# Soil Model Effects On the Response of Offshore Structures Under Impact Loads

**Ahmed H. Ahemer[1] , Prof. Dr. Anis A. Mohamad Ali[2]**

***1Civil Engineering Dept, Basrah Oil Company / Basrah, Iraq***

***21 Civil Engineering Dept, Basrah University / Basrah, Iraq***

**ahmedalkfajy @gmail.com**

## Abstract

The offshore structures are now widely used in the field of the oil and gas activities that deal with drilling and exploration in the same time may be used for storage and transportation . Offshore structures are constructed in different forms according to their uses and their construction materials . In this paper a comparison in response under impact load from ship berthing is performed between offshore structures with embedded pile where the soil is treated as elastic and plastic model . AL-Basrah oil port (ABOP) is taken in consideration as a case study where two models are used , in the first model the pile is embedded in elastic soil with consideration of pile- soil interaction(PSI) while in the second model, the soil is treated as plastic material. For two models the finite element analysis is performed in linear behavior for piles and deck while the soil is treated as nonlinear in plastic model. A comparison between soft and stiff soil in elastic model is also done . The results are shown that the natural frequency of offshore structures in elastic model of soil is more than for plastic model.

**Keyword**: offshore , soil model , pile , impact load **.**

## 1-INTRODUCTION

Offshore platforms are designed to support the decks where the gravity concrete base or piles are used to fix the platform in its position . The platform during its lifetime is subject to different environmental loading like waves, winds and earthquake API [1]. R.S. Badel [2] studied the dynamic analysis of soil structure interaction for three soil types and layered soil are considered to investigate the effect of soil type on the structural behaviour . Ali mohammad [3] considered the behavior of the batter pile group under seismic loads where 3D Finite Element Method is developed to find the dynamic response where the constitutive model for soil is a Hardening Drucker-Prager model . In this paper the effect of different type of model on the response of offshore structures under dynamic load of an impact load is studied.



## 2 – PLATFORM DESCRIPTION

AL-BASRAH OIL PORT (ABOP) in the south of iraq is taken as a case study where the platform (A) in this port represents the mooring structure. This platform consists of fourteen piles for supporting the deck . The Water depth is 30 m and the superstructure is supported by piles without steel jacket where the piles are extended from lower part of deck to the supporting soil without any jacket or diagonal members. The batter steel piles are used with inclination (1:4) . The upper level of deck is above the Mean Sea Level(MSL) by 9 m and the pile length reaches to 34.5 m at the sea bed and to 81.5 m to the tip of it. The diameter for all pile is 1.20 m and different sections are used in construction the deck which have dimension 9.15m *12.19m . The pile is analyzed in elastic and plastic model for soil where the real situation deals with embedded piles in the soil figure(1).

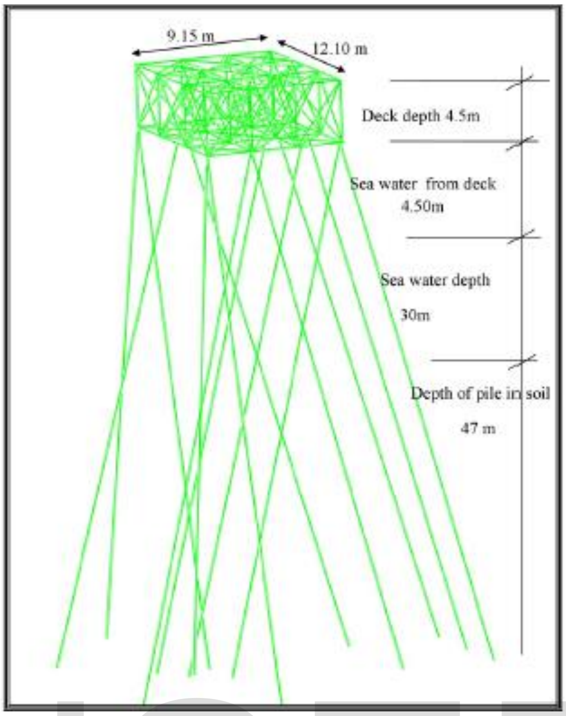


Figure (1) Dimension of platform (A).

## 3 FINITE ELEMENT ANALYSIS

Three dimensional finite element model for the AL-BASRAH OIL PORT (ABOP) is developed . ABAQUS program is used to perform simulation for the platform and the soil in linear or non linear behavior . In this work , the elements of soil , pile and other members are chosen according the physical behavior in one , two and three dimensions .

### 3.1 Elements of Problem

From ABAQUS program library , the elements are selected for each members according to its physical behavior under loads. Three dimensional brick element of soil is used (C3D20RP) , 20 nodes ,with linear pore pressure, and quadratic displacement[4] . For piles and members of deck, B32 element is selected for the simulation where each elements has three nodes to give more accurate results with quadratic polynomial equation and six degrees of freedom where three in translations and three in rotations, see figure (2,3).

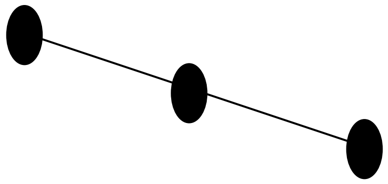

Figure (2) Quadratic frame element for pile.

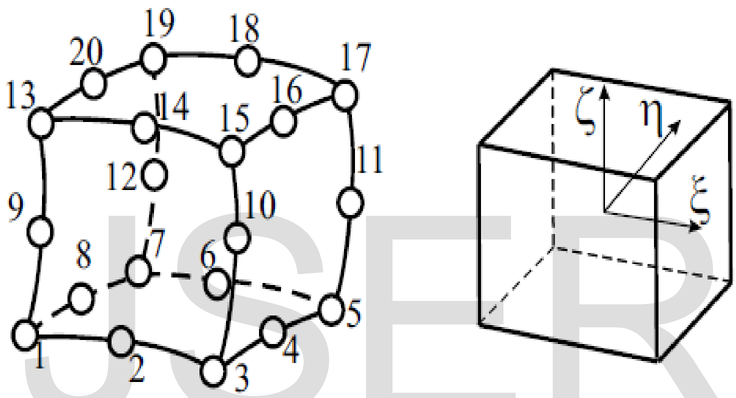




Figure (3) Brick element for soil.

