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Investigation and comparison of numerical methods in predicting the behavior of rebar in reinforced concrete hollow slab (from start to crack) in Abaqus finite element software

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Abstract

Nowadays, the use of reinforced concrete hollow slab system in building structures is widely accepted due to the provision of control criteria, the ability to be used in large openings and flexibility in architectural designs, and it is more responsive in terms of economic efficiency and time management. has it. The use of reinforced concrete hollow slabs is one of the effective methods in styling and reducing the dead load and consequently the earthquake load, and as a result achieving sections with smaller dimensions. The aim of the current research is to study the post-cracking behavior of reinforced concrete hollow slabs under Common loading situations and analyzed using the finite element method. Also, by using the obtained results and comparing them with the behavior of laboratory samples, it is intended to determine the optimal numerical model for predicting the behavior of reinforced concrete hollow slab, and to measure the accuracy of common design relationships. Modeling of hollow concrete slab sample in this study has been done using ABAQUS software, and the results of this study showed; The load coincident with the first crack in the CDP method was obtained for 10.18, 15.2, 34.20, and 44 for the concentrated joint, concentrated grip, wide joint, and wide grip modes, respectively. (DOI:**https//doi.org/10.52547/JCER.5.3.42**)

Keywords: reinforced concrete hollow slab; crack growth; SCC numerical method; CDP numerical method; Smeared Cracking numerical method

1. Introduction

The most important challenge for engineers in analyzing the behavior of reinforced concrete members is to predict how cracks form and spread and its effect on various components such as hardness, load, deformations, durability and serviceability of these members. Slabs are one of the important components of structures that are responsible for carrying most of the loads on the structure; There are various methods for predicting the behavior of common and solid signs, the most important of which are theories based on fault lines, which are widely used

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by designers. Regarding hollow slabs, despite their increasing use, it can be said that due to the variety of geometry and characteristics of holes or internal cavities of these slabs, there are many fields for research, which is especially important in The field of predicting the

occurrence and spread of cracks and its impact on the general behavior of the member is doubly important, especially that the various theories and relationships proposed by researchers in the field of crack analysis also have a lot of variety and according to the young The relative nature of this branch of science, the evaluation of their efficiency in hollow signs also requires extensive experimental and theoretical investigations.

The first research in the field of perforated slabs was done by Clark and Oduyemi [1], who specified in an article that the maximum amount of tensile hardening was created. In perforated slabs with tubular holes, it is subject to strain and cracked network of concrete in the natural axes of the section. In one of the conducted researches, it is emphasized that in general, the presence of longitudinal tubular holes reduces the rate of crack growth and also the cross-sectional strength of the slab, depending on the size of the holes and the dimensions of the slab[2],[3]. In another article, Al-Awazi and Al-Asadi [4], [5] point out that Turkish. In perforated slabs, they expand at a lower speed than in normal slabs.

Among others, the research conducted on the performance of hollow slabs after cracking was done by Schwetz [6], which shows the effect of cracking on the curvature of hollow slabs, and in which a numerical modeling is a solution for optimization. and provides reinforcement of hollow slabs.

In another research, Schwetz deals with the numerical and laboratory investigation of a hollow slab, and the laboratory model shows a behavior similar to the numerical sample in its linear behavior [6].

The use of hollow slabs is one of the effective methods in styling and reducing the dead load and consequently the earthquake load, and as a result achieving sections with smaller dimensions. On the other hand, due to the brittleness and brittle nature of concrete slabs, the presence of initial pressure on the concrete piece causes the concrete to stretch and crack later as a result of loading. Therefore, the comparative study of numerical methods for predicting the behavior after cracking of reinforced concrete hollow slabs is very important, which is considered in this study. Therefore, according to the above interpretations; In this research, an attempt has been made to analyze and compare the numerical methods of predicting the behavior of reinforced concrete hollow slabs after cracking.

