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Simulating the behavior of a piled raft foundation overlying a tunnel using FEM

Simuler le comportement d'une fondation de radier sur pieux recouvrant un tunnel en utilisant MEF

Haider Al-Laban & Mohammed Fakhraldin

Civil Engineering Department, Kufa University, Najaf, Iraq, haiderehsan22@yahoo.com

ABSTRACT: This paper presents a finite element analysis to investigate the behavior of the piled raft-tunnel system in rock and sand soil. Abaqus CAE finite element program is used to modeled and analyze the piled raft-tunnel system. Safety is a sign that it is focused on the service life of a traffic tunnel. It has affected the stresses and displacements of piled rafts of tall buildings. It has been analyzed with the sandy soil model, intact rock model, and debris rock model. The model conducted of the group (1×2) piled raft-tunnel, the clearance distance (H) is 130 mm from the pile tip to the top of the surface of the tunnel and the pile length (L) is 200 mm. A square cross-section of the tunnel is (100 × 100) mm acted on along the z-axis of model direction and it has a thickness of 2 mm. The vertical distance of the pile group base is 5 mm. Sandy soil model effected with a small value of stress 0.01809 MPa and high value of displacement 0.03844 mm otherwise in intact rock model and debris rock model gained the larger value of stresses and little value of displacements.

RÉSUMÉ: Cet article présente une étude par éléments finis pour étudier le comportement du système radeau-tunnel sur pieux dans les sols rocheux et sableux. Le programme d'éléments finis Abaqus CAE est utilisé pour modéliser et analyser le système radeau-tunnel sur pieux. La sécurité est le signe qu'elle se concentre sur la durée de vie d'un tunnel routier. Il a affecté les contraintes et les déplacements des radeaux empilés des immeubles de grande hauteur. Il a été analysé avec le modèle de sol sablonneux, le modèle de roche intacte et le modèle de roche de débris. Dans tous les modèles du groupe (1×2) radeau-tunnel sur pieux, la distance de dégagement (H) est de 130 mm de la pointe du pieu au sommet de la surface du tunnel et la longueur du pieu (L) est de 200 mm. Une section transversale carrée du tunnel est de 100 mm × 100 mm sur laquelle on agit le long de l'axe z de la direction du modèle et elle a une épaisseur de 2 mm. La distance verticale de la base du groupe de pieux est de 5 mm. Le modèle de sol sablonneux effectué avec une petite valeur de contrainte de 0.01809 MPa et une valeur élevée de déplacement de 0.03844 mm sinon dans le modèle de roche intacte et le modèle de roche de débris ont obtenu la plus grande valeur des contraintes et une faible valeur des déplacements.

KEYWORDS: numerical analysis, piled-raft, tunnel, sandy soil, rock

1 INTRODUCTION

(Das, 2019) assumes that the vertical stress of the foundation of a structure is flexible. In practice, the foundation is neither perfectly flexible nor infinitely rigid which is resting on the soil with elastic properties materials. The genetic classification of rocks from (McClean and Gribble, 2005) commonly used by geologist's groups rocks. The relationships of rock types in the classification frequently explain between different rock types within one large rock mass and provide a model to be tested by exploration. (Rao and Kameswara, 2011) uses of pile foundation to transfer loads through soft soil to a suitable bearing stratum and carry the foundation beyond the clear depth to provide safety in the case of the soil. (Lunardi, 2008) worked on the analysis of controlled deformation in rocks and soils of design and construction of tunnels that the deformation will occur as a result of excavation. It must be performed by theoretical means. The design stage is using analytical or numerical calculation instruments. Moreover, control of the deformation response occurs at the construction stage.

Won et al. (2006) developed the numerical method to verify by comparing the results with other numerical methods for pile groups. Through comparative studies, it has been found that the maximum load on the individual piles in a group is highly influenced by pile cap flexibility. The prediction of the lateral loads and bending moments in the pile cap is much more conservative in the present analysis than in FBPIer 3.0 and shows a larger lateral load and bending moment for various cap thicknesses.

