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Potential Liquefaction Of Loose Sand Lenses: Case Study in Surabaya East Coastal Plain, Indonesia

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Abstract: The zone of east coastal Surabaya becomes the object of development for the city, especially to the east coastal plain. Although in the recent years, that area does not have a structure or heavy construction and or a high rise building yet, but in the future the zone will turn into a business area with a variety of activities. The zone of east coastal Surabaya is an alluvium deposit area. This layer is considered as clay deposited from some rivers and sea. From general information, the typical soil stratigraphy consists of soft clay and silt layers with many sand lenses with or without coarse grained soil with a depth varying from 0.00 to 10.00 meters (m). The saturated sand lenses with a water table depth varies from 0.40 to 1.20 m is susceptible earthquake and it has a relatively large seismic amplification from base-rock due to geological and soil condition nature of the site. Liquefaction hazard of the sand lenses has to be anticipated and evaluated. For development of Surabaya city area toward the east coastal plain, all developer are recommended to give some criteria of sand lenses density and some consideration for anticipating the liquefaction hazard.

Keywords: Loose sand lenses, potential liquefaction, seismic amplification, liquefaction severity index, probability of liquefaction.

1. Introduction

All the areas of Surabaya city are located at 7^o SL, 113^o EL, and the position of town is close to Madura Strait. Surabaya city consists of five regions, namely: northern, southern, western, eastern and center part of the city. The area of Surabaya city spreads out from northern part (Gresik region) to eastern part (Sidoarjo region). The length of shoreline is about 20 kilometers.

Based on Fig. 1 (during observation from 1993 - 1999), it is known that the direction of development area moves to east coastal zone, although this time it has no big and tall building yet. However, in the future this zone will become a permanent resident area. The wide region is 2,822.487 hectares or 6.844 percent of the entire Surabaya city. Study area is commonly called "Delta Brantas," which extends to the eastern coast. The most parts of Surabaya east coastal zone are alluvium deposit area that has many sand lenses in the depth of 0.00 to 10.00 m and these sand lenses are with shallow ground water table that may show an indication of liquefaction possibility. Geographically it is the alluvium deposit zone that is bordered by Kali Porong and Kali Surabaya. Each part of this Delta Brantas has folding lands such as: Pucangan, Kabuh, Lidah and Pamekasan formations, respectively that have the Holocene characteristic. Liquefaction is one phenomenon that has to be predicted and anticipated as soon as possible because the possibility of liquefaction hazard can damage the building structure around this zone. In addition, Surabaya area is categorized as a zone of seismic source regions in Indonesia. The consequence is that Surabaya has a potential to earthquake hazard. Therefore, liquefaction potential of the loose sand lenses is one important aspect that needs to be considered.

Focus of this paper is to determine the potential liquefaction of the loose sand lenses in east coastal of Surabaya based on the field and laboratory research. This paper will also present some information such as: general geological condition, local soil condition, maximum acceleration with amplification factor from base rock to sand lenses, and prediction of potential liquefaction of Surabaya east coastal zone.

2. Background

Liquefaction susceptibility is the likelihood of liquefaction and ground failure during seismic shaking. Susceptibility for ground failure is a function of the geological materials and geotechnical properties of the deposit alone and is independent of the expected seismicity of the region. Factors affecting ground failure susceptibility include sedimentation processes, age of deposition, geological history, depth of water table, grain size distribution, and soil density. The susceptibility of liquefaction can be analyzed with measurement of soil

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properties [1], such as: relative density (Dr), standard penetration resistance (SPT), and cone penetration resistance (CPT). Research recently reviewed the state of the art of liquefaction resistance evaluation using CPT data and concluded that correlation with SPT data are preferable because of the wider data base of SPT.

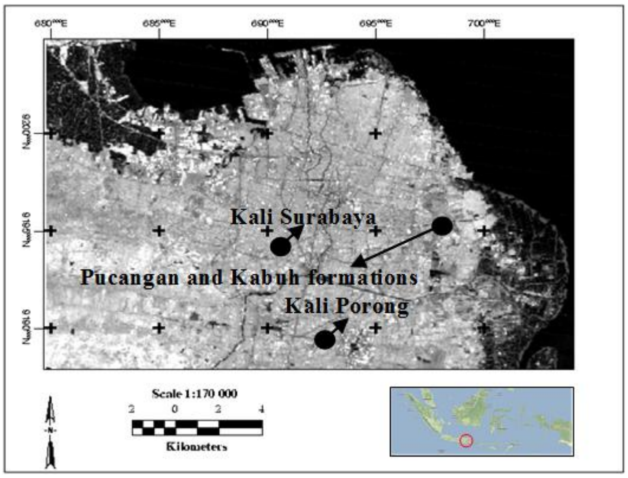

Fig. 1 Current Surabaya city map (ITS – Geographic data) .

Liquefaction will occur caused by a strong ground motion. It is a function of the magnitude (or intensity) of the earthquake, distance from the site to the source, general soil condition, duration of shaking, and return period. Typical measurements of the opportunity are ground acceleration (Peak Ground Acceleration or PGA) based on Modified Mercally Intensity (MMI), and Richter Scale (SR) magnitude. In this study, measurement of both the capacity of the soil to resist liquefaction caused by earthquake is established in a probabilistic analysis framework [2].

3. Liquefaction potential

The liquefaction of non – cohesive or sandy soil is the loss of mechanic endurance from soil, as a result of cyclic earthquake load or monotonic load. The loss of soil resistance is started by the loss of effective stress between the particles of soil caused by the increment of pore water pressure with degree of saturation between 95 – 100%.

The increment pore water pressure is occurred in the undrained condition or short term caused by a cyclic load. In liquefaction occurrence, the soil behavior changes to fluid-viscous. The loss of the mechanic endurance can be explained by Mohr-Coulomb theory:

$$\tau = c' + (\sigma - u)\ \mathrm{tg}\,\phi' \qquad (1)$$

For non cohesive sand, c’ = 0, the equation becomes:

$$\tau = (\sigma - u)\ \mathrm{tg}\,\phi' \qquad (2)$$

Liquefaction is occurred at the condition $u = \sigma$, then $\sigma' = 0$, finally $\tau = 0$.

There are many methods to evaluate the potential of liquefaction. One group of methods is based on Seed and Idriss method. Seed and Idriss analyzed the effect of an earthquake on the soil by the ratio of the average earthquake induced shear stress to the effective confining pressure. This ratio, the cyclic stress ratio (CSR), is obtained from:

$$CSR = \frac{\tau}{\sigma'_0} = 0.65\,\frac{\sigma_0}{\sigma'_0}.\,a_{max}.r_d \qquad (3)$$

where a_{max} is the maximum of PGA, r_d is the reduction factor for soil flexibility varying from one at the surface to 0.85 at a depth of 30 ft (10 m) and given by Iwasaki (1981) as:

$$r_d = 1 - 0.015d \qquad (4)$$

Liquefaction likely occurs if the cyclic stress ratio exceeds the critical cyclic stress ratio (CCSR), defined as the ratio of the cyclic strength of the soil over the effective overburden pressure. The critical cyclic stress ratio required to cause liquefaction can be evaluated from laboratory experiments on samples of materials or by empirical relationships with in situ test. Evaluation of potential liquefaction to sand lenses will be presented.

