Liquefaction Susceptibility Mapping of Kollam Coastal Stretch, Kerala, Considering Geotechnical Parameters

S. K. Sithara, S. Surya, Sayana Parveen, Liz Maria Damiyan, Vinayak Mohan, A. Muhammed Siddik, and S. Adarsh

Abstract The assessment of liquefaction potential is one of the important scientific problems for the geotechnical investigators. Liquefaction of loose saturated cohesionless soil during earthquake has been a major cause of damage due to earthquake for the buildings, earth embankments and other civil engineering structures. The study area of the coastal stretch of Kollam in western Kerala, India, mainly consists of coastal alluvial deposits and marine sand. Samples were collected along the length and width of coastal stretch of Kollam and are tested to obtain water content, dry density, fines content and the gradation curves. Limiting curves-based gradation criteria proposed by Tsuchida (1970) and empirical relation for stress ratio (SR) values obtained by Chien et al. (2002) were used for the calculation of liquefaction potential at sample locations. Spatial analysis of this data is done using QGIS to delineate the region into most liquefiable, liquefiable, less likely to be liquefiable and not liquefiable zones. The susceptibility map developed based on SR criteria is found to be in agreement with the liquefaction potential map developed by overlay of the two criteria which infer the dominant influence of dry density of the deposits of Kollam coastal stretch. Further, a ground truth examination of the final susceptibility map revealed that the zones in which water table lies within 0–5 m from ground level are more vulnerable to liquefaction in the Kollam coastal stretch. The proposed liquefaction susceptibility map can be used as a firsthand info on liquefaction potential of region which can aid in site-specific studies for future development.

Keywords Liquefaction · Kollam · Coastal · Stress ratio · Mapping

1 Introduction

Liquefaction has drawn much attention from engineers because it can create great damage to manmade structures. It causes ground to subside and to spread laterally, thus inducing buildings to tilt, damaging airport runways and earth embankments,

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and disrupting buried pipes and pile foundations. In the wake of the two devastating earthquakes of 1964, namely the 1964 Niigata and the 1964 Great Alaska earthquakes, engineers have carried out a great amount of research to study liquefaction and to predict its occurrence. There is a critical need to predict the occurrence and severity of soil liquefaction for engineering design, hazard mapping, urban planning and regulatory purposes.

The Kollam district classified under the moderate seismic zone; it means that the probability of earthquake in this zone is up to 6.9 magnitude (www.dmg.kerala.gov.in). The coastal areas of Kollam mainly consist of unconsolidated coastal alluvium and marine sand deposits of low bearing capacity. Kollam city being an important industrial area in Kerala, which is undergoing an increased growth in infrastructure development and urban settlement, the safety of structures must be ensured to prevent any disasters. To understand the regional liquefaction susceptibility of coastal stretch of Kollam, a study is carried out based on geotechnical characteristics.

Generally, two types of liquefaction hazard studies are carried out widely. The first type, based on historical liquefaction map, shows where liquefaction has occurred during the past earthquakes. The second type, a liquefaction hazard map, divides a region into areas having different degrees of liquefaction hazard (Green and Ziotopoulou 2001). Many researchers carried out studies in both. Youd and Hoose (1977) carried out a study based on historical earthquakes for the California earthquake. According to them, geological and hydrological factors mainly control the liquefaction susceptibility of soil. Many of the investigators have applied liquefaction hazard map concepts successfully.

Based on the observations made on the liquefaction failures due to Haicheng and Tangshan earthquake in China, Wang proposed Chinese Criteria in 1970. The key focus of these criteria is the percentage of "clay" present, the plasticity index and liquid limit of the soil. Based upon further field experiences and differences in testing methodologies, several modifications have been proposed to the Chinese Criteria (Seed and Idriss 1982; Finn et al. 1994; Seed et al. 2003). Based on the field performance data obtained from the Niigata earthquake of 1964, enhanced by the results of shaking table test on saturated sand deposits, ranges of grain size accumulation curves (limiting curves) for liquefiable soils were proposed (Tsuchida 1970; Iai et al. 1989).

