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Evaluating Liquefaction Potential using OCDI and Robertson Wride Methods in Parts of Bandar Abbas' Shahid Rajaei Port

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Abstract

In this paper, in addition to using the results of SPT and CPT tests performed at two different points of the site for Shahid Rajaei Port Development Project and using OCDI and Robertson and Wride methods, liquefaction potential of the area is evaluated. For this evaluation, earthquake magnitude and acceleration were considered to be 7 and 0.37g, respectively. Comparing the results of this evaluation, we found that with such incentive, the soil of this region has liquefaction. Thus, it is necessary that a suitable method be provided to enhance the soil of the project region. Given the fact that in previous phases, dynamic operations have been used for soil treatment and required equipment are available in laboratory, it is recommended that dynamic compression be used.

Keywords: liquefaction, CPT, SPT, confidence coefficient

Introduction

When deposits of saturated soil are rapidly put under incision in a bilateral manner, water pressure begins increasing within soil pores and in non-cohesive saturated soils, the pressure of pore water increases intensely and might grow to the extent that particles float independently and for moments, soil resistance and hardness might wear off completely. This so-called liquefaction phenomenon is presented in figure 1.

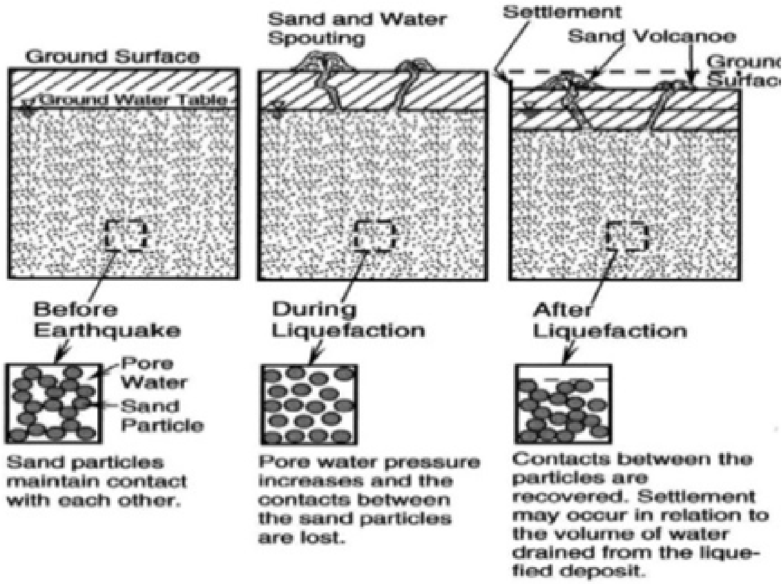


Figure 1. Process in which liquefaction occurs

Before carrying out every project, it is necessary that the construction site be fully investigated in geotechnical terms. In projects constructed in shorelines, due to the high groundwater balance and thus saturation of soil layers, it is predicted that the regional soil is susceptible to liquefaction. Hence, it is first necessary to investigate the soil in terms of liquefaction susceptibility by identifying different soil layers using geotechnical experiments. Then, by identifying liquefaction-susceptible substrata, we employ methods needed to evaluate liquefaction potential in the region under study. Eventually, besides considering the results of liquefaction evaluation results, upon occurrence of liquefaction phenomenon, given location conditions and existing facilities, best methods for treating regional soil are suggested.

Considering regional soil substrata in terms of liquefaction susceptibility

Predicting soil liquefaction susceptibility via gradation method

In this method, soil samples obtained from the location are layered with gradation and using the following uniformity coefficient, they are divided into figures 2 and 3.

$$U_c = \frac{D_{60}}{D_{10}} \tag{1}$$

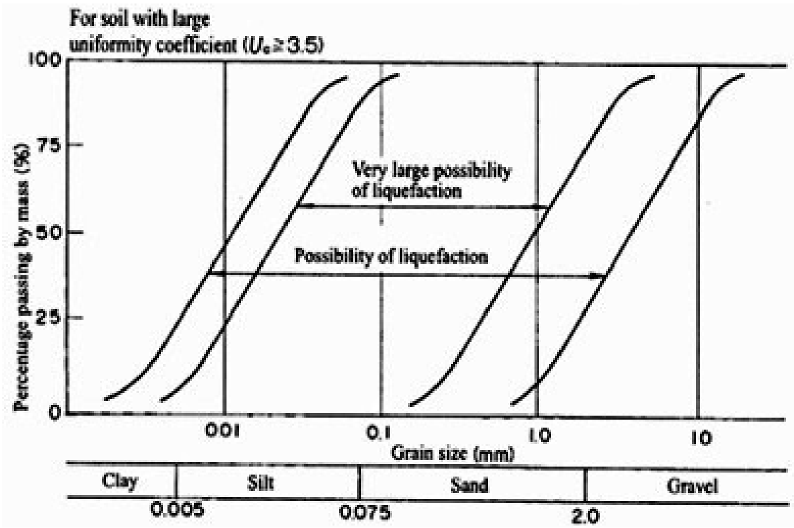


Figure 2. Area with possibility of liquefaction

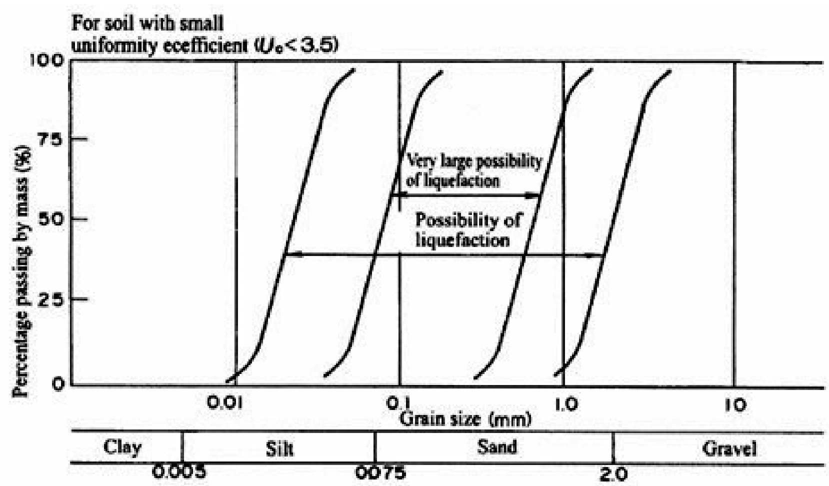


Figure 3. Area with possibility of liquefaction ($U_c < 3.5$)

Limit values of uniformity coefficient is equal to 3.5 in which U_c with the values of D60 and D10 are diameter or size of the particle, with 60 and 10 percent of which having passed the sieve. It is estimated that the when distribution curve of the size of grains does not include the liquefaction possibility range, the soil does not become liquefied.

