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Concrete Slabs on Cavitied Soil Grade

Ola Mazen Makki[1,*], M.H. Mezher [2,3], Muhammed Abd Attiya[4] and Laith Jawad Aziz [4]

[1]*Departement of Civil Engineering, College of Engineering, University of Al-Qadisiyah, Al-Qadisiyah, Iraq*
[2]*Computer Technical Engineering Department, College of Technical Engineering, The Islamic University, Najaf, Iraq.*
[3]*Computer Technical Engineering Department, College of Technical Engineering, The Islamic University, Babylon, Iraq.*
[4]*Department of Civil Engineering, College of engineering, University of Kufa, Najaf, Iraq*

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Abstract

Many structures like slabs are usually in contact with soil grades and such case made an interaction in the behavior between the soil and the slab. Gypsum may find randomly in the sandy soil and it may melt when exposing to water. Resolving gypsum forms many hidden voids inside the soil media and these cavities effect in the first degree on the ultimate capacity of concrete slabs. The present study discussed the effect of cavities forming in soil media on the concrete slab which rest on it. The study is an essential topic to understanding how the stresses develops from slab to the soil media, how could the transporter stresses have affected by cavities inside the soil, the influence of cavity and its size and shape on the slab failure capacity. The investigation involves discussing cavity shape, continuity, size, depth, eccentric loading, locations and study the case of cavity filling with stiffer material. It was concluded that, the circular cavity is the best shape because it distributes the stresses best than the other regular shapes. The nearest cavity and the larger cavity size deteriorated the concrete slab capacity due to weakness the concrete supporting.

Keywords: Slab on grade, soil with cavities, gypsum soils, Soil structure interaction.

1. Introduction

Soil structure interaction is a very essential topic nowadays because a lot of structures are in contact with soil and supported by it, especially the foundations. Rigid pavement, tank bases and spired footing (which supports one column) exposed widely to every weak occur in soil [1], [2]. Many researchers studied the interaction between soil and structures [1], [3] but few of them were investigated the effect of presenting a cavity into the soil [4], [5]. Cavities from usually at sandy soil due to the presence of gypsum into it, and the cavity volume depends on the gypsum amounts [6], [7].

From literature, it was concluded that, the concrete slab which rest on soil grade resist the load by many factors like: concrete compressive strength, steel reinforcement amount, soil density and the soil type. Also, the thickness of a concrete slab effects on bending at the first degree, in another word, increasing slab thickness prevent the slab from bending and allows for the slab to sank more into the soil which means more deflection [4], [5], [8]–[10]. It is worth to mention that, many previous researches simulate the soil as a Winkler model (which is a group of springs deflect with loading and soil compressibility expressed by modulus of subgrade reaction K) such as in the articles [11]–[15], but the three-dimensional model (elastic theory method) is more accurate to simulate soil and too suitable for the existence of cavities. This concept considered the soil must be assumed as an elastic, isotropic, homogenous, semi-infinite material (bounded from one side and extends in other directions infinitely) [16]. The elastic theory method simulates the soil as a material able to be compressed and soil details depend on elastic modulus (Young modulus) and Poisson's ratio. This method considered that, the stresses which transfer to soil develops as imbedded circles of stresses beneath the applied load and the size of this circular stresses depends on the width of basement of loading. Based on the above assumption, equations and charts for different types of the surface loading were introduced by reference [16]. In the present work, the chart shown in Fig. 1 is used to estimate the required soil dimensions. For this study, 2.5B (where B refers to slab width) has been used to determine soil container area, while 2B was used for determining soil height.

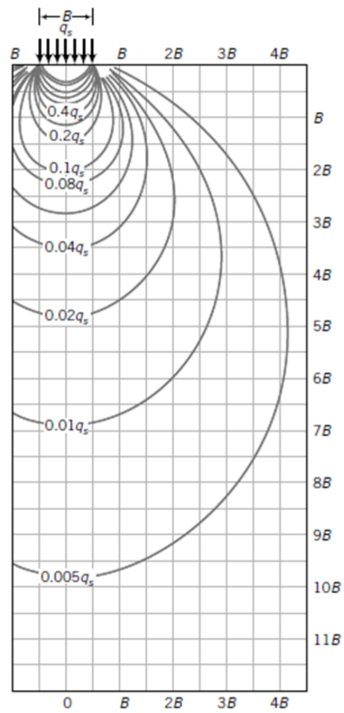

Fig. 1. Vertical stresses contour below a square foundation [16]

*E-mail address: Ola.Mazen@qu.edu.iq
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2. Methodology

Reference [4] investigated the effect of reinforced and plain concrete slabs which rest on cavitied sandy soil in different cavity depths experimentally. Finding suitable numerical model allows to discuss more parametric studies for such cases, so this research focus on finding a suitable simulation to verified it by the experimental work at [4] to read the stresses at soil, observe the overall behavior after void presence, read the stresses around the cavity, recording the stress below the slab and to simulate some different cases of parametric studies numerically. To explain the validity of the proposed numerical method for slab on elastic foundation with cavity, the experimental slabs were modeled and analyzed by using ANSYS program.

2.1. Models Simulations

Slabs which rest on voided sandy soils system were simulated in the ANYSY program. The cavity was simulated as a cylindrical empty space inside the soil media (which expressed as a SOLID 185). The concrete slab (SOLID 65) was contacted with the soil by contacts pair elements (Target-contact elements). Fig. 2 to Fig. 5. show the modelling procedures, meshing, contact elements, reinforcement and supports. The soil block bottom was chosen as all degree of freedom fixed.

Concrete slabs dimensions were selected to be (600*600*40mm) experimentally at reference [4], the elastic theory method [16] shows that, the applied stresses on a soil media spreads vertically, horizontally, and laterally in z-direction. As the elastic theory suggests, the load which is transferred vertically to the soil from square footing equals 7% of the total applied load at depth of 2B (where B is the footing width). According to this suggestion, the height of the soil medial should not be less than 1200 mm, while for the two other dimensions, 2.5B was used. In another word, soil dimension has to be (1500*1500*1200 mm). Fig. 6 illustrated the specimens names notations and the cases which were investigated.