Chaudhary and Amin, (2007) Investigated the application of a group of 1072 piles for controlling settlement of an important and sensitive structure founded on the weak rock. 2D axisymmetric and 3D finite element models are employed to

model the 9.0 m thick and 76 m diameter circular raft, underlying soil/rock, and a mix of annular and orthogonal pile layouts. It conducted the effectiveness of pile foundation in reducing settlement by comparing the results with the case of raft foundation alone. It showed the results of 2D axisymmetric and 3D FEM models are also compared and it is concluded that the numerically efficient 2D axisymmetric FEM model is capable of simulating the behavior of this complicated 3D problem with reasonable accuracy.

Zhao et al. (2008) studied the interaction between the pile and soft soil of the passive pile group subjected to soil movement was analyzed with a three-dimensional finite element model by using ANSYS software. The soil was assumed to be elastic-plastic complying with the Drucker-Prager yield criterion in the analysis. The large displacement of soil was considered and contact elements were used to evaluate the interaction between pile and soil. The influences of soil depth of layer and number of piles on the lateral pressure of the pile were investigated, and the lateral pressure distributions on the (2×1) pile group and on the (2×2) pile group were compared. The results show that the adjacent surcharge may result in significant lateral movement of the soft soil and considerable pressure on the pile.

Lee et al. (2010) conducted the study on a full scale. It tested several of cylindrical fallouts were observed in a tunnel under construction and temporary grouting, as well as immediate backfilling, was performed to control cavity expansion.

Experimental as well as empirical approaches were employed to estimate the fallout size and boreholes were drilled immediately after the installation of permanent reinforcement and the accuracy of the proposed Tunnel Electromagnetic Prospecting System (TEPS), a non-destructive experimental testing method used to estimate the fallout volume, is verified with borehole core data. It is found that the empirical approach

based on a bulking factor is easy to apply if a reference value is available.

Al-Omari, et al. (2016) investigated the behavior of a piled raft tunnel system in sandy soils. Small scale model tested in a sandbox with loading. It is placed perpendicular to the raft using a hydraulic winch. Five configurations of substrates were tested in the laboratory. The Effects of the pile length (L), the number of piles in the set, and the clearance distance between the pile tip and the top of the tunnel. Surface (H) on the load-bearing capacity of the stacked raft tunnel system.

(Karkush and Aljorany, 2019 and 2020), studied the foundation of digester tank that the circular raft foundation supports 193 piles, and they are analyzed as piled-raft instead of pile group and a circular pile cap. Davisson's method and Brinch-Hansen method were checked the ultimate carrying capacity of tested piles. Both of the supporting piles and the subgrade soil were shared resistance to the applied load of the structure. The expected settlement was reduced because of the large diameter raft.

2 VERIFICATION OF NUMERICAL MODEL WITH CASE STUDY

In the current study, a full three-dimensional (3D) FE model is created on Abaqus CAE v.6.14 software. As shown in Figure 1, The piled raft-tunnel is carried out by examined behavior for vertical and horizontal stresses and magnitude of displacement which were created at the vicinity region of the tunnel and pile group. The behaviors of models are tested with three kinds of sandy soil, intact rock mass and debris rock.

