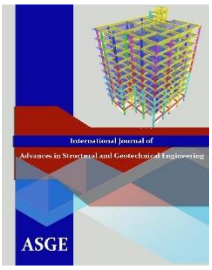

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Numerical Simulation of Trapdoor Problem and Mitigation using Discrete Element Method (DEM)

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ABSTRACT

The trapdoor problem is one of the ways to reproduce load transfers by the arching effect in a granular layer in non-complex conditions. In addition, many analytical solutions for the prediction of load transfer mechanisms are based on the trapdoor problem. However, some of the parameters required are still being widely discussed. In this study a numerical testing program was undertaken to investigate failure mechanisms induced by the active movement of a deep rectangular trapdoor underlying a granular soil using discrete element method (DEM) by PFC2D software. Some models were used to evaluate the performance for mitigation of trap door problem using geogrids installed at different layers. The results of the numerical analyses were discussed and verified by previous experimental works. Finally, it was concluded that using geogrids layers for mitigate this problem leads to additional confinement due to the interlocking effect of installation this type of ground improvement and using of several layers of geogrids at short distances leads to a significant reduction of displacements up to factor of 2.

Keywords: *Trapdoor problem, load transfers, Discrete Element Method (DEM), mitigation*

INTRODUCTION

The trapdoor problem has been long used by geotechnical researchers to study the soil behaviour in a wide range of applications such as tunnel design [1], vertical anchors [2] and embedded pipes [3]. Several attempts have been made to develop analytical methods based on experimental observations. Vardoulakis et al. (1981) [4] discussed solutions for the trapdoor force in active and passive modes based on laboratory tests. Vermeer and Sutjiadi (1985) [5] derived a solution for the trapdoor pressure in the passive mode using the available empirical data. Colin (1998) [6] proposed a method to determine the plane strain limit load acting on trapdoor buried in a Mohr-Coulomb soil. An extensive experimental study related to the distribution of earth pressure and surface settlement was carried out by [7]. Numerical analyses were also conducted by several researchers to investigate the soil-structure interaction associated with trapdoor problem. Tanaka and Sakai (1993) [8] investigated the progressive failure and scale effects of the trapdoor using an elasto-plastic finite element analysis. The numerical results were also compared with experimental data. Park and Adachi (2002)[9] performed a finite element analysis to study the distribution of earth pressure and the surface settlement profile in a jointed medium. The analytical and numerical methods mentioned above are based on the concept of continuum mechanics which has proven to work well in most geotechnical applications. However, there are cases where considering the discontinuous nature of the soil is more appropriate such as rockfall and particle flow problems. Since the first discrete element method code was introduced [10], it has been used extensively to investigate various engineering problems [11,12]. For the trapdoor problems in particular, formation of shear bands under active/passive conditions was investigated by [13] using the 2D discrete element analysis. In this study, a 2D numerical investigation using discrete element method (DEM) by PFC 2D software is conducted to examine the soil movement and earth pressure developing in a typical trap door problem and added geogrids layers to mitigate trap door problem. Emphasis is placed on the realistic simulation of the initial soil conditions using the discrete element method.

TRAP DOOR PROBLEM AND MITIGATION USING GEOSYNETHETIC

The trapdoor problem consists in moving vertically a trapdoor located at the basis of a granular layer Fig. 1. During the tests, the pressure acting on the trapdoor decreases due to load transfers occurring in the granular material. Load transfers are the consequences of intergranular rearrangements and modifications of the orientations of contact forces according to the pattern of an arch above the trapdoor [1,2,3].

