ADVANTAGES AND DISADVANTAGES OF USING SWEDISH WEIGHT SOUNDING FOR LIQUEFACTION ASSESSMENT

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ABSTRACT

Liquefaction resistance of soils can be evaluated either by laboratory or in-situ tests. The most common in-situ tests are CPT, SPT, Shear-wave Velocity measurement, and BPT. At the previous work of the authors, the SWST was used for liquefaction assessment of a susceptible area in the south of Iran. The procedure of such an analysis is based on the indirect use of SWST results through correlating them to CPT and/or SPT. This approach has its advantages and disadvantages. It is concluded that SWST can be used as a rapid low-cost test for liquefaction assessment either in preliminary assessments of ground in large projects or independently for liquefaction hazard analysis of low-budget small projects.

Keywords: Low-cost site characterization, penetration testing, liquefaction resistance, Swedish Weight Sounding Test (SWST)

INTRODUCTION

Evaluation of soil liquefaction resistance is an important aspect of geotechnical earthquake engineering. Liquefaction can be defined as the transformation of a granular material from a solid to a liquefied state as a consequence of increased pore-water pressure and reduced effective stress (Marcuson, 1978). Both laboratory and in-situ tests are used in liquefaction hazard analysis. Each has its advantages and disadvantages.

SWST has been frequently used for geotechnical reconnaissance of damaged areas after earthquakes (e.g. Towhata et al., 2002; 2004), But there are few reports on using SWST for liquefaction hazard analysis. At the previous work of the authors (Habibi et al., 2006a), SWST was used for liquefaction assessment of a reclaimed area in south of Iran (Habibi et al., 2006a). The detailed procedure of the assessment was described. In this paper, the reasons for such a usage are described and the advantages and disadvantages of the approach are also mentioned.

SWEDISH WEIGHT SOUNDING TEST (SWST)

SWST was firstly introduced by Geotechnical Committee of the State Railways of Sweden. It can be considered as the 1st standardized penetration test (Lunne et al., 1997). Also, it is one of the four penetration tests which are standardized by ISSMFE (1989). The test has been used for many purposes such as soil profiling, determination of the bearing capacity of shallow and deep foundations,

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determination of engineering characteristics of soils like shear strength or compressibility, etc. SWST is a common test in Scandinavian countries and also in Japan. The test has also been used in some other countries like Poland, Hungary, Czech, Slovakia, Singapore, Philippines and Algeria (Bergdahl et al., 1988). Use of the SWST in some areas of Tehran, Iran is also reported by the authors (Habibi et al., 2006b).

Manual type of the SWST (Fig. 1-b) consists of a screw shaped point (Fig. 1-a), some pieces of weights (totally 100kg), extension rods (22mm rods are standardized by ENV 1997:3-2000), and a handle for rotating the device. Soil resistance measurements can be reported as W_{SWST} or N_{SWST}. W_{SWST} is the weight which is needed for penetration of the rods. When no penetration happens by loading the rods up to 100kg, keeping the weight pieces, the device is rotated and the number of half turns required for a defined penetration is recorded (N_{SWST}).
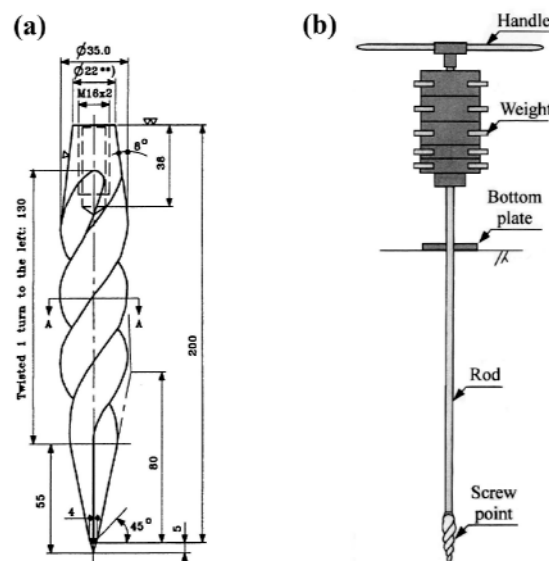
Figure 1- (a) SWST screw shaped point (ENV 1997:3-2000)
(b) Schematic view of the SWST (from Tsukamoto et al., 2004)

USING IN-SITU TESTS FOR LIQUEFACTION ASSESSMENT

Comparison between in-situ and laboratory tests
Liquefaction resistance of soils can be evaluated by laboratory tests. But usually some of the parameters of the soil change during the conventional sampling operations. The most important ones are differences in soil fabric produced by different methods of preparing specimens, the history of prior seismic straining, over consolidation ratio and lateral earth pressure coefficient, the length of time under sustained pressure and specimen non-uniformity produced in high pore-pressures (Kramer, 1996).

