

## Liquefaction Potential Assessment for Basrah Soil Based on Standard Penetration Test Values

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### Abstract

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Most of the crustal depth shocks are situated within the geographic border of the earthquake risk map for Iraq. The number of earthquakes rises, and a pattern emerges, with their magnitudes ranging from 2.7 to 7.2. Recently, many parts of Iraq have been affected by earthquakes. Under such loads, soil can be liquefied, which might destroy the ground and buildings. Therefore, bore log data, grain size distribution, N-values of the standard penetration test, and an earthquake risk map are used to assess the liquefaction potential. The liquefaction parameters are calculated using Idriss and Boulanger (2014). It is chosen based on the amount of sand and fines present. Five earthquakes with magnitudes ranging from 5-7 and an interval of 0.5 have been selected. The purpose of this research is to assess the liquefaction potential of some areas in Basrah city that are located on medium to very dense sandy soil. The results indicate a high probability of liquefaction at a shallow depth in some sandy areas, indicating the need for a liquefaction prevention method.

**Keywords:** Earthquake; Safety Factor; SPT; Liquefaction; Basrah soil

### 1. Introduction

Liquefaction is a phenomenon that could occur in soil due to an earthquake. Numerous studies and descriptions of the liquefaction of granular soils could happen during shaking loads, blasting, soil compaction, and vibroflotation (Seed, 1971) (Du, 2019). The liquefaction mostly occurs in saturated granular soil with a shallow groundwater level (Youd, 2001). It would induce high excess pore pressure, leading to reduce strength and stiffness of soil (Boulanger, 2012).

Hence, liquefaction causes massive damage to the structure during historical earthquakes (Seed, 1967), (Lee, 2004), (Lee, 2007), (Chao, 2010), (Mondal, 2018), and (Hossain, 2020). Furthermore, the effects of liquefaction on structures built on saturated granular soil, which caused damage and displacements, must be considered (Huang, 2012; Karakan, 2018). Thus, liquefaction is crucial to study for the Iraqi building code in the design of new infrastructure (Al-Taie, 2014).

An extensive study has been undertaken under seismic stress conditions to evaluate the liquefaction capability of granular soil. (Youd, 2001) suggested a simplified method to assess a soil's susceptibility to liquefaction that involved evaluating the soil's resistance to cyclic stress using a liquefaction safety factor. The equation specifies this parameter as shown in equation (1):

$$FS = \frac{CRR}{CSR} \quad (1)$$

Where: FS is a factor of safety, CRR is the cyclic resistance ratio, and CSR is the cyclic stress ratio. The CSR is greater than the CRR, which leads to FS being less than 1 and the soil layer being liquefiable. This procedure was established by (Seed, 1971) to estimate soil liquefaction potential based on N-values. The other parameters include stress reduction factor (rd), probability of liquefaction (LPI), and factor of safety (FS), which can be assessed in four different ways: (Seed, 1983) (Andrus, 1999) (Cetin, 2004), and (Boulanger, 2014).

More information has been added to a number of works (Devi, 2017; Ahmad, 2018; Hossain, 2020; and Wadi, 2021) to present new findings about parts of the liquefaction analysis framework and to analyse and expand on the study case's history.

The basic framework in this paper is based on evaluating of the cyclic stress ratio (CRR) and the factor of safety (FS) against liquefaction, measuring the soil resistance. The N values obtained from the SPT must be corrected. The equations below have main factors that are used to analyse the probability of liquefaction (PLI) in this paper and depend on (Boulanger, 2014) as shown in the equations below:

$$CRR_{M=7.5\sigma'v=1atm} = \exp\left(\frac{(N1)_{60cs}}{14.1} + \left(\frac{(N1)_{60cs}}{126}\right)^2 + \left(\frac{(N1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N1)_{60}}{25.4}\right)^4 - 2.8\right) \quad (2)$$

$$LPI = \int_0^{20} FS \cdot W(z) \cdot dz \quad (3)$$

$$FS = 1 - FL \text{ for } FL < 1 \quad (4)$$

$$FS = 0 \text{ for } FL > 1 \quad (5)$$

$$Wz = 10 - 0.5z \text{ for } z < 20 \text{ m} \quad (6)$$

$$Wz = 0 \text{ for } z > 20 \text{ m} \quad (7)$$

The classification of the PLI can be seen in Table 1. A relatively new approach was proposed by (Sonmez, 2005) using the method (Lee, 2004). The term "liquefaction severity index" or LSN, was used rather than liquefaction index risk IR as illustrated in the equation below. It is the main difference between this new method and others. Table 2 displays the categorisation.

