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Evaluation of Liquefaction Susceptibility of Soils in Kerala, India based on Equivalent N-Value and Equivalent Acceleration

Akshay Vikram[1], Alex Abraham S M[1], Greeshma M R[1], Iswarya Ani[1], Muhammed Siddik A[2] and Adarsh S[3]

[1]B Tech Student, T.K.M. College of Engineering, Kollam, India
Email: akshayvikram1010@gmail.com
[2]Assistant Professor, T.K.M. College of Engineering, Kollam, India
[3]Associate Professor, T.K.M. College of Engineering, Kollam, India

Abstract. Liquefaction of soil is one of the important concerns for the geotechnical investigators, as it leads to major casualties after natural disasters like earthquakes. Potential of liquefaction mainly depends on the soil type and the magnitude of earthquake. Developing a liquefaction susceptibility map is one of the essential steps in disaster preparedness and this study proposed a novel framework for developing liquefaction susceptibility maps by correlating the soil investigation data with equivalent acceleration obtained using the site response analysis. The usefulness of the method is demonstrated by developing the liquefaction susceptibility map of soils across state of Kerala, India. In this approach, first the standard penetration test (SPT) N-values of soil from a specific location was subjected to a correction corresponding to the fine content and plasticity index of the soil, to get the equivalent N-value. Then, the equivalent acceleration was analysed through site response analysis using Proshake 2.0 software for a peak acceleration of 0.16 g. The obtained results were corrected for a wave correction to scale down the earthquake magnitude corresponding to the study area. Subsequently, the point correspond to equivalent N-value and equivalent acceleration was superimposed with the universal reference liquefaction chart proposed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) Japan to identify the zone of liquefaction susceptibility of the study area. The method is validated with different case histories from Kerala and extended to different soil types across the state.

Keywords: Liquefaction, Standard Penetration Test, Earthquake, Acceleration, N-value

1 Introduction

Soil liquefaction is one of the most complex phenomena studied in geotechnical earthquake engineering. Darve (1996) considered liquefaction as a specific feature of loose and saturated sandy soils. Soil liquefaction occurs when a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress such as shaking during an earthquake or other sudden change in stress condition, in which material that is ordinarily a solid behaves like a liquid. The effects of soil liquefaction on the built environment can be extremely

damaging. Buildings whose foundations bear directly on sand which liquefies will experience a sudden loss of support, which will result in drastic and irregular settlement of the building causing structural damage, including cracking of foundations and damage to the building structure itself, or may leave the structure unserviceable afterwards, even without structural damage. Soil liquefaction leads to loss of bearing strength, lateral spreading, sand boil, flow failures, ground oscillations, floatation, settlement, overturning of structures Therefore evaluation of liquefaction susceptibility for design of structures is needed. The major threat recently faced by Kerala was soil piping, which was occurred due to liquefaction.
Liquefaction prediction and assessment charts have been widely used for evaluating liquefaction potential. The liquefaction charts are characterized by the relationship between the Cyclic Stress Ratio (CSR) versus field measured value such as standard penetration test (SPT) N values (Seed et al. 1983, 1985), cone penetration test (CPT) q-values (Robertson and Wride 1998) and shear wave velocities (Andrus and Stokoe 2000; Shelly et al. 2014). The developed liquefaction charts mentioned above are for an earthquake magnitude of 7.5. For other magnitudes, magnitude scaling factors are introduced to correct the cyclic stress ratio, based on assumption that there exist an equivalent number of cycles for a given earthquake (Youd and Idriss 2001). But earthquake motions at given sites generally have different waveforms and durations that vary considerably in space and time depending on characteristics of sites. Therefore, wave forms and duration of earthquake should be considered in liquefaction prediction and assessment charts.

