LIQUEFACTION ANALYSIS FOR KUTCH REGION USING DETERMINISTIC INSITU ANALYSIS SOFTWARE

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Abstract - *The 2001 Bhuj-Gujarat earthquake, of magnitude (Mw=7.7) that occurred on January 26, which resulted in the most devastating effects called seismic soil liquefaction. After 16 years results of back analysis of soil using deterministic in-situ liquefaction analysis approach presented in this paper confirms that the presence of liquefiable layer contributed to the lesser factor of safety which may lead to foundation failure of structures in upcoming seismic events. In this paper, a new deterministic in-situ liquefaction analysis software LiqSvs1.0 is used. It includes estimation of the vertical settlement, lateral displacement, and overall liquefaction potential induced by the earthquake is calculated for Kutch region.*

***Key Words*: Liquefaction, SPT, Cyclic Resistance Ratio (CRR), Cyclic Stress Ratio (CSR), Factor of Safety (FS), Overall Potential (IL), Settlement.**

1. INTRODUCTION

Kutch (Kachchh) is the largest district of India located in Gujarat. Geomorphologically, Kutch is categorized into four major trending zones as Costal zone, Kutch mainland, Banni plains, and two Ranns.

The traces of liquefaction and various types of extensional cracks, most of them related to liquefaction and lateral spreading were identified after the 2001 earthquake. The areas around Bhuj were identified with abnormal increase in soil moisture after the earthquake. During 2001 earthquake the seismically induced settlement of building with shallow foundations on liquefiable soil has resulted in significant damage.

Looking to the recent development and industrial growth of the Kutch-Gujarat especially the biggest growth areas of Mundra, Mandvi, Kandla, and Bhuj etc; it is a prime requirement of evaluating seismic hazard possibilities. We have witnessed worst earthquake in Kutch in the year 2001. Also, in present times we have observed increase in seismic activities. So the assessment of liquefaction and proper choice for foundation is the vital necessity to mitigate liquefaction.

One of the major effects caused by the secondary effect of earthquake is liquefaction phenomenon. Due to the 2001 Bhuj earthquake the Liquefaction lead to large failures of structure and devastating collapses in the form of sudden settlements, lateral spreading etc. Before preparing and studying mitigation ways for such failures it is required to understand ways and causes of failures and estimation of factor of safety, overall liquefaction potential and cumulative settlement.

2. LIQUEFACTION

The term liquefaction was first initially introduced in 1953 by Mogami and Kubo. The study of soil liquefaction and its devastating effects came into practice after the earthquake in 1964 at Niigata and Alaska, which had a significant number of liquefaction damages on buildings and structures.

Soil liquefaction is a phenomenon whereby a saturated or partially saturated soil to a great or significant extent losses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition and causing it to behave like a viscous liquid. The process of liquefaction take place when the pore water pressure becomes equal to the total stress under repeated loading.

Mathematically, $\tau = (\sigma - \mu) \tan\varphi$

The liquefaction phenomenon can be described as the reduction of shear strength due to pore pressure build-up in the soil skeleton .When saturated loose sands are subjected to earthquake loading, an upward propagation of shear waves takes place. However the duration of cyclic stress application is so short as compared to time required to drain, that soil volume contraction cannot occur immediately and excess pore water pressure builds up progressively. When this excess pore water pressure equals total stress, it reduces effective stress to zero and sands completely lose their stiffness & shear strength temporarily; such a state is called as initiation of liquefaction.

3. LIQUEFACTION POTENTIAL

Liquefaction potential is the evaluation of resistance of soil to liquefy. There are various methods to assess soil liquefaction. They are mainly divided into laboratory methods and field methods. The field study mainly deals with Cone penetration test and Standard penetration test. The laboratory methods include Direct shear test, Triaxial shear test, Centrifuge tests, Ring shear test, Torsion shear test, Shake table test.

4. LIQUEFACTION POTENTIAL CRITERIA

The liquefaction estimation or calculation requires two variables which are defined based on cyclic stress approaches are as follows:

A. Cyclic Resistance ratio (CRR):

The capacity of soil to resist liquefaction is represented as Cyclic Resistance ratio. The most commonly used method for determining the liquefaction resistance is to use the data obtained from the SPT test.

