

Preliminary study of soil liquefaction hazard at Terengganu shoreline, Peninsular Malaysia

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Abstract. Terengganu is a shoreline state located in Peninsular Malaysia which is a growing hub for port industries and tourism centre. The northern part offers pristine settings of a relax beach areas whereas the southern part are observed to be a growing centre for development. The serious erosion on soil deposit along the beach line presents vulnerable soil condition to soil liquefaction consists of sandy with low plasticity and shallow ground water. Moreover, local earthquake from nearby fault have present significant tremors over the past few years which need to be considered in the land usage or future development in catering the seismic loading. Liquefaction analysis based on field standard penetration of soil is applied on 546 boreholes scattered along the shoreline areas ranging 244 km of shoreline stretch. Based on simplified approach, it is found that more than 70% of the studied areas pose high liquefaction potential since there are saturated loose sand and silt deposits layer ranges at depth 3 m and up to 20 m. The presence of clay deposits and hard stratum at the remaining 30% of the studied areas shows good resistance to soil liquefaction hence making the area less significant to liquefaction hazard. Result indicates that liquefaction improving technique is advisable in future development of shoreline areas of Terengganu state.

1. Introduction

Soil liquefaction effect in built environment often relates to lack of information and knowledge of the regional setting especially in the sense of geological aspect and the seismic characteristic. The deadly events reported in moderate to high seismic region around the world present fatalities and catastrophic failure of the buildings and civil engineering structures [1-4].

Furthermore, some human activities such as land reclamation and alteration of natural landscape contribute to the probability occurrence of soil liquefaction events and their sudden negative impact [5]. Anthropogenic impacts can cause limited aspect of resistance and capabilities of the soil environment towards such hazard [1]. Careless action and incentive on land development due to missing information and limited knowledge of regional setting often contribute to the multiplication of economic collapse. Therefore, we are exposed, unnoticeably or under the demand of land usage and development, to the risk of soil liquefaction.

We should be aware and take note that there are no absolute solutions against soil liquefaction. It is recommended to make a preliminary investigation as simple, representable and easily access overview Hence integrated measures can be taken to prepare proper planning and design in any land usage and development in adapting to the unforeseen events in the near future [6]. Towards promoting safe built environment and future development, implementation of existing workflow in assessing soil liquefaction potential is very important but most significantly an increasing role from the authority should be addressed in assessing soil liquefaction information follow by the prevention and mitigation program.



The common approach to define soil liquefaction potential is that it is the product of resistance of the soil and loading of ground motion [7]. Based on this definition or namely simplified method, the evaluation of soil resistance and earthquake loading can be conducted separately in the first place, but have to be combined for the final result which is termed as safety factor against soil liquefaction.

There are very few scientific literatures from local scale however reliable information can be observed from neighboring countries such as Indonesia and Thailand [8]. The analysis conducted involves different complexity levels and variety of methods. Examples of similar studies dealing with soil liquefaction and soil liquefaction assessment at the near about regional geological setting and seismicity characteristics promotes the use of simplified method in quantifying the hazard.

In this paper, the aim is to present a study on soil liquefaction assessment at Terengganu shoreline, Peninsular Malaysia. A total of 6 illustrations summarizing the findings related to soil liquefaction are presented: soil composition, SPT-N distribution, zone of saturation, grain size distribution plot in liquefaction margin, liquefaction susceptibility margin and liquefaction potential layer. In general, vulnerable soil towards soil liquefaction consists of saturated sandy soil type and when combines with intense ground motion, the soil will lose its shear strength and behaves as a viscous liquid in split second. The first five illustrations including charts are preliminary screening which notes all fundamental factor that influence liquefaction susceptibility. The last illustration presents results that have been analyzed using the simplified method. By this study, we try to introduce illustrations in which could be interesting to be applied to other prone areas of the region.