The liquefaction susceptibility of central kerala (ernakulam) was evaluated using factor of safety, calculated from csr and cyclic resistance ratio (crr) by akhila et al., (2019). Even though csr and crr based estimates are popular for evaluation of liquefaction susceptibility, performing dynamic spt or cpt becomes inevitable for the field data collection, by simulating the seismic conditions in the field. The liquefaction chart presented in Japanese guidelines by ministry of land, infrastructure, transport and tourism (mlit 2007) is a simplified approach, which considers the equivalent n value and equivalent acceleration for the assessment of liquefaction potential. This study applies the use of mlit chart, for evaluating the liquefaction susceptibility of soils in the state of Kerala, india. This method is capable of accounting the influence of the waveforms and duration of earthquake without performing the real field simulation. In this procedure, the liquefaction susceptibly of any location can be assessed by marking in a 2d plane between equivalent acceleration and equivalent n-value. The equivalent acceleration is modified by applying appropriate correction accounting for the seismic vulnerability of kerala.

2 Methodology

The borehole log details of various sites in Kerala are collected. The SPT N value corresponds for a depth ranges from 0-3.5m is taken. Collection of geotechnical investigation data for different soils in Kerala involves both the SPT N values and laboratory results. Equivalent N value (N_{65}) is the SPT N value (N) corresponding to effective vertical stress of 65 kPa (Sassa and Yamazaki 2017). MLIT (2007) had introduced the equation (1) for deriving equivalent N value from SPT N value.

$$N_{65} = \frac{N-0.019(\sigma_v' - 65)}{0.0041(\sigma_v' - 65)+1} \qquad [1]$$

Where σ_v' =effective over burden pressure of the subsoil
Effective overburden pressure is calculated with respect to ground at the time of standard penetration test by using Terzaghi's principle. When the fine content is relatively large, Equivalent N value should be corrected before applying.

Table 1. Corrections of equivalent N value (Source : MLIT 2007)

Case 1	Case 2	Case 3
Plasticity index <10 or can't be determined or fine content <15% then the equivalent N value after correction should be set as N_{65}/C_N, C_N is the correction factor of equivalent N value corresponding to fine content.	Plasticity index >10% and <20% or fine content >15%, then the equivalent N value after correction should be set as both $N_{65}/0.5$ and N+ ΔN Where ΔN =8+0.4(Ip-10)	Plasticity index is 20% or greater and fine content is > or equal to 15%, then the equivalent n value after correction should set as N+ΔN the range should be determined with respect to corrected equivalent N value

Equivalent accelerations . MLIT, 2007 proposed the method (equation (2)) of calculating the equivalent acceleration from the effective overburden pressure and maximum shear strength.

$$\alpha_e = 0.7\frac{\tau_{max}}{\sigma_v'}.g \qquad [2]$$

Effective overburden pressure (σ_v') is calculated using Terzaghi's effective stress principle. Maximum shear stress (τ_{max}) is calculated using software Proshake. Equivalent accelarations are calculated for soil layer using maximum shear stress obtained from the results of the seismic response analysis of ground.
ProShake is a computer program for one-dimensional, equivalent linear ground response analysis. Proshake consist of three managers they are input manager, Solution Manager and Output Manager. The Input Manager organizes the input data which include soil model, thickness of soil layer, Unit weight of soil, Shear wave velocity, shear parameters and input motions. The Solution Manager is where the actual site response analyses are executed. The solution manager displays all combinations of soil profiles and ground motions to allow the user to gauge the progress and completeness of the analyses as they are being performed. Shear stress time history can be plotted using the output manager. The liquefaction chart developed by MLIT is for an earthquake magnitude of 7.5. The chart is divided into four zones , which are Zone I liquefaction will occur, Zone II high possibility of liquefaction, Zone III low possibility of liquefaction, Zone IV

liquefaction will not occur. For other magnitudes, Sassa and Yamazaki (2017) had proposed wave correction coefficient (equation (3)) to correct equivalent acceleration.

$$C_\alpha = N_r^{-a} . N_{eff}^{a} \qquad [3]$$

N_r is effective number of cycles assessed for reference earthquake (1983 Central Japan Sea Earthquake at Akita Port, Japan) which is about 5. Liquefaction prediction and assessment simultaneously considers the influence of the waveforms and durations of earthquakes by plotting the equivalent acceleration which is divided by the wave correction coefficient, C_α.