The standard penetration test (SPT) is the most widely used test for liquefaction studies. The SPT N-value must be modified to include corrections for energy efficiency, overburden stress level, fines content, borehole diameter, barrel liner, rod lengths, aging and other factors. Recently, cone penetration test (CPT) has been used to develop CSR curves for the in situ evaluation of liquefiable soils. The CPT offers several advantages over the SPT including better standardization. The major earthquakes of Niigata in 1964 show that soil below 50% relative density would liquefy. Chien et al. (2002) performed a triaxial shear test on soil samples to understand the influence of fines content and relative density on liquefaction resistance.

Many of the investigators have used different concepts for developing liquefaction hazard map, viz., liquefaction potential index (LPI) map using standard penetration test data (Mhaske and Choudhury 2010), probabilistic liquefaction hazard (PLH) map and liquefaction potential map, based on geological and geomorphological conditions (Ganapathy and Rajawat 2012). A concept is usually selected based on availability of data and suitability of method.

Liquefaction susceptibility of a site depends on compositional and environmental factors of the soil as well as of the imposed loading characteristics. The relevant environmental and compositional factors are mineralogy, shapes and size distribution of particles, density, effective confining stress and saturation. A multi-tiered screening approach is commonly used in evaluating liquefaction triggering hazard. The evaluation method of each of these factors can range widely from project to project and simply could involve use of empirical correlations with in situ test indices [e.g., cone penetration test (CPT), tip resistance (qc) and sleeve friction (fs)] or could be much more involved, entailing detailed geologic studies and geotechnical sampling and laboratory testing (e.g., grain size distribution, water content and Atterberg limits) (Green and Ziotopoulou 2001). The screening criteria discussed herein are limited to compositional factors, mainly focusing on the geotechnical properties, of the soil.

2 Methodology

To identify the properties influencing liquefaction susceptibility, several investigators have tried to correlate liquefaction potential with geological, geotechnical and geomorphological criteria. The liquefaction susceptibility criteria proposed by Tsuchida (1970) based on the particle size analysis and the stress ratio (SR) criteria proposed by Chien et al. (2002) are used for the present study. The D_{60} values are obtained by sieve analysis, and the SR values are calculated from dry density and fines content. The obtained values are then interpolated using inverse distance method in QGIS to obtain the liquefaction potential map of Kollam coastal region. The resulted two thematic maps are integrated in QGIS by employing the UNION and overlay operations to develop the liquefaction susceptible map of the study area. The summary of the methodology used for delineating liquefaction susceptible region is shown in the flowchart in Fig. 1.

Of the many parameters influencing liquefaction, this study mainly focuses on the following geotechnical parameters to quantify liquefaction susceptibility:

Particle Size Distribution: The limiting curves proposed by Iai et al. (1989) are used for comparison. The soil samples whose gradation curves fall within the most liquefiable region in the limiting curve are assumed to have liquefaction susceptibility. To quantify this, the D_{60} values of the specimens are used. From the limiting curve, it is evident that the liquefiable soils have a D_{60} value ranging from 0.1 to 1.

$(SR)_{20}$: Chien et al. (2002) have given an empirical relation to calculate the stress ratio at 20 number of cycles in cyclic triaxial test. This value is used to express the liquefaction resistance of the soil. The soils with lower SR values are more susceptible to liquefaction.

Dry density (γ_d) is related with $(SR)_{20}$ under different fines contents (FC) as follows:

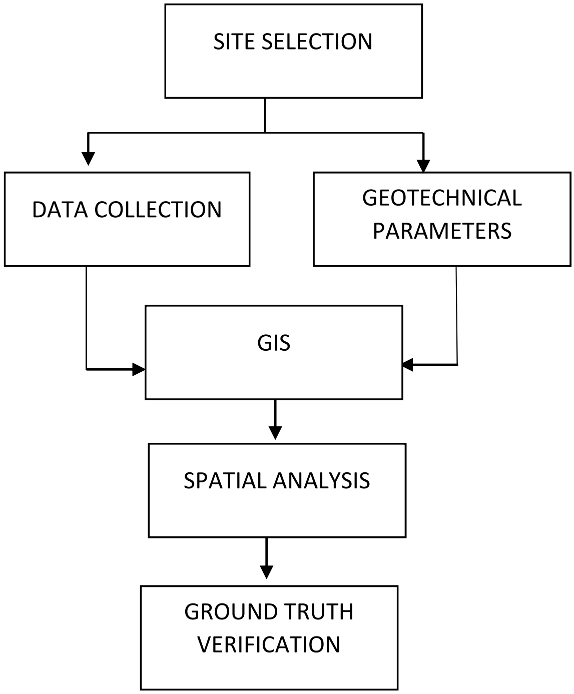

Fig. 1 Methodology of the study

$$(SR)_{20} = \boldsymbol{a}_1 \times (\boldsymbol{\gamma}_d)^{\boldsymbol{b}_1} \quad (1)$$