2. Research method and modeling

This study is analytical-applied as well as laboratory, and the method of analysis in this research is done using ABAQUS finite element software and ETABS software. After studying the background of the work and examining the relevant behavioral models and theories in the field of crack analysis in reinforced concrete sections, by selecting the results of a number of valid laboratory studies in the field of hollow slabs, the relevant samples were modeled and analyzed. is placed and the accuracy and efficiency of the relevant models are checked and the most suitable behavioral models are selected.

Then, by using the relations proposed by the regulations and authoritative references in the field of designing hollow slabs, the accuracy of the application of these relations was measured and the necessary solutions for the optimal design of hollow slabs according to the type of loading, support conditions and geometrical specifications. Holes will be provided

2.1. Concentrated load with simple support:

The compressive behavior of concrete is defined based on the modified Hagenstad model for both investigated methods. Tensile behavior of concrete based on Wahalatantri model is used for CDP method. In the initial model, the CDP method is used to check the hollow slab. In the above method, the damage criterion is used to reduce the strength of concrete after cracking. The dynamic and static solver can be used to solve the numerical models made by the above method, in this study, the dynamic solver was used due to the convergence problems of the static solver. The displacement force diagram of the model is compared with the experimental sample, which is shown in the figure below.

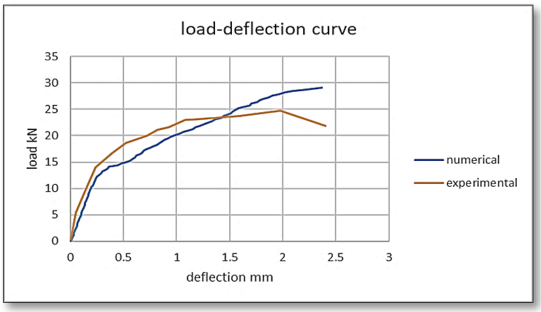

Diagram 1- Comparison of the displacement force diagram of the model with the laboratory sample in the case of a concentrated load with a simple support(Source: Researcher)

The tensile damage criterion has been used to investigate the crack growth process and as can be seen in Figure (1), the first cracking is shown at a load of 10.18 kN. Also, the criterion of the main maximum plastic strain has been used to check the crack initiation location, which is shown in Figure (2).

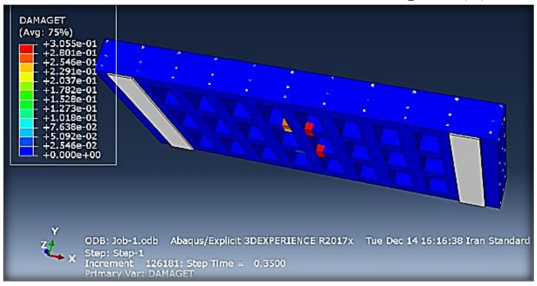

Figure 1- The picture of the investigation of the crack growth process using the tensile damage criterion in the case of a concentrated load with a simple support (Source: Researcher)

The cracks created in the hollow slab after applying the loading mentioned in the article, based on the criteria of tensile damage and maximum main strain, are shown in Figures (3) and (4).

Figure (5) display of stresses along the vertical axis (shear stress); The colors indicates that the stress is almost uniformly distributed on the surface of the slab.

Therefore, according to figure (6), the schematic representation of the stresses in the longitudinal direction of the rebars in the CDP method indicates that the rebars have reached yield in the central part of the slab.