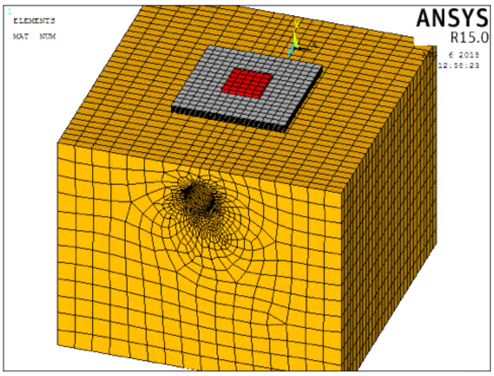


Fig. 2. Soil, slab and cavity meshing

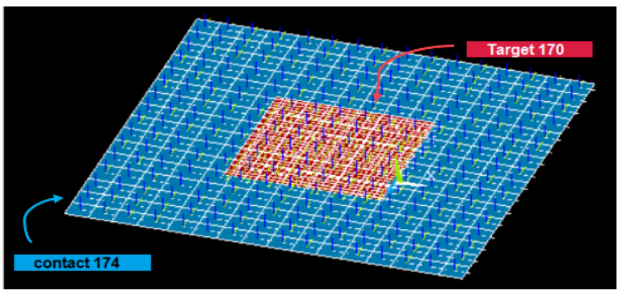


Fig. 3. Contact pair elements

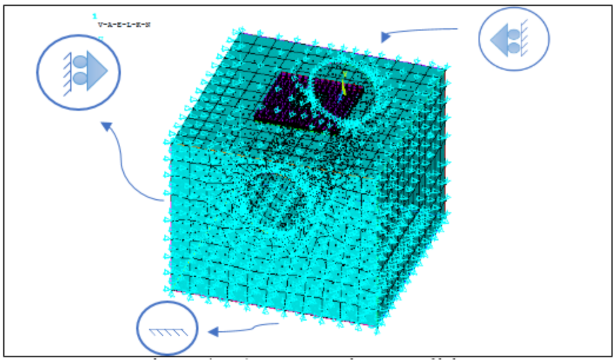


Fig. 4. Supporting condition

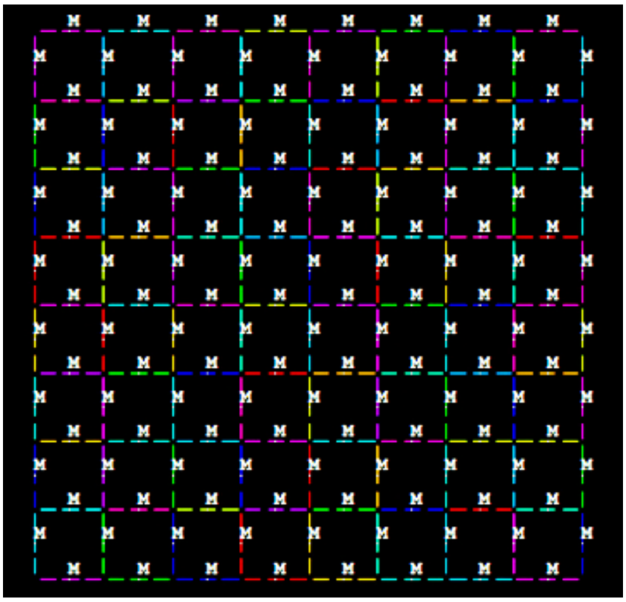


Fig. 5. Reinforcement meshing

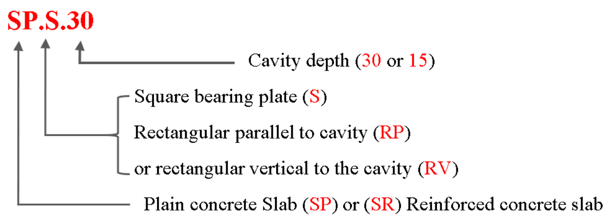


Fig. 6. Specimens' symbols definitions

2.2. Validation of the Program

After trying many meshing sized, nineteen elements in each side of soil volume and fifteen elements for slab model gives the best fitting results with the experimental results with a tolerance value equals 6%.

3. Results and discussions

3.1. Reference group results

A comparison between the load-deflection curves (at center) between experimental and numerical slab specimen is shown in Fig. 7. The numerical analysis shows the same slab behavior for the experimental test. From Fig. 7., which represents the nodal displacement shape for the specimen, the stress develops to the soil takes a circular shape exactly below the slab which deflects due to the applied load in different amounts while the farer areas from the slab were not affected by the load. For reinforced slab (Fig. 8.), the stresses beneath the slab enlarged more than the plain concrete due to its ability to sank more into the soil because is stronger than the plain slab. The red region represents the lowest region in stresses values. Also, it can be observed that, the square steel plate - used in this model- logically worked on distribute the load to the soil as equal circles. It is worth to mention that, the expected shape for stresses which develops wo the soil in accordance to the elastic model theory was observed in the numerical result clearly.

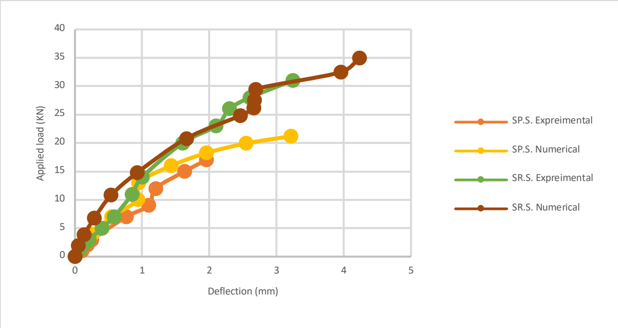
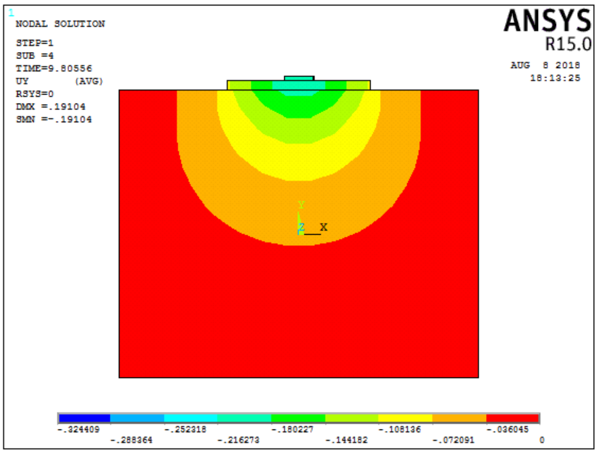
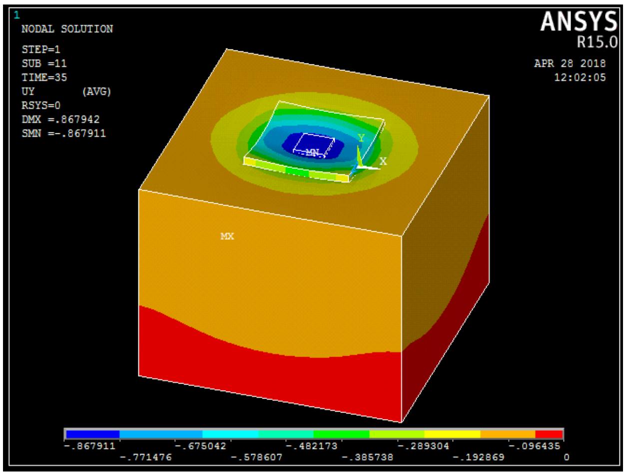


Fig. 7. Experimental and numerical comparison for specimens SP.S. and SR.S.



(a)



(b)

Fig. 8. Vertical nodal displacement (a. Plain concrete, b. Reinforced concrete)

3.2. Group one specimen

The amount of validation between numerical and experimental results are explained in Fig. 9 to Fig. 12 for the first group of models with cavities, in which the degree of validation ranged from 1.013 to 1.11. The nodal displacement mode- shown in Fig. 13, explain that, for square bearing plate models, the stress transferred uniformly on soil with contain cavities, and the reinforced model exposed more stress to the soil due to its strength.

When discussing the rectangular bearing plate, it can be noting that, the stresses which transferred to the soil is larger in the long direction of the bearing plate, which means the longer side of bearing plate transfer the stress to a farer side of the soil. Also, it can be noting that, the cavity weakens the soil continuum exactly below the slab which will force the slab to rest on the soil sides (shoulders) as a stronger support. Also, Fig. 13 shows the general share failure mode of soil by large scales. The red color represents the case of no stress, and the blue color represents the higher stress.

