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IDENTIFICATION OF LIQUEFACTION HAZARD IN THE COASTAL AREA OF MERAK-ANYER, BANTEN BASED ON CPT AND SPT DATA

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ABSTRACT

The coastal area of Merak-Anyer, Banten is located in the high seismic zone therefore it is highly susceptible to seismic hazard such as liquefaction. Earthquake triggered liquefaction could cause destructions to buildings and infrastructures, thus it can hinder evacuation efforts during an earthquake event. Knowledge of the spatial distribution of liquefaction hazard potential in the coastal area is required as part of the hazard mitigation measures. This paper presents the results of the liquefaction hazard susceptibility analysis in Merak-Anyer, Banten based on geotechnical investigation. Liquefaction analysis was carried out using cone penetration test (CPT) and N-SPT methods with earthquake magnitude of 7, peak ground acceleration of 0.25 g and local groundwater level. Analysis results showed that all investigation points in the coastal area of Merak-Anyer are prone to liquefaction and its associated settlement. The high liquefaction zone includes the areas of Rencana Pelabuhan Cilegon, Cigading, Mercu Suar dan Cinangka which correlates with the occurrence of loose sand – loose silt at the surface to the depth of 10 m with cone resistance (qc) < 10 MPa and N-SPT <10.

Keywords: earthquake, liquefaction, susceptibility, cone penetration test (CPT) and N-SPT.

INTRODUCTION

Earthquake triggered liquefaction could cause destructions to buildings and infrastructure, generates cracks and even building collapse. Liquefaction occurs due to sudden increase of pore pressure at the saturated coarse grained low density sediment layer triggered by high co-seismic activity. The sudden increase of pore pressure weakens the strength of sediments hence the bearing capacity is reduced or even lost.

Earthquake triggered liquefaction in the saturated low density granular sediment is manifested as lateral spreading of building instability due to loss of bearing capacity (Seed & Idriss, 1971; Bowles, 1988; Kramer, 1996). The impacts of liquefaction could endanger the lives of people and cause terrible economical loss, therefore identification of liquefaction susceptibility zone is very important for an area with high earthquake potential.

Characteristics of the subsurface prone to liquefaction are site specific and depend on the local geology, sedimentation process, density, hydrogeology and seismicity (Youd & Perkins, 1978). The data required for liquefaction potential analysis were obtained from field investigation such as standard penetration test (SPT) and cone penetration test (CPT). Liquefaction analysis was carried out using Robertson & Wride (1989) (Figure 4) formula using CPT data and Blake (1997) formula for SPT data. Subsurface profiles were constructed from CPT and SPT data to clarify the depths and thicknesses of sediments prone to liquefaction. These profiles were further used to construct the microzonation of liquefaction susceptibility.

The knowledge of liquefaction hazard zone and potential in the coastal area is highly required as the basis of mitigation plan and regional planning purposes. Any regional development and mitigation measures in a seismically active area must consider the microzonation of liquefaction susceptibility.

This paper aims to present the microzonation of liquefaction susceptibility using subsurface geological data of Merak- Anyer coastal area.

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METHODOLOGY

The study area is located in the coastal area of Merak-Anyer, Banten, which consists of loose unconsolidated Quaternary alluvial sediments (Lumban & Poedjoprajitno, 2012; Santosa *et al.,* 1991) (Figure 1). Geotechnical borings and CPT data (Soebowo *et al.,* 2009) showed that the density of the Merak-Anyer alluvial sediment is very loose to medium from the depth of 5 to 25 m.

According to the seismic zone map of the Department of Public Works 2010, the Merak-Anyer, Banten area belongs to the high and active seismic zone (seismic zone category 3 - 4), with bedrock peak ground acceleration 0.2-0.5g. This area is located within the North West- South East oriented fault zone (Santosa, 1991). According to historical records, a large magnitude earthquake had occurred in 1833 and 23 February 1903 which caused massive destructions and claimed numbers of lives (New Comb & Mc Cann, 1987).

The methods employed in this study consist of measurements of phreatic groundwater levels, subsurface geotechnical investigation and liquefaction potential analysis.

Phreatic groundwater levels of this area were obtained by field measurements in dug wells, boring wells and from CPT tests. The groundwater levels vary from very shallow to shallow (-0.5 to -4 m) and in several places the level are > 4 m (Figure 2). The shallow groundwater level facilitates the near surface rise of pore water pressure during an earthquake event thus enables liquefaction to occur.

