Dynamic Analysis of oil-contaminated Sand

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1. ABSTRACT

Soil contamination with oil has a significant impact on its engineering behavior.
Due to the prevalence of oil contamination in soils around the world, many researchers have been interested in studying the effect of oil contamination on the mechanical properties of soil. However, the dynamic behavior of oil-contaminated soils has been studied by few or almost rare research. This article studies the dynamic behavior of oil-contaminated sand at different oil concentrations (0%, 2%, 4%, 8%) by weight of the soil. Plaxis 2D version 8 was used for dynamic numerical modeling of oil-contaminated sand by applying dynamic seismic waves to contaminated sand models. The results show that exposed earthquakes on oil-contaminated sand with different oil concentrations cause an increase in the settlement of the building constructed in the soil with increasing oil concentration in the sand. The vertical and horizontal strain of the contaminated sand increases with increasing oil contamination in the sand. Horizontal deformation of sand with low oil concentrations is affected more by the dynamic waves of the earthquakes than sand with high oil contamination concentrations.

Keywords: Numerical modeling, Plaxis, oil contamination of soil, dynamic behavior, earthquake

2. INTRODUCTION

Spillage of Oil may occur due to Wars, storage tanks problems, pipeline breaks, oil drilling, and transportation of oil, which causes contamination of oil in the soil and all the surrounding area. According to Singh et al (2008), [1], when oil is released, it stays in the soil pores, modifying the soil behavior.

The destruction of oil storage tanks and oil wells during the Gulf War in Kuwait from August 1990 to February 1991 caused crude oil to seep into the soil, [2]. According to Singh, Srivastava, and John (2005), [3], the sudden release of petroleum products amounting to approximately 240 milliliters during the Gulf War represented the largest petroleum release event since 1978 when the record began to be kept. Ijimdiya (2012), [4], stated that oil exploration caused oil spills into the environment of the Niger Delta in Nigeria, causing environmental degradation. In the United States of America Despite the culture of good maintenance of oil tankers, oil spilled from storage tanks, and the soil was polluted, [5].

Oil contamination in the soil leads to changes in the properties and characteristics of the soil. Many researchers focused on studying the geotechnical properties of soil contaminated by oil. Hasan et al. (1995), [6], stated that oil contamination of Kuwaiti sand causes decreasing in permeability and strength, while it causes increasing compressibility and CBR values with the presence of up to 4% oil by soil weight. Puri. (2000), [7], showed that the angle of internal friction of contaminated soil decreased amount of 20 to

25 % and the hydraulic conductivity depends on the viscosity of the contaminant oil.

On the other hand, earthquakes are likely to occur in oil-contaminated areas, especially in oil fields. In 1983 an earthquake occurred in the Kettleman North Coalinga oil field, also Dome Oil Field in California was affected by an earthquake in 1985, as well as Bushehr in Iran (2014), [8]. Therefore the dynamic characteristics of the polluted soil should be studied, Although there is very little or almost a rare number of research papers on this topic. Naeini, and Shojaedin (2014), [8], performed Dynamic triaxial tests on oil-contaminated sand samples for studying liquefaction of contaminated soil during dynamic loading, showing that sand liquefaction resistance increases with the increase of oil contamination in the sand to 8% contamination percentage, while with the increase in oil contamination, the liquefaction resistance decreases.

3. Materials and Methods

Characteristics of soil used

The soil used in this research is sand collected from Agrod district, Suez governorate, Egypt. The sand was wet sieved in 0.075 mm sieve size, according to ASTM C 117 – 95, [9] to remove all silt grains found in the sand. sand had been contaminated with oil of specific gravity of 0.9050 at 15°C and a viscosity index of 90, after being air-dried to have four different concentrations of oil contamination in the sand (0%, 2%, 4%, and 8%) of its dry weight. The properties of used contaminated sand with different oil concentrations are listed in Table (1).

Table (1), Properties of sand with different oil contamination

Soil type	Friction angle	unsaturated unit weight kn/m^3	poison ratio	Dynamic young's modulus kn/m^2
Sand with 0% oil	29.12	15.85	0.339	198728.68
Sand with 2% oil	21.23	16.19	0.389	78629.20
Sand with 4% oil	19.727	16.67	0.398	49164.45
Sand with 8% oil	18.711	17.39	0.404	25268.77

Model Geometry

2D Plaxis version 8 was used for the dynamic analysis of oil-contaminated sand. The model consists of 30 meters thick of sand, containing a building of 4 floors and a basement, as shown in figure (1). Each floor is 3m high which represents a total height of 12m above ground, while the basement is 2m deep. The walls and floors of the building were modeled in Plaxis as plates and their properties are shown in table (2). A finite element mesh was established for the model as shown in figure(2). Two monitoring points were identified in the model, one was in the left corner of the building's basement to monitor the building's movement and displacement, and the other was identified in the soil under the basement directly to observe the strain in the soil.

