THE INFLUENCE OF BAG'S SHAPE AND INTERNAL FRICTION ANGLE OF SAND ON ULTIMATE CAPACITY OF SAND-BAG BY USING ANALYTICAL AND NUMERICAL ANALYSE

A. Haddad[1] and M. Bahrehdar[2]

[1]Assistant Professor of Civil Engineering Dept, Semnan University, Semnan, Iran, Telefax: +982313354121
Email: ahadad@semnan.ac.ir
[2]Graduate student of Civil Engineering Dept, Semnan University, Semnan, Iran
Email: mohammadbahrehdar@gmail.com

ABSTRACT

The main goal of this paper is the study of bag's shape influence and internal friction angle of sand on ultimate compression capacity of sand-bag system under vertical load. In present paper, first ultimate value of compression capacity of sand-bag system will be measured by using analytical method under boundary condition like semicircle and semi-ellipse geometric form. Then the maximum of compression capacity of sand-bag system will be studied for different values of internal friction angles of sand. And so, mechanical behavior of sand-bag system will be analyzed for measuring of that compression capacity maximum, under semi-ellipse, semicircle segments and different internal friction angles of sand by using ABAQUS finite element software in three-dimensional form. In this method sand and polypropylene polymer bag behavior were defined by using Mohr-coulomb and Elastic-Plastic methods. The results show that compression capacity of sand-bag system will be increased under external loads with increasing of sand internal friction angles.

Keywords: Sand-bag system, compression capacity, geometric form, numerical method

INTRODUCTION

The soil-bag system consists of the soil constrained into a polymeric bag which is defined based on tension strength, size, geometric form of polymeric bag and the characteristics of building materials filling inside it which depend on internal friction angle of the soil (Haddad et al. 2011). When soil-bag system undergoes vertical loading, tension force produced into the bag cover causes to increase vertical force (N), consequently, this causes to increase the force between soil particles (μ= soil friction coefficient and $F=\mu.N$).

The kind of filling materials mostly depends on the application of soil-bag system and availability of building materials. The most important characteristic implemented into the structure of soil-bag system is tension strength of the polymer implemented in the bag. Bags implemented into soil-bag system are generally built of polyethylene or polypropylene polymers. The structures equipped with soil-bag system enjoy abundant technical and economic advantages compared to similar concrete and stony structures. Among the applications of soil bags, the construction of emergent structures temporarily, equipment in the bed of inner-urban roads in order to decrease the vibrations resulted from traffic (Nakagawa et al. 2008), reinforcement of embankment layers in technical buildings including retaining wall (Tatsuoka et al. 1997) and increase in loading capacity of shallow foundations can be addressed (Matsuoka et al. 2003). Earth reinforcement using of soil-bag system causes to increase bearing capacity and it causes to minimize transformation of foundation bed influenced by the imposed load. The results of simple pressure test on the foundation reinforcement with soil-bag system by (Yongfu et al. 2008) show that when soil-bag system is exposed on external load, it exhibits high strength which a fundamental portion of this strength is resulted from tension force generated in the cover of polymeric bag.

Of other characteristics of soil bags, the absorption of vibrations resulted from traffic load can be addressed. Due to elastic quality and instant transformation, replacing in roads infrastructure, soil bags can play a fundamental role in decreasing damages resulted from vibration of traffic load in roads. In this research, (Nakagawa et al. 2008) addresses to study a method to decrease the vibrations resulted from the traffic of heavy vehicles on residential houses along the sidewalks. The first suggestion for analysis of mechanical behavior of single soil-bag system was presented by (Matsuoka et al. 2003) to determine the maximum bearing capacity under vertical loading. In this analytical model, several hypotheses were considered. These hypotheses include remaining bag thickness as fixed during loading, lack of friction in common surface

between bag and soil, non-sticky being of materials inside the bag and Plane strain conditions. After that, (Tantono. 2008) present semicircular geometric form for boundary conditions of soil-bag system in order to determine its bearing capacity. In this paper, initially, in order to examine the effect of geometric form on pressure strength of soil-bag system, a new geometric form in semi-elliptical shape will be presented for boundary conditions of soil-bag system using of analytical method. Then, using of numerical method, soil-bag system model will be examined in three-dimensional state.

