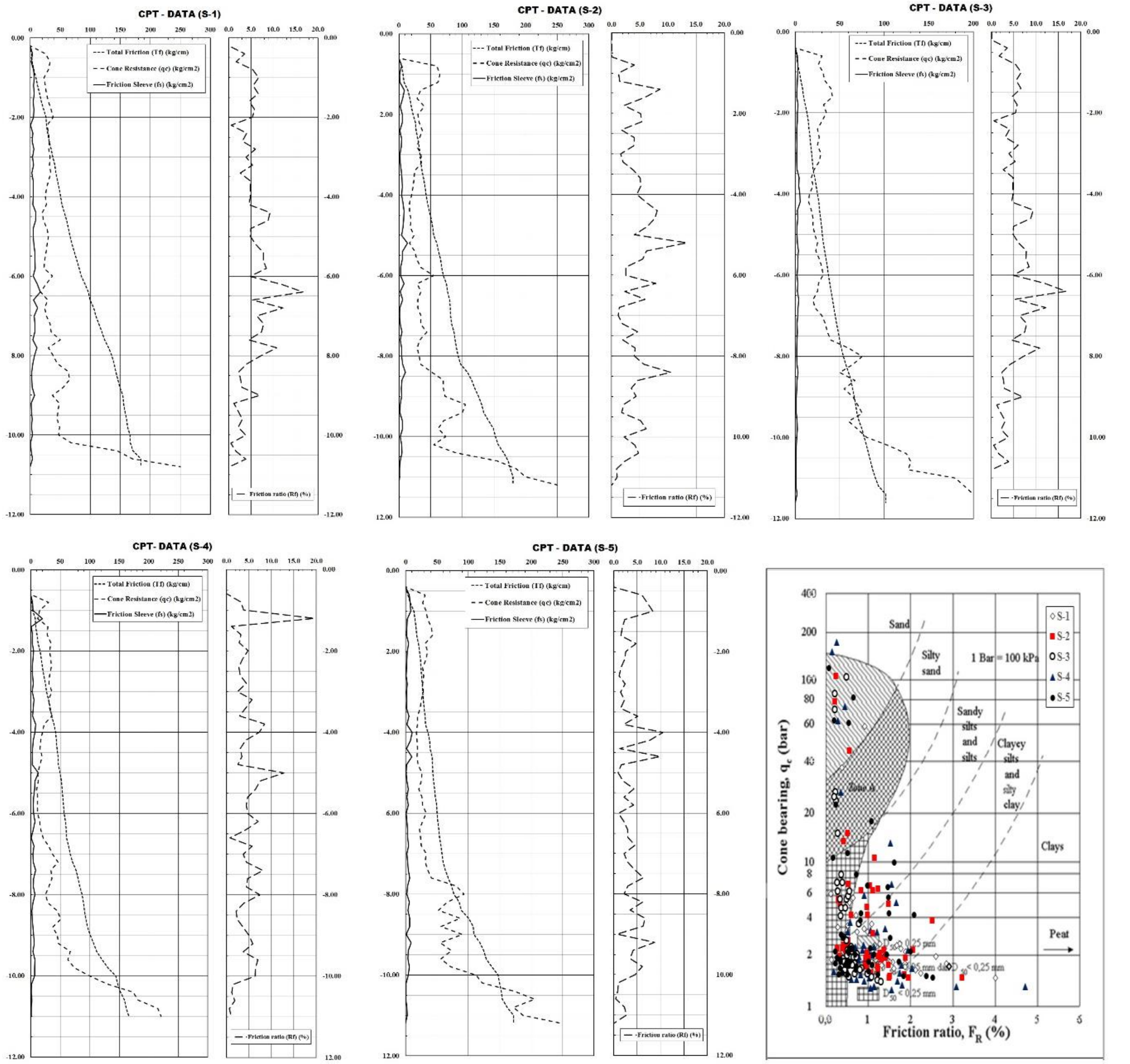

Fig. 2 - Cone penetration test (CPT) - based data of study site and early identification of potential liquefaction on study area (Robertson, 1985)

