

Studying the Behavior of Axially Loaded Single Pile in Clayey Soil with Cavities

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Received on: 4/1/2011

Accepted on: 5/5/2011

Abstract

This paper deals with the interaction between cavities and adjacent axially loaded pile in clayey soil using the three dimensional finite element program (ANSYS 11.0). Three dimensional SOLID45 and SOLID65 elements were used to model the soil and the reinforced concrete pile respectively. Druger- Prager model is chosen to simulate the non-linear elastic-plastic clayey soil, concrete model is used to simulate the non-linear behavior of concrete pile, the steel bars are assumed to be embedded in concrete section.

A comparison of the behavior of load-settlement curve, shear stress on pile (τ_{xy}) and lateral soil stress on pile (σ_x) is made for cases of the variation in the cavity positions in the vertical direction (Z-direction) with case of no cavity. It has been found that the effect of the cavity on the shear stress along pile length (τ_{xy}) and on the lateral soil stress on pile (σ_x) is ignored to the depth greater than (20%) of the pile length from the ground level. Furthermore, the load-settlement curves are quite difference if compared with reference case of no cavity due to the cavity position near the face of pile.

Keywords: Axial load, Single pile, Clayey soil, Cavity, Shear Stress, Lateral Soil Stress.

دراسة تصرف الركيزة المنفردة المحملة محورياً في التربة الطينية الحاوية على الفجوات

الخلاصة

يتناول هذا البحث التداخل الحاصل بين الفجوات و الركيزة المجاورة المحملة محورياً في التربة الطينية باستخدام برنامج (ANSYS 11.0) للعناصر المحددة ثلاثية الابعاد. تم استخدام العناصر الثلاثية الابعاد (SOLID45) و (SOLID65) لتمثيل التربة و الركيزة الخرسانية المسلحة على التوالي. تم تمثيل التربة الطينية المرنة-اللدنة غير الخطية باستخدام نموذج (Druger- Prager)، اما الركيزة الخرسانية ذات التصرف اللاخطي تم تمثيلها باستخدام نموذج (concrete)، تم افتراض ان قضبان حديد التسليح مطمورة ضمن مقطع الخرسانة. اجريت مقارنة لتصرف منحنى الحمل - الهبوط، اجهاد القص على الركيزة (τ_{xy}) و اجهاد التربة الجانبي على الركيزة (σ_x) في حالة تغيير مواقع الفجوة في الاتجاه العمودي (محور Z) مع حالة انعدام الفجوة. وجد ان تأثير وجود الفجوة على اجهاد القص على طول الركيزة (τ_{xy}) و على اجهاد التربة الجانبي على الركيزة (σ_x) يهمل لعمق اكبر من (20%) من طول الركيزة من مستوى الارض. بالاضافة الى ذلك، تختلف منحنيات الحمل-الهبوط بشكل كبير اذا ما قورنت بالحالة المرجعية (حالة انعدام الفجوة) نتيجة لموقع الفجوة القريب من وجه الركيزة.

1. Introduction

Several attempts have been made during the last decades to explain the behavior of piles in soil; some

of these attempts are based on numerical approaches. One of the main numerical methods is the finite element approach. (Abdelrahman and Elragi, 1997)

investigated the load-displacement behavior of axially loaded pile in sandy soil using the finite element program ANSYS (5.4). They made a comparison between the results of finite element analysis and laboratory test results which found to be quite close. (Smith, 1980) and (Chow, 1992) summarized the numerical methods used in the analysis of vertically loaded single pile. (Soltani, 2008) studied the effect of the nonlinear behavior of soil and the contact between the sidewall of the pile and soil on the pile foundations while they are under lateral loading and bending moment by using ANSYS program.

(Aziz, 2008) investigated the behavior of a laterally loaded pile embedded into cohesionless (sandy) soil of Al-Najaf city with cavity. An experimental and numerical study presented the interaction between cavity and adjacent pile in sandy soil. Numerical simulations were conducted using (3DSPARNO) program. The computer program uses a finite element technique to solve the three dimensional problems of variations in the cavity locations in Y-direction (the cavity traction in the direction perpendicular to the paper) and to simulate the effects of irregular shapes of cavities which exists as a close space into natural soil of Al-Najaf city.

(Mroueh and Shahrour, 2002) examined the effect of the impact of construction of urban tunnels on adjacent

Pile foundations. It was carried out using an elastoplastic three-dimensional finite element modeling. Numerical simulations are performed in two stages, which concern, respectively, the application of the pile axial loading and the construction of the tunnel in presence of the pile foundations.

Analysis was carried out for both single piles and groups of piles. Results of numerical simulations show that tunneling induces significant internal forces in adjacent piles.

