Lateral behavior of geogrid-reinforced unconnected piled raft

Mohsen Zokaei *[1], Mohammad H. Karami[2].

1. M.S. degree of geotechnical engineering, Shahed university, Tehran, Iran, mohsen.zokaei@yahoo.com
2. Assistant professor, Civil engineering department, Faculty of engineering, Shahed university, Tehran, Iran, mkarami@shahed.ac.ir

Abstract

Studying the behavior of deep foundations and piled rafts under different loads has been considered from many years ago. Lateral displacement of unconnected piled raft system is an important issue which should be controlled under static and dynamic load. In order to make the design of piled raft cost-effective, piles can be disconnected from the raft and a gravel cushion should be used between the pile heads and the raft to reduce stress concentration at pile heads considerably. However, large lateral displacements of unconnected piled rafts, as a defect, can be controlled by using geogrid in gravel cushion. In this paper, the lateral behavior of unconnected piled raft has been investigated via 3D models in ABAQUS software. In this regard, the effect of position and number of geogrid layers are studied.

Key words: Unconnected pile, ABAQUS, Geogrid, Lateral load.

1. Introduction

In designing a foundation, the first option which should be selected is a shallow foundation. In some cases, a large amount of settlement is expected for raft and a group of piles can be used under the raft whether connected or unconnected. Although connected piled raft or pile groups can be used some times, it is more cost-efficient to use unconnected piles with gravel cushion below huge structures.

Because of large vertical and lateral loads and moments, in the connection part of the pile heads and raft of connected piled rafts, there is great stress concentration which makes a design inappropriate. As an alternative, piles and raft can be disconnected from each other and a gravel cushion should be below the raft. The gravel cushion helps to distribute stress below the raft [1] [2] and decrease the stress at pile heads [3]. Unconnected piles are not considered as structural members and are applied as reinforcement of soil.

The most important defect of unconnected piled raft is its large lateral displacement which is caused by great loads such as earthquake, hydrostatic loads and so on. Only some numerical researches are conducted about lateral behavior of unreinforced unconnected piled rafts and effect of seismic loads on them [4] but there is no research about reinforced unconnected piled raft and no discussion about controlling lateral displacements. To decrease the lateral displacement of unconnected piled rafts, several approaches can be used such as: embedment depth of raft, shear key, geosynthetics and so on [5]. Using geosynthetics is an appropriate option which can improve the vertical [6] [7] and lateral behavior of unconnected piled raft.

Usually, a group of piles or piled rafts used in piers and abutments of bridges, harbors and so forth are subjected to static or dynamic lateral loads, which should be studied to prevent serious damages. Although a 2D (plain strain) model can be an appropriate one for simulating piled raft [5], in this investigation, 3D models are used to decrease calculation errors. In all cases, the raft is subjected to vertical load at first stage of calculation and lateral load is applied at second stage. According to the experimental results of literature, numerical results are verified. Finally, the effect of the reinforcement of gravel cushion on lateral behavior of reinforced unconnected piled raft is investigated.

2. FEM simulation and verification

The simulation of piled rafts are based on some simplifications and assumptions which should be verified according to experimental results [8] (Fig. 1). Centrifuge test results of a unconnected piled raft is selected from literature (which has 4 unconnected aluminium piles and a steel raft). Because of symmetric geometry and load of this model, only a forth of model is simulated in ABAQUS software to simplify the model and save time.

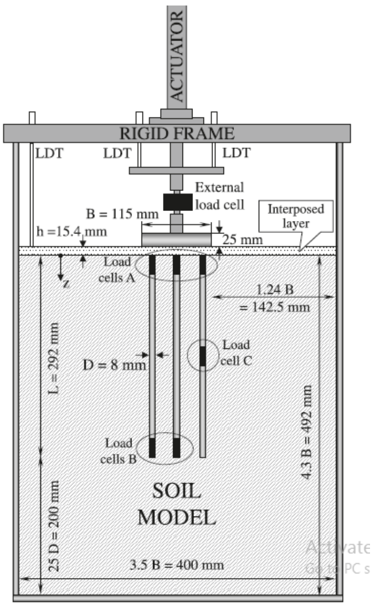

Fig. 1. Centrifuge test of unconnected piled raft [8].