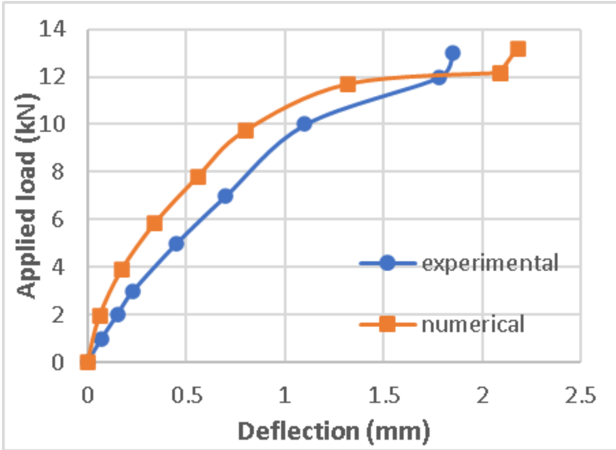


Fig. 9. Specimen SP.S.30

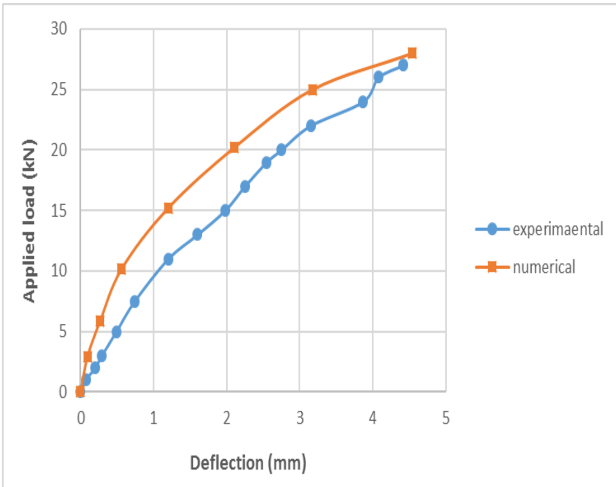


Fig. 10. SR.S.30

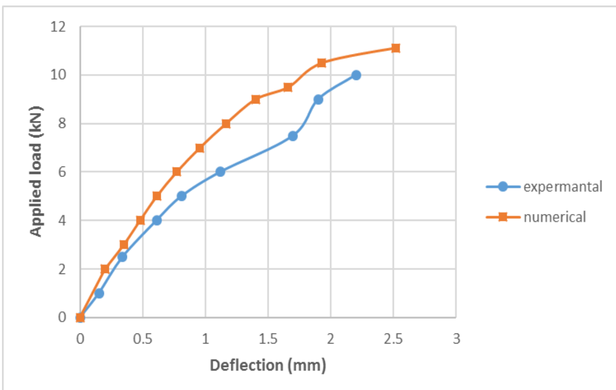


Fig. 11. SP.RP.30

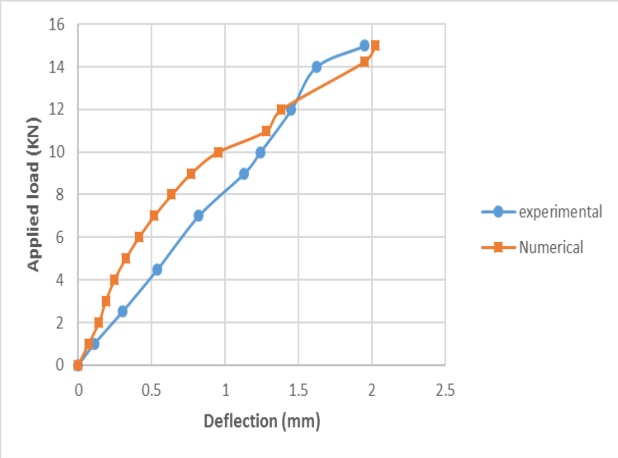
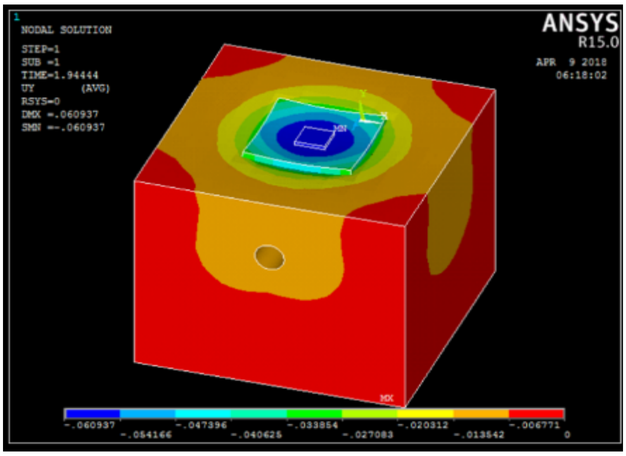


Fig. 12. SP.RV.30

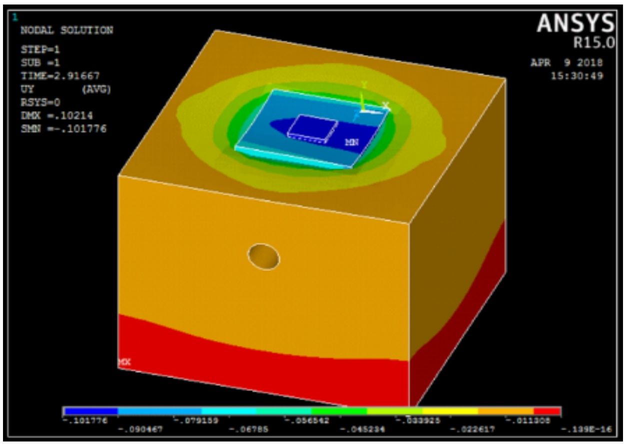
3.3. Second group of specimens

Fig. 14 to Fig. 19, view the load-deflection curves for the center of slab for experimental and numerical models for specimens contain cavities at depth equals 180 mm. The curves indicate the same behavior to the experimental slabs results. The cavity existence weakens the soil media (as shown in Fig. 20.), so the slab supported the load by resting on soil which is at cavity sides (shoulders zone) until the bending at the slab center causes to its failure.

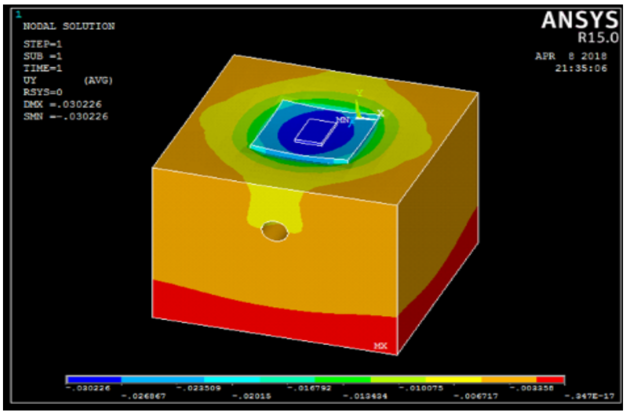
For the reinforced concrete slab, it can be noting that, slab resting on the shoulders zone is shown clearly in this model because the existence of steel reinforcement in the specimen which is raised the ultimate load of the slab. For specimen SP.RP.15, the nodal displacement shape (shown in Fig. 20.) showed that, the parallel to cavity direction plate distributes the load towards its direction. For the parallel rectangular plate, the general shear failure of the soil (which is about to occurs) is shown clearly due to the applied load and cavity existence. The lower layers were not affected by the applied load. The rectangular slab (RPP.S.15) which is laid towards the cavity direction resists the applied load by subjecting to the shoulders zone which is shown in Fig. 20. as a deformed zone.