In contrast, field tests allow the properties of the soil to be measured in their existing state, where the complex effects of existing stresses, chemical, thermal and structural conditions are reflected in the measured properties (De Groot and Sandven, 2004). Therefore, for most of the projects which their budget can not afford sophisticated undisturbed sampling techniques like ground freezing, using in-situ tests is the suitable approach for liquefaction assessment.

Basics of using field tests for liquefaction assessment
Using an in-situ test for liquefaction assessment is based on the assumption that test results can reflect the initial state and excess pore pressure generation characteristics of the soil. In this approach, liquefaction case histories are used to evaluate liquefaction resistance of the soils. Liquefaction resistance is characterized in terms of measured in-situ test parameter and earthquake loading of the

investigated earthquakes in terms of Cyclic Stress Ratio. The result is a complex of points in a graph in which, each point shows liquefaction occurrence or non-occurrence. A boundary can then be drawn to conservatively separate two mentioned groups of points. The curve would be a lower bound for liquefaction occurrence (Fig. 2).
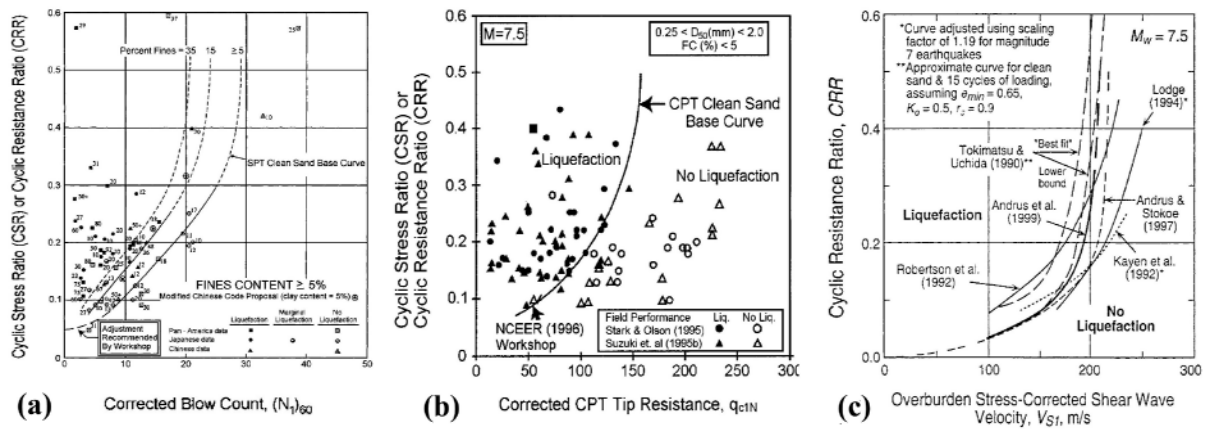

Figure 2- Liquefaction resistance criteria for common in situ tests (a) Standard penetration Test, (b) Cone Penetration Test (CPT), (c) Shear Wave velocity measurement (Youd et al., 2001)

The most common in-situ tests which are used for evaluation of liquefaction resistance are Standard Penetration Test (SPT), Cone Penetration Test (CPT), Shear-wave Velocity (V_S) measurement, and the Becker Penetration Test (BPT) (Youd et al., 2001). Because of the more extensive databases and past experiences SPT and CPT are generally preferred, but the other tests may be applied at gravely soils or where access by large equipment is limited (Kramer, 1996). The problem with SPT results is the ratio of transferred energy during the tests. Though, in general, the CPT is more repeatable than SPT and is preferred test, where possible (Robertson, 2004).

USING SWST FOR LIQUEFACTION ASEESSMENT

The procedure
Some investigations have been performed on liquefaction case histories by SWST (Tsukamoto et al., 2004). However, a SWST-based typical graph for evaluating liquefaction resistance has not been presented so far. Thus, SWST results can not be directly related to the field behavior of the soil. There is an indirect approach for using SWST data in liquefaction studies. In such an indirect approach, SWST results transformed to the equivalent results of another in-situ test using some correlations and evaluation procedure will be applied based on the calculated data. Because CPT and SPT are the most common tests for liquefaction assessments, it is reasonable to transform SWST data to the equivalent CPT and/or SPT. Fig. 3 shows the procedure of evaluating liquefaction resistance of soils in direct and indirect approach.

