Study Numerical Simulation of Stress-Strain Behavior of Reinforced Concrete Bar in Soil using Theoretical Models

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Abstract

Nonlinear analysis for reinforced concrete members (R.C.) with two types of bars also with unsaturated and saturated soils was used to represent the models. To control the corrosion in the steel bar that used in R.C. member and decrease the cost, the geogrid with steel bar reinforcement are taken in this study to determine the effect of load-deflection and stress-strain relationships. The finite element method is used to model the R.C. member, bars and soil. A three-dimensional finite element model by ABAQUS version 6.9 software program is used to predict the load versus deflection and stress versus strain response with soil. The results for the model in this study are compared with the experimental results from other research, and the results are very good. Therefore, it was concluded that the models developed in this study can accurately capture the behavior and predict the load-carrying capacity of such R.C. members with soil and the maximum stresses with strains. The results show plastic strain values in the R.C. member with saturated soil are larger than their values in unsaturated soil about (54%, 58%, and 55% and 52%) when the geogrid ratios are (without geogrid, 60%, 40% and 20%) respectively, with the same values of stresses.

Keywords: Numerical; Reinforced; Concrete; Bar; Geogrid; Saturated Soil; Models; Stress; Strain; Method; Analysis.

1. Introduction

The effect of Soil-structure interaction between soil and member for any structures is very interesting and important field of study in civil engineering. Reinforced concrete member as a structure is the most important part of whole structures and their behavior has an important effect on quality of buildings. Member can influence of many parameters in the building. For the best design it is necessary to known behavior of the reinforced concrete member with the soil [1- 4].

Modern reinforced concrete R.C. members are used to develop deformations in their regions [5]. The occurrence of longitudinal bar regions can crucially affect the behavior of such members. This study extends a previously proposed modeling approach for R.C. bar elements whose response is affected by R.C. member with soil. The model is representing to steel and geogrid bars as a reinforcement.

The geogrid have advantage for its strength as reinforcement in reinforced concrete member [6] .This geogrid used in the soil- structure members to treat corrosion and its shape gives it more bonds with concrete. Therefore, this geogrid is useful in structures that have contact with soil or saturated soil which may be contents many types of liquids where it represents bars reinforcement for this structure like any member with soil.

Geosynthetics are widely used for separation, protection, drainage, filtration and sealing [7]. In addition, high-strength geogrids have been more successfully used in geogrid reinforced bridge. Geogrid reinforcement constructions show significant advantages in terms of economic aspects against classical concrete structures. It is also well known from large-scale experiments and field tests that geosynthetic-reinforced constructions have a much higher bearing capacity than calculated and that the deformations are much lower than expected. Therefore, it is quite evident that the compound behavior of geosynthetic and soil is not yet completely understood [7].

Geosynthetics have been increasingly used as reinforcing construction material. Many projects such as roads, retaining walls, etc. Many types of products (geogrid, geotextile, geocell, geomebrane, etc.) are available in engineering process .Each product is designed to solve a particular range of civil engineering problems [8-12].

The developed Finite Element (F.E.) models account for R.C. structures behavior was concluded that the developed models can accurately capture the behavior and predicts the load –carrying capacity of R.C. members [13-16]. There are several software, theoretical and experimental methods deal with R.C. member [17-24]

To control the corrosion effect for the steel bar reinforcement in the R.C. member, need the another type of reinforcement. This type must be with less cost and gives the required capacity to the member. Therefore, the geogrid have been used in this study to find the behavior of member with two types of reinforcement, and study the different ratios of geogrid with steel reinforcement. Also, the behavior of R.C. member with this reinforcement when taken with soil, it gives a best conception of the designer. In this research many types of bars are used: steel bar and geogrid reinforcement with R.C. member in saturated and unsaturated soils. The commercial finite element software ABAQUS was used to develop finite element model capable of simulating the effect of reinforcing bars in reinforced concrete member with soils. This study used interaction properties in the present model with two kinds of bars and soils to get the stress-strain relation for reinforced concrete member. The stress-strain relations are studying for different ratios of bar reinforcement (steel and geogrid bars) .All these parameters studied with the effect of unsaturated and saturated soil. This study is very important to control for corrosion and to increase the capacity and strength of foundation when know the behavior of R.C. bars in saturated and unsaturated soils.
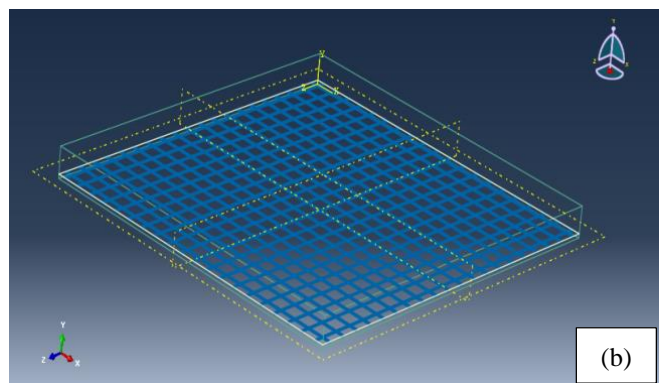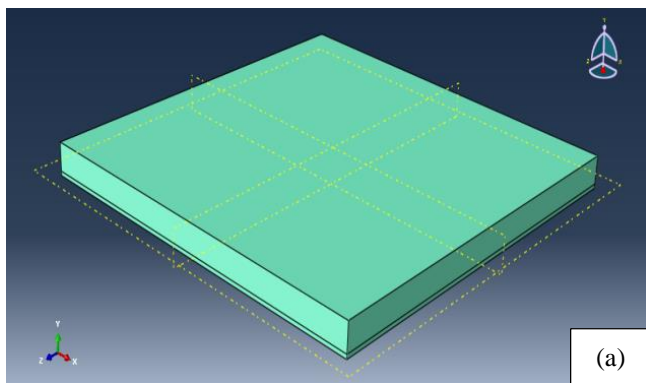
2. Finite Element Modeling