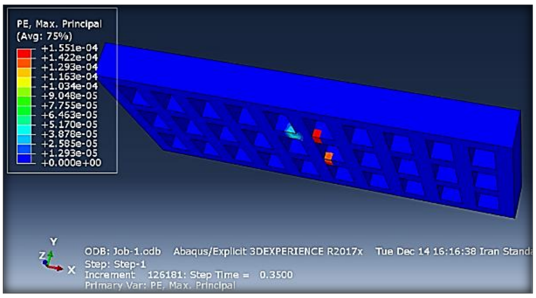

Figure 2- The picture of the location of the crack initiation using the criterion of the main maximum plastic strain in the case of concentrated load with a simple support(Source: Researcher)

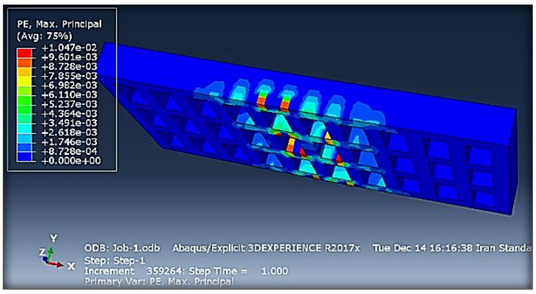

Figure 3- The cracks created in the hollow slab after applying the load based on the tensile damage criterion in the CDP method(Source: Researcher)

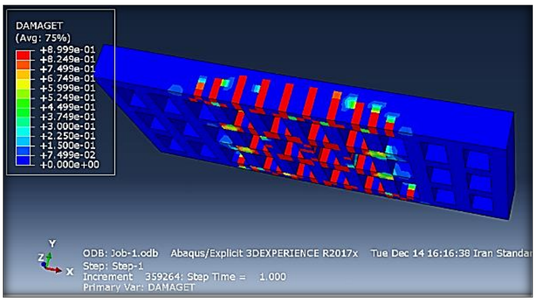

Figure 4- The cracks created in the hollow slab after applying loading based on the maximum main strain criterion in the CDP method

In addition to the aforementioned method; Another method called SCC has been used to model concrete and investigate the propagation of cracking in concrete. In the above method, only the static solver can be used to solve the numerical model, which leads to convergence problems of the solver. The compressive behavior of concrete can be defined in a non-linear way as in the previous method. But in this method, it will not be possible to reduce the hardness of loading after cracking. For this reason, the damage criterion cannot be defined and checked in the above model. The force-displacement diagram of the numerical model made by the above method is compared with the force-displacement diagram of the experimental model in diagram (2), which is in good agreement and shows no difference worth mentioning in the calculations. The figure below compares the load-displacement diagram of the laboratory mode and the numerical mode of smeared cracking.

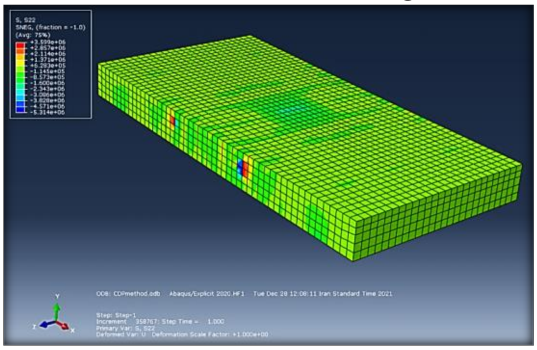

Figure 5- Image of stresses along the vertical axis (shear stress) in the case of concentrated load with simple support

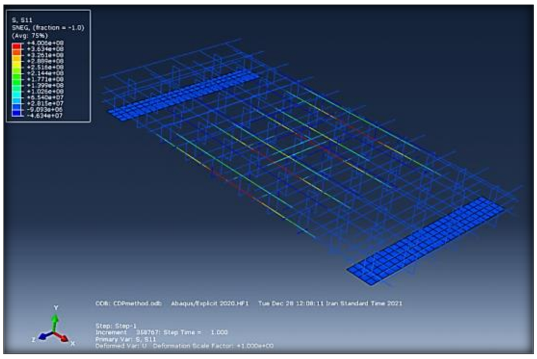

Figure 6- Schematic representation of the stresses in the longitudinal direction of the rebars in the CDP method in the case of concentrated load with simple support

Also, the main maximum plastic strain occurred during the first crack at a load of 6.58 kN, which can be seen in Figure (7).