## 4 SOIL CONSTITUTIVE MODEL

A constitutive model for soil in elastic and plastic behavior are used where laboratory tests are performed to define the parameters for each models . However, in recent years the finite element analysis is used to represent the constitutive models of soil and to find its response in the same time , the soil behavior according to constitutive model is compared with site results.

## 4.1 PLASTIC MODEL

Elastic and plastic strain are sustained when the plastic material subjected to load and there isn't recover to its original state . According to the elasticity theory the Hook' low is the best to find the elastic strain while the plasticity theory is needed to estimate the plastic strain. The plasticity theory is developed to predict the materials behavior under loads if it is exceeding the elastic limit[5] . In this theory, there are parameters to describe material and to give mathematical model for estimation the material in elastic or plastic strain .There are many plastic models for soil and in this paper the cam clay model is used.

### 4.1.1CAM Clay Model

Cam clay model is depended on plasticity theory to predict the change in volume under different loading cases [6]. According to the critical state theory , the cam clay model is developed to predict the strength of soil under pressure and the volume changes by the shearing. The critical state theory deals with three important parameters , effective mean stress ($p'$), deviatoric stress (shear stress) $q$ and specific volume (v). Depending on the effective principle stresses the effective mean stress and shear stress are calculated as

$$p' = \frac{1}{3}(\sigma'_1 + \sigma'_2 + \sigma'_3) \qquad (1)$$

$$q = \frac{1}{\sqrt{2}}\sqrt{(\sigma'_1 - \sigma'_2)^2 + (\sigma'_2 - \sigma'_3)^2 + (\sigma'_3 - \sigma'_1)^2} \qquad (2)$$

and the specific volume is defined as $\upsilon = 1+e$ . In ($p'$- q ) plane as shown in figure (4), the yield surface for Cam clay is un ellipse and governed by

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$$\frac{q^2}{p'^2} + M^2\left(1 - \frac{p'c}{p'}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (3)$$

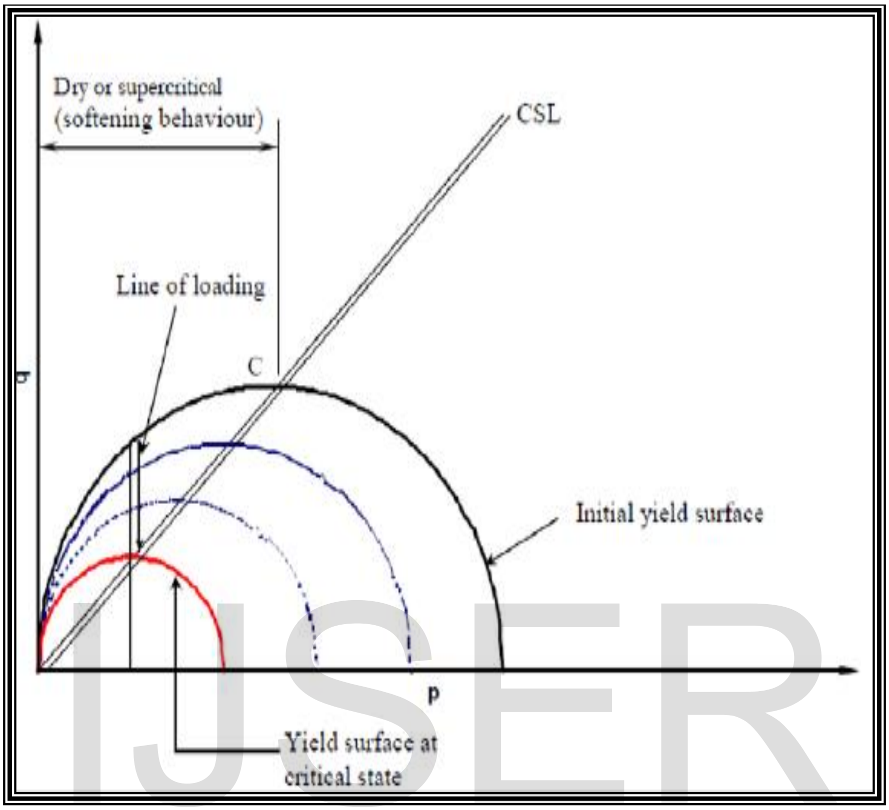


Figure (4) Cam clay yield surface(5).

## 5 SOIL EXPREMENTAL TESTS

### 5-1 Triaxial Test

This method is used to find the shear strength for different types of soils and to find the relationship of stress –strain for different values of confined pressures . The soil sample in this test is subjected to pressures in all around and then applying vertically loads on sample until reaches failure .

Radial and axial strains are recorded to find the elastic properties for soil like Poisson's ratio , ν and Young's Modulus(E) and shear strength of soil (cohesive and internal soil friction). Figure (5) Shows the results of tests for three samples.

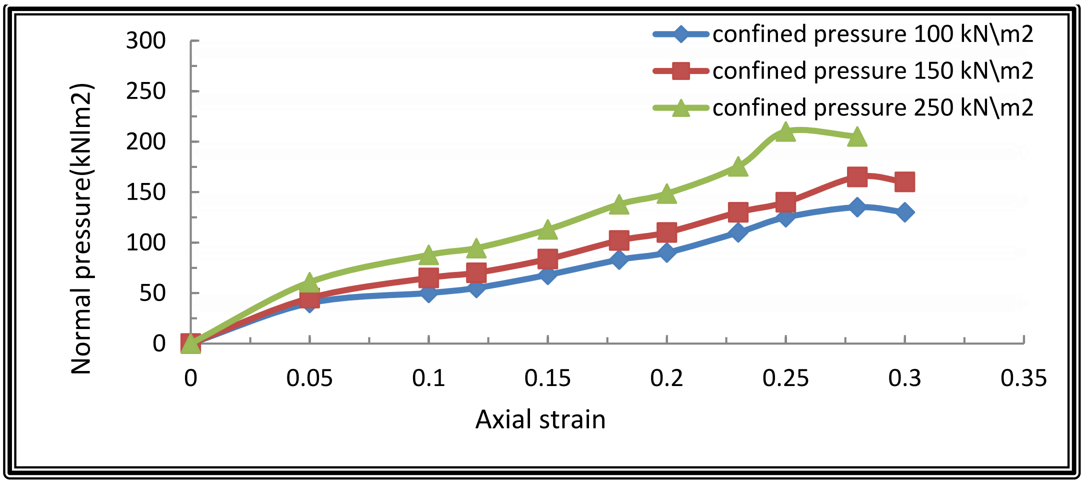


Figure (5) Triaxial compression test.

