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Geotechnical Characteristics of Liquefaction in Shahid-Rajaei Port Site (Bandar Abbas, Hormozgan Province) by Using GIS

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ABSTRACT

One of the seismic geotechnical phenomena is the occurrence of liquefaction in soil layers. This phenomenon occurs in non-dense saturated silty sandy sediments in which the saturated soil completely loses its strength and hardness due to the intense stress applied to it and behaves like a liquid. This stress can be due to earthquakes or sudden changes in soil stress. In this case, the shear strength of the soil is zero and it loses its bearing capacity. Soil liquefaction resistance can be determined by laboratory and field methods. The main purpose of this study is to determine the liquefaction potential zoning and the amount of sedimentation due to liquefaction based on the standard penetration resistance test (SPT) using the method of Sied et al. (1983) in Shahid-Rajaei wharf, Bandar Abbas located in Hormozgan province. In the present study area, 304 boreholes were drilled, according to the type of soil and the groundwater level. The results show that the average N_{SPT} in the region is equal to 35 and the highest percentage of soils in the region based on Unified classification in SM category and according to the zoning status, the degree of liquefaction varied at different depths and according to the liquefaction index, the amount of subsidence in different sections is determined, so that the maximum amount will be in the southern part of the port.

1. Introduction

One of the issues that have been considered by many researchers in the field of seismic geotechnics in recent years is the phenomenon of liquefaction. Liquefaction refers to a situation in which unsaturated non-saturated soils decrease in shear strength due to increasing pore water pressure and consequently large deformations. With this phenomenon, saturated sands lose a large percentage of their shear strength due to seismic loading and the soil particles are immersed in the shear stresses like a liquid. According to case studies, soil liquefaction is one of the most important causes of serious damage to vital arteries, residential buildings and public urban facilities. Liquefaction can cause lateral displacement of the ground, flow ruptures, loss of bearing capacity, or asymmetric subsidence of structures and boiling of sand. This phenomenon has been observed in various earthquakes such as Alaska (1964), Niigata (1964), Loma Prieta (1989), Kobe (1995), Chi Chi Taiwan (1999) and Bushehr (2013) (Plafker, 1972; Ishihara and Koga, 1981; Arnadóttir and

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Segall, 1994; Igarashi et al., 1995; Ma et al., 2001; Golzari et al., 2013; Sharifi Teshnizi et al. 2019a,b; 2020a,b). The Manjil and Rudbar earthquakes in 1990 had the greatest effects on Iranian liquefaction. Since liquefaction-prone layers are present in many areas, soil remediation operations should be performed on these layers to reduce the risk of liquefaction. Because the cost of soil remediation operations is generally very high, accurate estimation of liquefaction potential, in addition to safe aspects, can also economically reduce the cost of these projects (Poorbehzadi et al., 2019; Reisi Dehkordi et al., 2019; Arjmandzadeh et al. 2020; Ebad Ardestani et al., 2020; Karimizad et al. 2020; Golian et al. 2021; Sharifi Teshnizi et al. 2021).

In many past destructive earthquakes such as the Niigata earthquake in Japan (1964), Lausanne Philippines (1990) and Kocaeli in Turkey (1999), the phenomenon of liquefaction has been observed on a large scale in a liquefaction-prone area that causes extensive damage to buildings and roads, bridges, dams, etc. Among these damages, deformation (including subsidence and rotation) (surface foundations of structures) has been observed in abundance, in order to estimate the seismic values of surface foundations based on liquefied soils and also to provide solutions to improve their seismic behavior. Factors affecting the behavior of these foundations must be determined, which requires extensive research in this field (Day, 2002; Erdik, 2001; Iai, 2016; Yazdi and Sharifi Teshnizi 2021; Samui, 2021). However, due to the complexity of the problem and the number of parameters affecting the behavior of such foundations and soils, comprehensive design methods for surface foundations located on soils with liquefaction capability have not yet been proposed. Research in this field is divided into three groups: laboratory, field and modeling:

After destructive earthquakes, many researchers such as Tokimatsu and Yoshimi (1983), by attending the accident site, collected information such as the amount of subsidence according to the dimensions of the structure, soil characteristics of the study area, etc. and diagrams have provided to evaluate the behavior of foundations.

Centrifugal and seismic table experiments have been performed in different centers of the world to investigate the seismic behavior of surface foundations based on liquefied soil and the factors affecting subsidence, which can be tested by Yoshimi et al. (1984), Liu and Dobry (1997) Dashti et al. (2010a,b) Hassanzadeh et al. (2011), Jafarian et al. (2012), Wang et al. (2015), Gao Dan et al. (2018), Monkul Mehmet et al. (2017), Banović et al. (2019), Tsinidis et al. (2020), and Roy et al. (2021).

Some researchers use numerical methods such as finite element and finite difference and apply advanced behavioral models for liquefied soils that have the ability to consider the production and dissipation of water pressure of cavities created in earthquakes to study the seismic behavior of surface foundations. They have dealt with liquefied soils. In this research, the results of centrifuge, seismic table or field observations have been used to validate the performance of the numerical model. These studies include Elgamal et al. (2005), Popescu et al. (2006), Andrianopoulos et al. (2010), Shahir et al. (2011), Karamitros et al. (2013), Li et al. (2020), Ma and Luo (2021). In this research, the factors affecting the foundation subsidence such as foundation dimensions, input earthquake, and dimensions of the structure located on the foundation, overhead pressure due to the weight of the structure and foundation, the thickness of the liquefaction layer and its characteristics, etc. have been investigated.

Considering the condition of underground soil layering and the amount of load under the foundation, according to the number of floors of buildings in the present projects, the most appropriate methods to solve the problem of bearing capacity and subsidence and reduce liquefaction potential are the use of soil improvement methods. Therefore, in these conditions, one of the methods is to improve the stability of the soil reinforced with fine piles and geogrids. Soil reinforced with fine piles is soil that is reinforced with geogrids by fine piles buried in soft soil, in order to control the initial stability and subsidence as well as differential subsidence (Sharifi Teshnizi et al., 2019a). Studies show that most liquefaction criteria have been extracted using experimental and laboratory relationships. In this research, according to the results of geotechnical boreholes drilled in the area of Shahid-Rajaei pier, located in Hormozgan province and Bandar Abbas city, its liquefaction status has been evaluated and using maps prepared in ArcGIS environment of the study area. Zone should also be used. Extraction of geotechnical maps can help the designer at different depths to have different geotechnical parameters, extract the amount of hazards at different depths and during the construction of the structure and design time, the best solution and the least costly method to deal with Use with it.

2. Material and Methods

2.1. Liquidation

Liquefaction was first proposed by Mogani et al. (1953) on the issue of the failure of the Calaveras Dam in California. He explained the liquid reason for the dam's earthen wall as follows: (i) If the water pressure of the cavities between the soil grains is so high that it can withstand the load, it may cause the soil grains to be separated by water, as if the existing soil condition. The condition of the quicksand has changed, meaning that by moving a part of the material inside it, pressure builds up, and by moving another particle, it then moves and gradually flows like a liquid; (ii) This phenomenon is more common in saturated, loose (low-density or non-dense) soils and sandy soils. This is because loose sand tends to compact due to the load, but compacted sand tends to increase in volume. If the soil is saturated with water, such as soil below groundwater or sea level, then water fills the space between the solid grains (cavity space). Now, if pressure is applied to the soil, this pressure is applied to the water in these spaces. It enters the void in front of the water, trying to get out of the soil cavities under pressure and flowing somewhere with less pressure (usually the water moves to the ground surface or upwards).