This research aims to study the interaction between cavity and adjacent axially loaded pile embedded in clayey soil. In general, the formation of cavity in soil may be attributed to the gypsum dissolution or decomposition of organic matter that leads to generate many cavities of different irregular shapes at various locations below ground surface. In this study, the variation of cavity positions in the vertical direction (Z-direction) is investigated by using numerical method (finite element ANSYS 11.0 program).

2. Analytical Models

A commercially available finite element program (ANSYS 11.0) is employed to simulate the soil-pile-cavity interactions. Drucker Prager model is chosen to simulate clay soil. Also, concrete model is used to represent pile.

2.1 Soil Model

The 3-D Solid 45 is used for modeling the homogeneous soil; the element is defined by eight nodes brick element having three degrees of freedom at each node, translations in nodal X, Y and Z directions and considers nonlinearities of plasticity, creep, nonlinear elasticity, swelling, large displacements and strains (ANSYS Manual). The soil is assumed to be homogeneous isotropic, and elastic-perfectly plastic (Moaveni, 1999).

2.2 Pile Model

The 3-D Solid 65 elements were used to model the concrete. The Solid 65 element has eight nodes with three degrees of freedom at each node, translations in nodal X, Y and Z

directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing (ANSYS Manual). The rebar capability of this model was considered (the steel bars are assumed to be embedded in concrete section) (Reddy et.al, 2007).

2.3 Contact Surface

The interaction at the pile-soil surface is represented by using the 3D contact element CONTACT174 which represents the weaker material "soil" and TARGET170 which is used to represent the 3-D "target" surfaces (the stronger material "pile"). This target surface is discretized by a set of target segment elements (TARGET170) and is paired with its associated contact surface (CONTACT174) via a shared real constant set (ANSYS Manual).

3. Verification of the Model

In this section, a vertical bored pile studied by (Ismael, 2001) by adopting a finite element method program (ANSYS 11.0) has been considered for the validation of the program developed during this study.

The pile parameters and cemented sand soil parameters are shown in tables (1) and (2) respectively. Due to symmetry, one quarter of this problem is considered; the finite element mesh is shown in Figure (1). The boundary conditions for the problem are: the bottom face of the model (BDFH) is fixed (restricted in all directions); the side zones (ABDC, AGHB, GEFH, and ECDF) are hinged (restricted in X and Z directions) as shown in Fig. (1).

Figure (2) shows the results of the present study compared with previous work of (Ismael, 2001). The results of the present study with (ANSYS 11.0) show a good agreement with the

experimental results over a large part of the curve.

4. Case Study

This parametric study of the research is dealt with the behavior of the single pile under axial load; comparison of the results is made in case of no cavity and in case of the variations of the cubical cavity locations in Z-direction (in the vertical direction).

In these analyses soil, pile and cavity are represented by three dimensions (the cavity idealization as a hole subtracted from soil volume). In this study, numerical simulations were conducted by means of the finite element program (ANSYS 11.0) which provides flexible features for the analysis of the three dimensional and non-linear Soil-Pile-Cavity interaction problems.

The cavity location is assumed to be identical to the center line of pile. As a result to the symmetry, the half of model is used as shown in figure (3). The outer boundary conditions of the mesh are: fixed at the bottom of the model (restricted in X, Y and Z directions), hinged against displacements at the sides of the model (restricted in X and Y directions). At the top face of the model, the degree of freedom is free in all directions.

The soil domain considered from the center line of pile is (6.25 m) in X direction and (6 m) in Y direction. The depth of soil is taken as (20 m) as seen in Figure (3). The pile diameter is (0.5 m), the pile length is (15 m) embedded in clayey soil, and the material properties of concrete, steel reinforcement and soil are shown in table (3).

For all model tests in this research, the cubic cavity position in X-direction and

Y-direction are constant. In X-direction, the cavity is located at horizontal distance equal to ($X=0.25$ m) from the front face of the pile to the left side of the cavity, while the distance in Y-direction is fixed at ($Y=0.75$ m) due to symmetry. The distance in Z-direction is considered as a vertical distance from ground surface level to the top of the cavity which is varied to ($Z=1.3, 1.5, 3, 6, 9, 12, 15$ m) as illustrated in Figure (3).

5. Results and Discussion

The results obtained from (ANSYS 11.0) of this research will be discussed through the effect of cavity on vertical displacement, lateral soil stress on pile and shear stress on pile.

5.1 Effect of Cavity on Vertical Displacement (U_z)

The finite element results were used to generate axial load – vertical displacement curves (P-Y curves) at pile head for the cavity cases at depth ($Z=1.3, 1.5, 3, 6, 9, 12, 15$ m), in addition to no cavity case as shown in Figure (4).