Considering liquefaction susceptibility of regional soil for the site of Shahid Rajaee Development Project

By performing geotechnical experiments conducted, project site is generally comprised of 5 layers as follow:

1) The first layer is a layer caused by exploitation activity and filled with materials comprising a mixture of sand and gravel.

2) The second layer is a sandy and silty clay layer. The number of standard penetration blows shows looseness of the layer.

3) The third layer is a fine-grained layer comprising silt and clay, with the upper section being silty, which is laid upon a clay layer.

4) The fourth layer is identical to layer 2.

5) The fifth layer is a silty layer along with clay and gravel.

To better understand the abovementioned layers, a profile obtained by geotechnical experiments in part of the area under study is shown in figure 4.

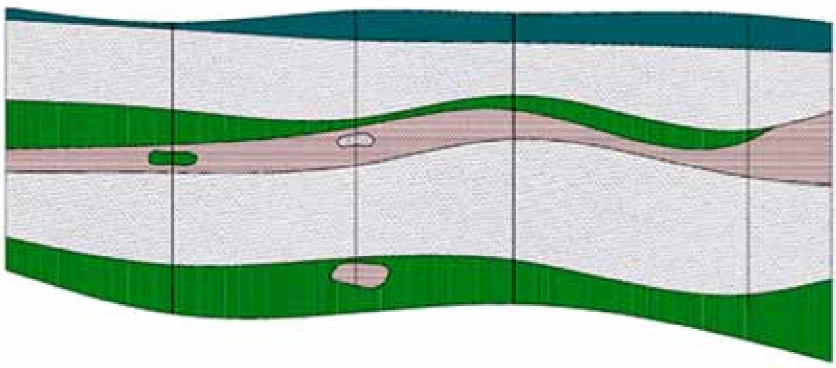


Figure 4. Profile obtained by experiments performed in the area for considering soil layers.

Given blow counts of standard penetration test recorded for second and fourth layers and thus loose sand layers and soil saturation, the region is susceptible to liquefaction. Hence, it is necessary to control it in terms of liquefaction potential.

Evaluating liquefaction potential using OCDI

According to the technical standard OCDI-2002, evaluation of liquefaction potential of soil layers must be performed as in the following procedure:

A) Once soil layers, for example a combination of sandy soils, have been saturated, it is predicted that liquefaction will develop in it.

B) Predicting liquefaction and judgment regarding soil layers must be done by picking an appropriate measure that is inferred from the results of gradation experiments and SPT.

On occasions where it is difficult to evaluate liquefaction potential based on SPT value methods and gradation, we can perform according to a tri-axial revolution experiment which shows the results of a process in detail.

Calculating equivalent N

First, we calculate the value of N for effective tension overload and recorded N's with the following equation:

$$(N)_{65} = \frac{N - 0.019(\sigma'_V - 65)}{0.0041(\sigma'_V - 65) + 1.0} \quad (2)$$

σ_v is effective soil tension with regards to land height during SPT test. Equivalent N65 values are corrected due to the effective overload pressure of 65 KN/m2. This conversion reflects the fact that liquefaction prediction has already been performed based on N values near surface water.

Equivalent acceleration

First, maximum shear tension is calculated for each soil layer and then using the following equation, the equivalent acceleration is achieved.

$$\alpha_{eq} = 0.7 \times \frac{\tau_{max}}{\sigma_{\acute{v}}} g \quad (3)$$

3-3-Predicting liquefaction using the values of equivalent acceleration and equivalent N:

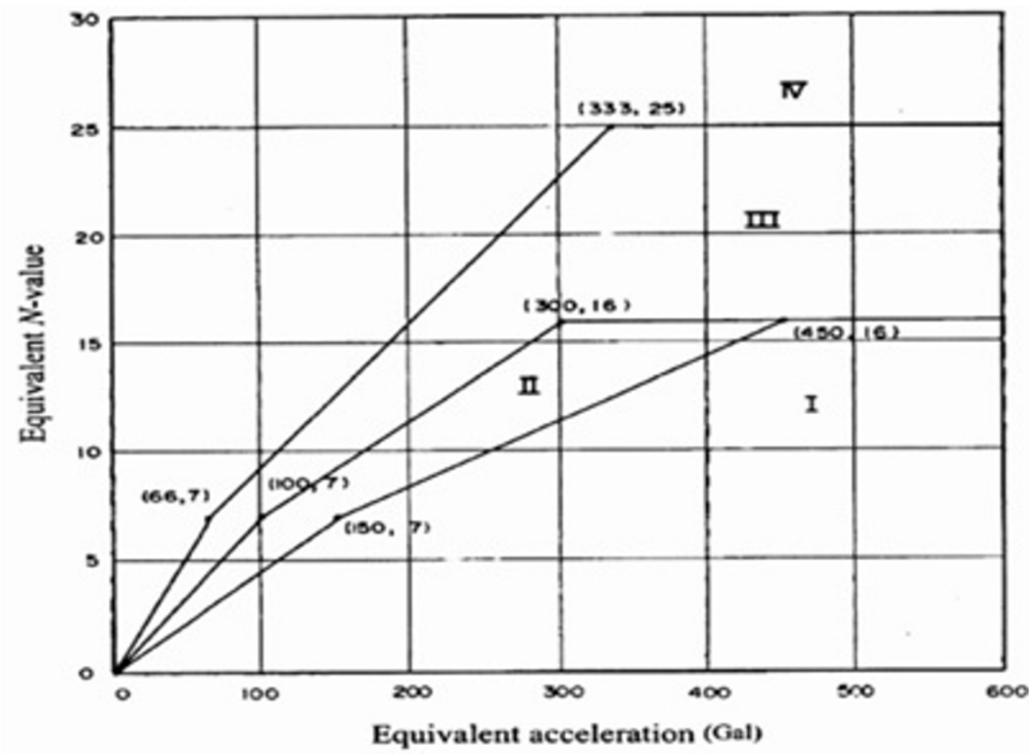


Figure 5. Soil layers classification using the values of equivalent acceleration and equivalent N

Since in predicting liquefaction, we should consider factors other than physical phenomena e.g. safety degree of constructions, we cannot easily and without any precondition, predict each criteria and judgment for evaluating different results. The rule for predicting and evaluating this event and liquefaction in order to predict results is that we consider the standards listed in table 1. In this table, prediction refers to highness or lowness of a physical phenomenon. In contrast, liquefaction evaluation refers to liquefaction possibility and judgment regarding whether the land liquefies.