If the pressure is applied rapidly and is large enough or repeated in large numbers (such as what happens in an earthquake or the pressure exerted by a storm) that the water does not have time to move away. The next (next cycle) that re-enters the load flows out through the soil grains, then a pressure is created in the water that goes far beyond the stress that holds the solid grains together. Contact between soil grains is the only way by which the weight of the building and its underlying layers is transferred to the soil layers at a lower depth or bedrock. Now when the soil loses such a structure and the contact between the solid grains is lost, it no longer shows any resistance (loses its ability to transfer shear stress) and flows like a fluid. Although the concept of soil liquefaction was previously known to engineers, it came to the attention of engineers after the 1964 Niigata and 1964 Alaska earthquakes. Liquefaction was also a major cause of the devastation of San Francisco in the 1989 Lomaprietta earthquake and the port of Kobe in the 1995 Hanshin earthquake. Also, the severe destruction that occurred in the residential area and suburbs of Christ Church in New Zealand during the 2010 Canterbury earthquake and more severely in the 2011 New Zealand earthquake was all due to soil liquefaction (Sharifi Teshnizi et al., 2019a).

In many developed countries, construction regulations force engineers to consider the effects of soil liquefaction on the design of buildings, stairs, dams, and retaining structures. A type of soil liquefaction occurs when the effective soil stress is reduced to zero, as a result of which the shear strength of the soil is completely lost. The following shows how the shear strength changes to create shear strength:

$$\sigma' = \sigma - u \quad (1)$$

$$\tau = \sigma' \tan\phi' + c' \quad (2)$$

$$\tau = \sigma' \tan\phi',\ c' = 0 \quad (3)$$

$$\tau = (\sigma - u)\tan\phi' \quad (4)$$

$$u = \sigma \rightarrow \tau = 0 \rightarrow Liquefaction \quad (5)$$

Such a situation can be due to a uniform load such as a single sudden change in overhead stress (such as a sudden increase in load on an earthen dam) or a periodic load such as repeated repetition of stress conditions for the sample. In both cases, due to the change in load, a large amount of pore water pressure is created in a loose saturated soil, and then the soil is lubricated like a fluid. This phenomenon is due to the large load applied to the soil, which creates a large amount of pore water pressure in the soil, a pressure that is transferred from solid soil grains to water in the soil pits due to undrained load, with increasing pressure The water of the effective stress cavities is reduced and as a result the resistance of the soil is reduced and the soil is liquefied. This phenomenon is especially saturated and relatively dense in relatively fine non-cohesive soils (such as medium to fine sand and coarse silt) where the soil has relatively low permeability and diffusion of pore water due to shock or sudden vibrations caused by earthquakes or other Factors (such as severe explosions) are not possible in them, they are of great importance (Yoshimiand Tokimatsu, 1997).

Therefore, in non-cohesive soils, the total shear strength is a function of the effective stress of the particles, and if the pore water pressure increases sharply, it may equal this value with the total stress and reduce the effective stress to zero, in which case the soil shear strength tends to zero. And soil, like liquids, becomes fluid and destroys the structures built on it. Basically, the occurrence of this phenomenon in heavy structures built on liquefied soils, due to the need for high shear strength of the soil, is more important and in light structures such as irrigation canals is less important. However, if there are heavy structures in the irrigation network (such as bridges, siphons, high embankments, etc.) if constructed on liquefied soils; significant damage may be caused to the structure in the event of an earthquake or severe vibration movements.

Liquidation also affects the way ground surface movements and displacements occur. The effects of liquefaction can be better understood by studying the evidence related to the historical events of this phenomenon. Liquefaction often occurs when: non-stick soil, loose soil and saturation and the occurrence of earthquake shock that has a large size and duration and vibrations resulting from the earthquake, followed by non-drained conditions. Fig. 1 shows the effects of liquefaction and the hazards created by liquefaction. Factors affecting liquefaction are divided as follows, which are described below (Kramer, 1996):

Soil factors: concluded cyclic shear stresses, damping properties, granulation characteristics and grains, initial relative density, soil texture (method and type of soil grain formation).

Environmental factors: concluded earthquake history of the region, geological history (age, semantification), soil lateral pressure coefficient (K_o), primary effective overhead

Earthquake factors: concluded the magnitude of the earthquake, earthquake duration.

2.2. Criteria for Evaluating Liquefaction Potential

After the 1964 earthquake in Niigata, Japan, and the devastation caused, many geotechnical engineers made extensive efforts to establish an accurate criterion for evaluating the liquefaction potential, and as a result, this effort provided the main factor (Seed and Idriss, 1983).

- Soil type,
- Standard Penetration Test (N_{SPT}),
- Maximum ground acceleration.

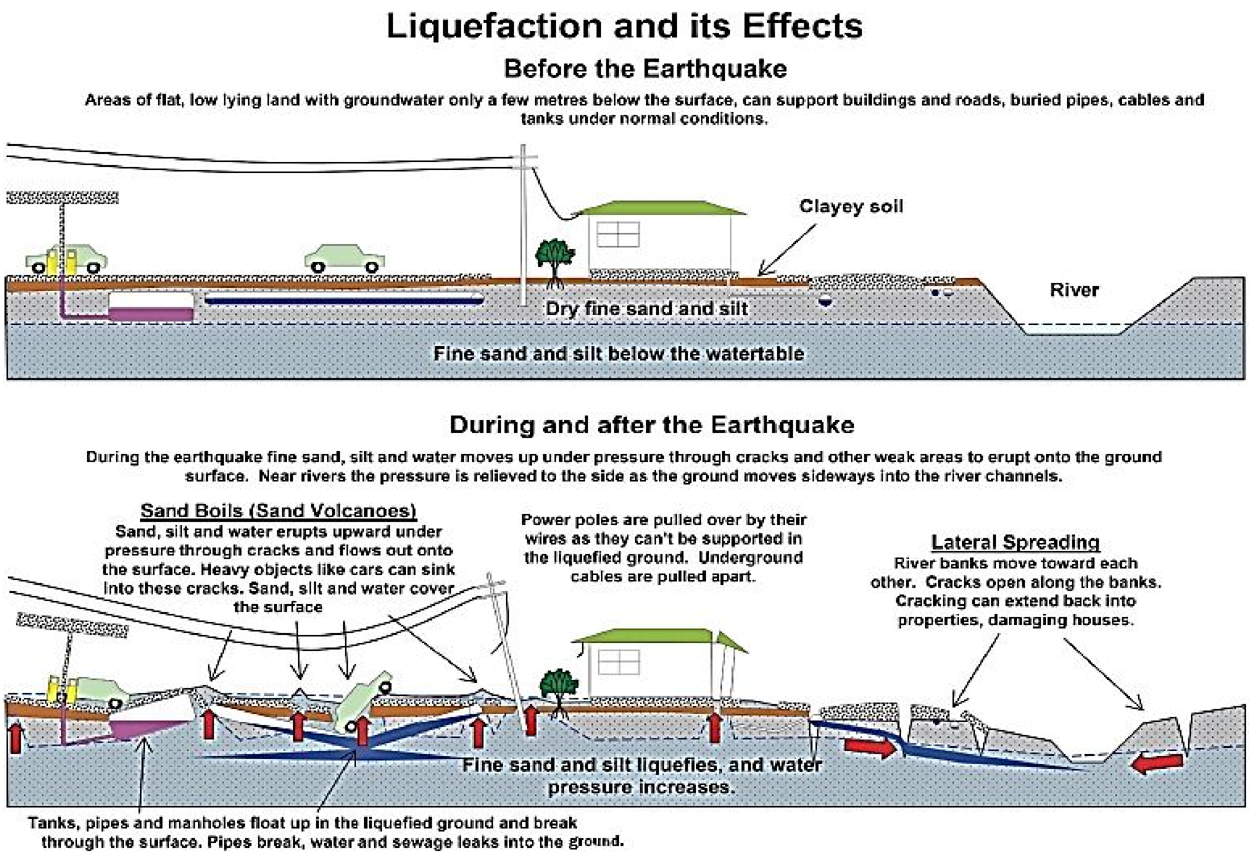

Figure 1. Hazards of liquefaction (Kramer, 1996)