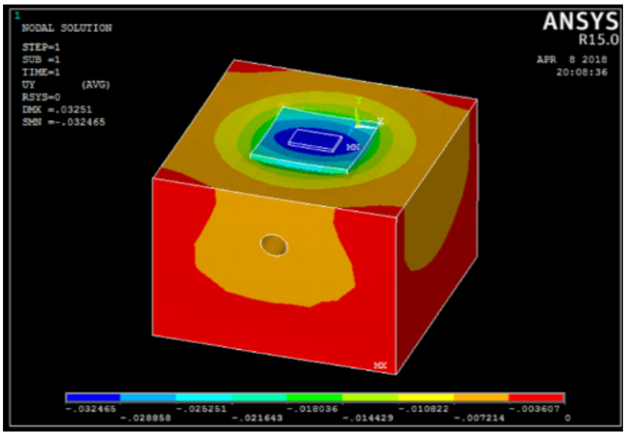
SP.S.30



SR.S.30



SP.RP.30



SP.RV.30

Fig. 13. Nodal solution for the 350-depth cavity group

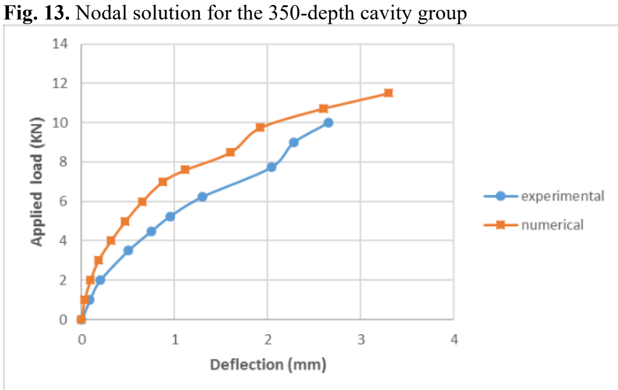


Fig. 14. SP.S.15

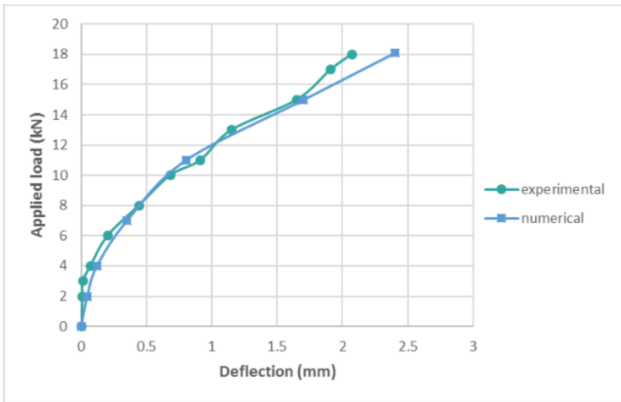


Fig. 15. SR.S.15

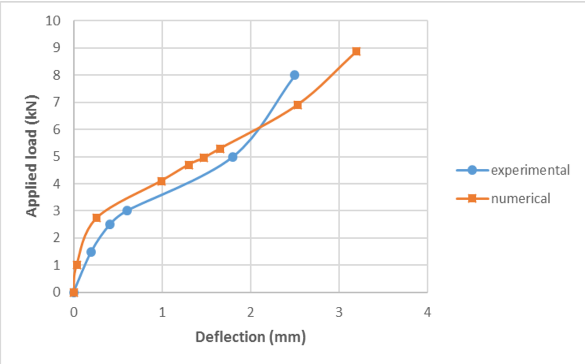


Fig. 16. SP.RP.15

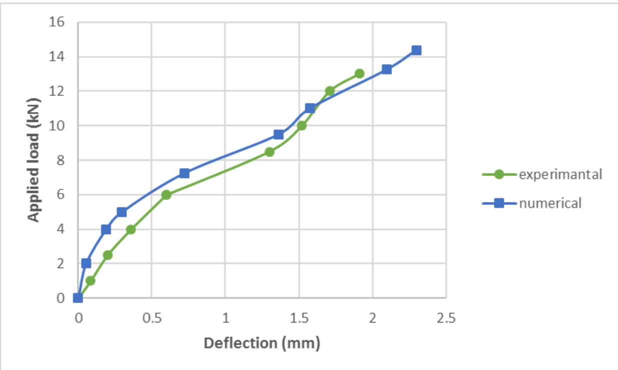


Fig. 17. Specimen SP.RV.15

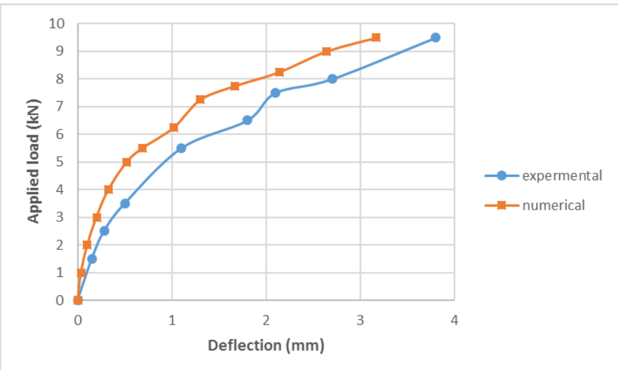


Fig. 18. Specimen RPP.S.15

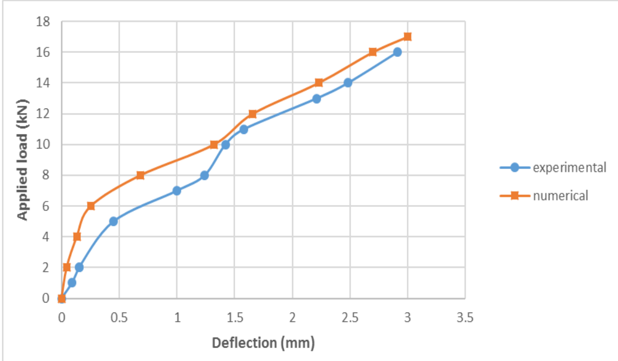
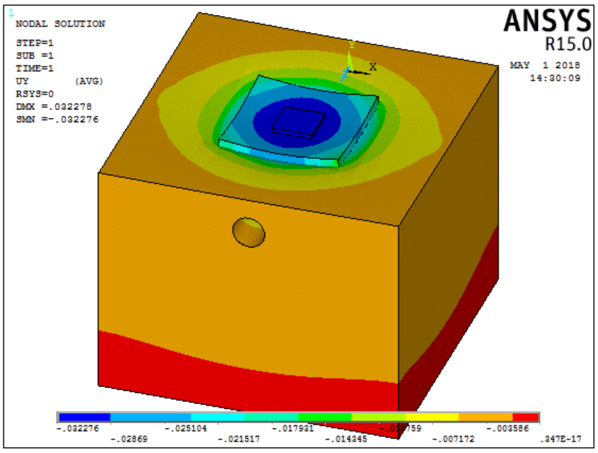
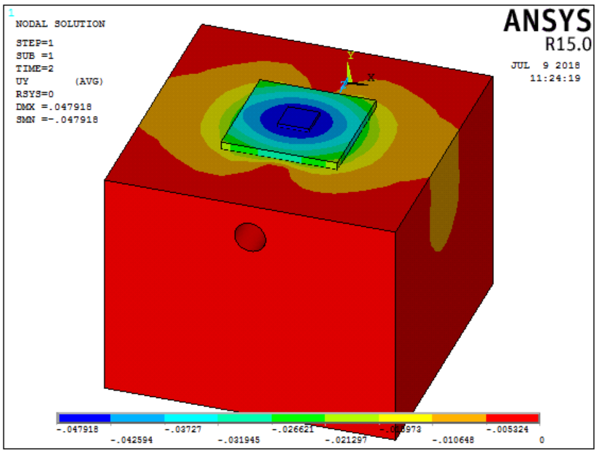