The subsurface geotechnical investigation consisted of 8 (eight) geotechnical borings up to the depths of 20 - 30 m, standard penetration tests (SPT) in each geotechnical borings every 1.5 m, undisturbed samplings and cone penetration test (CPT). The N-SPT value from each geotechnical borings were used to analyze the subsurface density (Terzaghi & Peck, 1967) and liquefaction potential. 19 CPT tests were carried out using 2.5 ton capacity pushing equipment to obtain cone resistance and friction ratio profiles required for liquefaction potential analysis. Interpretation of cone resistance and friction ratio values are used to obtain the subsurface lithology based on Robertson (1986) method (Figure 3).

Geotechnical laboratory analysis was carried out on samples recovered from geotechnical borings to obtain grain size distribution and Atterberg limits. The results were used to classify the type of subsurface soil and the fines content required for liquefaction potential analysis.Identification of liquefaction potential from subsurface stratification was performed using grain size distribution (Tsuchida, 1970) and correlation of cone resistance with friction ratio (Robertson & Campenella, 1985).

Numerical analysis of liquefaction potential was performed using LiqIT software using CPT data with scenario of earthquake magnitude 7, peak ground

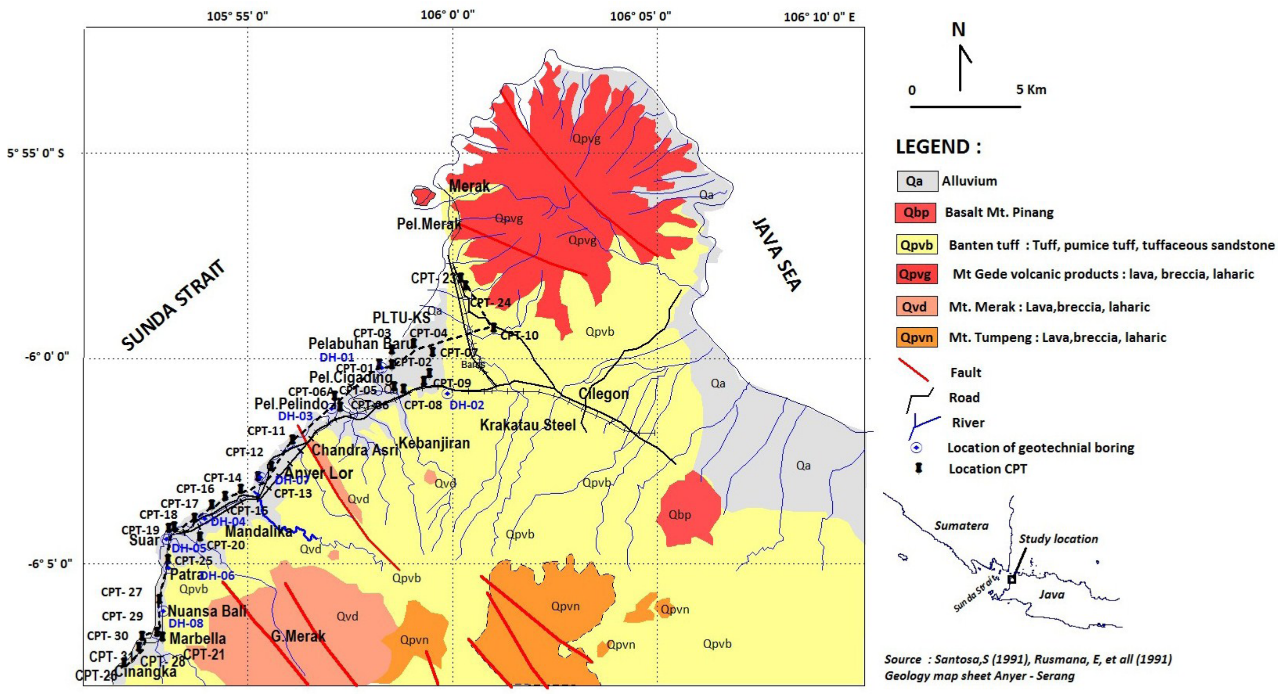


Figure 1. Geological map of Merak-Anyer area (modified from Santoso, 1991 & Rusmana, 1991).