This study used the reinforced concrete (R.C.) member with unsaturated and saturated soil with two kinds of bars (Steel bars and geogrid) are used as reinforcement. This R.C. member with soil is modeled and represented as follow:

2.1. Elements

Full modeling of member, soil, reinforcing elements and loading are performed using finite element method package ABAQUS. The interaction between the member and the soil in the vertical direction is normal hard contact, without penetration, while in the other direction is tangential behavior. The interaction between the member and the reinforcement (steel bar and geogrid) is embedded.

R.C. foundations with saturated and unsaturated soils and using steel bar and geogrid reinforcement are represented in the models shown in Fig.1 by the following elements:

- Member with Soil, 8-node linear brick, reduced integration element (linear brick);
- Steel Reinforcement, 2-node linear 3-D truss element (truss element);
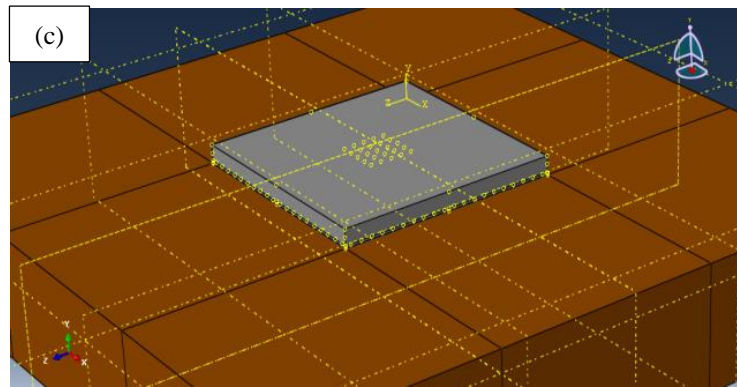- Geogrid, 4-node quadrilateral surface element (node elements).

Figure 1. Finite Element Models: (a) Member Model; (b) Member with Steel and Geogrid reinforcement; (c) Interaction and Load Area Model

2.2. Plastic Models

The plastic analysis for the present model is divided as:

- Member: Concrete damage plasticity;
- Soil: Mohr-coulomb plasticity;
- Bar reinforcement (steel and geogrid): Classic metal plasticity.

2.3. Reinforcement Model

The simulation for steel and geogrid bars as follow:

- The steel bars were simulated as a multiple trusses embedded inside the concrete;
- The Geogrid was simulated as a surface embedded inside the concrete (the surface was modeled with a rebar option which can simulate the actual geogrid properties).

