Numerical Analysis of Treatment of Highly Expansive Soil by Partial Replacement with Crushed Concrete

Khawla A. Aljuari1*a, Mohammed Y. Fattah2,b, and Harith E. Ali3,c
1Civil Engineering Department, University of Mosul, Nineveh, Iraq.
2Civil Engineering Department, University of Technology, Baghdad, Iraq.
3Engineering Technical College, North Technical University, Nineveh, Iraq.
*khawlah.ahmad@uomosul.edu.iq, *myf_1968@yahoo.com,
chb_alhaded@yahoo.com
*Corresponding author

Abstract. The major goal of this research work is to treat one type of the known problematic soil (expansive soil) by partial replacement with crushed concrete material which is found in large quantities and distributed on large area of Mosul city. Numerical analysis using Geo-Studio program 2007 is utilized to analyze this problem. Several parameters are considered in this study such as; thickness of the crushed concrete layer of (20, 30, 40, 50, 60, and 70) cm, width of crushed concrete layer is equal to width of footing B, 1.5B and 2B, soil with low and high suction and the time required to complete swelling are studied. All the mentioned parameters were studied with and without presence of footing. The main results of the analysis showed decreasing in vertical swelling upon increasing the thickness and width of the crushed concrete layers. The use of crushed concrete layers is more active in lowering the vertical swelling of high suction soil than that of low suction soil. Finally, the increase in thickness of the crushed concrete layers reduces the increase in vertical swelling with time.

Keyword: Expansive unsaturated soil; crushed concrete; finite element analysis; Geo-Studio; footing.

1. Introduction
Expansive soil is a term called for a clayey soil which has the ability to shrinkage and swelling due to climatic changes in moisture content. The class of swelling of expansive soil depends mainly on numerous parameters for example the initial water content, initial density, clay minerals composition, clay content, soil structure, depth of soil, confining pressure and salt concentration...etc. [1-5]. The movement of clayey soil up and down is considered a sever threatened to specially light weight structures like one story building, airport, pavement road and footing [6-8]. The engineering designer prefers replacement the problematic expansive soil by good soil properties, but this method is much costly and time consuming. Moreover, it requires heavy equipment for extrusion, transportation and compaction the soil. So, scientists proposed many methods to get better the characteristics of expansive soil. The chemical additives such as lime, cement, fly ash and asphalt considered the most traditional and familiar method used for stabilizing swelling soil [9-12]. Other ways were suggested for limiting the dangerous of expansive soil by mixing it with sand [13].

Recently, waste materials are used for controlling swelling characteristic and improving the engineering properties of expansive soil, where Khattab et al. [14] utilized industrial waste lime to reduce swelling and increase the strength soil parameters. On the other hand, Signes et al. [15] and
Bekhitia et al. [16] investigated on the behavior of swelling and strength of cemented bentonite clay soil treated with waste tire rubber fibers. The results showed that the swell potentials and swelling pressure decrease gradually when tire rubber fiber content and cement increase. As well as, Selvakumar and Soundara [17] reused the waste expanded polystyrene (EPS) beads to form geofoam granules column to decrease the swelling pressure and potential of expansive soil. Al-Mosul city north of Iraq was subjected to destroy due to terrorist attacks. Many buildings which were constructed of concrete were demolished. So that, crushed concrete is available for use in several applications in large quantities. In this study, a numerical analysis is made to simulate a method of treatment of swelling soil below footings by partial replacement with crushed concrete. Layers of crushed concrete underneath footing are used with different thicknesses and widths. The soil with low and high suction values is also enhanced.

2. Materials and boundary conditions

Swelling soil from Al-Majmoah region within Al-Mosul city is selected as an expansive soil in modeling this problem. The physical and engineering soil properties are listed in Table 1. The materials properties of expansive soil, crushed concrete and footing which are enhanced in classifying the problem are displayed in Table 2. The suitable choice of the model required input some material properties. The Soil Water Characteristic Curve SWCC and the hydraulic conductivity curves for Al-Majmoah soil are plotted in Figures 1 and 2. GeoStudio program has the ability to obtain these two curves indirectly depending on the parameters of the SWCC and the saturated coefficient of permeability, applying the equation proposed by Fredlund and Xing [18].