2. Study area

Terengganu offers a wide coverage of pristine beaches stretching approximately 244 km distance. The beach is quiet and is a home to scattering peaceful fishing village. A number of resorts located in the shoreline areas are constructed a very simple way as to accommodate tourist and local travellers. The shoreline areas are well preserved in the northern coast district: Besut and Setiu as there are very few development and changes in the natural environment. As the stretch line reaches the capital state of Terengganu, the beaches are no longer picture-perfect due to serious level of erosion. The erosion is caused by strong waves during monsoon season, coastal development projects and various made-made structures. Table 1 presents the abbreviation and general information of shoreline district in Terengganu state. A collection of 546 borehole reports at 95 locations along the shoreline of Terengganu state made it possible in addressing the depth of the studied areas. The type of beach is sandy type for all districts. The population are observed to be high in developing areas and the main city (Kuala Terengganu). Figure 1 presents the Terengganu state map and studied location. The dotted line indicates the studied shoreline areas.

Table 1. Abbreviation and general information of shoreline district of Terengganu state

No	Shoreline District	Code Name	Type of Beach	District Population	Main Economic Sector	Future Development
1	Besut	T1	Sandy	136,563	Tourism/Fishery	Tourism Hub
2	Setiu	T2	Sandy	54,563	Tourism/Fishery	Tourism Hub
3	Kuala Terengganu	T3	Sandy	337,553	Tourism/Fishery	Conurbation
4	Marang	T4	Sandy	95,283	Tourism/Fishery	Tourism Hub
5	Dungun	T5	Sandy	149,851	Main Port	Port Expansion
6	Kemaman	T6	Sandy	166,750	Main Port	Port Expansion