It is interesting to note that the load-displacement curves are different if compared with no cavity case due to the cavity position which is studied at a close distance from the pile facing (at $X=0.25$ m) (the cavities exist in the region of the passive stability of the pile). It should also be noted that the load-displacement curve for all the models expect for cases of cavity at depths $Z=3$ m and $Z=9$ m are the same up to (500 kN) load, beyond this load the load-displacement curves exhibit some difference in values. It can be seen from Figure (4) that the effects of the cavity position in Z-direction are very high for the cases of cavity depths ($Z=1.3$ m, $Z=3$ m and $Z=15$ m) and

generally decrease at cavity depth ($Z=12$ m) at which the P-Y curve is much closer to the case of no cavity. Also, it can be seen the lowest resistance of the soil is investigated in case of cavity ($Z=1.3$ m) (the soil is weakest and the vertical displacements develop rapidly with increasing axial load).

5.2 Effect of Cavity on Lateral Soil Stress (σ_x)

Figure (5) presents the influence of the cavity position in Z-direction on the lateral soil stress distribution (σ_x) along the pile length due to axial load increments of (1000, 1500, 2000, 2500 and 3000 kN) for all cases of cavity depth ($Z=1.3, 1.5, 3, 6, 9, 12, 15$ m) and for case of no cavity.

It is clear from Figure (5) that the maximum values of the lateral soil stress (σ_x) are observed at the ground surface level, and then these values decrease with the increase of the depth below the ground surface level. Moreover, the soil stress on pile (σ_x) at depth (2 m) from the ground level decreases for all models of cavity position in Z-direction if compared with the reference case of no cavity which may be attributed to the reduction in soil volume due to cavity. Also, all figures show that the magnitudes of the lateral soil stress distribution (σ_x) along the pile length are of negative sign (compression). But, in case of the cavity depth ($Z=1.5$ m) the magnitudes of the lateral soil stress are turned to positive sign (tension), this is due to the fact that the cavity position leads soil particles toward the right side of the cavity as illustrated in figure (5-c)

For the load increment (axial load $P=2000$ kN) as shown in figure (6), the effect of the variation in the cavity location in Z-direction for the lateral soil stress distribution (σ_x) is limited to

20% of the pile length from the ground surface (at depth equal to (3 m)). But, in case of cavity depth ($Z=15$ m) the soil stress would increase near the location of cavity.

5.3 Effect of Cavity on Shear Stress on Pile (τ_{xy})

Figure (7) shows the effect of the cavity position in Z-direction on the shear stress distribution (τ_{xy}) along the pile length due to axial load increments of (1000, 1500, 2000, 2500 and 3000 kN) for all cases of cavity depth ($Z=1.3, 1.5, 3, 6, 9, 12, 15$ m) and for the case of no cavity. It is obvious from curves that the maximum values of shear stress on pile (τ_{xy}) occur at the pile head (the ground level) and then decreases with depth until depth equal to (8 m) under ground level and then return to increase especially above the base of the pile. The distribution of shear stress on pile in cases of cavity at depth ($Z=1.3$ m) and ($Z=3$ m) shows some difference if compared with the case of no cavity.

A comparison is made for the load increment (axial load $P=2000$ kN) for all cases as shown in figure (8), it is found that the effect of cavity position in Z-direction for the shear stress distribution (τ_{xy}) extended to 20% of the pile length from the ground surface (at depth equal to (3 m)). Furthermore, the shear stress on pile increases at the ground surface especially in case of cavity positions ($Z=1.3, 3, 15$ m) and decreases at depth equal to (2 m) under the ground level in cases of the cavity depth ($Z=1.3, 3$ m).

6. Conclusions

The following are the main conclusions that can be drawn from finite element results of soil-pile-cavity interaction:

1. The lowest resistance of the soil is investigated in case of cavity depth

($Z=1.3$ m) where the vertical displacements develop rapidly with increasing the axial load.

2. The effect of cavity position on the shear stress and on the lateral soil stress on pile is neglected to the depth ($Z > 3$ m), in other words, at depth greater than 20% of the pile length, but in case of the cavity position at depth ($Z=15$ m) from the ground level, the lateral soil stress on the pile is increased.
3. The shear stress on the pile increases at the ground surface especially in case of cavity positions at ($Z=1.3, 3, 15$ m) from the ground level.
4. The lateral soil stresses on the pile are transformed to tension in case of cavity location at depth ($Z=1.5$ m) from the ground level if compared with other cases.

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Table (1): Pile parameters (after Ismael, 2001).

Properties	Values
Width (B), m	0.1016
Length (L), m	2.25
Modulus of elasticity(E_p),kN/m ²	20 000 000
Poisson ratio (ν)	0.2
Unit weight (γ), □□kN/m ³	23

Table (2): Cemented sand soil parameters (after Ismael, 2001).