ANALYTICAL METHOD

At the beginning of each research, it is necessary the previous studies and the past physical models in respect of the desired studied issue and regarding to results which the researchers have expressed for their works, shall be compared to new studies.

Evaluation of Soil-Bag System with Semicircle Cross-Section

In Fig. 1a, mechanical behavior of the single soil-bag system under monotonic vertical pressure is shown based on the simplified model by Tontono (Ansari et al. 2011).

Then, considering the vertical pressure on soil-bag system (P_V), vertical and horizontal stress between soil particles (σ_h and σ_v) and 1-1 and 2-2 cross-sections in soil-bag system which is shown in Fig. 1b, it has determined the maximum bearing capacity of soil-bag system. In continue, considering cross-section of soil-bag system with initial width B_0, initial height H_0 and the length l and a semicircle with $H_0/2$ in radius for boundary conditions, initial perimeter and volume are determined as follows.

$$L_0 = 2B_0 + \pi H_0 \tag{1}$$

$$V_0 = B_0 . H_0 . l + \pi . \left(\frac{H_0}{2}\right)^2 . l \tag{2}$$

Now, if soil-bag system undergoes vertical displacement δv, changes in perimeter and width of soil-bag system are equal to:

$$H = H_0 - \delta_V \tag{3}$$

$$V = V_0 \rightarrow B = \frac{B_0 H_0 + \frac{\pi H_0 \delta_V}{2} - \frac{\pi (\delta_V)^2}{4}}{(H_0 - \delta_V)} \tag{4}$$

$$L = \frac{2B_0 H_0 - \pi H_0 \delta_V + \frac{\pi (\delta_V)^2}{2} + \pi H_0^2}{(H_0 - \delta_V)} \tag{5}$$

Circumference strain of polymeric bag obtained from the above-mentioned data is equal to:

$$\epsilon_{bag} = \frac{L - L_0}{L_0} = \frac{\delta_V (\pi \delta_V + 4B_0)}{2(H_0 - \delta_V)(2B_0 + \pi H_0)} \tag{6}$$

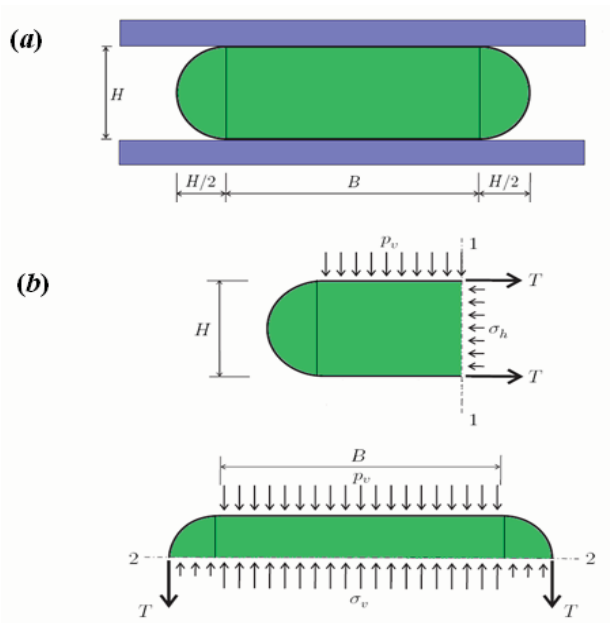

Fig. 1 (a). Section of a vertically compressed soilbag with semicircular boundaries (b). Free-body diagram of the left part of the soilbag 'cut' at cross section 1-1 & the upper part of soilbag 'cut' at cross section 2-2.