2.4. Boundary Condition

The modeled boundary conditions are assumed that the vertical boundaries are free vertically, and the load applied at the load area as shown in Figure 2.
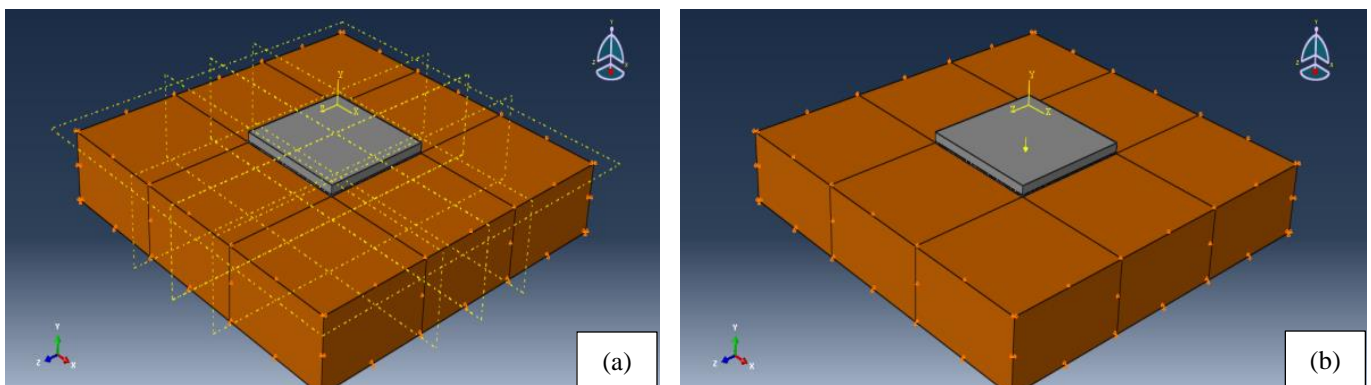

Figure 2. Boundary Condition: (z) Member; (b) Member and Loading

3. Material Model

The dimensions of member are 2×2 m with 0.15 m thickness and with 0.4×0.4 m area for applied load. The numerical simulations for behavior R.C. bars for two types of reinforcement (steel and geogrid reinforcement) with unsaturated and saturated soil using finite element models by ABAQUS software program are used. The properties for concrete which has a compressive strength fc´ and young's modulus of elasticity E are 35MPa and 24000MPa respectively. The properties of soil, steel and geogrid reinforcement are shown as follow:

3.1. Soil Constitutive Law

This elasto-plastic model requires the parameters shown in Table 1.

Table 1. Soil Parameters

Soil Parameter	Unsaturated	Saturated
Young's modulus (E)	50 MPa	40MPa
Poisson ratio (v)	0.3	0.49
Cohesion (c)	90 KPa	50 KPa
Friction angle ($\phi°$)	20°	0
Dilatancy angle ($\Psi°$)	0	0

3.2. Steel Model

The steel bar was modeled using elasto-plastic constitutive model with the parameters shown in Table 2.

Table 2. Steel bars parameters

Young's modulus (E)	Poisson ratio (v)	Yield stress (f_y)
200000 MPa	0.3	420 MPa

3.3. Geogrid Model

The geogrid was modeled using elasto-plastic constitutive model with the parameters shown in Table 3.

Table 3. Geogrid parameters

Young's modulus (E)	Poisson ratio (v)	Bearing Strength
67000 MPa	0.2	100 KN/m

4. Results and Discussion

The results in Figure 3 show a good similarity with, and give a good agreement between, the experimental results [1] and the present theoretical F.E. model results for this study. The only difference between the two results is for the failure loads at the center and at 487mm from the center is about 5%. Thus, the present model in this study can give good results with which to study the behavior of R.C. foundations in unsaturated soil and saturated soil with many parametric studies. The load is applied vertically and the vertical displacement (deflection) appears with this load accordingly. The load–displacement relationships for R.C. Foundations are studied here with many variations and with two types of soil: unsaturated and saturated.
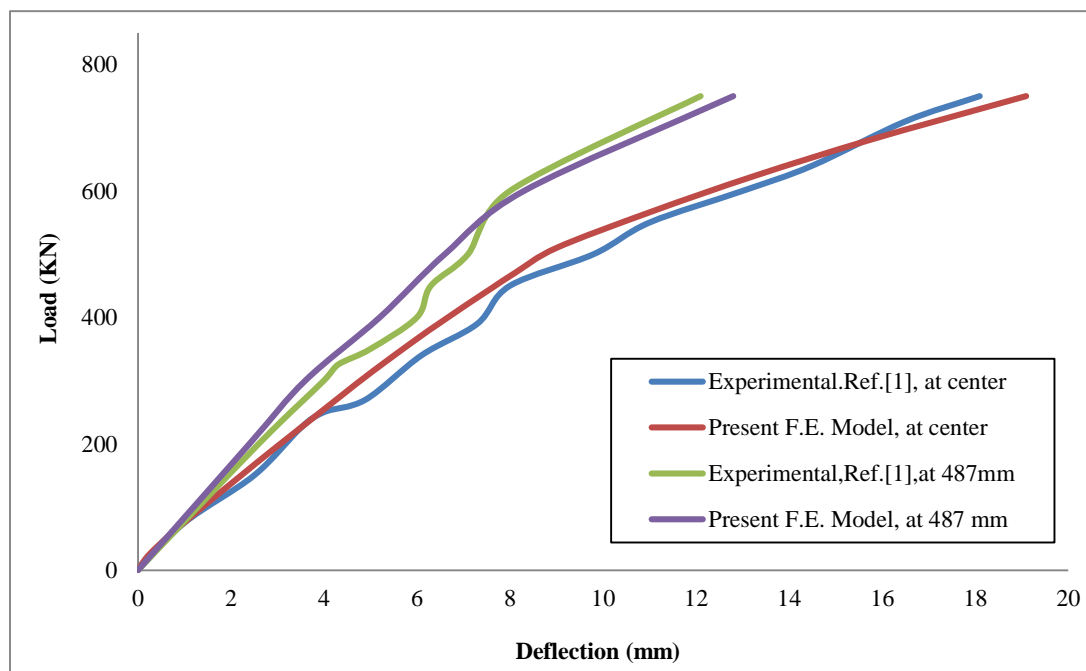