Properties	Values
Modulus of elasticity(E_s),kN/m ²	25000
Poisson ratio (ν)	0.37
Cohesion, kN/m ²	20
Unit weight (γ), □□kN/m ³	18.5
Angle of internal friction (ϕ),deg.	35
Angle of dilation (ψ),deg.	0
Angle of friction (δ_a),deg.	26.25
Adhesion, (C_a), kN/m ²	13.33

Table (3): Concrete pile, steel reinforcement and soil properties used in the analysis.

	Concrete	Reinforcement	Soil
Modulus of elasticity (E) (kPa)	25,000,000	200,000,000	22,000
Poisson's ratio (ν)	0.3	0.3	0.45
Cohesion (S_u) (kPa)	-	-	55
Angle of internal friction (ϕ)	-	-	0°

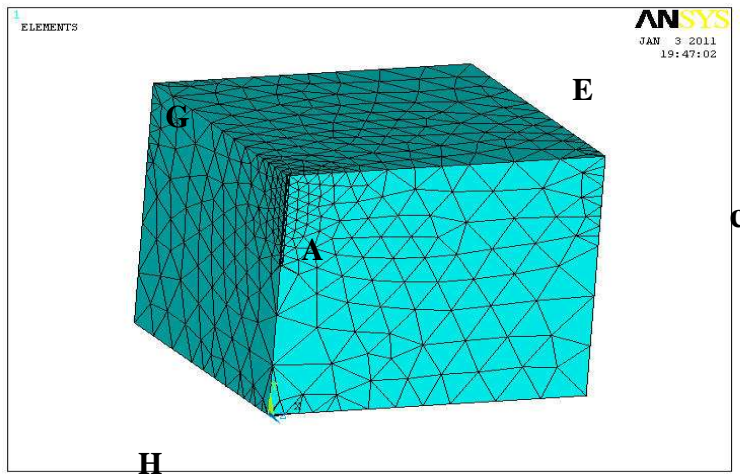


Figure (1): Finite element mesh for the single pile (present study ANSYS).

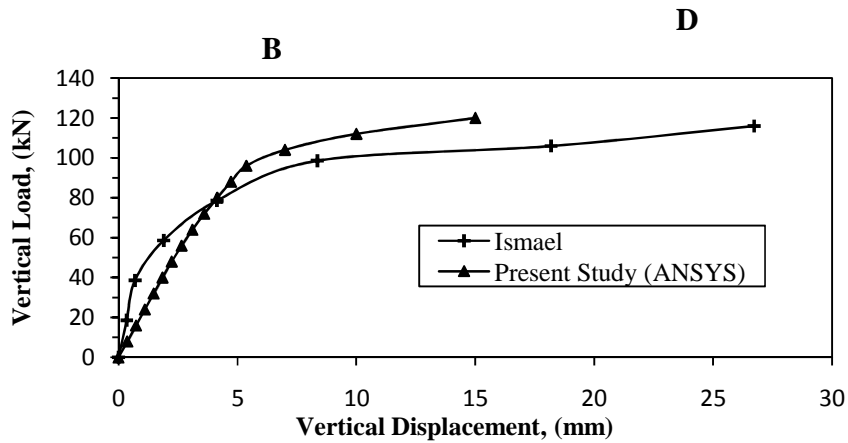


Figure (2): Comparison between present study and (Ismael, 2001) for vertical bored pile.

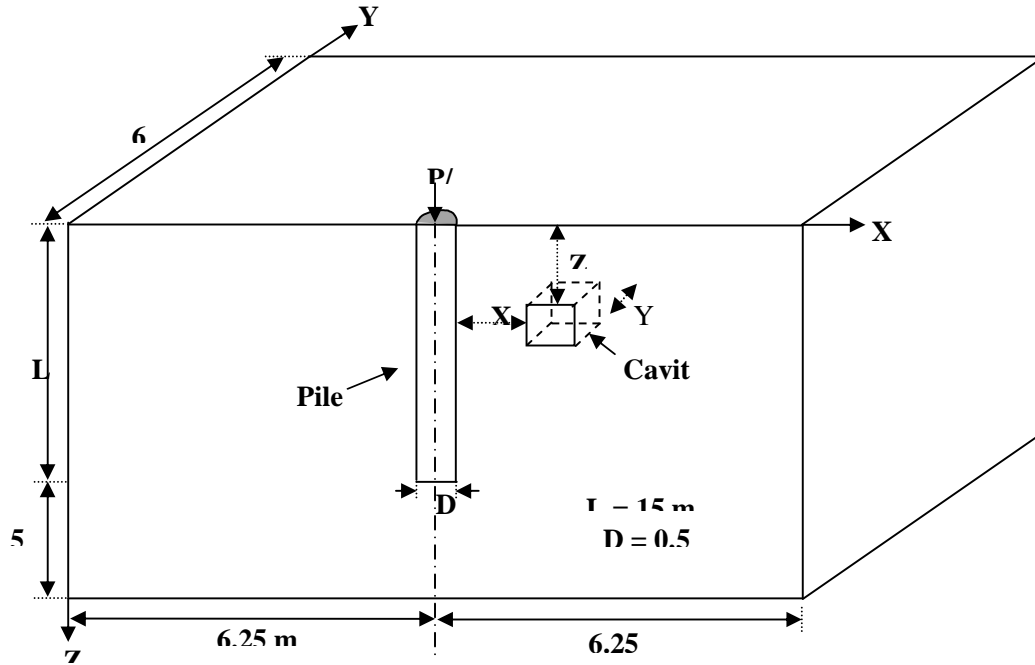


Figure (3): Soil domain used for all models and dimensions of pile and cavity.