## 5-2 Consolidation Test

The consolidation tests are performed to calculate the quantity and rate of volume reduction in a horizontally confined clay sample which is subjected to applied different vertical pressure. The consolidation curve is plotted between the applied load and measured voids ratio. The obtained data is very important in calculating the peconsolidation pressure, coefficient of secondary compression, coefficient of consolidation, compression index and swelling index of the soil , see figure (6).

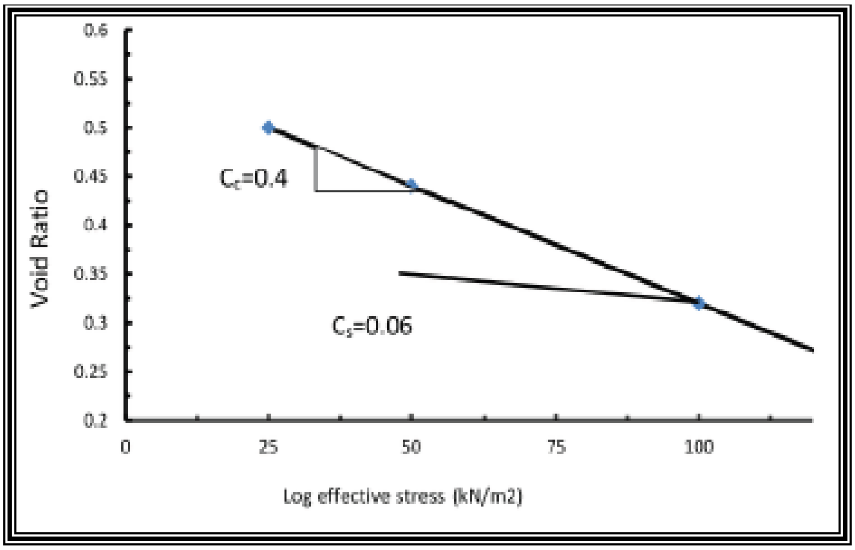


Figure (6) Consolidation test

**5-3 Soil –Steel Shear Test**

The interface shear box test is very important in the Geotechnical Engineering using a classical direct shear equipment. A square plate represent shear box (100 mm * 100 mm) move laterally at middle-depth was used in contact with steel plate. Vertical stress is applied by adding dead loads on a hook, horizontal displacements are observed. The correct interface shear stress values are obtained by subtracted the shear stress value consistent to the frictional between the lower and the upper parts of box from the measured interface shear stress. The main purpose this test was to estimate the mechanical properties of interface between clay soil and steel plate figure (7) .

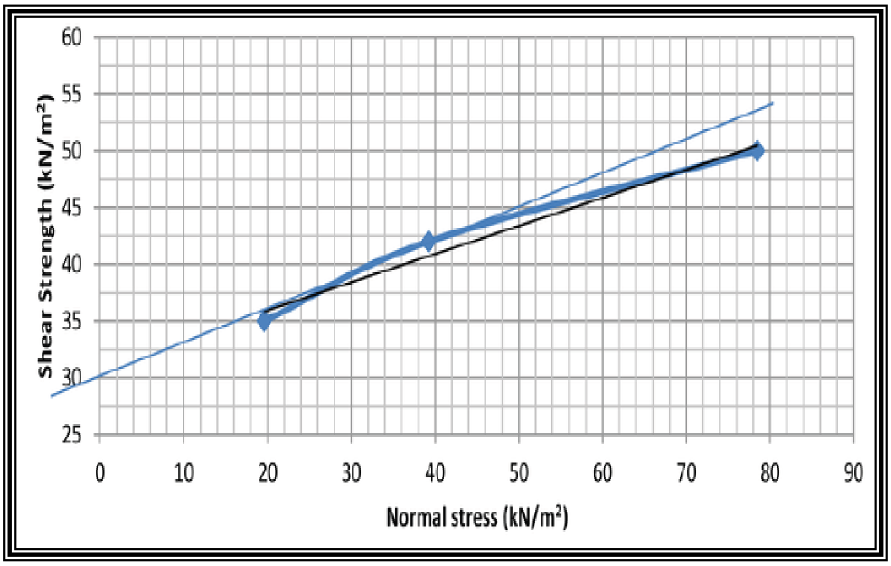


Figure (7) Shear - Steel test.



## 6- Cam Clay Parameter

The Cam clay model is used to represent a soil in the plastic model . Parameters are taken from the tests and the yield criteria for surface failure in the cam clay model is an important step . The past field condition is needed to define the initial yield surface. The calculated three mean stresses are signed on the figure (8) and the critical state line intersects the yield failure surface through the maximum deviatoric stress . Figures (9) shows the deviatoric relation with volumetric strain and mean effective stress under loading. All parameters to represent soil are shown in table (1).