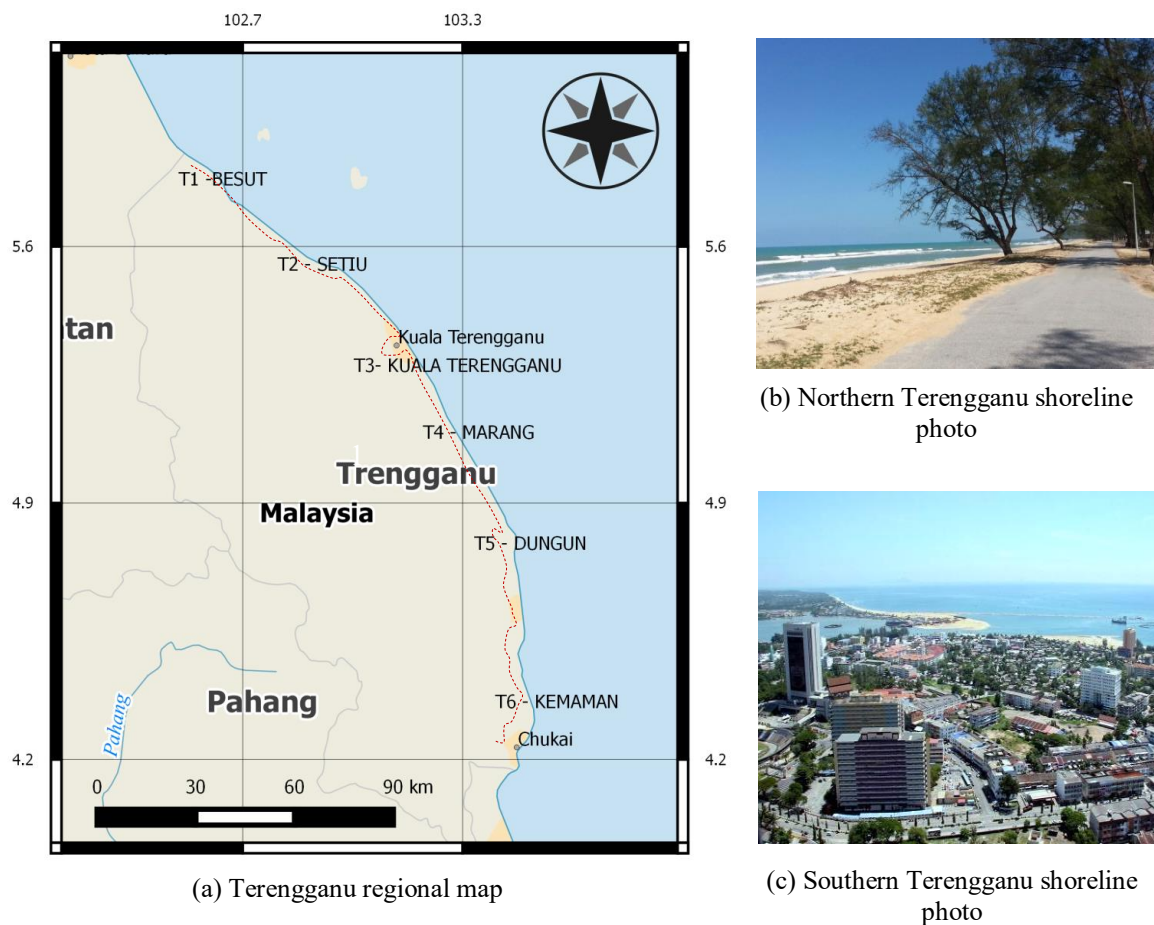


Figure 1. Terengganu state general information

3. Method

Figure 2 presents the flowchart of the study development. Site visit on the studied location have been conducted to record general information of the areas. Prior to site visit, standard penetration test (SPT) report is collected from various local municipalities and geotechnical engineering consultancies for infrastructures purposes. Later, related soil parameters is extracted and by using linear stratigraphy correlation method, the illustration of soil profile, SPT-N distribution, zone of saturation and liquefaction potential layer is produced. The grain size properties from laboratory reports is also extracted to further examine soil using gradation curves of liquefiable margin and liquefaction susceptibility margins.

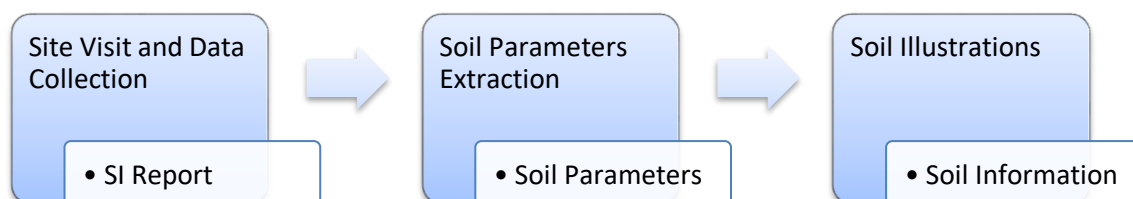


Figure 2. Flowchart of study development

3.1. Soil liquefaction screening

The screening was conducted by extracting basic information of the soil from site investigation (SI) report by means of SPT. 5 illustrations is developed for this purpose to investigate into soil liquefaction susceptibility of the region. Soil composition illustration presents general layer of soil type containing gravel, sand, clay and silty layers. The soil hardness is observed by developing the SPT-N distribution by defining 6 level of hardness ranging from soft soil to hard stratum which correlates to the number of blows. Another governing factor is the ground water table. The zone of saturation illustration defines two different areas of saturation and non-saturation zone.

The grain size distribution plot in liquefaction margin presents limit curve for soil liquefaction possibility [9]. Another chart adapted for this study is the liquefaction susceptibility margins[10]. According to researchers [11], by using simple terms relating moisture content (w_c), liquid limit (LL) and plasticity index (PI) the margins define whether or not finer particles are prone to liquefy. Soils with (i) $w_c/LL > 0.85$ and $PI < 12$ are vulnerable to liquefaction, soils having (i) $w_c/LL > 0.80$ and (ii) $12 < PI < 18$ are moderately susceptible to liquefaction and further laboratory testing for fine-grained soils located in this range is recommended whereas, soils having $PI > 18$ are considered to be non-liquefiable.

3.2. SI report, soil sampling, SPT-N correction

The SI report collected presents information of the ground according to B.S 1377: Part 9: 1990, "Determination of the penetration resistance using split-barrel sampler", using a self-tripping hammer of 63.5 ± 0.5 kg weight of designated design. Soil samples were taken in the form of undisturbed or disturbed but representative when drilling. The disturbed samples are used for laboratory classification tests. The samples were sealed in polythene bags before sending to laboratory for further investigation whereas the undisturbed samples were collected by applying hydraulic thrust on thin wall sampling tubes of 60 mm diameter for very soft cohesive soils. The sampling tubes are later secured with wax to maintain water content. All the samples were placed in cushioned boxes and transported to laboratory to ensure minimum disturbance.

