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The numerical study of the effect of the crude oil contamination on the stability of clayey soil slope

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ABSTRACT: The presence of oily materials (crude oil contamination) in the clayey soil with low liquid limit (CL) causes the occurrence of changes in the stress-strain curve, wedge failure, plastic region, and strain energy of the soil slopes compared the uncontaminated soils due to the physical and chemical processes. These changes mostly cause the decrement in the safety factor against failure, the increment of the plastic region, and the decrement of the stability of the soil slopes. Yet, the effect of crude oil contamination on the parameters of the shear strength of the soil has been tested by the direct shear test as well as the bed reaction module by the plate loading test for various clayey and sandy soils. In this research, the effect of the oil contamination changes in the range of 0-16% (0-4%, 4-8%, 8-12%, 12-16%) on the safety factor of the stability of clayey soil slope has been studied by the numerical modeling of finite element method in ABAQUS software. The heights of clayey soil slopes are 10, 13, and 16 meters and the degree of the soil slope is 53. The results of this research show that the increment of the oil contamination will lead to the decrement of the stability of the clayey soil slope. It can be predicted that the safety factor value of the clayey soil slope can decrease up to 72% by increasing the oil contamination from 0 to 16%. Also, a 4% increment in the amount of crude oil contamination in clayey soil slope (12% to 16% oil contamination) can increase the horizontal displacement by 2 to 3 times, and vertical displacement by 3 to 4 times.

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1- Introduction

Oil contamination has various effects on the soil, including longtime change in the shear strength of the soil and direct effect on the water absorption and electrostatic charge. Therefore, it has a negative effect on the adhesion behavior of the clayey soil. Oil contamination has a direct effect on the elastic and plastic properties of the clayey soil, which can lead to a change in the stress-strain curve of the soil. It also causes a change in the special weight of the soil and, subsequently effective stress. The oil contamination can decrease the soil penetrability, which results in decreasing the velocity and discharge of the penetration. Due to the effect of the oil contamination on the soil behavior, we have studied this behavior by a comprehensive numerical study of a finite element method in ABAQUS software. Yet, the fulfilled investigations have been done by laboratory devices, but we have used numerical modeling in a finite element method regarding the previous researchers' laboratory data of soil slope with different heights and the effects of oil contamination on the stability of clayey soil slope have been investigated.

2- Methodology

The effects of oil contamination have been assessed in this research by using the loading of weight force on the stability of the soil slope. The modeling of the clayey soil slope with 10, 13, and 16 m height has been compared in two states of the presence and absence of the oil contamination (Figure 2).

The oil contamination percentage was 0, 4%, 8%, 12%, and 16% in this research (Table 1). All the numerical calculations were done by direct shear test [1].

The finite element software of ABAQUS was used for the modeling. In this research, the soil was in drainage condition with the behavioral model of linear elastic-perfectly plastic, and the Mohr-Coulomb failure criterion was used [2]. The safety factor was obtained by the limit equilibrium method.

For the validation of ABAQUS software, the uniaxial test of the clayey soil in two states without and with oil contamination (16%) has been modeled in the software, and the results have been compared with the real results of the laboratory uniaxial test [1]. Studying the laboratory

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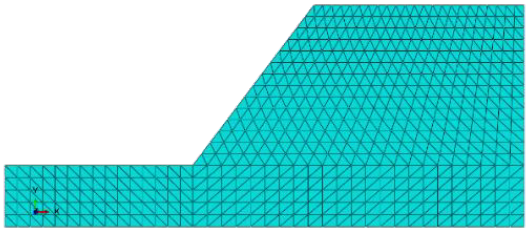
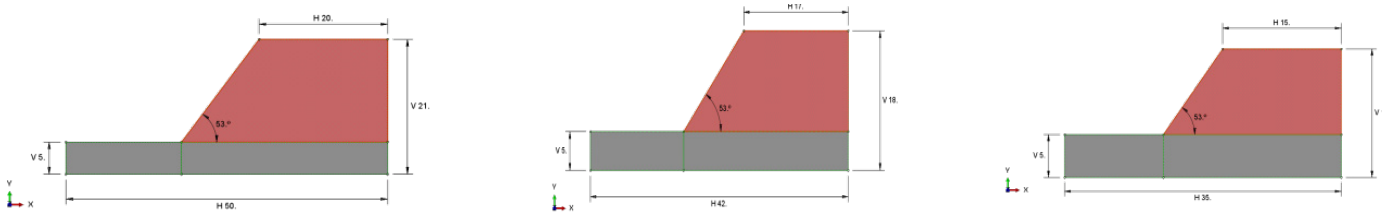