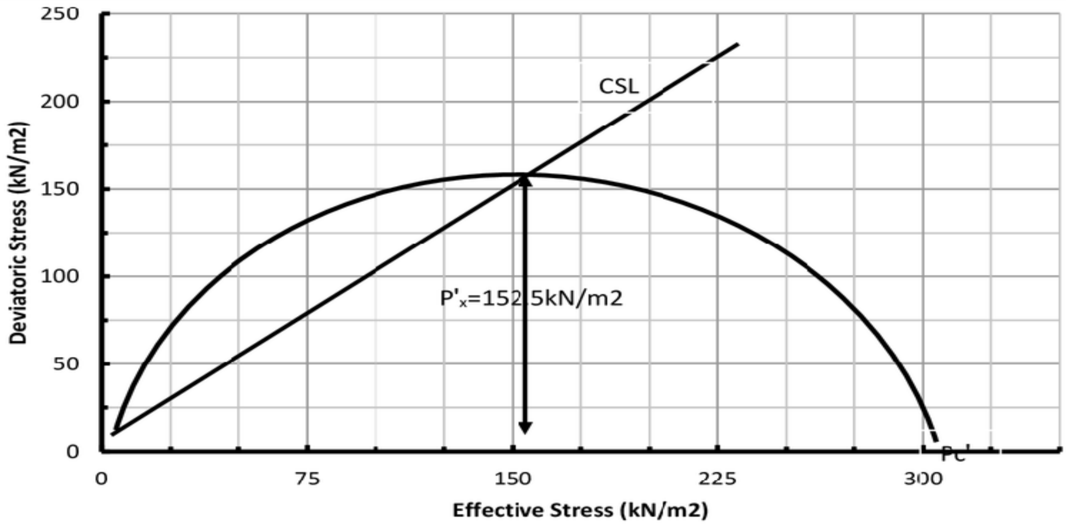


Figure (8) Critical State Line .

| Model Parameters | | | |
|---|---|---|---|
| 1 | General | Elasticity | Plasticity |
| *2* | *ρ(kg/m³)=2170* | *K=0.026* | *λ=0.174* |
| 3 | $e_0$=0.44 | *υ=0.3* | *Stress ratio M=1* |
| *4* | $\gamma_w$ *(kN/m²)=9.81* | | *Initial yield surface =152.5kN/m2* |
| *5* | *Shear stress (kN/m²)* | | *Wet yield & flow stress rate =1* |



Table (1) Cam Clay Parameter .

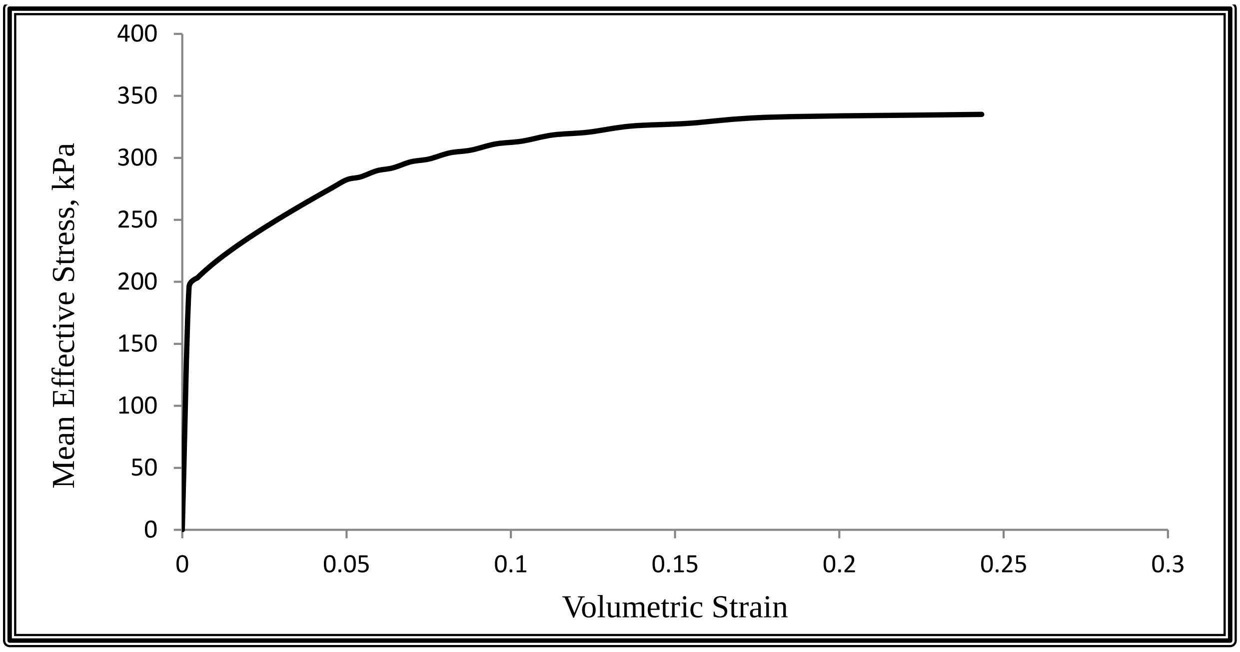


Figure (9) Strain –mean effective stress.

## 7 –Impact Load Representation

AL-Basrah oil port (ABOP) platform A1 is studied to find the responses when subjected to impact load in the berthing process . The reaction – time relation for C2000 H fender is used to simulate the load and (force –time) is performed in ABAQUS program to do port analysis[7]. The port is simulated in two case elastic and plastic model where the pile is embedded in elastic soil and the response is found in the deck and pile head through the displacement and shear force in addition to bending moment. The structure is analyzed taking into consideration the soil effect on the response of deck and pile where the deck displacement , shear and the moment in pile are measured . The reaction –time relation for C2000 H fender is used in this analysis figure (10).