Some empirical correlations have been proposed between SWST and CPT results (e.g. Tammirine, 1974; Bergdahl et al., 1988). Also, there are a number of correlations between SWST and SPT results (e.g. Inada, 1960; JGS, 1995; Tsukamoto et al., 2004). The great advantage of using Japanese SWST-SPT relations is the small variation of SPT Energy Ratio (E_R) in Japanese Practice. Because of good quality control and also uniform SPT operations in Japan, the E_R value of Japanese practice has a narrow range. The value of 72% can be considered as the average value of E_R in Japan (Ishihara, 1993). Also, as a result of a comparative investigation, Fig. 4 is obtained for E_R distribution in Japanese practice. As illustrated in Fig.3, the values of 69% to 73% can be estimated as the average. In addition, results of some investigations about E_R in different countries which are proposed by Euro Code 7 (ENV 1997:3-2000) confirm the previous values. As indicated in Table 1, two types of SPT hammer systems are common in Japan with the average E_R values of 65% and 78%. Simply averaging those ratios, the value of 71.5% obtains.
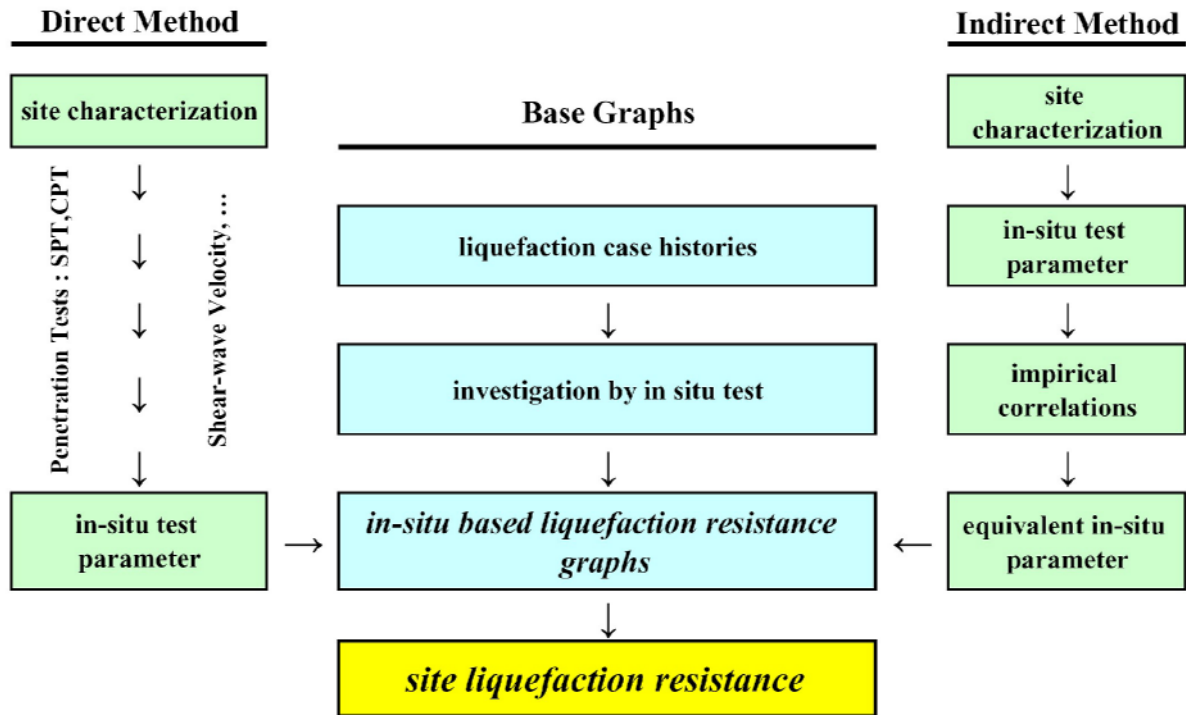
Figure 3- The procedure of evaluating liquefaction resistance in direct and indirect approach
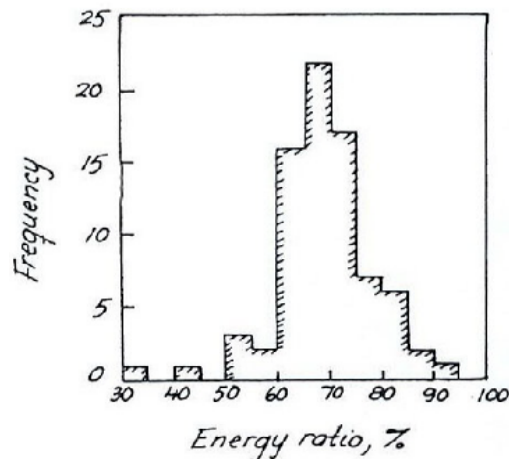

Figure 4- E$_R$ distribution in Japanese SPT practice (Kovacs and Salomone, 1984)

