# Effects of homogeneous hydrocarbonic contamination on the bearing capacity of in-situ concrete piles buried in silty sand

Arashk Sabzipour Hafshejani* and
Alborz Hajiannia

Department of Civil Engineering-Geotechnic,
Najafabad Branch,
Islamic Azad University,
Najafabad, Iran
Email: arashk.sabzipour@yahoo.com
Email: alborzhn@yahoo.com
*Corresponding author

Saeid Eslamian

Department of Water Engineering,
Isfahan University of Technology,
Isfahan, Iran
Email: saeid@cc.iut.ac.ir

**Abstract:** So far, many researches have been done on the effects of hydrocarbon (especially oil) contamination on such soil strength and geotechnical indices as cohesion, angle of internal friction, shear strength, permeability, dry density, and so on. In the present research, effort has been made to model buried concrete piles with known dimensions, and study the effects of the length and diameter ratios ($L/L_0$ and $D/D_0$) on their load bearing capacity using the results of previous researches, the values of the geotechnical and strength parameters of oil-contaminated silty sand (SM) specimens, and the PLAXIS 2D Software. Results have shown that with an increase in the percent hydrocarbon contamination, the ultimate load bearing capacity of a pile follows a gradual decreasing trend. Again, an increase in the pile length ratio causes an increase in the load bearing capacity, but one in the diameter ratio causes a decrease in the bearing capacity.

**Keywords:** hydrocarbon contamination; soil strength and geotechnical indices; length and diameter ratios; load bearing capacity; silty sand; PLAXIS 2D.

**Reference** to this paper should be made as follows: Hafshejani, A.S., Hajiannia, A. and Eslamian, S. (2017) 'Effects of homogeneous hydrocarbonic contamination on the bearing capacity of in-situ concrete piles buried in silty sand', *Int. J. Hydrology Science and Technology*, Vol. 7, No. 2, pp.124–133.

**Biographical notes:** Arashk Sabzipour Hafshejani received his MSc in Geotechnical Engineering (2015) from Islamic Azad University of Najafabad branch and BSc in Civil Engineering (2013) from Islamic Azad University of Khomeinishahr branch. He is an expert in the effect of oil contamination on bearing capacity of piles and soils, especially in oil contamination transport in soil medias. He published eight papers in national conferences held in Islamic Republic of Iran and one article in international journals.

Alborz Hajiannia received his PhD in Civil Engineering and Geotechnical Engineering from the Amir Kabir University of Tehran, Iran. He is currently a Assistant Professor of Geotechnical Engineering in Islamic Azad University of Najafabad Branch, Iran. He has published many papers in scientific journals and conferences mainly in geotechnic and civil engineering.

Saeid Eslamian received his PhD in Civil and Environmental Engineering from the University of New South Wales, Australia. He was a Visiting Professor in Princeton University, USA, and ETH Zurich, Switzerland. He is currently a Professor of Hydrology and Water Resources in Isfahan University of Technology, Iran. He is the Chief Editor of both *International Journal of Hydrology Sciences and Technology* (*IJHST*) and *Journal of Flood Engineering* (*JFE*). He has recently finished editing three-volume, *Handbook of Engineering Hydrology* and edited *Urban Water Reuse Handbook* by Francis and Taylor (CRC Group). He has published about 500 papers in scientific journals and conferences mainly in surface and groundwater, statistical and environmental hydrology and hydrometeorology.