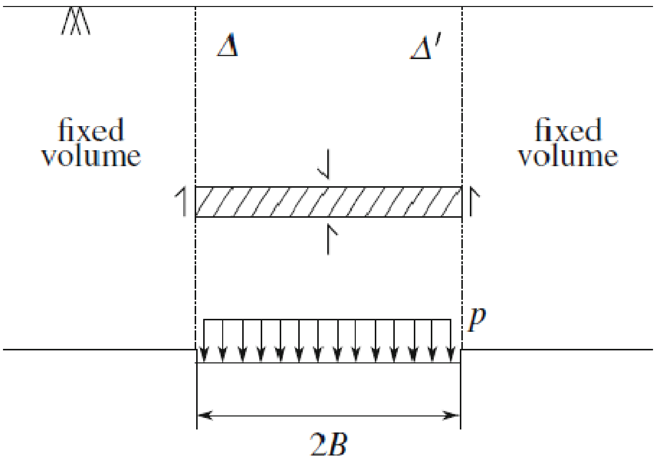

Fig. 1: Description of the trapdoor problem

This problem is similar to the study of the pressures in silos, described analytically by Janssen, where the pressure p acting at the bottom of a silo of width 2B filled with a granular material of density c, is given by

$$p = \frac{B\gamma}{K \tan\phi}\left(1 - e^{-(Kh/B)\tan\phi}\right) \qquad (1)$$

where K represents the ratio of horizontal stress to vertical stress on or near the walls of the silo, / the friction angle between the granular material and the walls and h the height of the granular material in the silo. For the specific case of pressure in silos, the coefficient K has been discussed by many authors in the past decades [1].

Using a geosynthetic layers as mitigation solution for trap door problems and to reduce differential displacement has been investigated before by others (such as Bray et al. (1993) and Bray (2001)), it was found that using different layers of geosynthetic especially geogrid reduce the differential displacement and surface settlement. This is due to the interlocking effect the installation of geogrids works as additional confinement.

THE DISCRETE ELEMENT METHOD (DEM)

The DEM was introduced by [15] for the analysis of rock mechanics problems and then applied to soils by [10]. According to the definition in the review of Cundall and Hart (1992), PFC2D is regarded as a discrete element code even though it allows finite displacements and rotations of discrete bodies, including complete detachment, and recognizes new contacts automatically as the calculation progresses. In the DEM, the equilibrium contact forces and displacements of a stressed assembly of particles are found by tracing the movements of the individual particles. These movements are the result of the propagation through the particle system of disturbances caused by specified wall and particle motion and/or body forces: a dynamic process. The speed of propagation depends on the physical properties of the discrete system.

The commercially available PFC2D software package was used for the Two-dimensional Discrete (or Distinct) Element Method (DEM) simulations presented here. PFC2D is suitable for modelling the stress-strain response of a granular assembly. The deformation of a granular assembly such as sand and rock as a whole is described well by this assumption, since the deformation results primarily from the sliding and rotation of the rigid particles and the interlocking at particle interfaces and not from individual particle deformation. The PFC2D particle-flow model includes “balls” and “walls”. Walls allow the application of velocity boundary conditions to assemblies of balls for purposes of compaction and confinement. The balls and walls interact with one another via the forces that arise at contacts. However, contacts may not exist between two walls; thus, contacts are either ball-ball or ball-wall. The calculations performed in PFC2D are via a timestepping algorithm that requires the repeated application of Newton’s second law to each particle, a force-displacement law to each contact, and constant updating of wall positions. The law of motion is applied to each particle to update its velocity and position based on the resultant force and moment resulting from the forces acting on it. The force-displacement law applied to each contact to update the contact forces is based on the relative motion between the two entities at the contact and the contact constitutive model. Also, the wall positions are updated based on the specified wall velocities.

PFC2D software provides a particle-flow model under the following assumptions:

- The spherical particles are treated as rigid bodies.
- The contacts occur over a vanishingly small area (i.e. at a point).
- The behaviour of the contacts is characterized using a soft contact approach wherein the rigid particles are allowed to overlap one another at contact points.
- The magnitude of the overlap is related to the contact force via the force displacement law, and all overlaps are small in relation to particle sizes.
- Bonds can exist at contacts between particles.
- All particles are spherical; however, the clump logic supports the creation of super-particles of arbitrary shape. Each clump consists of a set of overlapping spheres, and acts as a rigid body with a deformable boundary.

THE GRANULAR SAMPLE

The sample used in the simulations consisted of 3000 spherical particles whose radii were uniformly distributed between 0.02 and 0.04 mm. Grains interacted with each other at their mutual contact.