Table 1- Average E$_R$ values in some countries (ENV 1997:3-2000)

Country	Hammer	Release	ER$_r$ (%)	ER$_r$/60
North and South America	Donut	2 turns of rope	45	0,75
	Safety	2 turns of rope	55	0,92
	Automatic	Trip	55 to 83	0,92 to 1,38
Japan	Donut	2 turns of rope	65	1,08
	Donut	Auto-Trigger	78	1,3
China	Donut	2 turns of rope	50	0,83
	Automatic	Trip	60	1,0
United Kingdom	Safety	2 turns of rope	50	0,83
	Automatic	Trip	60	1,0
Italy	Donut	Trip	65	1,08

It should be noticed that the indirect use of an in-situ test result is a usual procedure in liquefaction assessments. For example there are very few liquefied sites from which BPT data have been obtained.

Though, for evaluating liquefaction resistance of soils, BPT results are used through estimating equivalent SPT N-values (Youd et al., 2001). Or some data in CPT-based flow liquefaction criteria are converted from measured SPT data (Robertson, 2004).

Some situations where using SWST is useful

SWST is a useful test for liquefaction assessment of the areas where there are some limitations for performing other tests like CPT and/or SPT. The limitations can originate from the lack of availability and testing equipments e.g. after an earthquake. The limitations can also originate from general ground conditions of the area. For example, to perform CPT and/or SPT in loose ground conditions, a stable access road is needed which could be expensive and time-consuming. Furthermore, there are some small projects in which the use of CPT and/or SPT can not be afforded.

The first step of a liquefaction hazard analysis is liquefaction susceptibility assessment (Kramer, 1996). There are several criteria such as historical, geological, compositional and state criteria by which liquefaction susceptibility can be judged. However, these criteria provide very useful information for assessment of liquefaction susceptibility, but there are always some uncertainties either in the procedures or in provided information which make the judgment difficult (Pyke, 2003). Using SWST is a fast solution for liquefaction susceptibility evaluation.

The accuracy of liquefaction hazard analysis in each site depends on soil spatial variability. So, the accuracy increases with the increase of test numbers. Because of the cost, it is not always possible to perform a large number of CPTs and/or SPTs in a specific site. The use of SWST between the primary boreholes and/or CPT test locations increases the accuracy of the analysis.

Advantages and disadvantages

Advantages

Like other probing (sounding) methods, the primary advantage of SWST is that a nearly continuous profile of penetration resistance is developed for stratigraphic interpretations. The continuous profile also allows more detailed definitions of soil layers and detecting thin layers or seams. The stratigraphic capability makes the SWST advantageous for developing liquefaction-resistance profiles. However, these criteria have not been released for SWST up to now.

In-situ tests may be classified in a number of ways e.g. by the cost (Clayton et al., 1995). SWST can be classified as a "low-cost in-situ test". Because of that, a large number of SWSTs can be performed with a rather low budget. This can be useful in all steps of a liquefaction hazard analysis. Particularly, when evaluating lateral extent of different soil layers are important, e.g. in liquefaction consequences criteria, it can considerably reduce investigation costs. Furthermore, either SWST is utilized as primary test for preliminary assessments or as complementary test for main liquefaction assessments, because of the simplicity of the apparatus and mechanism of test, Weight Soundings could be performed very rapidly.

Investigations indicate that manual type of SWST has the optimal performance/accuracy in the soils with rotational resistance between 2 to 40 ht/0.2m of penetration (Habibi, 2006). On the other side, some investigations show that engineering consequences of liquefaction are likely to be minimal if the normalized SPT blow counts exceed 15 (Pyke, 2003). By using the correlations available in the literature, the equivalent SPT N-value for the N_{SWST}=40 ht/0.2m is calculated about 15. Thus, it can be concluded that manual type of SWST is suitable for detecting liquefiable soils. Also, liquefaction usually happens in depths less than 15m (Youd et al., 2001). Therefore, considering the capabilities of SWST, it is possible to completely detect liquefiable depths.

The indirect method of using SWST introduces substantial additional uncertainty into the calculated resistance. But it should be noticed that sometimes using measured SPT results introduces more uncertainty than the indirect estimation through CPT and/or SPT based correlations. In fact, in spite of

countries like Japan where SPT practice is rather clear and E_R distribution has a narrow rang, in most of the countries the range of E_R variations is rather wide and the average value is not known. Though, in the situations where SPT practice has poor quality control and the E_R is not measured during the operations, it is possible that indirect use of SWST results has less error than direct use of SPT results.