Figure 3. Load-deflection relationship at Midspan in RC member with Unsaturated Soil, by experimentally [1] and the Present F.E. Model

4.1. Reinforced Concrete Member with Unsaturated Soil

In this study, two types of reinforcement bar are taken for R.C. member (foundation) with soil, a steel bar and geogrid reinforcement. Figure 4 shows the load-deflection relationship for a R.C. member with unsaturated soil. The results in Figure 4 show that, When the geogrid ratios become (60, 40 and 20%), the deflection increases by about (13.135, 8.47 and 4.207%), respectively, compared to the situation without geogrid (steel reinforcement only). The results show that the geogrid ratio is very important to satisfy the required capacity for the R.C. member. When the geogrid ratio becomes zero (without geogrid), the steel bars reinforcement give the required strength capacity for R.C. member. Also, when the geogrid ratio used with suitable ratio near to 20%, the R.C. member gives good strength capacity. When the geogrid ratio increased to more than 20%, the strength capacity decreased. This behavior for R.C. member as a result for the same failure load (ultimate load) with difference values of deflection, where the ratio of reinforcement which gives the less deflection in R.C. member, is taken as the best reinforcement.

The stress-strain relationship for R.C. member with steel bar reinforcement and difference ratios of geogrid in unsaturated soil is shown in Figure 5; the results show the plastic strain with maximum stress. When the geogrid ratios become (60, 40 and 20%), the plastic strains increase about (3.7, 2.6 and 1.3%) respectively, compared to the situation without geogrid (steel reinforcement only). The behavior of R.C. member with effects of stresses shows that the R.C. member without geogrid and with steel reinforcement only, gives the higher strength than, when the geogrid used. When the stress increased the strain increased, but the values of strains for R.C. member without geogrid give smaller values of strain compared with the other ratios of reinforcement when geogrid is used. When the stresses arrive to the plastic stage, the behavior of R.C. member with all reinforcement ratios gives the same behavior. Thus, the maximum stresses with plastic strain in horizontal direction effected at the member when in elastic stage, and don't effected in the plastic stage, therefore, the R.C. members give the same behavior with very small difference even if the ratio of reinforcement are different. Figure 6 shows the stresses distribution at the end of R.C. members with different ratios of steel bar and geogrid reinforcement with unsaturated soil.
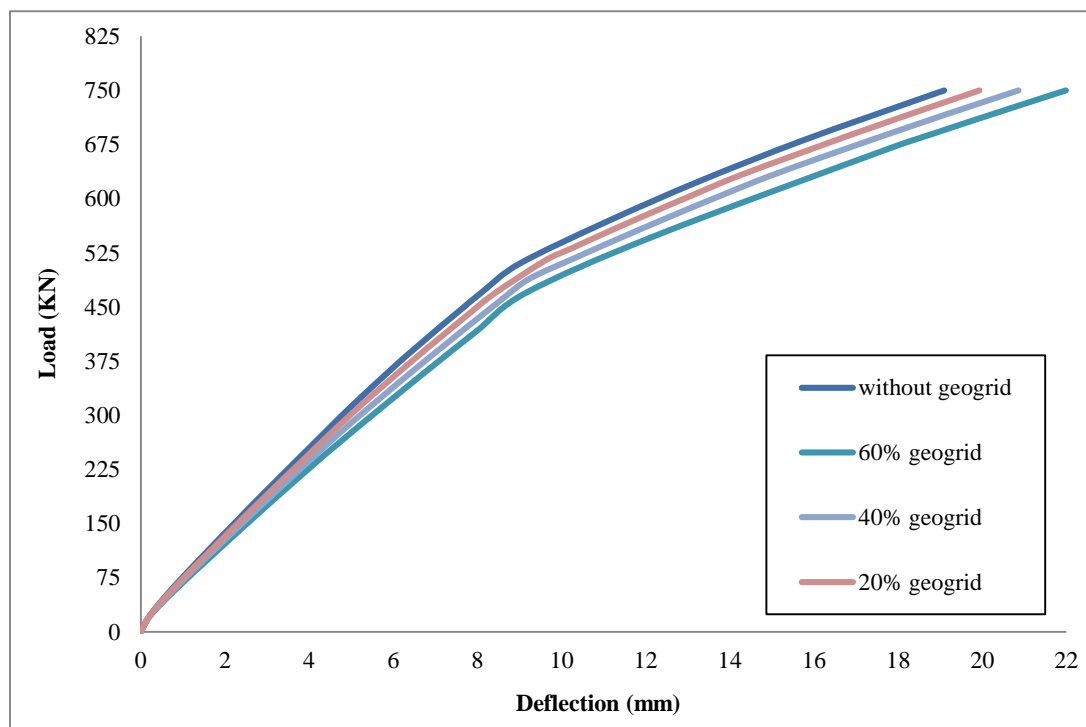