$$LSN = \int_0^{20} PL(z) \cdot w(z) \cdot dz \quad (8)$$

The evaluated LSN and LPI for the southeast Basrah fine soils revealed that the severity values fall into the extremely low severity class. The potential liquefaction index for M is 7.5. On the other hand, it has a strong liquefaction potential, while those for M = 6.5 and 7.0 are moderate. The liquefaction potential index for M = 6.0 was found to be low. Although the southeast part of Basrah's soils is made up of finer grained soils than sands, liquefaction was not expected to be a problem during the earthquake. However, both lateral spreading and liquefaction could result in significant damage in the Basrah region during large earthquakes of M = 6.5 (Husain, 2016)

**Table 1.** Classification of liquefaction potential index (Sonmez, 2003)

Liquefaction potential index (LPI)	Liquefaction potential classification
0	Non-Liquefaction
0 < LPI ≤ 2	Low
2 < LPI ≤ 5	Moderate
5 < LPI ≤ 15	High
PLI < 15	Very High

**Table 2.** Classification of liquefaction potential index(Sonmez, 2005)

Liquefaction severity index(LS)	Liquefaction severity classification
$85 \leq LSN \leq 100$	Very high
$65 \leq LSN \leq 85$	High
$35 \leq LSN \leq 65$	Moderate
$15 \leq LSN \leq 35$	Low
$0 < LSN < 15$	very low

(Wadi, 2021) estimated the liquefaction safety factor in their research in Nigeria's Upper Benue region, using the simplified approach provided by (Boulanger, 2014). It is possible to build soils resistant to liquefaction and buildings that can withstand earthquakes in this area in the future.

In view of the above, the current study is designed to explore the possibility of liquefaction of sandy soil areas in Basrah Iraq's southernmost metropolis. The data from standard penetration test (SPT) borelogs, fine percentage, and soil physical properties have been used to determine the liquefaction potential. The Liq software is used to assess the likelihood of soil liquefaction by taking into account all possible levels of earthquakes.

Basrah city, the area of study, is situated in southeast Iraq between latitudes of  $30^{\circ} 30' 03''$  N north and longitudes of  $047^{\circ} 48' 59''$  E, as seen in Table.3. Basrah is the largest port in Iraq, but the city also has large shipping, logistics, and transportation industries. It is a part of the plain alluvial region, which is largely distinguished by its full simplicity in the northern and eastern governorates. At the same time, some valleys and hills, such as Jabal Sanam, exist in the western and southwestern districts. In Qurna, the rivers Tigris and Euphrates converge. The combined stream is referred to as the Shatt Al-Arab river. Basrah is a low-lying floodplain and delta at the height of 5 meters where the Shatt Al-Arab enters the Arabian Gulf above mean sea level and roughly 110 km from the Gulf. The investigation area is situated at an elevation of 5 m in the southern and eastern regions of the Basrah soil.