Table (2), Properties of plates of modeled building

Plate position	Normal stiffness KN/m	Flexural rigidity KNm^2/m	Weight KN/m/m
Basement	$1.2*10^7$	$1.6*10^5$	20
Rest of building	$9*10^6$	$6.75*10^4$	10

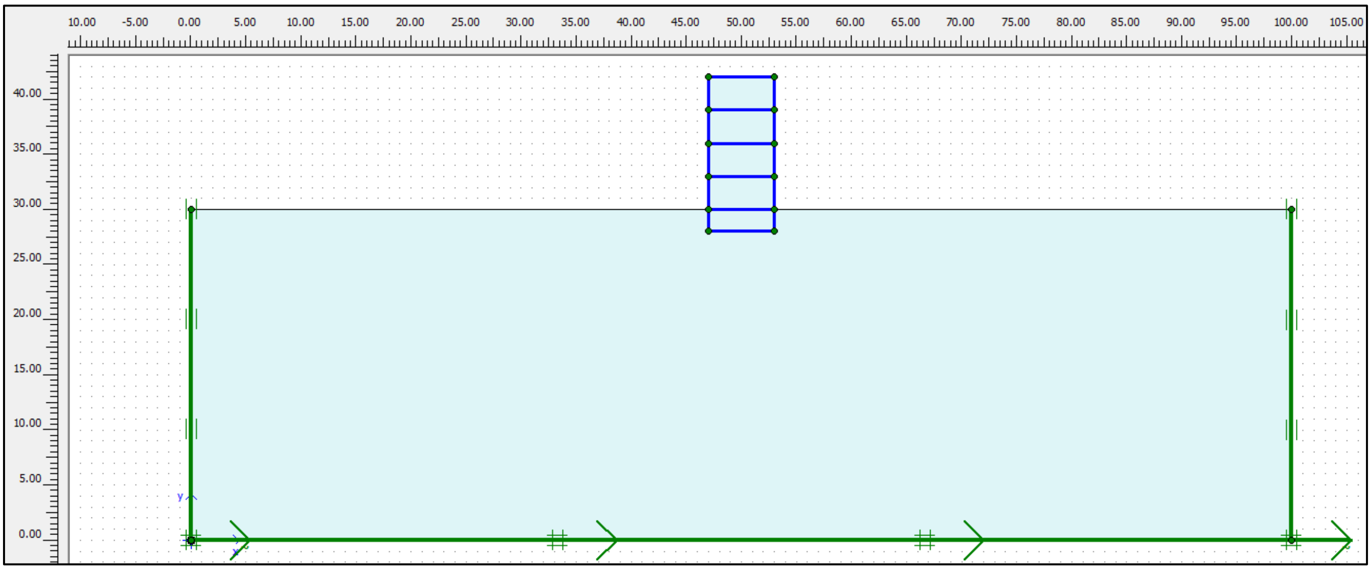


Figure (1), Geometry of sand and building model

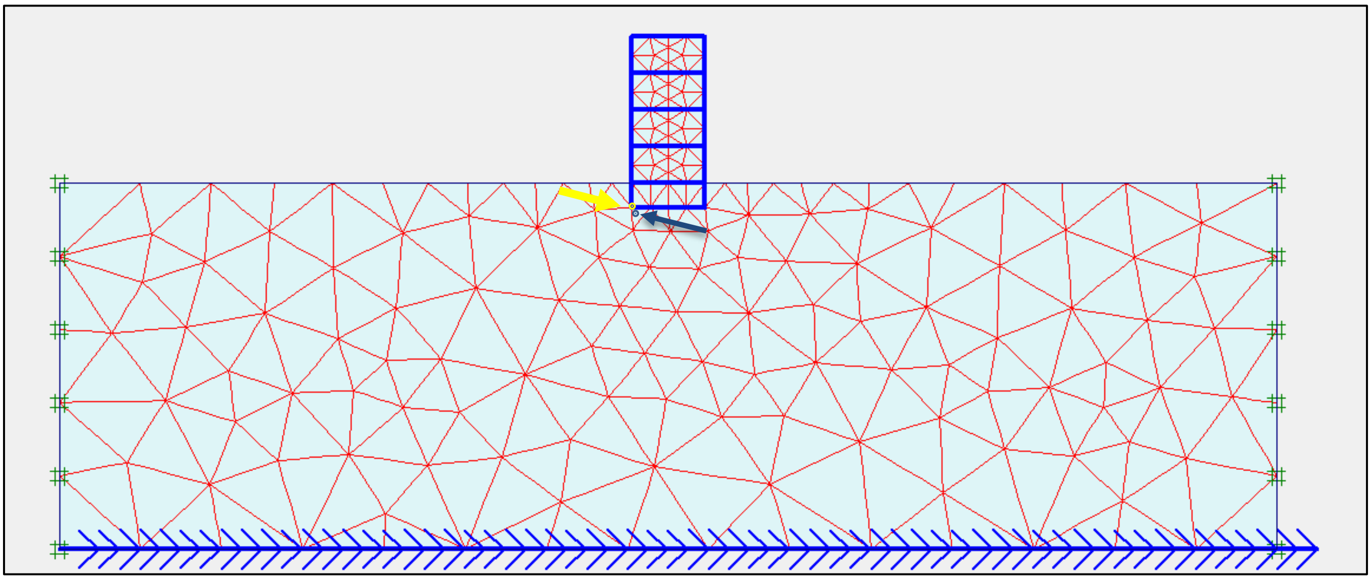


Figure (2), Finite element mesh and monitoring points

Dynamic loading

The dynamic loading used to model sand soil contaminated with different concentrations of oil contaminations is in the form of an earthquake accelerogram as shown in figure (3), which is of Upland earthquake that occurred on February 28, 1990 in the city of Upland in San Bernardino County, California, United States with a magnitude of 5.7 Richter scale.

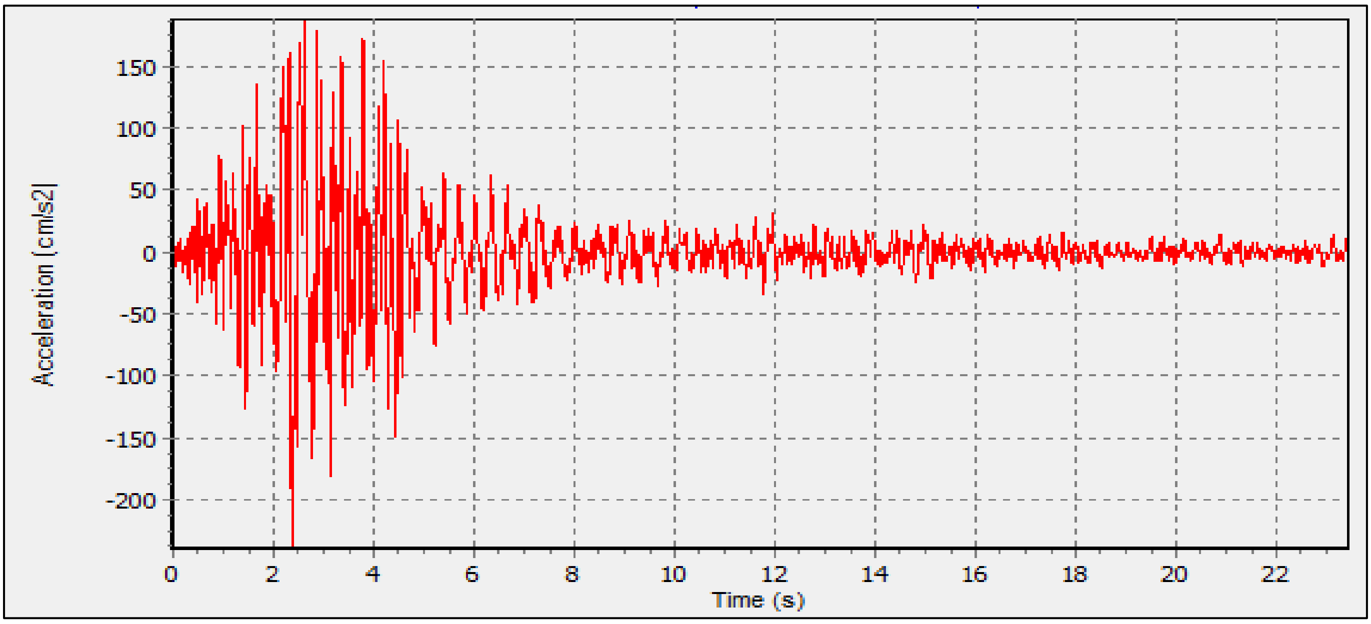


Figure (3), Upland earthquake accelerogram

4. Results and Discussion:

Applying earthquake waves to the sand models caused deformations of sand and the building constructed on it in both horizontal and vertical directions as shown in figure (4), which shows a snapshot of deformation in one of the sand models during the application of induced earthquake waves.