## 1 Introduction

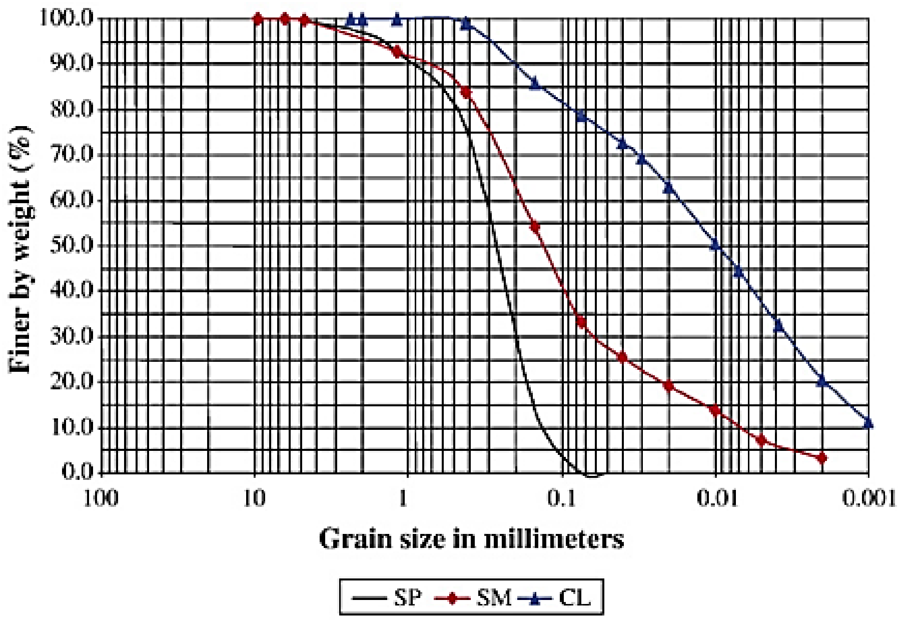
In recent years, the human activities have considerably altered his surrounding nature; not only the air and water, but also the soil and its surrounding environment have undergone and faced irrecoverable changes and contaminations due to human activities. Meanwhile, hydrocarbon compounds have had eye-taking share in soil contamination. This contamination (especially that with the crude oil) occurs through various sources among which leakage from oil transfer pipes, natural oil leakage, oil discharge from sea/land establishments, dust from oil-associated gas burning, and oil transportation or storage are very important and play vital role in spreading and dispersion of hydrocarbon contaminators in the soil medium and its surrounding aquifers. Hydrocarbon compounds (specifically crude oil) considerably affect not only the physical and apparent, but also the chemical properties of soils; in civil engineering, changes in the strength and geotechnical parameters of soil are quite serious. In granular soils, the changes are in the physical properties while in cohesive ones, the texture and structure are affected (Mohammadi Akbarabadi et al., 2010). Changes in physical properties (apparent cohesion, angle of internal friction, percent optimum moisture content, maximum dry density, and atterberg limits) affect slope stability, foundation load bearing capacity, and the like. A change in any of the mentioned parameters, can lead to a change in the maximum load tolerated by the soil or its surrounding foundations. Oil leakages in Kuwait (during the Persian Gulf War), in Valdez, Alaska (due to tankers' crashes), and from oil transfer pipes in Saudi Arabia are among the very serious oil contaminations in the respective area soil.

Researches on the effects of oil contamination on the strength and geotechnical parameters of soil are numerous. Evgin and Das (1992), concluded, through their triaxial tests on contaminated and uncontaminated quartz samples that the angle of internal friction in fully oil saturated samples (both compacted and non-compacted) was considerably reduced. Alsanad et al. (1995) have done their studies on Kuwaiti sandstone samples aiming at determining the effects of oil contamination on their strength properties, permeability, and compactibility. Khamehchiyan et al. (2007) have performed their laboratory studies on the SM, SP, and CL soil samples aiming at determining the effects of crude oil contamination on their geotechnical properties. Pandey and Bind (2014), concluded, through their tests on alluvial soil soaked with motor oil, that the reason for the changes in geotechnical properties of oil contaminated soils is the entrapment of hydrocarbon materials in the pores and voids of the contaminated medium. In addition to the above mentioned studies, those of Aiban's (1998), Sheen et al.'s (1999), Kermani and Ebadi's (2012), Rahman et al.'s (2010), etc., are noteworthy.

In this research, it has been tried to study and find the load bearing capacity of buried piles with different oil contaminations and different length and diameter ratios considering the values of the geotechnical and strength parameters of specimens contaminated with hydrocarbon materials. Among the important applications of the results of this research, is their use in the design of coastal oil platforms that are facing hydrocarbon contamination problems.

In this research, we will first introduce the tested soil sample and its strength and geotechnical parameters under different percent contaminations. Next, the base model, modelling process, and related software have been introduced and then the ultimate values of the bearing capacities and effects of piles length and diameter ratios on the bearing capacity have been evaluated through the modelling results.