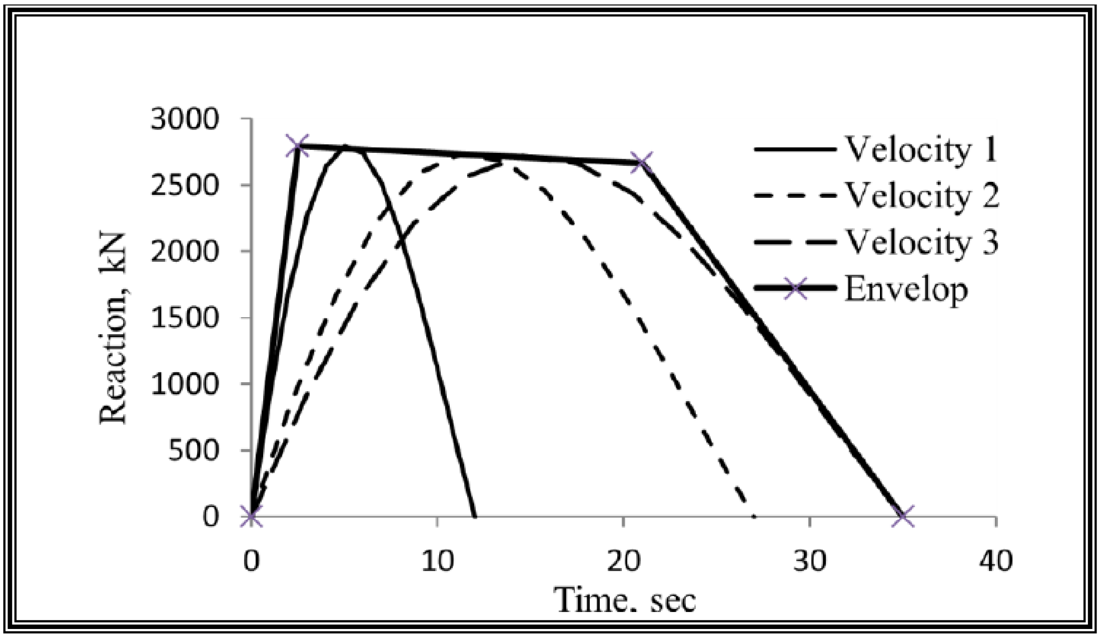


Figure (10) The reaction –time relation for C2000 H fender

## 8- Results and Discussion

The reaction –time relation for C2000 H fender is used to simulate the impact activity on the port. AL-Basrah oil port figure (11) is used as a case study to find the response under the load . The results show that the natural frequencies and mode shapes are found by eigenvalue analysis . The natural frequencies of structure are shown in figure (12) for the elastic and plastic model of soil with different embedded length of pile . The deck displacement of elastic model is less than for deck which is supported by embedded piles in elastoplastic soil as shown in figures (13,15). The shear force and bending moment at the pile head in plastic model are less than for elastic model. The difference in results due to the fixation of pile in elastic model is close up to the sea bed which makes the rotation in pile head in elastic model more than for plastic model.

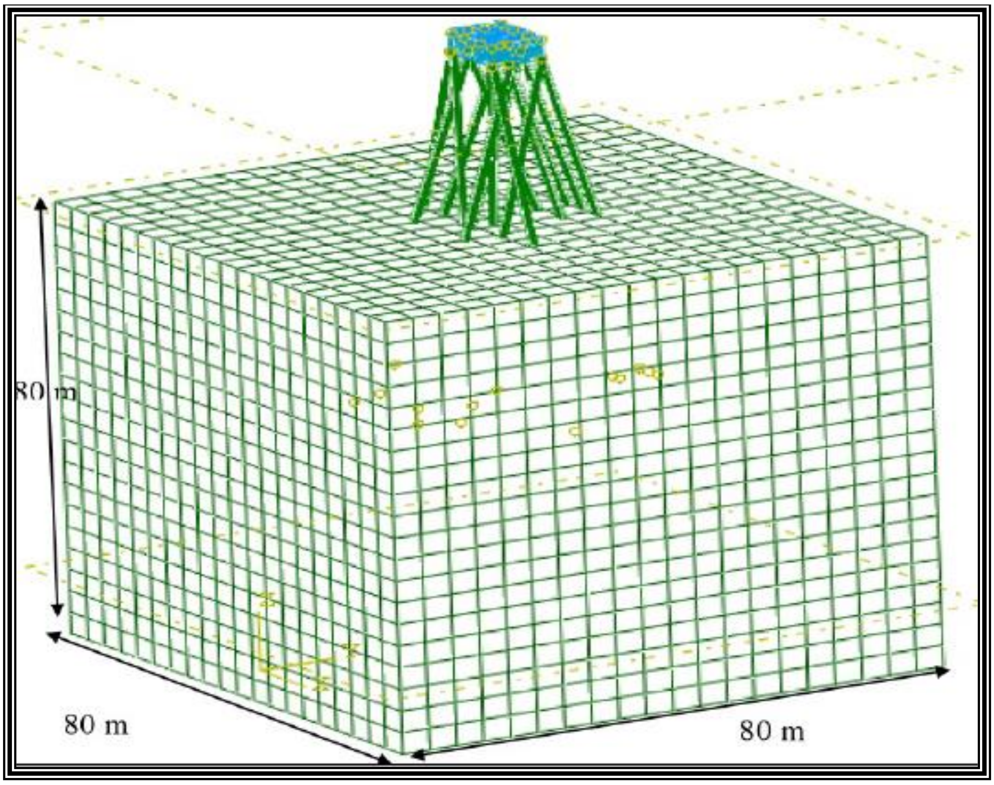


Figure (11) AL-Basrah oil port Model.