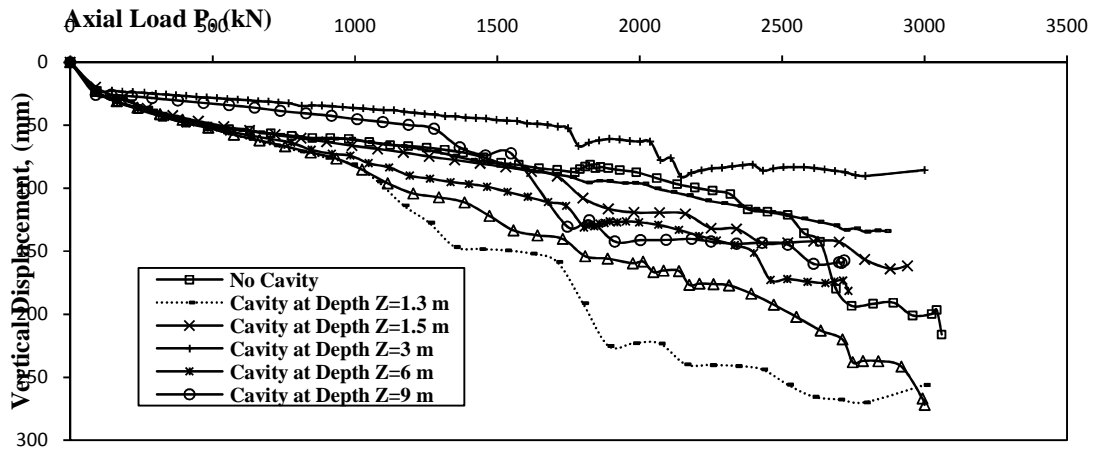


Figure (4): Influence of cavity position in Z-direction on axial load- vertical displacement curves.