N_{eff}= effective number of cycles which is half the number of half waves above 0.6 × τ_{max} in the time history of the shear stress variation due to irregular seismic waves. The constant 'a' depend on relative density of soil. The point corresponds to corrected equivalent N value and Corrected equivalent acceleration is superimposing with liquefaction chart developed by MLIT Japan to identify the zone of liquefaction susceptibility of the study area. The liquefaction chart proposed by MLIT is characterized by the relationship between the equivalent N value versus equivalent acceleration. The MLIT chart has been constructed for reference earthquake of Central Japan Sea 1983. For other earthquake magnitudes, wave correction coefficients are used to correct equivalent acceleration. The State of Kerala lies in seismic zone 3. As the history of major earthquakes is practically absent in the State, the Peak Ground Acceleration of 0.16g of a real case history occurred at nearby state Tamilnadu is taken as the input. Possibility of liquefaction is evaluated by the zone in which the point lies.

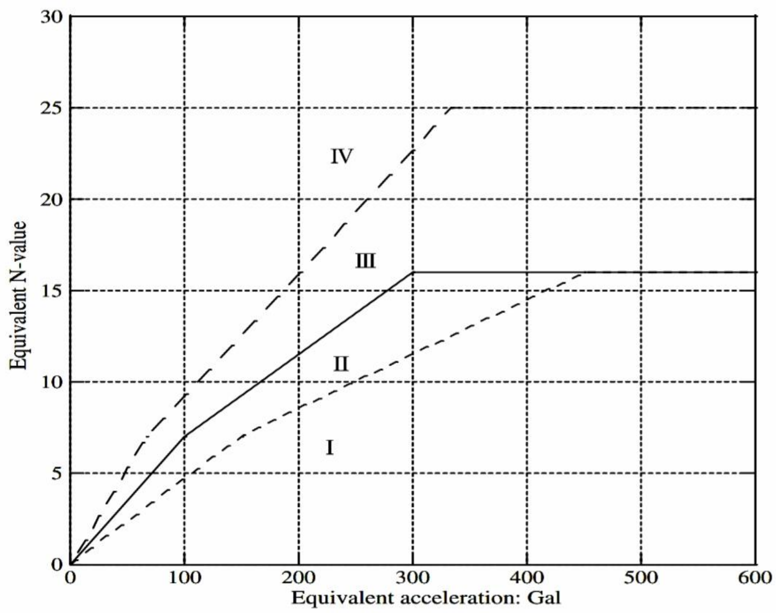

Fig. 1. Liquefaction chart showing four zones for liquefaction prediction and assessment (Source : MLIT 2007)