SIMULATION DETAILS

The sample had initial dimensions of 12 m wwith and 3.0 m height and the trap door width is 2.0 m as shown in Fig. 1. The sample was generated by numerically simulating the ‘dry pluviation’ experimental sample preparation technique. This preparation method resulted in a loose sample and is thought to replicate well the slow sedimentation of grains under gravity. Table 1 indicates the micromechanical parameters used for the simulation.

SCHEME OF THE GEOGRIDS SIMULATION

Modelling geogrid in PFC2D is consisting of a string of bonded particles. The spherical particles bonded together by contact and parallel bonds as shown in Fig. 2. The contact bond acts only at the contact point and can transmit only a force, while the parallel bond acts over a circular cross-section between the two particles in contact and transmit both a force and a moment. Table 2 indicates the micromechanical parameters of geogrids used for the simulation and Fig.3 shown Trap Door model include the geogrid layer about 2.0 m from the bottom of the model.

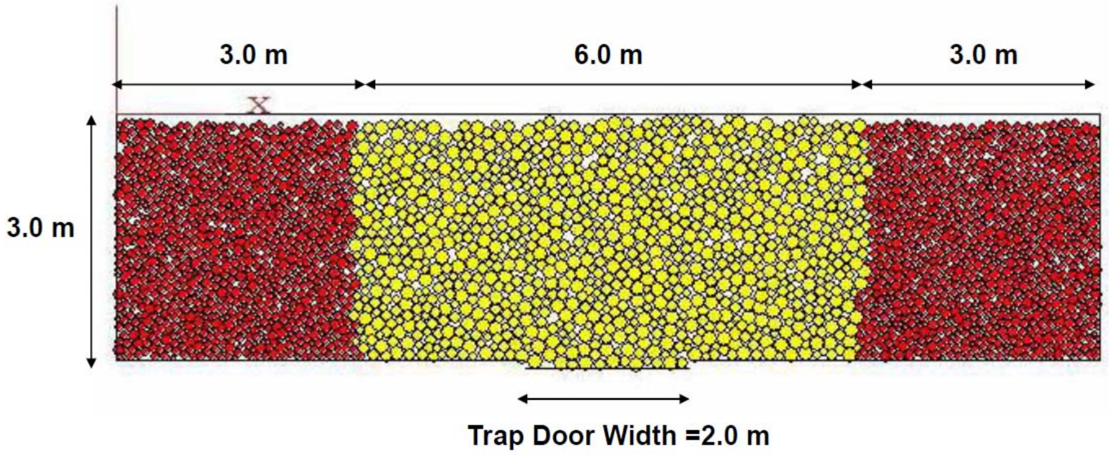

Fig.1: Trap Door Model Using PFC2D

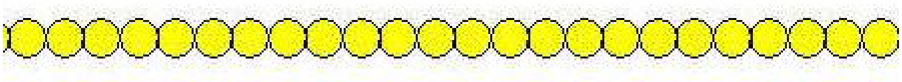

Fig.2:Geogrid Model Using PFC2D

Table 1: Micromechanical parameters used for the simulation.

Wall Parameters		Ball Parameters	
Wall Normal Stiffness kn	$1E^3$ kN/m	Ball Normal Stiffness kn	1E3 kN/m
Wall Shear Stiffness ks	$1E^3$ kN/m	Ball Shear Stiffness ks	1E3 kN/m
Wall Friction	0.3	Ball Friction	0.5
		Ball Density	2650 Kg/ m3
		Number of Balls	3000
		Balls Ball Radius of Natural soil	
		Min Radius	0.02m
		Max Radius	0.04m
		Ball Radius of Fill	
		Min Radius	0.03m
		Max Radius	0.06m
		Initial Radius Multiplication Factor	1.6

Table 2: Micromechanical parameters of geogrids used for the simulation.