Table 1: Mechanical properties of unconnected piled raft

Parts	φ Internal friction	γ (kg/m^3) Density	E (kPa) Elastic modulus
Reinforced concrete	------	2500	25000000
Sand	35	1800	7000
Cushion	36	1900	8000
Geogrid	------	------	183000

ABAQUS software can simulate complicated interactions among different parts of piled rafts. In this regard, interaction of piles, steel cylindrical box and raft with soil is considered as frictional contact in the tangential direction with a coefficient of friction. Additionally, geogrid layers of parametric study are embedded in gravel cushion. The result of numerical and experimental investigations are presented in Fig. 2. Clearly, the numerical results are precise enough and the simplifications of model can be used for parametric study.

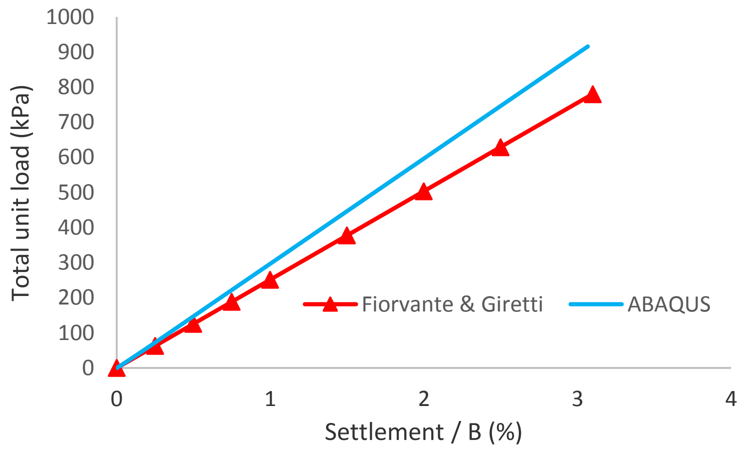

Fig. 2. Numerical and experimental results of unconnected piled raft

Schematic view of the position of loads and the different parts of unconnected piled raft is presented in Fig. 3. All of parametric studies have the same amount of vertical load. Vertical load is subjected at the center of raft and the lateral load is subjected at the center of one side of the raft. Mohr-Coulomb criterion is assigned for subsoil and sand cushion. Furthermore, pile, steel box, raft and geogrid layer is assumed elastic. Elements of geogrid are Membrane and C3D4 structure elements are considered for soil, raft and piles parts of the models (in verification and parametric study). All of the degrees of freedom are fixed at the bottom of model and for the boundaries of soil, roller supports are assigned. Generated mesh of unconnected piled raft and the vertical displacement of soil is shown in Fig. 4. Because of lateral and vertical loads and the geometry of model, half of the model should be simulated. The vertical load- settlement behavior of unconnected piled raft is shown in Fig. 5.