Parameter of peak ground acceleration (PGA) at Central Jakarta region was determined by numerous national and international institutions. Indonesia was found near significant flaws two-lane main earthquake, the circum-Pacific belt (the ring of fire) (Hinga, 2015) and Alpine Transidiatic lane with 17% of the world's biggest earthquakes (Lüschen et al. 2011). The Indonesia Archipelago has several distinctive features that make the region one of the most active tectonic zones in the world. Three tectonic plates converge in the area leading to complicated geological and tectonics mechanisms (Reid, 2012). Seismotectonic on Fig. 3. Indicated that the high historical seismicity of the Indonesia regions (Irsyam et al. 2015; SNI-1726, 2019). Probability analysis for case histories of Central Jakarta region uses magnitudes and distances for 500 years only with PGA less than 0.42 gal.

Alluvial deposit of Central Jakarta was traversed the flow of water underground. Ground water table at Central Jakarta region was found between 5.0 to 7.0 m as shown as groundwater basin in Fig. 4. Basic aquifer system was formed by Miocene impermeable sediments (Kagabu et al. 2011). Silty sand and sand layer layers was existed at depth of 6.00 to 10 m in saturated condition, these layers were concerned to have susceptibility to liquefaction potential and or were predicted as a liquefiable layer.

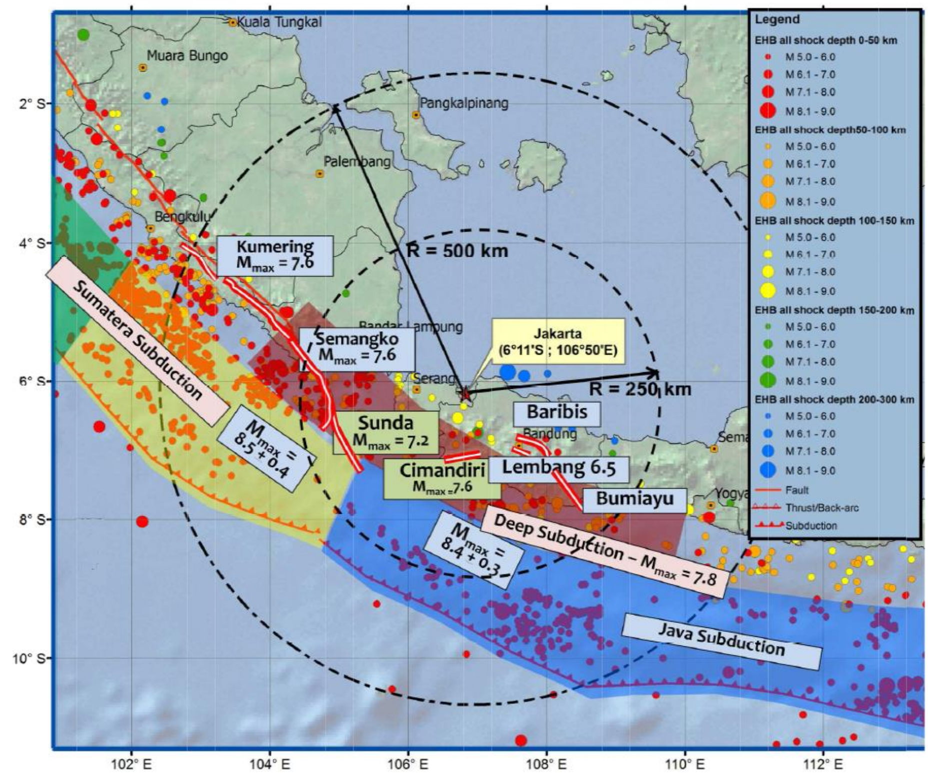

Fig. 3 - Seismotectonic map of Sumatera and Java Island which show the seismic source influencing Jakarta city (with permission from Irsyam et al. 2015)