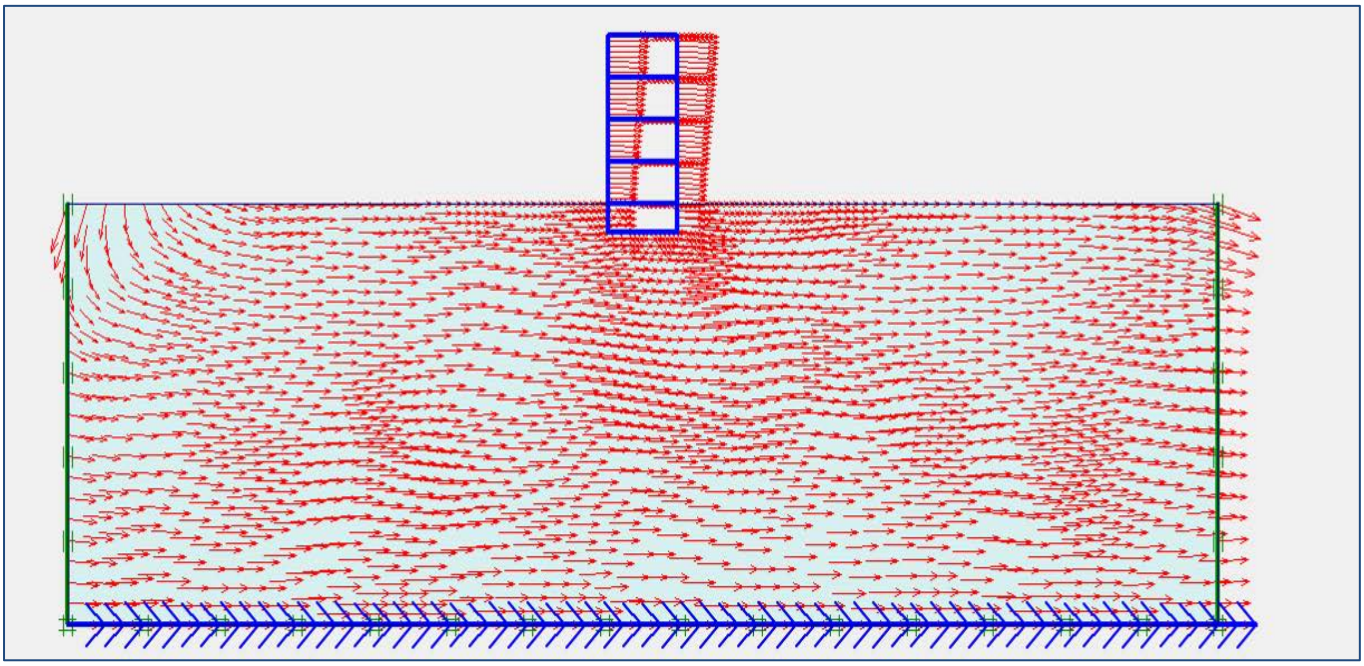


Figure (4), Total deformation of 0% oil-contaminated sand at dynamic loading time = 4.8s

The relationships between time and horizontal acceleration of earthquake waves that affected the building basement are represented for sand soil models with the four oil contamination concentrations (0%, 2%, 4%, and 8%), as shown in figure (5), which illustrates that values of maximum horizontal acceleration inversely proportional to the percentage of oil contamination in sand soil, having its maximum value in the model of sand with 0% oil contamination concentration followed by sequential decreasing with increasing percentages of oil contamination in sand soil.