In Fig. 1b, considering stresses as equal in vertical and horizontal directions, the following equations are obtained.

$$\Sigma F_x = 0 : \sigma_h \times H \times l - 2T = 0 \quad (7)$$

$$\Sigma F_y = 0 : \sigma_v \times B \times l + \sigma_v \times \frac{H}{2} \times l - 2T - p_v \times B \times l = 0 \quad (8)$$

Considering the passive earth pressure coefficient and vertical and horizontal stresses, it can be written.

$$\sigma_v = K_p . \sigma_h \quad (9)$$

The compression capacity of soil-bag system with semicircular cross-section is equal to:

$$F_{limit} = 2\left(\sigma_y\right)_{bag} \times t \times \left[\frac{B.K_P}{H} + \frac{K_P}{2} - 1\right] \times l \quad (10)$$

Evaluation of Soil-Bag System with Semi-Elliptical Cross-Section

In this paper, presenting new boundary conditions in semi-elliptical geometric form which is shown in Fig. 2a, it is addressed to determine the compression capacity of the single soil-bag system under vertical loading. (Bahrehdar. 2012)

In Fig. 2a, the vertical pressure (P_V) is imposed on soil-bag system. a_0 and b_0 are halves of initial big and small diameters of semi-ellipse, respectively. H_0 and B_0 are initial height and width of soil-bag system. As we know, ellipse stretching is defined by exiting from its center which is equal to:

$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2}, 0 < e < 1 \quad (11)$$

When e goes towards zero, the ellipse is changed into circle and when it goes towards one, the ellipse will become stretcher. By solving the equation (11), a will be obtained.

$$a = \frac{b}{\sqrt{1-e^2}} = \frac{H}{2\sqrt{1-e^2}} \quad (12)$$

When e-value becomes zero, the ellipse will become a circle; as a result, the relations presented for semi-elliptical conditions are converted into the relations presented by Tantono for semi-circle conditions. But if e-value is non-zero, the ellipse will become stretcher and a new equation for the compression capacity will be obtained for soil-bag system. In continue, considering H_0 as initial height, B_0 as initial width and l as the length, initial perimeter and volume will be obtained as follows.

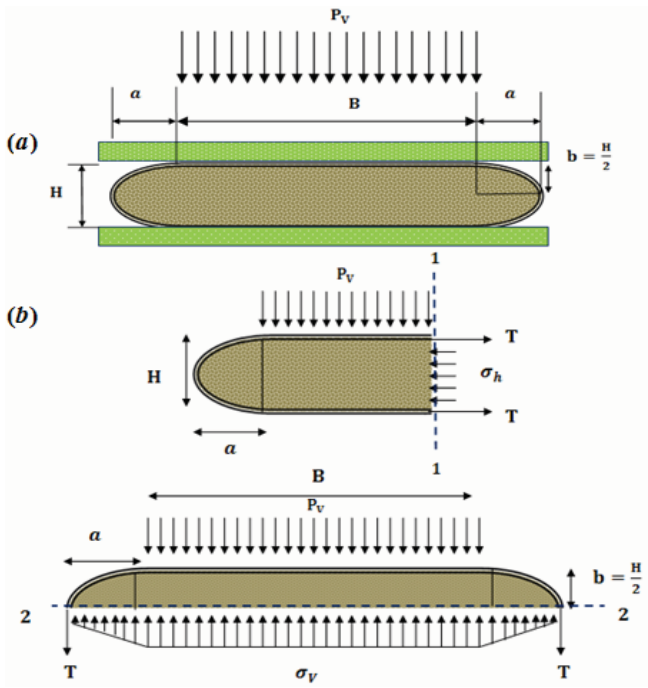

Fig. 2 (a) . Section of a vertically compressed soilbag with semi-elliptical boundaries (b). Free-body diagram of the left part of the soilbag 'cut' at cross section 1-1 & the upper part of soilbag 'cut' at cross section 2-2.

$$L_0 = 2B_0 + (\frac{\pi . H_0}{\sqrt{2}} . \sqrt{\frac{2-e^2}{1-e^2}}) \quad (13)$$

$$V_0 = B_0 . H_0 . l + \frac{\pi . H_0^{\ 2}}{4} . \frac{1}{\sqrt{1-e^2}} . l \quad (14)$$