B. Cyclic Stress Ratio (CSR):

The seismic demand of soil layer is represented by Cyclic Stress Ratio.

If the cyclic stress ratio caused by the earthquake is greater than the cyclic resistance ratio of in situ soil then liquefaction could occur during an earthquake.

5. FACTOR OF SAFETY

Liquefaction potential is estimated in terms of factor of safety. The liquefaction analysis culminates in determining the factor of safety against liquefaction. If cyclic stress ratio (CSR) caused by the anticipated earthquake is greater than the cyclic resistance ratio (CRR) of the in-situ soil, then liquefaction could occur during the earthquake. Thus, the factor of safety (FS) against liquefaction may be defined as

FS = CRR/CSR

Where CRR represents the resistance of soil to liquefaction and CSR represents the stress caused by the earthquake load. The higher the factor of safety, the more resistant is the soil to liquefaction. In general if the FS ≤ 1, then the soil is considered to liquefy otherwise the soil is safe against liquefaction.

6. LIQUEFACTION POTENTIAL INDEX

Liquefaction Potential Index (LPI) as originally defined by Iwasaki et al. (1978) weighs factors of safety and thickness of potentially liquefiable layers according to depth. It assumes that the severity of liquefaction is proportional to:

1. Cumulative thickness of the liquefied layers;

2. Proximity of liquefied layers to the surface; and

3. Amount by which the factor safety.

7. OBJECTIVE

For the present study, liquefaction analysis is carried out by using standard penetration test (SPT) data. The deterministic in-situ liquefaction analysis software LiqSVs 1.0 by Geologismiki is used. The liquefaction analysis method is according to Boulanger & Idriss (2014). The Overall liquefaction potential is calculated according to Iwasaki.

The main objectives of the study are,

- To identify liquefaction-prone areas.
- To predict the probability of liquefaction.
- To determine the factor of safety from the deterministic analysis.
- To estimate the vertical settlement caused due to liquefaction.
- To estimate the lateral displacement caused due to liquefaction.

Kutch region consists of the larger area for the present study the data from 12 boreholes is collected for analysis. Water table is the most important factor for liquefaction as only saturated sediments can liquefy. The depth of the water table measured during drilling for Kutch varies from 0m to 50m, for the present study the areas having water table up to 7m in Kutch mainland and coastal regions are considered these are Bhuj, Madhapar, Anjar, Gandhidham, Bhachau, Kandla, Mandvi and Mundra. Some variations in water table were observed, however, during different seasons, like that in monsoon and in summer.

The standard penetration tests were conducted, as per IS-code. The measured SPT-N value however, depends on many factors such as hammer types, samplers used, drilling methods, types of rod used during drilling, borehole size, test procedure. The standard penetration test were done up to 7m of 150mm diameter in all the 12 boreholes. During drilling the soil samples, both disturbed and undisturbed, were collected for geotechnical investigation. The STP N-values measured are generally low at shallow depth. However the blow count increases at the greater depths. The blow count more than 50 were not encountered even after 6-7 m depth which indicates that the shallow layer of the study area has a liquefied behavior. The SPT N-value are corrected from the estimation of CRR.

Table-1 Borehole lithology of the study area.

BH no.	Location	Depth	SPT	Lithology
1	Bhuj	1-3	5	Coarse sand
		3-5	9	Silty sand
		5-7	11	Silty sand and coarse sand
2	Bhuj	1-3	12	
		3-5	9	Coarse sand
		5-7	15	Coarse sand with

				silt
3	Madhapar	1-3	13	Silty sand
		3-5	16	Coarse sand with pebbles
		5-7	49	Silty sand with clay
4	Anjar	1-3	11	Coarse sand
		3-5	19	Medium fine sand
		5-7	36	Weathered S.St.
5	Gandhidham	1-3	13	Coarse sand with clay
		3-5	15	Coarse sand
		5-7	39	Silty sand
6	Bhachau	1-3	7	Coarse sand with silt
		3-5	13	Silty sand
		5-7	11	Silty sand
7	Kandla	1-3	4	Silt and clay
		3-5	4	Silt and clay
		5-7	5	Silt and clay
8	Kandla	1-3	4	Silt and clay
		3-5	6	Silt and clay
		5-7	8	Silt and clay
9	Mandvi	1-3	7	Sand
		3-5	11	Sand
		5-7	12	Sand with clay
10	Mandvi	1-3	7	Sand
		3-5	13	Sand
		5-7	9	Sand
11	Mundra	1-3	3	Coarse sand
		3-5	5	Coarse sand
		5-7	6	Coarse sand
12	Mundra	1-3	9	Coarse sand
		3-5	12	Coarse sand with silt
		5-7	21	Silty sand

Table-2 Basic geotechnical properties of the study area.