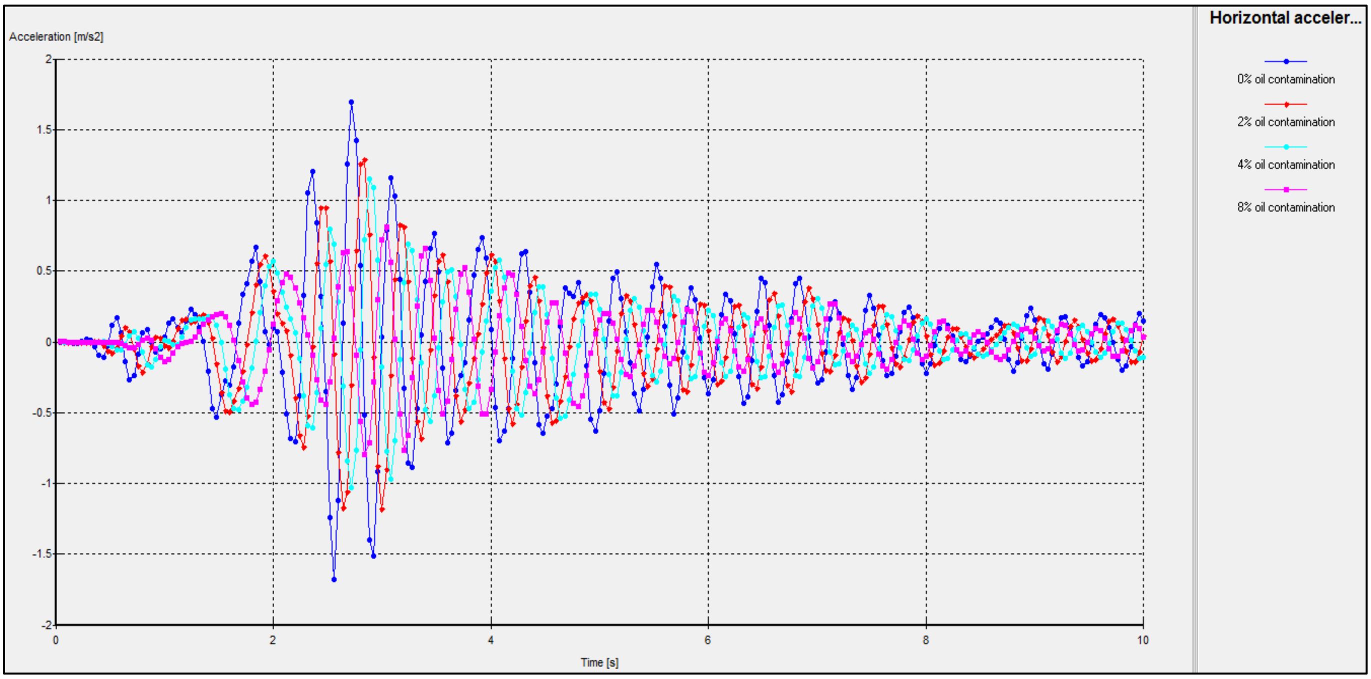


Figure (5), horizontal acceleration of earthquake waves in the basement of the building

The vertical displacement of the basement of the building is monitored during the application of earthquake waves in sand models versus time. The Time and vertical displacement relationships are represented as shown in the figure (6), illustrating that the percentages of sand oil contamination have a clear effect on increasing the vertical displacement in the direction of the negative Y-axis, which leads to more settlement of the building with increasing concentration of oil contamination in the sand, which is due to the effect of oil contamination in decreasing angle of internal friction of sand and increasing sand unit weight which in turn causes increasing vertical principle stresses leading to more settlement, especially in case of lower stiffness of sand due to oil contamination.