The result of soil liquefaction could be settlement, sliding, boiling, or even the destruction of the building, bridge, roadway, railroad, and earth dam. According to some previous research, liquefaction occurred on sand lenses due to earthquake will cause not only liquefaction but also the tensile – cracks. Liquefaction of sand lenses can also induce the differential settlement of upper structure. Based on the data above, it is important that the liquefaction phenomenon at study area be predicted and anticipated.

4. Loose sand lenses

The region of Surabaya east coastal plain has many sand lenses. The direct zone is located in the eastern part of Surabaya city. The surface soils are alluvium and marine deposits of loose fine sand, silts, sandy clays, and soft clays. The surface soils are approximately 8000 years old and increase in age with depth. In the location are always found coral shell fragments in soils of similar origin. Current geologically mapping indicates some joints between Pucangan, Kabuh, Lidah, and Pamekasan area (Fig. 2).

Soil conditions were obtained from examination of over 464 data that consist of boring log; SPT; and CPT. Points of observation and the name of each location are shown in Fig. 3 and Table 1, respectively. There are 66 points of bore hole at study area. Most boring logs showed the ground water table to be approximately 0.4 to 1.20 m of the surface. However, fluctuation of ground water table is influenced by tides and heavy rains, so that they were considered realistically by an assumption if the water table was only located at the ground surface.

Boreholes relatively close to one another were combined into composite boring logs based on the similarity of soil types and soil location in the profile. Averages of layer thickness, layer depth, and penetration resistance (SPT and CPT) were used to generate the composite logs.

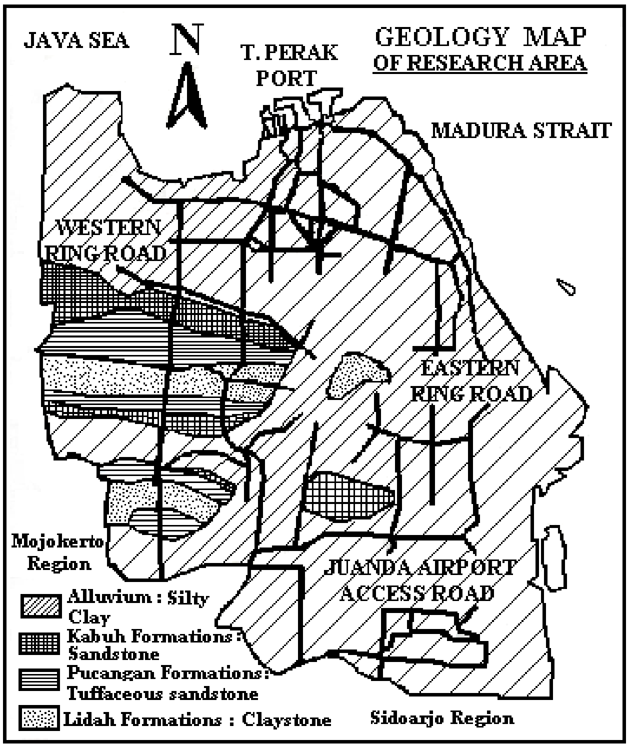

Fig. 2 Geology formations (ITS-Geology data).

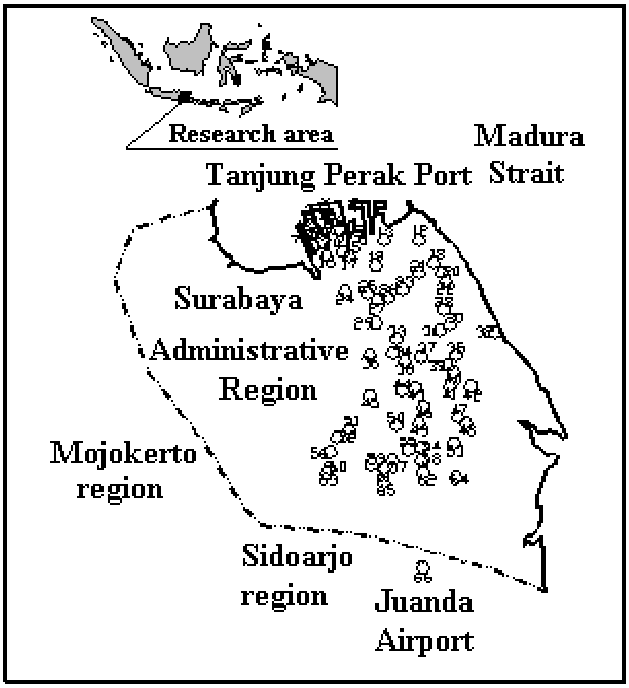

Fig. 3 Locations of boreholes (ITS – data).

Table 1 Name location of bore hole

The Observation Points of Surabaya East Coastal Plain Area			
No.	Names of Place	No.	Names of Place
1	Dermaga Ujung	34	Gedung R.Menular Anak / RSUD Dr. Soetomo
2	KPLP. Tanjung Perak	35	Kalisari
3	Gudang 505 / Jl. Nilam Timur	36	Jln. Basuki Rahmat
4	PT. Dok – Perak Barat	37	Sinar Galaxi Jl. Manyar Kertoarjo
5	PT. Kayu Mas / Jl. Nilam Timur	38	Shopping Centre Jl. Manyar Kertoarjo
6	PT. PAL Ujung (1)	39	Keputih / FNGT- ITS / Sukolilo
7	Jl. Nilam Timur Perak	40	Jl. Arif Rahman Hakim / Keputih / ITS / Sukolilo
8	Perak - Ujung	41	Kopertis Wilayah VII / Keputih / ITS
9	Jl. Prapat Kurung-Perak	42	Keputih
10	Kompleks Pertamina / Jl. Perak Barat	43	Kampus STIPAK / Klampis Ngasem
11	Kantor BMG Pelabuhan Tanjung Perak	44	Ngagel Jaya Utara / Ngagel Madya
12	Tambak Wedi	45	Bir Bintang / Jl. Ratna
13	Semampir / Wonokusumo	46	Universitas 17 Agustus / Semolowaru
14	Kodikal Surabaya	47	Medokan Semampir (1)
15	PT. PAL Ujung (2)	48	Medokan Semampir (2)
16	Tanjung Perak	49	Puri Indah / Medokan Semampir
17	Kompleks AKABRI LAUT Bumimoro	50	Kantor P & K / Jl. Jagir
18	Jl. Kedung Cowek-Kenjeran (1)	51	Kompleks Rumkital (RSAL) Surabaya
19	Tenggumung Baru	52	PLN / Jl. Ketintang Baru
20	Pantai Ria / Kenjeran	53	Wonoayu / Rungkut
21	Gading Indah Utara	54	Puri Indah / Rungkut
22	Jl. Kedung Cowek-Kenjeran (2)	55	Universitas Surabaya / Jl. Kompleks Kalirungkut
23	Proyek sekolah guru Kedung Cowek	56	Kantor Dinas Kesehatan / Jl. A.Yani
24	Bank Umum Nasional / Jl. Karet 67	57	PT.Kimia Farma Kawasan SIER / Rungkut Industri
25	Pertokoan Stasiun Semut	58	PT. Warna Agung / Rungkut Industri
26	Rangkah	59	Kantor Statistik Sensus / Rungkut
27	Rumah sakit Adi Husada cabang Kapasari	60	P2AT Gayung Kebonsari / Wonocolo
28	Kompleks Kenjeran	61	PT. Kedawung Subur / Rungkut
29	Mulyorejo	62	YKP / Gunung Anyar
30	Kalisari / Mulyosari	63	Kebonsari Gayungan
31	Perumahan Kalijudan	64	Perum Joyo Bekti / Gunung Anyar
32	Sisi pantai Laguna	65	Perumnas Menanggal
33	Universitas Airlangga (Gedung Penelitian)	66	Kantor BMG Lapangan terbang Juanda

