Evaluation of Liquefaction Potential of Tripoli Soil Using SPT

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Abstract: Liquefaction is a phenomenon in which the strength and stiffness of a saturated cohesion less soil (sands and silts) is reduced. When liquefaction occurs, the strength of the soil decreases and hence the ability of a soil deposit to support foundations for buildings and bridges is reduced. The reduction of strength and stiffness may cause by earthquake shaking and/or other rapid loading. The district area of Tripoli was subjected to a spatial evaluation of liquefaction occurrence in order to delineate the most soil's liquefaction resistance. Standard Penetration Test (SPT) was used to identify and characterize liquefiable deposits and map the hazardous area. Earthquake as a cause of liquefaction phenomenon through shaking of saturated soils was also revised within Tripoli area to determine the probability of liquefaction enhanced by earthquake hazards. Three zones were geographically distributed each shows its own susceptible characteristics to liquefaction hazards.

Keywords: Liquefaction, earthquake, standard penetration test, Libya, Tripoli

INTRODUCTION

Liquefaction is a phenomenon occurs in loose, saturated cohesionless units (sands and silts) and responsive clays when they experienced a sudden loss of strength and stiffness. Liquefaction also results in localized bearing capacity failures, and during extreme settlement in the area of waste containment unit.

Liquefaction has been also responsible for incredible amounts of damage in chronological earthquakes around the world. This phenomenon occurred where the spaces between individual particles of soils are completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together since water pressure is relatively low prior to an earthquake. Increased water pressure can also generate landslides and cause the collapse of dams. Susceptibility of a site to liquefaction depends on a series of parameters including but not limited to:

- Soil void ratio.
- Soil density.
- Soil permeability.
- Geological history of site.
- Ground Water level.
- Nature of the earth quake shaking

Earthquake shaking is responsible for increasing water pressure to the point leading soil particles to move with respect to each other. The two different soil responses to earthquake shaking reported by Robertson and Wride (1998); the flow liquefaction and cyclic softening were defined as liquefaction due to both mechanisms lead to similar consequences, although their mechanisms are slightly different.

History of earthquakes in Libya

Libya, located at the north central margin of the African continent, has experienced a considerable intra-plate tectonic, particularly in its northern coastal regions, as a result of the relative motion of the African and European plates. According to the studies published in the last twenty years, the earliest records of earthquakes in Libya are documented in the Roman period (3rd and 4th century A.D.). There is a gap in information along the Middle and Modern Ages, while the 19th and early 20th century evidence is concentrated on effects in Tripoli, in the western part nowadays Libya. The Hun Graben area (western part of the Gulf of Sirt) has been identified as the location of many earthquakes affecting Libya, and it is in this area that the 19 April 1935 earthquake (Mw = 7.1) struck, followed by many aftershocks. The earthquakes which affected Libya up to 1935, though not necessarily located in this country, are presented through a summary of the available information and with a specific reference to the most recent critical interpretation offered by a few studies published in the last twenty years. The most important earthquakes considered by the aforementioned studies are listed according to two time frames, up to 1900 and from 1901 to 1935 .

Our proposed method is to establish on a case study in Tripoli, where a dense collection of subsurface test borings was assembled to distinguish potentially liquefiable materials. As liquefaction hazard mapped, it will remain relatively constant as the existing liquefaction susceptibility maps are based solely on geology.

SITE DESCRIPTION

Location of study area

The study area is located at Tripoli area (Northwestern of Libya), the area is bounded by coordinates East: N :325334.21 E:132035.83 E:130757.05N:325240.60west and covers about 143.78 km^2 (Figure, 1).

Figure (1): map of the study area

Geology of the Region

The geology of the study region showed Quaternary age sediments of fluvial environment. Due to the composition of the sediments mainly fine silts mixed with clay, the sediments naturally susceptible to liquefaction and when combined with the earthquake activity. Two formations covered the investigated area; Jeffara and Gargaresh Formations.

Jeffara Formation was introduced by Desio et al (1963). It consists mainly of fine materials mostly silt and occasionally with gravels and caliche bands. The investigated depth in this formation about 14 m.

Whereas Gargaresh Formation described by Lexique Stratigraphique International (1960) consists mainly of calcarenite sandstones of Tyrrhennian age. This formation makes steep cliffs along the shore of the Mediterranean, stretching from Tajura in the east of Tripoli to Tunisian border in the west. The calcarenite sandstone layers including shell fragments and inter-bedded with occasional silt lenses. The investigated depth in this formation about 14 m.

