Experimental investigation for the behavior of concrete slab rests on sandy soil contains cavities

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Abstract. Cavities formation into soil media is a very common problem that occurs in the gypseous soils (in which the gypsum content equals 2% and more). The gypsum dissolves by water flow leaching and leaves cavities in different shapes and sizes. In slab on grade system, the American concrete institute (ACI 360) recommends, the concrete slab transforms the load to the ground by about less than 50% of the allowable bearing capacity thereof, but when the soil contains cavities and excavation, the concrete slab behavior will change. In order to investigate the changing in behavior, twelve concrete slabs were prepared and tested on a soil media contains cavities. The investigated parameters were: cavity depth, steel wire reinforcement existence, bearing load plate shapes, and the load distributed parallel or perpendicular to the cavity. From the experimental results, it has been concluded that, the plain and reinforced concrete slab capacity decreases by (30.7%) and (7.4%) when a cylindrical continuous cavity forms at (30%) mm depth from the soil surface. However, when the cavity forms at a distance equal to (15%) from the soil surface, the plain and reinforced concrete slab capacity reduced by (70%) and (61%) respectively.

Keywords: Slab on grade, Cylindrical cavity, Slab on voided soil, Soil supported slab, slightly gypseous soil.

1. Introduction

Concrete slabs, which are upheld by a soil medium, is a widely used type of constructions because of its durability, mastery to overcome subgrade weakness, and ability to resist hard climate conditions. It is difficult to get an integral relation between concrete slabs and soil action because of the complexity of soil itself. The soil is a non-homogeneous and anisotropic medium, it behaves as a non-linear state, and moreover, its properties may change and vary with climate and time. In contrast to concrete which can be analysed as an isotropic, linear behavior material [1]. Gypsum (CaSO₄) is a salt diffuses in many of the world soil lands. It covers 6.7% of the world gypsum’s land. [2] Gypsum soils (which are the soils that contain more than 2% of gypsum content [3]) are a strong kind of soil and have good properties when it is dry. The worrisome matter is when constructing a heavy building on it then the soil gets wet. In that case, a gigantic loss of strength will happen, and the worst is when the water flows inside the soil causing reduce of mass by gypsum leaching [1]. When gypsum leaching occurs, cavities in different shapes and sizes will form inside the soil [4] (see Figure 1.). Cavities existence weakens the bearing
capacity of the soil [5]. As a result, and in the first level, cavities may cause differential settlement for the building, and next, the passive effect may aggravate to a construction collapse. It is worth to mention that, the ACI-360 committee defines slabs on grade as the member which transfer the load to the soil by less than 40%. [6] In this paper, the effect of cavities caused by gypsum dissolution on the concrete slabs on grade was discussed.

![Image](image_url)

**Figure 1.** The cavity in different shapes and sizes [4].

2. **Experimental procedure**

To simulate the slab on a cavited soil system as a real matter, a concrete slab and soil container box were made in the laboratory. The system was provided by a hydraulic press gaged jack of (20 Ton) capacity. All the details are explained below.

2.1 **Soil preparation work**

A wooden box of (1500x1500x1300 mm) was made as a container for the sandy soil. These dimensions were detected from the elastic theory curves method [7]. According to this theory, the load diffused laterally in the soil by 2.5B in each direction and 2B for the depth (where B is the slab width). The wooden box contains two doors that used for formation cavities. The cavities are supposed to be in continuous cylindrical shape. It was made by putting a PVC plastic pipe into the soil media in specified depth, then the soil above it will be compacted. After compacting finishing, the PVC pipe pulls out from the box doors, as shown in figure 2. The amount of soil which is filled the container was detected from the standard Procter test. The soil was well graded sand with a gypsum content equal 4.8 %. The soil was chosen as gypous to simulate the nature reality case. The test showed that the optimum density of the soil was 1844 Kg/m³ and the optimum water content was 12%.