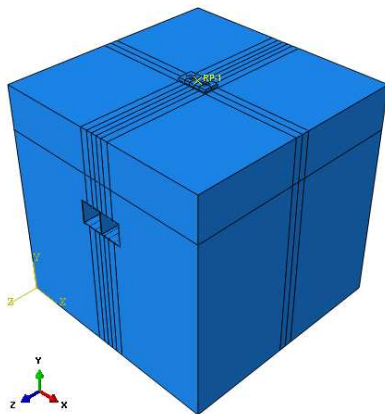


Figure 1. Piled raft-tunnel model

Dimensions of the model are (1 m) length, (1 m) width, and (1 m) height. The mechanical properties of piled, raft, and tunnel are made of the smooth aluminium hollow section (Al-Omari, Al-Azzawi and Al-Abbas 2016) for sandy soil as follows in table 1. The pile group (1×2) has a square cross-section of 25 mm × 25 mm and thicknesses of 1.5 mm. The spacing between piles is 75 mm. The foundation of the raft is located at the center of the model. The thickness of the raft is 12 mm with a length of 140 mm and a width of 65 mm. A square cross-section of the tunnel is 100 mm × 100 mm acted on along the z-axis of model direction and it has a thickness of 2 mm. The vertical distance of the pile group base is 5 mm, the pile length (L) is 200 mm. The clearance distance (H) is 130 mm from the pile tip and of the top the surface of the tunnel as depicted in Figure 2.

Table 1. Mechanical properties of the used aluminum alloy (Al-Omari, Al-Azzawi and Al-Abbas 2016)

Property	Value
Minimum yield strength (N/mm ²)	275
Minimum ultimate yield strength (N/mm ²)	310
Minimum % of elongation	12
Modulus of elasticity (MPa)	70000
Poisson's ratio	0.33

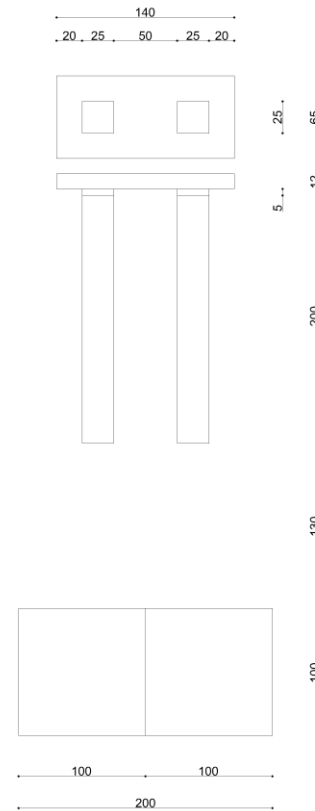


Figure 2. Dimension of Piled raft-tunnel model

(Lee, Sagong, Cho and Choo 2010) was working on a rock that it had carried out of the experimental study of two boreholes of fallouts during excavation on tunneling in Korea. The material properties were being considered at this simulation with both of Intact rock mass model and debris rock model as shown in table 2.

Table 2. Material Properties of Intact rock mass and weak zone (debris) (Lee, Sagong, Cho & Choo 2010).

Parameter	Intact rock mass	Weak zone (debris)
RMR	41-61	-
Q	1-10	-
Elastic modulus (MPa)	4800	650
Poisson's ratio	0.25	0.27
Unit weight (KN/m ³)	26	21
Cohesion (MPa)	2	0.2
Friction angle (°)	37	30
Tensile strength (MPa)	1	0.1

(Al-Omari, Al-Azzawi and Al-Abbas 2016) was examined some of the physical properties of test sandy soil. The soil is modelled as elasto-plastic material according to the Drucker-Prager constitutive relation. That dry unit weight of sandy soil was 15.92 KN/m³, the angle of internal friction and cohesion

were (37°), (0.3 KN/m²) respectively. The Young modulus was 50 MPa and the Poisson's ratio was 0.35. The numerical results obtained that the piled raft-tunnel in sandy soil was act on a concentrated load by an ultimate of 2.01 KN.

Mesh of elements were 8-nodes solid elements for all of the piles, raft, tunnel, and the tank of sandy soil and rocks as well.

In this verification, the model of the group (1×2) piled raft-tunnel of (H) equal to 130 mm and value of (L) was 200 mm.

The percentage of calibration is 60.5% between the Raid R. Al-Omari et al. model and piled raft-tunnel model under sandy soil behavior. Figure 3 viewed the maximum magnitude of load and settlement (2.01 KN), (40.3 mm) respectively while the yield value of load and settlement was (0.402 KN), (4.3 mm) respectively.