DATA COLLECTION AND ANALYSIS

Estimation of liquefaction susceptibility incorporates evaluation of geotechnical borehole data for late Quaternary deposits, textural and groundwater conditions conducive to failure. Analyses of liquefaction susceptibility were performed using the Seed Simplified Procedure (Seed et al., 1983) that incorporates data on groundwater conditions, overburden load, SPT data and the cyclic stress ratio.

The data collection was facilitated by a review of geotechnical reports for twenty boreholes from Alcotub Bureau Consultants in their Tripoli office (Table, 1).

Table (1), Studied sites with their coordinates

No.	Sites	Coordinates	
1	Tajoura	N :325334.21	E:132035.83
2	Maetega	N: 325430.89	E:131602.20
3	Borj-Albahar	N:325335.68	E: 131005.54
4	Haiti	N:325330.88	E:131005.54
5	Qaeda al bahrya	N:325412.29	E:13138.36
6	Hy_Alandulis	N:325240.60	E:130757.05
7	Dhmani	N:325346.77	E:131245.18
8	Almansura	N:325255.55	E: 131034.78
9	Fekeni	N:325237.19	E:131032.23
10	Sedi Al masri	N:325203.52	E:131249.78
11	Bab ben Gasher	N:325221.9	E:131140.42
12	Al-rayadya	N:325147.13	E:13165.23
13	Al- felah (Shaby)	N:3636386.389	E:214829.235
14	Al-felah (Tiff)	N:321518.63	E:13855.66
15	Al-felah (Alamya)	N:3636742.568	E:214363.548
16	Al-felah (yamata)	N:3636030.924	E:214413.067
17	Al-felah (Nafed)	N:321518.63	E:13855.66
18	kremya	N:3624275.142	E:209548.725
19	Al-rayhan factory	N:324442.98	E:13443.23
20	Jdydah prison	N:325147.13	E:13165.23

Boreholes' records reviewed to create a database of sites evaluated for liquefaction potential. A spreadsheet was constructed using data from logging of geotechnical site investigation from Alcotub Bureau Consultants.

The database was constructed with the following constraints:

- The geotechnical site investigation projects included boreholes reached 20 meter.
- The locations of the boreholes were plotted on a project site map identified as to their surface elevation, longitude and latitude.
- The geotechnical site investigation projects used in this research were intended for soil foundations reports.
- The sandy material that had the highest liquefaction susceptible was used to assign the practice criteria within specific borehole for that location.

Accordingly, the practice criteria used incorporated soil type, blow count, and groundwater information that were obtained from geotechnical site investigations without modification or filtering of the original borehole logs.

Evaluation of Liquefaction Potential by Empirical Methods

Geotechnical subsurface information used to evaluate the potential for liquefaction. The most general techniques using standard penetration test (SPT) blow count (commonly referred as to the ―N-value‖) follows certain protocols:
1. Estimation of the cyclic stress ratio (CSR) at various depths within the soil by the earthquake.
2. Estimation of the cyclic resistance ratio (CRR) of the soil, which is required to cause initial liquefaction of the soil.
3. Factor of safety assessment against liquefaction potential of in situ soils.

Based on their definitions, the CSR and the CRR are normalized cyclic shear stresses to the effective overburden stress. Also, the comparison can be made through the concept of Safety Factor (FS) which defines as the ratio of resistance to loading, expressed in Eq. (3.8). As it is designed, when FS becomes one or less, the soil will liquefy.

The following steps are followed to determine the Liquefaction Potential of Cohesion less Soils using Simplified Procedure:

Step 1: The subsurface data used to assess location of the water table, SPT blow count (N), mean grain size (D50), unit weight, and fines content of the soil (percent by weight passing the IS Standard Sieve No. 76μ).

Step 2: The total vertical stress (σv) and effective vertical stress (σ'v) for all potentially liquefiable layers within the deposit were evaluated.

Step 3: The following equation were used to evaluate the stress reduction factor rd (Figure, 2):

rd = 1 – 0.00765z for $z \leq 9.15$m and.

rd = 1.174 – 0.0267z for $9.15 < z \leq 23$m.

where(z) is the depth below the ground surface in meters.