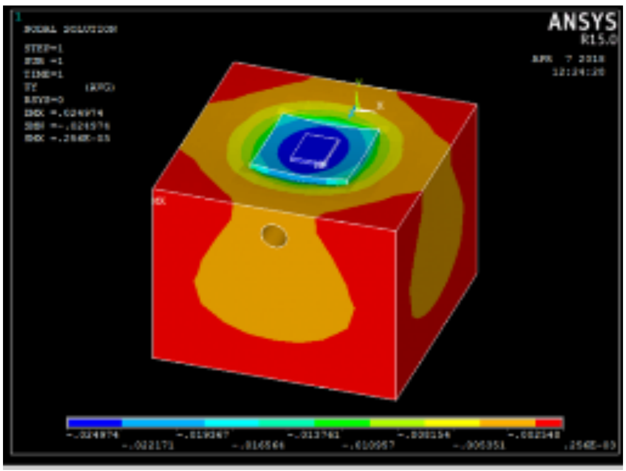
Fig. 19. Specimen RVP.RV.15



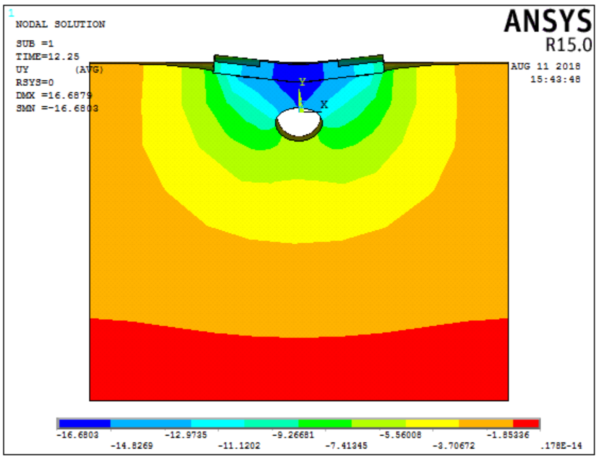
Specimen SP.S.15



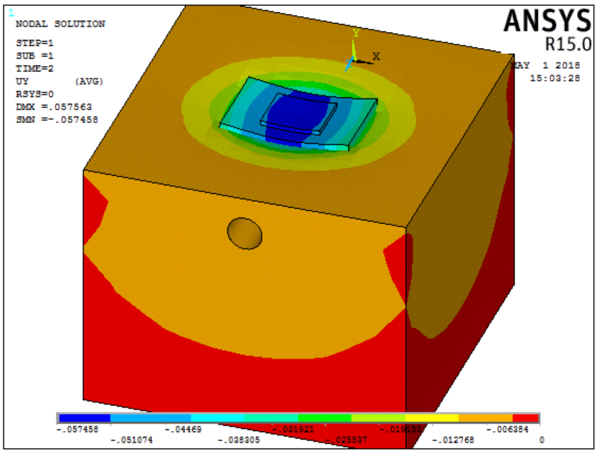
Specimen SR.S.15



Specimen SP.RP.15

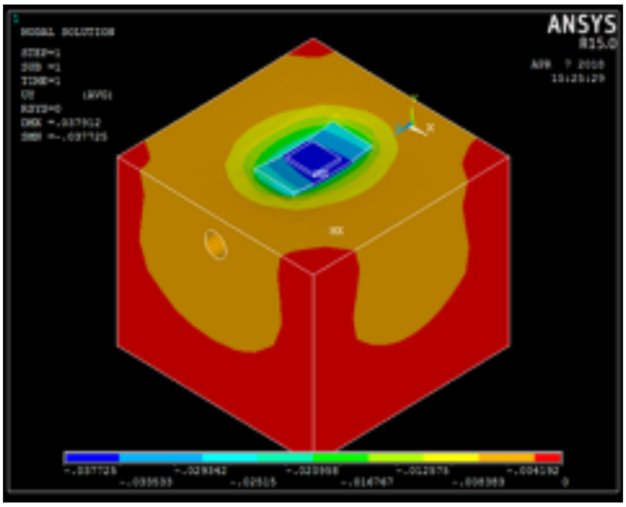


d. Specimen SP.RV.15



Specimen RVP.RV.15

Fig. 20. Behavior of deformation for the models after loading



Specimen RPP.S.15

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3.4. Stress-Displacement Curves around the Cavity.

Drawing the stress displacement curve around the cavity is necessary for illustrating the way in which the stresses distribute around the cavity as well as to maintain the displacement around the cavity. Here, specimen **SP.RP.30** and **SP.RV.30** were chosen (randomly) for showing the stresses around the cavity. A similar result distribution has been found for all the others specimens. Fig. 21 shows the nodes which form to the cavity in the specimens, a ring of nodes below the center of slab was selected to show the results as shown in Fig. 21 , in which every node was named by defined numbers

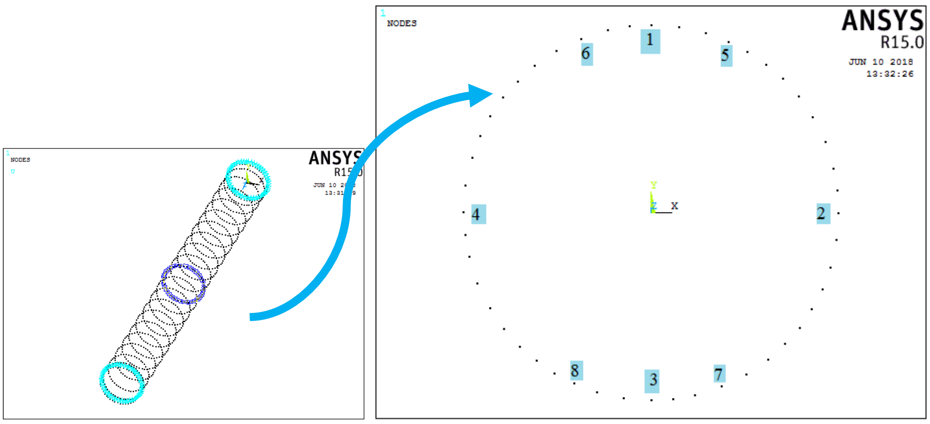


Fig. 21. The nodes surrounding the cavity and its numbering

From the results shown in Fig. 22, for the specimen **SP.RP.30**, the lower points of the cavity are too close and has the smallest displacement due to stress evanesce. The points at the side of cavity have a match result due to symmetry. The upper points of the cavity record the higher displacements. Point 1 introduced the higher stresses value and the larger displacement due to it has the nearest position to the stresses. The same discussion may notice from the results of the stress displacement curve for specimen SP.RV.30 (Fig. 23).

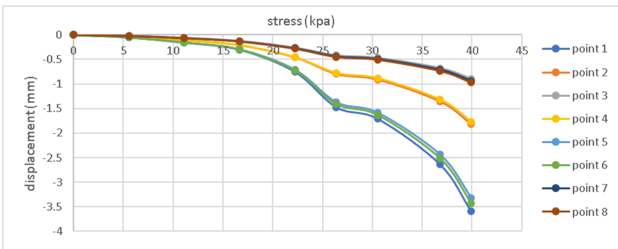


Fig. 22. Stress- displacement curve of SP.RP.30 specimen around the cavity

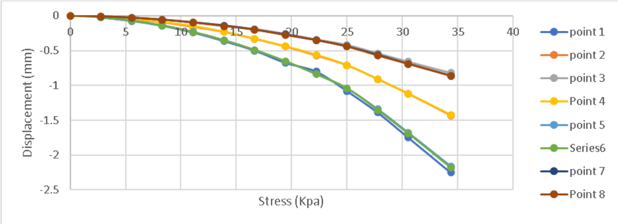


Fig. 23. Stress- displacement curve of S6 specimen around the cavity

3.5. Soil Under Slab Stresses

SP.RP.30 specimen were chosen to investigate the stresses beneath the slab. The other slabs models exhibit similar typical results. The surface below the slab was selected and five nodes were assigned for drawing the stress-displacement curves for the soil in Fig. 24. It can be noting that (from Fig. 25), the central point shows the higher stress intensity due to its load concentrated on it and also shows the higher displacement for the same reason and because its overcome the slab bending at its position. Point 1 and Point 3 express the same magnitudes for stresses and displacement so as points 2 and 4, due to symmetry and because of the bearing plate is rectangular, so it develops the same stresses to these similar points.