Table 1. Prediction and evaluation on liquefaction of soil layer according to ranges of I-IV

Liquefaction evaluation	Liquefaction prediction	Range shown in figure 5
Will occur certainly	Occurrence of the event is highly probable	I
Based on *judgment*, liquefaction will happen and if you're in doubt, the liquefaction evaluation test must be performed based on tri-axial recursive test.	Occurrence of liquefaction is highly probable	II
Either this liquefaction will not happen or perform tri-axial test to evaluate it. For important structures, do the evaluation assuming that it happens. Also, do the tri-axial test.	Occurrence of liquefaction is highly probable	III
Liquefaction does not happen	Liquefaction occurrence probability is too low	IV

Given the fact that considerations have been based on clean sand, before incorporating equivalent N in figure 5 and range determination, equivalent N must be corrected for fine contents in the following way.

Correcting equivalent N based on fine-grain percentage in soil

a) When plasticity index is less than 10 or if it cannot be determined, or if the amount of fine contents is less than 15 percent, the value of N must be corrected with CN coefficient as follows. Compensation factor can be obtained from the following figure according to the percent of fine contents.

We get the coefficient from figure 6.

$$(N)_{65}/C_N \tag{4}$$

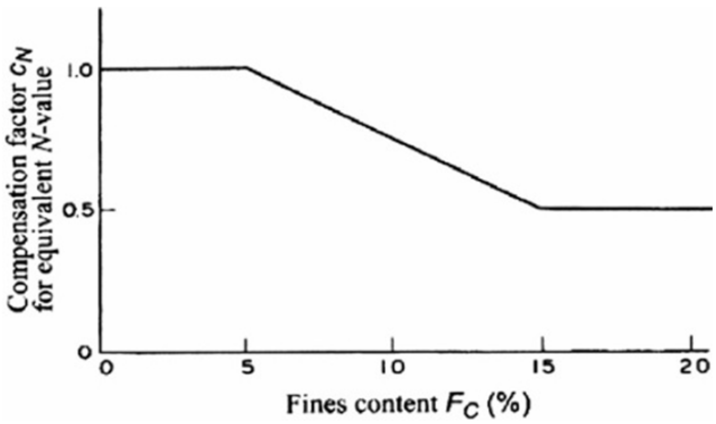


Figure 6. Calculating CN based on fine contents percentage

b) When elasticity is greater than 10 and less than 20 and the ratio of fine contents is 15 percent or more, the value of equivalent N must be compensated by ((N_{65}), 0,5) (5) and then be set to N+ΔN, as follows from the equation below.

$$\Delta N = 8 + 0{,}4^*(I_p - 10) \tag{5}$$

By calculating N+ΔN and equivalent acceleration from equation 3, we determine the from figure 5's diagram as follows.

i) When N+ΔN is within range I (use range I).

ii) When N+ΔN in within range II (use range II).

iii) When N+ΔN is within the range of III-IV and N_{65}/C_N is within the range of I or II or III (use range III).

iv) When N+ΔN is within the range of III-IV and N_{65}/C_N within the range of IV (use range IV).

Here, even when the value of equivalent N (after compensation with $N_{65}/0.5$ goes within the range of I or II, the III range is used for the case of iii because results obtained from compensation of fine grain values is highly conservative.

c) When elasticity index is equal to or greater than 20 and fine contents ratio is equal to or greater than 15%.

Equivalent N values (after compensation) must be taken as N+ΔN. Range must be determined based on N values (after) and equivalent acceleration.

Correction methods (a) to (c) using elasticity index and fine contents ratio are shown briefly in figure 7.

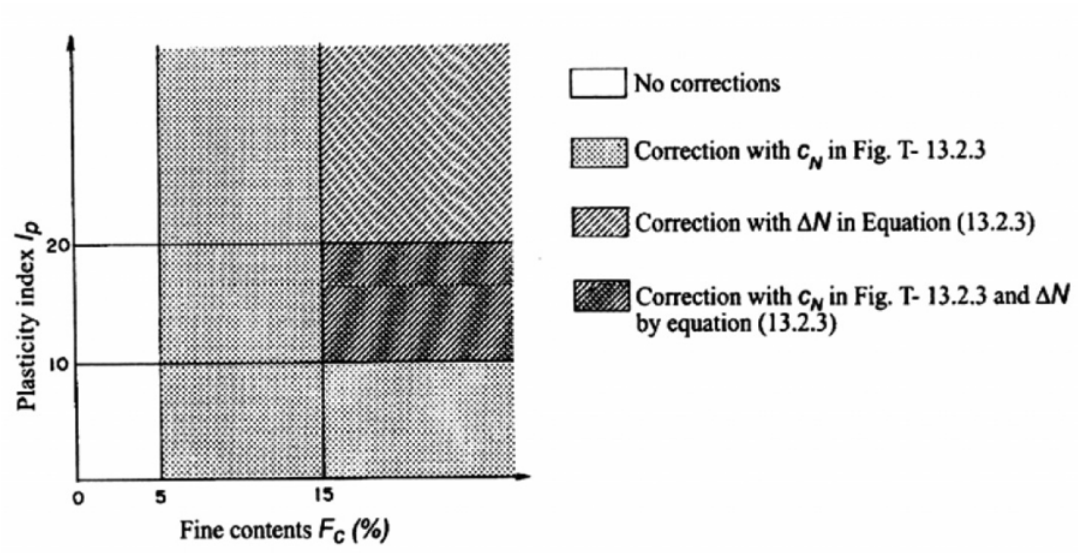


Figure 7. Calculation of correction factor CN based on fine contents ratio

Evaluation of liquefaction potential using Robertson & Wride

In this method, first, loading factor is calculated using the method simplified by of Seed and Idriss as in equation 6.

$$CSR = 0.65\frac{\sigma_0}{\sigma'_0}\times\frac{a_{\max}}{g}r_d \tag{6}$$

In the simplified method, construction site specifications are hidden in the reduction coefficient rd, so that this coefficient estimates the average response of a collection of soil cross sections to a set of input moves.