Geogrid Parameters	
Geogrid Normal Stiffness kn	1E3 kN/m
Geogrid Shear Stiffness ks	1E3 kN/m
Parallel bond radius pb_rad	0.001m
Parallel bond normal stiffness pb_kn	4.2E8 kN/m
Parallel bond shear stiffness pb_ks	5.0E2 kN/m
Parallel bond normal strength pb_nstren	1.53E5 kN/m
Parallel bond shear strength pb_sstren	1.2E4 kN/m
Geogrid Friction	0.30
Geogrid Density	2650 Kg/ m3
Number of Balls	3000
Balls Ball Radius	0.03 m
Length of Geogrid	6 m

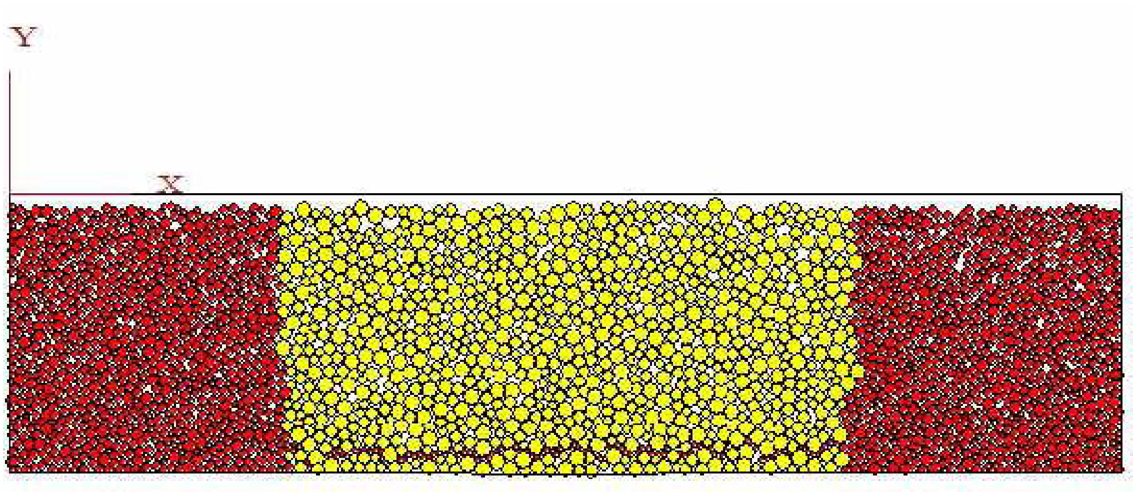

Fig.3: Model with One Layer of Geogrid

RESULTS AND DISCUSSION

TRAPDOOR MECHANISM

To understand the trapdoor mechanism, the force network developing in the area surrounding the trapdoor is shown in Fig. 4 for three different values of trapdoor displacements as shown in Fig.5 . As the trapdoor moves down a relatively small value (0.01 m), the force network immediately above the trapdoor disappears indicating that a failure zone has developed and the force network above the failure zone became denser and thicker. This is explained by the arching process that lead to the redistribution of pressures in the vicinity of the trapdoor. As the trapdoor translates down to 0.05 m, the stresses carried by the arch increased excessively leading to the destruction of the arch. Consequently, the force network became lighter and thinner. The arch destruction process continues as the trapdoor moves further
downward. When the trapdoor displacement reached 0.4 m, the arching phenomena could not be observed anymore.