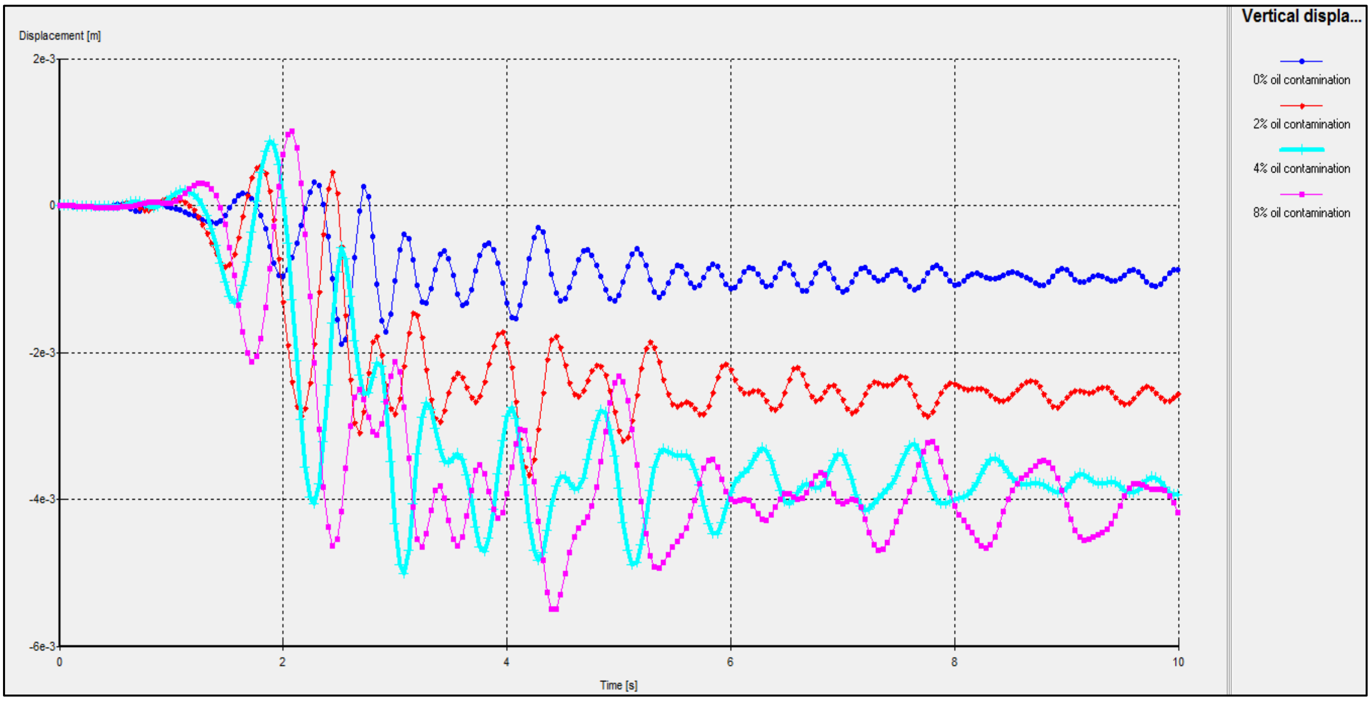
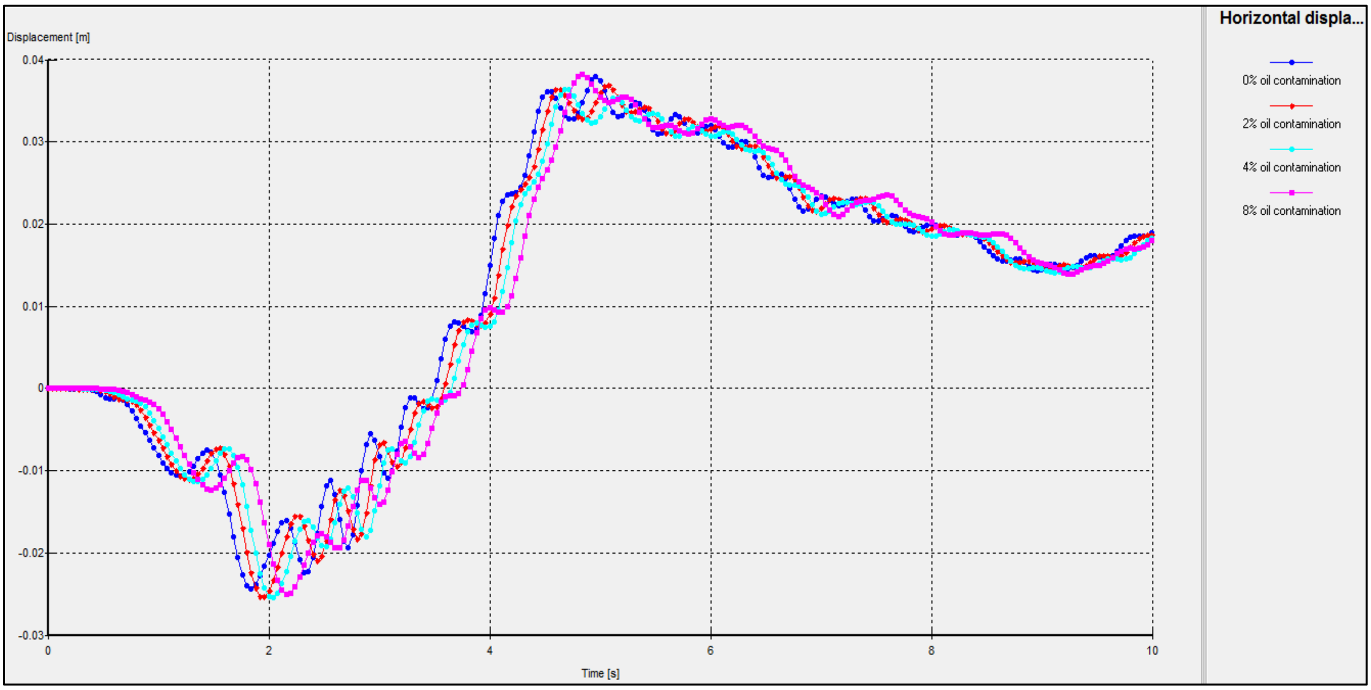