**Figure 1** Gradation of the soil sample (see online version for colours)




*Source:* Khamehchian et al. (2007)

## 2 Specifications of the studied soil samples

In the present research, soil samples consist of silty sand (SM) adapted from the work of Khamehchiyan et al. (2007), with a gradation curve as in Figure 1. The samples were tested and evaluated under oil contaminations of 0, 4, 8, 12, and 16% (by volume) and a constant solid particle density of 2.57. The after-test strength and geotechnical properties of the samples are shown in Table 1.

**Table 1** Geotechnical specifications of SM soil samples contaminated with oil

| *Oil content (%)* | *C* ($KN/m^2$) | φ *(deg)* | ψ *(deg)* | *K (m/s)* | γ ($KN/m^3$) | $\gamma_{sat}$ ($KN/m^3$) | *E* ($KN/m^2$) | *n* |
|---|---|---|---|---|---|---|---|---|
| 0 | 27.2 | 33 | 3.517 | 1E-5 | 21.56 | 21.60 | 4,982.1 | 0.26 |
| 4 | 19.5 | 32.9 | 3.398 | 4.36E-6 | 20.46 | 21.42 | 4,464.3 | 0.27 |
| 8 | 22.7 | 32 | 2.332 | 3.16E-6 | 19.98 | 21.24 | 4,815.3 | 0.28 |
| 12 | 21 | 26.2 | 0 | 5.21E-7 | 19.42 | 21.24 | 3,981.1 | 0.28 |
| 16 | 33.6 | 26 | 0 | 6.95E-8 | 18.60 | 21.12 | 2,112.8 | 0.29 |

*Source:* Khamehchian et al. (2007)

It is to be noted, of course, that values related to the samples' angles of lateral dilation have been found using the equation proposed by Schanz and Vermeer (1996) [equation (1)].

$$\sin \psi_{(\text{deg})} = \frac{\sin \varphi_{(\text{deg})} - 0.5}{1 - 0.5 \sin \varphi_{(\text{deg})}} \tag{1}$$

As shown in Table 1, with an increase in the percent oil contamination, the angle of internal friction, permeability, and dry specific weight of the samples have experienced decreasing trends. It seems that this is due to the effect of oil characteristics and chemical properties on the soil and also due to increasing lubrication properties in the constituent particles of the soil.

## 3 Software and modelling process

### *3.1 PLAXIS software*

PLAXIS is a numerical analysis software program that analyses and models geotechnical problems through finite element method and is used to determine the stability and deformations in geotechnical structures. One can model elastoplastic deformations, static analyses, consolidation analyses, and ground water problems through the 2D finite element and advanced soil modelling programs integrated in its 2D software package. The program is also capable of modelling soil, individual structural elements, soil-structure interaction, and such geotechnical structures as foundations and so on. In this research, use has been of the PLAXIS 2D program that is used in 2D finite element analyses. A very important parameter that is easily calculated from the program outputs is the maximum tolerable load or the ultimate bearing capacity of the modelled structure (Fathollahzadeh, 2014).

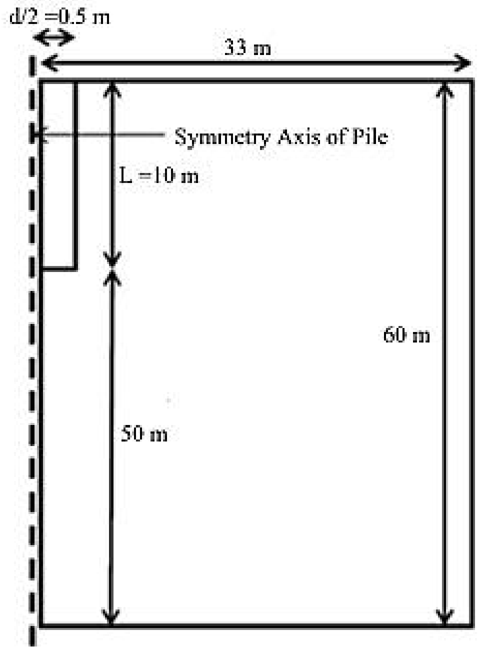
### *3.2 Modelling process and limits*

For the modelling of the base pile, use has been made, in this research, of an in-situ concrete pile with the apparent specifications shown in Table 2, and since the pile is axisymmetric, half of its diameter (D/2) has been modelled. According to Figure 2, the pile's extreme boundaries have been assumed so far away as to make the loading stresses and deformations negligible (Shooshpasha and Sharafkhah, 2013).