Fig. 1. Mesh geometry problem



c. H=16 m **b. H=13 m** **a. H=10 m**

Fig. 2. The geometry of soil slope

Table 1. the specifications of used materials

CL16	CL12	CL8	CL4	CL0	SOIL TYPE
16	12	8	4	0	OIL CONTENT (%)
25.52	20.57	20.33	32	35	LI
13	14.3	14.7	16.1	20	PI
1810	1800	1830	1850	1860	ρ_d (kg / cm^3)
0.3	0.3	0.3	0.3	0.3	ν
2.5	10	12.5	22.5	15	E(Mpa)
0.0175	0.018	0.022	0.0275	0.075	C(Mpa)
34.5	28.7	28	27.4	26.1	φ

results, the uniaxial strength in the state of uncontaminated was 3.5 kg/cm^2, and 0.62 kg/cm^2 for the 16% contaminated. Comparing these results with the data obtained by the modeling of uniaxial test modeling in the software, we can find out that the errors of these two methods in two states of uncontaminated and 16% oil contamination were 1.1% and 4%, respectively.

3- Results

The SRF of the soil slope will decrease by increasing the oil contamination. Also, the SRF value will decrease 40% to 60% by increasing the slope height by 3 m in the constant oil contamination. The safety factor of soil slope will significantly decrease up to 60% by increasing the oil contamination in the range of 0 to 4% (Figure 3).

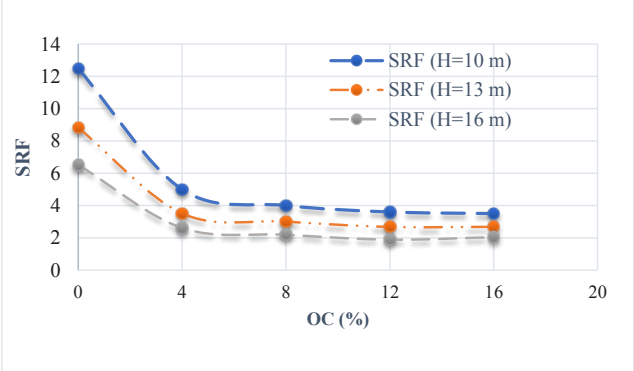


Fig. 3. The changes in SRF value according to the oil contamination at different heights

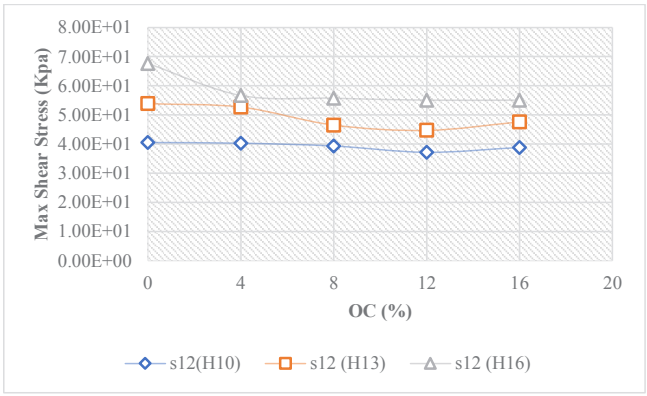
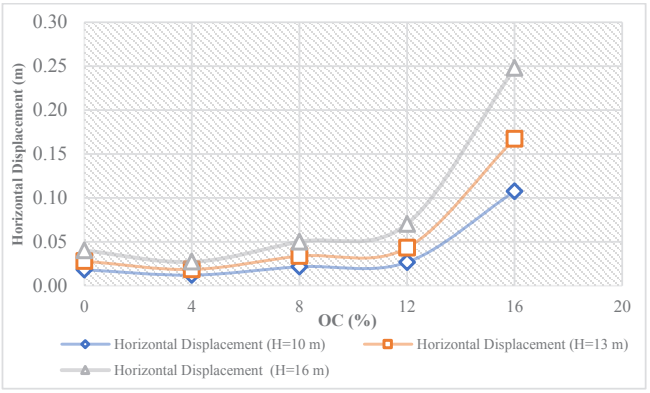
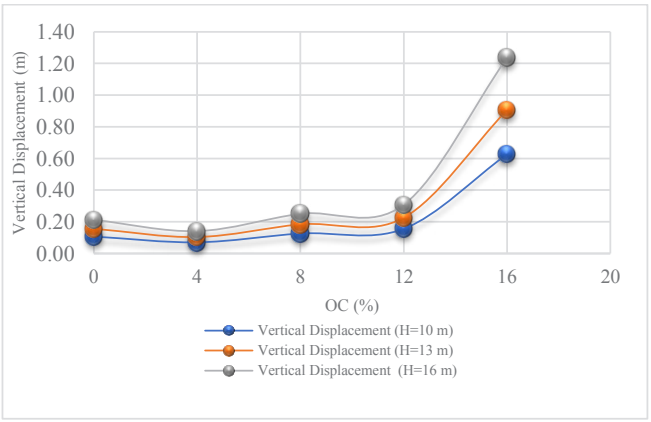