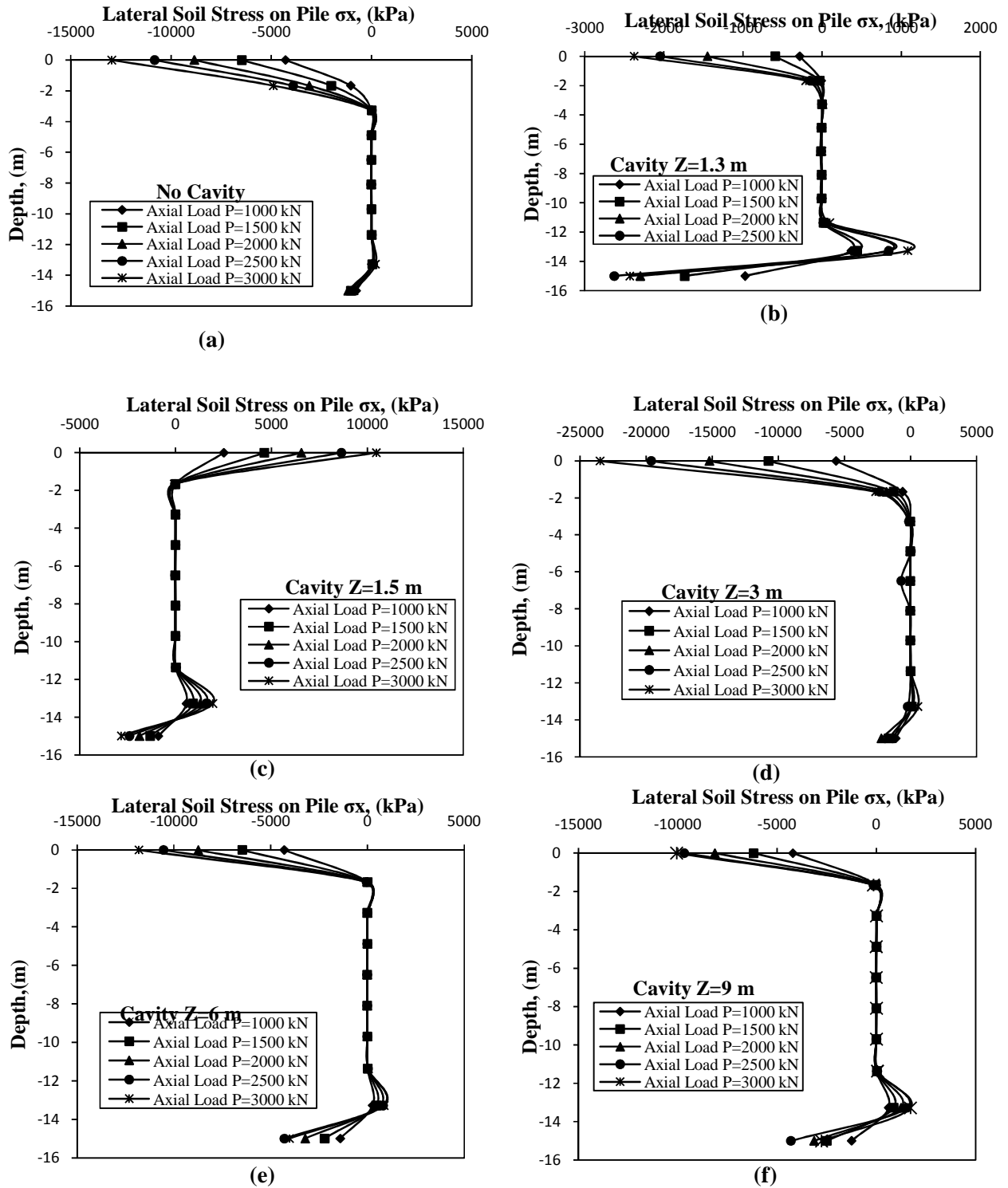


Figure (5): Curves showing the lateral soil stresses on pile (σ_x) versus depth (below natural ground surface) at several axial load levels.

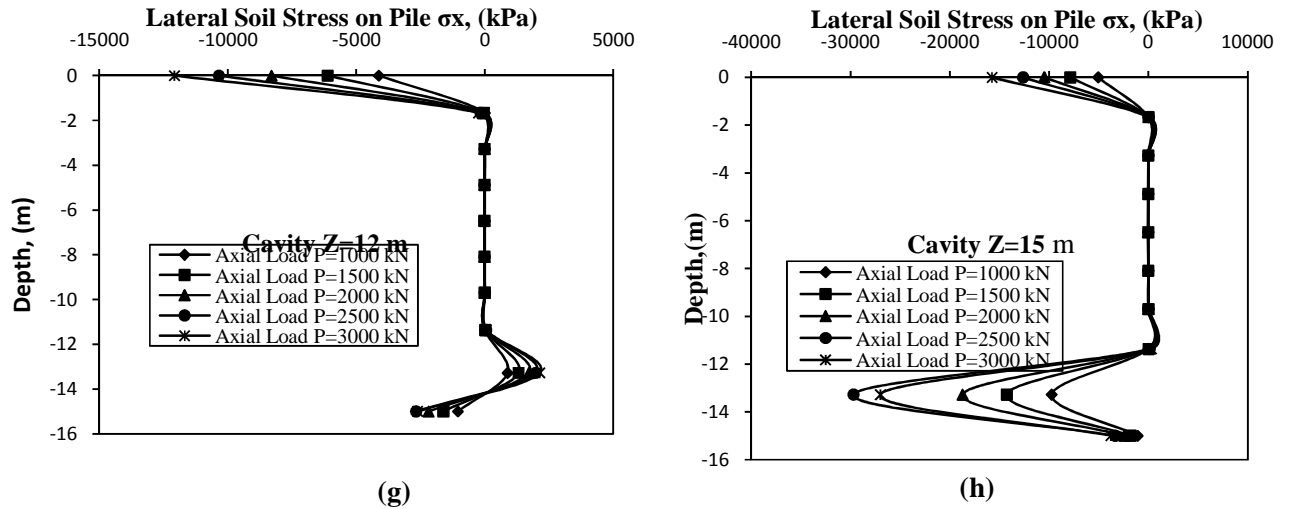


Figure (5): Curves showing the lateral soil stresses on pile (σ_x) versus depth (below natural ground surface) at