**Table 2** Apparent specifications of the pile being studied

| *Pile specifications* | *Description and values* |
|---|---|
| Geometry | Spherical |
| Type | In-situ concrete |
| Length (cm) | 1,000 |
| Diameter (cm) | 100 |
| Length/diameter ratio | 10 |

**Figure 2** Modelling limits and dimensions




It is worth mentioning that since the soil studied in this research is of SM genus, its Poisson coefficient has been assumed equal to 0.333, and to take into account the effects of slippage on the pile surface or its top, the boundary regions around it have been defined by the program's Interface choice. In this research, the piles have been assumed as linear elastic with no pores, and the meshing is very fine. Since the friction angle of the soil-pile interface boundary region has been proposed (by different researchers) equal to 0.7 to 1 time that of the soil angle of friction for insitu concrete piles, the reduction coefficient has been taken equal to 0.8 in the $R_{int}$ Software, and the soil behaviour has been modelled using Mohr-Coulomb's full elasto-plastic model. The pile specifications can be defined using its Young modulus, Poisson ratio and specific weight; here, they have been assumed equal to 21 GPa, 0.15, and 25 kN/m$^3$ respectively It is worth mentioning that since the soil studied in this research is of SM genus, its Poisson coefficient has been assumed equal to 0.333, and to take into account the effects of slippage on the pile surface or its top, the boundary regions around it have been defined by the program's Interface choice. In this research, the piles have been assumed as linear elastic with no pores, and the meshing is very fine. Since the friction angle of the soil-pile interface boundary region has been proposed (by different researchers) equal to 0.7 to 1 time that of the soil angle of friction for insitu concrete piles, the reduction coefficient has been taken equal to 0.8 in the Rint Software, and the soil behaviour has been modelled using Mohr-Coulomb's full elasto-plastic model. The pile specifications can be defined using its Young modulus, Poisson ratio and specific weight; here, they have been assumed equal to 21 GPa, 0.15, and 25 kN/m$^3$ respectively (Shooshpasha and Sharafkhah, 2013).

Hence, using the above points and the information in Tables 1 and 2, the modelling of the pile with the given specifications was carried out separately for different oil contaminations of 0, 4, 8, 12, and 16%, and the results of the software analyses were thoroughly studied. It is worth mentioning that a parameter *f* [as in equation (2)] has been introduced to determine the effects of the pile length/diameter variations on the bearing capacity and show its reduction rate compared with the base pile dimensions.

$$f = \frac{q_u(cont)}{q_u(uncont)} \tag{2}$$

where $q_u$(cont) and $q_u$(uncont) are the ultimate bearing capacities of the piles in contaminated and uncontaminated soils respectively.

## 4 Results and outputs

An important result and output of the modelling and analytical processes in the PLAXIS 2D Software is the load-displacement curves for the model introduced to the software for the purpose of observing the behaviour of the elements, and even estimating the maximum load carried by the modelled element; hence, load-displacement curves for base piles buried in soils with 0, 4, 8, 12, and 16% oil contamination are shown respectively as $P_0$, $P_4$, etc., in Figure 3.

As shown, regarding the stress level, $P_0$ (no contamination curve) stands higher than other curves, but $P_{16}$ stands lower; in other words, an increase in contamination causes a decrease in the stress tolerated by the buried pile. This could be due to increasing of lubrication characteristic in the soil constituent particles with increasing of the oil contamination. In fact, an increase in contamination causes a decrease in the stress tolerated by pile.

In this research, use has been made of Terzaghi (1942) method to find the ultimate bearing capacity of the pile under investigation; in fact, the ultimate bearing capacity in this method is equal to the load corresponding to a settlement equal to 10% of the pile diameter. Table 3 shows the ultimate bearing capacity found according to Terzaghi (1942) method.