where a_1 and b_1 are function of fine content,

$a_1 = 0.059 – 0.0078 \times FC + 0.0015 \times FC^2$, and

$b_1 = 5.311 + 0.0247 \times FC - 0.0714 \times FC^2$

3 Study Area

Kollam district covers an area of 2491 km^2 in the southernmost part of Kerala. It is situated on the southwest coast of India between north latitudes 9° 10′ and 8° 45′ and east longitudes 76° 25′ and 77° 15′. The district is bounded by the Lakshadweep Sea on the west and Tamil Nadu state in the east. Along the northern boundary lie Alappuzha and Pathanamthitta district, while to the south lies Thiruvananthapuram district. It has a maximum length of 75 km in the E–W direction and maximum width of 45 km in the N–S direction.

The district can be broadly divided into three geological provinces—the westernmost Quaternary alluvial deposits followed by a narrow N–S zone of late Tertiary sediments and the easternmost Precambrian metamorphics. Geo-morphologically,

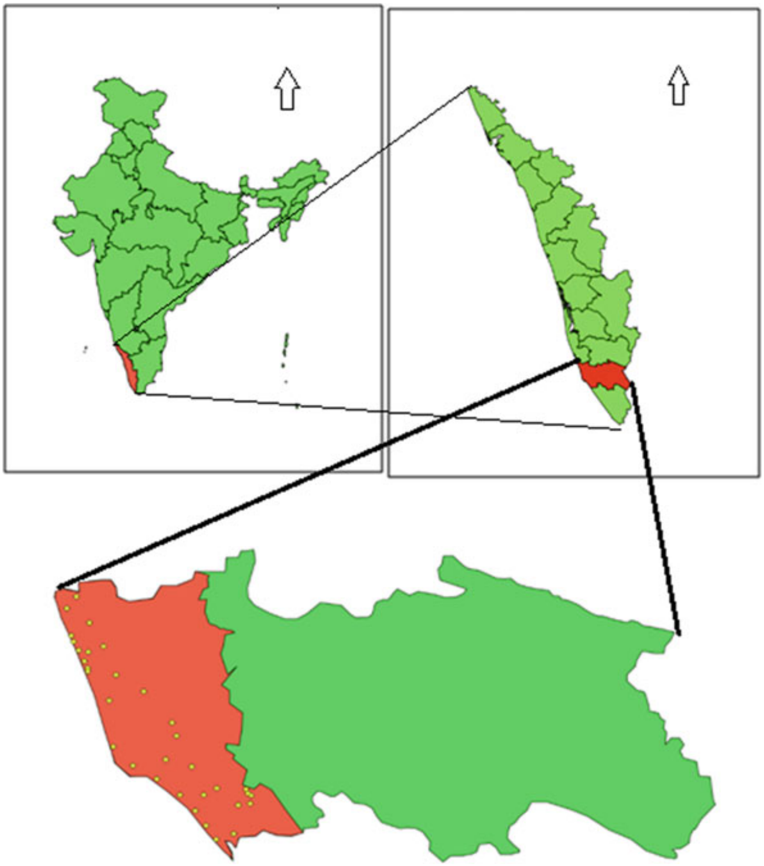

Fig. 2 Location map of study area and sampling points

the district can be divided into three units from west to east as the coastal plain, the midland and the high hill region. The coastal plain has a maximum width of 4 km in the north and gradually narrows down to less than 0.5 km toward south. It is nearly level to very gently sloping terrain depicting deposition of all forms like strandlines, flood plain and tidal flats. The coastal plain has several backwaters known as Kayals in Kerala, the prominent being Ashtamudi Kayal, Paravur Kayal, Panmana Kayal and the Sasthamcotta Kayal.