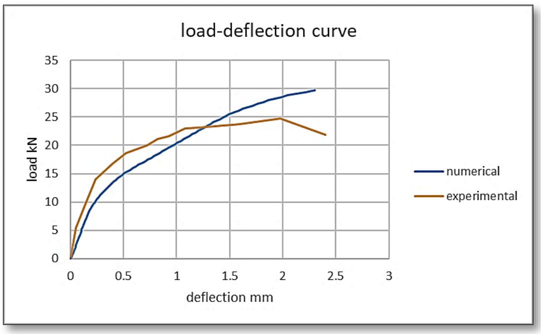

Diagram 2- The force-displacement diagram of the numerical model made by the scc method with the force-displacement diagram of the experimental model in the case of concentrated load with a simple support

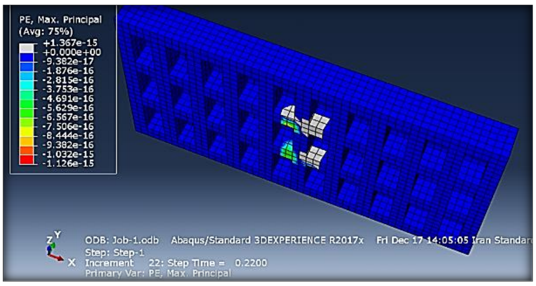

Figure 7 - The image of the main maximum plastic strain during the first crack in the scc method in the case of concentrated load with simple support

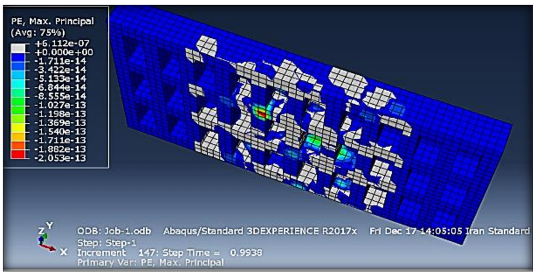

Figure 8 - The image of the main maximum strain after applying loading in the scc method

The main maximum strain after applying the load, which indicates the cracked areas in the concrete, is shown in Figure (8).

Therefore, based on the analysis done, finally, the load-displacement comparison chart obtained from the two CDP and Smeared Cracking methods is in the form of chart (3).

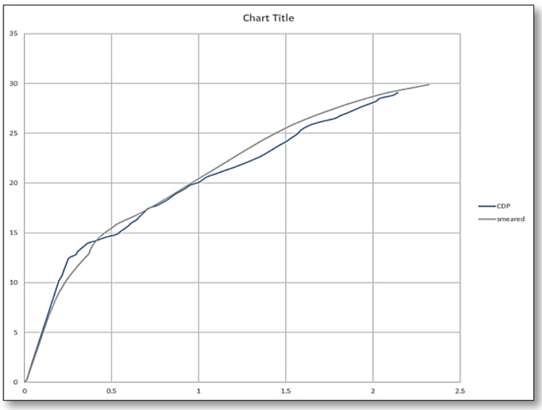

Diagram 3- Load-displacement comparison diagram resulting from CDP and Smeared Cracking methods in the case of concentrated load with simple support

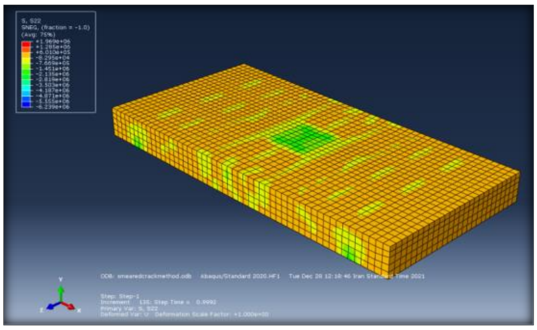

Figure 9- Display of stresses along the vertical axis for semi-concentrated load and simple support in Smeared Cracking method