**Table 3.** The coordinates of the borehole of the study area

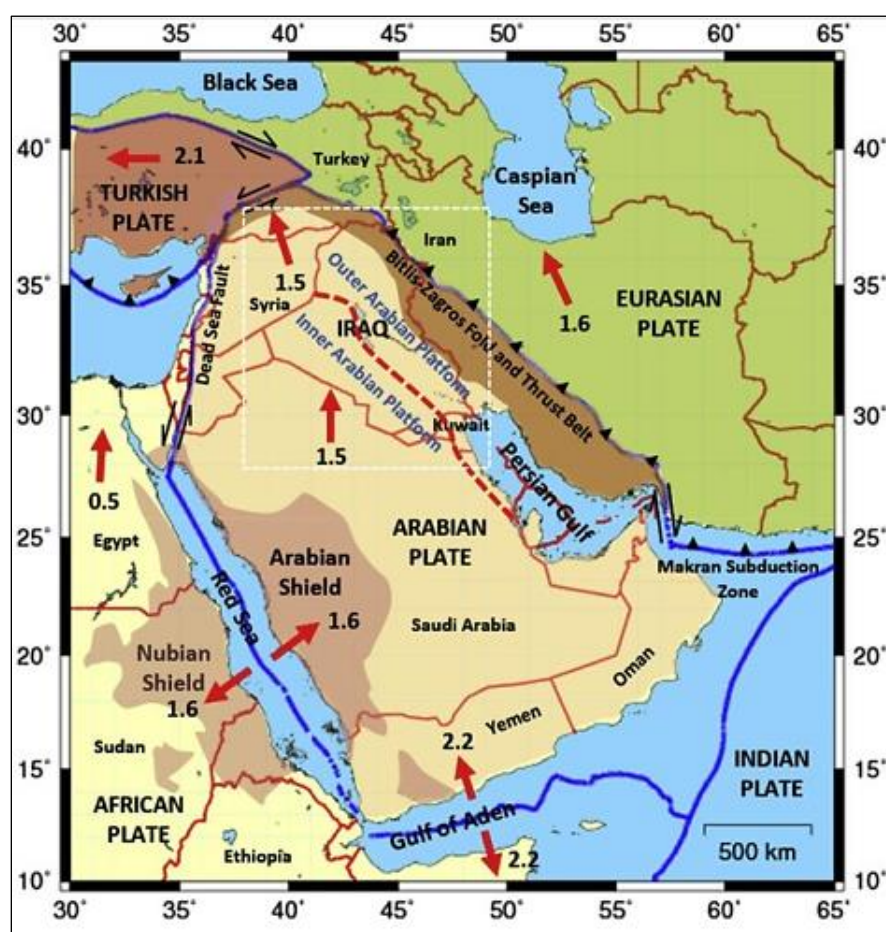
Boreholes	Names	Latitude <sup>o</sup>	Longitude <sup>o</sup>
BH1	Al-Shuaiba	30.423365	47.629513
BH2	Al-Zubair	30.366359	47.708842
BH3	Khour-Al Zubair1	30.247501	47.833199
BH4	Khour-Al Zubair2	30.222288	47.782097
BH5	Safwan	30.122561	47.694394
BH6	Um-Qaser	30.033433	47.916277

## 2. Geology and Tectonic Setting

The Dibdibba Formation covers extensive areas in the southern and central parts of Iraq and comprises sand, silt, gravel, and clay. It is classified as poorly sorted sand and sandstone, together with gravel. The majority of the sand and sandstone is quartz, with 84.2% of monocrystalline and crystalline quartz grains. There are approximately 8.5% rock pieces and 7.3 % feldspar in this sample. (Jassim, 2006) found that most of the Dibdibba gravels are made up of acidic and intermediate igneous rocks. There is also a small amount of metamorphic rocks, limestone, and chert.

Almost the entire country of Iraq is situated within the Arabian Plate's north-eastern region (Abdulnaby 2019). The Arabian plate is separated into the shield and platform. The platform includes the western part of the Kingdom of Saudi Arabia, other Arabian Gulf countries, Jordan, Syria, Lebanon, Iraq, and Palestine. In addition, it is divided into outer and inner platforms (Fig. 1). The shield covers the western part of the country.

The recent tectonic situation of Iraq is governed the collision between the Arabian and Eurasian plates (Almutury, 2008). The collision began during the early Tertiary and continues (Numan, 1997). The Taurus and Zagros mountain belts and the foreland basin within the Arabian Plate were formed as a result of the collision (Fouad, 2010). Thus, previous tectonic events, particularly the convergence of the Arabian and Eurasian plates, it is what contributed to the structural geology and neotectonics of Iraq (Abdulnaby, 2019).