Up to a depth of 10.00 m below the ground surface, actually the soils at the zone consist of alternating layers of clay and sand. Fig. 4 shows typical results of soil layers at Surabaya east coastal plain. The silt and clay vary from medium stiff to soft, while the sand layers are loose to medium dense. From the drilling on this alluvium area, the closer to the beach, the more the sand lenses. The thickness of sand lenses varied from 0.5 to 8 meters and it was not continued. Sand lenses SPT N-values of near surface [< 30 ft (10 m] varied from 0 to 18. Cone resistance (q_c) values of near surface varied from 0.5 to 200 kg/cm^2 (Fig. 5). Most of boring logs examined gave a description of the soils based on the Unified Soil Classification System (USCS). Average of fines content of the sand lenses (silty sand or SM) was about greater than 12 %. From Tsuchida graphic (Fig. 6) using sieve analysis data, data plotted from Figs. 4 and 5 shows sand lenses classified as potentially liquefiable soils.

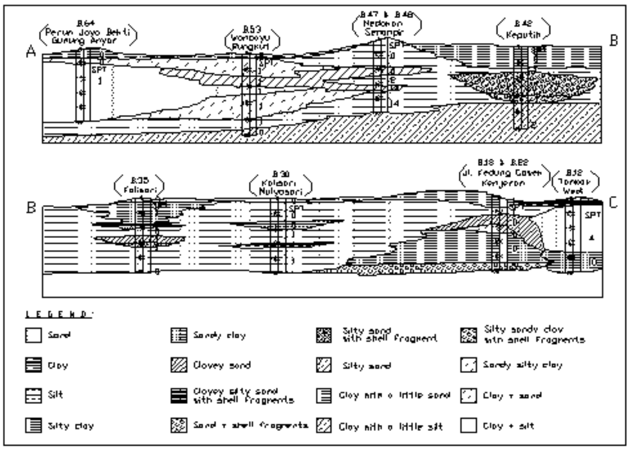

Fig. 4 Typical soil layers at Surabaya east coastal plain identified from soil investigation [3].

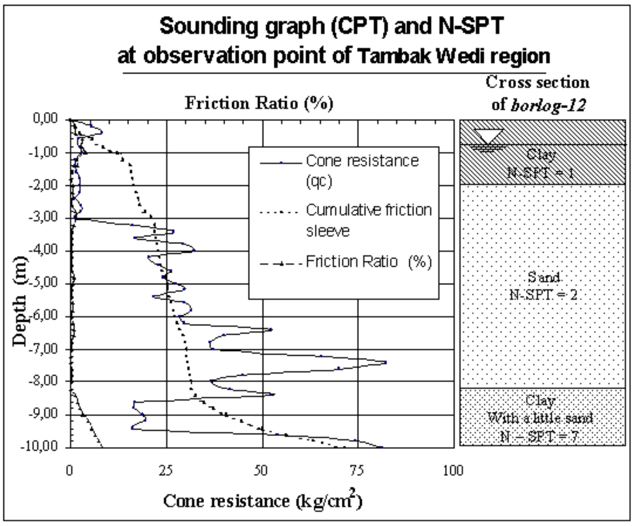

Fig. 5 Typical field test result from cone penetration test showing sand lenses stratum in Tambak Wedi region (Geoteknik – ITS data).

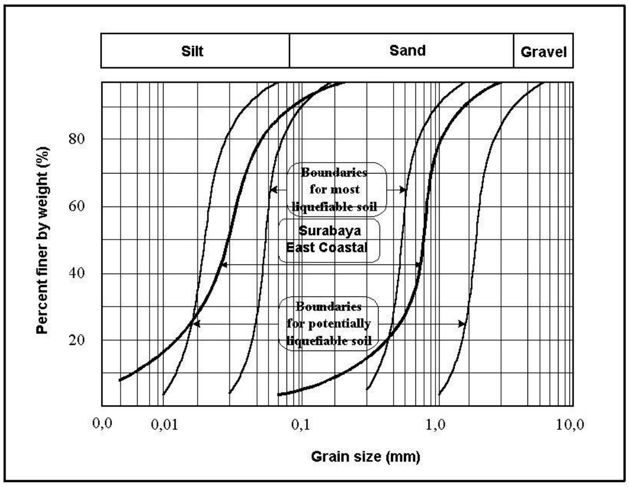

Fig. 6 Identification of liquefiable soil at Surabaya east coastal plain based on sieve analysis of Tsuchida graphic (Geoteknik – ITS data).

Selection of correlation is a critical matter in liquefaction analysis. There are many correlations in order to generate dynamic parameters, which could be used for the liquefaction analysis. Table 2 shows the laboratory testing result for dynamic parameters from Surabaya east coastal plain [2].

Table 2 Dynamic parameters Surabaya east coastal plain

Soil	Layer	(G_{max}) [ksf]	(D) [%]	γ [kcf]
Sand	Upper	300 – 500	0.05 – 0.12	0.088 – 0.090
	Lower	750 – 2500	0.08 – 0.17	0.092 – 0.101
Silt	Upper	100 – 250	0.06 – 0.09	0.090 – 0.094
	Lower	500 – 2250	0.07 – 0.15	0.093 – 0.118
Clay	Upper	75 – 175	0.03 – 0.08	0.093 – 0.095
	Lower	350 – 1750	0.04 – 0.10	0.094 – 0.120

5. Seismicity

Surabaya area is one of seismic zones in Indonesia [4]. Surabaya area is classified as a zone earthquake hazard with medium potential level. The zonation of Surabaya area is based on seismic risk analysis. Maximum acceleration at base rock can be estimated using seismic potential analysis. Variables input uses magnitude (M) and hypocenter distance (R) parameters. In one case, earthquake sources are selected and considered as a variable to study area. For the past 40 years (1960 – 2000), Geophysical Station at Tretes, East Java, recorded earthquake data due to seismotectonic and volcanic mechanism.