Then using Robertson & Wride method, we calculate the factor of soil capacity or resistance (CRR) in the following way.

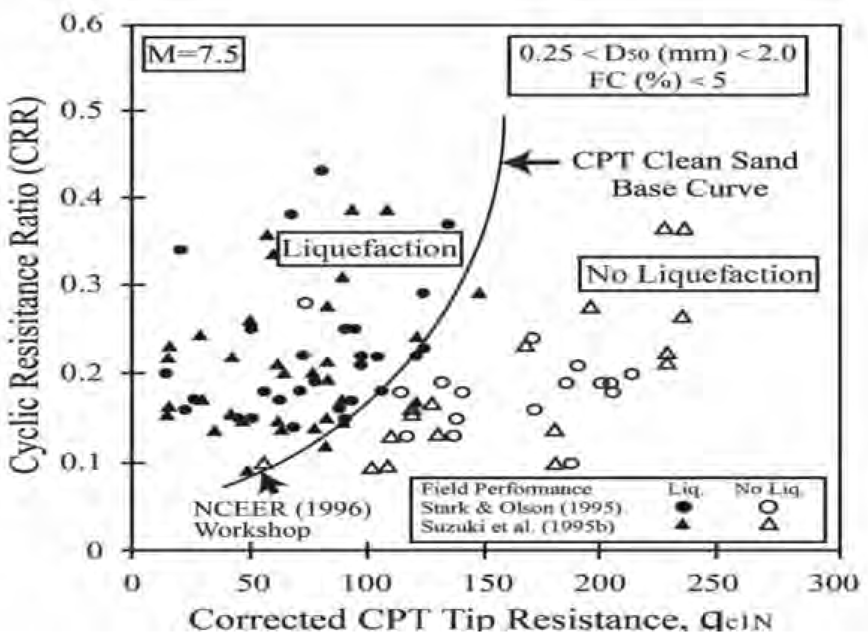


Figure 8. Suggested curve for calculating CRR based on CPT data of different projects by Robertson & Wride (NCEER, 1997)

The procedure suggested by Robertson & Wride for calculating CRR is a method with a certain trend suggested by Youd et al in 2001 as shown in flowchart of figure 5. Calculating CRR and CSR from equation 6, liquefaction potential can be defined in the form of confidence coefficient versus liquefaction as follows:

$$FS_L = \frac{CRR}{CSR} = \frac{Resistance}{Loading} \tag{7}$$

This method was published in 1997 in a workshop named NCEER where the world's elite and active geotechnical engineers gathered for a consensus on liquefaction. This special method employs the index of soil behavior type IC. There is an iterative method used for finding corrected IC, which leads to tiresomeness of manual calculations. For using computer programs, however, it is a simple method. First of all, IC is calculated with iterative method in one step. In step 2, corrected qc is calculated. In the third step, corrected qc (QCIN) is corrected for fine-grain value in IC. Correction factor of fine-grained contents depends on soil's behavior. In step 4, CRR7.5 is determined.

$$Q = \frac{q_c - \sigma_0}{P_a}\left[\frac{P_a}{\sigma_0}\right]^n \tag{8}$$

In this regard, IC is somehow used to calculate n or tension strength. We first start with n=1.

If I_c>2.6, the soil is probably clay and the hypothesis was correct. In this case, our soil is either strong clay or that it is clay-rich or that is plastic. To control liquefaction, we continue with the procedure.

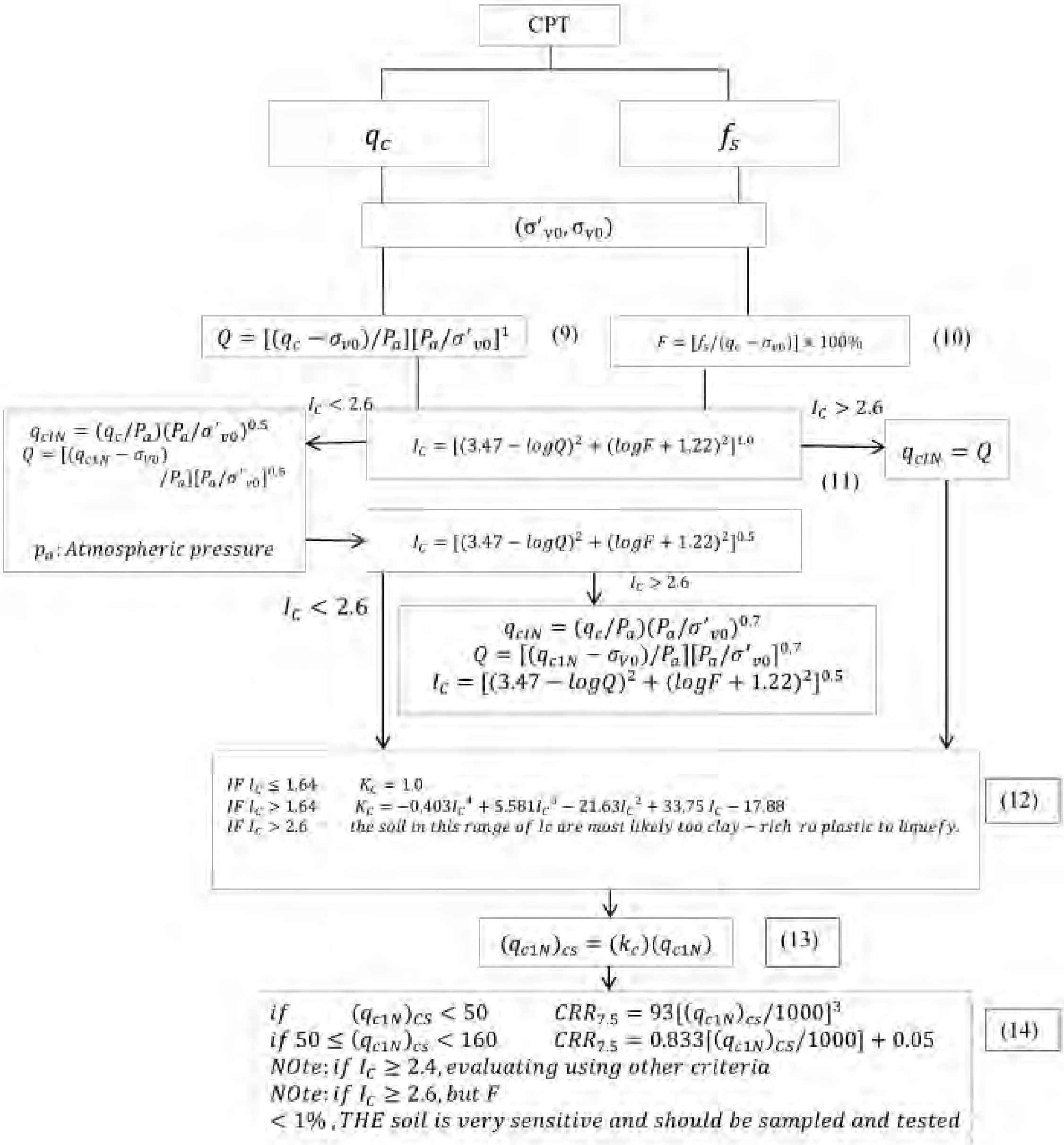
If I_c>2.6, our initial presumption about I_c was wrong and we must perform the above calculations again.