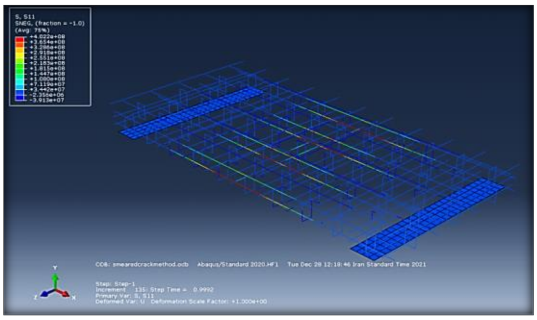

Figure 10- Showing the stresses in the longitudinal direction of the rebars in the smeared cracking method

As can be seen in the diagram (3); In the case of concentrated load with simple support, both methods agree well up to a loading of 7 kN, but after that the Smeared Cracking method tends to show an almost trilinear mode. Therefore, in general, the two methods have a relatively similar performance in the case of simple support with semi-concentrated loading, and the slope of the displacement load diagram is almost close to each other.

Figure (9) shows the stresses along the vertical axis for the semi-concentrated load and simple support in the Smeared Cracking method, which, like the CDP method, is approximately uniform according to the coloring of the stress distribution, and due to the shape of the loading, the concentration of shear stress in the loading area is less.

Figure (10) shows the stresses in the longitudinal direction of the rebars in the smeared cracking method and as in the CDP method, they have reached yield in the center of the slab.

In general, in the concentrated loading model with a simple support, the behavior of the CDP method in the linear region has a greater slope than the spreading crack mode. Both methods have good compliance, but due to the definition of failure in the plastic rupture method, the accuracy of the results is closer to the laboratory sample.

So far, a load equal to 30 KN according to the laboratory sample was applied to the hollow slab sample on an area of 0.13 x 0.13 square meters and the results were analyzed. In the next part, the sample model made for two broad and semi-concentrated loading conditions (same as the laboratory load) and two simple and fixed support conditions and their combination are examined.

2.2. Wide load with simple support:

For the extended load case, the extended force equal to 60 KN was applied widely to the supports on both sides, and the load-displacement diagram was as follows.

According to the diagram (4) for the case of extended load with simple support, the slope of the linear part of the CDP method diagram is higher and this linear function continues up to the load of 33.6 kilonewtons. But in the Smeared Cracking method, the performance is still almost three-line, and the slope of the initial part is gentler and has a linear performance up to the load of 19.2 kN. Also, the load equivalent to the first crack in the CDP method was equal to 34.2

kilonewtons and for the smeared cracking method it was equal to 42.19 kilonewtons and the cracks were shown in Figure (11).

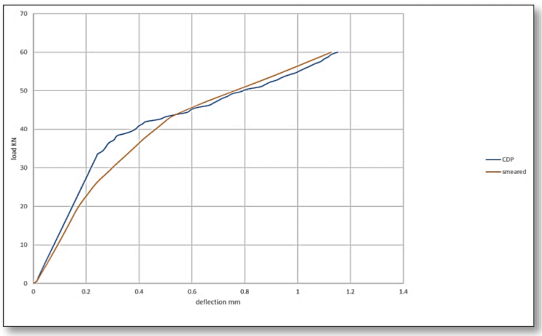

Diagram 4- Comparison diagram of load-displacement resulting from two CDP and Smeared Cracking methods in the case of extended load with simple support

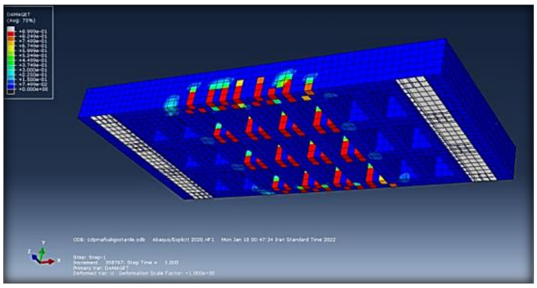

Figure 11- CDP cracking (tensile damage t model) in the case of extended load with simple support