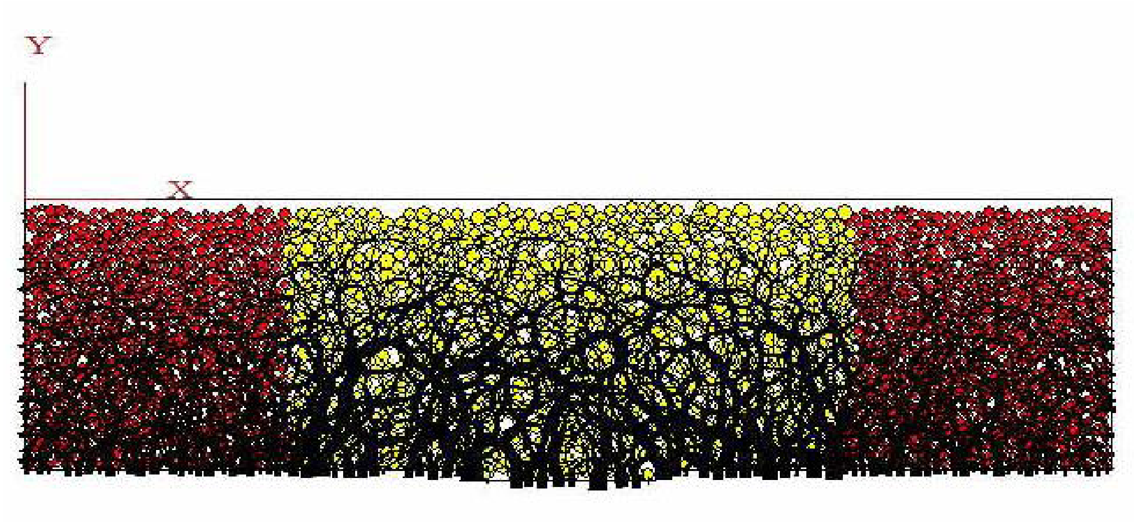

Fig.4: Contact Force After Cycling the Model under Gravity

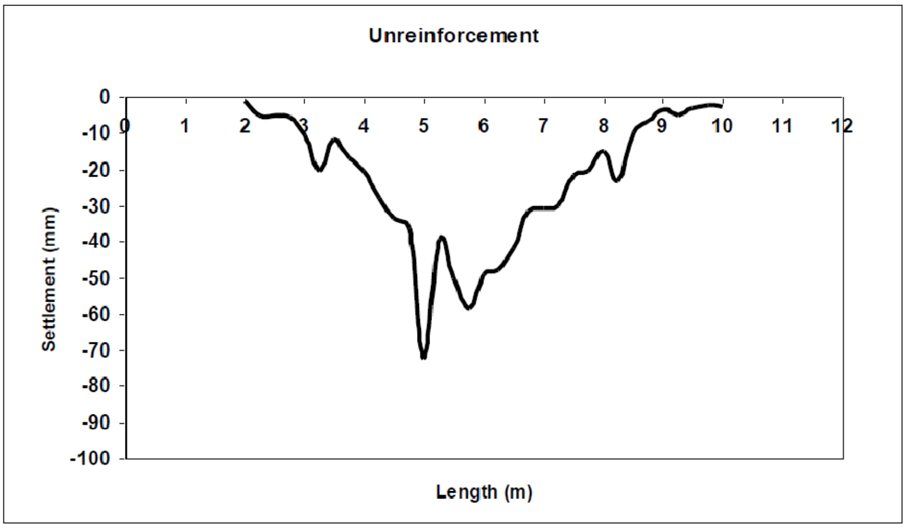

Fig.5: Monitoring Displacements at Surface after Trap Door Movement

FORCE ACTING ON THE TRAPDOOR

The pressure acting on the trapdoor is calculated by averaging the trapdoor contact forces . The average stress acting on the trapdoor significantly decreased when the ratio of trapdoor movement to the soil height was relatively small. For trapdoor displacement of 0.05 m, the minimum pressure acting on the trapdoor is found to be approximately 20% of the original value. Further increase in the trapdoor displacement resulted in an increase in the calculated pressure on the trapdoor.

SURFACE DISPLACEMENT

To examine the surface settlement, the positions of the particles on the top of the packing are recorded. Figure 6 shows the positions of the particles along a vertical cross section (@ z = 0.15 m). For trapdoor displacement of less than 0.1 m that corresponds to arching above the trapdoor as indicated above, the surface settlement remained unchanged. At this stage, displacement occurred within the volume immediately above the trapdoor. The soil outside the failure zone is supported by the arch. As the trapdoor displacement increases, the failure zone grows leading arch collapse. Consequently, the surface settlement emerged. By examining Fig.5 and Fig.6, the arches started to collapse when the trapdoor displacement reached a value between 0.5 and 0.6.