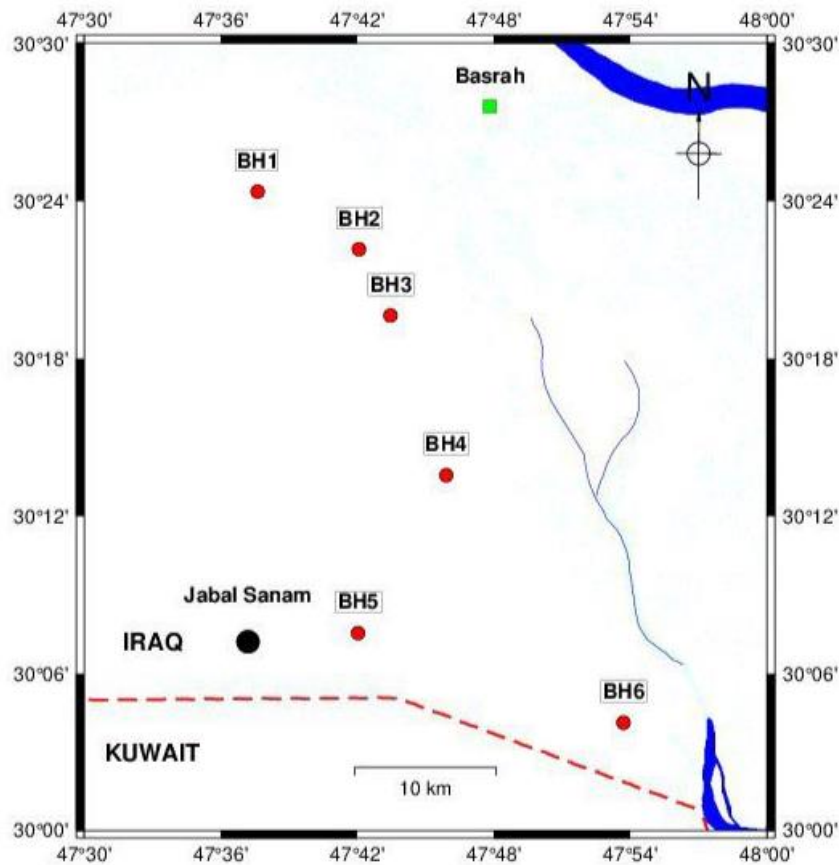


**Fig. 1.** Tectonic setting of the Arabian plate; red arrows indicate plate motions in centimetres per year (after Abdulnaby, 2019)

### 3. Materials and Methods

Six boreholes were drilled to a depth of 30.0 m in Basrah city. The borehole locations are shown in Fig. 2. The SPT-N values were used to record the soil type and consistency of cohesive and non-cohesive soils. The number of blows for each 300 mm penetration following the seating blows is known as the N-value. By adjusting the N-value following ASTM D 1586 and the test equipment specifications, obtained the N1 by considering the effects of the hammer energy, borehole diameter, sample technique, and rod length. Many programmes support engineers LiquefyPro 5.5 is one of the programmes in

CivilTech engineering to assess the possibility of liquefaction under earthquake circumstances. It incorporates the most recent publications of the (NCEER/NSF, 1998) Workshop (1997) and SP117 Implementation developed by Geologismiki. This paper considers it to allow the user to manage the parameters that are used within the calculation. SPT data, fine content, median diameter, and influence depth comprised the input parameters. The measure was managed for every single borehole. The fine content reaches a maximum value of 50%. In this proposed study, the fine content is between 10% and 28%, and the earthquake magnitudes of ( $M = 5, 5.5, 6, 6.5,$  and  $7$ ) with a maximal horizontal ground acceleration of  $0.25g$  are considered to evaluate the liquefaction resistance of soils. The water table, however, is almost always deeper than 2 m in most of the region. As a result, the liquefaction susceptibility grows with decreasing saturation, and soil with low moisture content can only liquefy under intense and prolonged earthquake shaking (Sherif, 1977). Basrah's saturated sandy and silt sandy soils must therefore be evaluated for liquefaction resistance to increase the ground's suitability for buildings that can withstand earthquakes. To investigate the worst-case scenario of liquefaction, the groundwater level has stayed at a depth of 1 m for all selected boreholes in the current study.