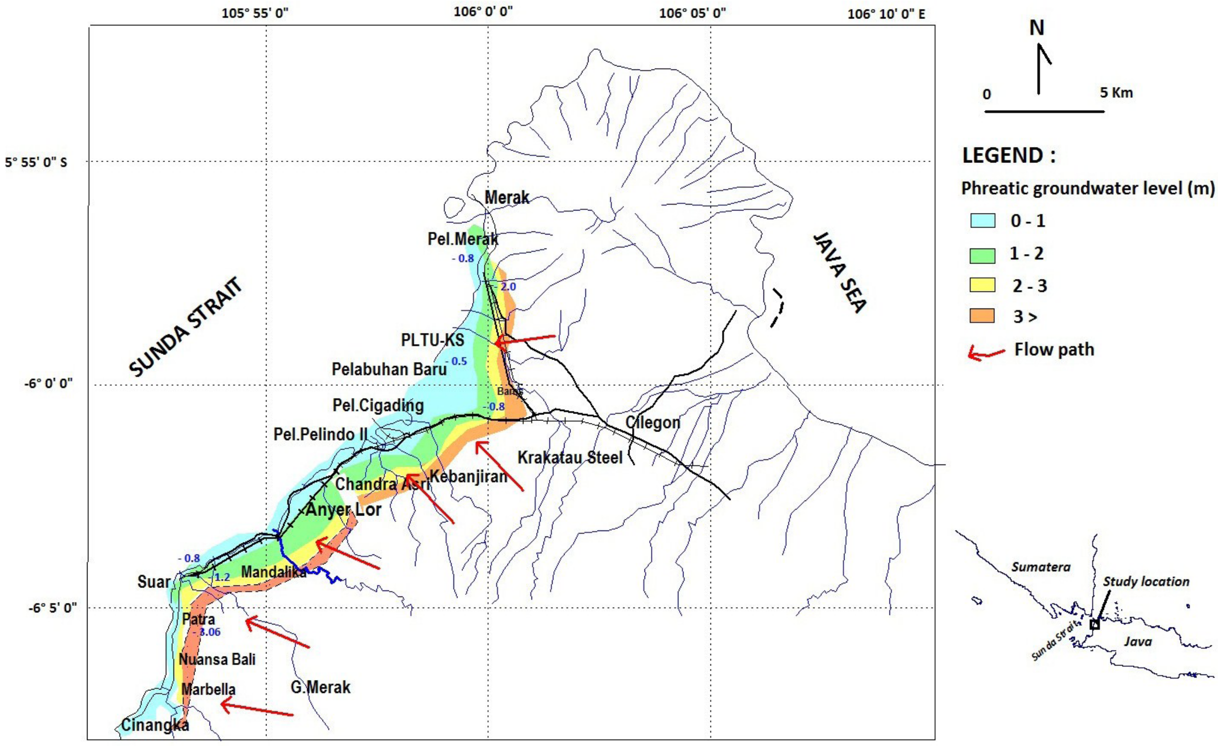


Figure 2. Phreatic groundwater level map based on field measurements.

acceleration (p.g.a) 0.25 g, the earthquake source is North West Merak of 100 km away and groundwater level reaches the surface due to earthquake shakings.

The numerical analysis consisted of the following procedure:

1. The cyclic stress ratio resulted due to earthquake is calculated as (modified Seed, 1996):

$$CSR = 0.65 \frac{\sigma_0}{\sigma_0^{'}} a_{\max} r_d \quad \text{...} \quad 1)$$

where,

- 0.65: weighting factor to calculate uniform stress cycle required to raise the same pore pressure due to irregular earthquake shakings
- σ0 : total vertical stress
- σ0' : effective vertical stress
- amax: peak ground acceleration
- rd: stress reduction coefficient (Seed & Idriss, 1971)

2. Calculation of cyclic stress ratio (CRR) based on CPT data using Robertson & Wride (1995) & SPT data using Blake (1997) method.
3. Evaluation of liquefaction potential is achieved by calculating the factor of safety (F.S) of the granular sediment resistance to liquefaction as the following:

$$FS = \frac{CRR_M}{CSR_f} \quad \text{..} \quad 2)$$

where,

- CRR_M : cyclic resistance ratio corrected by the earthquake magnitude (M)
- CSR_f : cyclic resistance ratio corrected by the factor of safety

We used factor of safety (FS) >1 to indicate the safe resistance to liquefaction and FS <1 to indicate liquefaction prone sediments.