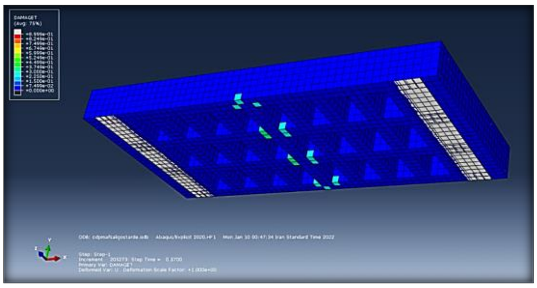

Figure 12- The first crack of CDP (tensile damage t) in the case of extended load with simple support

The cracks created in the hollow slab after applying the load, based on the criteria of tensile damage and maximum principal strain, are shown in the following figure 11 and 12.

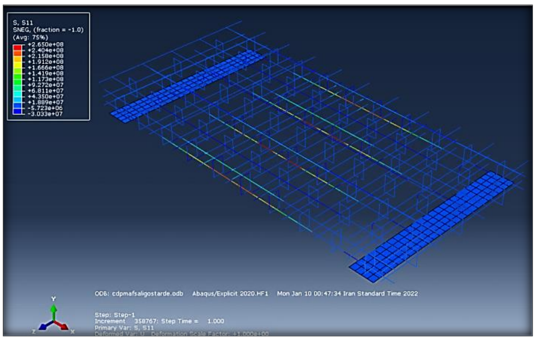

Figure 13 - Showing the stresses in the longitudinal direction of the rebars in the CDP method of simple support extended load

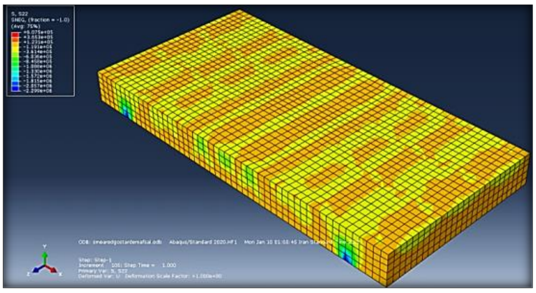

Figure 14 - Display of stresses along the vertical axis for the case of extended load and simple support in the Smeared Cracking method

As can be seen in the picture (12); The first cracks are formed in the middle part of the slab and are of the tensile type that occurred in the extended load state with a simple support.

As can be seen in the picture (12); The first cracks are formed in the middle part of the slab and are of the tensile type that occurred in the extended load state with a simple support.

Figure (14) shows the stresses along the vertical axis for the case of wide load and simple support in the Smeared Cracking method, and according to the figure above, the distribution of stresses is approximately uniform.

Figure (15) showing the stresses in the longitudinal direction of the rebars in the Smeared Cracking method of the extended load with a simple support, which have yielded in the middle part of the slab. In general, in the case of extensive loading with simple support in both methods, the cracks start and expand in the middle part of the slab opening. According to the definition of tensile failure in the CDP method, there is more accuracy in the display and prediction of cracks, while the prediction of cracks in the propagation crack method is less accurate and mostly has a uniform behavior. In this case, the plastic rupture method shows more hardness and its linear performance continues up to higher loading values.

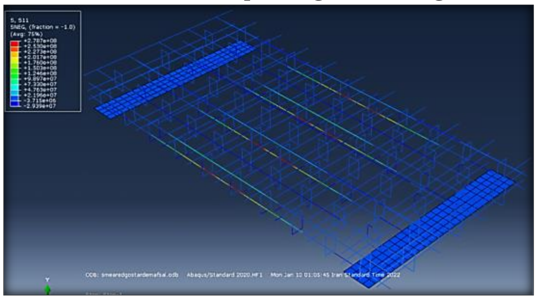

Figure 15 - Showing the stresses in the longitudinal direction of the rebars in the Smeared Cracking method of the extended load with a simple support