In liquefaction assessment, the potential for occurrence and related effects are usually considered, which include the following factors: geological criteria and site condition, soil type and its natural porosity, percentage of soil fines, history of stress, how saturation, Load head stress, loading condition, limiting pressure, number of cycles due to dynamic load, relative density, earthquake magnitude (Kramer, 1996). Soil properties are very important in assessing the occurrence of liquefaction, and the first and most common studies in this regard were conducted in the 1970s by Dam et al. at the University of California, based on earthquake magnitude and characteristics in place of soil strength and hardness. The method proposed by Seed et al. (2003) is based on the largest earthquake acceleration (E_{max}) and (N_{SPT}) related to the SPT corrected for overhead and energy of E_{60} and the magnitude of the earthquake (M) as well as the percentage of fine particles (rejected). From sieve number 200, less than 0.07) are also effective. The simplified Seed and Idriss (1971) method evaluates their liquefaction capability by relating the standard infiltration number to the cyclic shear strength of soils (Seed and Idriss, 1971). This method is commonly used to assess liquefaction risk due to the abundance of standard penetration test data and the ease with which this test can be performed. There are other methods that are based on the standard infiltration number of soils, but since the simplified method of Seed and Idris has been widely used, it has been used and evaluated by many researchers and many revisions have been made and improved. As an example, the following can be mentioned: (Chang et al., 2011; Chung and Rogers, 2011; Lee et al., 2004; Sonmez, 2003). Chang et al. (2011) have examined the ability of various liquefaction risk assessment methods based on the standard penetration number. The researcher and his colleagues assessed the risk of liquefaction with the earthquake in 1991 in the Chichi region of Taiwan and the occurrence of liquefaction in different parts of the region with geotechnical data related to the region and compared the results with existing events. The results of their study also confirm that the simplified method of Seed and Idriss (1971) is a faster and more reliable method compared to other existing methods based on the standard penetration number. Youd et al. (2001) used the latest corrections to the simplified method, made in 1998 by a committee of 20 experts in liquefaction studies. The result of this work of the group was published in 2001. In the updated method of Seed and Idris (1971), two separate methods have been considered to calculate the cyclic shear stress caused by earthquakes and the cyclic shear strength of soil. The magnitude of the earthquake, the amount of fines and the effective pressure of the slag are involved in estimating the cyclic shear strength of the soil.

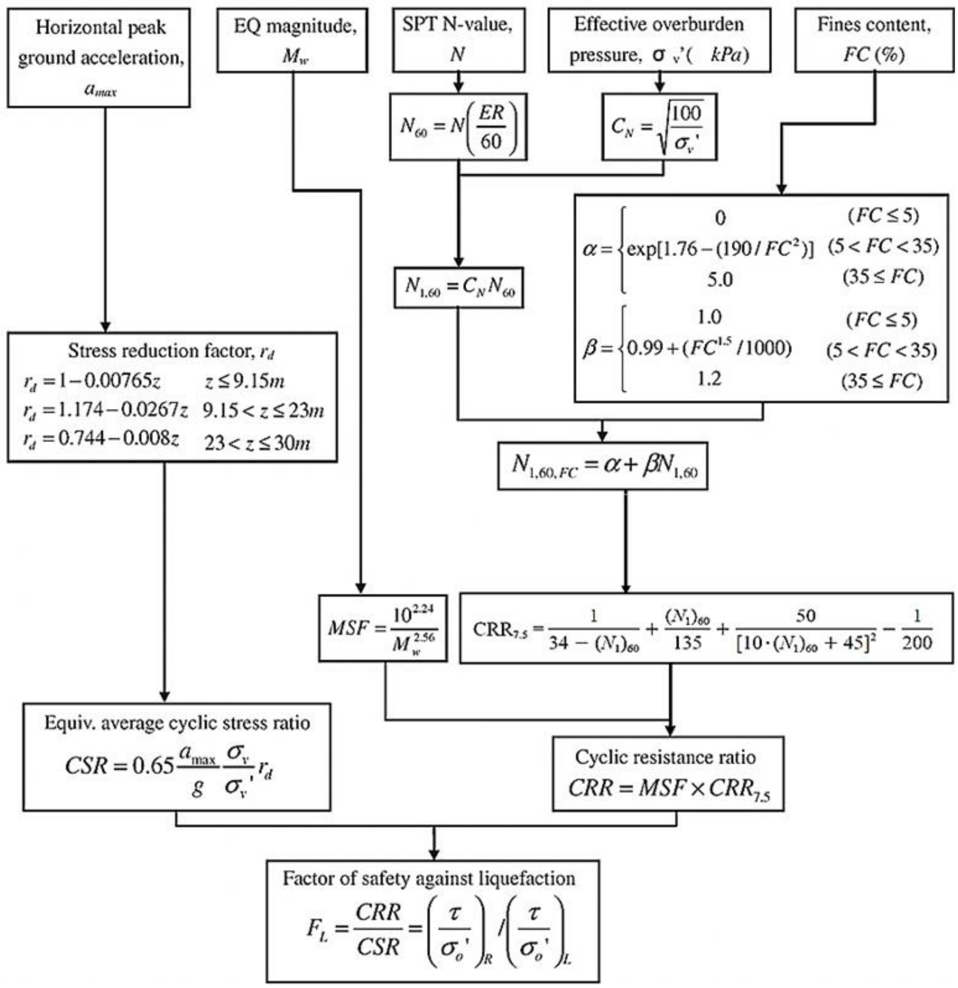

Figure 2. Algorithm for calculating the safety factor against liquefaction, modified by (Chang et al., 2011)

The stress reduction coefficient proposed by Seed and Idris has also been reviewed. The following figure shows the diagram of calculating the safety factor by the updated method of Seed and Idris. The calculations include saturated sand layers up to 20 meters below the surface, because according to previous field observations, liquefaction is usually found in shallow sand layers (less than 15 m) horizontally or with a low slope on alluvial sediments and or alluvial fans have been observed (Youd et al., 2001). The method was presented in Fig. 2.