BH no.	Fines (%)	D50	Soil Class	Depth of water table
1	11.00	0.26	SP	5 m
	4.00	0.5	SM	
	25.00	0.30	SP	
2	3.00	0.19	SP	3 m
	12.00	0.30	SP	
	26.00	0.27	SP	
3	11	0.13	SP-SM	6 m
	6	0.27	SP	
	21	0.59	SM	
4	6	0.13	SP	6.5 m
	15	0.41	SP	
	11	1.15	NA	
5	13	0.37	SP-SC	7 m
	16	0.27	SP	
	27	0.54	SM	
6	4	0.36	SP	4.7 m
	6	0.42	SM	
	7	0.41	SM	
7	-	-	CH	3 m
	-	-	CH	
	-	-	CH	
8	-	-	CH	At G.L.
	-	-	CH	
	-	-	CH	
9	3	0.19	SP	3 m
	5	0.22	SP	
	11	0.25	SP	
10	12	0.27	SP	At G.L.
	5	0.56	SP	
	20	0.15	SP	
11	4	1.41	SP	2 m
	7	0.21	SP	
	6	0.42	SP	
12	6	0.30	SP	3 m
	3	0.40	SP	
	11	0.23	SM	

(S.St- sandstone; NA- not available)

Table-3 Calculation Properties.

Earthquake Magnitude	7.70
Peak ground acceleration	0.36g (Kutch-Zone V) (Zone factors based on Intensity of shaking IS-1893, 2002)
Calculation method	Idriss & Boulanger (2014)
Sampling method	Standard Sampler
Borehole diameter	150mm
Rod length	1.00m (above ground)
Hammer Energy ratio	1.00
Round corrected SPT	Nearest
Influence Thickness	7 m
Cn Formula	Kayen et al.
Lateral Displacement	For all boreholes the ground is level no slope was observed (no calculations will be performed).