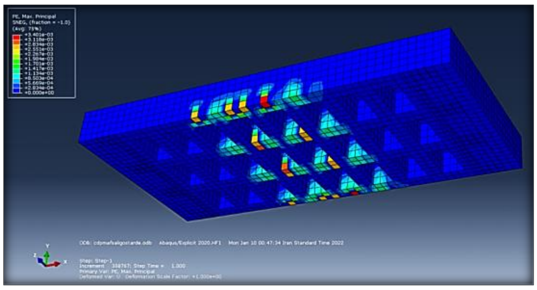

Figure 16- The maximum principal strains for the case with a simple support

As can be seen in Figure (17); The crack initiation location based on the maximum principal strain is shown in the figure above, which is consistent with the failure model

The main maximum strain after applying the load, which shows the cracked areas in the concrete in the smeared cracking method, is shown in Figure (18).

The criterion of the main maximum plastic strain has also been used to check the crack initiation location in the Smeared Cracking method. As can be seen in the figure (19), the initial cracks are some distance from the center of the slab, unlike the CDP method.

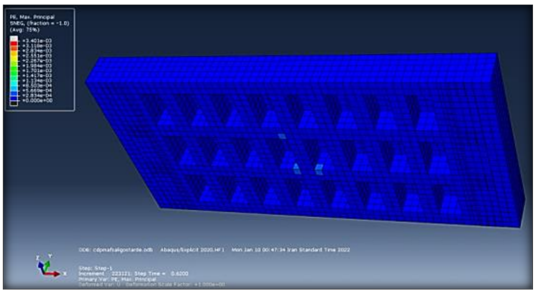

Figure 17 - The image of the crack initiation location based on the maximum main strain in the extended load mode with simple support

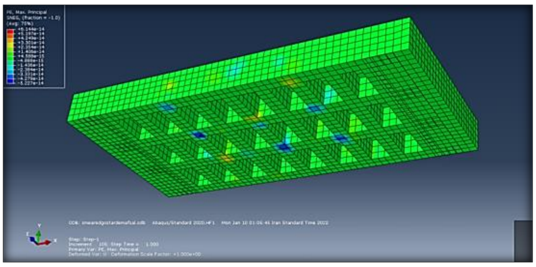

Figure 18 - The image of the main maximum strain after applying the load in the smeared cracking method and in the extended load mode with a simple support

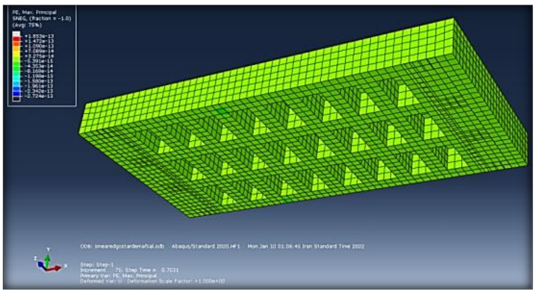

Figure 19 - The standard image of the main maximum plastic strain to check the crack initiation location in the smeared cracking method and in the extended load mode with a simple support

Figure (20) showing the stresses along the vertical (shear) axis for the case of wide load and simple support in the CDP method, which has a uniform value according to the color scheme.

The figure (21) shows the stresses in the longitudinal direction of the rebars in the CDP method.

The figure (22) shows the stresses along the vertical axis for the case of extended load and supporting support in the smeared cracking method, and according to the image, the stress distribution is almost uniform.

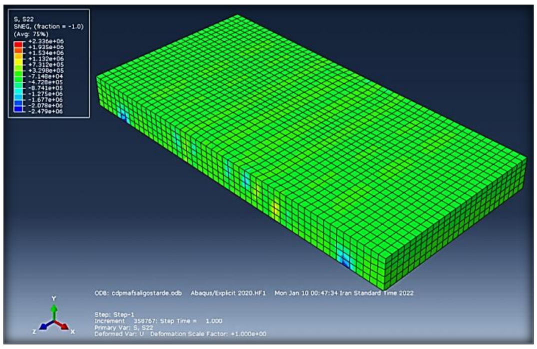

Figure 20 - Showing the stresses along the vertical (shear) axis for the extended load and simple support in the CDP method