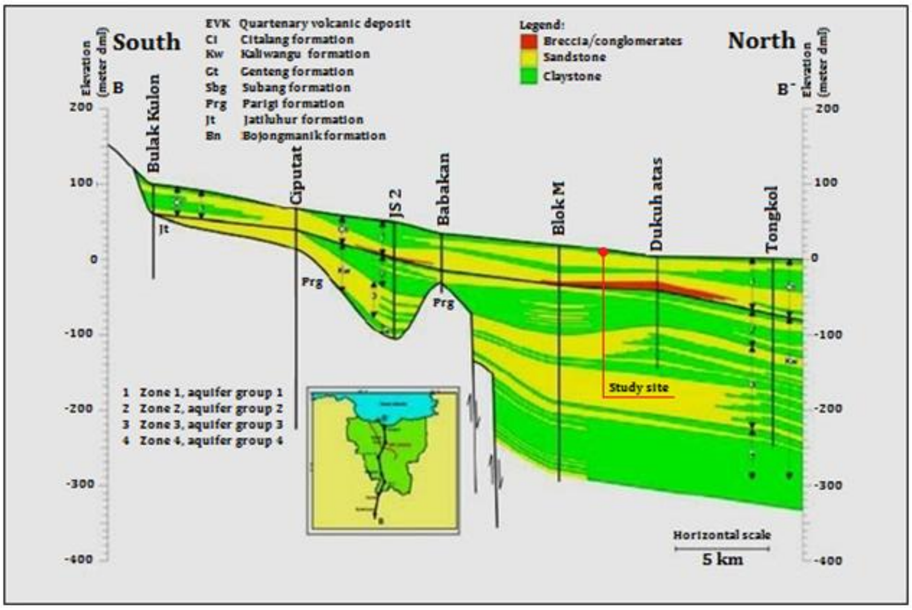

Fig. 4 - Hydrostratigraphy cross-section of DKI Jakarta (with permission from Hutasoit, 2011) in determining depth of ground water table on study area

Critical layer was necessary to the estimation $q_{c,1}$ and R_f for a given case history. Selection of the critical layer is required to estimate the soil stratum which the weakest of continuously soil layers from a liquefaction point of view. This study used normalization procedures routinely in CPT-based liquefaction triggering in one second after earthquake when determining correction value of q_c ($q_{c,1}$) (Moss et al. 2006). Normalization scheme be appointed through an assessment of effective vertical stress using iterative procedure. This procedure was applied to all soil layers where reasonable data existed and inherent variability. Fig. 5 shows the raw tip (q_c) and friction ratio (R_F) plotted in determining an initial estimate of the normalization exponent (c) and value of the modified normalized CPT tip resistance ($q_{c,1mod}$) after determining of $q_{c,1}$. Correction of equivalent uniform cyclic stress ratio (CSR^*) with using magnitude-correlated duration weighting factor (DWFM) was calculated by the dependent variable consisted of the maximum or peak horizontal ground acceleration or PGA (a_{max}), the total and effective vertical stresses (s_v) and (s_v'), and the nonlinear shear mass participation factor(r_d). Threshold limits were analyzed with using engineering geostatistical in determining probabilistic for liquefaction (P_L). This study used the correlation of contours of probability of liquefaction (for P_L=5, 20, 50, 80, and 95%). Probabilistic analysis was only considered and selected for silty sand and sand only layers. Herein, cohesive soils would not be considered as the liquefiable layers and calculation of probabilistic discontinue.