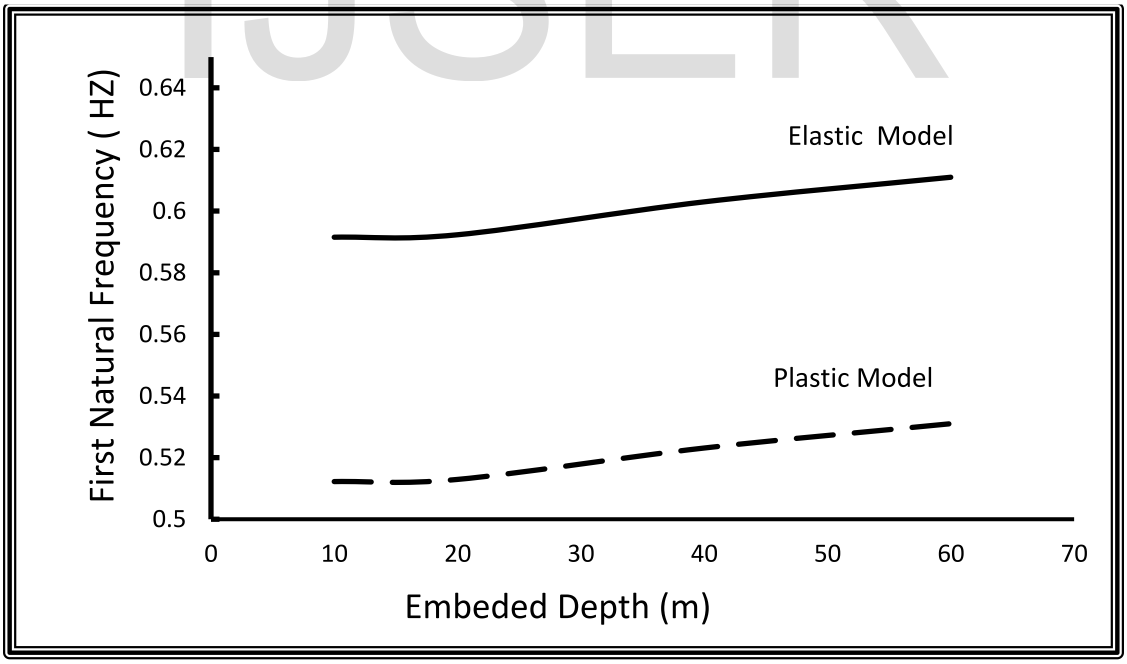


Figure ( 12) Natural frequencies for elastic and plastic Model .

| Item | Elastic Model | Plastic Model |
|---|---|---|
| Max. Deck Displacement( cm) | 10.61 | 11.78 |
| Max. Axial force(kN) at P1 | 1134 | 1270 |
| Max. Shear force (kN) at P1 | 315 | 286 |
| Max. Bending Moment (kN-m) at P1 | 967 | 880 |

Table(2) Maximum value of structural response of different soil model.

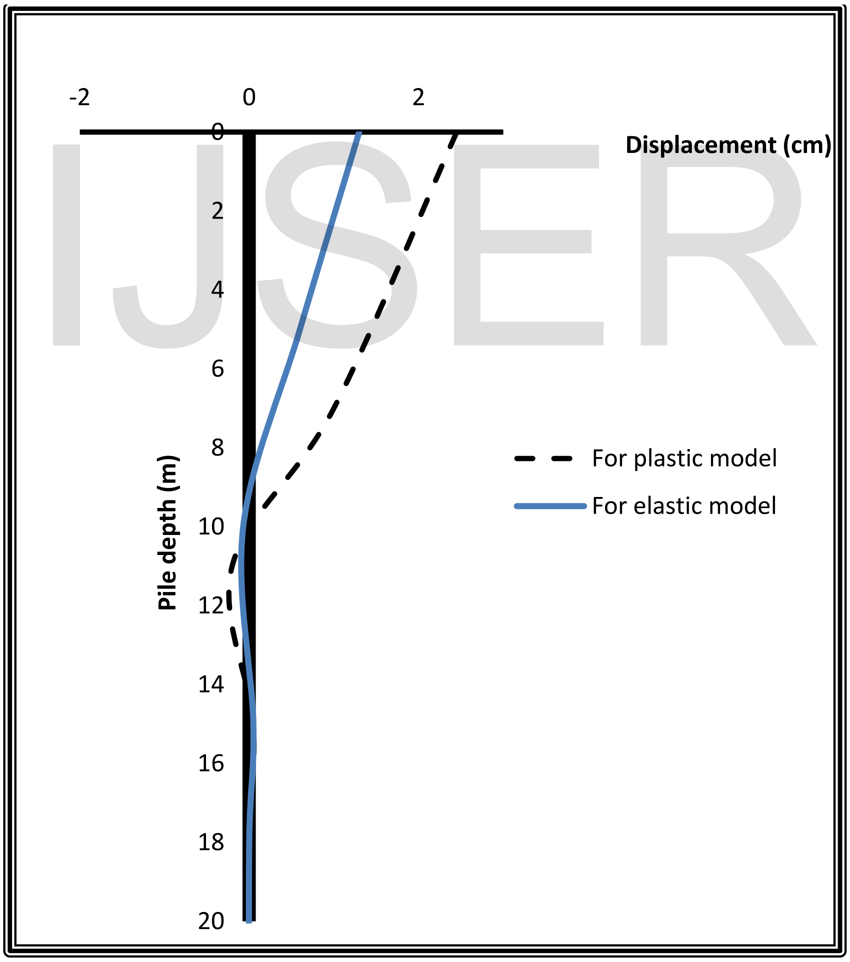


Figure (13) Pile displacement along length.

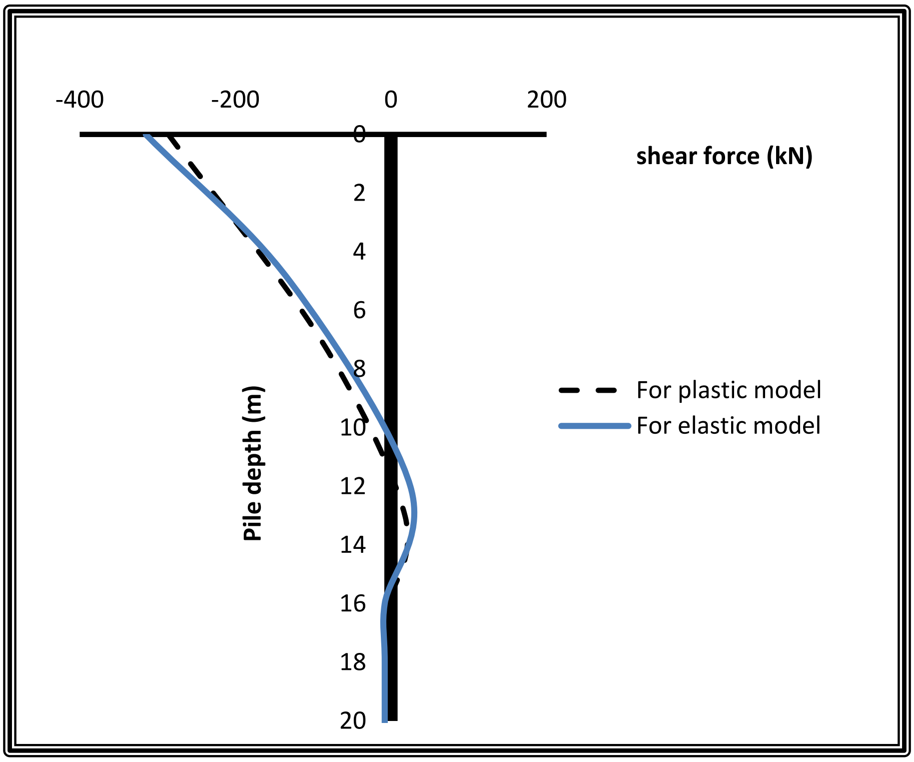


Figure (14) Pile shear force along length .