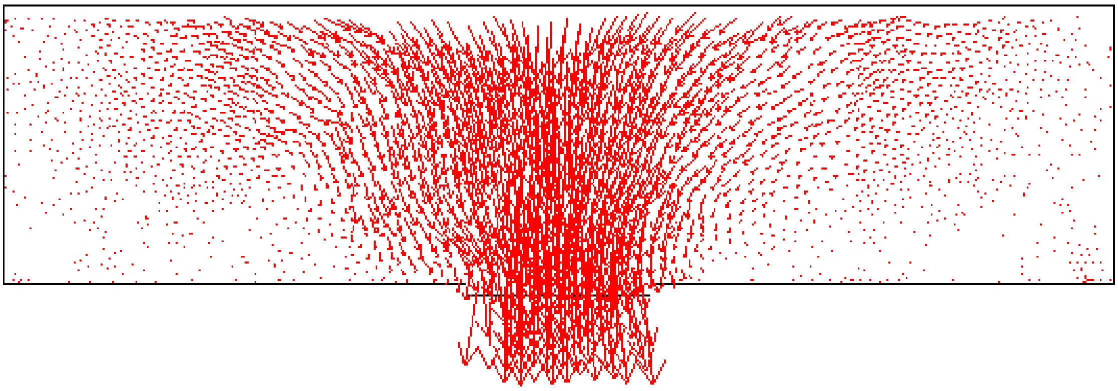

Fig.6: Displacement Vectors After Trap Door Movement

STRESS DISTRIBUTION

Stresses are calculated using the average volume of a cube of 0.05 m each side. The Von Mises stress distribution for the 0.05 m thick layer (@ z = 0.10 m to 0.7 m) for five different trapdoor displacements are shown in Fig.5. The arching phenomena started to develop as the trapdoor moved 0.01 m downward, the stress increased significantly in the soil to compensate for the stress carried by the trapdoor. Increasing the trapdoor movement resulted in increasing the size of the failure zone and decreasing the stresses acting on the arch the arch had diminished. This can be explained by the stresses acting on the arches exceeding the arch bearing capacity leading to its destruction.

MIGITATION USING GEOGRIDS

As Shown in Fig.7 using Geogrid layer beneath the soil can be very effective for reducing differential displacement and settlements , where the interlocking effect the installation of geogrids works as additional confinement and use of several layers of geogrids at short distances leads to a significant reduction of displacements. One layer of geogrid can reduce the settlements by a factor of 2.

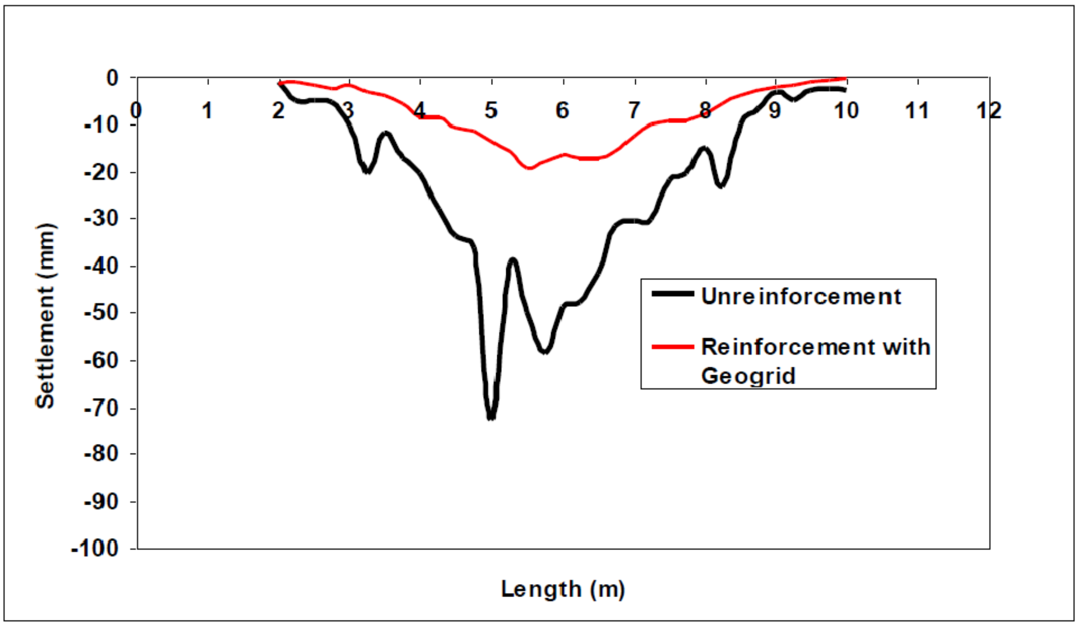

Fig.7: Monitoring Displacements at Surface after Reinforcement with One Layer of Geogrid