Fig. 4. The changes of maximum shear stress against the changes of oil contamination in the heights of 10, 13, and 16m



a



b

Fig. 5.The changes of maximum displacement against the oil contamination in the heights of 10 m, 13 m, and 16 m

The shear stress is at its maximum value at the toe of the slope, and the increment of oil contamination will make the plastic region bigger in the soil slope. So, the increment of oil contamination will lead to instability and the decrement of the safety factor of soil slope. The oil contamination will cause the decrement of the shear stress mobilized on the soil slope. The changes in maximum shear stress according to the oil contamination changes in different heights are shown in Figure 4.

One important parameter in designing the soil slope is the investigation of vertical and horizontal displacement. The increment of oil contamination in soil with different heights will lead to the increment of horizontal displacement. For example, by increasing the oil contamination (0 to 16%) at the height of 16 m, the horizontal displacement will increase from 5cm to 25cm. Also, the vertical subsidence of soil slope has been increased from 20cm to 120cm. The trend of the increment of vertical and horizontal is significant in the range of 12% to 16% oil contamination. In this range, the increment of oil contamination will cause the increment of horizontal displacement about 2 to 2.3 times and the vertical displacement about 2.6 to 3.8 times (Figure 5).

Based on the relations proposed by various researchers, the soil slope will be stable if its safety factor is more than 1; but based on the code, the minimum safety factor of the stability of soil slope in the static mode should be 1.5 [3]. Therefore, due to the obtained safety factor by the numerical modeling, we can conclude that all the soil slopes are stable. In this research, the trend of safety factor changes and the changes in soil slope displacement due to the increment of oil contamination is nonlinear; in fact, the soil slope will become unstable and fail with the increment of only 2% to 4% oil contamination increment. This trend can be well seen in the large changes in safety factor between the state of uncontaminated and the contamination of 4%.

4- Conclusion

The increment of oil contamination will lead to the reduction of clayey soil adhesion. So, the shear strength of the clayey soil will significantly decrease. It can be predicted that the amount of safety factors will decrease up to 72% (at different heights) by increasing the oil contamination from 0 to 16%.

A 4% increase in oil contamination of soil slope (compared the uncontaminated soil) can decrease the safety factor of soil slope by 60%. So, we can say that it can be said that in the range of 0 to 4% oil contamination, the safety factor has been significantly decreased and made the soil slope unstable.

By the increment of oil contamination (from 0 to 16%), the plastic strain surface will become larger. It means that the plastic strain value is zero in an uncontaminated state, but the plastic strain will start to become greater from the toe of the slope after the occurrence of contamination and the plastic strain surface will become larger.

The mobilized maximum shear stress will decrease due to the increment of oil contamination. The reason for this phenomenon is the decrement of intrinsic adhesion of the clay due to the oil contamination increment which can affect the existing stresses in the slope.

The effect of the oil contamination increment on the maximum mobilized shear stress will increase by the increment of soil slope height. The increment of slop height up to 16 m can decrease the maximum shear stress by 14% which is so significant.

The horizontal and vertical displacement will increase about 2-2.3 and 2.6-3.8 times, respectively, by the increment of oil contamination. The increment of displacement (horizontal and vertical) is significant in the oil contamination range of 12% to 16%.

The trend of changes in displacement, shear stress, and safety factor of the soil slope under oil contamination is nonlinear. In fact, it is supposed that a 2-4% increment of oil contamination in clayey soil can cause the soil slope to become unstable and fail.

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