In this situation, we take n equal to 0.5 and repeat calculations for Q and I_c.

If I_c <2.6, our first presumption was correct and the soil is probably non-grained and plastic. Now, we go to the next step.

If I_c <2.6, this shows that our assumption was wrong and the soil is probably silty.

In this step, we take n equal to 0.7 and repeat calculations for Q and IC.



CRR7.5 obtained from the above must be corrected in the following way for vertical overloading tension.

$$CRR_{7.5} = CRR_{7.5}.k_{\alpha}.k_{\sigma} \quad (15)$$

k_{α} is the correction factor for initial shear tension equal to 1. Active members in NCEER concluded that using k_{α} is not recommended in engineering operations of geotechnical quakes.

k_{σ} , correction tension for overloading tension is shown in figure 9.

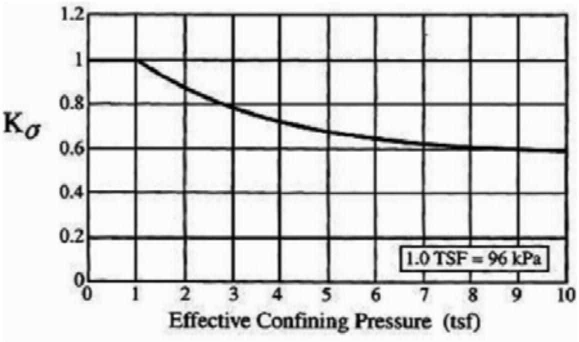


Figure 9. Overloading tension factor for correction CRR7.5 (NCEER)

Next comes the results of evaluating liquefaction potential using Robertson & Wride using the liquefaction software Liquefy Pro.

Now that CRR7.5 is obtained based on the CPT method, confidence coefficient against liquefaction F.S. is calculated by dividing CRR7.5 on CSRM. Corrected domain factor CSR (CSRM) is represented with MSF[1] that is used to regulate the value of CRR7.5 for domains smaller or greater than 7.5. Measurement coefficient values obtained by different researchers are shown in figure 10.

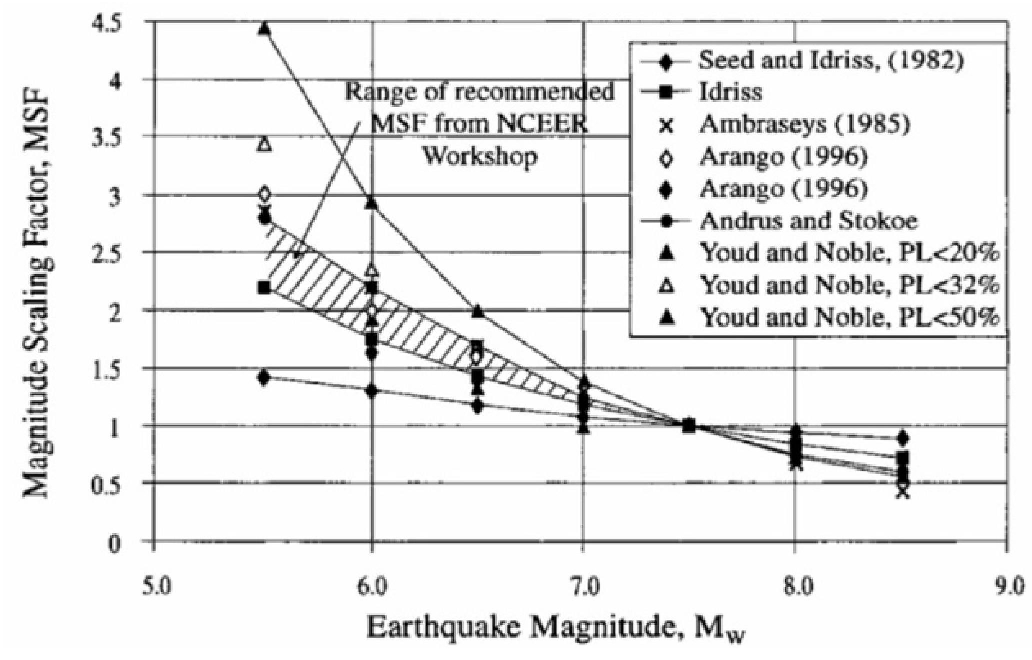


Figure 10. Measurement factor in different studies

MSF suggested by NCEER, 1997 is as follows.

$$MSF = 10^{2.24} / M^{2.56} \tag{16}$$

If $F.S < 1$, the layer placed in respective depth will be liquefied.