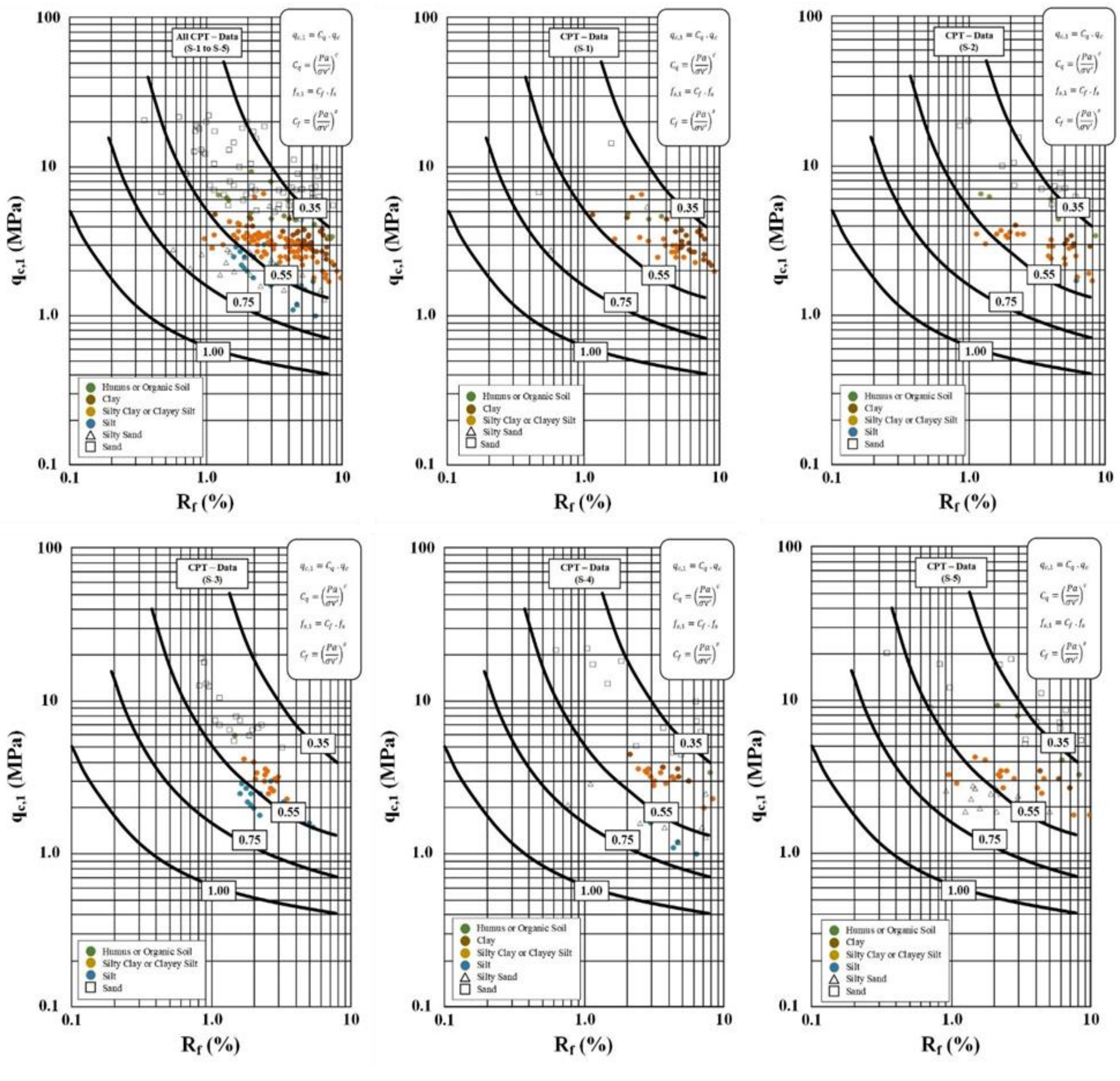

Fig. 5 - Raw data of tip (qc, 1) in determining c following normalization procedure

3. Result and Discussion

As a probabilistic consideration of liquefaction potential of Central Jakarta consists of: location and area. From geology references at the previous discussion, the central of Jakarta is a layer of soft clay soil and loose sandy soil originating from alluvial deposits. The soil layers encountered were matched for alluvial deposit characteristics. All CPT – sample data (S-1 to S-5) plotted graphically as shown as Fig. 5 identified that the prediction of liquefiable soil layer of alluvial type deposits found were as silty sand and or sand. Silty sand and or sand were existed in the thin layer or a lenses form or the thick layers. The silty sand lens layer existed in a thickness range from 0.20 to 0.60 m and was as a discontinue layers on silty clay or clayey silt layers. Most of the sand layers as an aquifer layer and as a base of soft clay (silty clay or clayey silt layers) was started from 8.0 m to the hard layers or a base rock with variation thickness between 8,0 to 12,0 m. Groundwater table was set in a range from 5.40 m to 7.20 m. The silty sand or sandy soil layers in this area was concerned to have the potential for liquefaction in the event of a strong earthquake. Fig. 6 shows the distributions of probability of liquefaction potential especially for silty sand and sand. Correlation of contours shows the probability of liquefaction (for PL=5, 20, 50, 80, and 95).