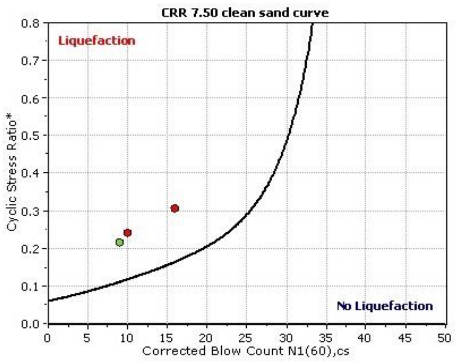

Fig-1 CRR Curve for BH1

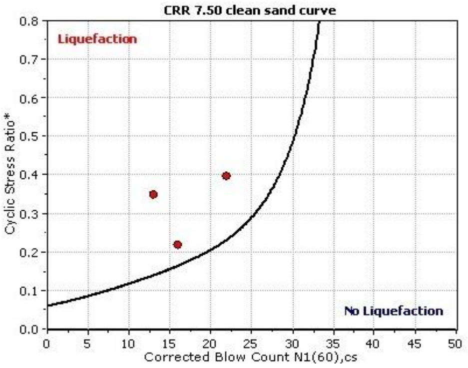

Fig-2 CRR Curve for BH2

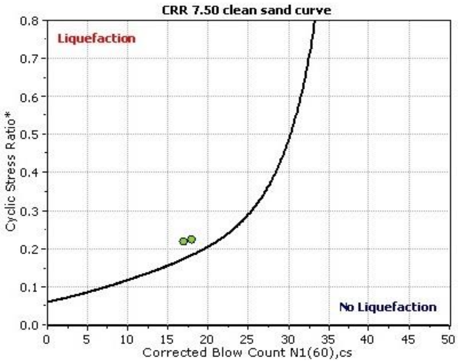

Fig-3 CRR Curve for BH3

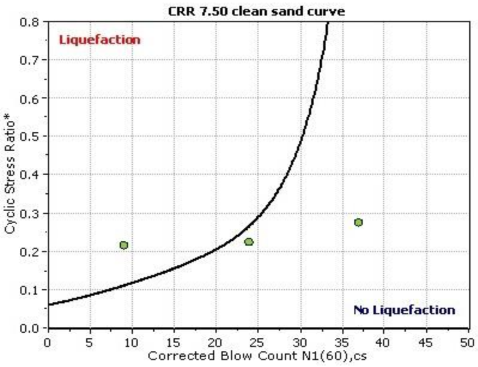

Fig-4 CRR Curve for BH4

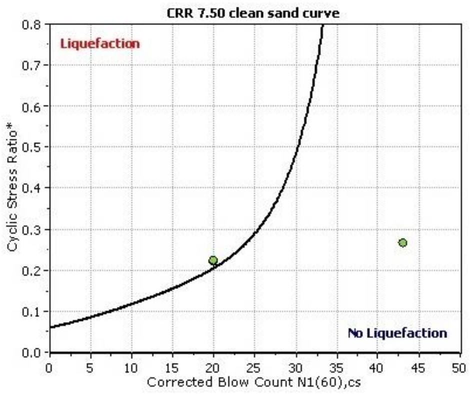

Fig-5 CRR Curve for BH5

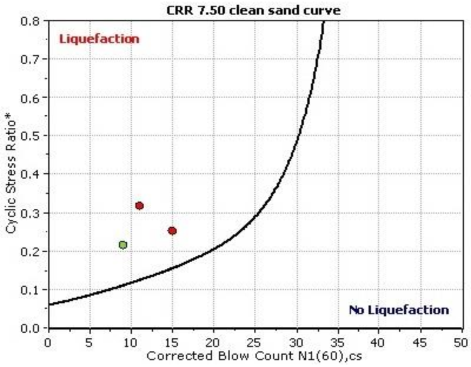

Fig-6 CRR Curve for BH6

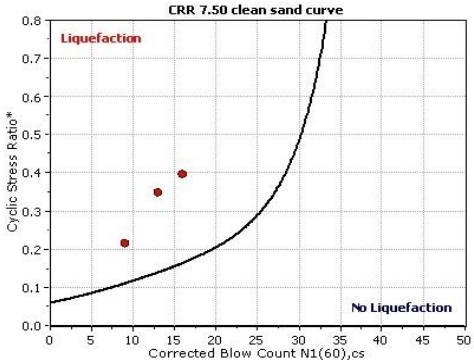

Fig-7 CRR Curve for BH9

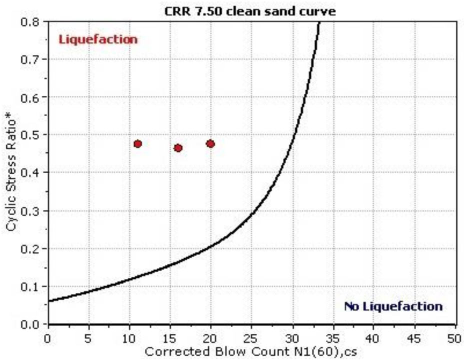

Fig-8 CRR Curve for BH10

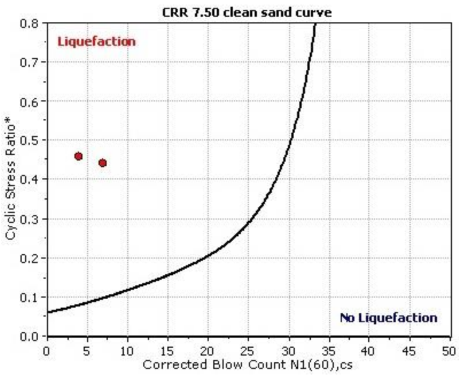

Fig-9 CRR Curve for BH11

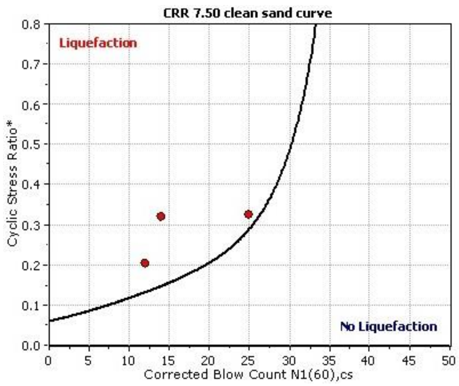

Fig-10 CRR Curve for BH12

Table-4 Liquefaction susceptibility criteria

BH No.	CRR			CSR		
	1m	3.5m	6m	1m	3.5m	6m
1	4.0	0.118	0.165	0.215	0.493	0.539
2	0.165	0.140	0.233	0.218	0.347	0.395
3	4.0	4.0	4.0	0.219	0.223	0.285
4	4.0	4.0	4.0	0.217	0.221	0.251
5	4.0	4.0	4.0	0.231	0.268	0.325
6	4.0	0.156	0.125	0.215	0.259	0.315
9	0.111	0.140	0.165	0.215	0.347	0.395
10	0.125	0.206	0.165	0.474	0.474	0.465
11	0.080	0.098	0.098	0.458	0.442	0.441
12	0.132	0.148	0.290	0.204	0.321	0.891

Table-5 Estimated factor of safety for 0.36pga.

BH No.	FACTOR OF SAFETY		
	1m	3.5m	6m
1	2.0	0.493	0.539
2	0.757	0.403	0.590
3	2.0	2.0	2.0
4	2.0	2.0	2.0
5	2.0	2.0	2.0
6	2.0	0.623	0.397
9	0.517	0.403	0.417
10	0.264	0.435	0.355
11	0.176	0.222	0.223
12	0.650	0.461	0.891

Table-5 Overall liquefaction potential according to Iwasaki and estimates vertical settlement

BH No.	I_L	$S_{v\text{-}1D}$
1	18.54	45.35 cm
2	25.26	56.29 cm
3	0.00	0.00 cm
4	0.00	05.00 cm
5	0.00	00.00 cm
6	18.33	44.83 cm
9	33.18	69.17 cm
10	40.43	60.03 cm
11	49.22	103.46 cm
12	21.33	52.02 cm

I_L: Overall Potential

$S_{v\text{-}1D}$: Estimated Vertical Settlement due to saturation