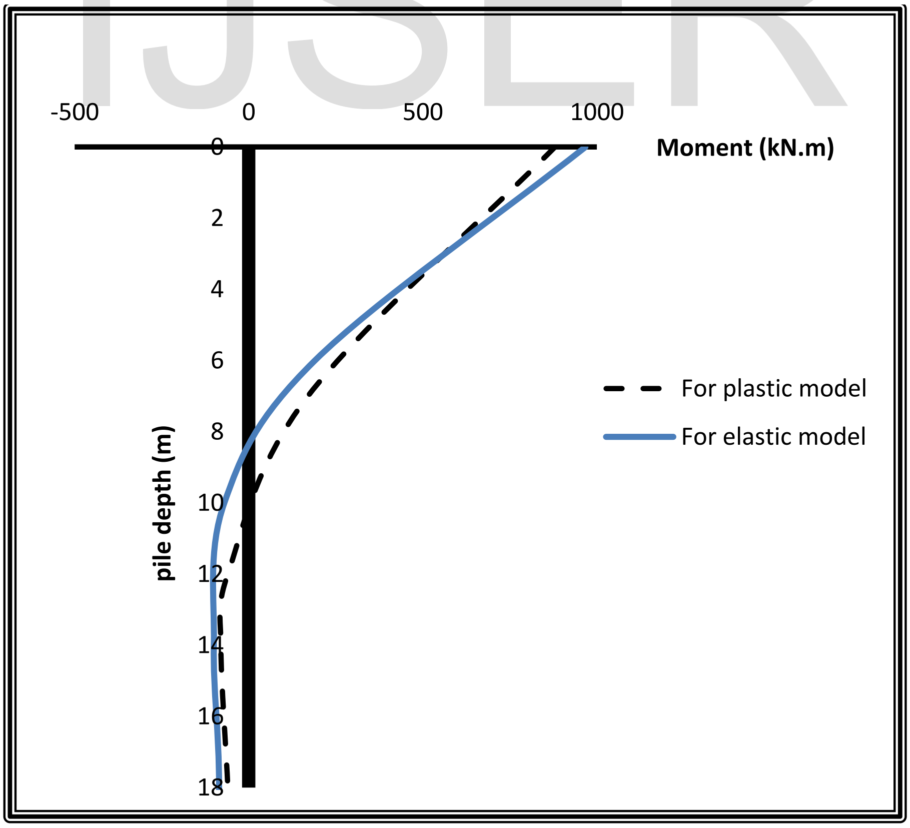


Figure (15) Pile bending moment along length.

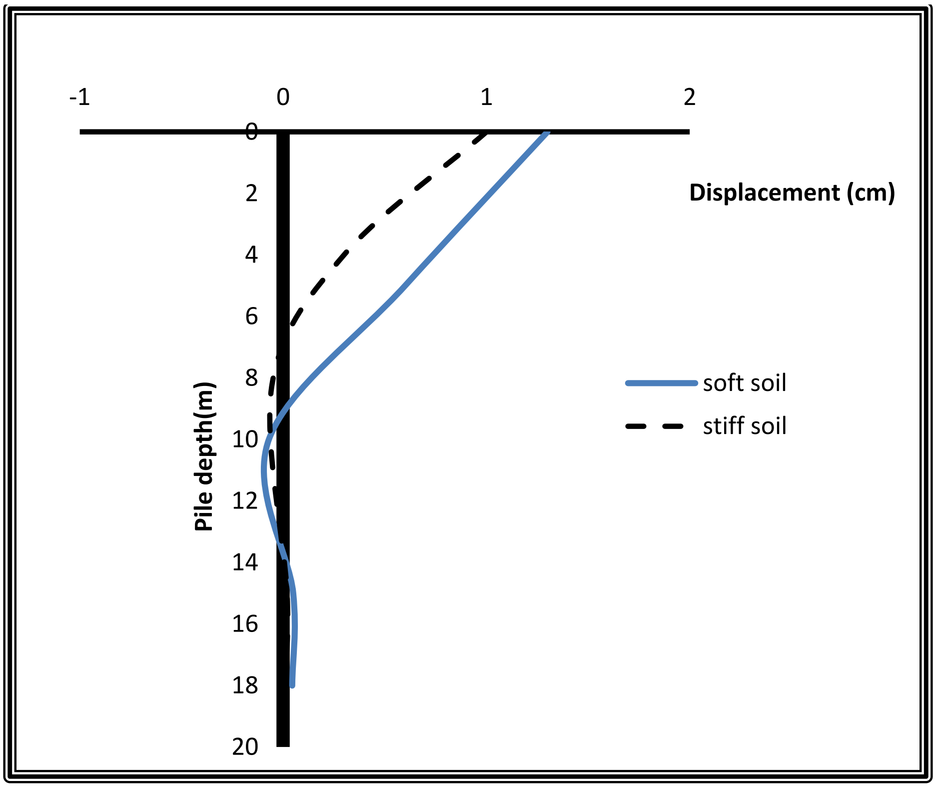


Figure (16) Pile displacement along length for soft and stiff soil.