Now, if soil-bag system undergoes δv, considering that the volume of soil-bag system is assumed as fixed during compressing, secondary perimeter, changes in perimeter strain and width are equal to:

$$H = H_0 - \delta_V \quad (15)$$

$$V = V_0 \rightarrow$$

$$B = \frac{B_0 H_0 + \frac{1}{\sqrt{1-e^2}} . \left(\frac{\pi H_0 \delta_v}{2} - \frac{\pi (\delta_v)^2}{4} \right)}{(H_0 - \delta_v)} \quad (16)$$

$$L = 2B + (\frac{\pi . H}{\sqrt{2}} . \sqrt{\frac{2-e^2}{1-e^2}}) \quad (17)$$

$$\epsilon_{bag} = \frac{L - L_0}{L_0}$$

$$= \frac{\delta_v \left(4B_0 + \pi \delta_v . \sqrt{\frac{2-e^2}{2(1-e^2)}} \right)}{2(H_0 - \delta_v) \left(2B_0 + \pi H_0 \sqrt{\frac{2-e^2}{2(1-e^2)}} \right)} \quad (18)$$

Now, considering (P_V) as vertical pressure on the soil-bag system, σ_h and σ_v as horizontal stress and vertical stress between soil particles and 1-1 and 2-2 cross-sections in soil-bag system which are shown in Fig. 2b, the compression capacity of soil-bag system is obtained. Considering tensions in vertical and horizontal directions as equal, the following equations are obtained.

$$\Sigma F_x = 0 : \sigma_h \times H \times l - 2T = 0 \quad (19)$$

$$\Sigma F_y = 0 : \sigma_v \times B \times l - 2T - p_v \times B \times l + \sigma_v \times \frac{H}{2.\sqrt{1-e^2}} \times l = 0 \quad (20)$$

Considering the passive earth pressure coefficient and vertical and horizontal stresses it can be written.

$$\sigma_v = K_p . \sigma_h \quad (21)$$

where for granular soil with friction angle ϕ, the passive earth pressure coefficient is equal to:

$$K_P = \frac{1 + \sin\phi}{1 - \sin\phi} \quad (22)$$

$$F_v = p_v \times B \times l \quad (23)$$

The compression capacity for soil-bag system with semi-elliptical cross-section is equal to:

$$F_{v,limit} = 2(\sigma_y)_{bag} \times t \times \left[\frac{B . K_P}{H} + \frac{K_P}{2.\sqrt{1-e^2}} - 1 \right] \times l \quad (24)$$

The Comparison Between Bearing Capacity of Soil-Bag System and Semi-Elliptical and Semi-Circular Cross-Sections

By considering fixed dimensions for the size of the width and height of soil-bag system and a variable length for it, the volume for two models is considered as fixed. In Table 2, mechanical characteristics of soil materials and polymeric bag (from polypropylene type) is shown.

Table 1 Geometric characteristics of soil-bag system in analytical and numerical method.

Parameter	H_0 (cm)	B_0 (cm)	l (cm)	V_0 (cm^3)	e	$\delta_{v\text{-peak}}$ (mm)	$F_{V\text{-Limit}}$ (kN)
Semicircular	7	17.5	17.5	2817.5	0	19.1	205.8
Semi-elliptical	7	17.5	17.5	2817.5	0.85	21	220.543

Table 2 Mechanical characteristics of soil and polymeric bag of polyethylene type.

Properties'	E (MPa)	$\sigma_{v(bag)}$ (MPa)	φ (°)	ψ (°)	ν	C (kPa)	t (mm)
Soil	40	-	30	3	0.33	1	-
Bag	140	35	-	-	0.33	-	1

From diagram presented in Fig. 3, it is concluded that the vertical bearing capacity for soil-bag system with semicircular cross-section is equal to 205.8 kN with the maximum vertical displacement of 19.1 mm. If semi-circle cross-section changes into semi-elliptical cross-section by exiting from 0.85 centrality, the value of the vertical bearing capacity will be equal to 220.543kN with the maximum vertical displacement of 21mm. It is observed that by changing semicircular cross-section into semielliptical cross-section, vertical bearing capacity of soil-bag system will increase by 14.743kN.