In order to measure the ratio of soil cyclic resistance, corrections should be made to the standard infiltration number obtained from field harvesting so that these raw numbers can be standardized and can be used in calculations. Eq. 1 is the basis for making the necessary corrections to the raw numbers.

$$(N_1)_{60} = N_m C_N C_E C_B C_R C_S \tag{6}$$

When the standard penetration number is measured, the effective slag pressure correction factor is the hammer energy ratio correction factor, the borehole diameter correction factor, the drill rod length correction factor and the sampling factor for the sampling type. The recommended values for each of these factors are listed in Table 1 (Robertson and Wride, 1997). Liquefaction is often associated with the expansion of sand boiling. During an earthquake, followed by an increase in the pore pressure caused by the earthquake, the upward flow of the pore water causes upward forces in the soil particles. These forces weaken the upper part of the soil mass and can carry particles to the surface and cause so-called sand boiling (Kramer, 1996). Ishihara (1985) investigated soil conditions using fault reports related to liquefaction from two earthquakes with a magnitude of 7.5 Richter and calculated the thickness of the top layers necessary to prevent damage due to liquefaction on flat ground (Ishihara, 1985). According to Fig. 3, if the intersection of the thickness coordinates of the surface layer (non-liquefied) and the lubricating layer is located to the left of the maximum acceleration curves of the earth (hatched part), liquefaction effects can be observed on the earth surface.

Table 1. N_{SPT} corrections for granular materials (Robertson and Wride, 1979)

Correction factor	Equipment type	Symbol	Recommended value
Slag pressure	-	C_N	$[P_a/\sigma_v]^{0.5}$
	-		$C_N \leq 1.7$
Energy ratio	Donut Hammer	C_E	0.5 - 1.0
	Safety Hammer		0.7 - 1.2
	Automatic-Trip Donut Hammer		0.8 - 1.3
Borehole diameter (mm)	65 - 115	C_B	1.00
	115 - 150		1.05
	15 - 200		1.15
Drill rod length (m)	Less than 3	C_R	0.75
	3 - 4		0.80
	4 - 6		0.85
	6 - 10		0.95
	10 - 30		1.00

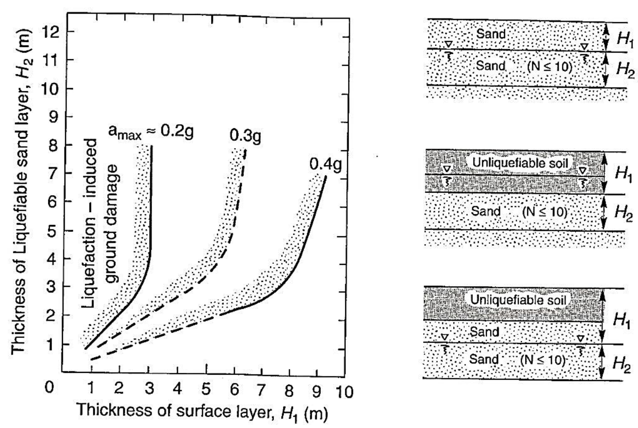

Figure 3. Relationship between the thickness of the liquefied layer and the thickness of the layer located on it in structures for which liquefaction has been observed on the ground (Kramer, 1996)

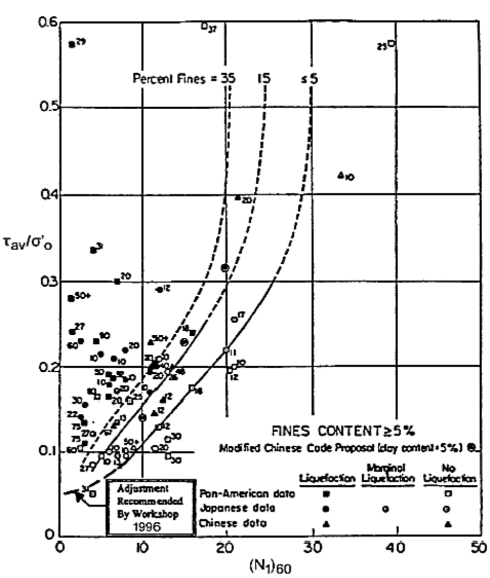

Figure 4. Diagram of liquefaction calculations based on N_{SPT} (Seed et al. 1983)

Figure 5. Shahid-Rajaei wharf plan

Using SPT induction, the relevant data are extracted from Fig. 4 (Seed et al., 1983). For more accuracy and control of liquefaction evidence, field surveys are performed after each seismic event.

2.3. Study Area

Shahid-Rajaei port is located 23 km west of Bandar Abbas, the capital of Hormozgan province, and with an area of more than 4800 hectares (operational area and coastal area), has an annual capacity of accepting more than 88 million tons of goods. Shahid-Rajaei Port Complex has started its official activity in the west of Hormozgan since 1985 and today it has become a strategic and development-oriented port in the country. In 2012, this port exchanged goods with 80 ports in the world. The establishment of the Shahid-Rajaei Port Special Economic Zone was approved by the Cabinet on 1997. The port has 18 gantry cranes, and about 40 berths, and with the largest and most advanced container terminals in the country, has the ability to dock a variety of ocean-going ships. Therefore, in order to expand this port, the study of liquefaction studies is of great importance. Fig. 5 shows the current state of the port and how it is expanded.

3. Results and Discussions

3.1. Geotechnical Survey

Due to the importance of this port, as one of the important ports of Iran, various boreholes have been drilled to identify the geological and geotechnical status of the region, which is shown in Fig. 6 of the different boreholes positions, drilled in different parts of Shahid-Rajaei port. Fig. 7 shows the frequency of drilled boreholes based on depth. According to this information, the number of drilled boreholes is equal to 304 boreholes and the maximum borehole depth is 79 m, the average depth of boreholes in this area is equal to 30 m and the minimum depth is equal to 5 m. Fig. 8 shows the histogram of the N_{SPT} values in the drilled boreholes. The results show that the highest N_{SPT} in the region is 89 and the lowest is 1 and the average is 35.

Fig. 9 shows the different soils of the region according to the Unified classification. Most of the available soils according to Unified classification (UCSC) are SM category, then CL, ML and CL-ML, respectively. Fig. 10 shows the histogram and the rate of change and statistical analysis of the percentage passing through the #200 Sieve, with an average percentage passing through the #200 Sieve equal to 53%.