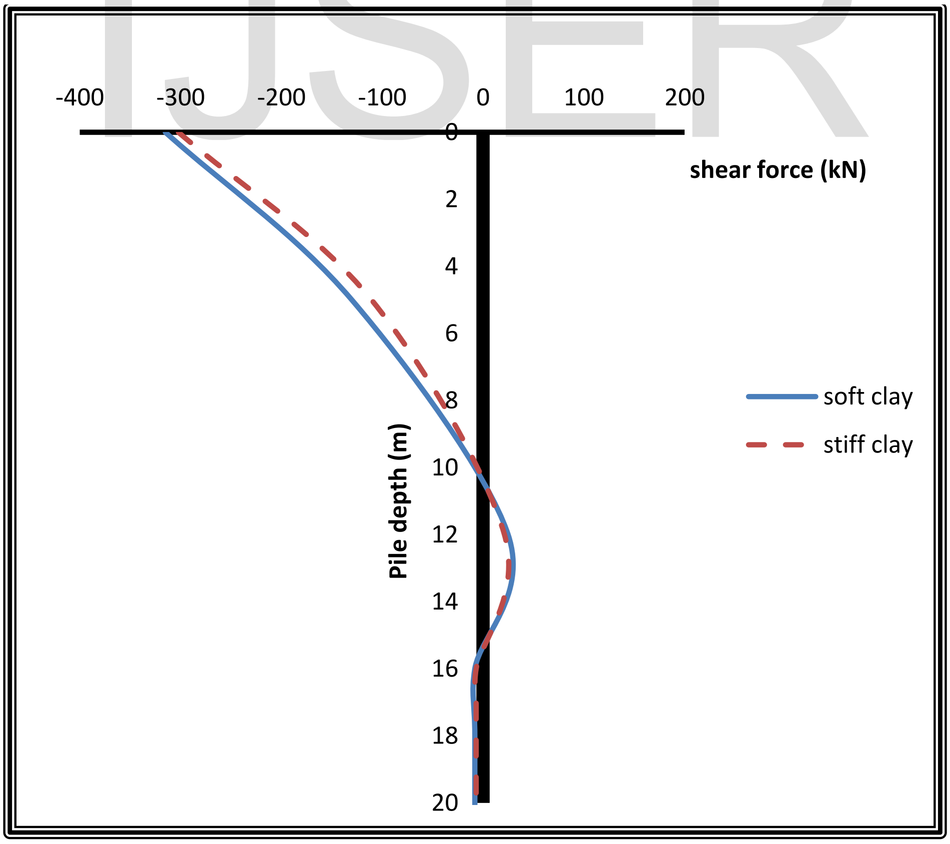


Figure (17) Pile shear force along length for soft and stiff soil .

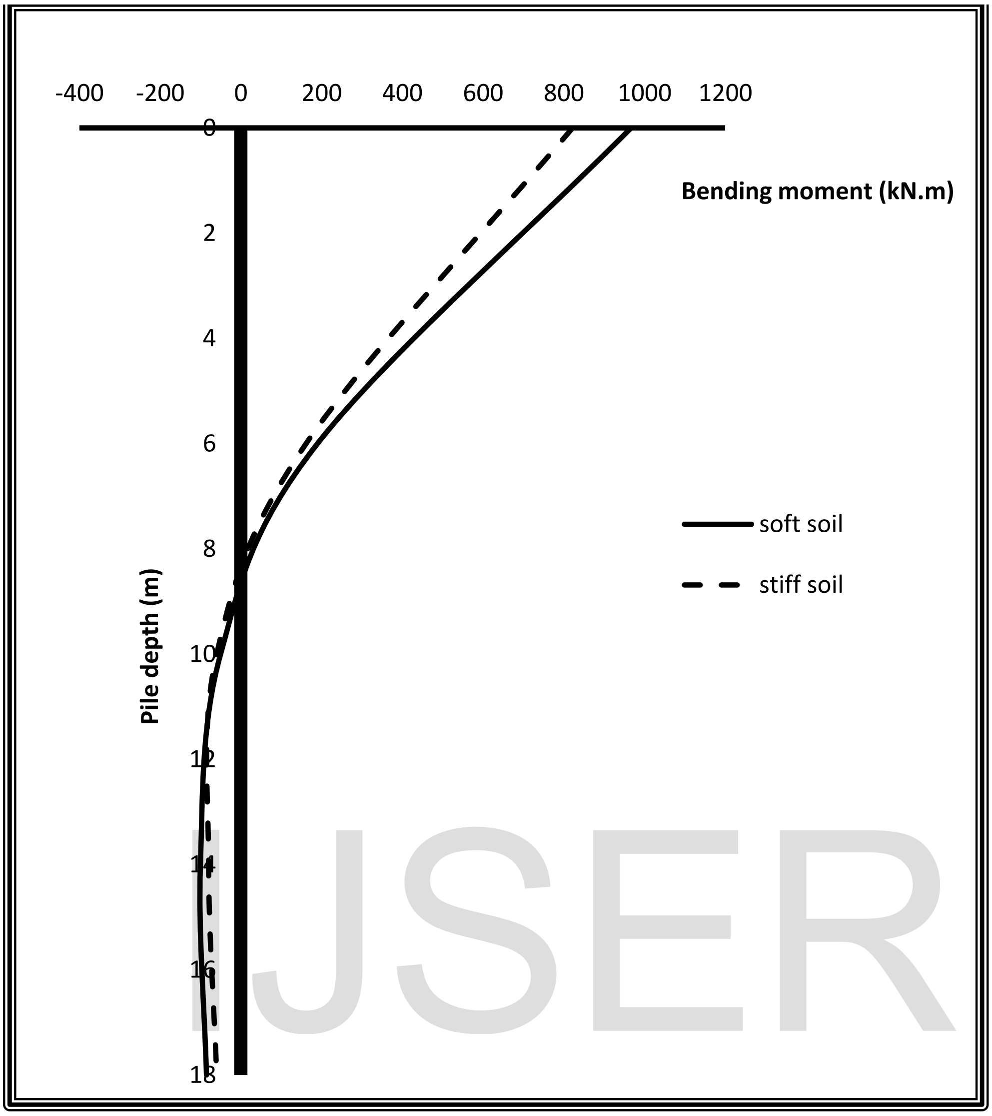


Figure (18) Pile Bending moment along length for soft and stiff soil .

## 9- conclusion

The main conclusions are :

1- The natural frequencies for structure at elastic model of soil are more than for plastic model by amount reaches +15%.
2- The natural frequencies is less effected when the embedded pile length in more than 50m due to the restrain behaves as constant for deep pile.

**3-** There is a sensitivity of soil to the used model and there are effects on the response of structure.

**4-** There is an increase for the magnitude of response of structure in soft soil more than for stiff soil.

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