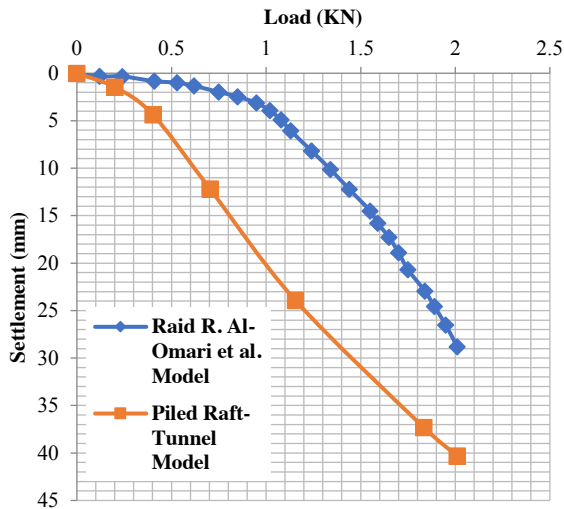


Figure 3. Vertical settlement versus vertical load of Calibration model between Raid R. Al-Omari et al. model and piled raft-tunnel model

3 RESULTS AND DISCUSSIONS

Table 3 describes the maximum magnitude of stresses and displacements. These are generated from applying the ultimate load (2.01 KN) to the sandy soil model, intact rock model and debris rock model. The intact rock mass model is given a maximum value of stress and displacement 0.03426 MPa and 0.0007347 mm, respectively. The debris rock model was impacted more than the sandy soil model where the ultimate values of stress and displacement were 0.02713MPa and 0.004737 mm, respectively. Sandy soil model was less value of Young modulus than of the previous model, therefore, it had effected of a higher value of displacement 0.03844 mm and little stress 0.01809 MPa at the neighbouring area of piled and tunnel.

Table 3. Result summary of models

Models	Ultimate stress (MPa)	Ultimate displacement (mm)
Intact rock mass	0.03426	0.0007347
Debris rock	0.02713	0.004737
Sandy soil	0.01809	0.03844

2D clustered column shown in Figures 4 and 5 compared values of vertical rectangles for the von mises stress for sandy soil model, debris rock model and Intact rock model 1.8E-02 MPa, 2.7E-02 MPa and 3.4E-02 MPa respectively.

Figure 6 shows the red region on the top of the piled-raft tunnel with sandy soil as much as widely to reach for a maximum value of magnitude of displacement 0.038 mm.

Von Mises stress for sandy soil model of Figure 7 was

0.01809 MPa that it is obvious on vicinity area of piles because the region is very close for applied load from piled-raft.

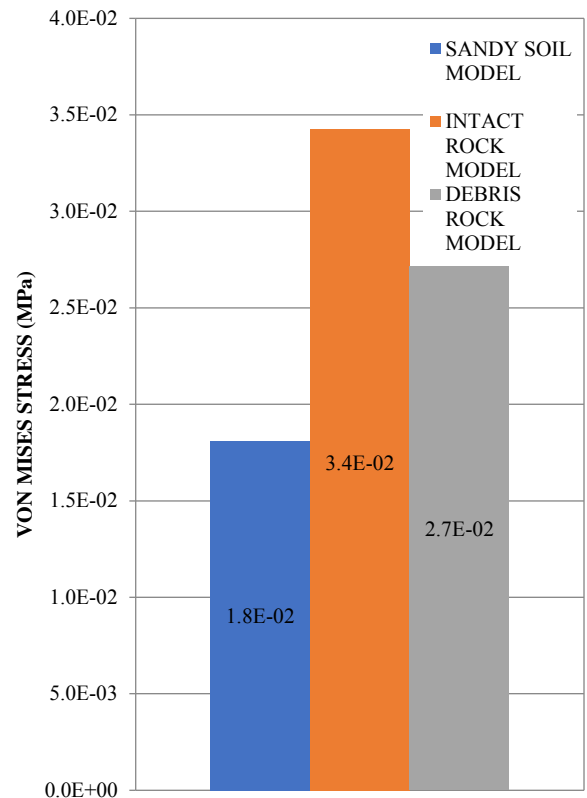


Figure 4. Comparison of von mises stress for sandy soil model, debris rock model and Intact rock model