Estimation of liquefaction induced settlement was performed using Ishihara & Yosemine is (1990) method. Meanwhile for the liquefaction susceptibility analysis Iwasaki (1982) method was used which employed the susceptibility to infrastructure locations as indicated by the Liquefaction Index (IL) parameter. The liquefaction index is obtained from:

$$I_L = \int_0^{20} Fw(z)dz \quad \text{..} \quad 3)$$

Where:

- for Fs < 1.0 and F = 0 for Fs >1.0 and w(z)=10-0.5z,
- w(z) : the function of liquefaction potential with depth
- z : depth (meter)

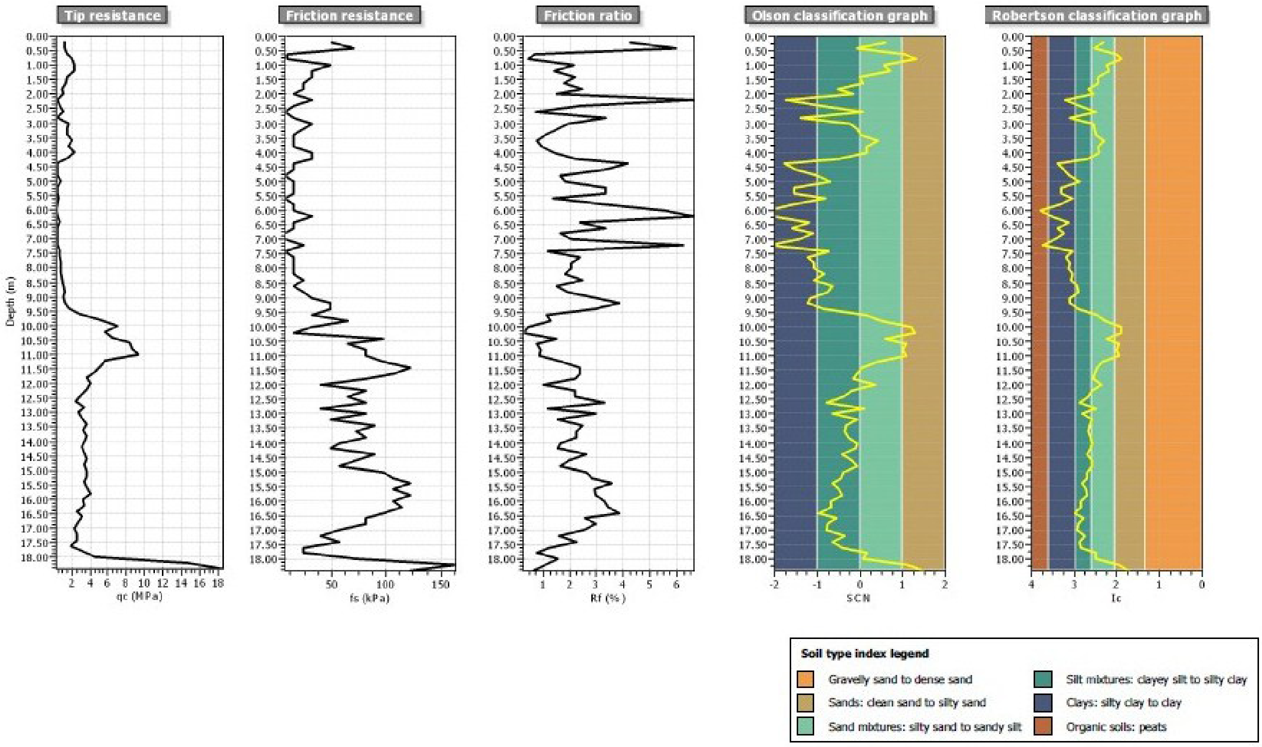


Figure 3. Interpretation of soil type based on cone resistance and friction ratio of CPT 09 site using Robertson(1986) method.