The condition of this problem imposes using two types of boundaries; hydraulic and stress/strain boundary conditions, which are utilized for flow and stress analysis of finite element method, respectively. However, in flow analysis, a steady-state model was enhanced to get initial suction and a transient model was utilized to get the final suction conditions. For the steady-state model, pressure head boundary conditions were applied to the model and the resultant pore pressure/suction values were obtained as shown in Figure 3. For the transient analysis, time dependent boundary conditions were assigned to the ground surface in the form of the surface head. For stress/strain analysis of swelling stage, both of the two sides of the proposed model are permitted to move in the vertical direction while they are prevented to move in the horizontal direction. So, rollers are placed along the two sides of the suggested model as visualized in Figure 3. At the base of the soil geometry of the swelling stage is prevented from moving in both directions and is simulated by hinge boundary as captured in Figure 3. On the other hand, the top surface is left to move freely.

Table 1. Physical and engineering properties of Al-Majmoah soil.

| Property                  | Value          |
|---------------------------|----------------|
| Atterberg limits          |                |
| Liquid and plastic limits (%)| 51, 39        |
| Shrinkage limit (%)       | 12             |
| Linear shrinkage (%)      | 20.75          |
| Soil classification       | CH             |
| Specific gravity          | 2.8            |
| Total soluble salts (%)   | 5.6            |
| Organic matter (%)        | 1.8            |
| Sulphate salts            | 0.45           |
| Gypsum content (%)        | 5.12           |
| Grain size analysis       |                |
| Sand, Silt, Clay (%)     | 14, 34, 52     |
| Standard compaction       |                |
| Max. dry unit weight (kN/m$^3$) | 14.4         |
| Optimum moisture content (%)| 27.4         |
| Modified compaction       |                |
| Max. dry unit weight (kN/m$^3$) for | 16.8         |
| Optimum moisture content (%)| 13.8         |
| Standard compaction       |                |
| Swelling pressure (kN/m$^2$) | 175            |
| Swelling potential (%)    | 8.35           |
Table 2. Properties of expansive soil, crushed concrete and footing used in the FEM analysis.

| Material                          | Property                              | Value     |
|----------------------------------|---------------------------------------|-----------|
| Initial state of expansive soil  | Effective elastic modulus (kPa)       | 50000     |
| (linear-elastic model)           | Dry unit weight (kN/m³)                | 14.4      |
|                                  | Poisson's ratio                       | 0.495     |
|                                  | Dry unit weight (kN/m³)                | 14.4      |
|                                  | Poisson's ratio                       | 0.495     |
|                                  | Load response ratio                   | 1.0       |
| Swelling stage (linear elastic model) | k-saturation (m/day)             | 1.77×10⁻⁴ |
|                                  | k-function method                     | Fredlund-Xing Function            |
|                                  | Maximum suction (kPa)                 | 1×10⁵     |
|                                  | Minimum suction (kPa)                 | 0.01      |
|                                  | Residual water content (m³/m³)        | 0.0       |
| Crushed concrete layer           | Effective elastic modulus (MPa)       | 30        |
|                                  | Poisson's ratio                       | 0.2       |
|                                  | Dry unit weight (kN/m³)                | 21        |
|                                  | Effective elastic modulus (GPa)        | 21        |
| Concrete footing                 | Poisson's ratio                       | 0.2       |
|                                  | Dry unit weight (kN/m³)                | 24        |

Figure 1. SWCC of expansive soil.

Figure 2. Hydraulic conductivity of expansive soil.

Figure 3. Boundary conditions assigned for the footing model.
3. Finite element mesh
The mesh generation is an important step in the method called finite element. The discretization of the whole domain is created automatically in GeoStudio program. A uniform size mesh was employed for the whole domain of the model that consisted of soil, crushed concrete layers and footing. The selected element size is (0.25×0.25) m. The type of the chosen element is 8 noded quadrilateral isoparametric element of rectangular grid of quads and triangles is utilized to represent the soil, footing and crushed concrete layers as visualized in Figure 3.

4. Results and discussion
There are several strategies dependent to show the effect of using crushed concrete layer underneath footing on swelling phenomena of highly expansive soil. These strategies are listed down:
- The thickness of crushed concrete layer.
- The width of crushed concrete layer.
- Investigating the influence of initial suction of the soil treated with crushed concrete layer.
- Studying the duration of swelling completion of soil treated with crushed concrete layer.