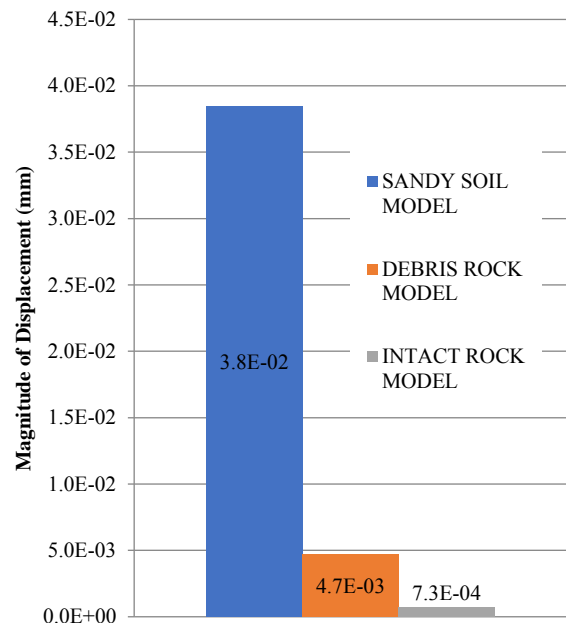


Figure 5. Comparison of the magnitude of displacement for sandy soil model, debris rock model and Intact rock model

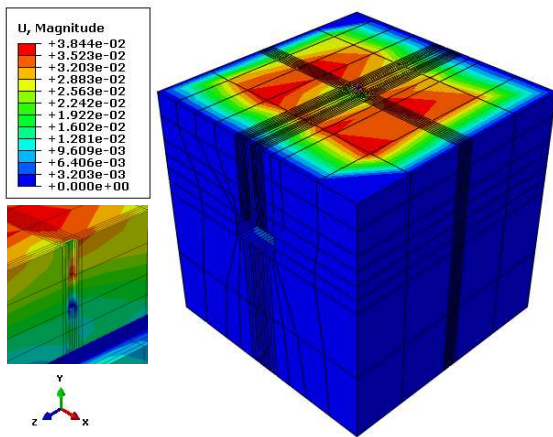


Figure 6. Magnitude of displacement for sandy soil model

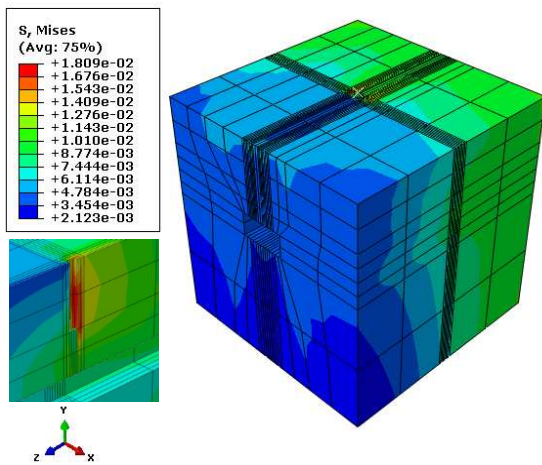


Figure 7. Von Mises stress for sandy soil model

4 CONCLUSIONS

1. The ultimate displacement of the sandy soil model is 0.03844 mm which is a higher value than intact and debris rock models. Because of Young modulus of sandy soil too much smaller than intact and debris rocks.
2. The value of ultimate stress of intact rock model is 0.03426 MPa bigger than values debris rock model and sandy soil model.
3. A full three dimensions' model of the piled-raft tunnel was created on Abaqus CAE v.6.14 software which is given an obvious result of stresses and displacements.
4. The vicinity area of the tunnel is more risk of applied load on the top of piled-raft foundation and it must take into consideration besides the design stage. Considering the tunnels under the piles is important and must be studied.
5. Foundation is an important part of every building, which interfaces the superstructures to the adjacent soil or rock below it. The superstructure loads will be transferred to the underlying soil or rock.

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