Hypotheses based on historical seismicity, geological, seismic reflection and refraction, and potential field data have been proposed to explain the current seismicity at study area. However, almost entirely source points of seismotectonic from subduction zone deriving from southern of Java Island were considered dominantly influencing to Surabaya area (Fig. 7). Point sources from seismotectonic mechanism adjacent to folding or fault zone in Pucangan, Kabuh, Lidah, and Pamekasan area have extremely little influence on the ground shaking, because the sources points having the magnitude (M) > 5.0 SR were not found in this zone. Fig. 8 shows the distribution of seismic source points nearby Surabaya area. None of these models appears to be universally accepted by the scientific community. However, there does seem to be a trend toward the definition of seismic zones that would encompass the possible tectonic features proposed by some models and the recorded seismicity. Using the location of the epicenters of past earthquake, proposed to modeling of seismic sources shown in Fig. 9 and Fig. 10 [2]. Function of attenuation was selected based on subduction earthquake mechanism [4]. Attenuation function from Crouse (1991) is selected and assumed the same with mechanism of earthquake caused by subduction zone. Critical earthquake models using USGS method is box source type of shallow and deep earthquakes, respectively. The results of maximum acceleration (PGA) recommendation values of ground surface for Surabaya area based on seismic risk analysis with attenuation function from Crouse are shown in Fig. 11.

6. Liquefaction analysis of sand lenses

Based on Seed and Idriss method, the critical depth of liquefaction occurs at depth between 0.9 until 12.7 m from ground surface. While in Surabaya east coastal plain, the sand lenses are between the depth of 0.00 and 10.00 m from ground surface. The following discussion presents analysis about sand lenses at one part of Surabaya east coastal plain zones.

6.1 Liquefaction analysis based on CPT

Based on the Pecker graphic [5], relative density (D_r) has a great influence on sand soil liquefaction cyclic stress. The density relative at interest area is less than

50%. As shown in Fig. 12, the liquefaction cyclic stress occurred on the sand soil stratum of Surabaya east coastal plain zone is the lowest. Some parameters of liquefaction cyclic stress (τ/σ'_v) were determined by correlation between relative density relative (D_r) and cone resistance (q_c) from sounding or CPT test.

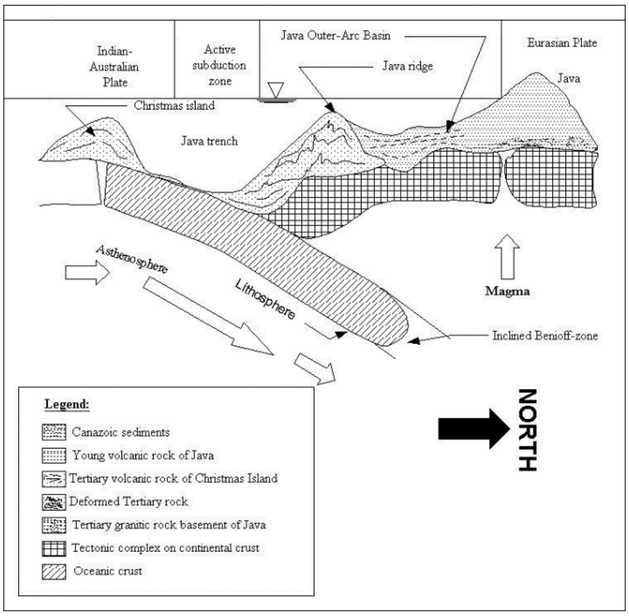

Fig. 7 Cross section showing geological condition related to seismic activities of Java Island (Geophysical Station data).

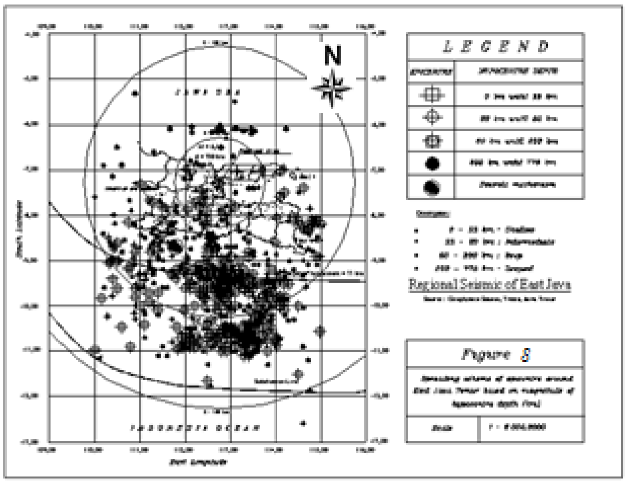

Fig. 8 The distribution of seismic source points having greatly influence to Surabaya east coastal plain zone (Geophysical Station Data, Tretes, 2001).

Liquefaction analysis based on CPT test apply Seed and Peacock method, their method uses overburden pressure, mean of grain size distribution (D_{50}), critical cyclic stress ratio or CCSR (τ_{av}/σ'_0), and relative density (D_r) parameters Fig. 13 shows one study to determine mean grain size distribution of sand lenses stratum from CPT tests at Medokan Semampir.

From Medokan Semampir data, at this area can be analyzed strain magnitude for soil layer of full saturated sandy soil from 0.00 to 6.00 m depth, ground water table at ground surface, average of cone resistant (q_c) value of 5 kg/cm^2, γ = 1.619 g_r/c_c, and D_{50} = 0.382 mm, and earthquake magnitude (M) = 7.0 SR (Richter Scale). Relative density can be defined by cone resistance (q_c) and overburden pressure (σ'_v) using the equation:

$$D_r = 10.2\left(\sqrt{\frac{q_c}{\sigma'_v + 0.7}}\right) \quad (5)$$

By using this equation, it is obtained D_r = 25% in each depth of sand lenses layer for Medokan Semampir region. Then, cyclic stress ratio (CSR) is obtained by using Equation (3). Table 3 shows sample data of Surabaya east coastal plain zone from Medokan Semampir. Parameter of was determined by τ value on Table 3 using mean of grain distribution of D_{50} = 0.382 mm, then it was obtained σ_{dc} / $2\sigma_a$ = 0.25 with number of cycles = 10 for earthquake magnitude (M) = 7.0 SR. Cr value was put of 0.57 because the values of relative density from sand lenses were between 0% and 50%.