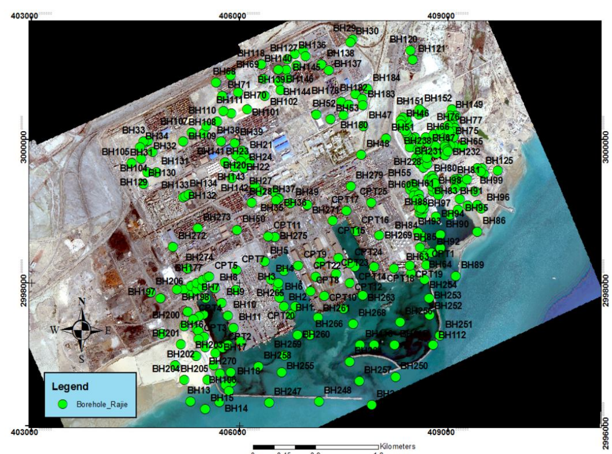

Figure 6. Different boreholes positions in Shahid-Rajaei port

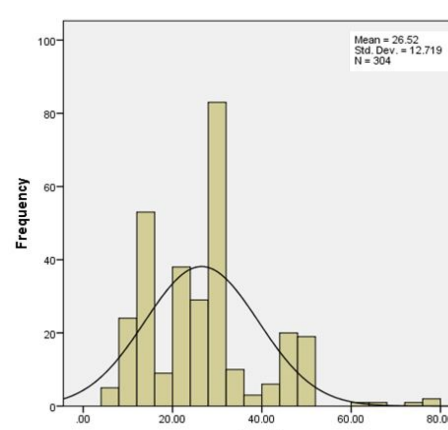

Figure 7. The frequency of drilled boreholes based on depth

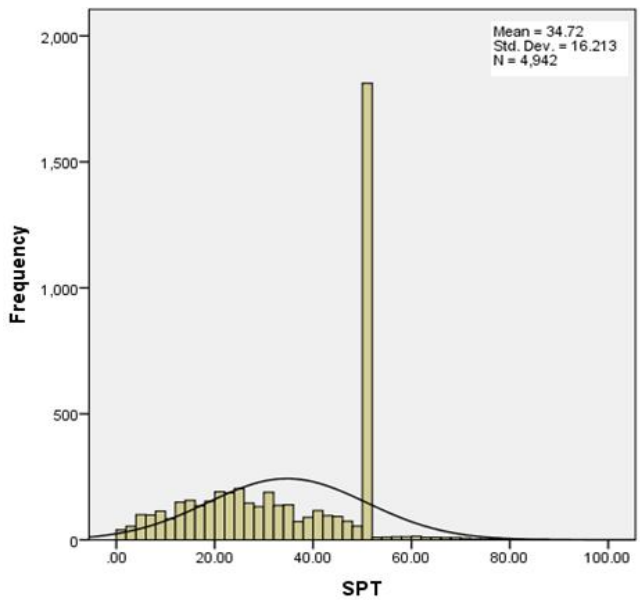

Figure 8. N_{SPT} histogram in the boreholes of the study area

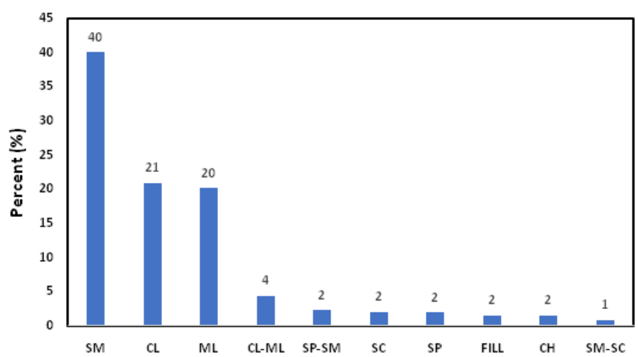

Figure 9. USCS based percentage of different soils

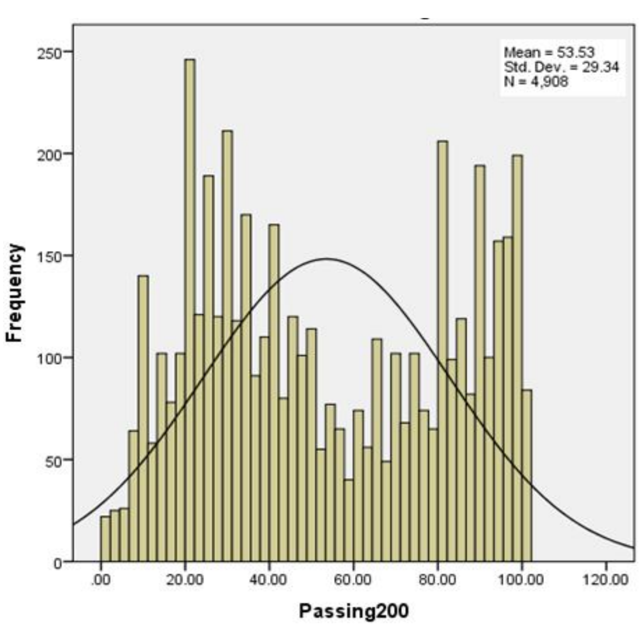

Figure 10. Histogram of the percentage passing through the 200 sieve in the soils of the region

3.2. Liquidation zoning

According to the analysis and statistical results of boreholes drilled in this area, liquefaction analysis has been done at any depth and the method of analysis has been considered as 5 m, which in every 5 m zoning maps related to the parameters F.S has been calculated for liquefaction at these depths, and then according to the method of liquefaction at each depth, the amount of subsidence was determined, which according to this amount of subsidence, zoning maps have been calculated. Figs. 11 and 12 show the geological and geotechnical sections of Shahid-Rajaei port area according to the drilled boreholes. In geological sections, the highest percentage of soil in the area is SM type, which most materials can be sand, and in some parts, clay lenses and clay layers can be seen. Figs. 13 to 14 show the rate of change of liquefaction coefficient at different depths from 5 to 40 m, so that it can be said that at a depth of 5 m in the southern regions has the lowest liquefaction coefficient and the highest liquefaction coefficient. It can be seen in a large area of the pier. At a depth of 5 to 10 m, the largest area is related to areas without liquefaction, followed by areas that are related to probability and fully liquefied, and the highest amount of liquefaction in the northeast to southwest. At depths of 10 to 15 m, most of the area is related to non-liquefied areas, followed by areas with liquefaction and liquefaction. The liquefied zone ranges from northeast to southwest. According to the results obtained at depths of 15 to 20, it shows that the highest area is related to non-liquefied area and the lowest area is related to liquefied and susceptible areas, which is mostly in the northeast to southwest of the area. According to the obtained results, the liquefaction coefficient varies at a depth of 20 to 25 m and the highest area is related to areas without liquefaction and areas prone to liquefaction and probable areas with liquefaction in the east, center and southwest of the region.

Figs. 15 to 28 show the amount of changes and zoning of the settlement due to liquefaction at different depths from 5 to 40 m in Shahid-Beheshti wharf. According to the results, the amount of subsidence has expanded to some depths. As the obtained results, it shows that the maximum amount of subsidence due to liquefaction up to a depth of 5 m is equal to 23 cm, and the maximum area of subsidence due to liquefaction will be related to subsidence below 7 cm. The highest amount of subsidence is seen in the south of the region. The highest amount of subsidence due to liquefaction up to a depth of 10 m will be equal to 43 cm and the lowest below 14 cm, which is the most subsidence in the south of the region. The highest amount of subsidence due to liquefaction up to a depth of 15 m is equal to 53 cm and the minimum amount is less than 14 cm, and this maximum amount of subsidence is seen in the southwest to northeast of the region. Also, the maximum amount of subsidence due to liquefaction up to a depth of 20 m is equal to 72 cm and the minimum amount is less than 23 cm, and this maximum amount of subsidence is seen in the southwest to northeast of the region.

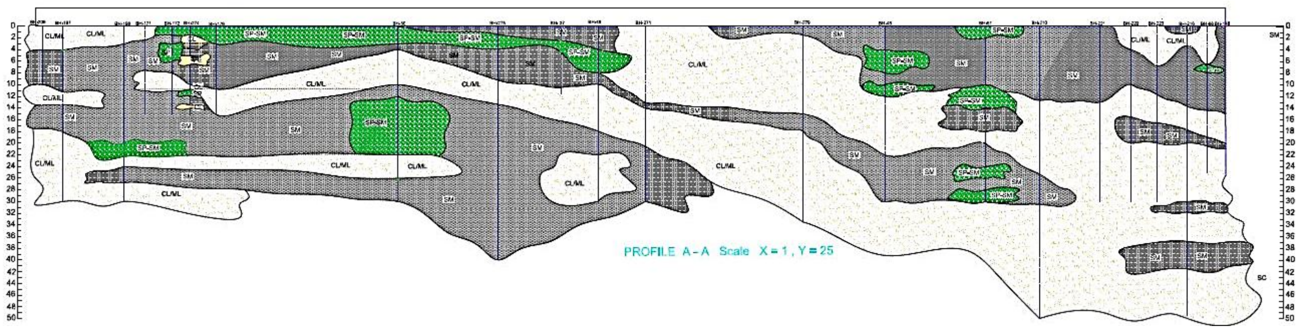

Figure 11. Geotechnical section of Shahid-Rajaei wharf in the east and west directions