Disadvantages

The main disadvantage of using SWST for liquefaction assessment is the indirect use of test results through converting the SWST data to the equivalent penetration resistance of CPT and/or SPT. However, SWST-based liquefaction resistance profiles have not developed up to now, but through collecting the available liquefaction site investigations data and also performing new SWSTs, it is possible to propose some liquefaction resistance profiles in the future. However, up to that time, revising the available correlations between SWST and CPT and/or CPT with new data decreases the uncertainty of the indirect approach.

As mentioned, SWST is optimal for soils with resistance between 2 and 40 ht/0.2m. Below that limit, because of the discontinuous measurement of the resistance, the accuracy of SWST measurements decreases and also in high resistances (N_{SWST}>100 ht/0.2m) the repeatability of the results is not clear (Habibi, 2006). Though, using SWST out of the mentioned limitations decreases the accuracy of the measurements. It seems that for high-resistance soils, heavy penetration tests like SPT or non-contact tests like shear-wave velocity measurement are suitable. Also for soft soils (N_{SWST}<2 ht/0.2m), in-situ tests such as Light Dynamic Probe (DPL) or Mackintosh Probe can be utilized. Like SWST, Mackintosh Probe is a low-cost in-situ test which can be performed simply, rapidly and with low budget (Fakher et al., 2006).

Testing soils for liquefaction assessment should always be accompanied by soil sampling for validation of soil type identifications (Youd et al., 2001). Through performing standard type of the SWST, no soil sample retrieves. Therefore, in cases where drilling boreholes are not planned in investigation program, performing auger boring or percussion drilling is necessary.

An important point about SWST is the effect of friction along the rods on the test results (ENV 1997:3-2000, JIS A 1221-2002). This effect is considerably high, particularly when there are fill material or peat layers in the site (e.g. Broms and Flodin, 1988; Habibi, 2006). Though, using SWST results in those cases should be accompanied with caution.

In general, using penetration tests for liquefaction assessment through utilizing simplified procedure (and consequently SWST), introduces some uncertainty to the analysis (Pyke, 2003). For example, the simplified approach is only valid for low overburden pressures (depth below 15m) and low static shear stresses (level grounds). Also, the effects of age and over consolidation on liquefaction resistance are not clearly included in the results of simplified procedure (Pyke, 2003). Furthermore, it should be considered that simplified procedure is generally conservative and using it, results in overestimated results (Youd et al., 2003).

A CASE STUDY

A case study of using SWST for liquefaction assessment of an area is done by the authors and the detailed procedure of the assessment is described (Habibi et al., 2006a). In the following paragraphs, the situations in which the research program has done, is illustrated and the advantages of using SWST in the case are also mentioned.

The studied site is located at the west of the Shahid Rajaei Port Complex in south of Iran which is one of the most important ports of Iran (Fig. 5-a). A very large project is planned for development of the port which is aimed to achieve about 5 million TEU container terminal capacities. The geotechnical ground investigations of the project was one of the most extensive site characterization works in Iran which consists of field works like drilling of shore and marine boreholes, disturbed and undisturbed

sampling, excavating trial test pits and performing a large number of in-situ tests such as SPT, CPT, CPTU, SCPTU, Vane shear test, Pressuremeter test, Dynamic Probing tests, etc. Also, a large number of conventional and sophisticated laboratory tests like resonant column test, cyclic triaxial test, etc. have been overtaken as well as in-situ tests.

The area of the project was rectangular in shape and approximately 85 hectares in size which is divided into two phases with an 1100*480 m^2 area in phase I and the remaining area for phase II (Fig. 5-b). Because the ground level of some parts of the project was below the sea-level, they were hydraulically filled with dredged materials. Most of them are located on the western zone of the project (Phase II) where some SWSTs were performed. Most of the soils in the studied area are saturated loose silty sands that are hydraulically filled. Based on the local conditions, it could be concluded that the fast drainage of the loose layer during an earthquake is not possible. Thus, the area is potentially liquefiable and liquefaction hazard assessment of the area is necessary.
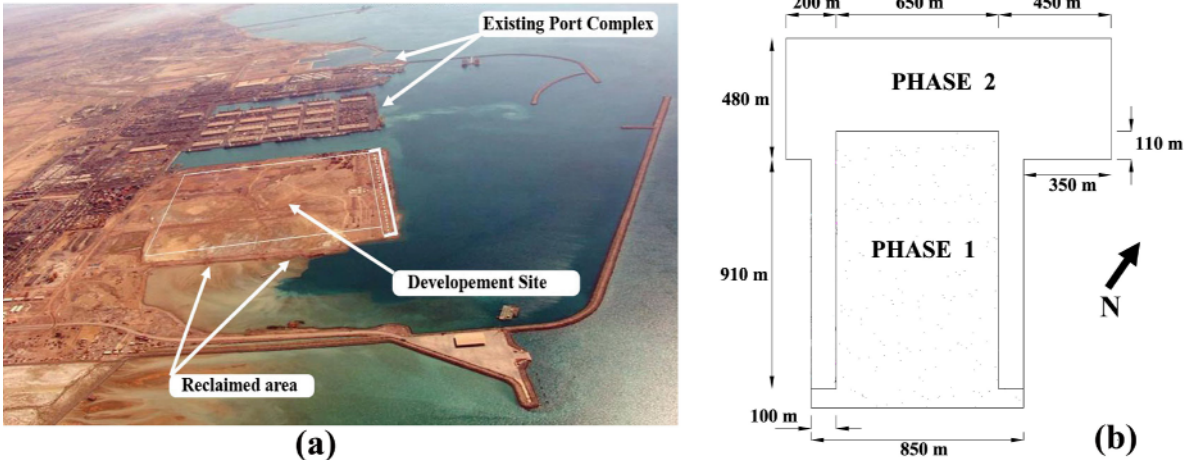