Figure 4. Load –deflection Relationship for R.C. member with steel bar and difference geogrid ratios in unsaturated soil
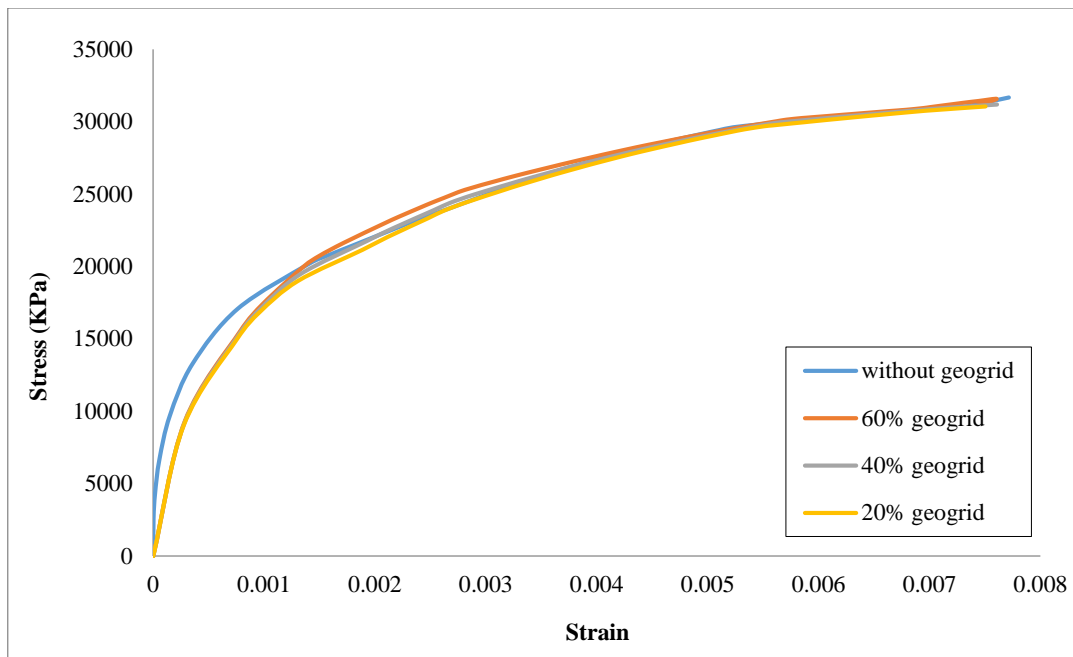