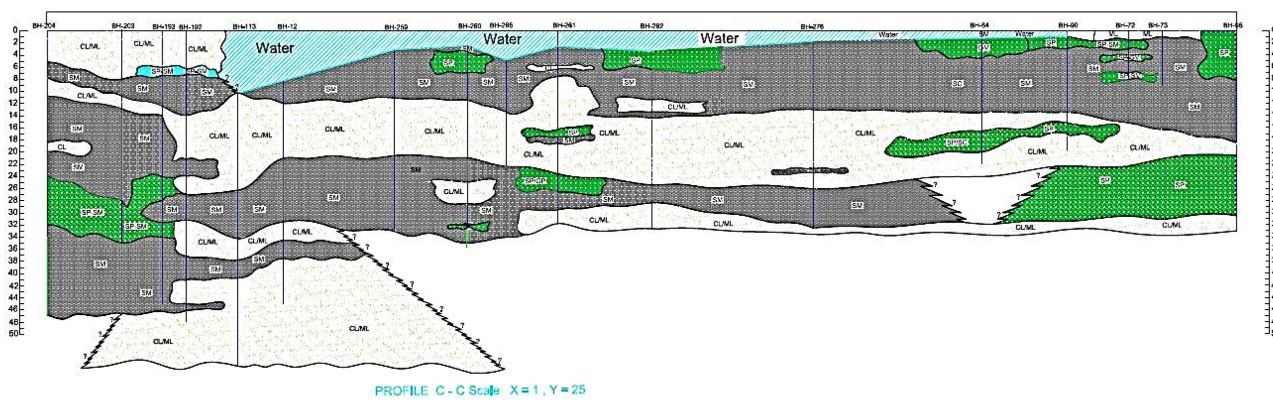

Figure 12. Geotechnical section of Shahid-Rajaei wharf in the north and south directions in the sea area

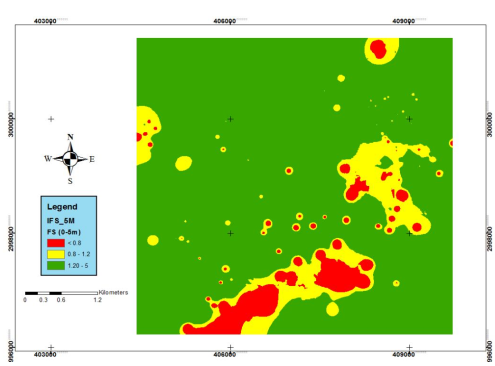

Figure 13. Zoning and changes of F.S liquefaction in the study area at a depth of 5 m

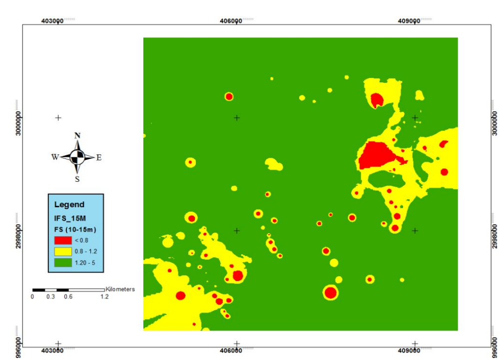

Figure 15. Zoning and changes of F.S liquefaction in the study area at a depth of 15 m

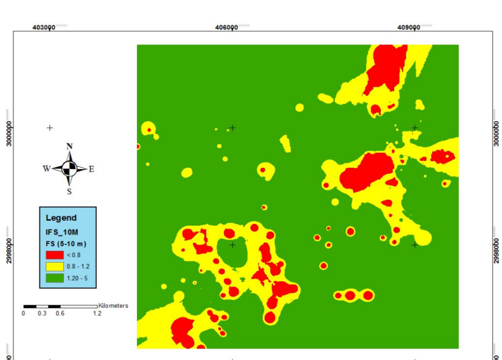

Figure 14. Zoning and changes of F.S liquefaction in the study area at a depth of 10 m

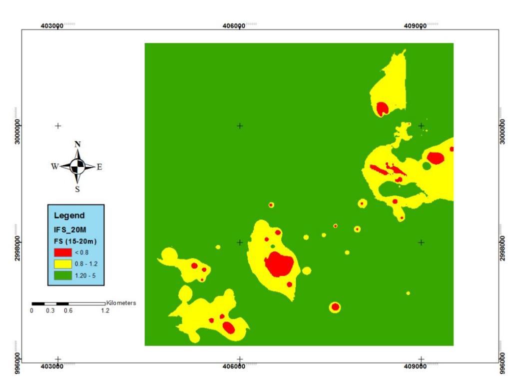

Figure 16. Zoning and changes of F.S liquefaction in the study area at a depth of 20 m

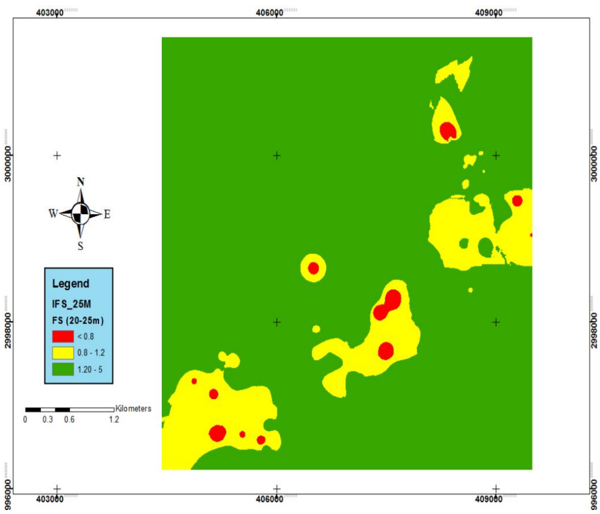

Figure 17. Zoning and changes of F.S liquefaction in the study area at a depth of 25 m

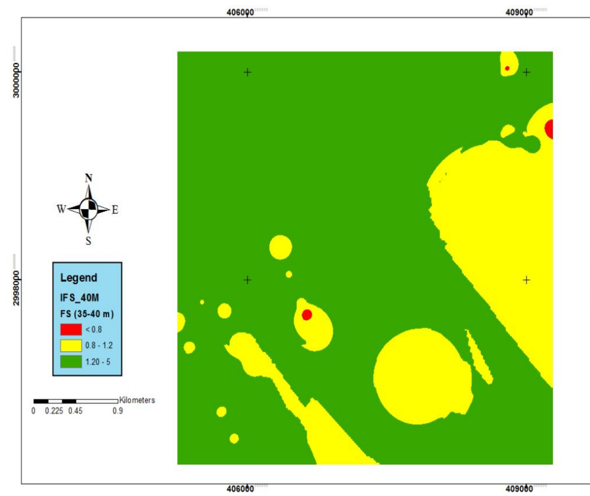

Figure 20. Zoning and changes of F.S liquefaction in the study area at a depth of 40 m