4.1 Thickness of crushed concrete layer
The thickness of crushed concrete layer plays as an important factor on swelling properties of highly expansive soil. So, the thickness of crushed concrete layer is varied through the analysis. Therefore, it is taken as (20, 30, 40, 50, 60, and 70) cm which represents the thickness of sub base materials that is usually used in the field. Figure 4 shows the correlation between the vertical swelling and the thickness of crushed concrete layer for different cases of width of crushed concrete layer with and without footing. It is clear that the vertical expansion approximately decreased linearly upon additional thickness of the crushed concrete layer for all cases mentioned above. This behavior can be explained by two reasons; the first reason is the amount of removal expansive soil increased with increasing the thickness of crushed concrete layer, the second reason is the expansive soil (active material) replaced by crushed concrete which is consider in active material.

Moreover, the slope of the curves when using a layer of crushed concrete of thickness 20 cm is more than that when using layers with different thicknesses, where the amount of reduction in the vertical expansion has approximately the same values when the thickness of crushed concrete is increased from (30 to 70) cm. The percent of reduction in vertical expansion increased with increasing the thickness of the crushed concrete layer for all cases as shown in Table 3. The maximum percent of reduction in the vertical expansion are ranged between (69.8 - 80.4) % when a layer of crushed concrete of thickness 70 cm is used. It clear, that the average reduction percent in the vertical swelling is more than 28 % when a layer of crushed concrete of thickness 20 cm is utilized.

![Figure 4](image-url)
Table 3. Reduction percent in vertical expansion of low suction soil.

| Thickness of crushed concrete (cm) | Width of crushed concrete (m) without footing | Width of crushed concrete with footing (m) |
|-----------------------------------|---------------------------------------------|------------------------------------------|
| 0                                 | 2.0                                         | 0                                         |
| 20                                | 32.03                                       | 16.20                                     |
| 30                                | 34.64                                       | 32.40                                     |
| 40                                | 50.34                                       | 44.51                                     |
| 50                                | 59.96                                       | 51.96                                     |
| 60                                | 68.16                                       | 60.89                                     |
| 70                                | 78.03                                       | 69.83                                     |

4.2 Width of crushed concrete layer

The amount of swelling of expansive soil is sufficiently affected by the width of footing. Therefore, three widths of the crushed concrete layer are considered in this study, the selected width of the crushed concrete layer is equal to the width of footing (B), then increasing the width of crushed concrete layer by B/4 and B/2 from each side as captured below in Figure 5.

![Figure 5. Width of the crushed concrete layer.](image)

Two cases are considered in this analysis; the first case used crushed concrete only with different layer thickness, the second case used crushed concrete layer which has different thicknesses with the presence of a footing. Figure 6 displays the correlation between vertical expansion and the width of crushed concrete layer only. It can be shown that the vertical expansion increased with additional width of crushed concrete layers which has the thickness of (20 and 30) cm. This behavior can be explained by the swelling pressure generated below the crushed concrete layer that made it bend upward, however the amount of bending increased with increasing the width of the crushed concrete layer as visualized in deformed mesh in Figure 7. On the contrary, the vertical expansion decreased at width of 3.0 m then increased at width of 4.0 m for crushed concrete layer with thickness ranged from 40 to 70 cm. That is related to the increase in thickness of the crushed concrete layer made the weight of the crushed concrete layer is bigger, so the bigger weight overcomes the swelling of soil and reduces it, whereas at width of 4.0 m of crushed concrete layer, the swelling of soil overcomes the weight of crushed concrete layer because the weight is distributed to wider width thus the vertical swelling increased.

The correlation between the vertical expansion with width of crushed concrete layer with footing is plotted in Figure 8. The vertical expansion decreased linearly with increasing the width of crushed concrete layer with presence of footing because additional weight from footing was added to the weight of crushed concrete layer to overcome the swelling pressure of soil, so the vertical swelling decreased. The maximum decrease in the vertical swelling due to increase the width of crushed concrete layer with footing from (2 to 3) m and at layer thickness 50 cm is 33.6%. The amount of reduction in the vertical expansion is approximately equal, so the curves have the same slope.
Figure 6. Correlation between vertical swelling and width of crushed concrete layer without footing.

Figure 7. Deformed mesh of crushed concrete layer of thickness 20 cm with width 3.0 m without footing.