[1] Magnitude Scaling Factor

Evaluating liquefaction potential for the region under consideration by using methods of parts 3 and 4

By performing CPT and SPT tests in the region under study and employing the methods explained in parts 3 and 4, as seen in figures 11 to 18, the region becomes liquefied for acceleration of 0.37 g and magnitude of 7 in layers 2 and 4 and especially layer 2 where sandy layer is loose.

$$MSF = 10^{2.24} / m^{2.56} = 10^{2.24} / 7^{2.56} = 1.19$$

a_{max}/g	Mw	Hw(m)	FS_{cl}	MSF
0.37	7	2.7	1	1.19

Layer Characteristics					a_{eq} Calculation				SPT Correction					SOIL	LIQ.
z(m)	N_{SPT}	γ(kN/m³)	FC	PI	σ_v (kN/m²)	σ'_v (kN/m²)	r_d	a_{eq} (gal)	N_{60}	C_N	ΔN	N'_{60}	N''_{60}	CLASS	Prediction
2	9	19.1	0	NPL	38.26	N.A.	0.985	N.A.	N.A.	1.0	0.0	N.A.	N.A.	IV	Very Low
3.5	38	21.9	0	NPL	76.77	68.77	0.973	329	37.4	1.0	0.0	37.4	37.4	IV	Very Low
5	14	22.5	0	NPL	112.48	89.48	0.962	366	12.3	1.0	0.0	12.3	12.3	II	High
6.5	20	22.6	0	NPL	147.22	109.22	0.950	388	16.2	1.0	0.0	16.2	16.2	IV	Very Low
8	12	23.1	0	NPL	184.81	131.81	0.939	399	8.4	1.0	0.0	8.4	8.4	II	High
10.5	10	23.8	100	10	249.75	171.75	0.894	394	5.5	0.5	0.0	11.1	5.5	II	High
17	55	22.5	38	NPL	383.32	240.32	0.720	348	30.1	0.5	0.0	60.1	30.1	IV	Very Low
18	50	22.5	38	NPL	405.86	252.86	0.693	337	26.2	0.5	0.0	52.5	26.2	IV	Very Low
20	67	22.6	38	NPL	451.49	278.49	0.640	314	33.6	0.5	0.0	67.1	33.6	IV	Very Low
21	77	22.4	36	NPL	470.82	287.82	0.613	304	38.0	0.5	0.0	76.1	38.0	IV	Very Low
22	75	22.2	36	NPL	488.65	295.65	0.587	294	36.3	0.5	0.0	72.6	36.3	IV	Very Low
25	56	22.0	36	NPL	549.69	326.69	0.507	258	24.6	0.5	0.0	49.2	24.6	IV	Very Low
27.5	50	24.0	63	NPL	658.73	410.73	0.500	243	18.0	0.5	0.0	35.9	18.0	IV	Very Low
26.5	50	23.6	63	NPL	671.72	413.72	0.500	246	17.9	0.5	0.0	35.7	17.9	IV	Very Low
29.5	50	23.6	63	NPL	695.29	427.29	0.500	246	17.3	0.5	0.0	34.7	17.3	IV	Very Low

Figure 11. Evaluation of liquefaction potential using soil classification and explanations given in part 3.