![Image](image_url)

**Figure 2.** Cavities work formation.

2.2 **Press system configuration**

A steel frame of I-sections was built around the wooden container. The frame was used to hold a gaged hydraulic jack press. The jack was hanging using its adjustable rotary ring, which is used to tweak the hunger arm, where welding is Forbidden to avoid the thermal damage of the oil inside the jack as shown in figure 3.
2.3 Test specimens

In this research, twelve concrete slabs were prepared. Ten specimens are of (600*600*40 mm) dimensions, three of them were reinforced by (9 φ 4 mm) at (65 mm) spacing, and the others were plain. The compressive strength of the concrete (f’c) equals (30 MPa). The maximum aggregate size in the mixture was (9.5 mm). The last two specimens were of (600*400*40 mm) and (600*300*40 mm). One plain slab and one reinforced slab were used as a reference and tested on soil without a cavity. Cavities in two positions were made, (350 and 180 mm) below the soil surface (which are equal (30 and 15%) of the soil continuum total height). The steel bearing plate used were: square of (200*200*20 mm), rectangular of (300*200*20 mm) parallel to the cavity direction, and rectangular of (300*200*20 mm) perpendicular to the cavity direction. Table 1 shows the specimens details.

Table 1. Tested specimen details (all dimensions in mm)

| Group | Slab | Dimension | Reinf. details | Steel plate dim. |
|-------|------|-----------|----------------|------------------|
| Reference | | | | |
| SP.S. | 600*600*40 | | | 200*200*20 |
| SR.S. | 600*600*40 | | 4@65mesh | 200*200*20 |
| | | | | |
| Group 1: 15% cavity depth | | | | |
| SP.S.30 | 600*600*40 | | | 200*200*20 |
| SR.S.30 | 600*600*40 | | 4@65mesh | 200*200*20 |
| SP.RP.30 | 600*600*40 | | | 300*200*20 (parallel to cavity direction) |
| SP.RV.30 | 600*600*40 | | | 300*200*20 (Vertical to cavity direction) |
| | | | | |
| Group 2: 15% cavity depth | | | | |
| SP.S.15 | 600*600*40 | | | 200*200*20 |
| SR.S.15 | 600*600*40 | | 4@65mesh | 200*200*20 |
| SP.RP.15 | 600*600*40 | | | 300*200*20 (parallel to cavity direction) |
| SP.RV.15 | 600*600*40 | | | 300*200*20 (vertical to cavity direction) |
| RPP.S.15 | 600*300*40 | | | 200*200*20 |
| RPV.RV.15 | Parallel to cavity | | | 300*200*20 (Vertical to cavity direction) |

Three dial gages were fixed at the concrete slab centre and two opposite diagonal corners to read the deflection at these points. The gages were fixed at the top surface of the concrete slab specimen as shown in figure 4.
3. Tests results and discussions
The load deflection curves and comparing studies were discussed in the following section.

3.1. References models results
As shown in figure (5), when a slab tested sandy soil without cavity, the ultimate load of the plain slab was (17KN) and the reinforced was (32KN). The increment in the ultimate load equals (70.58%) when the slab is reinforced. The figure below shows the behavior of concrete slabs under loading.

![Figure 5. References results.](image)

3.2. Cavity depth effect on reinforced concrete slabs
The failure load of the reinforced concrete slab reduced by (7.4%) and (61%) when there is a cavity located at depth (30%) or (15%) respectively, below the surface of the slab as in figure 6.

![Figure 6. Effect of cavity depth on reinforced concrete slabs of group one.](image)
3.3. Cavity depth effect on plain concrete slabs

The difference in the ultimate load of the slabs in the case of no cavity, cavity existence at depth (30%), and cavity existence at depth (15%) were illustrated in figure 7. The results show that the slab loss about (30.7 %) of its capacity when there is a cavity located at depth equals (30%) and about (70%) when there is a cavity located at depth equals (15%).