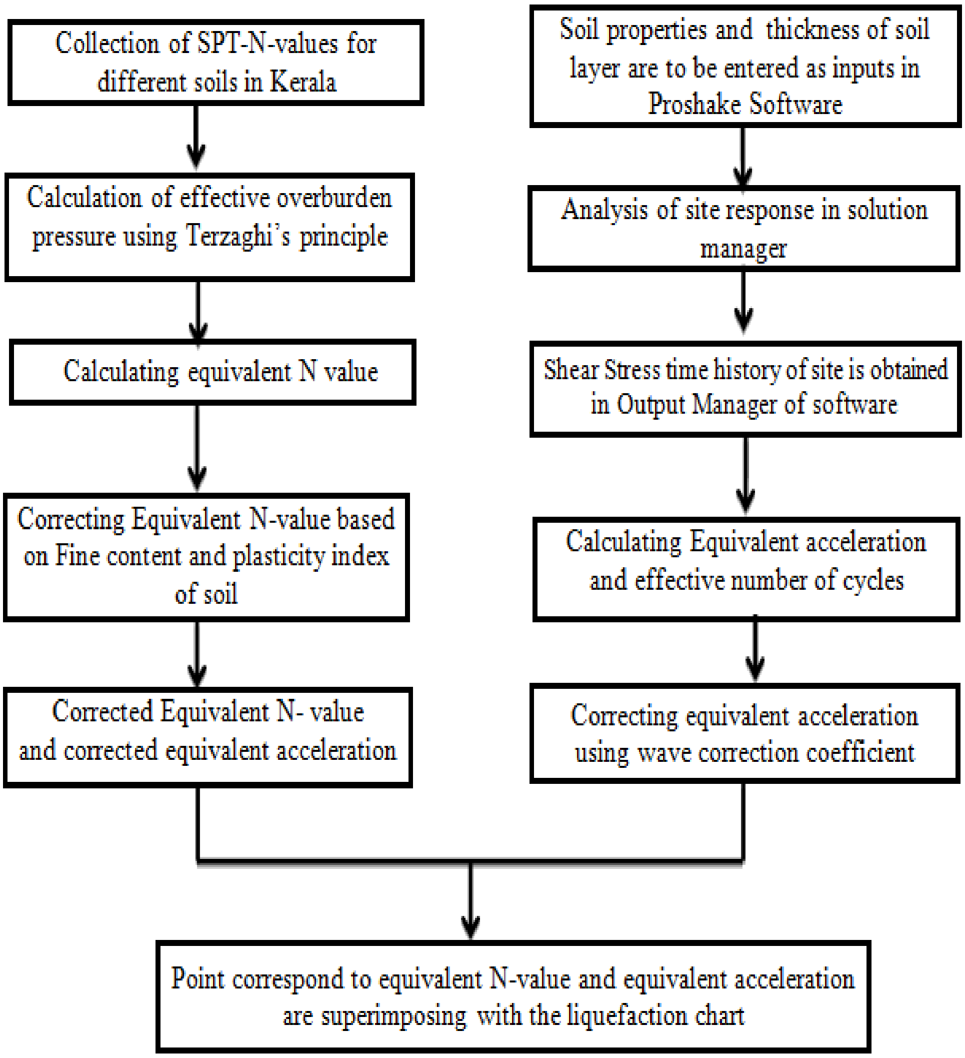

Fig. 2. Flowchart of methodology

3 Data Collection And Site Details

Standard penetration test provides samples for identification purposes and provides a measure of penetration resistance which can be used for geotechnical design purposes. Standard penetration test is conducted by the free fall of safety hammer from a height of 750 mm. The corresponding SPT N value is measured and assigned in borehole log. Bore hole log is collected along with SPT N values. Soil properties like index properties and engineering properties are also collected.

Fig. 3. Location of bore hole sites in Kerala

The data collection on the characteristics, depth of the soil and the SPT value of 15 sites including Achankovil (Kollam), Kollam District Hospital, Mannar (Alappuzha), Kalamassery (Ernakulam),Victoria College (Palakkad), Thekkady (Idukki), Shangumugham (Trivandrum), Vennikulam (Pathanamthitta), Pothencode (Trivandrum),Karunagapally(Kollam), Kalpetta (Wayanad), Ponnani(Malappuram), Peralassery (Kannur), Chavakkad (Thrissur) and Kozhikode Medical College were analysed. The depth of the soil considered is in the range 0-3.5m and the soil type observed are Reddish brown clay, Brown sand clay, Red sandy soil, Yellow lateritic sandy clay, Brown lateritic sand, Grey sand, Reddish clayey sand with gravel, Brown sand, Black fine sand etc.

4 Result And Discussions

Soil profile details and standard penetration test N value data of all site are subjected the analysis for identification of liquefaction potential. The sample calculation results of site Achankovil is shown in Table 2. The points correspond to corrected equivalent N value and corrected equivalent acceleration are plotted in the Liquefaction chart (Figure 5). The same procedure is applied for remaining sites. Liquefaction chart of all sites are plotted here and are analyzed. Calculated equivalent N- values and the corrected Equivalent acceleration for different sites are listed in the Table 3.

Table 2. Calculated results of site Achankovil, Kollam

Parameter	Value
Site	Achankovil, Kollam
Depth	3.5m
Cohesion	56 kPa
Angle of internal friction	24.3
Relative density, Dr	20.28%
Shear wave velocity	74.37m/s
SPT N value of soil layer	9
Top layer soil type	Reddish brown clay for a depth of 1.6 m
Unit weight of top layer	19 kN/m^3
Bottom layer soil type	Brown sandy clay for a depth of 1.9 m
Unit weight of bottom layer	18 kN/m^3
Equivalent N value	9.02
Fine content	62.8%
Plasticity index, I_p	25
Correction, N+ΔN	14
Corrected equivalent N value	23
Equivalent acceleration, α_e	41.138 Gal (Galileo)
Maximum shear stress	3.87 kPa (Fig. 4.)
Correction, C_α	0.948
Corrected equivalent acceleration	43.38 Gal (Galileo)