Figure 5- Shahid Rajaei Port Complex development project (a) Situations of existing port, development site and reclaimed area, (b) Development site dimensions (Phases I and II)

Figure 6- Investigation truck is trapped due to the loose ground conditions in dredging material

The investigation program of the hydraulically filled areas was focused on drilling boreholes and performing a number of SPTs and also CPTs (Sahel, 2006). But ground conditions of the area showed that programmed investigations couldn't be performed in the present state of the area. Fig. 6 shows the result of driving the investigation truck through the dredged material. As a result, the investigation program would be executive only by developing some stable access road to the test points. This procedure took some time and consequently caused a delay in the investigations time-table.

On the other side, SWSTs was performed in a little period of time. In up to twelve points Weight Soundings were undertaken which rather covered the reclaimed area in the west side of the Phase II (910*100m^2). In the mentioned area, the dredged materials were filled above a thin layer of soft rock

which exists in most of the parts of the project. The depths of filled materials to the thin rock layer differ from 3.4m to 2.1m in different areas. Because the original materials were dredged from the sea bed, the area comprises of rather uniform fine sands with different fine contents. Also because of the filling operation which was hydraulically, the fills are loose and saturated in most of their depth. The level of ground water in the area is rather high and differs from 0.4m to 2.4 m from the ground level. There are also areas in the north of this narrow rectangular which comprise two layer, hydraulic fill in the bottom and a dray coarse sand fill on top. The liquefaction assessment is done for both areas, with or without the upper fill layer.

Based on values which are proposed by the Iranian Code of Practice for Seismic Design (Standard 2800-05) for ground acceleration of different parts of the country, the Shahid Rajaei Port site is located in zone 2 with high earthquake hazard. Thus, the horizontal ground acceleration for design purpose in this area is 0.3g. In the research, the assessment is done for different levels of earthquake magnitude as M_W =7.5, 7 and 6.5. And for the upper and lower bound of Magnitude scaling factors for M_W =7 and 6.5. Therefore there will be five series of results for different levels of magnitudes and conservatism and consequently five series of comparison graphs.

Table 2. Specification of soil layers in penetration points

Penetration point No.	2	3	4	5	11	12	13	14	15	16	18	19
Penetration depth (m)	3.5	2.9	2.8	2.0	2.7	3.1	3.4	3.3	2.1	3.1	3.0	2.9
Depth of W.T. (m)	2.4	1.7	1.0	0.4	1.4	1.4	1.3	1.3	0.4	1.0	1.0	1.0
Soil Classification	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM	SM
Fines Contents (%)	19	19	24	21	22	22	24	24	26	23	23	19

Table 2 shows the depth of soundings and soil strata information like soil classification, fines content and depth of water table. This information is obtained from drilled boreholes near each sounding point which were parts of the comprehensive site investigation program of the project. Where the sounding point was between two different boreholes, the data have obtained from interpolation of these two series of information. Also because the in-situ tests for determination of the unit weights of the soil were not performed in these locations, the values of 16 and 19.5 KN/m^2 are assumed for unit weights of the soil above and below the ground water level, respectively.