Table 3 The example of analysis based on CPT

Depth (ft)	γ . h (lb/ft^2)	a_{max} / g	r_d	τ_{av} (lb/ft^2)	σ'_v (lb/ft^2)	τ (lb/ft^2)
5.0	502.74	0.1	0.99	32.351	190.24	13.555
10.0	1005.48	0.1	0.98	64.049	380.48	27.110
15.0	1508.22	0.1	0.97	95.093	570.72	40.664
20.0	2010.96	0.1	0.96	125.484	760.96	54.218

Liquefaction potential will be depended by existing soil shear strain magnitude (τ) liquefaction laboratory works and shear strain caused by earthquake (τ_{av}), if $\tau_{av} > \tau$ liquefaction will be occurred. For example, if the sand lenses layer of Surabaya east coastal plain zone has the relative density (D_r) ≈ 60 % or the cone resistant (q_c) value from CPT minimum 30 kg/cm^2, τ enlarger than τ_{av} values, there is “No Liquefaction.”

6.2 Liquefaction analysis based on SPT

SPT data will be used to determine critical cyclic stress ratio or CCSR (τ_{av}/σ'_0) based on Seed and Idriss method (1976). CCSR will be depended on earthquake magnitude (M) and fines content (f). For example, Medokan Semampir has the N value of SPT = 1 to 2, SPT data must be normalized and corrected by overburden pressure and energy ratio of hammer used in the investigation. The corrected N-value is calculated from:

$$(N_1) = N \times C_n \times ER \quad (6)$$

C_n and ER are the correction factor (overburden pressure and energy ratio, respectively). Table 4 shows analysis result to determine liquefaction potential.

Table 4. The example of analysis based on N – SPT

Depth (ft)	γ . h (lb/ft²)	C_n x ER	N (blow/ft)	N_1	(τ_{av}/σ'_v)	τ (lb/ft²)
5.0	190.29	1.820	2	3.640	0.045	0.856
10.0	380.48	1.588	2	3.176	0.040	15.219
15.0	570.72	1.953	2	2.910	0.438	21.687
20.0	760.96	1.357	2	2.710	0.037	28.156

Note:
1. Depth calculation used in feet (ft)
2. C_n = correction factor.
3. ER = correction factor.
4. τ_{av}/σ'_v from graphic of Seed method.
5. Original N-value of SPT from an interest area.

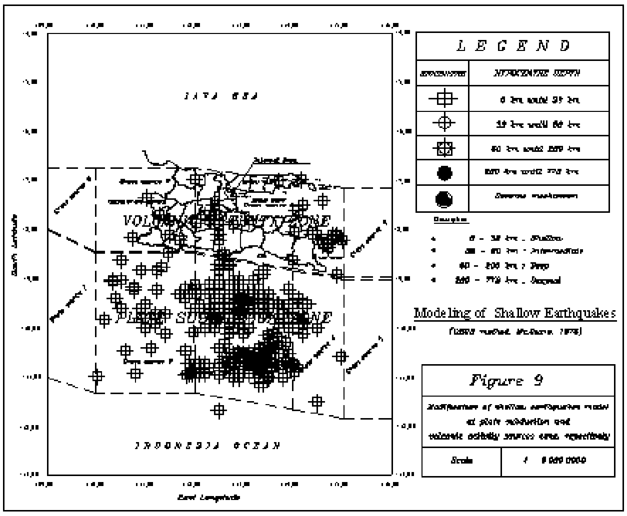

Fig. 9 Modeling of shallow earthquakes.

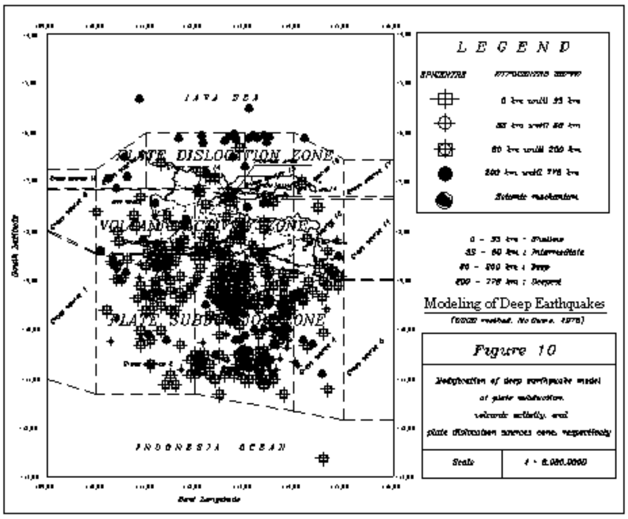

Fig. 10 Modeling of deep earthquakes.

6.3 Liquefaction analysis based on TCT

The experimental result of triaxial cyclic test (TCT) (Fig. 14) shows that sand samples from sand lenses brought from field in one location at Surabaya east coastal plain zone. There is an initial liquefaction starting at 10th cycles and loss all of its effective strength (liquefied) at 18th cycles with the conditions:

- Dr ≈ 50 % (relative density).
- D_{50} = 1.50 mm (mean grain size).
- $\sigma_3 = \pm 1.0$ kg/cm² = 100 kPa (confining pressure).
- Undrained condition and disturbed sample.

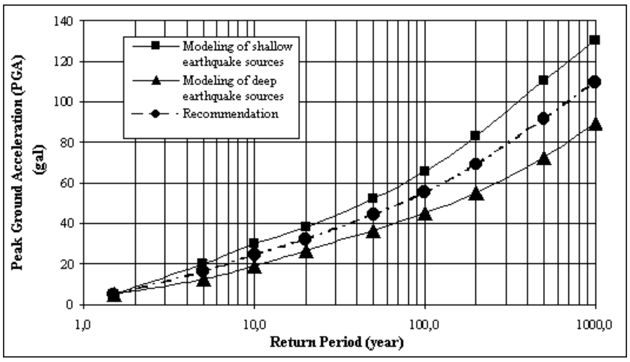

Fig. 11 The maximum acceleration recommendation values of at soil layers (PGA) for Surabaya area.

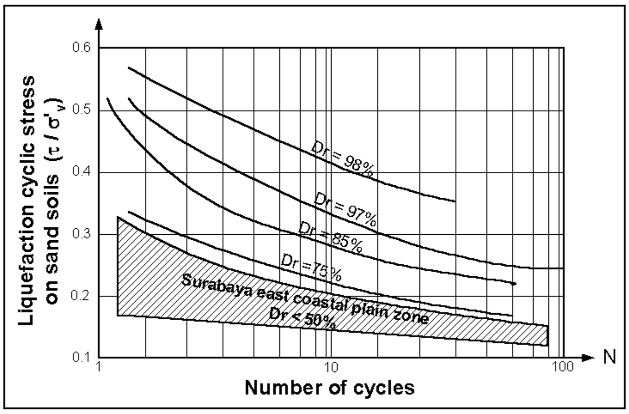

Fig. 12 Prediction of liquefaction cyclic stress values according to Pecker graphic.