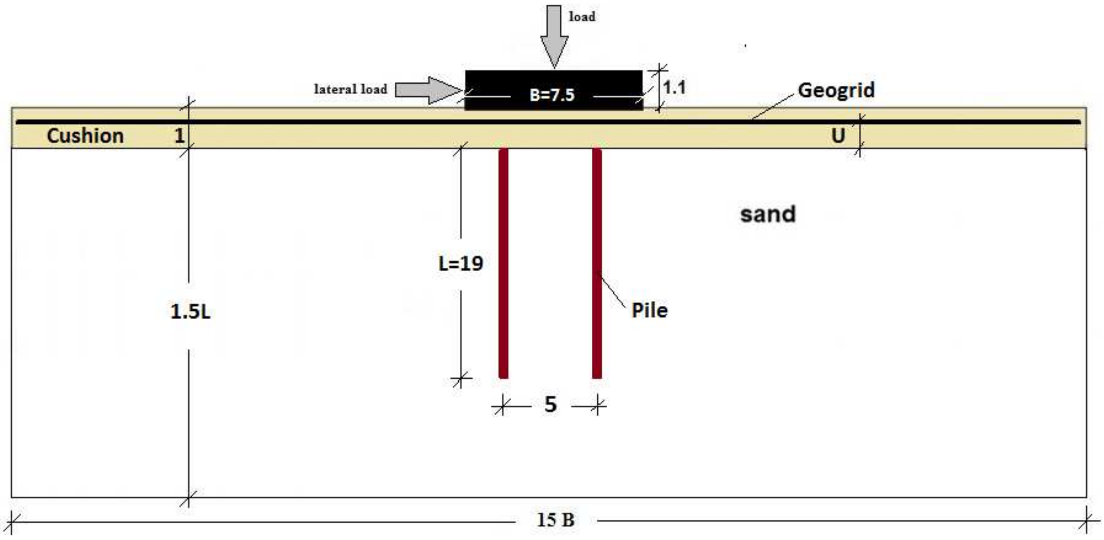

Fig . 3. Schematic view of reinforced unconnected piled raft (Dimensions in m).

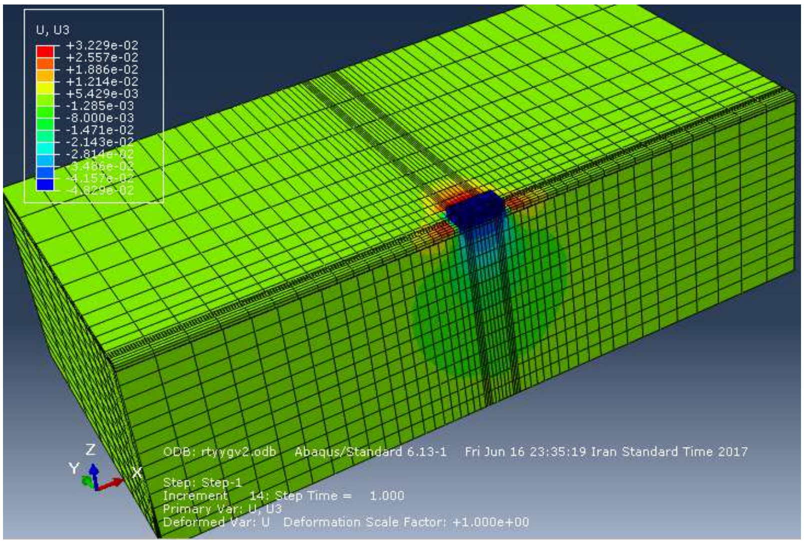

Fig. 4. Generation mesh and vertical displacement of unreinforced unconnected piled raft

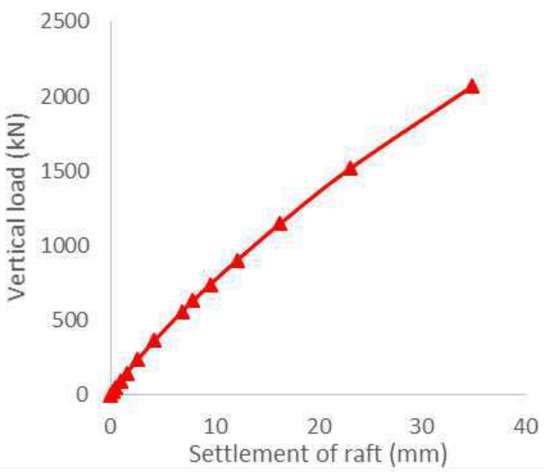

Fig. 5. Vertical load-settlement of unreinforced piled raft

According to verified model, boundaries of soil and cushion are extended to 15 times larger than raft width. Properties of reinforced concrete are assigned for piles and raft of parametric studies. The membrane elements which are used for geogrid layer do not have flexural resistance and just stand stresses parallel with surface of membrane elements. No rib or node of geogrid layer is modeled. Elastic modulus and poison ratio of geogrid are 183 MPa and 0.3 respectively. In parametric study, loads are applied in two steps which are for vertical and horizontal loads.