**Figure 3** Piles' load-displacement curves (see online version for colours)

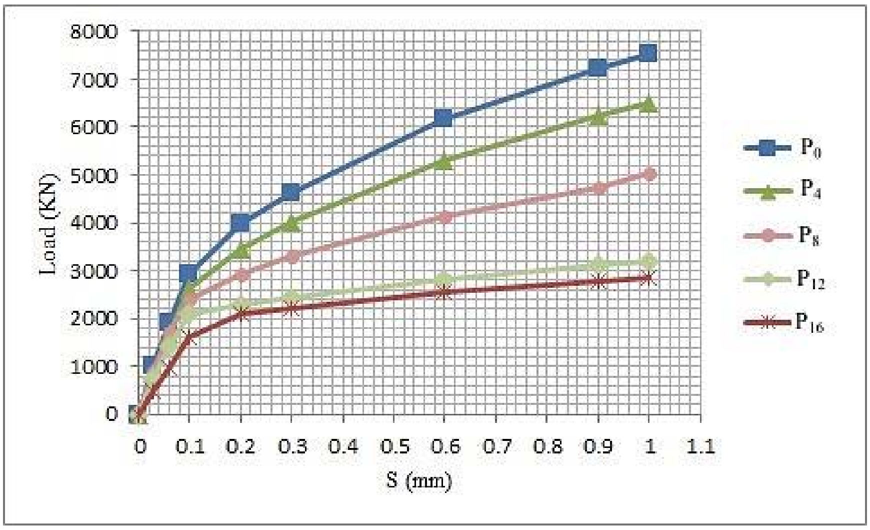



**Table 3** Ultimate bearing capacity of piles buried in contaminated soils

| *Oil content (%)* | *Ultimate bearing capacity of pile buried in silty sand (KN)* |
|---|---|
| 0 | 2,933.745 |
| 4 | 2,628.068 |
| 8 | 2,426.252 |
| 12 | 2,083.127 |
| 16 | 1,597.374 |

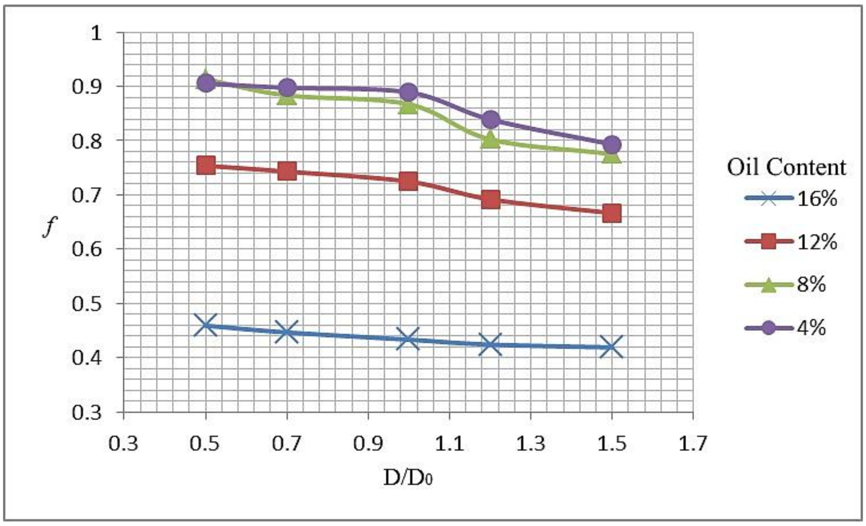
Actually, results in Table 3 show that with an increase in percent oil contamination, the maximum tolerable load or, in other words, the ultimate bearing capacity of the buried pile will experience a decreasing trend. These reductions in samples with 4, 8, 12, and 16% contamination compared with the 0 case, are 10, 17, 30, and 45% respectively.

### *4.1 Pile diameter effects on the bearing capacity*

Here, we will first keep the base pile length unchanged ($L_0$ = 10 m as in the previous case) and apply changes of 0.5, 0.7, 1, and 1.20 m in the pile diameter. The curves related to the bearing capacity reductions (*f*) are shown in Figure 4.

As shown, with an increase in the diameter ratio ($D/D_0$), the rate of the bearing capacity reduction of piles buried in contaminated soils increases too or, in other words, the bearing capacity decreases with more intensity. This trend is nearly unchanged up to a diameter ratio of 0.7 after which the effects on the results are more perceptible. The reason for the high bearing capacity reduction can be an increase in the lateral contact area of the buried pile with its surrounding oil contaminated soil caused by an increase in the pile diameter and also the strength weakening due to the oil lubricating effect. For instance, with 16% contamination, the load bearing capacity reduction is 12.5%.