The SPT-N value is subjected to a large number of variables that affect the results. SPT-N values are standardized to $N_{(1)60}$ values in reducing the significant variability [12]. Therefore correction factors are adapted study regardless of the equipment used at site. The approach is to ensure SPT-N data used is close representation of the actual subsurface condition. The equation for $N_{(1)60}$ is as follows:

$$N_{(1)60} = N_{SPT} \times C_n \times C_e \times C_b \times C_r \times C_s \quad (1)$$

where $N_{(1)60}$ is the final corrected SPT value; N_{SPT} is the raw SPT data measured at site; C_n is the overburden correction factor; C_e is the energy correction factor; C_b is the borehole diameter correction factor; C_r is the rod length correction factor; C_s is the sampler correction factor and C_b is the borehole diameter correction factor.

3.3. Evaluation of liquefaction potential

The simplified method was adapted in this study to calculate the factor of safety against liquefaction. In general terms, the stress generated by ground motion which results in soil liquefaction is defined as the cyclic stress ratio (CSR), and the strength of soil to resist the ground motion is defined as cyclic resistance ratio (CRR). There are various methods in evaluating the liquefaction potential, commonly used Boulanger Idriss (2014) [13], Cetin et al. (2004) [14] and Vancouver Task Force (2007) [15]. In this present study, Boulanger Idriss (2014) is used in tabulating the CSR and CRR. The equation for CSR and CRR as follows:

$$CSR = \frac{\tau_c}{\sigma'_{vo}} = \frac{0.65\tau_{max}}{\sigma'_{vo}} = \frac{0.65a_{max}\sigma_{vo}r_d}{(g)\sigma'_{vo}} \quad (2)$$

where a_{\max} is the maximum horizontal acceleration at the ground surface; τ_{\max} is the maximum horizontal shear stress in the liquefiable layer; σ_{vo} is the total vertical normal stress before the earthquake; σ'_{vo} is the effective vertical normal stress before the earthquake and r_d is the stress reduction coefficient

$$CRR_{\sigma=1, \alpha=0} = \exp \left\{ \frac{N_{(1)60}}{14.1} + \left(\frac{N_{(1)60}}{126} \right)^2 + \left(\frac{N_{(1)60}}{23.6} \right)^3 + \left(\frac{N_{(1)60}}{25.4} \right)^4 - 2.8 \right\} \quad (3)$$

where $N_{(1)60}$ is the final corrected SPT value

The 8.0 magnitude earthquake was assumed for all the analysis and through non-linear site response analysis 0.20 g was assumed for peak surface acceleration (PSA). The equation mentioned above is used to calculate the factor of safety against liquefaction (F_s) at each layer in the boreholes. The equation for F_s as follows:

$$F_s = \frac{CRR}{CSR} \quad (4)$$

where CRR is the cyclic resistance ratio and CSR is the cyclic stress ratio. $F_s \geq 1$ indicate the soil has no potential of liquefaction however when $F_s < 1$ the soil indicate possibility of liquefaction potential.

4. Results and Discussions

The findings are presented using simple illustrations and charts in highlighting the governing factor of soil liquefaction susceptibility. The importance of each findings related to soil liquefaction is discussed in this section.

4.1. Soil Composition

4 types of soil namely clay, silt, sand and gravel are highlighted in Figure 3. The soil composition shows deep layer of sand running top from the ground surface to the bottom of 30 meter. Hard stratum is found at depth of 11 meter onwards. The unique layers also show existence of silt type soil concentration in the middle of the shoreline distance which is located in coastal city of Kuala Terengganu. Clay type soil is found to be scattered along the shoreline which highlight resistance against soil liquefaction. It can be found at few places in Setiu, Kuala Terengganu, Dungun and Kemaman district.