Table 3. Typical calculations of induced shear stresses, liquefaction resistance and the FS

Depth	Field Data		Cyclic Stresses Calculations						Resistances Calculations							Safety Factors Calculations				
	W (Kg)	N (ht)	γ (kPa)	$\dot{\gamma}$ (kPa)	σ_v (kPa)	$\dot{\sigma}_v$ (kPa)	r_d	CSR	$(N)_J$	$(N)_{60}$	C_N	$(N_1)_{60}$	FC	$(N_1)_{60CS}$	$CRR_{7.5}$	$FS_{7.5}$	$FS_{7.0}$ Low	$FS_{7.0}$ Up	$FS_{6.5}$ Low	$FS_{6.5}$ Up
0.7		7	16.0	16.0	11.2	11.2	0.99	0.19	6.7	8.0	1.7	13.6	19	18.1	0.19	0.99	1.18	1.25	1.43	1.59
0.8		5	16.0	16.0	12.8	12.8	0.99	0.19	5.4	6.4	1.7	10.9	19	15.1	0.16	0.83	0.99	1.05	1.20	1.34
0.9		3	16.0	16.0	14.4	14.4	0.99	0.19	4.0	4.8	1.7	8.2	19	12.2	0.13	0.69	0.82	0.86	0.99	1.10
1		2	16.0	6.2	16.0	15.0	0.99	0.21	3.3	4.0	1.7	6.8	19	10.7	0.12	0.58	0.69	0.73	0.84	0.93
1.1	100		16.0	6.2	17.6	15.6	0.99	0.22	2.0	2.4	1.7	4.1	19	7.8	0.09	0.43	0.52	0.54	0.63	0.70
1.2	75		16.0	6.2	19.2	16.3	0.99	0.23	1.5	1.8	1.7	3.1	19	6.7	0.09	0.37	0.45	0.47	0.54	0.60
1.3	50		16.0	6.2	20.8	16.9	0.99	0.24	1.0	1.2	1.7	2.0	19	5.6	0.08	0.32	0.38	0.41	0.47	0.52

After calculating the CSR and CRR, the depth where liquefaction happens can simply be found by drawing the variations of CSR and CRR in depth (of a point) and see where the CSR is more than CRR. Also the comparison can be made by the concept of Safety Factor through the depth of the layer. Where the FS is less than one, liquefaction will initiate during the earthquake. Because the Analyses are done for different earthquake magnitudes and different levels of conservatism, several levels of liquefaction hazard are obtained. Table 3 shows the typical calculations of cyclic shear stresses, liquefaction resistance and Safety Factor for different levels of earthquake magnitudes and their upper and lower bounds, e.g. for point 19 in depth of 0.7m to 1.3m where liquefaction will happen through these levels. Based on the performed calculations, the depth of initiation of the liquefaction could be found for every point of penetration and for every earthquake magnitude for its upper and lower

bound. Table 4. illustrates the results of the liquefaction assessment of all penetration points. Also, based on these results a Zonation can be drawn for the investigated area which is the Final result of the liquefaction hazard assessment for this area, e.g. for M=6.5 low (Fig. 7).

Table 4. Final results of the liquefaction assessment (Depths of initiation of liquefaction [m])

Point No.	2	3	4	5	11	12	13	14	15	16	18	19
Mw=7.5	2.2~2.8	0~2.25	0~2.25	0~2.0	0~2.1	0~2.2	0~0.45 0.95~3.3	0~0.85 1.05~3.4	0~2.1	0~2.9	0~0.7 0.9~3.1	0~2.3
Mw=7.0 Up	2.25~2.75	0~2.2	0~0.6 0.85~2.3	0~2.0	0~0.65 0.9~2.1	0~0.8 1.0~2.2	0~0.4 1.05~3.3	0~0.85 1.1~3.4	0~2.1	0~0.85 0.95~2.9	0~0.6 1.0~3.1	0~0.6 0.8~2.25
Mw=7.0 Low	2.3~2.7	0~2.15	0~0.55 0.95~2.3	0~2.0	0~0.6 0.95~2.1	0~0.6 1.0~2.2	0~0.4 1.1~3.3	0~0.6 1.1~3.4	0~2.1	0~0.75 1.0~2.9	0~0.6 1.0~3.1	0~0.5 0.8~2.25
Mw=6.5 Up	2.35~2.65	0~2.1	0~0.4 1.2~2.25	0~2.0	0~0.5 1.0~2.1	0~0.5 1.05~2.2	0~0.35 1.2~3.3	0~0.45 1.2~3.4	0~2.1	0~0.5 1.1~2.9	0~0.5 1.0~3.1	0~0.4 0.9~2.2
Mw=6.5 Low	2.4~2.6	0~0.4 0.8~2.1	0~0.3 1.3~2.2	0~2.0	0~0.35 1.15~2.1	0~0.4 1.1~2.15	0~0.3 1.35~3.3	0~0.4 1.25~3.4	0~2.1	0~0.3 1.15~2.9	0~0.25 1.15~3.1	0~0.35 0.95~2.2