![Figure 7. Comparison between the cavity depth difference using a square plate.](image)

3.4. Comparison between plain and reinforced slab at two cavity depths

The effect of steel wire reinforcement on the ultimate load of the slab is illustrated in figure 8. The ultimate slab load enhanced by about (107 %) compared with the case of plain concrete. Figure 9 explained a comparison study between the specimens SP.S.15 and SR.S.15, to maintain the effect of steel wires existence. The results showed that the concrete slab capacity increased to (80%) when the slab is reinforced and on cavity at depth equals (15%).

![Figure 8. Comparison between plain and reinforced slab for Group one.](image)  
![Figure 9. Comparison between plain and reinforced slab for Group two](image)

3.5. Bearing plate shape effect on slabs with 30% cavity depth

As concluded from the experimental work, when a cavity forms at any depth, the soil will divide into two regions. The first region is the soil which lies on the sides of cavity (shoulders), and the second region is the soil lies in between slab bottom and the upper surface of the cavity (which is sometimes be a very thin shell and called by cover). Every group will share in load resistance but the shoulder
zone is stiffer than the cover zone. As shown in figure 10, the slab SP.RV.30 shows a failure load greater than the others, because the rectangular perpendicular plate transforms the load into the shoulder zone. Also, the slab SP.RP.30 shows the min. Failure load and max. deflection, since that the rectangular parallel bearing plate distributes the load towards the cavity (i.e.) the cover zone. From SP.RP.30 and SP.RV.30 results, the slab loss (50 \%) of its total capacity when the load was distributed towards the cavity direction. Whereas, when using a square plate in the specimen (SP.S.30), the ultimate load capacity of the slab reduces by about (15.38 \%) from the case of using a perpendicular bearing plate (SP.RV.30). The slab reduces (30 \%) of its capacity when using a parallel rectangular plate instead of a square bearing plate. From the results of (SP.S.30) test, the concrete slab capacity reduces (30.77 \%) of its total capacity in case of cavity existence at depth (30\%).

![Figure 10](image_url)

**Figure 10.** Effect of bearing plate shape on tested slabs for group one.

### 3.6. Effect of bearing plate shape on slabs on cavity 15\% depth

The slab SP.RV.15 shows a failure load greater than the others as shown in figure 11, because of that the rectangular perpendicular plate transforms the load into the shoulder zone. Also, the slab SP.RP.15 shows the minimum failure load and maximum deflection, due to that the rectangular parallel to cavity direction plate distributes the load towards the cavity ((i.e.) the cover zone). The slab loses (69.3 \%) of its ultimate load capacity when cavity exists at depth equals (15\%). Also the slab capacity reduces by (20 \%) when using steel plate parallel to the cavity direction instead of a square plate. Form curve SP.RP.15 and SP.RV.15, the slab capacity reduces to (62.5 \%) when the load distributed towards the cavity direction by the rectangular parallel steel plate. While when using a square bearing plate (SP.S.15), the ultimate load capacity of the slab reduces a (30 \%) of its total capacity from the case of using a perpendicular rectangular bearing plate.

### 3.7. Effect of minimizing slab dimensions

When using a square steel plate, and the slab area reduces from (600*600*40 mm) to (600*300*40 mm), the ultimate load capacity reduced by (5.26 \%) from the slab SP.S.15 (total area) and (78.9 \%) from (SP.S.) the case of without cavity (as explained in figure 12).

When changing the area of slab from (600*600*40 mm) to (600*400*40 mm) the ultimate load of concrete slab increases by (23.07 \%) from the case of total slab area (SP.RV.15). Figure 13 illustrated the effect of decreasing slab dimensions. This is a because a combination effect of two parameters, the first effect is that, the smaller slab area leads to little soil bearing pressure (i.e. the soil will not collaborate in resist the load such as the past
cases) and that will hasten slab failure, the second effect is that, when slab area is reduced, the deflection in the z- direction will reduced too, and that may late the slab failure.

**Figure 11.** Effect of bearing plate shape of slabs of Group two.

**Figure 12.** Effect of reducing the slab dimensions.

**Figure 13.** Effect of reducing slab dimensions.
3.8. Effect of cavity depth difference and using rectangular parallel steel bearing plate

The difference in the ultimate load of the slabs in the case of no cavity, cavity existence at depth (30%), and cavity located at depth (15%) were shown in figure 14. The results show the slab losses about (20 %) of its total ultimate load when the cavity location change from (30 to 15%).