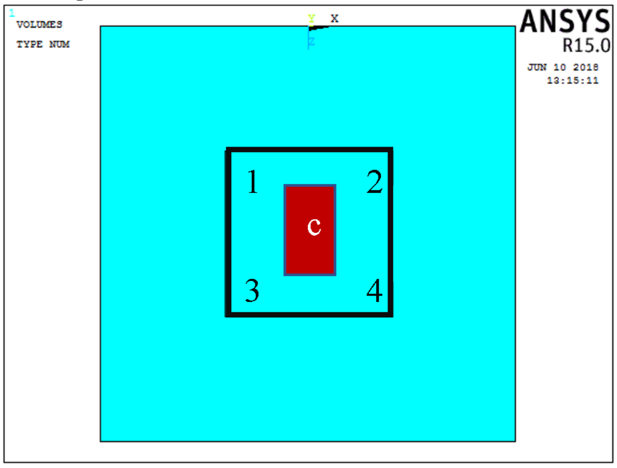


Fig. 24. Numbering the soil corners below the slab base

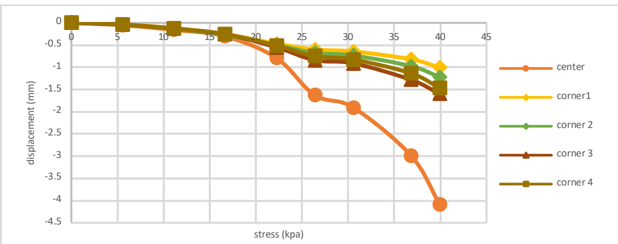


Fig. 25. Stress- displacement curve below the slab surface

3.6. Parametric Study

3.6.1. Continuous and un-continuous cavity influence

An un-continuous cavity was made exactly under the slab and do not extend longitudinally below the slab. ANSYS program allow to simulate such conditions of impossible laboratory made cases easily. In this model, a cavity of 500 mm diameter and 600 mm length has been modeled. In the same position and dimension, a continuous cavity was simulated in another model, to view the effect of cavity continuity. Fig. 26 shows the cavity modelling.

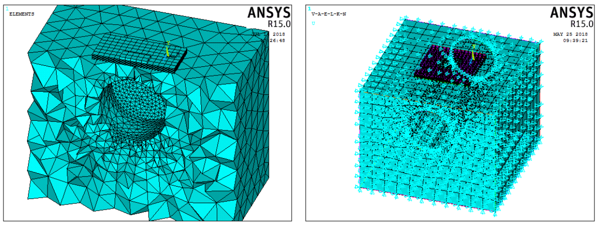


Fig. 26. Continuous and dis-continuous cavities modelling

After analysis, the load displacement curve has been illustrated and compared with the exactly same properties but with a continuous cavity. From Fig. 27, it can be concluded that, the concrete slabs fails in the same ultimate load but more deflection for the continuous cavity model, which refers to that, the slab effected not only by the cavity exactly beneath it but also it effected by the soil around it. Fig. 28 discusses the vertical displacement of model after loading.

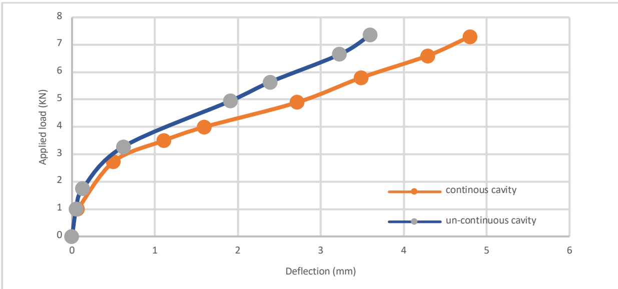


Fig. 27. load deflection curves compression between continuous and un-continuous cavity

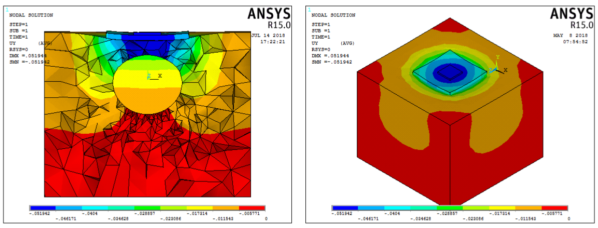


Fig. 28. The nodal vertical displacement of models after loading

3.6.2. Effect of cavity shape on the slab ultimate slab capacity.

In order to explain the effect of changing the cavity shape on the ultimate bearing capacity of the slab, a comparison was made between a cylindrical, polygon and square cavity at the same depth from the slab surface (350mm) and the same equivalent area for all the shapes. The cylinder cavity was chosen as a (250) mm radius, the square cavity area equivalents the area of the cylinder shape (i.e. 443mm side length), also the polygon shape cavity (which is of 7 sides) is with an interior radius of 250 mm as explain in Fig. 29.

Another three shapes were made, which were spherical, group of small spheres, and conical shapes. The spherical shape cavity was of (250) mm radius and of the same depth from the soil surface ((350) mm). The group of spheres consist of three spheres of (300) mm diameter. The conical shape also was of (350) mm depth from the soil surface and of initial radius equals (50) mm and final radius of (250) mm.

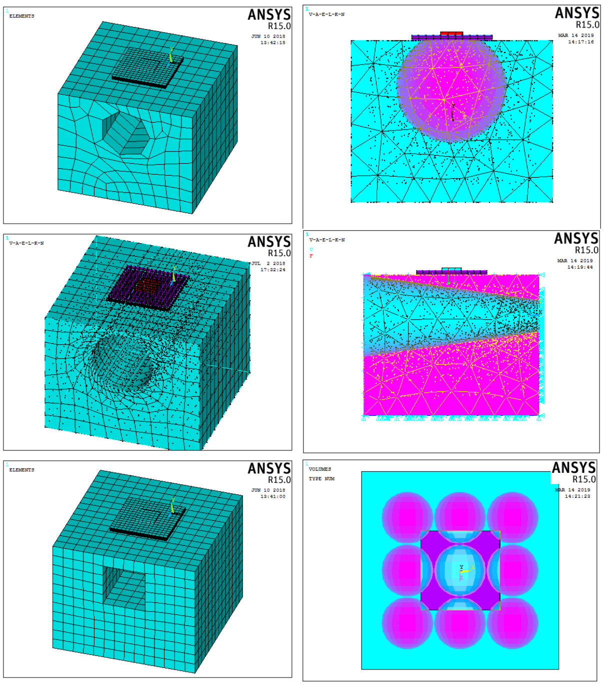


Fig. 29. Different cavities shapes simulating

Given on Fig. 30, The lower three curves which were consist of square, polygon, and cylinder cavities shows higher deflection and less failure load than the upper group of curves which is represented by spherical, conical, and group of small spheres because the difference in cavity geometry. From this study, it can be concluded that, the cylindrical cavity is capable to resist load more than square and polygon by (17.9) % and (2.5) % respectively because its curvature shape which can be transfer the load to the soil on the sides of the cavity. The conical cavity records the higher resistance when comparing with spherical and group of spherical by (12.8) % and (5.9) % respectively, because the area of cone decreases below the slab. There is a little difference in failure load between the spherical cavity and the group of spheres shapes, but there is a notable difference in deflection. The group of spheres gives a larger displacement because of a bigger weakness occurs soil area. From the nodal displacement Fig. 31, the areas with blue color refers to the larger amount of stress in the structure, while the red area indicates to the lower amount of stress in the structure. Also, it can be seen that, all the cavities were compressed from its top face due to slab loading, and the stress transformation to the soil media still matching with the elastic theory model.