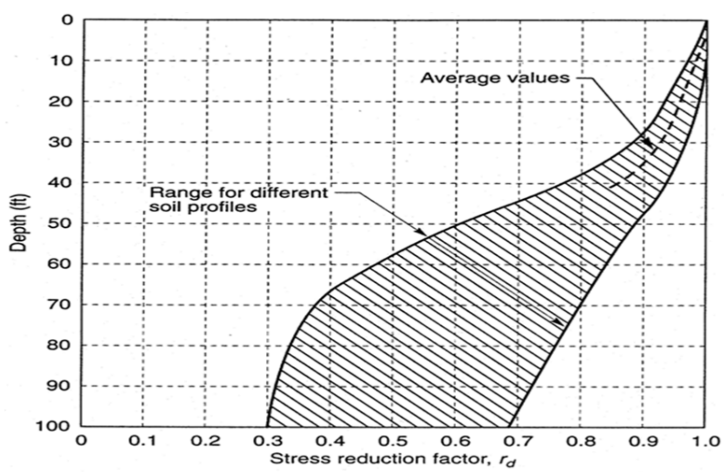

Figure (2): Seed and Idriss (1971) reduction factor range

Step 4: The Critical stress ratio induced by the design earthquake, CSR was calculated as:

$$CSR = 0.65\ (a\ max / g)\ rd\ (\sigma v / \sigma' v)$$

Where σv and σ' v are the total and effective vertical stresses, respectively, at depth z, a max is the peak horizontal ground acceleration (PHGA), and g is the acceleration due to gravity. For assessing liquefaction of soil layers underneath free standing water column, the height of free standing water is neglected and the water table is assumed at the soil surface.

Now for assessing liquefaction susceptibility using the SPT we use Step 5, to compute cyclic resistance ratio (CRR7.5) for Mw = 7.5 earthquakes. Cyclic resistance ratio, CRR for sites for earthquakes of other magnitudes or for sites underlain by non-horizontal soil layers or where vertical effective stress exceeds 1 atmospheric pressure is estimated by multiplying CRR7.5.

Step 5: The standardized SPT blow count (N60) which is the standard penetration blow count for a hammer with an efficiency of 60 percent is now evaluated.

The standardized SPT blow count is obtained from the equation: $N60 = N.C60$

Where C60 is the product of various correction factors.

Now the normalized standardized SPT blow count, (N1)60 are calculated using :

$$(N1)60 = CN * N60$$

Where Stress normalization factor CN is calculated from the following expression:

$$CN = (Pa / \sigma'v)\ 0.5$$

Subjected to $CN \leq 2$, where Pa is the atmospheric pressure. However the closed form expression proposed by Liao and Whitman (1986) may also be used:

$$CN = 9.79(1 / \sigma'v)\ 0.5$$

The CRR or the resistance of a soil against liquefaction is estimated from Figure (3) for representative (N1)60 values of the deposit.

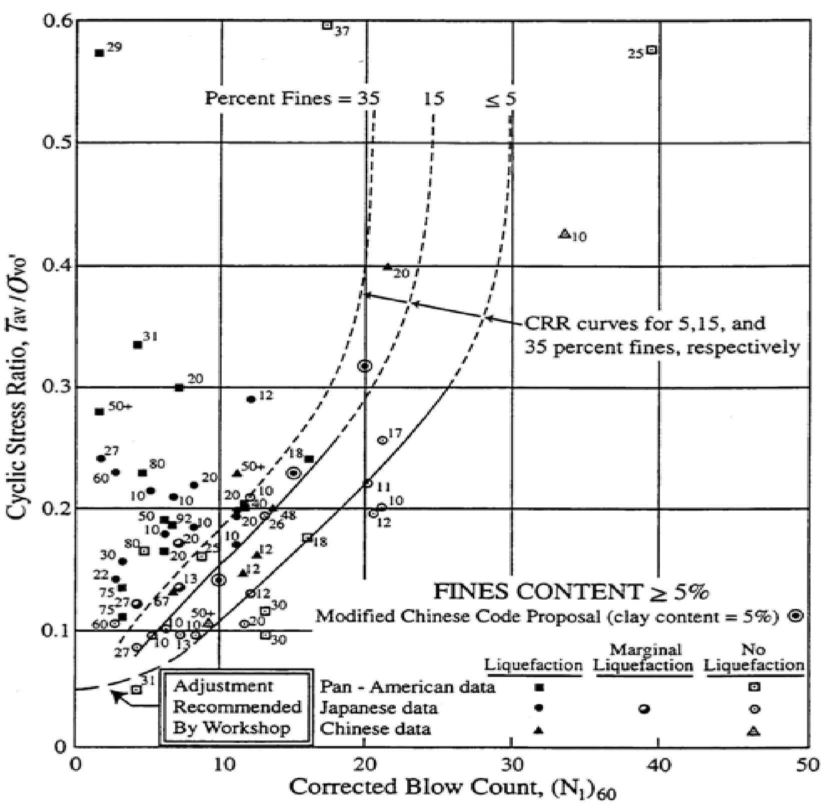

Figure (3): Simplified Base Curve Recommended for Determination of CRR from SPT Data for Moment Magnitude 7.5 Along with Empirical Liquefaction Data (after Youd and Idriss, 1997)