3. Effect of the position of geogrid

The position of geogrid (u) in sand cushion of unconnected piled raft is an important issue which can change the behavior of raft against static lateral loads. In this regard, 3 different positions are selected and geogrid layers are simulated in these positions. The distance between geogrid layer and pile heads are place at 0, 0.2 and 0.4 m. Lateral load- displacement behavior of raft are presented for reinforced unconnected piled raft with different positions of geogrid . Besides, behavior of unreinforced unconnected piled raft is shown (Fig. 6). Obviously, there is no considerable difference between responses of different reinforced piled rafts. However, the optimum position is 0.2 m from top of piles. Using geogrid layer in sand cushion has improved the lateral behavior of unconnected piled raft (Fig. 6). Because, the lateral movement of soil is not considerable near pile head; therefore, the resistance of geogrid layer can not be mobilized. On the other hand, when the geogrid layer is at 0.4 m from pile head or farther, although there is great stress and displacement in soil, there is no considerable interlocking forces and geogrid can not remain stable in gravel cushion. Contour of the tensile stress of geogrid is shown in Fig. 7. It is noteworthy that, the maximum tensile stress of geogrid is in elements which are near pile head (the pile which is nearer to lateral load).

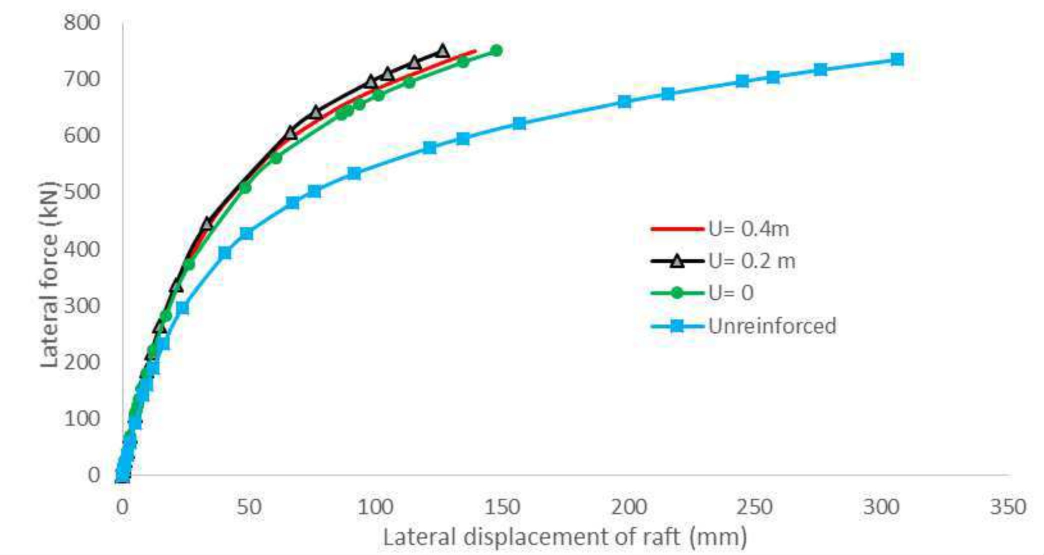

Fig. 6. Effect of position of geogrid layer on load- settlement behavior

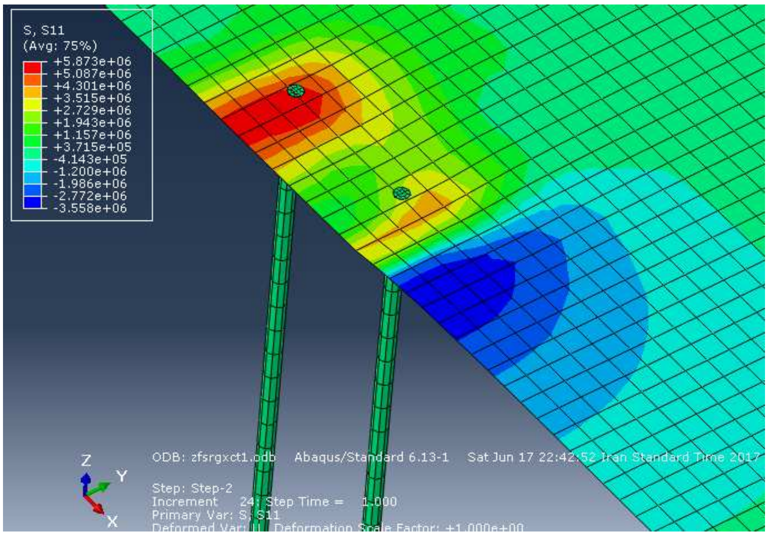

Fig. 7. Tensile stress of geogrid

4. Effect of the number of geogrid layers

In order to investigate the effect of the number of geogrid layers (N) on lateral behavior of unconnected piled raft, 1, 2 and 3 geogrid layers are put in the gravel cushion of unconnected piled rafts. The distance between every layer from its adjacent layer is 0.2 m. In all of cases, the first layer of gegrid is located at pile head. Increasing N improves the behavior of raft (Fig. 8).

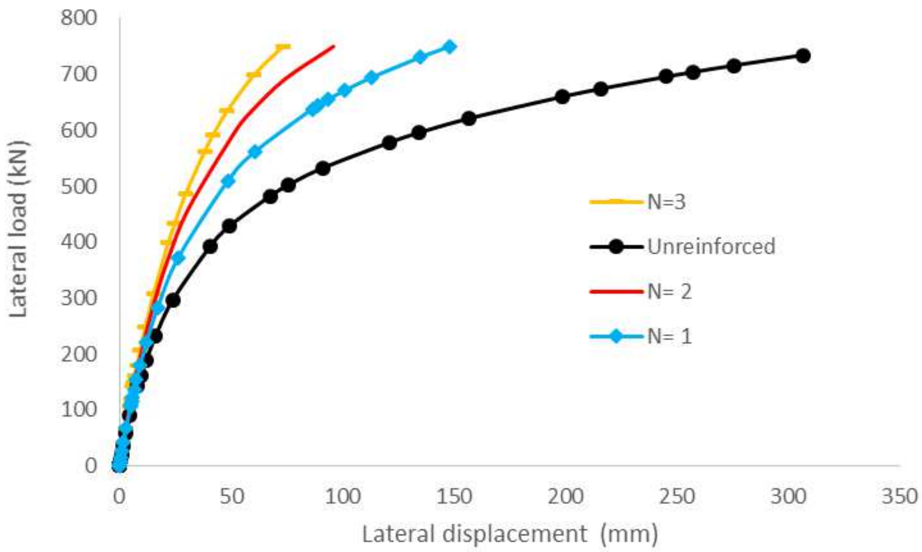

Fig. 8. Effect of the number of geogrid layers

Conclusions

3D models of reinforced and unreinforced unconnected piled rafts are simulated and their lateral behavior are discussed. This research is conducted to investigate the effect of a new approach to control the large lateral displacements of raft. According to the numerical results, following statements are concluded:

Using geogrid layer can decrease the lateral displacement of geogrid.

The optimum position of geogrid layer is 0.2 m from top of pile in gravel cushion.

The more amount of geogrid layers, the less lateral displacement of raft.

Maximum tensile stress of geogrid is in the elements near the top of pile.

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