In the presented model with semi-elliptical cross-section, when the value of exiting from centrality increases, geometric form of the ellipse will become stretcher. Consequently, this will cause to increase compression capacity of soil-bag system under external loads. Non-linear changes of exiting from semi-elliptical centrality compared to the maximum bearing capacity of soil-bag system is depicted in diagram of Fig. 4.

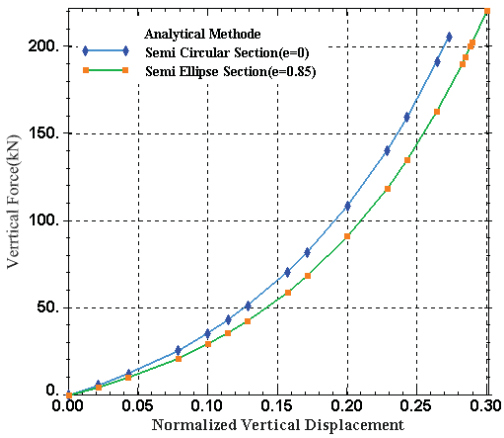

Fig.3 Changes of the displacement–vertical force of soil-bag system.

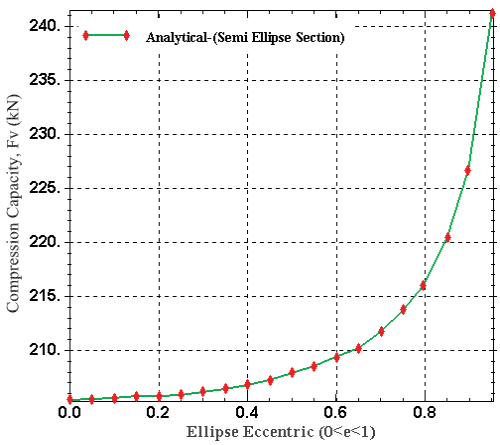

Fig.4 Changes in bearing capacity of soil-bag system according to exiting from centrality.

NUMERICAL EVALUATION OF SOIL-BAG SYSTEM WITH SEMICIRCULAR AND SEMIELLIPTICAL CROSS-SECTIONS

In this section, mechanical behavior of soil-bag system will be analyzed in order to determine its maximum bearing capacity using of semielliptical and semicircular cross-sections in ABAQUS finite element software. Geometric form of the pieces implemented in the model including polymeric bag, soil and loading plate are shown in Fig. 5.

The Interface and the Behavior of Materials Implemented in Soil-Bag System

In ABAQUS software (Hibbitt et al. 2010), mechanical contact between surfaces is defined using of surfaces which interact each other. ABAQUS present two kinds of contact behaviors for contact method based on the surface which are called as tangent behavior and vertical behavior. In ABAQUS /Standard Coulomb friction law is used for tangent behavior. In this state, frictional stress has a relationship with the pressure between two surfaces and if it reaches the following critical value, two surfaces will slide to each other.

$$\tau_{(critical)} = \mu F_v \tag{25}$$

Also, a limit can be defined for $\tau_{critical}$ which by increase in shear stress, the surfaces will slide over each other. It should be noted that hard contact method is used for vertical behavior. The characteristics of contact interaction implemented for soil-bag system and loading plate are shown in table 3. One of cases which should be determined for the defined elements, is the characteristics of their materials. As we know, the behavior of models which are analyzed, should be defined for the program. The model which is designed in this paper, includes a rigid loading panel which is placed on polymeric bag filled of sandy soil. The desired models for polymeric bag and the soil are considered perfect elastic-plastic and mohr-coulomb, respectively. The required parameters for characteristics of materials (soil and polymeric bag) are shown in Table 2. (Ansari et al. 2011)

