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Research Article

THE INVESTIGATION OF THE STRESS CONCENTRATION AND CRUSHING ON THE BOLTED CONNECTIONS OF COLD-FORMED STEEL STRUCTURES SECTIONS UNDER CYCLIC LOADING

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ABSTRACT
This study has studied the behavior of steel structures connections, cold-formed with the bolt, besides finite element modeling and geometric non-linear analysis and materials under cyclic loads with the ANSYS14 program and comparison with a laboratory specimen. Then, using the same model in five specimens which their connections type were end-bearing and friction, modeling and moment-rotation cyclic diagrams were compared. Finally, the stress concentration and crushing of the area around the holes which were in contact with the bolts head, was studied and compared. Then, the suitable strategies were presented. The results of this research prove that the connection specimens which prestressing force has been applied on screws, and the coefficient of friction between the contact surfaces has been defined, considering that some part of the force before the drill site is tolerated by friction, therefore, they appear a more rigid connection. This can increases the friction coefficient up to 0.6 and reinforces the cold-formed steel structures connections without a minimum cost. As a result, the number of holes can be reduced due to the further bolts freightage in the model.

Keywords: *Bolted Connections, Cold-Formed Steel Sections, End-Bearing and Friction Connections, Stress Concentration*

INTRODUCTION
The use of the cold-formed steel structures system has considerably increased in many countries in recent years because of the numerous advantages such as high speed and quality of construction and suitable seismic performance. These structures can be a cost-effective design in comparison with hot rolled steels (Mirghaderi and Bagheri, 2008). Given that one of the main issues in each structure is the connections of that structure, sometimes they blurt out some problems at their junction due to the big differences in the behavior of the connections of these structures with the hot rolled steel sections that can be due to the low thickness compared to the hot-rolled sections (Yu *et al.*, 2002). In this article there is an in vitro model is used which consists of a beam, columns with the channel section and the curved wing channel beams that a continuous band pass sheet is used in the beam-column connection that connect the beamand columns sides by a bolt (BagheriSabbagh *et al.*, 2010; BagheriSabbagh *et al.*, 2012; BagheriSabbagh, 2011; BagheriSabbagh *et al.*, 2011). In this research, the finite element method has been used to model the specimens. In order to be able to study the connection behavior until the destruction stage, the analyses have been done as non-linear including geometric and materials method. For this purpose, Ansys14 software has been used and loading has been applied on the specimens in a cyclic form. The model was verified by extracting the curved charts and moment-rotation push. Then, by the selection of the area around the holes which are in contact with the bolts surface, the stress concentration was investigated and suitable strategies were presented.

MATERIALS AND METHODS
Principles and Methods
Laboratory Specimen Details
In the conducted laboratory researches, the nominal dimensions have been shown according to Figure 1, in which the thickness of the steel profiles is equal to 3Mm and band pass sheet thickness is 8mm. additionally, properties of the bolts have been shown in Figure 1.

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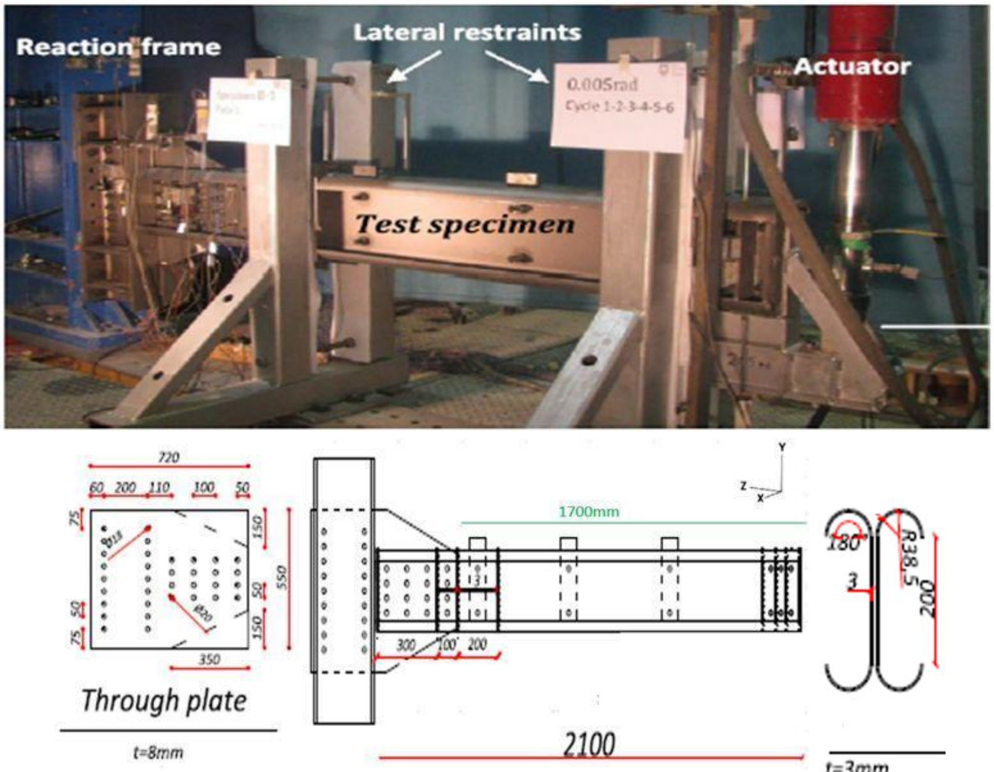