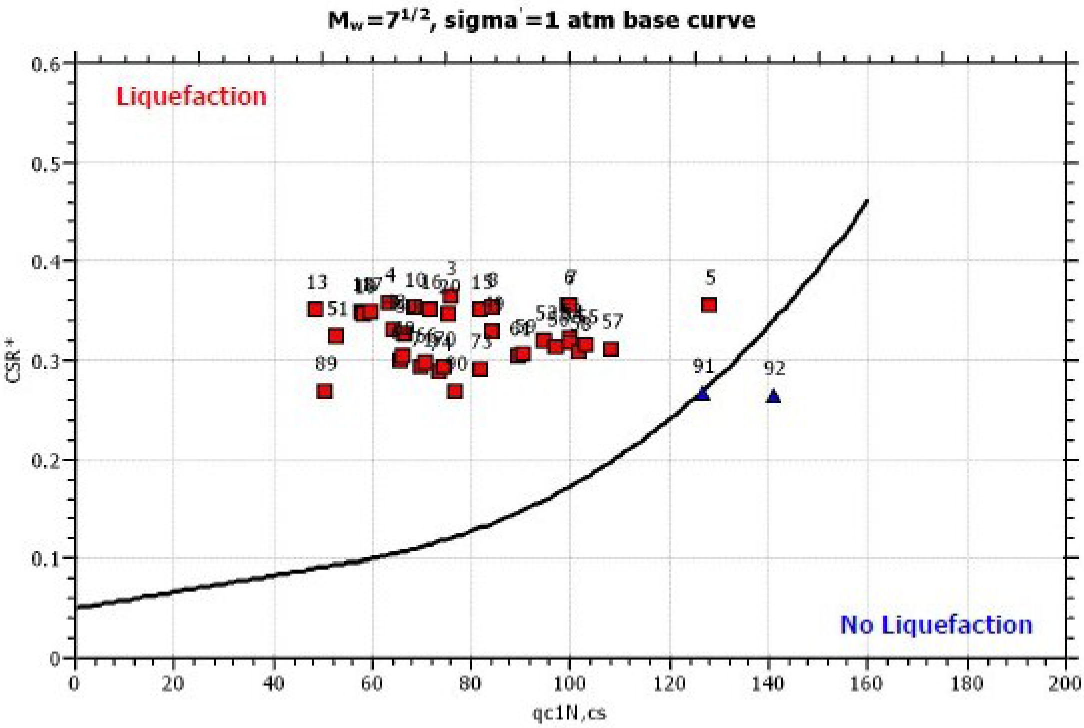


Figure 4. Liquefaction potential analysis results using CPT data by Robertson & Wride (1989) showing the depth and thickness of liquefaction prone sediments and total settlement.

RESULTS AND DISCUSSION

Subsurface engineering geological profile

Subsurface profile based on geotechnical boreholes, CPT soundings and SPT values shows that the engineering geology of the study area consists of coastal plain deposit of fine to coarse sand containing shells, peat deposit of clay and organic soils and alluvium of silt, sand and gravels (Figure 5).

Figure 5 shows that the sand and sand-silt mixture near the surface with thickness of 8-10 m have low to medium density with cone resistance qc<10 MPa and N-SPT<10. The occurrence of very loose to loose layers near the surface in an active seismic zone indicates the high susceptibility to earthquake triggered liquefaction. It is obvious that the sand and sand-silt mixture layers (Figure 5) are prone to liquefaction.

Identification of Liquefaction Potential

According to liquefaction analysis using CPT and SPT data by Robertson & Wride (1988) method using earthquake magnitude of 7 and peak ground acceleration at the surface of 0.25 g and earthquake source from North West of Anyer, the zone that prone to liquefaction and non liquefaction were identified (Figure 6a). Liquefaction potential tends to occur in the near surface of loose to medium density sand up to the depth of 8 m with cone resistance (qc) <10 MPa and N-SPT <10. The calculations of total settlement induced by liquefaction in several locations mostly varied from 0.5 to 22 cm and even reaches ± 50 cm in the coastal area like Cigading, the new port location and Cinangka.