The samples were collected throughout the coastal stretch of Kollam covering a certain width along the coast. About 34 samples were collected. The sample locations were chiefly along the coastal stretch of Kollam and in the environs of the Kayamkulam Kayal, Ashtamudi Kayal and Paravur Kayal. Location map of study area and sampling points are provided in Fig. 2.

4 Results and Discussions

Grain size distribution can affect the dynamic loss of soil strength and liquefaction. Hence, the property of each soil sample was studied by performing sieve analysis and analyzing the parameters obtained from the test. The results obtained are compared with the limiting criteria for each parameter to define liquefaction potential of each location. These point data were used to interpolate the liquefaction potential of whole study area. The spatial distribution of local liquefaction potential formed the key information to arrive at a conclusion regarding the liquefaction susceptibility. The gradation curves for uniformly graded soil along with standard curve are presented in Fig. 3.

First, the spatial distribution of D_{60} values is prepared and presented in Fig. 4.

Next, SR values are determined, and the spatial distribution of SR values is provided in Fig. 5.

Finally, the liquefaction susceptibility map is prepared by the weighted overlay of integration of the two maps (Figs. 4 and 5). The liquefaction susceptibility map is given in Fig. 6. A careful perusal of Fig. 6 shows that the regions having D_{60} value less than 1 are more susceptible to liquefaction. Region with SR value less than 0.357 is susceptible to liquefaction. Also, an independent comparison of Fig. 6 with Figs. 4

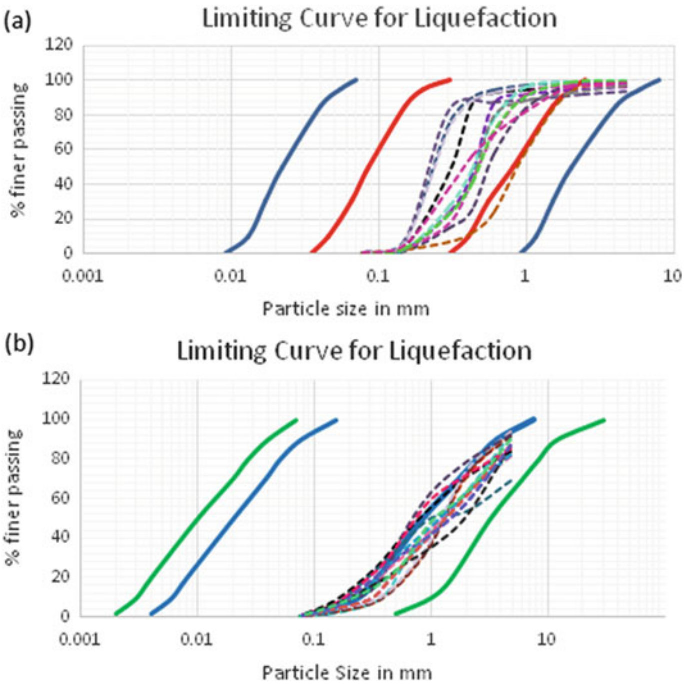

Fig. 3 Gradation curve comparison **a** for uniformly graded soils, **b** for well-graded soil