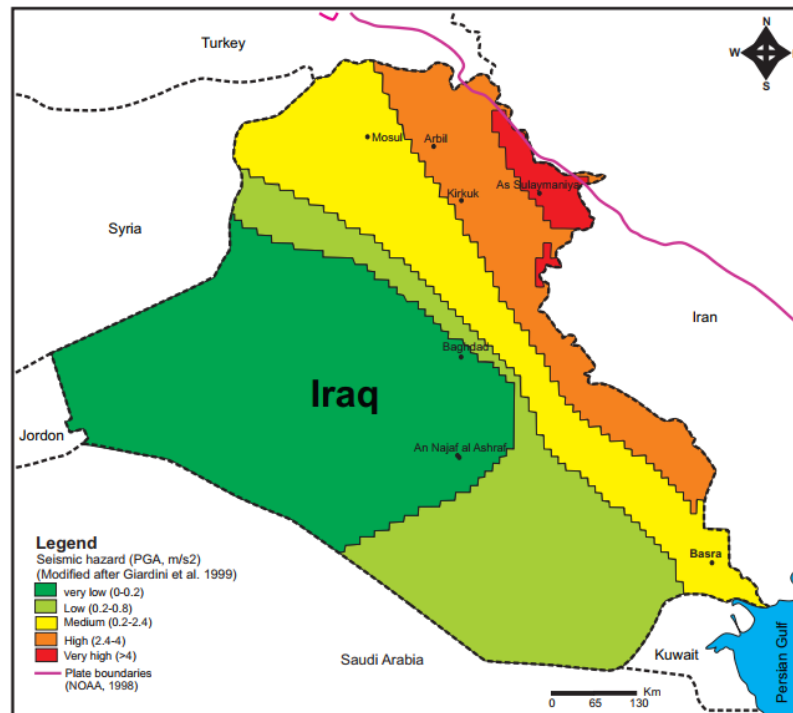
**Fig. 2.** Distribution of boreholes in the study area

#### 4. Seismology of the Study Area

Iraq is situated at the convergent tectonic boundary between the Arabian and Eurasian plates, which is along the line of the Tauroz-Zagros mountain ranges, as illustrated in Fig. 1. Iraq is a part of the Alpine belt along this line. This plate is categorized as an active seismic zone that produces intense earthquake activity. Iraq has been affected by the epicenters of the earthquake, showing the potential for high seismic hazards in the future. The northern part of the country is more likely to experience a high-magnitude earthquake in the next 50 years (Onur, 2016).

It lies within the seismically active portion. However, it appears to have a low seismic hazard due to its distance from major plate boundaries (Fig. 3). The probability of ground motion of 2% , the likelihood of reaching in 50 years' time. Within the western desert, the magnitude peaks at 7.3 M (Abdulnaby, 2019).

Characterizing the cyclic loading and considering the earthquake's duration require parameters from the seismic event, such as the peak ground acceleration (PGA) and the magnitude(M). The procedure to estimate these values is similar to that adopted in the groundwater depth estimation if the assessment represents a back analysis; both parameters are estimated from the recordings of the strong motion stations near the site. In this study, PGA was taken as 0.25 g. For this purpose, scientists have worked to develop a framework for the earthquake that is anticipated to strike Basrah in 50 years.



**Fig. 3.** Seismic hazard distribution map of Iraq (modified after NOAA, 1998 and Giardini et al. 1999)

## 5. Soil Characterization

The soil classification is significant to research since the soil type affects its susceptibility to liquefaction. Six boreholes were therefore chosen in some regions of the Basrah governorate in the south of Iraq to test granular soil. Details on those six holes are shown in Fig.4, which displays the soil's vertical distribution. It is evident from the bore-logs data that BH1 includes the Al-Shuaiba region. Accordingly, in the first three meters of medium-dense silty sand, the SPT values were between 22 and 27, and the fine content ranged from 13 to 29%. The strata below have SPT values of more than 50 and are classified as very dense sand to very dense silty sand. The BH2 that is located in Al Zubair is classified as a mixture of medium dense silty sand and hard clayey silt, and the deeper layers are very dense silty sand. The BH3 represents the Khour\_Al Zybuir-1 (Petrochemical) zone, which is to the east-west of Al Zubair. The soil is described as hard brown clayey silt with very high SPT.