Grain size analysis of sand samples from Merak – Anyer shows that according to Tsuchida (1970) classification (Figure 6b) the sand layer in Merak-Anyer area are easily liquefied. Meanwhile the identification of liquefaction potential using cone resistance and friction ratio data from CPT measurement by Robertson & Campanella curve (1985) showed that most of sand and sand-silt mixture lie within liquefaction susceptible zone (zone A) (Figure 6c)

Liquefaction Susceptibility

Based on the results of liquefaction potential analysis based on CPT and SPT data in Merak-Anyer area (Figure 7), the microzonation of liquefaction hazard susceptibility could be divided into:

Highly susceptible zone

This zone covers the new port plan location, Cigading, Light House and Cinangka. This zone contains loose sand and sand-silt mixture of peat and beach ridge sediments. The phreatic groundwater level in this area is relatively shallow. The liquefaction index (IL) > 15 are found between 4 - 10 m depth. Destructions of important structures like the port, roads, bridges and buildings are highly likely when earthquake induced liquefaction occurs. Structural mitigation is required in this area to reduce the impacts of liquefaction triggered destructions.

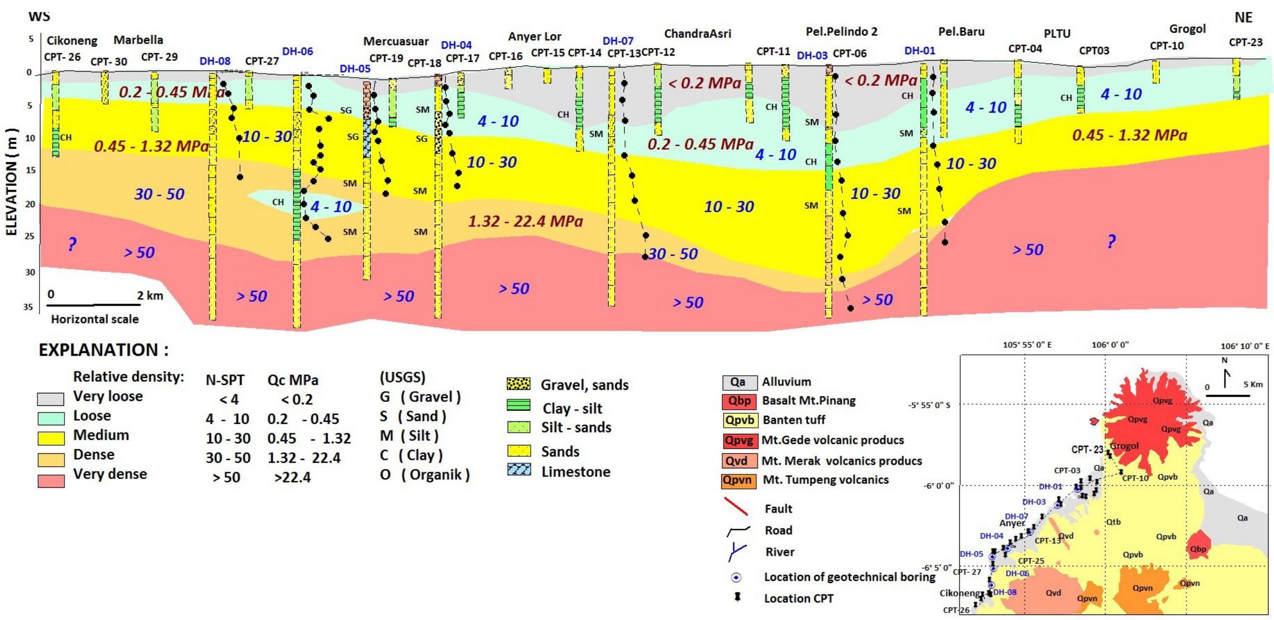
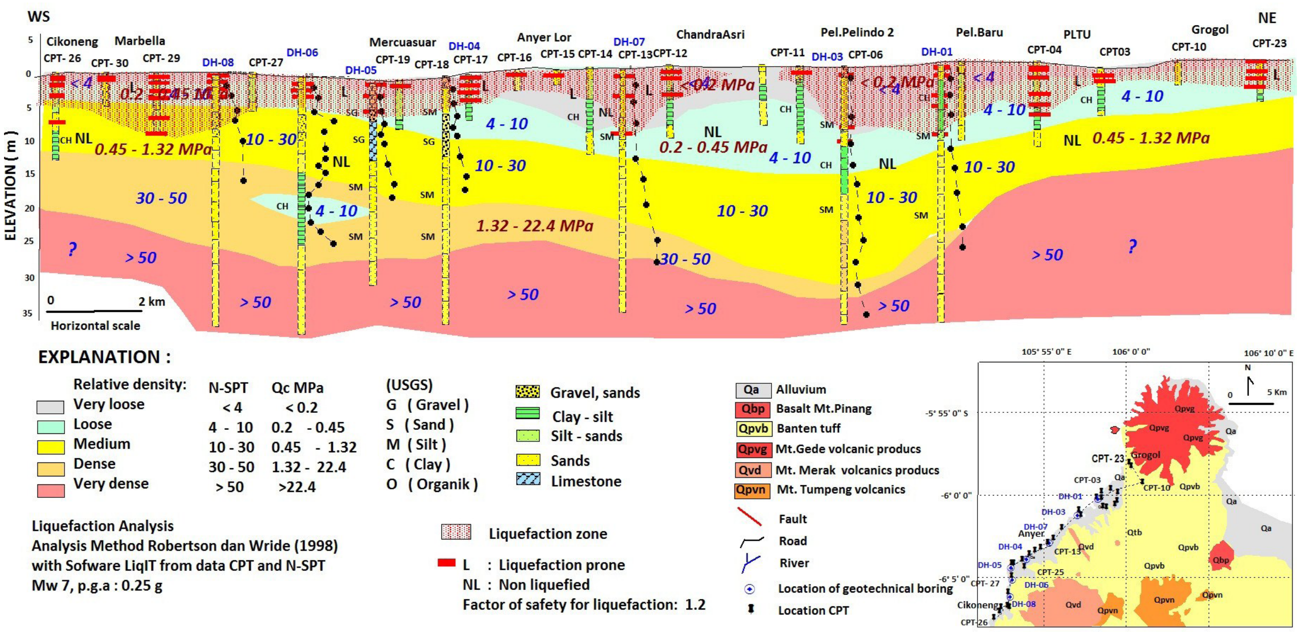
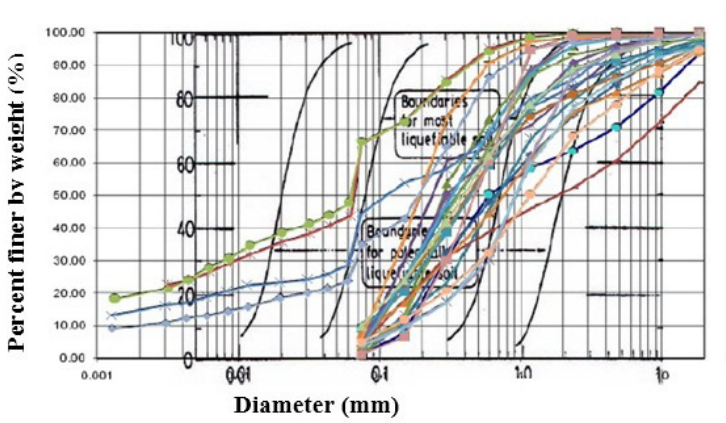