![Figure 14. Comparison between cavity depth difference using rectangular plate.](image)

3.9. Effect of cavity depth difference and using rectangular perpendicular steel bearing plate

The difference in the ultimate load of the slabs in the case of no cavity, cavity located at depth (30%), and cavity located at depth (15% mm) are shown in figure 15. The results show that the slab loss about (15.38 %) of its total ultimate load when the cavity converge to the surface by (170 mm). Noting that, placing the bearing plate perpendicular to the cavity leads to increase in the overall slab resistance because the load has been distributed towards the stronger soil bath.

When minimizing the slab dimensions from (600*600*40 mm) to (600*400*40 mm), and using a rectangular perpendicular plate, the ultimate load of the slab increases (23.07 %) because the lesser slab span leads to minimizing cracks in the other smaller direction.

![Figure 15. Rectangular vertical plate with cavity depths comparison.](image)

4. Failure modes

All the specimens failed by flexural. For specimen SP.S. and SR.S. (Figure 16. A and B), the failure line occurs in the three paths. The direction of the paths depends on the gravel’s particles in concrete and soil.
For specimens SP.S.30 (Figure 16.C), SP.RP.30 (Figure 16.D), SP.S.15 (Figure 16.E), RPP.S.16 (Figure 16.G) and RVP.RV.15 (Figure 16.F), the failure path occurs parallel to cavity direction, which is the weak path.

For specimens SP.RV.30 (Figure 17.H.), SP.RP.15 (Figure 17.I), and SP.RV.15 (Figure 17.J), the specimens crashed for three part, because the rectangular steel plate transfers the load in a path vertical to the cavity direction. For specimens SR.S.30 the cracks separated in a direction parallel to the cavity (Figure 17.K)), and the transversal cracks was little when comparing with specimen SR.S.15 (Figure 17.L)), due to the shallower cavity.

Figure 16. Failure mode of specimens.

Figure 17. Failure mode of specimens.
5. Conclusions

In accordance with the results, the following points have been found:
1. The existence of steel wire reinforcement leads to increase the slab on grade capacity by (70.58 %) in the case of without cavity.
2. The ultimate bearing capacity of the reinforced concrete slab decreases by (7.4 %) and (61 %) in the case of cavity existence at depth (30%) and (15% mm), respectively.
3. The plain concrete slab capacity decreases (30.77%) of its capacity when a cavity exists at depth (30 %), and (70 %) when cavity is found at depth (15%) in case of square loading plate.
4. In the case of cavity existence at depth equals (30% and 15%), the ultimate capacity of reinforced concrete slab rises to (115 and 80 %), respectively, when compared with the plain slab.
5. The slab loses about (50 %) of its ultimate capacity when the load distributed towards the cavity direction by the rectangular plate (in the case of cavity existence at depth 30%), and when using a square plate for the same cavity depth, the ultimate load reduces by (15.38 %) when comparing with using perpendicular rectangular plate.
6. The slab loss about (62.5 %) of its ultimate capacity when the load distributed (by the rectangular plate) towards the cavity which is of (15%) depth, and when using a square plate, the ultimate load reduces by (30 %) when compared with the perpendicular rectangular plate.
7. When the slab dimension reduces to (600*300*40 mm), the ultimate bearing capacity of the slab reduced by (5.26 %) at (15%) cavity depth.
8. When the slab dimension reduces from (600*600*40 mm) to (600*400*40 mm), the ultimate bearing capacity of the slab increased by (23.07 %) at cavity depth equals (15%).
9. When the cavity depth reduces from 30% to 15%, the ultimate load of slab reduces (30.7 %) when using square bearing plate, (25 %) when using the rectangular parallel to cavity direction, and (6.6 %) in the case of the load distributed by rectangular plate oriented perpendicular to cavity direction.

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