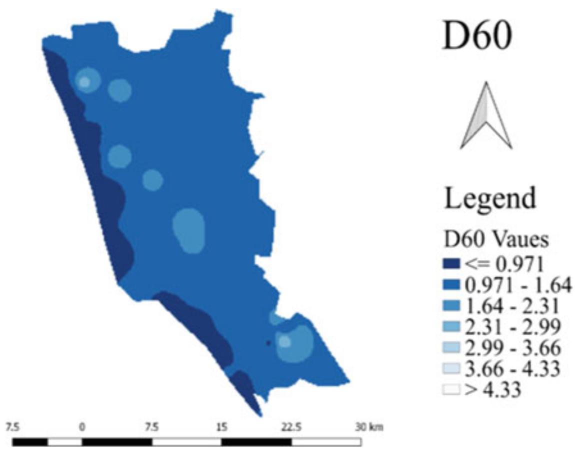

Fig. 4 Spatial distribution of D_{60} values

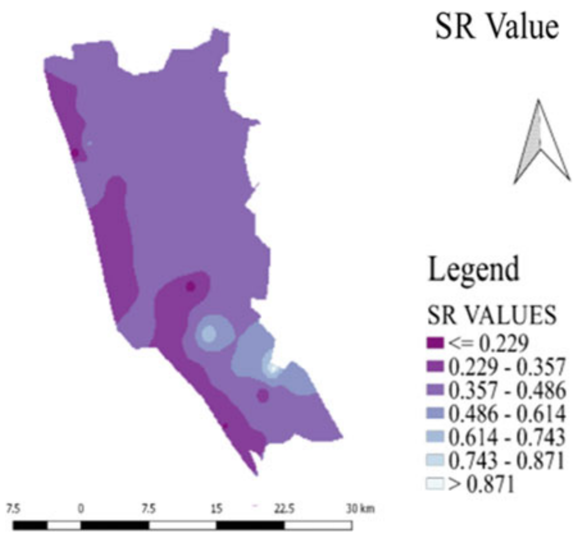

Fig. 5 Spatial distribution of SR values

and 5 shows the striking similarity of the final map with Fig. 5. This clearly infers the role of SR and hence influences of density of soil on liquefaction of the study area, which is the additional parameter considered in computation of SR.

Next, the liquefaction susceptibility map is overlayed with the water table data (Fig. 7) to check the water table data of the liquefaction susceptible areas.

From Fig. 7, it is noted that the depth to water table of susceptible region ranges mostly from 0 to 5 m. Hence, the liquefaction susceptibility of the area is also attributed to the effect of water table, as the soil layer gets saturated which eventually increases the liquefaction susceptibility of the study area.

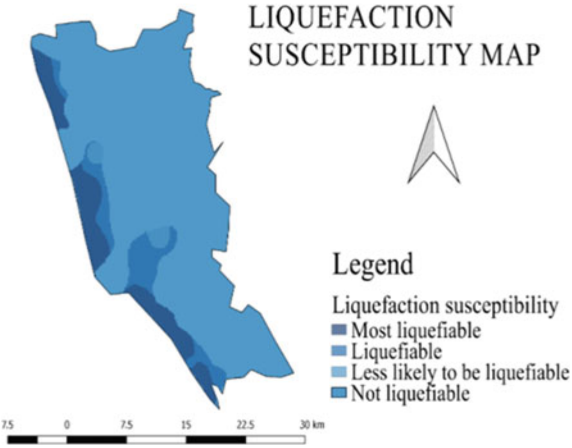

Fig. 6 Liquefaction susceptibility map of the study area

Predicting the liquefaction potential of a region is challenging, and the most studies used the test data of SPT test and cyclic triaxial test; this study followed a simplified procedure which checks the geotechnical parameters for the assessment of liquefaction susceptibility.

5 Conclusion

This study attempts to delineate the liquefaction susceptibility of Kollam coastal stretch through experimental methods which can constitute a preliminary information map on regional liquefaction potential. The cyclic stress ratio obtained indirectly through an empirical relation and the gradation curve quantified based on D_{60} is the parameter considered for the map preparation.

Important conclusions drawn from the study are presented below:

1. The coastal stretch extending to a range of width from 0.5 to 2.5 km is mostly susceptible to liquefaction.
2. The most susceptible areas consist of coastal alluvium and marine sand, which are mostly unconsolidated sediments.
3. The geology of susceptible areas consists of marine and fluvial deposits of Holocene age which conforms to the geologic criteria proposed by Youd and Hoose (1977).
4. Dry density has a greater influence in determining liquefaction susceptibility as observed from overlayed map. As dry density increases, the resistance to liquefaction increases.
5. The depth to water table of susceptible region ranges mostly from 0–5 m which increases the chance of soil layer to get saturated, and this increases the susceptibility.