Figure 8. Correlation between vertical swelling and width of crushed concrete layer with the presence of footing.
4.3 Change the degree of saturation of the soil treated with crushed concrete layer
The degree of saturation of the soil treated with crushed concrete was changed to show its effect on the vertical swelling. So, the water content at optimum and at 90 % of the dry side of standard compaction curve of Al-Majmouah soil was considered. The soil suction for low water content increased. The vertical expansion of the soil treated by crushed concrete layer with and without footing and with different widths of footing increased with decreasing the initial water content of soil for all crushed concrete layer thickness as shown in Figure 9. The amount and percent of increase in the vertical expansion for natural soil reached 9.5 cm and 63.8%. The additional percent in the vertical expansion related to reduction in the initial water content of the soil remained approximately constant at all crushed concrete layer thickness with different widths as shown in Table 4. Utilizing the crushed concrete layer is more active in reducing the vertical swelling of the soil with low initial water content than that of high initial water content. The vertical swelling of the soil with low initial water content reduced with increasing the thickness of the crushed concrete layer. The maximum percent of decrease ranged between (68.7-79.9) % when the thickness of the crushed concrete layer increased from 0 to 70 cm as shown in Figure 10 and Table 5. Fattah et al. [19] concluded that increasing the initial water content resulted in steep reduction in suction stresses, so that this decrease was reflected in this study on swelling.

![Figure 9](image1.png)
**Figure 9.** Correlation between vertical swelling of soil of low initial water content with thickness of crushed concrete layer.

![Figure 10](image2.png)
**Figure 10.** Comparison between vertical swelling of soil of low and high initial water content with thickness of crushed concrete layer.
Table 4. Percent of increase in vertical swelling between low and high initial water content.

| Thickness of crushed concrete (cm) | Width of crushed concrete (m) | Width of crushed concrete with footing (m) |
|-------------------------------------|-----------------------------|------------------------------------------|
| 0                                   | 63.8                        | 63.8                                     |
| 20                                  | 64.2                        | 64.2                                     |
| 30                                  | 64.1                        | 64.4                                     |
| 40                                  | 64.1                        | 64.4                                     |
| 50                                  | 64.1                        | 64.4                                     |
| 60                                  | 64.2                        | 65.6                                     |
| 70                                  | 63.8                        | 64.9                                     |

Table 5. Reduction percent of vertical expansion of high suction soil.

| Thickness of crushed concrete (cm) | Width of crushed concrete (m) | Width of crushed concrete with footing (m) |
|-------------------------------------|-----------------------------|------------------------------------------|
| 0                                   | 0                           | 0                                        |
| 20                                  | 31.35                       | 35.20                                    |
| 30                                  | 34.05                       | 34.59                                    |
| 40                                  | 49.90                       | 46.99                                    |
| 50                                  | 59.61                       | 54.35                                    |
| 60                                  | 67.84                       | 62.31                                    |
| 70                                  | 78.02                       | 72.35                                    |

4.4 Studying the duration of swelling completion of soil treated with crushed concrete layer

The process of swelling is assumed to continue for 365 days during the analysis. Some parameters are taken in consideration such as the thickness of crushed concrete layer, the width of crushed concrete layer for soil with low initial water content. The vertical expansion increased continuously via time up to the maximum values at the end of the assumed year for analysis as captured in Figure 11. The soil expansion increased rapidly at the beginning time then the rate of swelling decreased.

![Figure 11. Correlation between vertical swelling of soil with crushed concrete layer and time.](image)

The rate of swelling decrease with increasing the thickness of crushed concrete layer, where large amount of swelling reached at times (17, 72, 109, 164, 264) days for soil treated with crushed concrete layer of thickness (70, 60, 50, 40, 30) cm, respectively. Fattah et al. [19] observed that the pressure of
swelling is relatively unchanged or gently increases for the suction values below the air entry value (i.e., in the zone of boundary influence). The pressure of swelling increases rapidly in the transition zone compared to the soil suction. The rate of pressure of swelling increase in the residual zone decreases compared to the soil suction. The pressure of swelling also increases with the initial value of soil suction.

5. Conclusions

- The vertical expansion reduced linearly with additional thickness of the crushed concrete layer; the maximum percent of decrease is ranged between to (69.8-80.4) %.
- Generally, the vertical expansion decreased via increasing the width of crushed concrete layer with and without the presence of a footing.
- The vertical expansion of soil that has low initial water content decreased with increasing the thickness of the crushed concrete layers. The use of crushed concrete layers is more effective in reducing the vertical swelling for soil with low initial water content than high initial water.
- The vertical swelling increased continuously with time. The rate of swelling decreases with increasing the thickness of crushed concrete layer.
- The use of crushed concrete layer to reduce the vertical swelling is more effective for high suction soil than that low suction soil.

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