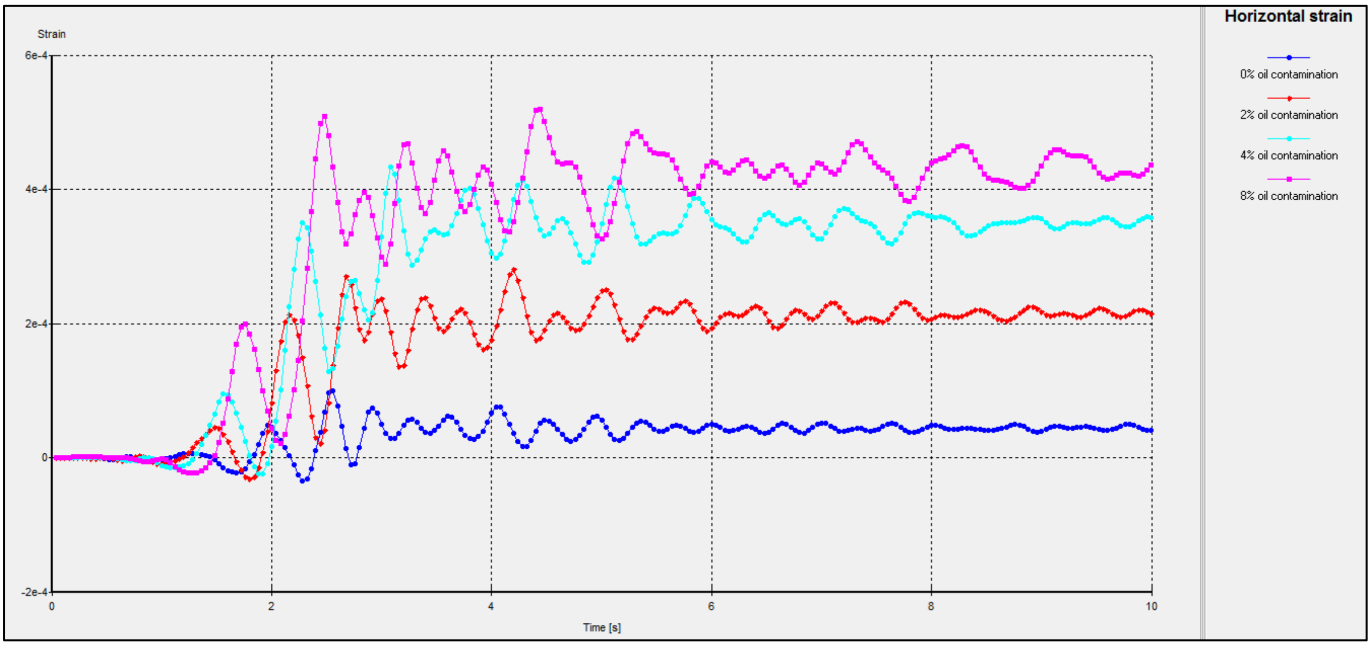
Figure (6), vertical displacement of the basement of the building

Applying earthquake waves on models of sand with different concentrations of oil contamination leads to the occurrence of horizontal displacement in all parts of the sand model. By monitoring horizontal displacement in the basement of the building it turns out the following, sand with a lower concentration of oil contamination was affected by the earthquake waves more strongly than sand with higher concentrations of oil contamination, as shown in figure (7), this is due to the effect of oil contamination on decreasing the horizontal wave acceleration.