The first meter, designated as Khour-Al Zybuir-2 BH4, is made up of hard, brown clayey silt with a 33 SPT value. Regarding the borhole drilled in Safwan BH5, the first meter is categorized as medium dense silty sand with a 16 % fine content and moderate SPT values. On the other hand, the bottom profile is defined as very dense silty sand with high SPT values. On the other side, Um-Qasser (BH6) revealed 2.5 m of soil that is classified as medium-dense silty sand. Sand is present in very dense layers



from 3 to 20 m, and the SPT values are 50. In brief, the soil in the region of the study's first three meters can be characterised as medium silty sand with low SPT values. In some areas, Dense silty sand with N-values greater than 50 blows/30 cm is believed to be present in layers up to 30 meters deep.

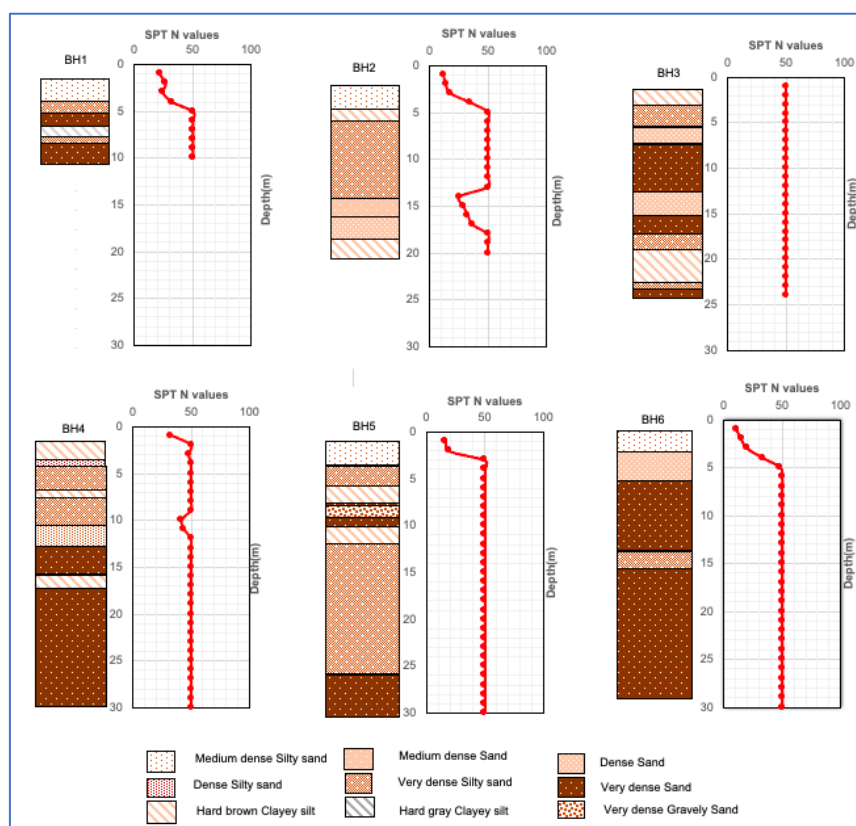
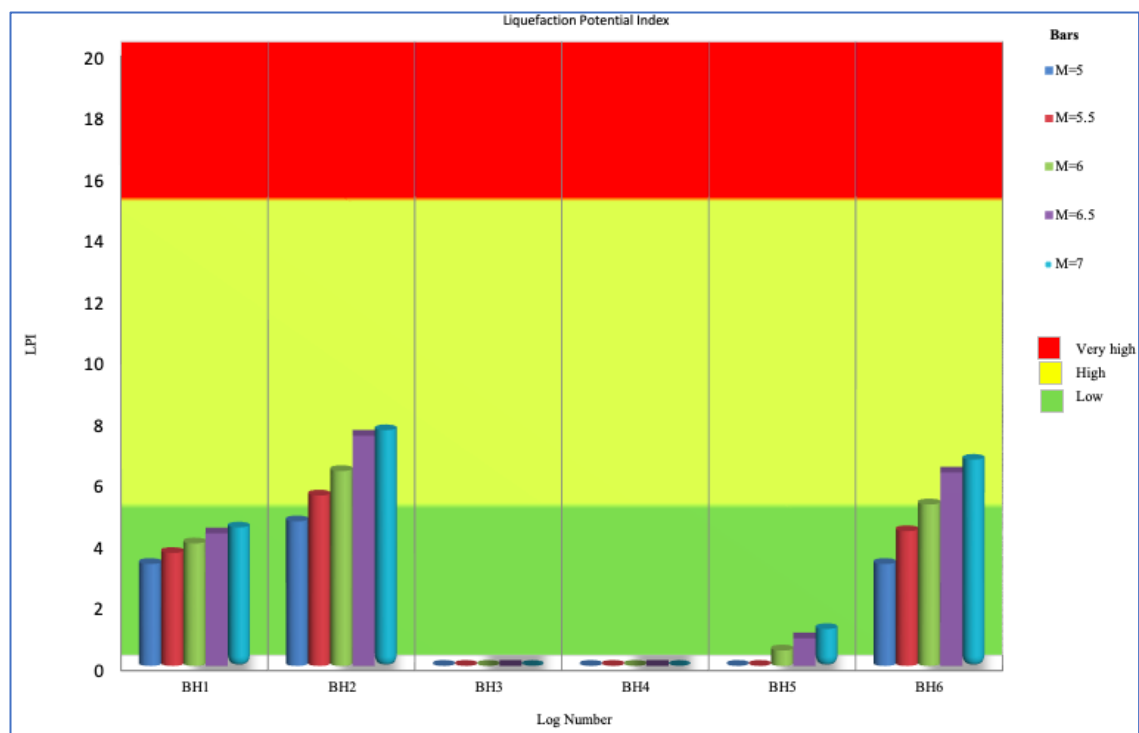