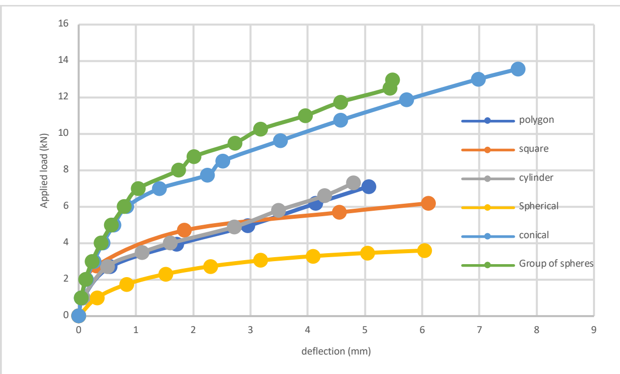
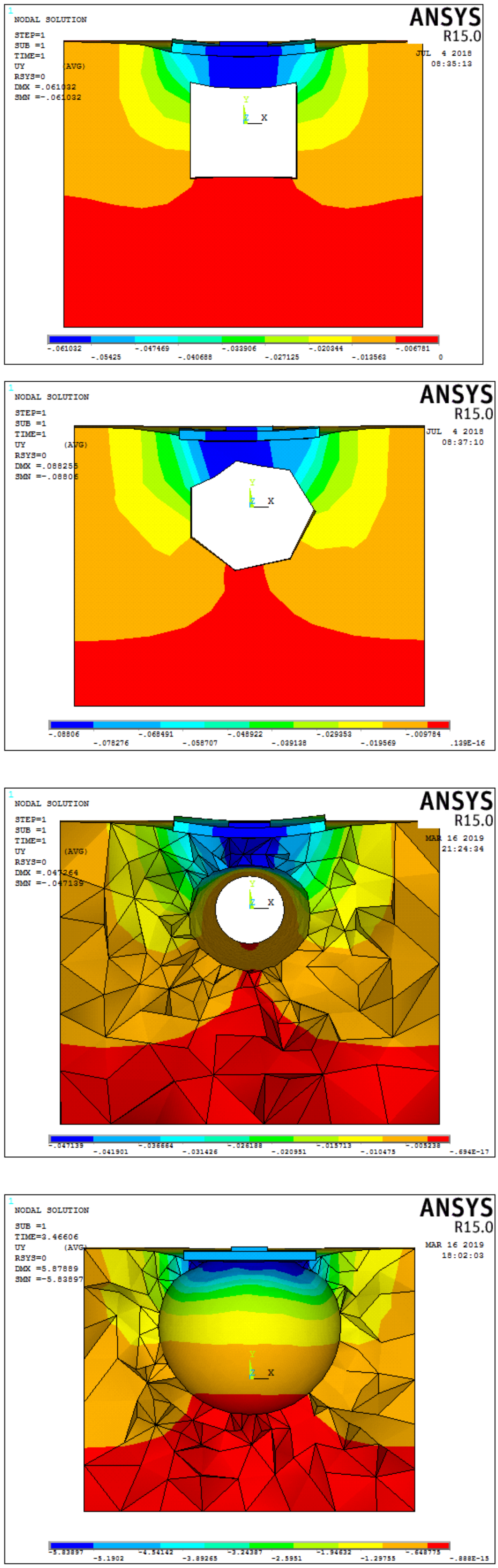


Fig. 30. Comparison between load deflection curves for multiple shapes of cavities



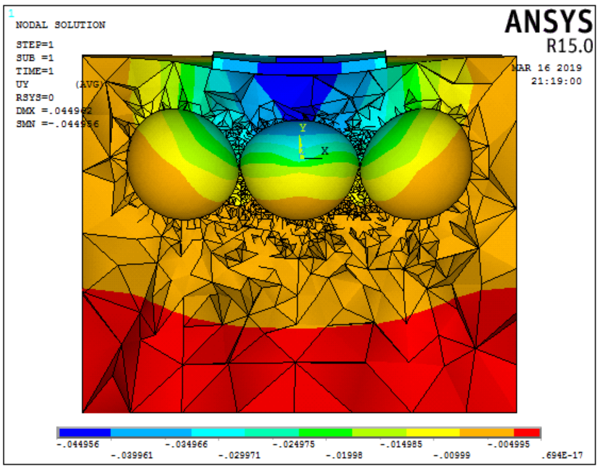


Fig. 31. Nodal displacement for different cavities shapes

3.6.3. Effect of Load Eccentricity

A 160mm cavity diameter at 180mm depth from soil surface were simulated. Two values of eccentricity were selected. There were ex equals 80mm and 160mm (with ez =0 mm), as explained in Fig. 32. Fig. 33 shows the results of three models tests at three different eccentricity loads (ex=0,80 and 160mm), where the deflection measured at the center of the slab. From this study, it can be concluded that, when using an eccentric load, the deflection of the concrete slab reduces with slightly increasing in the ultimate load, due to load exclusion from cavity zone, which is a weakness region. The vertical displacement digram explained at Fig. 34.