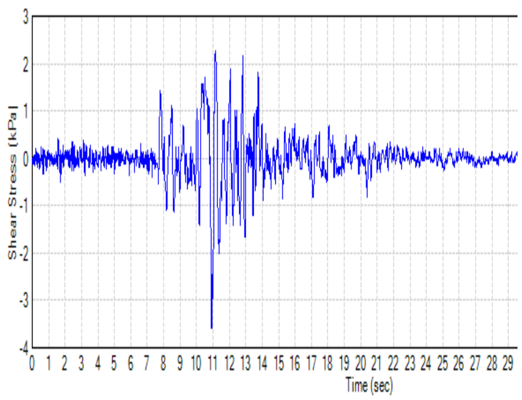

Fig. 4. Shear Stress Diagram obtained from Proshake

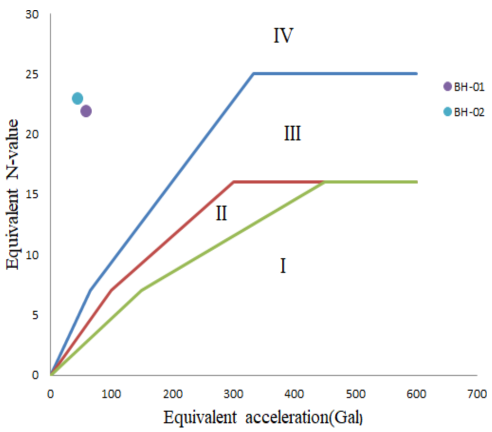

Fig. 5. Liquefaction Susceptibility of site Achankovil, kollam marked in Liquefaction Chart

Table 3. Corrected Equivalent N- values and the corrected Equivalent acceleration for different sites

Place	Bore Hole	Spt N Value	Corrected Equivalent N Value	Corrected Equivalent Acceleration (Gal)
ACHANKOVIL, KOLLAM	BH 01	9	23	43.38
	BH 02	8	22	54.00
KOLLAM DISTRICT HOSPITAL	BH 01	3	33	54.97
	BH 02	7	8	0.29
MANNAR, ALAPPUZHA	BH 01	2	21	50.98
	BH 02	4	22	47.99
	BH 03	2	22	40.45
	BH 04	1	19	71.55
KALAMASSERY, ERNAKULAM	BH 01	51	63	2.23
	BH 02	45	57	32.85
	BH 03	51	65	56.03
	BH 04	39	53	2.26
PONNANI, MALAPPURAM	BH 01	6	8	150.83
	BH 02	7	10	69.26
	BH 03	4	6	180.19
	BH01	8	14	38.14
VICTORIA COLLEGE,	BH 02	6	11	28.50
PALAKKAD	BH 03	10	14	35.52
	BH 04	22	38	2.19
	BH 05	15	33	61.06
THEKKADY, IDUKKI	BH 01	7	17	35.97
	BH 02	1	2	2.17
SHANGUMUGHAM,	BH 01	9	8	1.92
TRIVANDRUM	BH 02	11	19	1.88
VENNIKULAM,	BH 01	20	22	60.57
PATHANAMTHITTA	BH 02	51	51	2.62
	BH 03	32	69	2.57
	BH 04	38	79	43.98
KARUNAGAPALLY, KOLLAM	BH 01	2	2	2.01
	BH 02	4	4	47.94
	BH 03	4	4	45.72
	BH 04	7	7	44.56
KALPETTA. WAYANAD	BH 01	7	8	67.17
	BH 02	15	29	2.24
	BH 03	20	22	2.66
PERALASSERY, KANNUR	BH 01	6	12	75.80
	BH 02	23	23	62.49
	BH 03	10	21	3.21
	BH 04	17	35	2.68
	BH 05	18	37	2.72
CHAVAKKAD, THRISSUR	BH 01	3	4	72.58
	BH 02	3	7	3.48
	BH 03	3	4	84.01
POTHENCODE, TRIVANDRUM	BH 01	20	40	39.83
	BH 02	15	30	51.30