Figure 5. Subsurface stratification profile and plots of N-SPT value in Merak-Anyer Banten area.



a)



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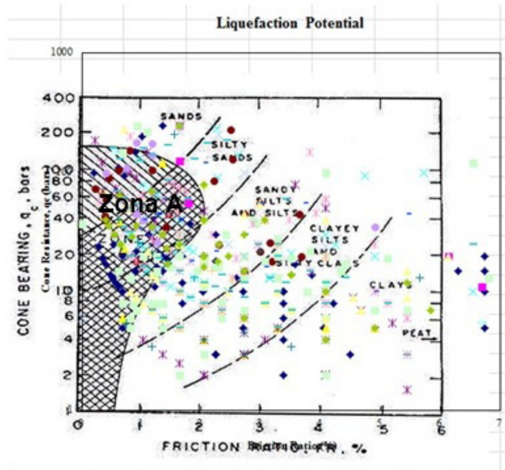

c)

Figure 6. a). Subsurface stratification profile of liquefaction prone (L) and non liquefied (NL) sediments in Merak-Anyer Banten based on CPT and N-SPT analyses.
b). Liquefaction analysis based on grain size distribution
c). Identification of liquefaction potential based on CPT data (cone resistance, qc versus friction ratio) (Robertson & Campanella, 1985)

Medium Susceptible Zone

This zone covers Merak Port, Krakatau Electric Power Plant, Anyer Lor and Mercusuar (Light House). This zone consists of uncompacted sand with shallow phreatic groundwater level sensitive to liquefaction. The liquefaction index (IL) in this area is 5 - 10. Civil constructions in this area must usethe appropriate type of foundation based on the subsurface bearing capacity.