Step 6: CRR7.5 was corrected for earthquake magnitude (Mw), stress level and for initial static shear using correction factor MSF (Table, 2), according to (Figure, 4):

CRR = CRR7.5. MSF

Table (2): CSR correction.

magnitude , M	correction CSR=7.5 / (MSF)
5.5	1.5
6	1.32
6.75	1.13
7.5	1
8.5	0.89

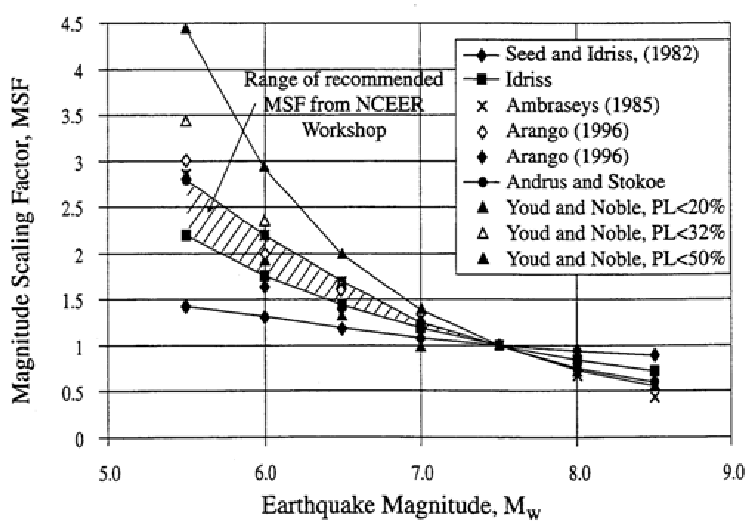

Figure (4):Magnitude Scaling Factors Derived by Various Investigators (After Youd and Idriss, 1997)

Step 7: The factor of safety against initial liquefaction, FS, is calculated as:

FS = CRR / CSR

Where CSR is as estimated in step 4 when the design ground motion is conservative, earthquake-related permanent ground deformation is generally small if FS ≥ 1.1.

RESULTS AND DISCUSSIONS

The results obtained from 20 data points was used to develop the liquefaction susceptibility map. Before plotting each of the points screening practice criteria for liquefaction potential was applied. Accordingly, the study area divided into three zones. Zone one includes Tajoura, Maetega and Qaeda Al bhrya sites (Table, 3), while zone two includes Borj-Albahar, Qaeda al bhrya , Haiti, Dhmani, Almansura, Fekeni, Sedi Al masri, and Bab ben Gasher sites (Table, 4). So, the other sites including Hay_Al andulis, Al-rayadya, Al- felah (Shaby), Al-felah (Tiff), Al-felah (Alamya), Al-felah (yamata), Al-felah (Nafeda), kremya, Rayhan factory, and Jdydah prison forming zone three (Table, 5).

The final product is shown on the map (Figure, 5) delineates areas that have conditions documented to create liquefaction. Hence, the liquefaction hazard map can be used as a planning means and gives a guideline for developing site-specific investigations in areas that have liquefaction susceptible environment.

Table (2), The depth and factor of safety of zone (1)

Sites	Depth (m)	F.S
Tajoura	8.1	1.28
Maetega	1.5	0.49
Qaeda al bhrya	2.2	0.63

Table (3) , Depth and factor of safety of zone (2) sites

Sites	Depth (m)	F.S
Borj-Albahar	0.5	0.73
Qaeda al bhrya	2.2	0.63
Haiti	3	0.73
Dhmani	0.5	0.58
Almansura	2.5	0.44
Fekeni	3.8	0.73
Sedi Al masri	3	0.87
Bab ben Gasher	1.5	0.97