I_L = 0.00 – No Liquefaction

I_L between 0.00 to 5 Liquefaction not probable

I_L between 5 to 15 Liquefaction Probable

I_L > 15 – Liquefaction certain

8. CONCLUSIONS

An overview of a different method to evaluate the liquefaction potential is presented in this paper. The back analysis of soil confirms the presence of liquefied soil at foundation level. The factor of safety is calculated at 1m, 3.5m, and 6m these values can be used for design consideration. Hence it can be concluded the areas having high water table up to 5m are more susceptible to liquefaction and these study areas are not suitable for construction activities. A more rigorous study can be carried out by increasing the numbers of the boreholes and depth of the boreholes.

REFERENCES

[1] Mogami T, Kubu K (1953) "The behaviour of soil during vibration" 3rd International Conference on soil Mechanics and Foundation Engineering, Zurich. Paper No152–155.

[2] Biswas, S.K. and Khattri, K.N. "Geologic study of earthquake in Kutch, Gujarat, India" Journal of the Geological Society India, (2002) 60(2), 131–142.

[3] D. Ramakrishnan, K. K. Mohanty, S. R. Nayak and R. Vinuchandran "Mapping the Liquefaction induced soil moisture changes using remote sensing technique: an attempt to map the earthquake induced liquefaction around Bhuj, Gujarat, India" Geotechnical and Geological Engineering (2006) 24:1581-1602.

[4] Manish H. Sharma, and Dr. C.H. Solanki "Liquefaction Hazard Mapping" International Journal of Civil Engineering and Technology (IJCIET)" (2013) Volume 4 Issue 3.

[5] V.K. Dwivedi, R.K. Dubey, S. Thockhom, V. Pancholi, S. Chopra and B.K. Rastogi "Assessment of Liquefaction potential of soil in Ahmedabad Region, Western India" J. Ind. Geophys, Union (March 2017) v.21, no. 2.