Figure 5. Stress-strain Relationship in R.C. member Model in (Unsaturated Soil) with Steel Bar Reinforcement and Different Ratios of Geogrid in unsaturated soil
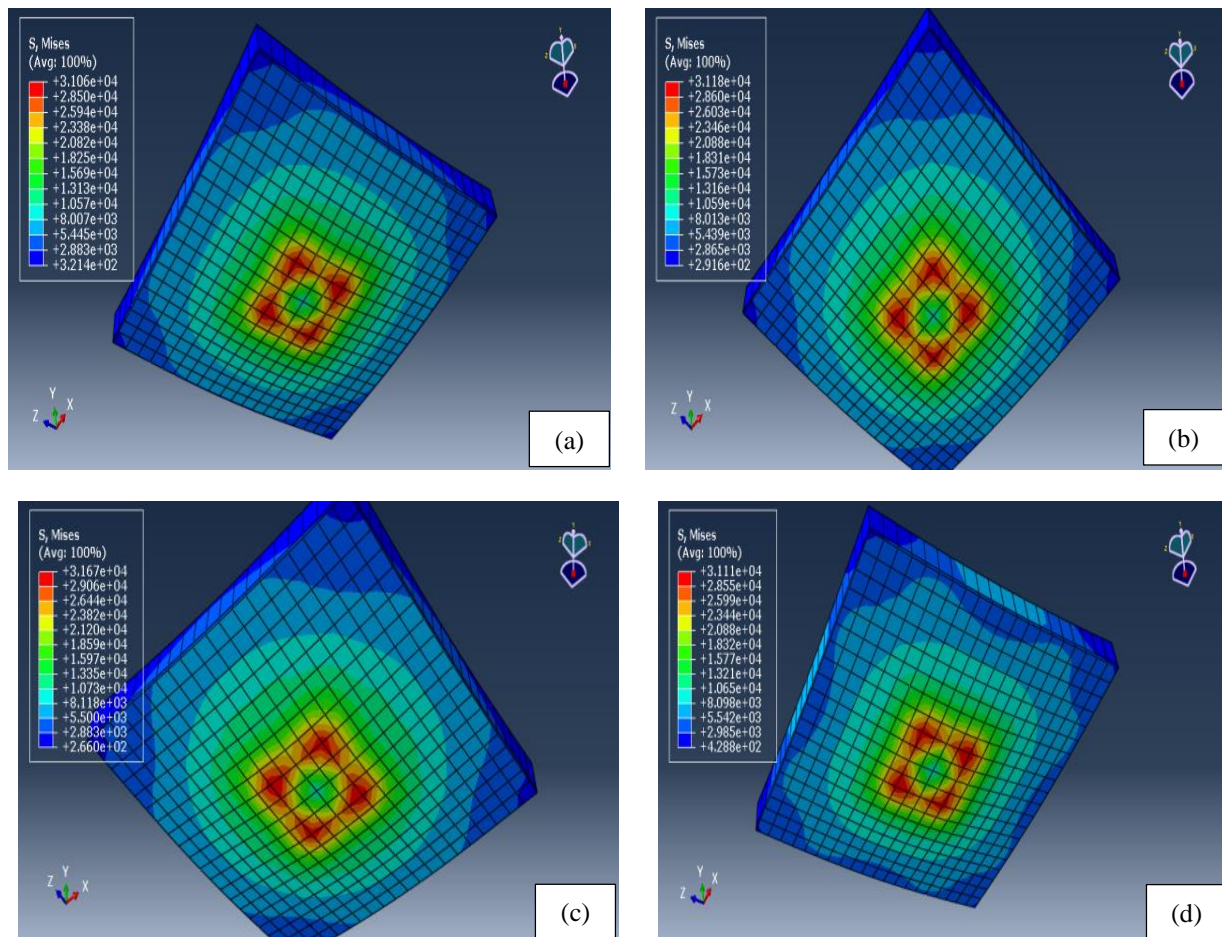