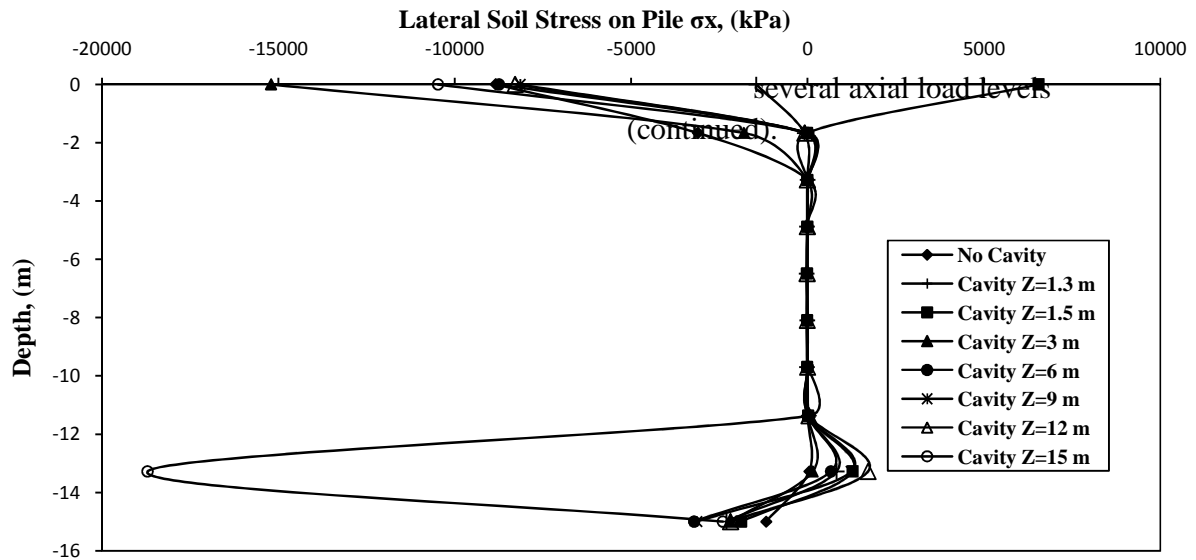


Figure (6): Comparison of the lateral soil stress distribution with depth at axial load $P=2000$ kN.