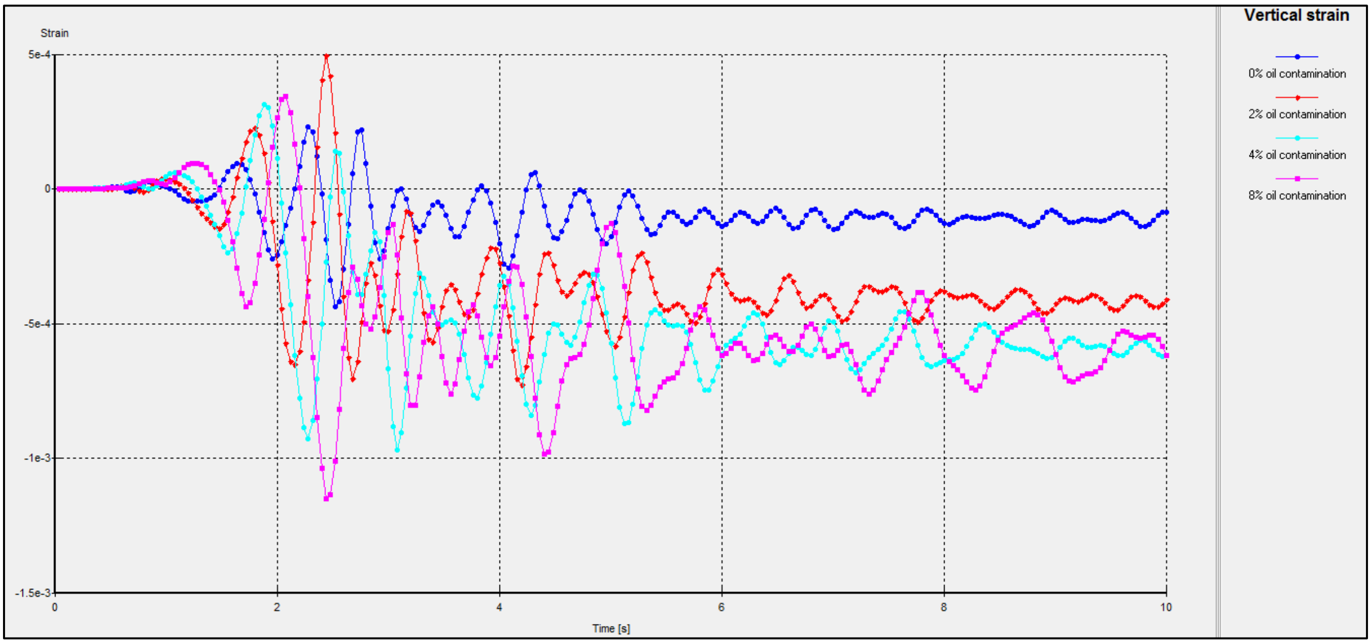


Figure(7), Horizontal displacement of the basement of the building

Oil contamination in sand leads to an obvious decrease in its stiffness which in turn leads to an increase in sand strain so, sand with higher concentrations of oil contamination has more horizontal strain in tension direction than sand with low concentrations of oil as shown in figure (8), which represent the horizontal strain at the monitored point located in the sand below the left corner of the building during applying earthquake waves. While vertical strain in the same point is greater in compression direction for the sand of higher concentrations of oil than lower concentrations as shown in figure (9).



Figure(8), Horizontal strain of the point below the basement of the building



Figure(9), Vertical strain of the point below the basement of the building

5. CONCLUSION:

1. Oil contamination of sand is the main reason for earthquake waves acceleration attenuation in the sand, where the earthquake wave maximum horizontal acceleration in the monitored point in sand decreased by 47.9% from 0% oil-contaminated sand to 8% oil-contaminated sand.
2. Buildings constructed on contaminated sand with oil are more likely to the settlement during the tremors of the earthquake, where the settlement which was monitored in the left corner of the building constructed in oil-contaminated soil, increased by 264% with the increase of oil contamination concentration in sand from 0% to 8% of the soil weight.
3. Despite the effect of oil contamination on decreasing the stiffness of the sand, which is supposed to make it displaced horizontally due to the earthquake dynamic waves more than slightly contaminated or non-contaminated sand, but the effect of oil contamination of sand on the attenuation of the horizontal acceleration of the earthquake's waves, Make the most oil-contaminated sand has a maximum horizontal displacement during earthquakes less than the least oil-contaminated sand.
4. Oil-contaminated sand when exposed to an earthquake dynamic waves causes horizontal strain in the direction of tension that increases with increasing concentrations of oil contamination in the sand.
5. The vertical strain of the oil-contaminated sand which resulted from the earthquake tremors increases in the compression direction with increasing concentration of oil contamination in the sand.

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