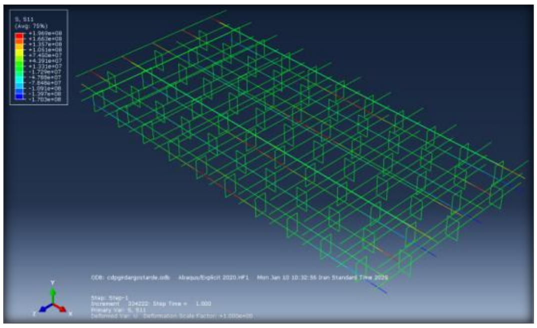

Figure 21- Showing the stresses in the longitudinal direction of the rebars in the CDP method of the extended load of the girder support and the rebars

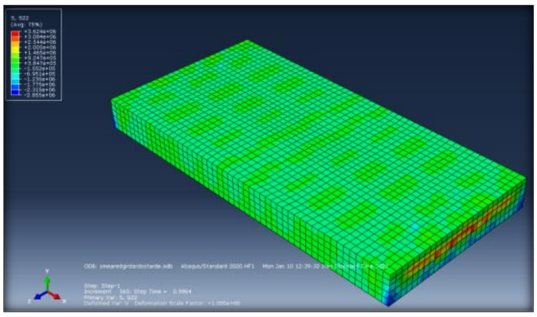

Figure 22 - Display of stresses along the vertical axis for the extended load and supporting support in the smeared cracking method

In general, in the case of extended load with girder support, the cracks start from the support area, with the difference that in the CDP method, the crack occurs in the upper web and in the Smeared Cracking method, the crack occurs in the lower slab. In this case, the slab shows a relatively harder performance in loading in the CDP method.

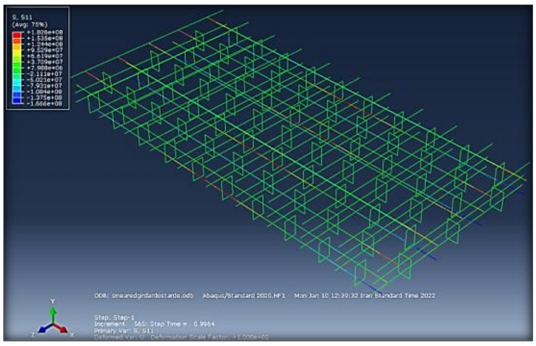

Figure 23- Showing the stresses in the longitudinal direction of the rebars in the smeared cracking method of the extended load of the girder support

3. Conclusion

Based on the analysis done in this study, the results obtained are as follows:

1) Schematic representation of stresses in the longitudinal direction of the rebars in the CDP method indicates that the rebars have reached yield in the central part of the slab.

2) The main maximum plastic strain occurred during the first crack at a load of 6.58 kN.

3) In the case of concentrated load with simple support, both methods are in good agreement with each other up to a loading of 7 kN, but after that the Smeared Cracking method tends to exhibit an almost trilinear mode.

4) Two methods in the case of simple support with semi-concentrated loading have relatively similar performance and the slope of the displacement load diagram is almost close to each other.

5) Showing the stresses along the vertical axis for the semi-concentrated load and simple support in the Smeared Cracking method, which, like the CDP method, is approximately uniform due to the coloring of the stress distribution, and due to the shape of the loading, the concentration of the shear stress in the loading area is less. be

6) Displaying the stresses in the longitudinal direction of the rebars in the smeared cracking method

and as in the CDP method, they have reached yield in the center of the slab.

7) In general, in the concentrated loading model with a simple support, the behavior of

8) the CDP method in the linear region has a greater slope than the spreading crack mode. Both methods have good compliance, but due to the definition of failure in the plastic rupture method, the accuracy of the results is closer to the laboratory sample.

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