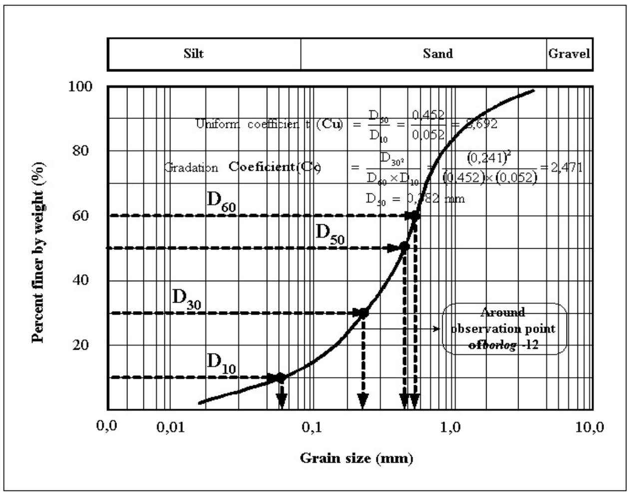

Fig. 13 Mean grain size distribution (D_{50}) of sand lenses layer at Medokan Semampir (point 47th, 48th, and 49th).

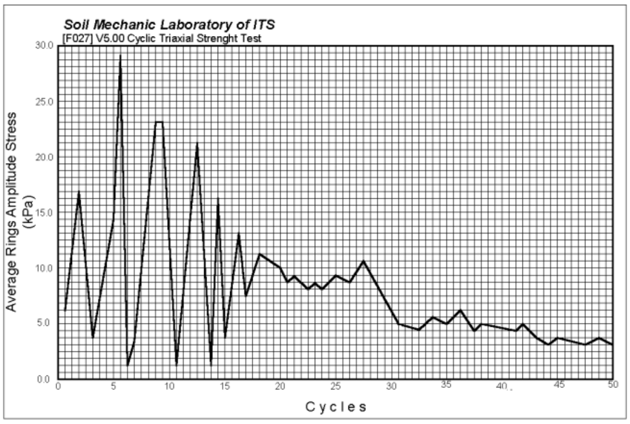

Fig. 14 Liquefaction analysis by triaxial cyclic test.

6.4 Liquefaction analysis based on ZM

The optimum seeking of Zhang method (ZM) is used to observe the potential liquefaction to the sand lenses. The equation is like this:

$$LP = 35G(M) + 32G(\sigma_{v0}) + 71G(q_c) + 34G(a_{max}) + 39G(D_{50}) \quad (7)$$

- LP = Liquefaction potential:
  If LP > 321 → Liquefaction happening.
  If LP < 321 → Liquefaction not happening.
- M = Maximum Earthquake magnitude ($M \approx 6.0$).
- σ_{v0} = Vertical effective overburden pressure.
- q_c = CPT type resistance ($q_c = \pm$ 20 kg/cm^2).
- a_{max} = Maximum PGA (a_{max} = 0.10 g).
- D_{50} = Mean grain size (D_{50} = 0.15 mm).
- $G_{(*)}$ = Grade factor appropriated with each variables (M, σ_{v0}, q_c, a_{max}, and D_{50}).

From the statistic calculation to the Surabaya east coastal zone is obtained LP value about 412, so this zone has liquefaction potential. Fig. 15 shows some coefficients of variation (COV) of soil data.

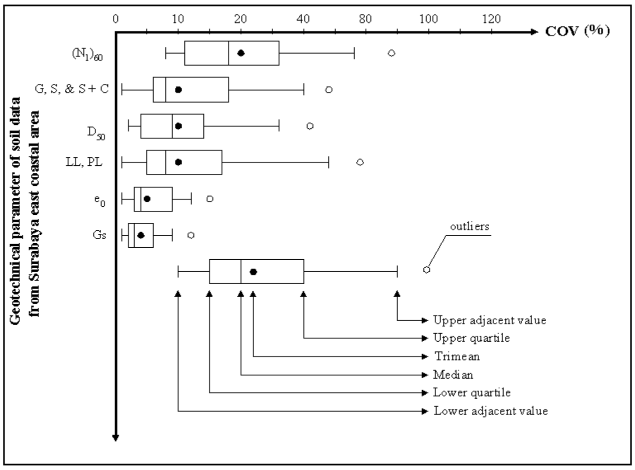

Fig. 15 Coefficient of variation (COV) of soil data.

6.5 Liquefaction analysis by SHAKE

Based on some research results in Japan and in Indonesia close to the characteristic of sand lenses layer at Surabaya east coastal plain zone showed that those sand lenses can have a liquefaction potential.

The results of running of software package SHAKE91 using El-Centro earthquake characteristic show that the sand lenses are susceptible to liquefaction potential. Fig. 16 shows El-Centro acceleration versus time input at base rock scaled to maximum acceleration for Surabaya east coastal plain zone.

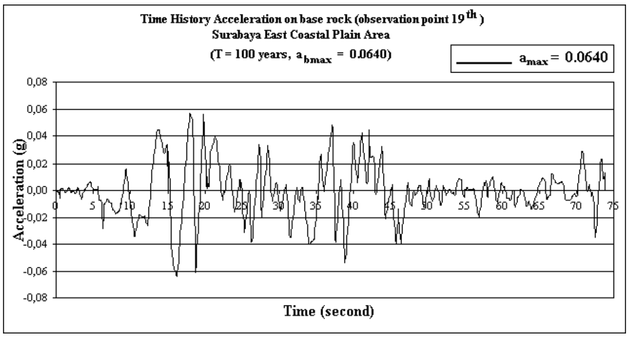

Fig. 16 Acceleration versus time El-Centro earthquake for input at base rock scaled to maximum acceleration for Surabaya East Coastal Plain Area.

Recent study on seismic risk considering local ground condition shows that a possible significant amplification factor is anticipated for site, which lies above loose sand lenses deposits using this software. Based on the previous research, the equation of amplification factor can be defined as:

$$Af = \frac{(a_{max})_{ground\ surface}}{(a_{max})_{base\text{-}rock}} \quad (8)$$

Fig. 17 shows acceleration versus time response at ground surface as a result of wave propagation analysis considering local condition for Surabaya east coastal plain zone (at observation point 19th from Table 1 around Tenggumung Baru region). Fig. 17 shows that the amplification factor from base rock to ground surface greatly depends on earthquake characteristics. It is shown by this analysis that significant amplification occur due to thick alluvium clay deposit that is for Surabaya city is assumed continuous to a depth of 240 m to reach tertiary base rock. Low frequency earthquake characteristics tend to give greater amplification on sand lenses deposit. Recent study indicated that the average of amplification factor for Surabaya area has a range from 1.2 to 2.9.