Figure 6. Stresses distribution in RC member with steel bar reinforcement and difference ratios of Geogrid in unsaturated soil: (a) geogrid 20%; (b) geogrid 40%; (c) geogrid 60%; (d) without geogrid

4.2. Reinforced Concrete Member with Saturated Soil

Two types of reinforcement bar are taken for RC member (foundation) with soil, a steel bar and geogrid reinforcement. Figure 7 shows the load-deflection relationship for a R.C. member with unsaturated soil. The results

shown that, When the geogrid ratios become (60, 40 and 20%), the vertical displacement increases by about (25, 17.7 and 9.5%), respectively, compared to a situation without a geogrid (steel reinforcement only). The behavior of R.C. member in saturated soil with difference ratios of geogrid and steel reinforcement shows that, when increased the geogrid ratio, the deflection increased, and the values of deflection in R.C. member with saturated soil are larger than their values when the soil is unsaturated. As a result of this behavior, the saturated soil decreased the strength capacity for R.C. member by increased the deflections.

The stress-strain relationship for R.C. member with steel bar reinforcement and difference ratios of geogrid in saturated soil is shown in Figure 8; the results show the plastic strain with maximum stress. When the geogrid ratios become (60, 40 and 20%), the plastic strains increase about (2, 1 and 0.8 %) respectively, compared to the situation without geogrid (steel reinforcement only). The behavior of R.C. member with difference ratios of reinforcement shows that, the geogrid ratios increased the strains, but these strains values become very close at the plastic stage and give the same behavior for stress-strain relationship. The effect of saturated soil gives the R.C. member smaller capacity than unsaturated soil. Since, this member carries the ultimate stresses smaller than their values in unsaturated soil. This means that, the R.C. member in saturated soil becomes less capacity to carry the stresses. Figure 9 shows the stresses distribution at the end of R.C. members with different ratios of steel bar and geogrid reinforcement with saturated soil.
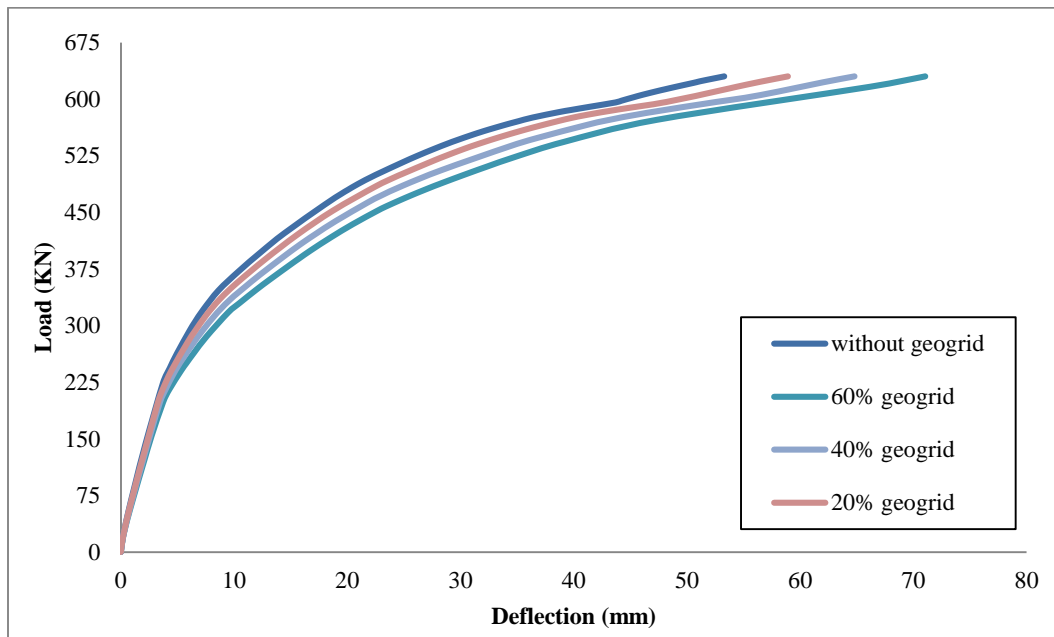

Figure 7. Load –deflection Relationship for R.C. member with steel bar and difference geogrid ratios in saturated soil
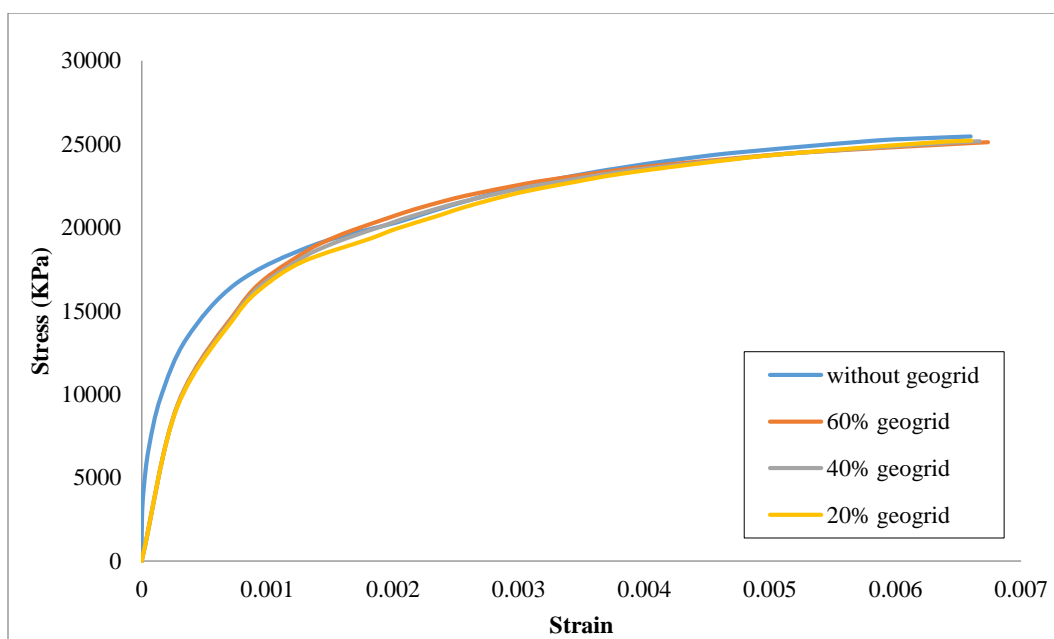