Table 3 Soil-bag loading panel interface properties

Interface	Friction coefficient	Friction angle	Separation allowed
Soil-bag	0.57	30	Yes
Bag-loading panel	0.5	26	No

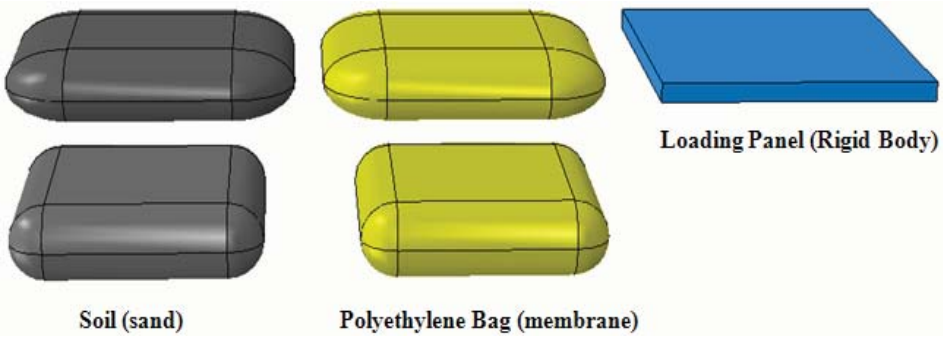

Fig. 5 Main parts for the assembly of a soilbag

Boundary Conditions and Elementing

Boundary conditions are implemented to create terms and conditions in some parts of model until the model shall remain as fixed or move in a pre-determined value. In static analysis, enough boundary conditions should be provided to prevent the model movement as a rigid body. If not, the movement of rigid body is not restricted and causes to create non-inversion of hardness matrix and this causes the structure analysis shall be interrupted before accomplishment.

In order to solve the problem, two steps are considered. Initial step is defined by the software, and second step is implemented by the user. Boundary conditions for the models are such that in both steps, the lower surface of polymeric bag has no motion in vertical direction.

Element type

The used software in this research has various elements which can be used depending on the model and kind of analysis. For the above-mentioned element, several special elements are used. The kind of elements implemented for the soil model is in the form of 8-noded linear 3D elements (C3D8), whilst the bag by 4-noded quadrilateral membrane (M3D4) elements. The assemble model of soil-bag system along with the finite element meshes is depicted in Fig. 6.

NUMERICAL RESULTS

Changes in Mechanical Behavior of Soil-Bag System under Vertical Loading

When the analysis was performed, visualization environment should be used to observe solution results. When soil-bag system undergoes vertical pressure (P_V), it will undergo δv displacement in vertical direction which this displacement will increase when vertical pressure increases. Diagram of Fig. 7 shows changes in vertical displacement of soil-bag system against vertical loading. By the diagram, it is concluded that the vertical bearing capacity of soil-bag system with semicircular cross-section against vertical loading of 162.312kN at the maximum displacement is 25.2mm. If the cross-section is considered as semi-elliptical, the vertical bearing capacity of soil-bag system of 187.36kN at the maximum displacement will be 29.4mm.

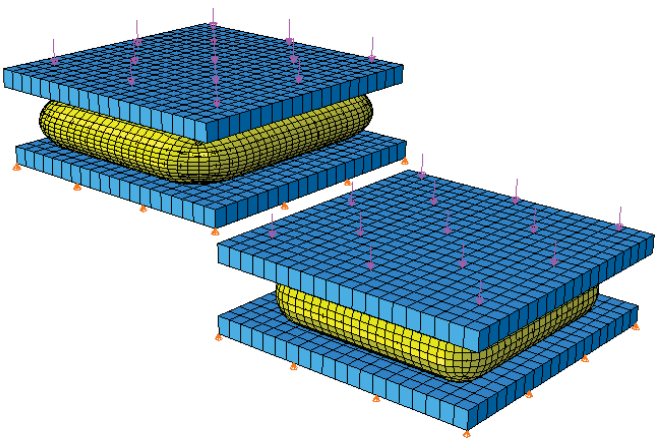

Fig. 6 Geometry, mesh and boundary condition for soilbag

Diagram of Fig. 8 shows bearing capacity of soil-bag system for changes in internal friction angle of the soil from 25-45 degree. By diagram of figure 8, it is concluded that when internal friction angle of the soil increases, bearing capacity of soil-bag system will increase.