Fig. 4. Subsoil profile of boreholes in some area in Basrah

## 6. Results and Discussion

Based on the categorization of Tables 1 and 2, LPI and LSN values have been characterised in this work concerning the bore-logs findings that are plotted, and a coloured background shading has been added. For five distinct earthquake magnitude scenarios ( $M = 5.0, 5.5, 6.0, 6.5,$  and  $7.0$ ), the  $PG = 0.25$ . The results demonstrate that BH1 has a low probability of liquefaction with a modest increase as  $M$  increases. The BH2's PLI is modest at  $M=5$  and rises gradually as  $M$  rises from moderate to high liquefaction risk at  $M=5.5$ . Due to the soil's structure, which is classified as highly dense silty sand and sand with SPT values higher than 50. In all conditions, BH3, BH4, and BH5 remain stable with no signs of liquefaction. The LPI for BH6 at  $M = 5.0$  shows liquefaction sensitivity. At  $M = 5.5$ , this remains constant. However, it demonstrates significant liquefaction at  $M=7.0$  and is in high danger due to a progressive increase in LPI with an increase in  $M$ .

In general, the results illustrated in Fig. 6 show that the earthquake magnitude of Basrah soil has a moderate LPI of 7.0. whereas at an earthquake magnitude of 6.0, Basra soil has a low.



**Fig. 6.** Liquefaction potential index for the study area

LPI value. Considering that the site strata are made up of dense sands with very high SPT values, the result at depth further exhibits no evidence of liquefaction.

The LSN for BH1 is set to a modest expression of liquefaction with a slight increase in accordance with the severity index values depicted in Fig. 7. The BH2 reaches the high-risk area at  $M = 7.0$ . The BH5 is highly susceptible to liquefaction at all possible scales. The severity numbers for BH3, BH4, and BH5 can be seen to show little to no evidence of liquefaction. Notably, the first 3 meters have demonstrated greater susceptibility to liquefaction when taking recent sediment into account.

In conducting data analysis, the fact that geological factors play a significant role in the degree of liquefaction in saturated sand or sandy silt soils, such as depositional environment, age, and magnitude of ground shaking (Seed, 1983). The western part of Basrah soil ranges; from very dense subsoil high layers to medium compaction layers, mostly at a depth of 1-3 m. Fine-grained soils, such as clays and silts, are less prone to liquefaction than sandy soils. This is because fines-rich soils have higher blow counts (N-values), making them more resistant to liquefaction. In fact, because the liquefaction resistance of soil deposits grows with depth as adequate overburden pressure does, no liquefaction potential zones have been observed deeper than 15 m (after (Terzaghi, 1996) and (Peck, 1969)). Natural silty sand deposits are more likely to display contractive shear behaviours than clean sands because they are deposited in a looser state. According to (Ishihara, 1992), the type and extent of liquefaction damage are determined by how much the soil's shear strength has fallen and how much static shear stress it can support.