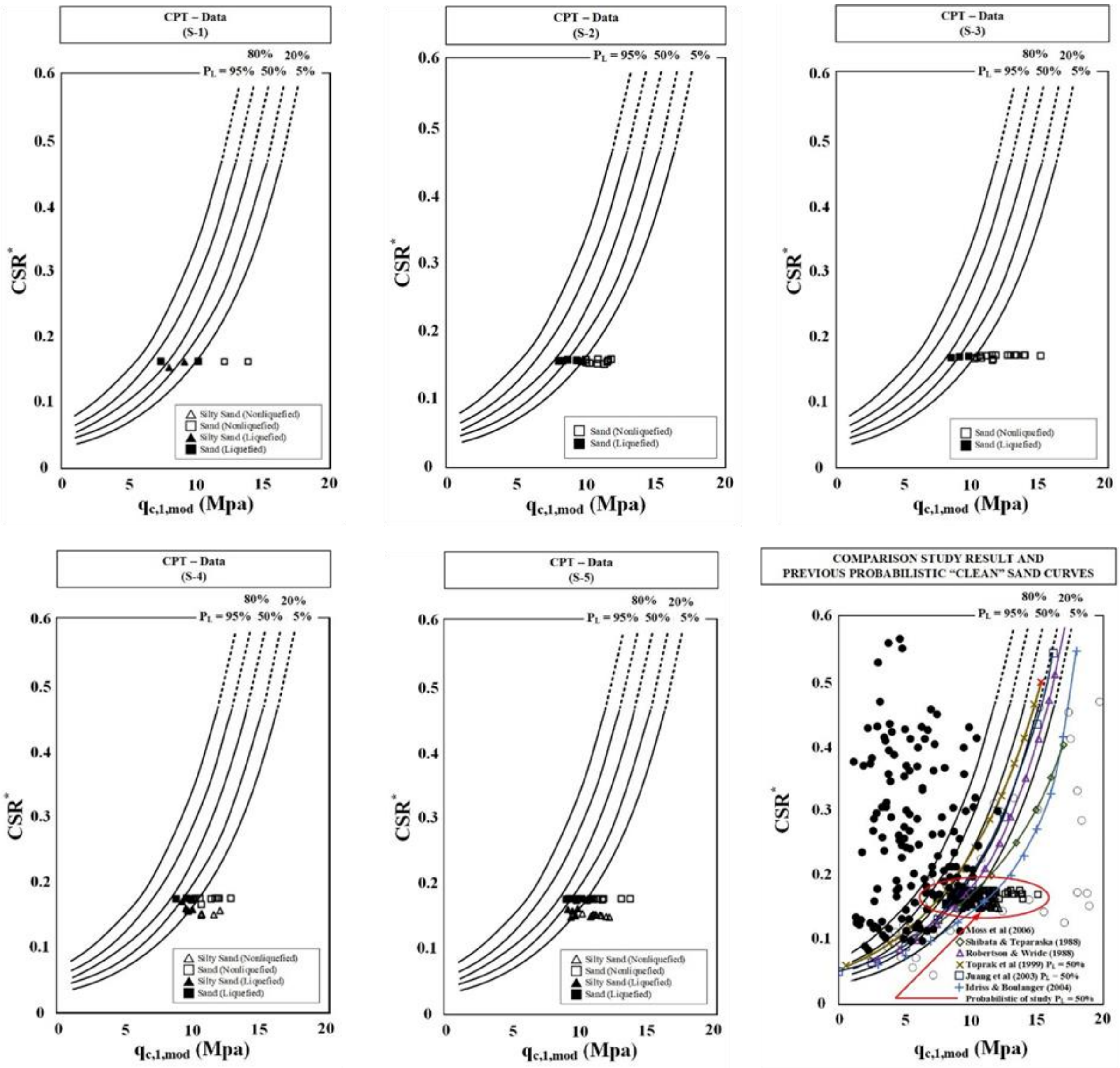

Fig. 6 - Probability liquefaction for 5, 20, 50, 80, and 95% of silty sand and sand layers
Full black circles/squares/triangles are liquefied and blank circles/squares/triangles are nonliquefied