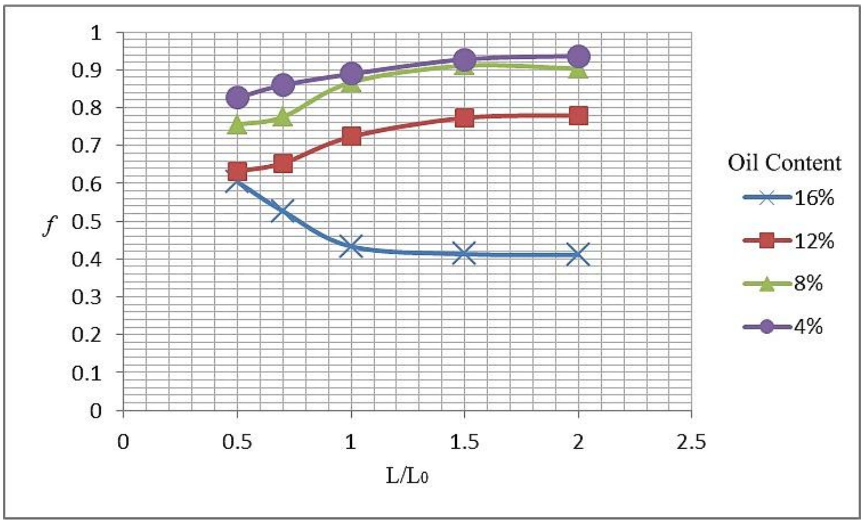
**Figure 4** Effects of pile diameter variations on its bearing capacity for similar contaminations (see online version for colours)




## *4.2 Pile length effects on the bearing capacity*

Unlike the previous case, we will now keep the base pile diameter unchanged ($D_0$ = 1 m) and apply changes of 5, 7, 10, 15, and 20 m in the pile length. The curves related to the bearing capacity reductions (*f*) are shown in Figure 5.

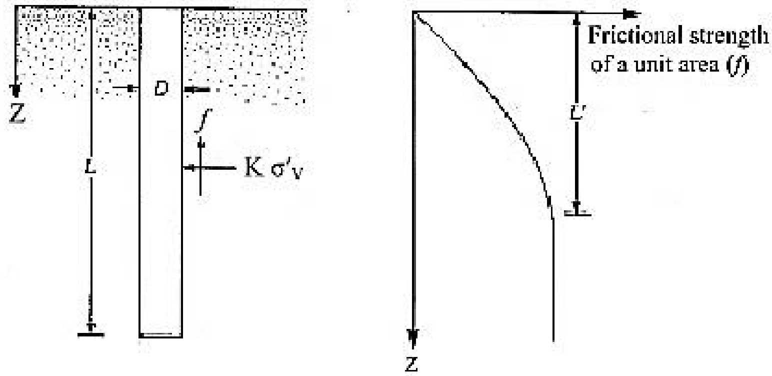
**Figure 5** Effects of pile length variations on its bearing capacity for similar contaminations (see online version for colours)




As shown, with an increase in the pile length ratio ($L/L_0$), the bearing capacity reduction rate of the pile in the contaminated soil is very high; the reason can be stated in Figure 6.

In fact, since (according to this figure) the variations of the vertical effective stress inside deep soil remain unchanged after a pile length of approximately 15D, an increase in the pile length after this region will cause an increase in the value of parameter f; this thwarts the effects of the reduction in the value of parameter f for pile lengths less than 15D and even cause a behaviour change in the pile performance. It is worth noting that for 16% contamination, the results are different; in fact, since, usually, 16% contamination is more than the percent moisture required for a complete saturation of the soil environment, the reduction rate of the bearing capacity for 16% contamination will increase.