6.6 Liquefaction analysis by LSI

A method is developed for compiling liquefaction hazard maps by mapping a parameter termed Liquefaction Severity Index or LSI [6]. LSI as a method of measurement of ground failure displacement is based on the displacement of lateral spreads on gently sloping late Holocene fluvial deposits, such as floodplains and deltas. By selecting a specific geologic environment, LSI is normalized with respect to site conditions. LSI values are evaluated for several earthquakes in East Java, and an equation is developed between LSI, earthquake magnitude (M), and distance from the seismic energy source (R) or seismic source zone to the interest area.

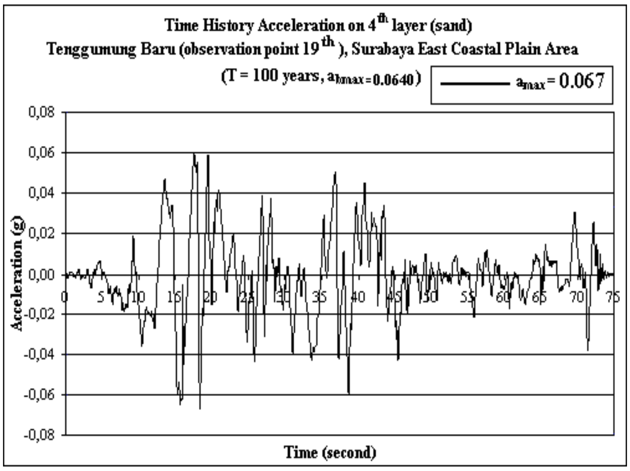

Fig. 17 Acceleration versus time response at ground surface of sand lenses deposit for Tenggumung Baru.

Evaluated hypothetically based on some earthquakes in America, [6] concluded that the influence of liquefaction potential is greatly depends on distance of seismic source. They suggested to use the equation for determining LSI:

$$\mathrm{Log}(\mathrm{LSI}) = -3.49 - 1.86\,\mathrm{Log}\,R + 0.98\,M \qquad (9)$$

This equation is only valid for western America and Alaska. Some researcher suggested the empirical equation that is probably valid for Indonesia region:

$$\mathrm{Log}(\mathrm{LSI}) = -2.94 - 1.32\,\mathrm{Log}\,R + 1.02\,M \qquad (10)$$

Fig. 18 shows the contours maps of LSI with 90% probability of nonexceedance in return periods of 100 years. LSI maps are useful for determining the relative liquefaction hazard and providing an index of possible maximum ground displacement.

6.7 Probability of liquefaction

Probability of liquefaction (P[L]) is required to find one location at Surabaya east coastal zone having potential to cause disturbance due to liquefaction. The probability of liquefaction is defined as the probability of exceedance of the critical acceleration (a_c) during future seismic events. Denoting the acceleration induced by future events as (a_s), the probability of liquefaction is computed from:

$$P[\mathrm{Liquefaction}] = P[L] = P\left[a_s\ \tilde{n}\ a_c\right] \qquad (11)$$

An alternative group of methods is based on in situ test-based characteristics of liquefaction resistance [7]. These methods use various statistical classification and regression analyses to assign probabilities of liquefaction to different combinations of loading and parameters. In this research, the liquefaction probability analysis for Surabaya east coastal plain zone uses an equation. The following expression for the probability of liquefaction (P[L]) [7] :

$$P[L] = \frac{1}{1+\exp\left[-\left(\beta_0+\beta_1\ln(CSR)+\beta_2\,(N_1)_{60}\right)\right]} \qquad (12)$$

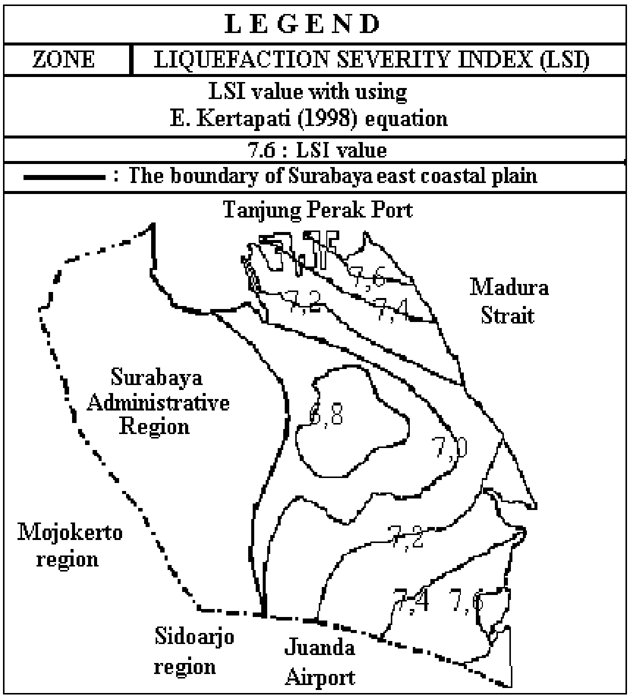

Fig. 18 LSI contour for return periods of 100 years.

The parameters β_0, β_1, and β_2 respectively are shown in Table 5. Liquefaction probability curves for the clean and silty sand cases are shown graphically in Figure 19.

Table 5 Regression model parameters for calculating probability of liquefaction (P[L])

Data*	Number of cases	β_0	β_0	β_2
All	278	10.167	4.1933	- 0.24375
SW – SP	182	16.447	6.4603	- 0.39760
SP – SM	96	6.4831	2.6854	- 0,18190

(*) A fines content of 12 % is used as the boundary between clean and silty sand (SM).

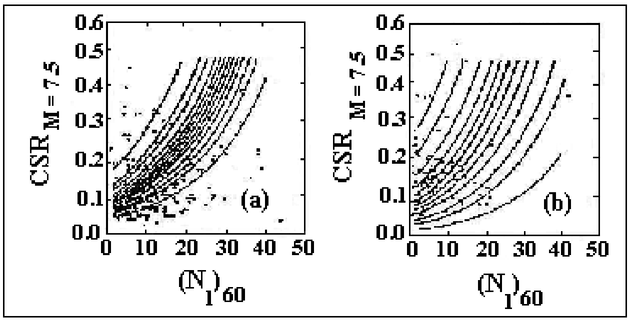

Fig. 19 Contours of equal probability of liquefaction for (a) clean sand (less than 12 % fines), and (b) silty sands (greater than 12 % fines) [7].

The probability of liquefaction was computed for the 66 composite borings for different exposure times using Eq. 11. In the 66 composite borings, a total of 87 potentially liquefiable layers were examined. The probability of liquefaction is computed in each potentially liquefiable layer within a composite boring. The highest probability of liquefaction among the layers is retained as the probability of liquefaction for that hole. The values reported herein are for a 100 – year time exposure, and are presented in Fig. 20.