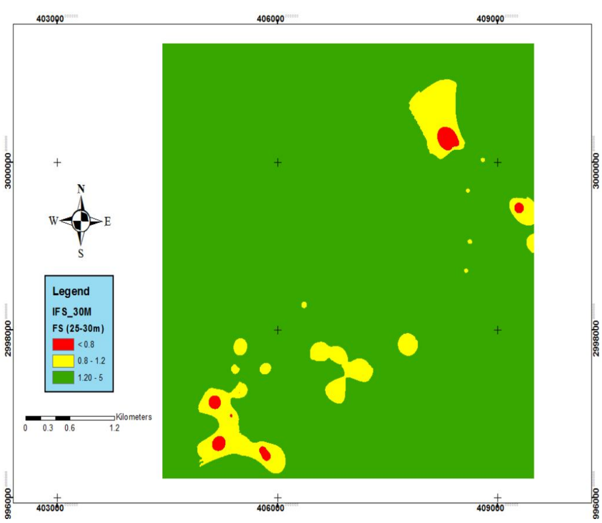

Figure 18. Zoning and changes of F.S liquefaction in the study area at a depth of 30 m

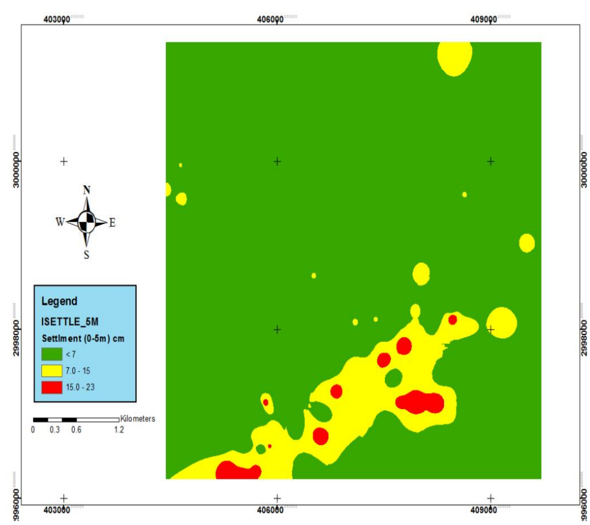

Figure 21. Zoning rate and changes due to liquefaction in the study area to a depth of 5 m

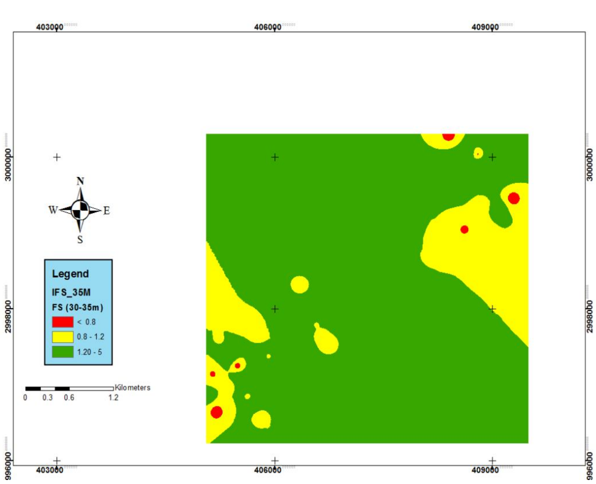

Figure 19. Zoning and changes of F.S liquefaction in the study area at a depth of 35 m

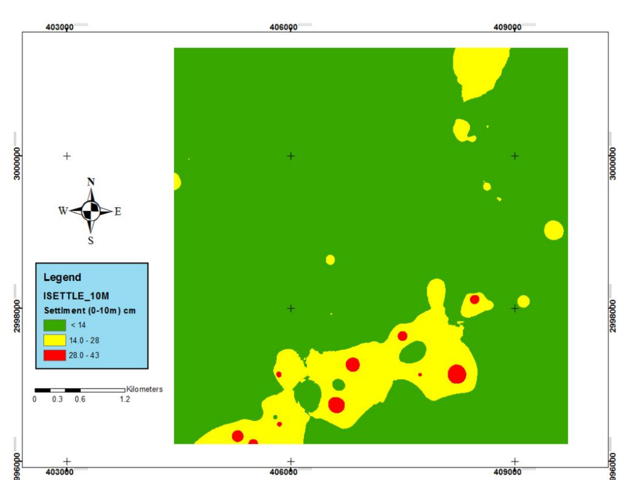

Figure 22. Zoning rate and changes due to liquefaction in the study area to a depth of 10 m

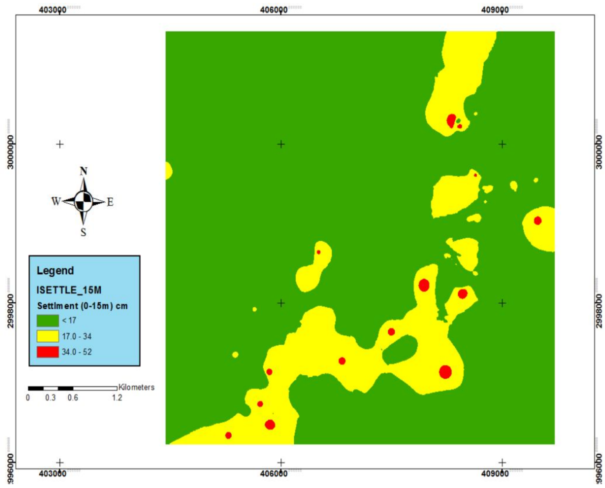

Figure 23. Zoning rate and changes due to liquefaction in the study area to a depth of 15 m

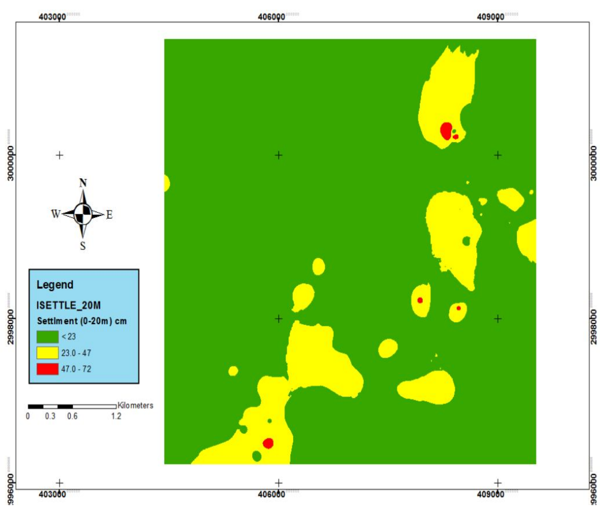

Figure 24. Zoning rate and changes due to liquefaction in the study area to a depth of 20 m

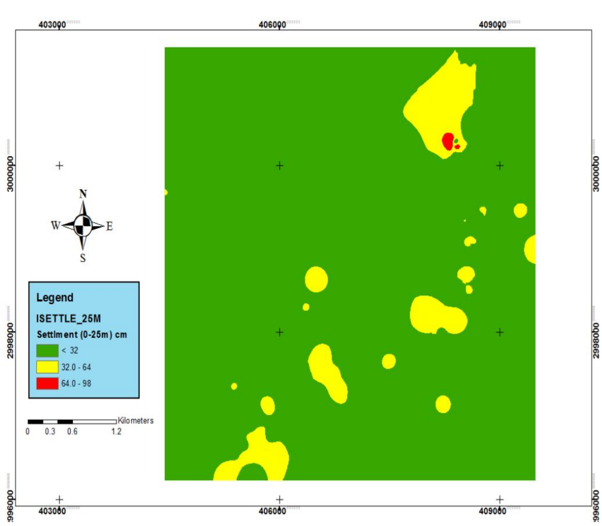

Figure 25. Zoning rate and changes due to liquefaction in the study area to a depth of 25 m