The site visit conducted along Terengganu shoreline reveals most areas are consisted of sandy type beaches which run from the northern district to the southern district. The existence of such natural formation are due to the high tide from South China Sea bringing in uniformly granular type deposits which in many literatures governs the soil liquefaction susceptibility [16]. Hence land expansion by land reclamation should be avoided at this particular shoreline as demonstrated by similar geo-environment setting [17]. The design of piling for future structures along Terengganu shoreline is advisable for this type of area.

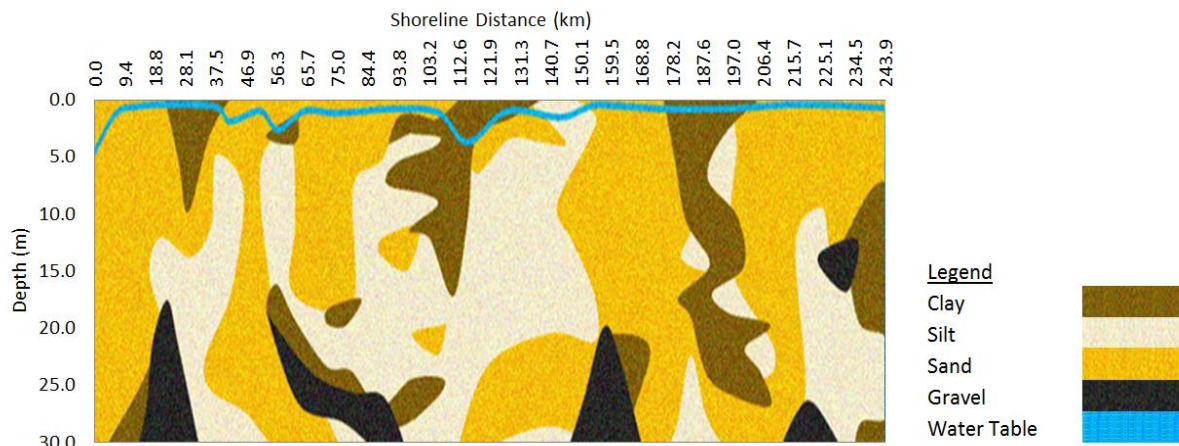


Figure 3. Soil composition of Terengganu shoreline

4.2. SPT-N Distribution

Figure 4 presents the SPT-N distribution of Terengganu shoreline. Loose and soft layer are found in great abundance in the first layer of the soil strata and this is presented with the low SPT-N values. For $N_{(1)60} > 30$, granular soils are unlikely to liquefy. The hard stratum is found at the starting depth of 7 meter from the ground surface.

In the context of earthquake, soft soil tends to amplify seismic wave resulting in increased energy and ground acceleration leading to destructive environment on the ground surface [18]. Recent literatures documented intense shaking due to the amplification of soft soil during earthquake. Therefore such basic information of the soil condition is a necessity in any land development.

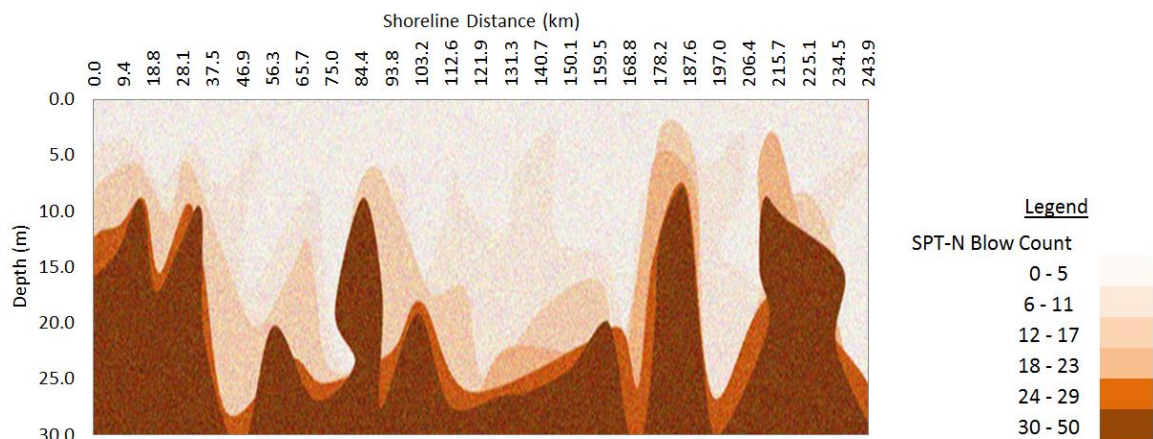


Figure 4. SPT-N Distribution of Terengganu shoreline

4.3. Zone of Saturation

Figure 5 presents the saturation zone of Terengganu shoreline. The yellow color indicate unsaturated zone whereas the blue indicate saturated zone. It was found from the compilation data that over 90% of the areas are saturated.