Fig. 6 shows the the probability of liquefaction (for PL=5, 20, 50, 80, and 95%) was determined by the equivalent uniform cyclic stress ratio (CSR*) and the modified normalized CPT tip resistance ($q_{c,1,mod}$). The soft soil consisting of silty clay or clayey soil; silt; and organic soil was not susceptible to liquefy since the deposits suffered by a large consolidation process during deposition process and the liquefaction analysis was discontinued. Fig. 6 also identifies that the probability of liquefaction (P_L) of Central Jakarta region has a range between 5 to 50%. Probability liquefaction also exposes that sand layers is more susceptible than silty sand layers. However, the sand layer at Central Jakarta is "not cleaner" than sand layer from Robertson and Wride (1998) results. Probabilistic curves show the characteristics of level liquefaction occurrence at study area. Recent updates of probabilistic curves were provided by Idriss & Boulanger (2006); Cetin et al. (2004); Moss (2003); Moss et al. (2006) and Juang et al. (2006). Probabilistic curves also identify the variance of seismic demand generating greatest in the high CSR range and exhibiting to greatest in the high $q_{c,1}$ range. The region where liquefaction and non-liquefaction data points merge can be thought of as a mixing zone between cohesionless and cohesive soil. In this zone lies the most likely threshold of liquefaction in the first time occured. This study only considered and selected for cohesionless soils (silty sand and sand layers). However, it is difficult in correlating strong ground shaking with occurrence liquefaction. Silty sand and sand as one part of alluvial sediments or deposits on study area, these layers can be densified and or reconsolidation particularly after earthquake with high penetration resistance. Previous studies shown that properties of silty sand and or sand on alluvial deposits were unchanged for pre- and post-earthquake subject to liquefaction. Otherwise, several locations especially for cohesionless soil layer changes in properties after the strong earthquake and penetration resistant is relatively lower than before ground shaking. These observations are consistent with critical state principles, which would predict that volume change from post-ground shaking reconsolidation would increase with the state parameter (i.e., increase with decreasing relative density for a fixed confinement). In this study, penetration resistance of sediments in triggering limit-state, or threshold will not be significantly affected by reconsolidation after strong ground shaking in the past.

The seismic hazard curves for PGA, 0,20 and 1,0 second spectral period has been developed and deagregated to obtain representing magnitudes and distances for 500 and 2500 years for Central of Jakarta. However, probability liquefaction (PL) for this study uses magnitudes and distances for 500 years only with PGA less than 0.42 gal and has reached the P_L closing to 50% despite the P_L value is quiet influenced by case of stiff thin layer at study area. Silty sand and sand layer as a part of alluvial deposit of Central Jakarta would give a much higher tip resistance than the surrounding fine deposits, thereby producing a stiff, thin, potentially liquefiable layer within softer surrounding material. Normalization using effective vertical stress was also a problem in determining exponent curves (c) since the saturated weight volume of silty sand and sand was unknown or not showing the true value; tip normalization factor (C_q) in measuring effective vertical stress using iteration process is same with trial and error. The other problem in determining total and effective vertical stress were difficult to avoid a linear relationship.

4. Conclusion

Evaluation results of probability liquefaction of silty sand and sand layers classified as a susceptible layer, however, the probability of the liquefaction occurred at study area are low in a ranging of 5 to 50%. Prediction of probability of liquefaction (PL) can be used as a basic design especially for the silty sand and sand layers existing at Central Jakarta region. Probability liquefaction (PL) for this study also uses magnitudes and distances for 500 years only with peak ground acceleration less than 0.42 gal.

Although there are still weaknesses from the method of Moss et al. (2006), this method can be used to find out the probability of liquefaction (PL) for CPT-data randomly from Central Jakarta region. CPT is an economical of field test and provides reliable in situ continuous soundings of subsurface soil. However, analysis of total and effective vertical stress should be more developed to generate some correlations required in determining the probability liquefaction of silty sand and sand layers accurately, thus the probability curves can be used to measure liquefaction characteristic without the borlogs and or SPT test.

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