To help predict the performance of other sites in Surabaya east coastal plain, a different representation of the results of this research was developed. The probability of liquefaction is plotted versus a liquefaction parameter T, and defined as:

$$T = \frac{(N_1)_{60}}{0.65\left(\frac{\sigma_0}{\sigma_0'}\right)} \tag{13}$$

The parameter includes the indirect relation due to unit weights between stresses and standard penetration and is a measure of the liquefaction resistance of the soil. Fig. 21 shows a plot of the liquefaction parameter T versus the probability of liquefaction for 87 layers for 20, 50, 100, 200, and 500-year time exposures. The data show a consistent trend for each exposure, and curves can be drawn through the points. This plot serves as a tool to evaluate the liquefaction potential in other parts of the Surabaya city as more standard penetration test data are generated from new projects. This procedure allows rapid integration of new geotechnical data into the model.

7. Conclusion and discussion

Since the observation to the sand lenses of the Surabaya east coastal plain zone if there is any liquefaction, and from all the details of liquefaction analysis above, it could be concluded that:

1. Surabaya is the delta zones and they are the alluvium zones that contain the sand lenses at the depth of 0.00 and 10.00 m on the saturated water condition. The sand lenses are the medium to loose, and contains 10 to 14% silt with relative density (D_r) under 50%. Liquefaction analysis by field test results shows the standard penetration test (SPT) has values (N_1) 0 to 18 and cone penetration test (CPT) has values 0.5 to 200 kg/cm^2. Liquefaction by laboratory testing with triaxial cyclic shows the critical point for the liquefaction event when the 18th cycles and the analysis results by optimum seeking founded the value of potential liquefaction as 412. In addition, the sand lenses have the grain gradation that can cause the liquefaction like the sand that has susceptibility to liquefaction. Thoroughly, every characteristic by the field and laboratory test showed that the sand lenses have liquefaction phenomenon.

2. LSI values evaluated for several earthquakes in East Java and using Equation 10 showed the LSI contours with 90% probability of non-exceedance in periods of 100 years has values of between 5 and 10 and the mean value of 7.5.

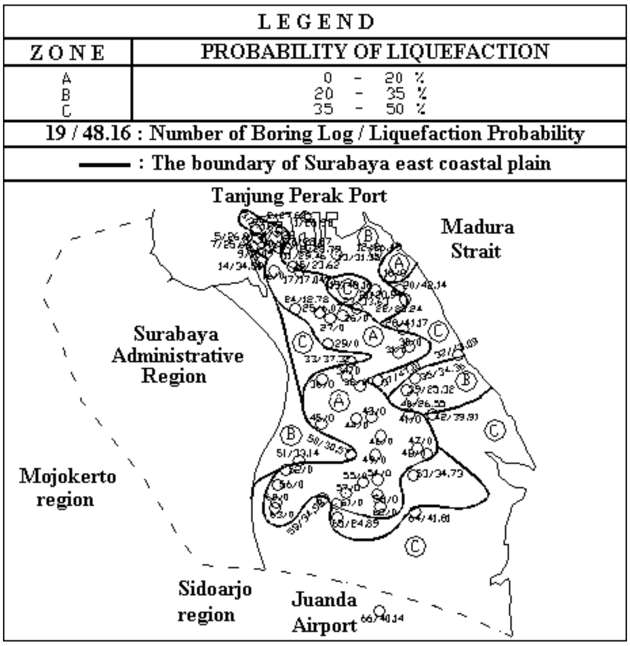

Fig. 20 Probability liquefaction for 100 – year exposure.

3. Based on the probability of liquefaction, the zone of greatest risk lies around the southern part of Surabaya east coastal. Much of the coastline has the lowest risk, whereas the central part of Surabaya east coastal plain zone has an intermediate risk based on the classification [1]. Three observation points of composite borings, 19th , 37th, and 32nd exhibited the highest probability of liquefaction 48.16%; 47.01% and 43.09%. The liquefaction potential for Surabaya east coastal plain ranges from 10 to 50% for a 100 – year time exposure. While Fig. 20 may be useful for general city planning, it should not be used to assess the potential at any specific site. The procedure used in this research, however, can be used. Fig. 21 can be used to assess liquefaction potential at other sites, which is close to Surabaya area for different exposures.

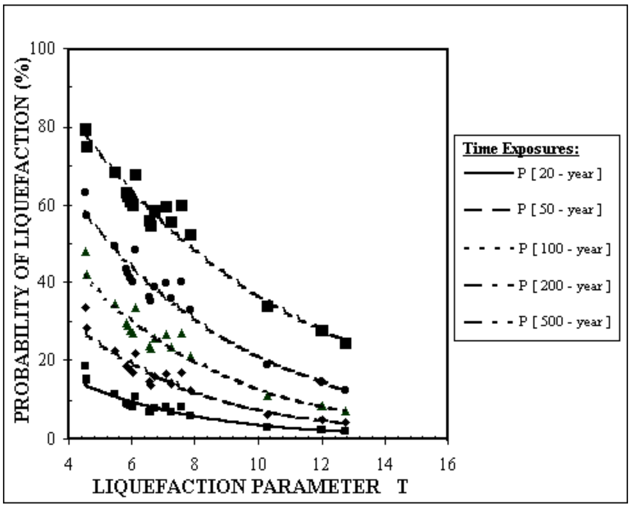

Fig. 21 Liquefaction parameter (T) versus probability of liquefaction (P [L]) for different time exposures at Surabaya east coastal plain zone.

References

[1] Anderson, L.R., and Keaton, J.R. Development of a liquefaction potential map. *Soil Dynamic and Earthquake Engineering Conference, Southampton, USA*, (1982).

[2] Agung, P.M.A., and Indarto. Earthquake liquefaction potential mapping for east coastal Surabaya Zone By geostatistics evaluation of SPT and probabilistic study return period of peak ground acceleration (PGA). *Development Of Quality Postgraduate Program Research - ITS, Surabaya*, (2001).

[3] Mochtar, N., Suwarno, E., and Widodo. Geotechnical maps of Surabaya administrative region. *Center Of Research, Of ITS, Surabaya, Indonesia*, (1988).

[4] Haresh, C.S., and Boen, T. Seismic hazard model for Indonesia. *Stanford University and T.Boen Consultant*, (1996).

[5] Agus, T. S. The potential liquefaction to the loose sand lenses in east side Surabaya zone as the observation, P*roceeding of Widyagama University, Malang, Indonesia*, (2001).

[6] Youd, T.L., and Perkins, D.M. Mapping of liquefaction induced ground failure potential. *Journal of the Geotechnical Engineering Division, ASCE*, Volume 104, No. GT.4, Proc. Paper 13659, (1978), pp. 433-446.

[7] Liao, S.S.C., Veneziano, D. and Whitman. R.V. Regression models for evaluating liquefaction probability. *Journal of Geotechnical Engineering*, ASCE, Volume 114 (4), (1988), pp. 389-411.