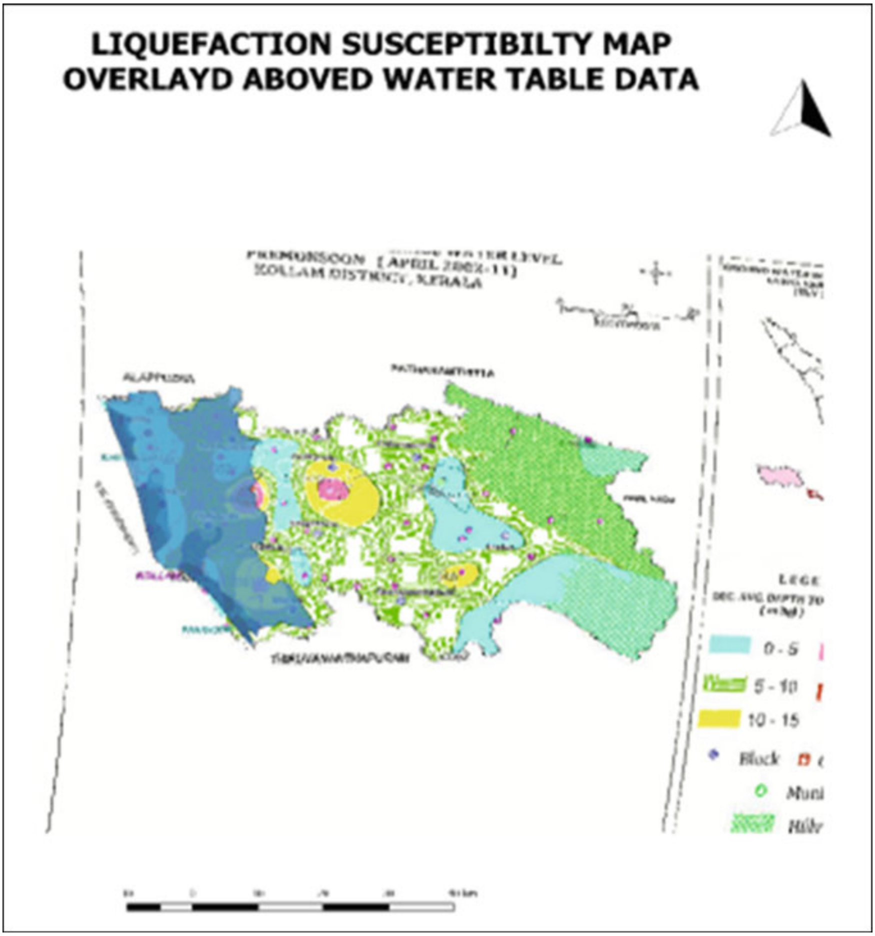

Fig. 7 Ground water table map overlaid with LSM of the area

References

Chien LK, Oh YN, Chang CH (2002) Effects of fineness content on liquefaction strength of reclaimed. Can Geotech J 43:903–914

District survey report of Minerals, KOLLAM district, by Department of Mining and geology (www.dmg.kerala.gov.in)

Finn WL, Ledbetter RH, Wu G (1994) Liquefaction in silty soils: design and analysis. Ground failure under seismic conditions, pp 51–76

Ganapathy PG, Rajawat AS (2012) Evaluation of liquefaction potential hazard of Chennai city, India: using geological and geomorphological characteristics. Nat Hazards 64:1717–1729

Green RA, Ziotopoulou K (2001) Overview of screening criteria for liquefaction triggering susceptibility, In: Proceedings of the tenth Pacific conference on earthquake engineering building an earthquake-Resilient Pacific 6–8 Nov 2001

Iai S, Tsuchida H, Koizumi K (1989) A liquefaction criterion based on field performances around seismograph stations. Soils Found 29(2):52–68

Mhaske SY, Choudhury D (2010) GIS-based soil liquefaction susceptibility map of Mumbai city for earthquake events. J Appl Geophys 70(216–225):217

Seed HB, Idriss IM (1982) Ground motions and soil liquefaction during earthquakes. Earthquake Engineering Research Institute, Berkeley

Seed RB, Cetin KO, Moss RES, Kammerer A, Wu J, Pestana J, Riemer M, Sancio RB, Bray JD, Kayen RE, Faris A (2003) Recent advances in soil liquefaction engineering: a unified and consistent framework. Keynote presentation, 26th annual ASCE Los Angeles Geotechnical Spring Seminar, Long Beach, CA

Tsuchida H (1970) Prediction and counter measure against the liquefaction in sand deposits. Abstract of the Seminar in the Port and Harbor Research Institute

Youd TL, Hoose SN (1977) Liquefaction susceptibility and geologic setting. In: Proceedings of the 6th world conference on earthquake engineering, vol 3, pp 2189–2194