Liquefaction indexes are used to provide relevant information addressing the damage resulting from soil liquefaction. Very dense sands with a safety factor of more than 1 are present in the formation at depths greater than 3 meters. This liquefaction hazard study will help engineers choose an appropriate ground improvement method (liquefaction mitigation method) and a foundation system for future construction in the investigated area. This process enabled us to overcome the limitations of some of the approaches, particularly from SPT. The results are displayed to highlight the locations that could be most affected.



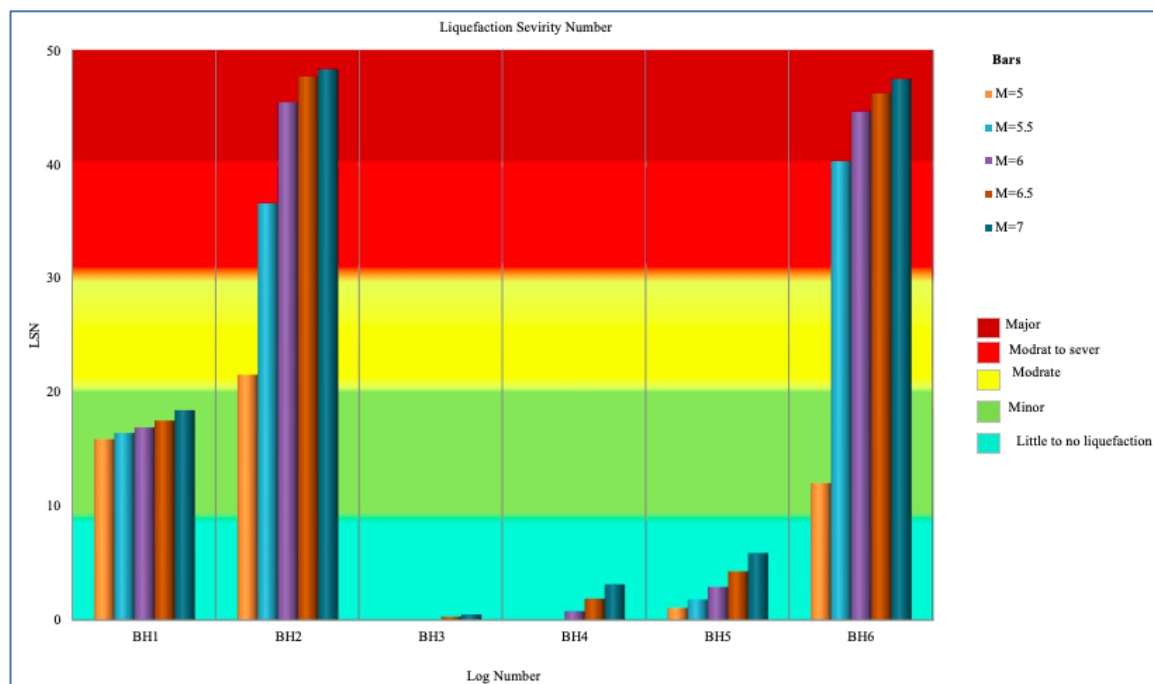


Fig. 8. Liquefaction severity number for area of study

## 7. Conclusions

Estimating the susceptibility of granular materials to liquefaction during earthquakes is a complex problem in geotechnical engineering. Analysis of the liquefaction at magnitude (M) = 5 with various earthquake magnitude scenarios demonstrates modest hazard. Three boreholes at M = 5.5 exhibit liquefaction susceptibility. The severe intensity of the devastation is indicated by Al Zubair and Um-Qasser zones. It is commonly assumed that only recent deposits or fills of saturated, cohesionless soils at shallow depths would liquefy in a strong magnitude earthquake. The majority of the site layers are made up of highly dense sands with high SPT values that have shown mainly no to moderate liquefaction, according to the study that has been done. SPT and fine contents affect the research area's potential for liquefaction. The engineers will use this liquefaction hazard analysis to determine an appropriate ground improvement technique and foundation system for an upcoming building in the study region.

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