Low Susceptible Zone

This zone covers East Anyer, Mandaloka, Nuansa Bali at the coast towards the hilly morphology. This zone consisted of highs formed by andesitic intrusion and breccias with liquefaction index (IL) < 5. The surface physical destructions due to liquefaction is unlikely to occur.

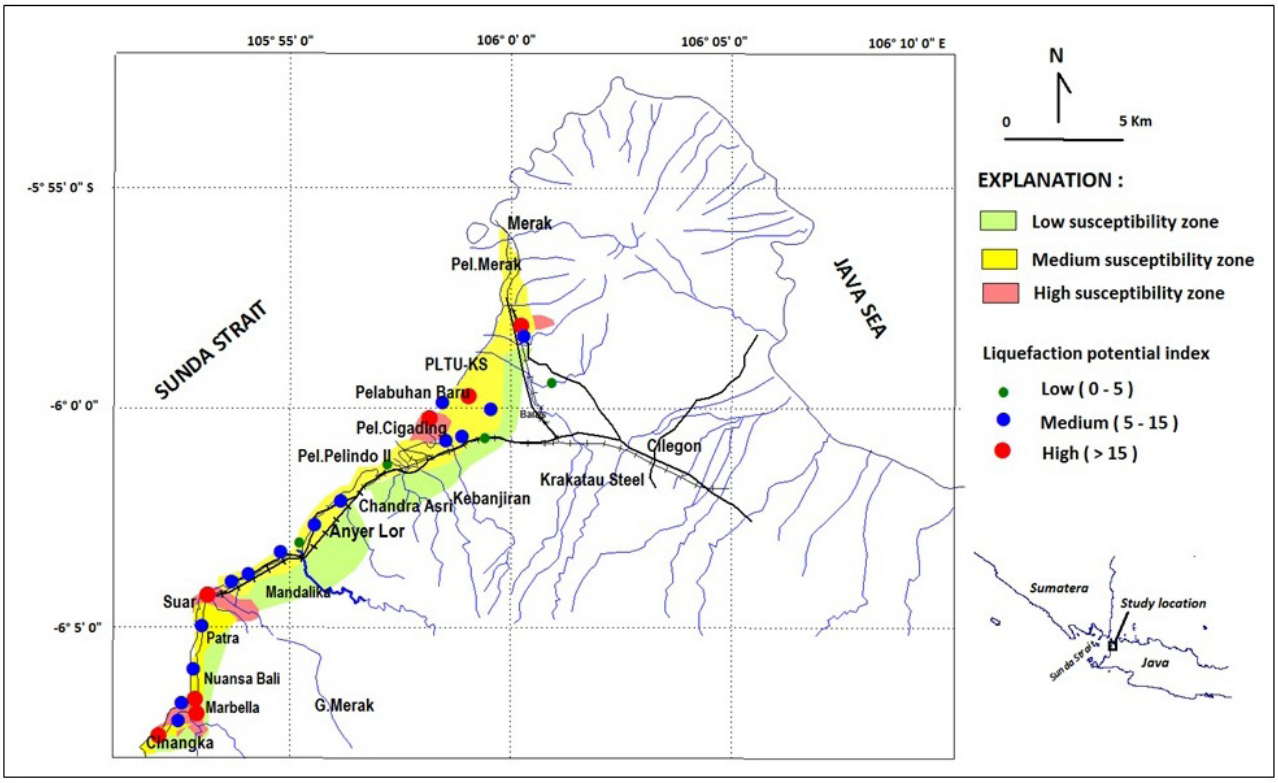

Figure 7. Microzonation map of Merak-Anyer liquefaction susceptibility.

CONCLUSION

The subsurface geological profile and liquefaction potential analysis in the coastal area of Merak-Anyer and the surroundings show the occurrence of very loose sand to medium dense sand from the depths of 0 to 10 m with cone resistance (qc) <10 MPa and N-SPT value <10 indicating liquefaction potential. Microzonation of liquefaction potential had been carried out using CPT dan SPT data. The results indicate that the high liquefaction prone zone is concentrated in the Planned New Port location, Cigading, Mercu Suar (Light House) and Cinangka with liquefaction index >15.

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