	BH 03	30	48	57.55
	BH 04	30	59	6.12
	BH 05	26	41	55.70
KOZHIKODE MEDICAL COLLEGE	BH 01	36	40	66.62
	BH 02	50	54	2.16
	BH 03	4	8	2.72
	BH 04	4	16	2.70
	BH 05	4	17.	2.78
	BH 06	17	18	2.97

This procedure is applied to all the borehole data of various sites to determine equivalent N value and equivalent acceleration. Liquefaction analyses have been done on all sites for a PGA of 0.16 g and an earthquake magnitude of 6. Figure 6 shows the liquefaction susceptibility of all the sites considered in this study.

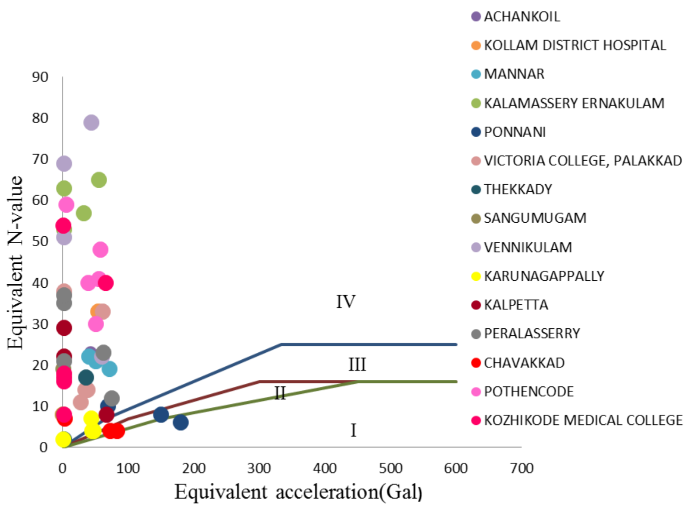

Fig. 6. Liquefaction susceptibility of various sites in Kerala State

Result shows that 1.85%, 5.56%, 3.7% and 89% of total boreholes lies in zone 1, zone 2, zone 3 and zone 4 respectively. The results reveal that most of the borehole lies in the 4^{th} zone, denotes those areas which are not susceptible to liquefaction. Hence the possibility of liquefaction is low in these sites.

Discussion

The result of the study area shows that the majority of the site considered for the study are falling in the Zone-4, which shows that the study regions are not susceptible to the liquefaction. Generally, SPT values are designed to geotechnical design purposes. The unavailability of geotechnical investigation data of soil from various spectrum is a barrier in evaluation of liquefaction potential of all sites in

Kerala. For prediction and preparedness against the liquefaction hazard, the government should take initiative in developing a geotechnical investigation data of soil where construction is not possible. Thereby, the prediction of liquefaction possibility of more sites can be done and liquefaction can be prevented by taking remedial measures. It can reduce the damages due to liquefaction in terms of life and assets.

5 Conclusions

Liquefaction prediction and assessment is a vital part of the earthquake resistant design of structures on liquefiable soils. Liquefaction prediction and assessment methods have been widely used for such design in practice, as well as for disaster prevention and mitigation. In this paper the liquefaction susceptibility of soils in kerala is evaluated using Liquefaction chart proposed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) Japan, which is a simplified liquefaction prediction and assessment method. Apart from the other, this method is capable of considering the influence of the wave forms and duration of earthquake. The SPT N values collected from the various construction sites are subjected to a correction corresponding to the fine content and plasticity index of the soil, to get the equivalent N-value. Then, the equivalent acceleration was calculated using maximum shear stress obtained from Proshake 2.0 software for a peak ground acceleration of 0.16 g. The obtained results were subjected to a wave correction corresponding to the earthquake magnitude of the study area. Subsequently, the point correspond to the equivalent N-value and equivalent acceleration was plotted in the reference liquefaction chart proposed by MLIT, japan to determine the zone of liquefaction susceptibility of sites. The result shows that majority of the study area lies in Zone 4, which is free from liquefaction.

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