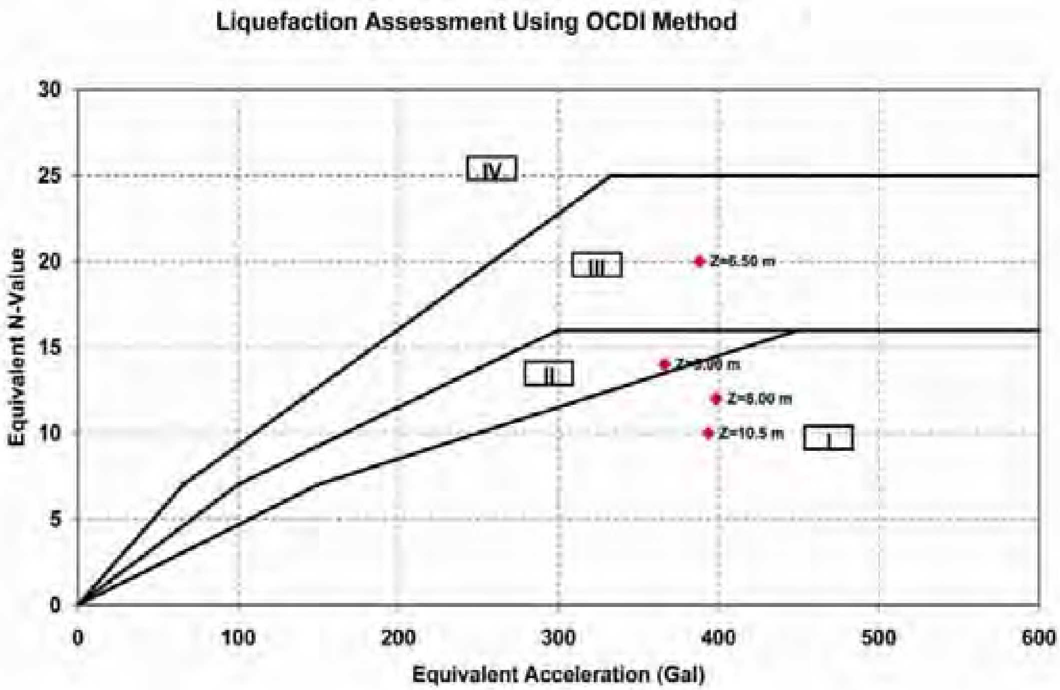


Figure 12. Soil layer classification for using OCDI method

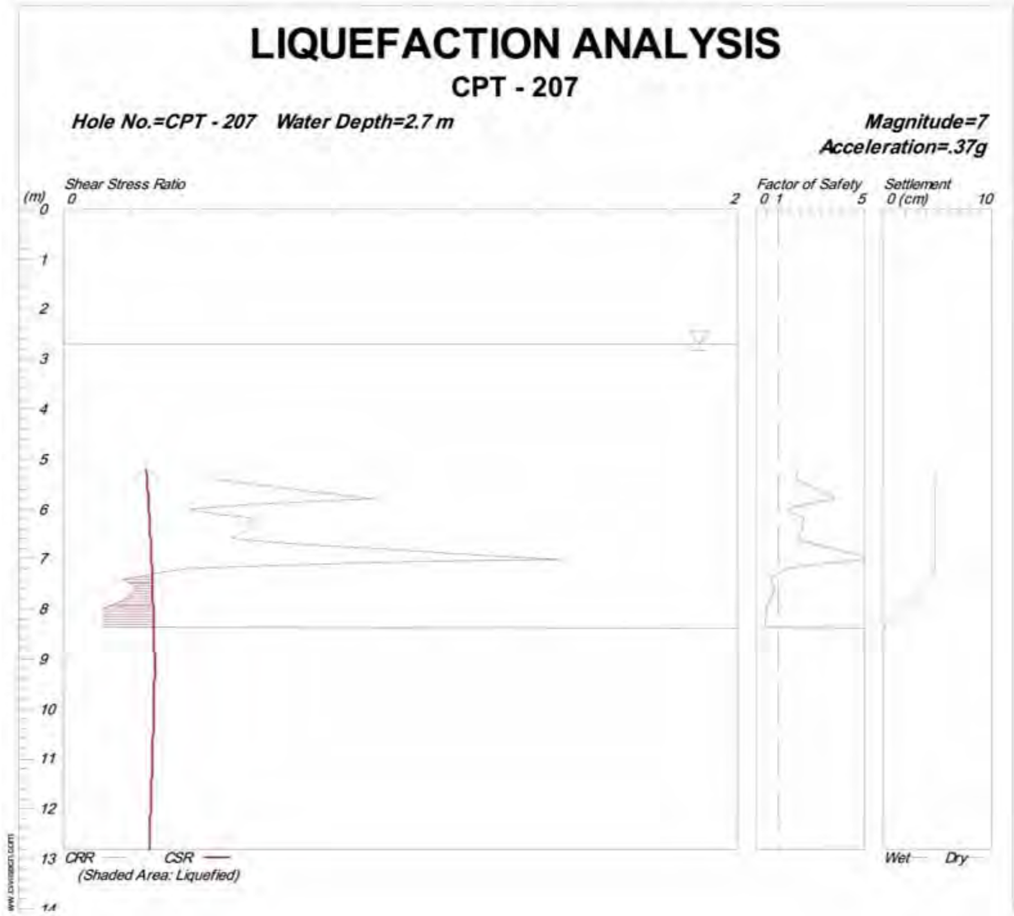


Figure 13. Liquefy Pro output making by use of Robertson and Wride method

a_{max}/g	Mw	Hw(m)	FS_{all}	MSF
0.37	7	-2.7	1	1.19

Layer Characteristics					a_{eq} Calculation				SPT Correction					SOIL	LIQ.
z(m)	N_{SPT}	γ(kN/m²)	FC	PI	σ_v (kN/m²)	σ'_v (kN/m²)	r_d	a_{eq} (gal)	N_{65}	C_N	ΔN	N'_{65}	N''_{65}	CLASS	Prediction
1.5	14	20.2	0	NPL	30.27	N.A.	0.989	N.A.	N.A.	1.0	0.0	N.A.	N.A.	IV	Very Low
2.5	36	20.2	0	NPL	50.45	N.A.	0.981	N.A.	N.A.	1.0	0.0	N.A.	N.A.	IV	Very Low
4.5	24	20.2	0	NPL	90.81	72.81	0.966	365	23.1	1.0	0.0	23.1	23.1	IV	Very Low
5.5	22	20.2	47	NPL	110.99	82.99	0.958	388	20.2	0.5	0.0	40.3	20.2	IV	Very Low
7	16	20.2	47	NPL	141.25	98.25	0.946	412	13.5	0.5	0.0	27.0	13.5	IV	Very Low
8.5	6	20.2	68	NPL	171.52	113.52	0.935	428	4.2	0.5	0.0	8.5	4.2	II	High
10.5	8	20.2	66	3	211.88	133.88	0.894	428	5.2	0.5	0.0	10.4	5.2	II	High
12.5	7	20.1	92	NPL	251.41	153.41	0.840	417	3.9	0.5	0.0	7.8	3.9	II	High
13.5	21	20.1	92	NPL	271.52	163.52	0.814	409	13.6	0.5	0.0	27.2	13.6	IV	Very Low
15.5	7	20.1	25	14	311.74	183.74	0.760	391	3.2	0.5	9.6	6.4	12.8	II	High
16.5	55	20.1	25	NPL	331.86	193.86	0.733	380	34.4	0.5	0.0	68.8	34.4	IV	Very Low
18.5	70	19.4	25	NPL	359.12	201.12	0.680	368	43.3	0.5	0.0	86.5	43.3	IV	Very Low
19.5	42	19.4	25	NPL	378.53	210.53	0.500	272	24.6	0.5	0.0	49.1	24.6	IV	Very Low
21.5	65	21.2	42	NPL	456.64	268.64	0.500	257	33.3	0.5	0.0	66.6	33.3	IV	Very Low
22.5	42	21.2	42	NPL	477.88	279.88	0.500	259	20.2	0.5	0.0	40.3	20.2	IV	Very Low
24.5	35	21.2	42	NPL	520.36	302.36	0.500	261	15.5	0.5	0.0	30.9	15.5	IV	Very Low
25.5	51	21.2	64	NPL	541.60	313.60	0.500	262	22.9	0.5	0.0	45.8	22.9	IV	Very Low
27.5	50	20.5	64	NPL	562.39	314.39	0.500	271	22.4	0.5	0.0	44.8	22.4	IV	Very Low

Figure 14. Evaluating liquefaction potential of another point using soil classification and comments given in part 3.

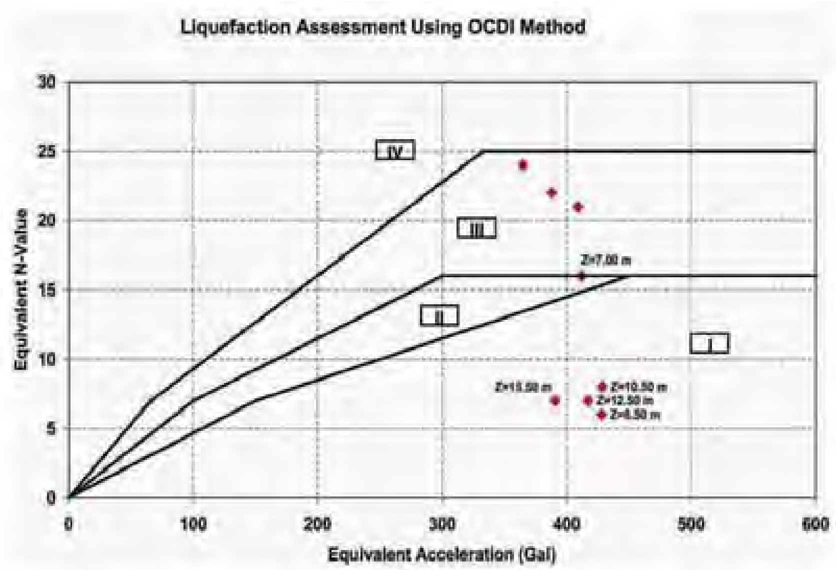


Figure 15. Classification of soil layer of another point of the region for use with OCDI method