**Figure 6** Frictional strength of a unit area for a buried pile




*Source:* Das (2011)

## 5 Conclusions

In this research, the load-displacement curves of the piles buried deep in oil-contaminated soils have been evaluated using strength and geotechnical parameters of the oil-contaminated SM specimens and the results and outputs of the PLAXIS 2D Software. Results of this research study have shown that with an increase in the percent of the SM contamination, the energy level tolerated by a pile buried deep in the soil will experience a decreasing trend. It can be concluded, therefore, that with an increase in the oil contamination in the soil continuous environment, not only will the soil strength and geotechnical parameters be affected, but there will also be a considerable reduction in the maximum load tolerated by such buried structures as deep piles. In other words, variations in such strength and geotechnical soil parameters as the apparent cohesion, angle of internal friction, optimum moisture, and maximum dry density due to oil contamination, will cause changes in the maximum load tolerated by soil or the foundation around it. Also, the effects of the increase in the pile length and diameter have shown that an increase in the diameter will increase the reduction rate of the bearing capacity while an increase in the length will decrease this rate. It is to be noted, however, that the effects of the diameter increase in the specimen with 16% contamination has shown a different behaviour because the percent contamination is more than the percent moisture required for the complete saturation of the soil environment.

## Acknowledgements

The authors are grateful to Dr. Mashalah Khamehchiyan (Associate Professor of Engineering Geology in Tarbiat Modares University, Tehran, Iran) and his colleagues due to using their experimental data from their research about effects of crude oil contamination on geotechnical properties of clayey and sandy soils (2007) in this work. Also, the authors would like to express their deepest appreciation to Islamic Azad University of Najafabad Branch, Iran for funding and supporting the current study.

## References

Aiban, A. (1998) 'The effect of temperature on the engineering properties of oil-contaminated sand', *Journal of Environmental International*, Vol. 24, Nos. 1–2, pp.153–161.

Alsanad, H.A., Eid, W.K. and Ismael, N.F. (1995) 'Geotechnical properties of oil contaminated Kuwaiti sand', *Journal of Geotechnical Engineering, ASCE*, Vol. 121, No. 5, pp.407–412.

Das, B.M. (2011) *Principles of Foundation Engineering*, 7th ed., SI, Cengage Learning Publisher, Stamford, USA.

Evgin, E. and Das, B.M. (1992) 'Mechanical behavior of an oil contaminated sand', in Usmen and Acar (Eds.): *Envir. Geotech. Proc. Mediterranean Conf.*, pp.101–108, Balkema Publishers, Rotterdam, The Netherlands.

Fathollahzadeh, S. (2014) *Mechanical and Dynamic Modeling of Earth Structures in PLAXIS*, 1st printing, Noavar Publications, Tehran.

Kermani, M. and Ebadi, T. (2012) 'The effect of oil contamination on the geotechnical properties of fine-grained soils', *Soil and Sediment Contamination: An International Journal*, Vol. 21, No. 5, pp.655–671.

Khamehchiyan, M., Charkhabi, A.H. and Tajik, M. (2007) 'Effects of crude oil contamination on geotechnical properties of clayey and sandy soils', *Engineering Geology*, Vol. 89, pp.220–229.

Mohammadi Akbarabadi, M., Yasrebi, S. and Khoshneshin-e Langaroodi, M. (2010) 'Effects of crude oil contamination on some of the geotechnical properties of sandy soil', *5th National Conference of Civil Engineering*, Mashhad, Iran.

Pandey, A. and Bind, Y.K. (2014) 'Effects of oil contamination on geotechnical properties of alluvial soil Naini, Allahabad', *International Journal of Innovative Technology and Exploring Engineering*, Vol. 3, No. 8, pp.39–42.

Rahman, Z.A., Hamzah, U., Taha, M.R., Ithnain N.S. and Ahmad, N. (2010) 'Influence of oil contamination on geotechnical properties of basaltic residual soil', *American Journal of Applied Sciences*, Vol. 7, No. 7, pp.954–961.

Schanz, T. and Vermeer, P. (1996) 'Angles of friction and dilatancy of sand', *Geotechnique*, Vol. 46, No. 1, pp.145–151.

Sheen, E.C., Lee, J.B. and Das, B.M. (1999) 'Bearing capacity of a model scale footing on crude oil-contaminated sand', *J. Geotech. Geolog. Engineering*, Vol. 17, No. 2, pp.123–132.

Shooshpasha, I. and Sharafkhah, M. (2013) 'Experimental and analytical investigation of the settlement of insitu concrete piles in sandstone', *Environmental and Civil Engineering Periodical*, Vol. 43, No. 4, pp.35–46.

Terzaghi, K. (1942) 'Disscussion of the progress report of the committee on the bearing value of pile foundation', *Proc. ASCE*, Vol. 68, pp.311–323.