Liquefaction phenomenon is most likely to occur in condition where the water table is very close to the surface as reported by previous study [19]. Monitoring extensive aquifers along the shoreline is important as to observe how the water flow underground especially when is come to the construction of substructure.

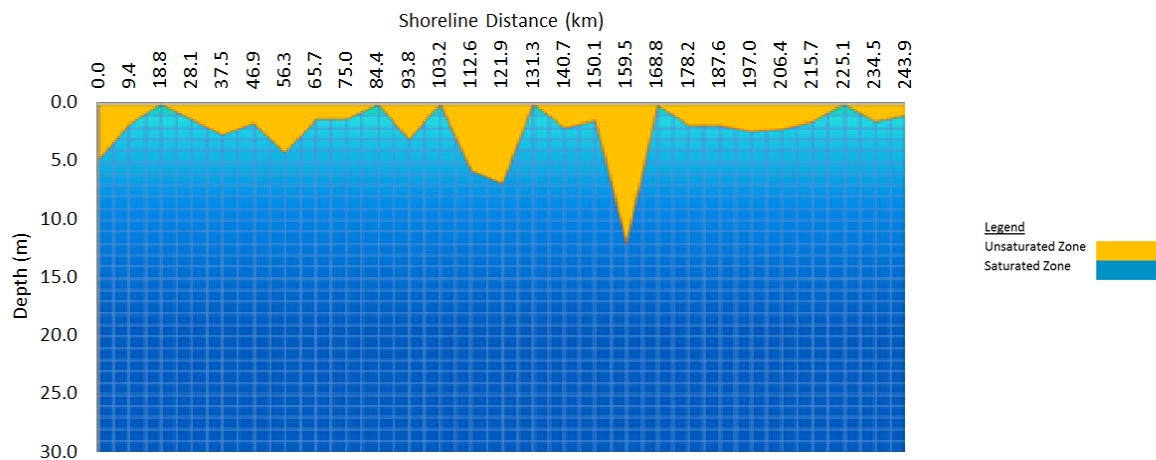


Figure 5. Saturation zone of Terengganu shoreline

4.4. Gradation curves of liquefiable margin and liquefaction susceptibility margins

A more detail soil liquefaction screening is presented in Figure 6 and Figure 7. The soil have high tendency to liquefy when fit in the curve indicated by the red line in the gradation curves of liquefiable margin. Another similar approach is to plot the soil parameters in liquefaction susceptibility margins. The value which falls in the yellow and red border indicate possibility of liquefy soil.