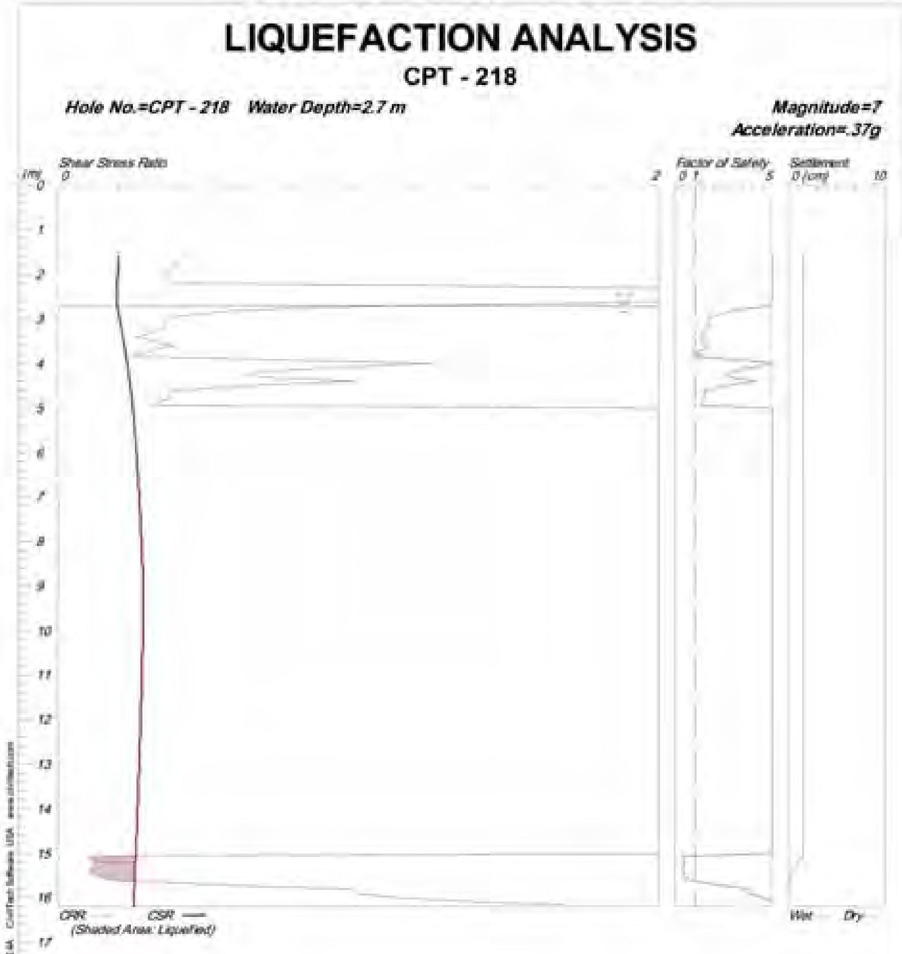


Figure 16. Liquefaction software output for the other point of the region under study using Robertson & Wride method

By paying attention to the output of the software used for input data (stimulation factor with the acceleration of 0.37 g and magnitude of 7) and test results of CPT and SPT performed in one point of the site using both methods of OCDI and Robertson and Wride, it is observed that both software suggest if such a stimulating factor is created, the respective region will be liquefied.

Now, for the same stimulation factor, we consider the results for CPT and SPT tests carried out in another point to get ensured about the integrity of the result obtained regarding loose sandy layer.

As inferred from the above results concerning the other point of the studied region, it can be concluded than the two layers of second and fourth saturated sands which were susceptible for liquefaction, will be liquefied as for the mentioned stimulating factor and close to it.

Conclusion

Given the methods explained above as well as the results obtained from field experiments (SPT and CPT) and comparison of the outputs for explained methods, it could be concluded that the investigated region will be liquefied and we should improve the depth and must determine the method of improving liquefied land. With regards to the fact that the second liquefied layer (layer #4) is located in lower depths (about 25 meters down the ground surface). Therefore, assuming a 25-meter overloading and sticky clay layer thereupon, the possibility of the liquefaction event and that of its effects reaching to the ground surface is extremely low. Thus, we set as criterion the improvement of the upper liquefied layer. Given existing ground conditions, we assume the ground level balance to be +4.5. Hence, with regard to the fact that the ground must be strengthened down the upper liquefied layer, the total depth of the layer that must be strengthened is equal to 12 meters. Applying Ishihara (1985)'s view as for destructive liquefying impacts reaching the surface as for the high thickness of upper liquefied layer, 12 meters are reduced to 8 meters (figure 17).

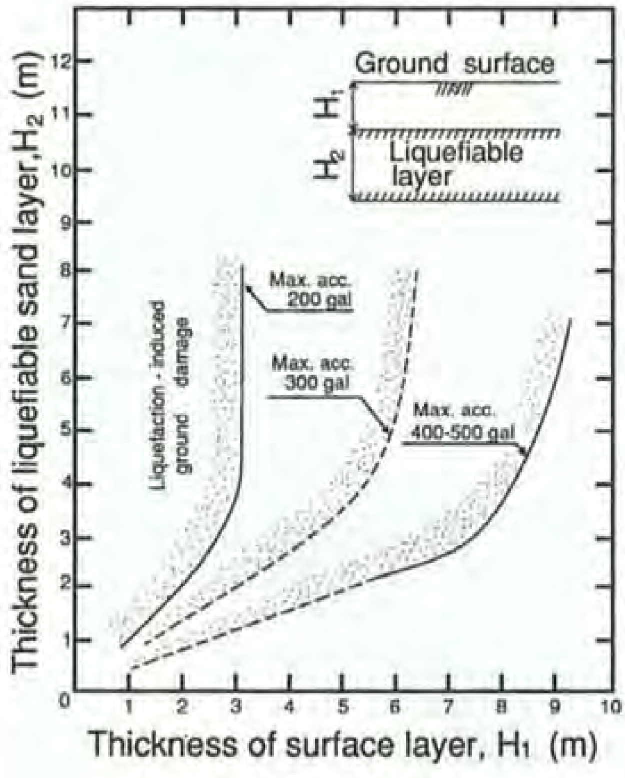


Figure 17. Suggested boundary curves to show liquefaction which leads to destruction

Finally, to improve this 8m depth, besides considering site conditions and existing facilities, it is recommended that dynamic compression method or energy transfer to the ground by impact be used.

Acknowledgement

Finally, I would like to give ultimate thanks and appreciation to the honorable wise professor Dr. Masoud Dehghani, and also Dr. Keyvan Sadeghi who cultivated the path for my studies during acquisition and collection.

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