Figure 8. Stress-strain Relationship in R.C. member Model in (Saturated Soil) with Steel Bar Reinforcement and Difference Ratios of Geogrid
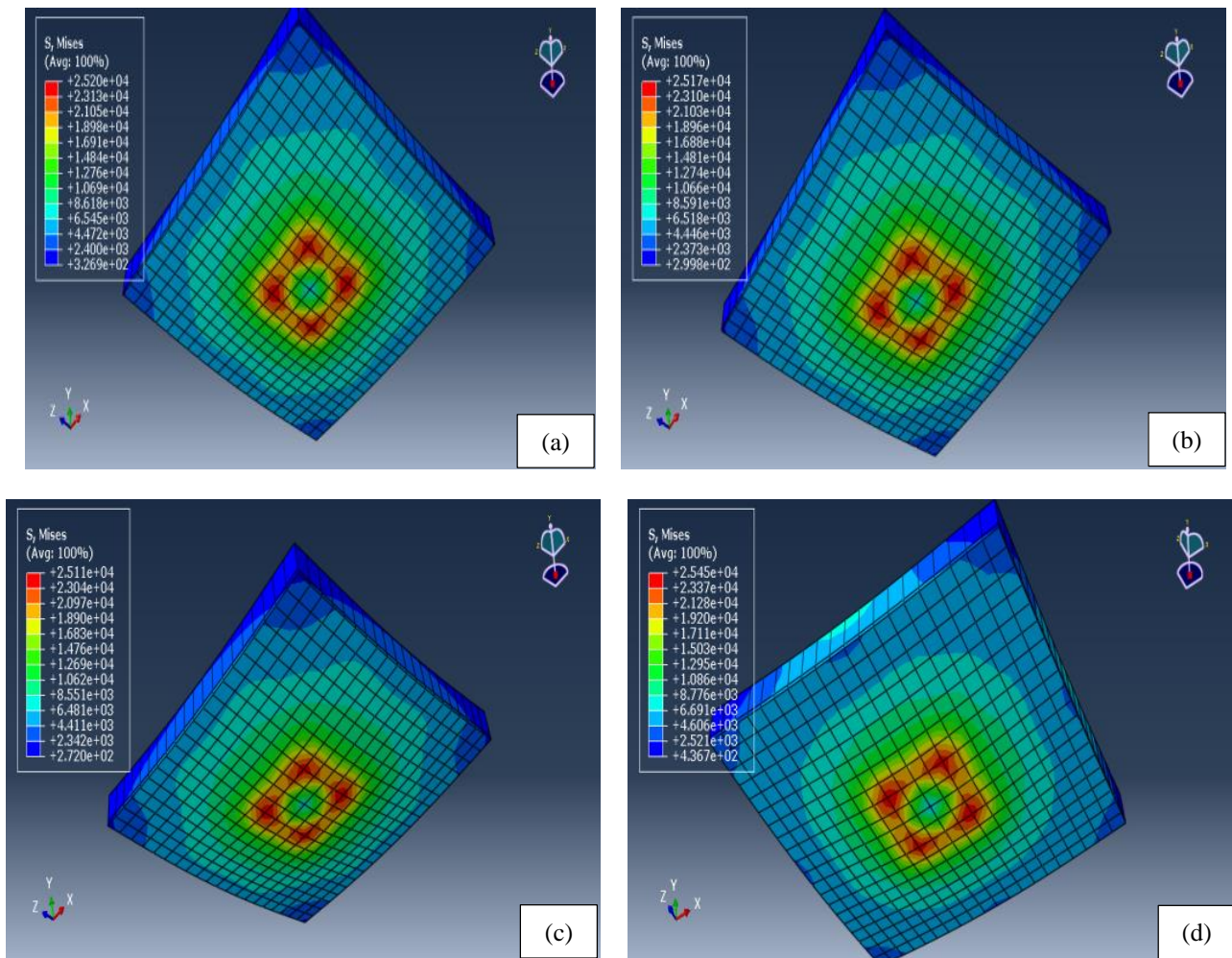
Figure 9. Stresses distribution in R.C. member with steel bar reinforcement, and difference ratios of Geogrid in saturated soil: (a) geogrid 20%; (b) geogrid 40%; (c) geogrid 60%; (d) without geogrid

5. Conclusions

- The present model can represent the R.C. member with unsaturated and saturated soil, and with many kinds of reinforcement bars like steel and geogrid reinforcement.

- The plastic strain values in the R.C. member with saturated soil are larger than their values in unsaturated soil about (54, 58, and 55 and 52%) for geogrid ratios (without geogrid, 60, 40 and 20%) respectively with the same values of stresses. Thus, the unsaturated soil gives less strength to the R.C. member.

- The stresses with strains at the plastic stage are in the horizontal direction for the R.C. member.

- The ultimate load for R.C. member without geogrid reinforcement in unsaturated soil is larger than its value when in saturated soil by 16%.Thus, the R.C. member with saturated soil is less strength capacity than when it is with unsaturated soil.

6. Conflicts of Interest

The authors declare no conflict of interest.

7. References

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