Figure 9 shows the diagram of changes in circumference strain of polymeric bag in different displacements with various thicknesses of 0.5, 1, and 1.5. From the diagram, it is concluded that when the thickness of polymeric bag increases, the circumference strain of polymeric bag decreases. When the thickness of polymeric bag is considered as 0.5mm, the maximum displacement will reach 30.48mm and the maximum circumference strain will reach 35.78%. But if we make thickness of polymeric bag as 3-fold, i.e. if we consider it as 1.5 mm, the maximum displacement will reach 22.48mm and the maximum circumference strain will be limited to 19.9%. Therefore, if we make the thickness of polymeric bag as three-fold, the displacement and circumference strain will be decreased 1.35-fold and 1.8fold, respectively.

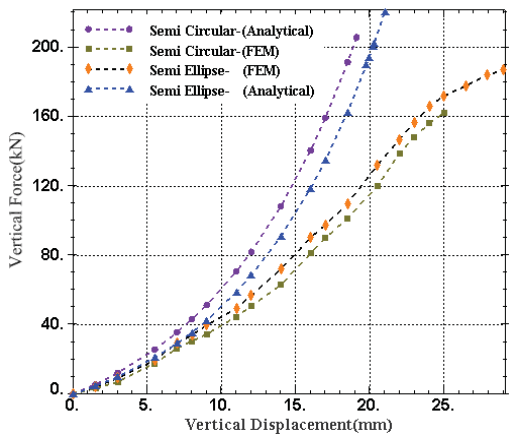

Fig. 7 Changes in displacement of soil-bag system compared to vertical loading.

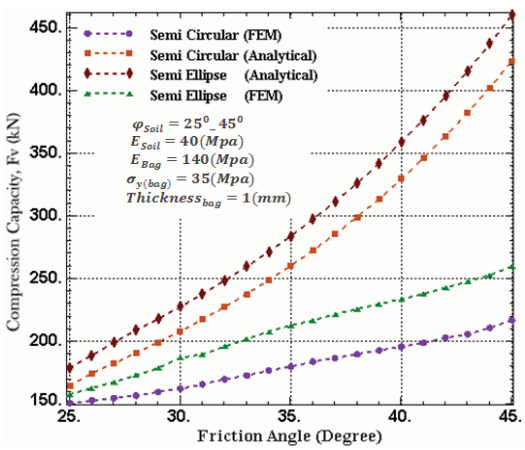

Fig. 8 Diagram of changes in internal friction angle of the soil to bearing capacity of soil-bag system.

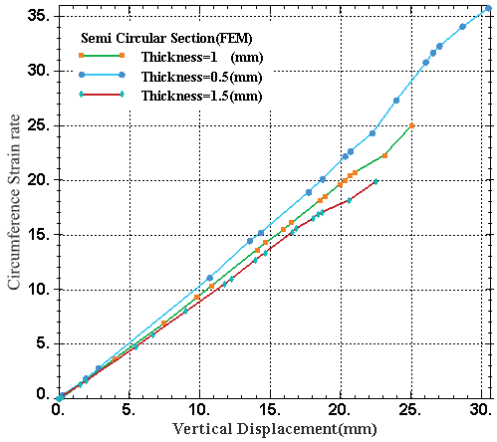

Fig. 9 Circumference strain rate–displacement relationship for a 3D assembly of soilbag under vertical compression for various bag thicknesses

.

In Fig. 10, geometric form of polymeric bag with semi-elliptical cross-section is shown before and after loading.