CONCLUSIONS

Using Geogrid layer beneath the soil can be very effective for reducing differential displacement and settlements , where the interlocking effect the installation of geogrids works as additional confinement and use of several layers of geogrids at short distances leads to a significant reduction of displacements. One layer of geogrid can reduce the settlements by a factor of 2. In conclusion the numerical modelling confirmed that geogrids can be a very effective mitigation solution to trap door problems although it should be pay more attention to this type of trap door mitigation solution . It would be the subject of our further investigation in our ongoing research in this field.

REFERENCES

1. Terzaghi, K. V. (1936). Stress distribution in dry and saturated sand above a yielding trap-door. Proceedings of the 1st international conference on soil mechanics and foundation engineering, Cambridge, MA, Harvard University press.
2. Meyerhof, G. G. and J. I. Adams (1968). "The ultimate uplift capacity of foundations." Canadian geotechnical journal 5(4): 225-244.
3. Takagi, N., N. Nishio, K. Yoneyama and K. Shimamura (1983). "Development of a strain measurement system for soils and its application to sand around a buried pipe." Soils and Foundations 23(3): 65-79.
4. Vardoulakis, I., B. Graf and G., Dudeshus (1981). "Trap-door problem with dry sand: A statical approach based upon model test kinematics." International Journal for Numerical and Analytical Methods in Geomechanics 5(1): 57-78.
5. Vermeer, P. A. and W. Sutjiadi (1985). The uplift resistance of shallow embedded anchors. Proceedings of 11st international conference on soil mechanics and foundation engineering, San Francisco.
6. Colin, C. S. (1998). "Limit loads for an anchor/trapdoor embedded in an associative coulomb soil." International Journal for Numerical and Analytical Methods in Geomechanics 22(11): 855-865.

7. Adachi, T., M. Kimura and K. Kishida (2003). "Experimental study on the distribution of earth pressure and surface settlement through three-dimensional trapdoor tests." Tunnelling and Underground Space Technology 18(2-3): 171.
8. Tanaka, T. and T. Sakai (1993). "Progressive failure and scale effect of trap-door problems with granular materials." Soils and Foundations 33(1): 11-22.
9. Park, S.-H. and T. Adachi (2002). "Laboratory model tests and FE analyses on tunneling in the unconsolidated ground with inclined layers." Tunnelling and Underground Space Technology 17(2): 181.
10. Cundall, P. A. and O. D. L. Strack (1979). "A discrete numerical model for granular assemblies." Géotechnique 29(1): 47-65.
11. Jensen, R P., P. J. Bosscher, M. E. Plesha and T. B. Edil (1999). "DEM simulation of granular media-structure interface: Effects of surface roughness and particle shape." International Journal for Numerical and Analytical Methods in Geomechanics 23(6): 531.
12. Zeghal, M. and T. B. Edil (2002). "Soil structure interaction analysis: Modeling the interface." Canadian Geotechnical Journal 39(3): 620.
13. Murakami, A., H. Sakaguchi and T. Hasegawa (1997). "Dislocation, vortex and couple stress in the formation of shear bands under trap-door problems." Journal of the Japanese Geotechnical Society: Soils and Foundation 37(1): 123-135.
14. PFC2D/3D (Particle Flow Code in2/3 Dimensions)Version 5.0,Itasca Consulting Group Inc.,Minneapolis,MN: ICG; 2014.
15. P.A.Cundall. “A computer model for simulating progres-sive large scale movements in blocky rock systems,”in Proceedings of the Symposium of the International Societyof Rock Mechanics, Nancy, France, 1971.
16. PFC2D/3D (Particle Flow Code in2/3 Dimensions)Version 5.0,Itasca Consulting Group Inc.,Minneapolis,MN: ICG; 2014.