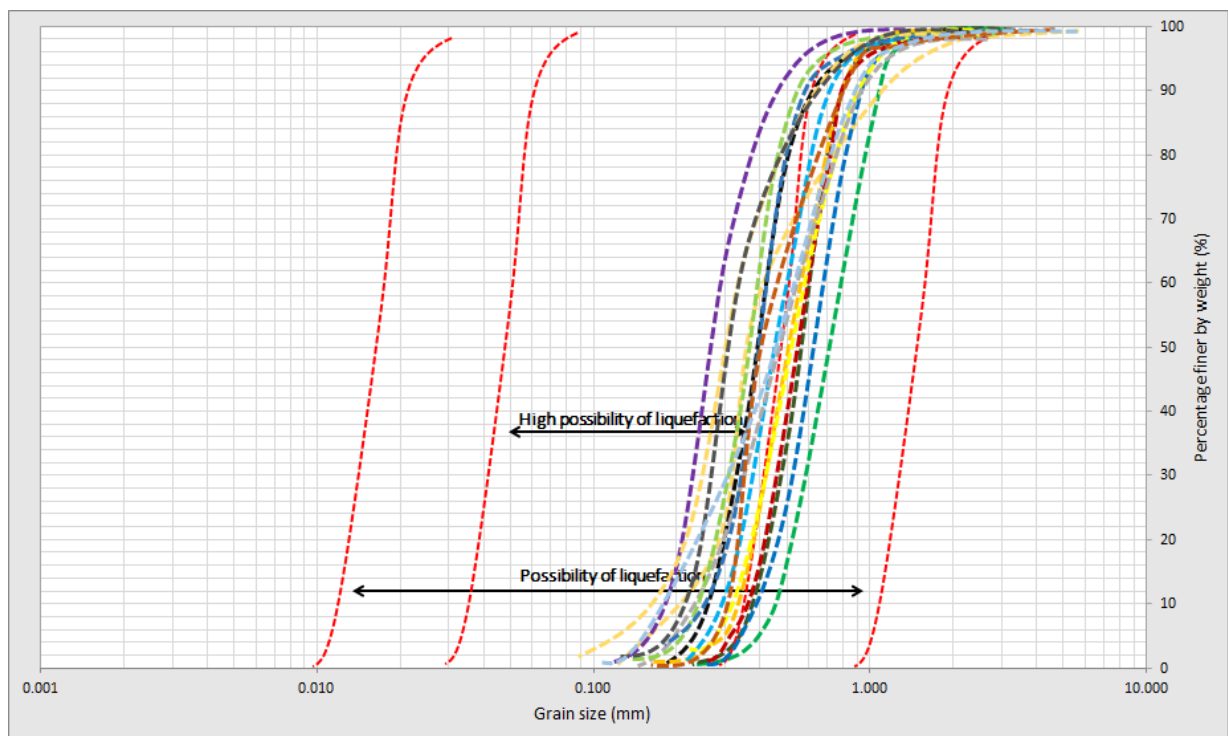


Figure 6. Gradation curves of liquefiable margin of Terengganu shoreline

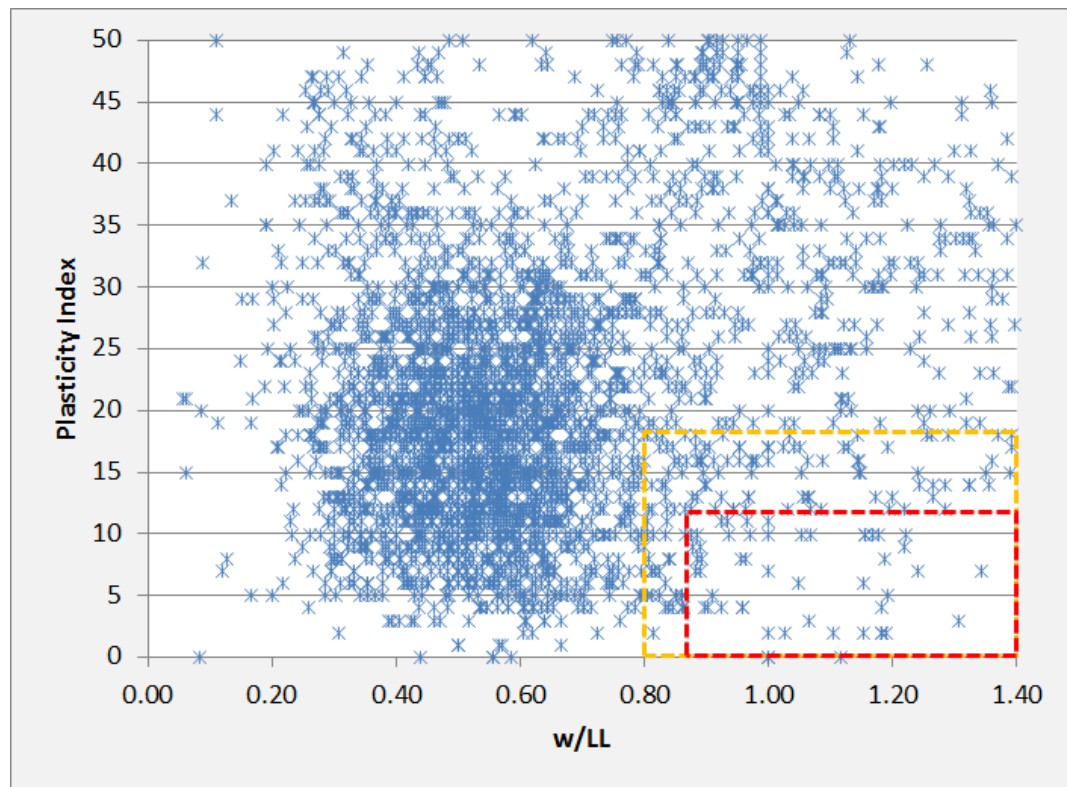


Figure 7. Liquefaction susceptibility margins

4.5. Liquefaction Potential Layer

By using simplified approach the liquefy layer is presented in Figure 8. The green zone indicate safe layer to hazard whereas the red zone indicate dangerous area with possibility of soil liquefaction occurrence. It is noticed that the soil layers prone to liquefaction have safety factor less than 1 and this occurs for soil layers lying between 0 to 30 m in scattered pattern. Some areas in the green zone denotes non liquefy soil mainly due to the existence of clay layer and the unsaturated zone.

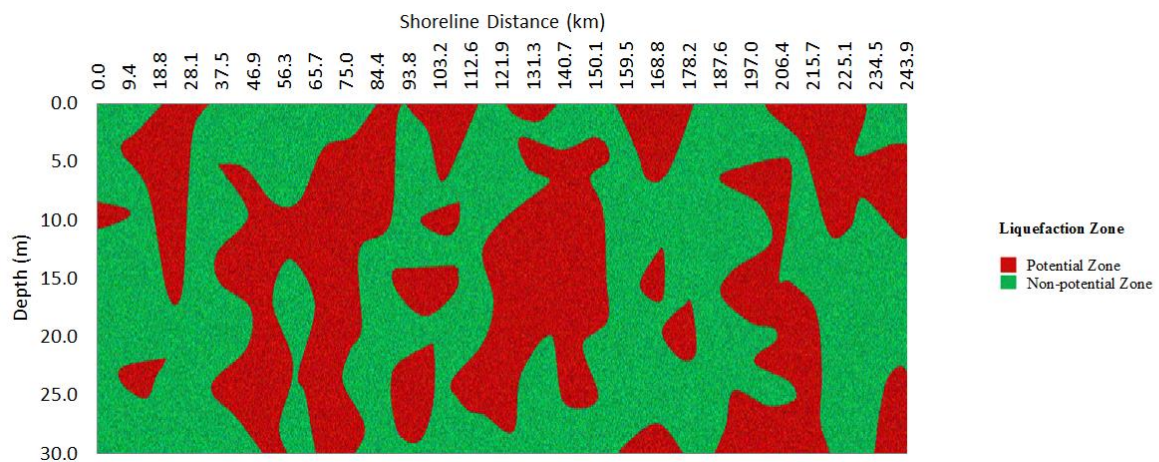


Figure 8. Liquefaction potential layer

5. Conclusion

The main conclusions drawn are:

1. Soil liquefaction screening was investigated and presented using illustrations and charts. The soil composition, SPT-N distribution and zone of saturation reveals deep layer of sand up to 30 m, soft layer of sandy deposits and saturation zone near ground surface which governs the liquefaction potential possibility.
2. The charts presented shows vulnerable deposits existence in the shoreline areas of Terengganu state in which the soil are of uniformly graded deposits indicating existence of clean sand.
3. The applied analysis based on SPT presents potential of liquefaction in Terengganu shoreline due to the presence of loose sandy silt layers in the first 20 m of soil profile.

Based on the findings of soil liquefaction screening and liquefaction potential analysis for Terengganu shoreline it clearly indicates the significant role of geotechnical information through illustrations and charts to be adopted in land usage, management and development. The early access to such information will lead proper preparation and mitigation in the sense of soil liquefaction or any other geo-hazards. Lacking information on regional setting which allows potential areas to be highlighted appears to be the main problem in promoting safe and quality built environment.

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