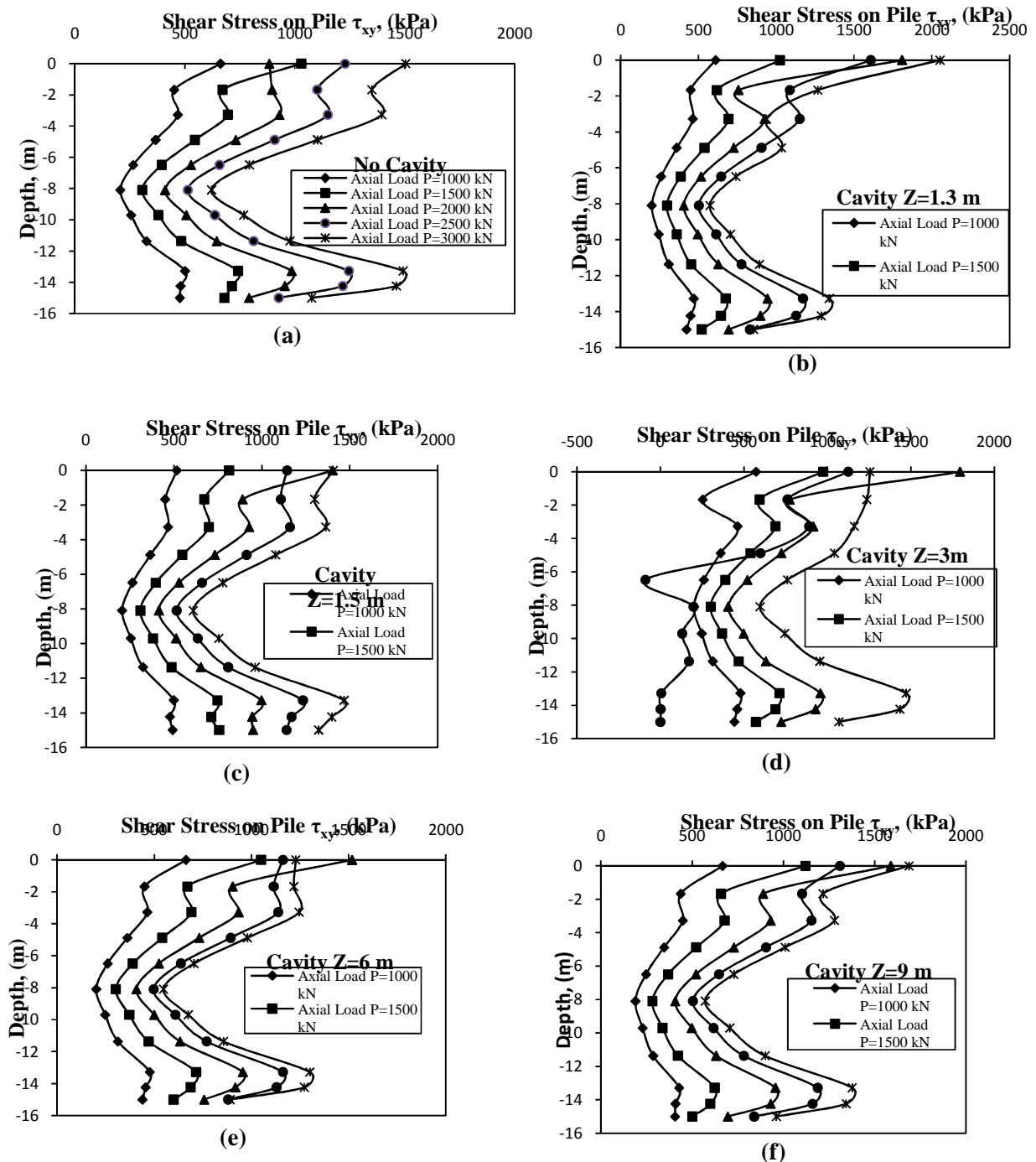


Figure (7): Curves showing the shear stresses on pile (τ_{xy}) versus depth (below natural ground surface) at several axial load levels.

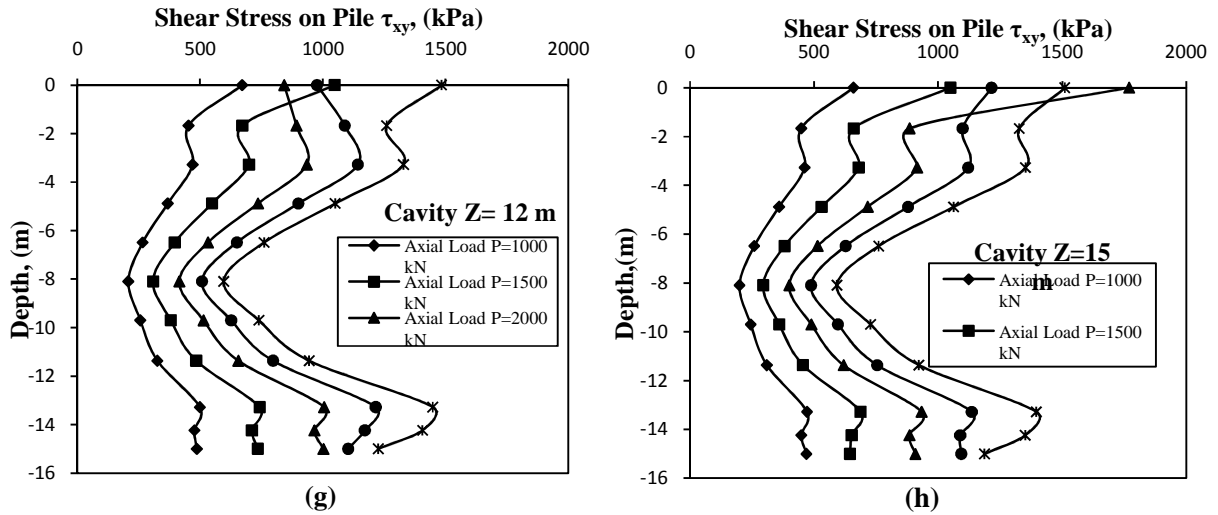


Figure (7): Curves showing the shear stresses on pile (τ_{xy}) versus depth (below natural ground surface) at several axial load levels (continued).

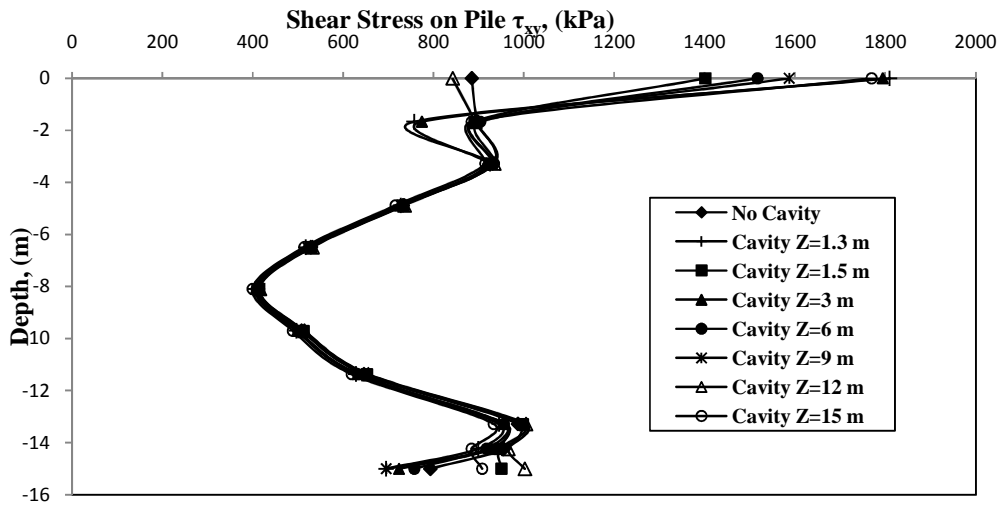


Figure (8): Comparison of the shear stress distribution with depth at axial load $P=2000$ kN.