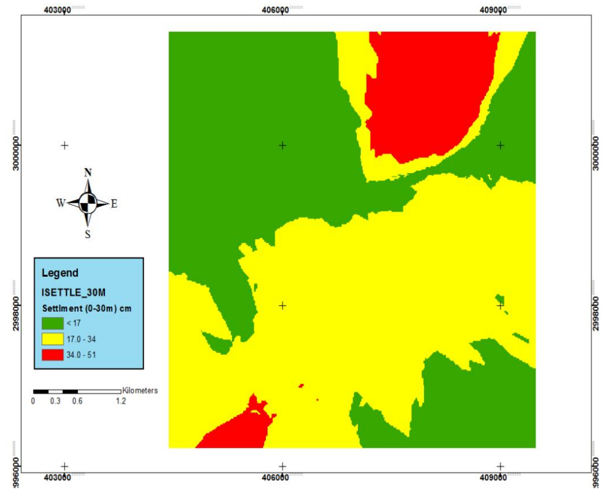

Figure 26. Zoning rate and changes due to liquefaction in the study area to a depth of 30 m

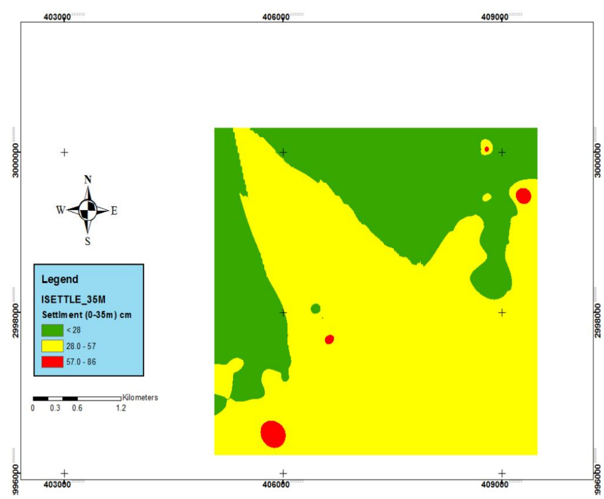

Figure 27. Discontinuity network properties (Hudson and Harrison, 1997)

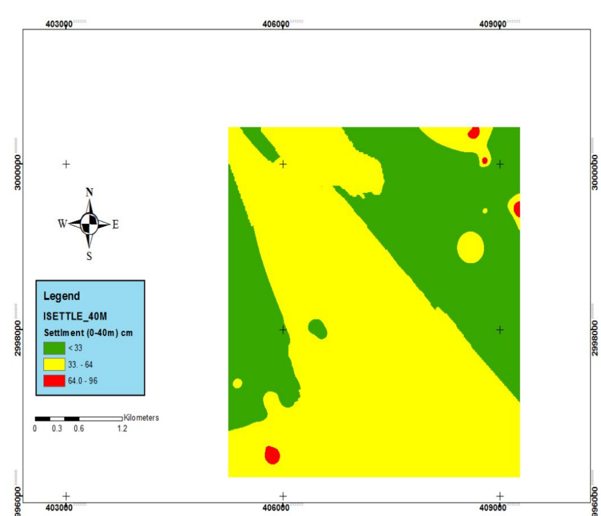

Figure 28. Discontinuity network properties (Hudson and Harrison, 1997)

Based on the results, it shows that the highest amount of subsidence due to liquefaction up to a depth of 25 m is equal to 98 cm and the minimum amount is less than 32 cm, and this is the highest amount of subsidence in the northeast of the region. The highest amount of subsidence due to liquefaction up to a depth of 30 m is equal to 51 cm and the lowest amount is less than 17 cm, and this maximum amount of subsidence is seen in the southwest and northeast of the region. The highest amount of subsidence due to liquefaction up to a depth of 35 m is equal to 86 cm and the lowest amount is less than 28 cm, and this maximum amount of subsidence is seen in the southwest of the region. Also, the highest amount of subsidence due to liquefaction up to a depth of 40 m is equal to 96 cm and the minimum amount is less than 33 cm, and this maximum amount of subsidence is seen in the southwest and northeast of the region.

4. Conclusion

It is impossible to avoid the dangers of earthquakes in seismically active areas. However, the application of some measures, which are the result of the experiences of past earthquakes, will reduce the damage. Since the hazards caused by earthquakes affect various facilities, structures and structures, to deal with seismic hazards in relation to various structures and facilities, design the characteristics of the structure against the destructive effects of dynamic forces on the structure. It has been common in the relatively distant past that, of course, various building codes and regulations, in an evolving process, directly or indirectly assess these dynamic effects. Ensuring the safety of the site against the occurrence of seismic geotechnical phenomena and determining the risk and percentage of probability of these phenomena in the construction site is related to the history of studies and research dating back to the previous section. It is not and its useful and effective life is limited to less than three decades. Despite the vast and significant efforts of research, academic and scientific centers around the world in recent years in this field to reach regulations and written recommendations and coordination of regulations in this area, it seems that there is still a relatively long way to go.

The safety of the site during an earthquake is highly affected by the occurrence of seismic geotechnical phenomena and rupture and movements of faults. These geotechnical hazards have been considered in various ways in different countries and have been used in design and construction regulations. Efforts have been made to create a uniform, consistent and scientific process for the use of regulations, which in any case is a continuation and evolution. To study these phenomena for cities and important sectors such as ports, geotechnical hazard maps, especially liquefaction and the resulting meeting, which is the result of assessing the potential for the occurrence of these phenomena, is recommended.

Existence of areas with high seismicity and the issue of land type in some ports of our country, including Shahid-Rajaei pier and the possibility of severe damage due to severe landslides and destructive geotechnical phenomena in prone areas, the need for research and studies Demands scope. Therefore, the need to identify areas prone to geotechnical destructive phenomena and its zoning in standard scales for the wharf becomes apparent. In the present study, an attempt has been made to study this issue of liquefaction in susceptible areas of different parts of the wharf.

A) According to the boreholes drilled in this area, the highest percentage of soil in the area was SW and CL and Cl-ML soils are in the next categories.

B) The extent of SW soil can be seen at different depths according to the drawing sections.

C) Due to the presence of sand layers with good to bad granulation, it is prone to liquefaction, which is one of the main reasons for liquefaction in this pier due to the high groundwater level and sea level and soil saturation.

D) Based on the obtained results, it shows that with increasing depth, the area of liquefaction prone areas decreases and increases with the possibility of liquefaction and no liquefaction due to changes in soil structure and soil compaction at lower depths, as well as Increase in the percentage of fine-grained and fine-grained layers at depths.

E) By increasing the amount of liquefaction-prone parts, it will increase the subsidence in the soil due to liquefaction.

F) The highest amount of liquefaction will be in coastal areas, especially in the wharves

G) The maximum amount of sedimentation due to liquefaction is equal to 98 m at a depth of 25 m and 106 meters at a depth of 45 m.

H) By changing the soil density, it will change the liquefaction coefficient and the settling rate.

I) During soil liquefaction, it reduces and lacks shear resistance in the soil, which causes liquefaction.

J) According to the zoning, it shows that changes in soil type can be effective in the rate of sedimentation and liquefaction coefficient.

K) Due to the identification of liquefied and susceptible areas at different depths, to expand the Shahid-Rajaei wharf and also to improve the wharf conditions in the area, it is better to improve the necessary methods such as injection, construction of dense sand columns and other methods to improve. The magnitude of the earthquake considered according to the 2800 Earthquake Regulations for this region was equal to 7.5 Richter.

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