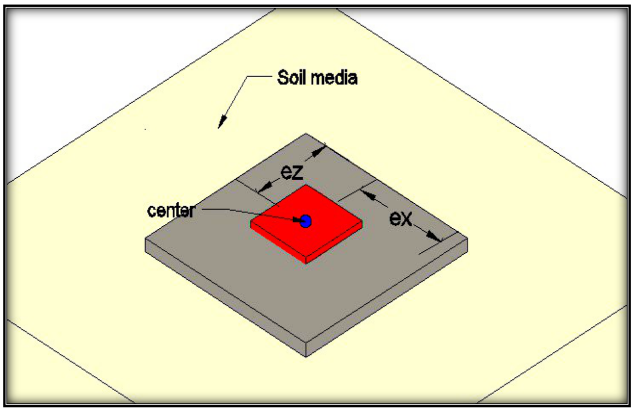


Fig. 32. Load eccentricity on model

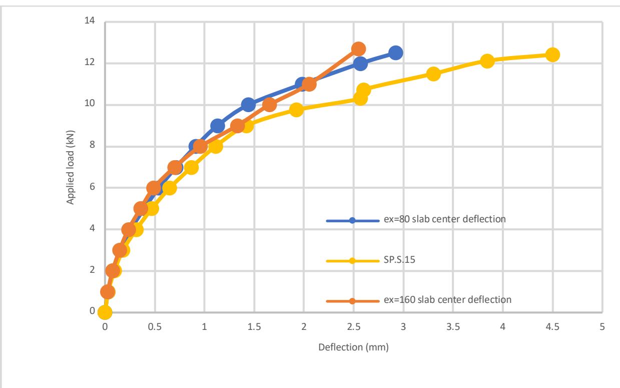


Fig. 33. Load versus deflection for the eccentric load study

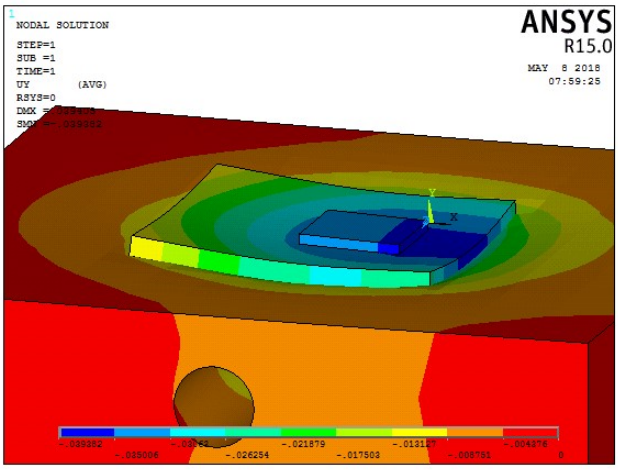


Fig. 34. Vertical deflection for eccentric load model

3.6.4. Effect of Changing the Lateral Distance of Cavity

In this case, a cavity with 160 mm and depth 180 mm from surface and on distance equals 300 mm from the slab center was modeled. The load deflection curve of slab SP.S.15 is plotted for comparison with the case of cavity at center. From Fig. 35, it can be found that, If the cavity forms exactly below the slab's edge instead of its center, the deflection at the center of slab decreases by about 68% while almost the failure load remains the same. From Fig. 36, which illustrated the vertical displacement for the model, it can be noting that, the deformations have not well symmetrical distribution because the more deflection occurs at the weaker zone from the model.

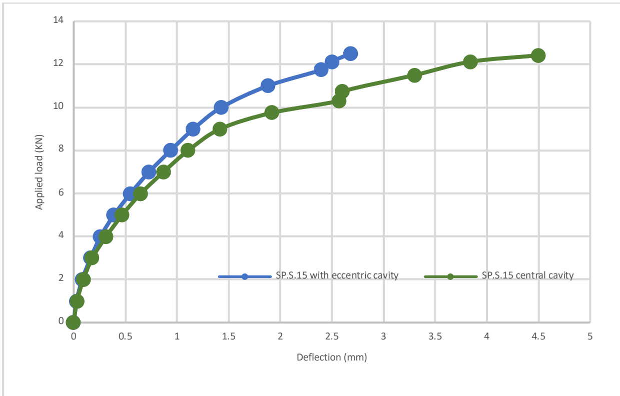


Fig. 35. Load deflection curves for lateral and central cavities models

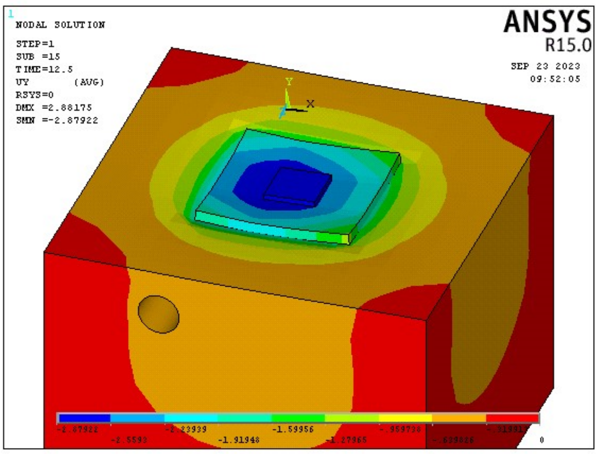


Fig. 36. Nodal solution for the lateral cavity

3.6.5. Cavity Filling

Filling cavities is one of the solutions for the voided soil. Altra-sound devices are essential in such case for discover the size and the depth of the hidden cavity. Cavities may fill with concrete by pumping it through the ground. Filling a cylindrical cavity by a fitting cylindrical concrete mix was discovered at this study. A cavity of 600 mm diameter and 350 mm depth was simulated in the program then filled with the same size of concrete, as explain in Fig. 37. It can be concluded from Fig. 38 that, the slab after filling the soil recover about 115% from the strength due to filling the void with concrete. The vertical displacement diagram (Fig. 39) of soil shows that, the wave of passing the stress into the soil changed in the presence of concrete inside it due to strengthening the soil with a material stiffer than it, so the load was resisted by the filling concrete with a significant effect.

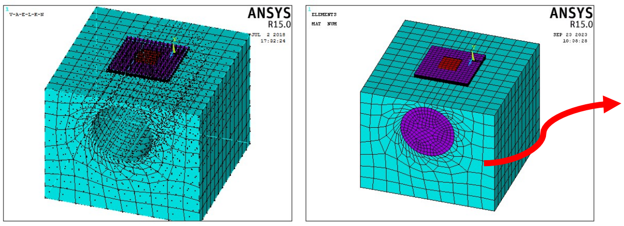


Fig. 37. Cavity simulation before and after filling

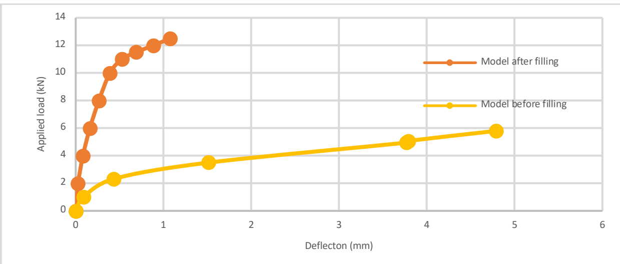


Fig. 38. Comparison results for filled and empty cavity

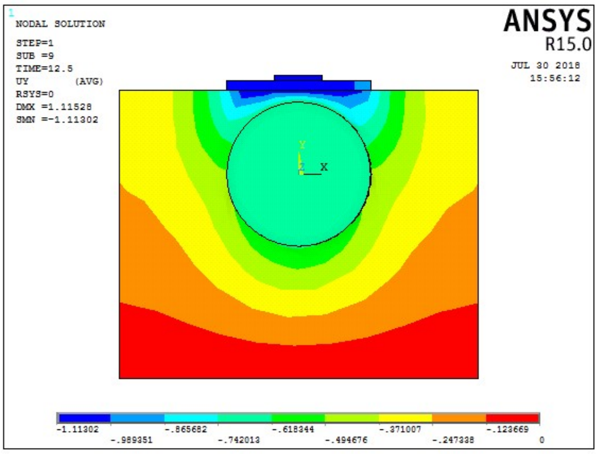


Fig. 39. Nodal displacement for filled cavity

4. Conclusions

The stresses which transfer to the soil take a circular form if the bearing load plate was square, and an ellipscal shape if the loading plate was rectangular, but any way the load develops to the soil in a manner matching with the elastic media theory. The cavity weakens the soil continuum exactly below the slab which will force the slab to rest on the soil sides (shoulders) as a stronger support. The presence of steel wire into the slab changes transfers more strength to the soil due to its high resistance capacity. When the cavity forms into the ground in a cylindrical shape or approach to be cylindrical, the failure load of slab rises by (2.5) % to polygon shape and (18) % for the square shape. Formation a cavity of a conical shape of a final radius equals the cylindrical cavity radius causes an increasing in the bearing load of slab equals (108) %, because the cavity total volume under the concrete slab reduces. Forming a cavity of a polygon shape rises the ultimate load capacity by (15.02) % from a square shape cavity of the same total area. The un- continuous cavity has no effect on the concrete slab failure load but it has a notable effect on the concrete slab deflection, where the deflection increased of the continuous cavity due to more soil weakness. When the load is applied eccentrically, the deflection of the concrete slab reduces with slightly increasing in the ultimate load, due to load exclusion from cavity zone, which is a weakness region. If the cavity forms exactly below the slab's edge instead of its center, the deflection at the center of slab decreases by about 68% while almost the failure load remains the same. Filling cavity with conventional concrete loads to recover about 115% of the model strength.

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