Furthermore, comparing the results of liquefaction assessment based on SWST results the comprehensive assessment which performed by utilizing laboratory and in-situ tests like resonant column, SPT and CPT showed a good consistency between the results (Habibi et al., 2006a).
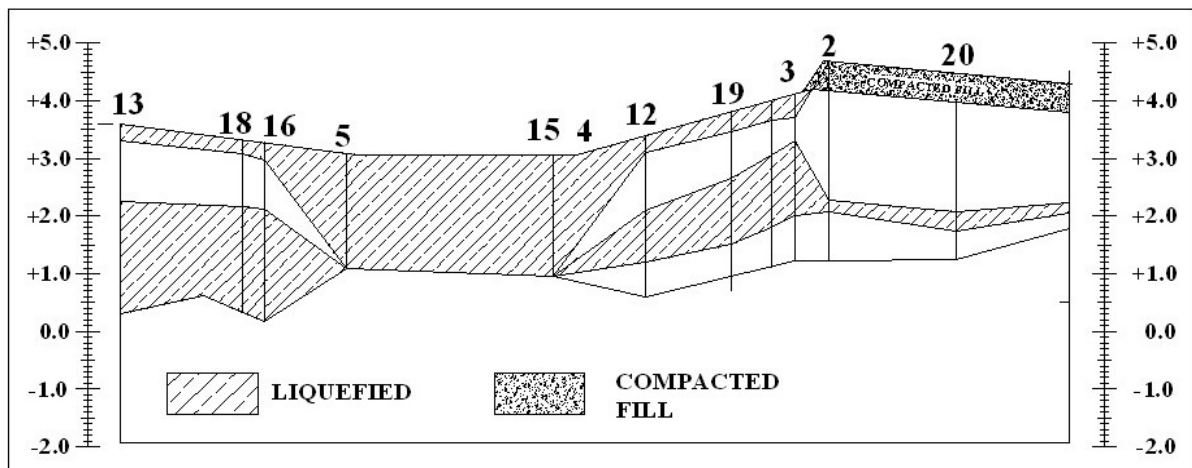

Figure 7. Liquefaction Zonation of the soil strata (Mw=6.5, lower bound)

Fig. 8 shows the average time for one meter sounding and retrieval based on the data collected on each sounding. As illustrated, 10min can be estimated as the average time for one meter of Weight sounding in this site. This result can be extrapolated to sites with similar ground conditions as the studied site. Considering the point that manual SWST has portable equipments, it can be concluded that investigation of the areas like the studied one can be undertaken very fast.
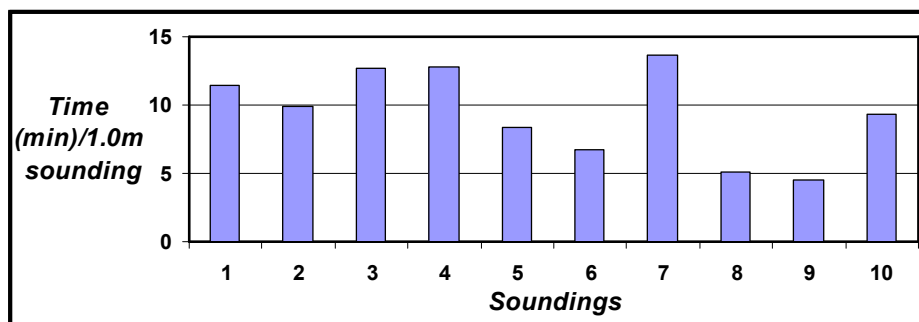

Figure 8- Average SWST penetration and retrieval time in soundings of the case study

CONCLUSIONS

- In liquefiable soils with medium density (N_{SWST}<40 ht/0.2m), manual type of the SWST can be used as well as other in-situ tests.
- In situations where there are some limitations for using common in-situ tests, e.g. in availability, budget or testing equipments, SWST can be used as an alternative. SWST can also be used for preliminary assessments or as a complementary test with the other tests.
- Because conventional SWST-based criteria for evaluating liquefaction resistance have not been presented up to now, SWST results are used indirectly in liquefaction assessments.
- The uncertainty of indirect use of SWST data can be reduced through using valid correlations which are proposed based on robust databases and high quality investigations.
- The Japanese SWST-SPT correlations are preferred than the others.
- Some advantages of using SWST are continuous profiling, more detailed definition of the soil layers and their spatial variability, simplicity, rapid ness, and being low-cost. Also, it can increase the accuracy of the results when is used as a complementary test.
- Some disadvantages of using the SWST for liquefaction assessment are indirect use of test results, lower accuracy for soft soils (N_{SWST}<2 ht/0.2m), need to soil sampling and existing friction along the rods.

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