[6] Ronald D. Andrus, Hossein Hayati, Nisha P Mohanan, "Correcting Liqurfaction Resistance for aged sands using measured to estimated Velocity Ratio", Journal of Geotechnical and Geoenvironmental Engineering,(2009) Vol. 135, No.6 June 1.

[7] A. Janalizadeh Choobbasti and S. Firouzian, "Assessment of cyclic resistance ratio of Babolsar Sandy Soil based on semi empirical relations", International Journal of Research & Reviews in Applied Science, Volume 2, Issue Jan'10.

[8] Biswas, S.K. and Khattri, K.N, "Geologic study of earthquake in Kutch, Gujarat, India", Journal of the Geological Society India,. (2002) 60(2), 131–142.

[9] Iyengar, R.N. and Raghukanth, S.T.G. "Strong Ground motion at Bhuj city during the Kutch Earthquake",. (2002) Current Science, 82(11), 1366–1372.

[10] Karanth, R.V., Sohoni, S.P., Mathew, G. and Khadkikar, A. "Geological observations of the Bhuj earthquake",. (2001) Journal of the Geological Society of India, 58, 193–202.

[11] Krinitzsky, E.L. and Hynes, M.E. "The Bhuj, India earthquake: lessons learnt for earthquake safety of dams on alluvium", Engineering Geology, (2002) 66(3–4), 163–196.

[12] Tuttle, M.P. and Hengesh, J.V. (2002) "Liquefaction, in Bhuj, India Earthquake of January 26, 2001" Reconnaissance Report (edited by Jain, S.K, Lettis, W.L, Murty, C.V.R and Barder,J.P). Earthquake Spectra, 18(Suppl.), 79–100.

[13] Andrews, D.C.A., and Martin, G.R., 2000. "Criteria for Liquefaction of Silty Soils", Proc. 12th WCEE, Auckland, New Zealand.

[14] Idriss, I. M., and Boulanger, R. W., 2004. "Semi empirical procedure for evaluation liquefaction potential during earthquake" Proceeding joint conference, The 11th International conf. of soil dynamics and earthquake engineering (SDEE), the 3rd international conf. on Earthquake Geotechnical Engineering (ICEGE), Berkeley California. pp: 32-56.

[15] Rastogi, B. K., Gupta, H., Mandal, P., et al., 2001. "The deadliest stable continental region earthquake occurred near Bhuj on 26 January 2001", Journal of Seismology (2001)5:609. October 2001, v.5, pp: 609–615.

[16] Seed, H. B., and Idriss, I. M., "Ground Motions and Soil Liquefaction During Earthquakes". (1982) Monograph, Earthquake Engineering Research Institute, Berkeley, California, v.134, no.5.

[17] Seed, R. B., Cetin, K. O., Moss, R. E. S., Kammerer, A. M., Wu, J., Pestana, J. M., Riemer, M. F., Sancio, R.B., Bray, J.D., Kayen, R. E., and Faris, A., 2003. "Recent Advances in Soil Liquefaction Engineering: A Unified and Consistent Framework", 26th Annual ASCE Los Angeles Geotechnical Spring Seminar, Keynote Presentation, H.M.S. Queen Mary, Long Beach, California, April 30, 2003.

[18] Youd, T. L., Idriss, I.M., Andrus, R. D., Arango, T., Castro, G., Christian, J. T., Dobry, R., Liam finn, W. D., Harder, L. F., Hynes, M. E., Ishihara, K., Koster, J. P., Laio, S. S. C., Marcuson, W. F., Martin G. R., Mitchell J. K., Moriwaki Y., Power M. S., Robertson P. K., Seed R. B., and Stoke, K. H., 2001. " Liquefaction resistance of soil; Summery report from the 1996 NCEER and 1998 NCEER/NSF workshop on evaluation of liquefaction resistance of soil Journal of Geotechnical and Geoenvironmental Engineering, ASCE, v.127, no.10, pp: 817-833.

[19] Youd, T.L., Member, ASCE, Idriss, I.M., Fellow, ASCE, 2001. Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/ NSF Workshops on Evaluation of Liquefaction Resistance of Soils, J Geotech. and Geoenvironmental Eng., v.27, no.4, pp: 297-313.

[20] Website: (https://geologismiki.gr/products/liqsvs/)

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