Table (4), Depth and factor of safety of zone (3) sites

Sites	Depth (m)	F.S
Hay_Al andulis	1.5	0.83
Al-rayadya	0.5	0.65
Al- felah (Shaby	No liquefaction (0.5)	0.54
Al-felah (Tiff)	2.6	0.51
Al-felah (Alamya)	2.5	0.51
Al-felah (yamata)	5.5	0.99
Al-felah (Nafeda)	8.9	0.63
kremya	5.5	0.99
Rayhan factory	6.5	1.00
Jdydah prison	4	1.15

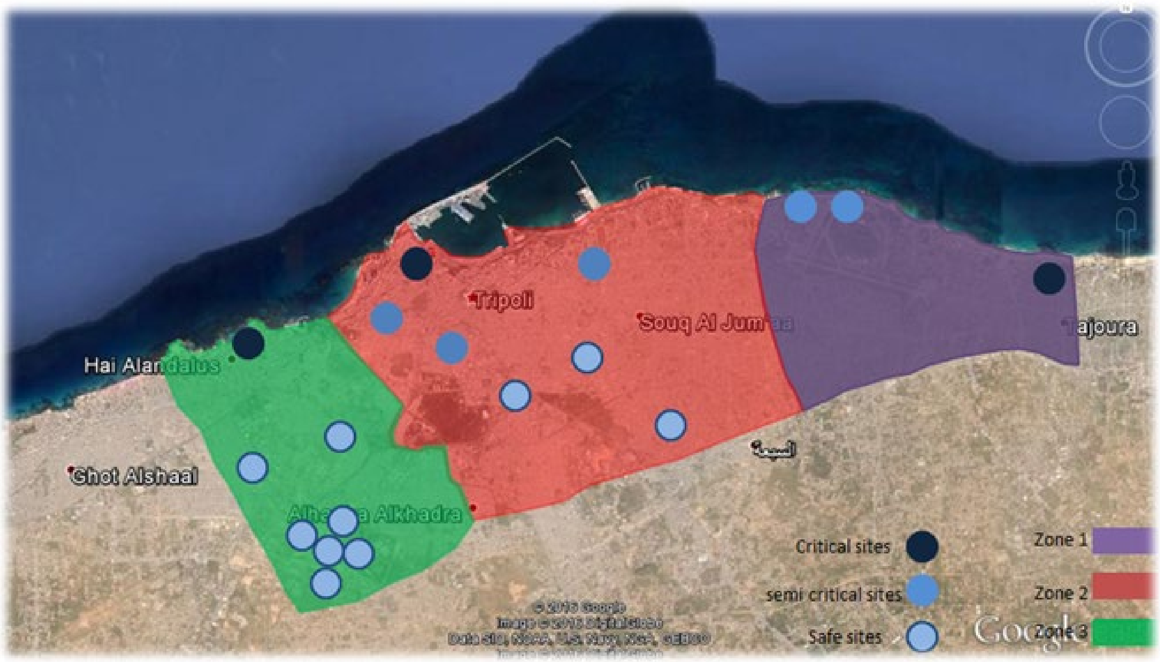

Figure (5): Liquefaction hazard map showing the three susceptible zones in the study area of Tripoli

SUMMARY AND CONCLUDING REMARKS

The evaluation of liquefaction potential in cyclic stress approach (CSR), and consequently in simplified procedure as a cyclic stress approach-based method, simply performs by a comparison of loading and soil resistance (CRR) throughout the mentioned soil deposit. In this approach, the earthquake loading characterizes by the amplitude of an equivalent uniform cyclic stress and liquefaction resistance by the amplitude of the cyclic stress required to initiate liquefaction (in the same number of cycles). By plotting the variation of equivalent cyclic shear stresses of an earthquake loading (τcyc) and the cyclic shear stress required to cause liquefaction (τcycL), throughout a soil strata in the same graph, the evaluation can be performed graphically. Liquefaction can be expected at depth, where the loading exceeds resistance. It should be noticed that the values of (τcycL) must correspond to the same earthquake magnitude, or same number of equivalent cycles as τcyc.

The method enables mapping the soil susceptibility to liquefaction hazards by which three zones recognized in the study area. Zone one form the eastern side showed strong susceptibility to liquefaction at a depth of 0.5 m. Zone two recognized in the middle of the study area showed possible occurrence of liquefaction in its soil but not strong as the case in zone one. Whereas zone three forming the rest of the study area in the west, reflect weak possibility to liquefaction at depth 2.6m with some areas show safe zones.

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