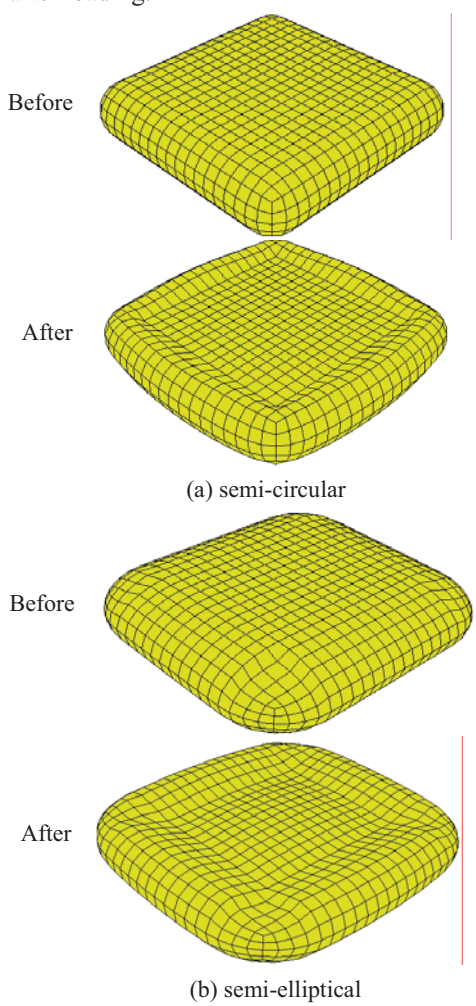

Fig. 10 Soil-bag , before and after compression

CONCLUSIONS

Regarding to the performed studies, it was observed that the geometric form of boundary conditions of polymeric bag plays a significant role in determining the vertical bearing capacity of soil-bag system. The boundary conditions of semi-ellipse by exiting from the centrality 0.85 has more capability to bear external load to the boundary conditions of semi-circle.

Regarding to the obtained results, in analytical method, when semi-circular cross-section changes into semi-elliptical one, vertical bearing capacity of soil-bag system will increase by 6.68 % . If the soil-bag system model is analyzed using of numerical method, its vertical bearing capacity will increase by 13.36 % by changing semi-circular cross-section into semi-elliptical cross-section.

Also, considering boundary conditions in semi-elliptical form, the required surface to construct polymeric bag in order to constrain the soil will decrease significantly, and in this respect, a significant saving will be happened in the consumed materials.

REFERENCES

Ansari Y, Merifield R, Yamamoto H, Sheng D. (2011). Numerical analysis of soilbags under compression and cyclic shear. Computers and Geotechnics 38 : 659–668.

Bahrehdar M. (2012). Numerical Simulation of a Soilbag behavior under Vertical and Shear Compressions.M.D. Thesis, Semnan University, Iran.

Haddad A and Bahrehdar M. (2012). Evaluation numerical modeling of soilbags in earth structures. Proc. 9th International Congress on Civil Engineering, Isfahan University of Technilogy (IUT) , Iran.

Hibbitt, Karlsson, Sorensen. (2010). ABAQUS Standard User's Manual. Version 6.10.

Matsuoka H, and Liu S. (2006).A new earth reinforcement method using soil bags. London: Taylor and Francis

Matsuoka H, Hasebe T, Liu SH, and Shimao R. (2003). Friction property of soilbags and some measures to increase soil bag resistances against sliding. In: Proc. of the 38th Annual Symposium on Geotechnical Engineering, Akita, Japan; 869–70.

Nakagawa Y, Chen G.L, and Tatsui T, Chida S.(2008).Verification of vibration reduction characteristics with soilbag structure. Shanghai, China; 17 – 20.

Tatsuoka F, Tateyama M, Uchimura T, Koseki J. (1997). Geosynthetic-reinforced soil retaining walls as important permanent structures. Geosynth Inte ;4(2):81–136.

Tantono SF and Bauer E. (2008). Numerical simulation of a soilbag under vertical compression . Proc. 12th Inte. Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India.

Yongfu X, Jian H, Yanjun D, and De'an S.(2008). Earth reinforcement using soilbags. Geotextiles and Geomembranes 26-(2008) :279–289.