Figure 1: The characteristics of the laboratory specimen

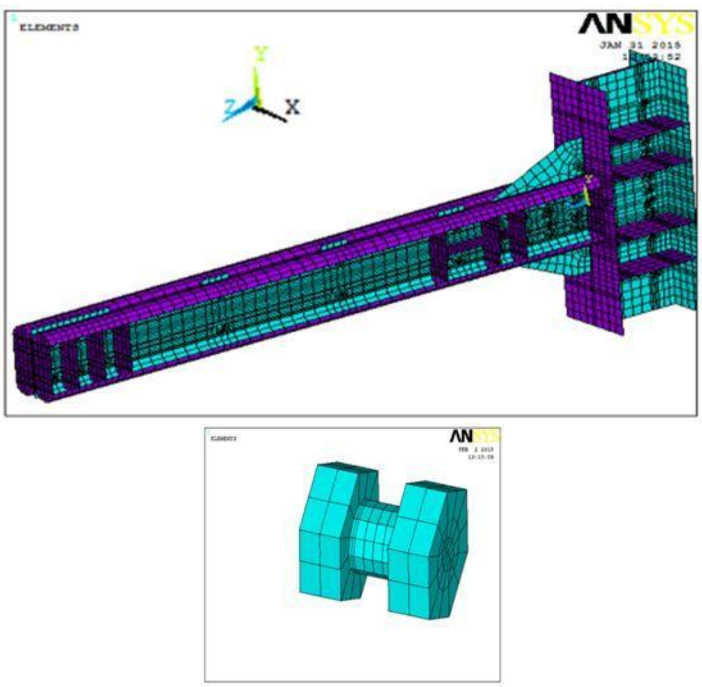

Figure 2: Model grid

Details of the Analytical Model

In making the geometry model, according to the specifications used in the laboratory specimen, we considered the thickness of the beams and columns and the thickness of the reinforcement sections within the beam sections equal to 3mm and 8mm respectively. The length of the beam were assigned in the z-direction, column height in the y-direction and the bolts in the x direction so that the steel profiles sections were precisely modeled as the surface in the in-plane in the Ansys14 program due to the frangibility of the planes. The diameter of bolts used on the column Φ18 and the bolts on the beam Φ20 were of type A325, the bolts were defined without looseness. Then, as shown in (2), the steel profiles as well as the bolts in three dimensions were meshed using the element shell181 and the element solid185 respectively.

The analysis was used for modeling the specimens using the application Ansys14. The boundary conditions, loading.... in the analytical model have been shown in Figure 3. According to the specifications used in the laboratory specimens, following values were considered: E = 2.1e5, ν= 0.33 and Mp = 67kn. The stress-strain curves of cold-rolled steel profiles were considered as Figure (4-A). Additionally, to define the bolts materials, following values were considered: E = 2.1e5 and ν=0.3

The stress-strain curve of the bolts was considered as figure (4-b) (Rumpf and Fesher, 1963). The hardening hybrid structure rule was applied as Von Mises stress.

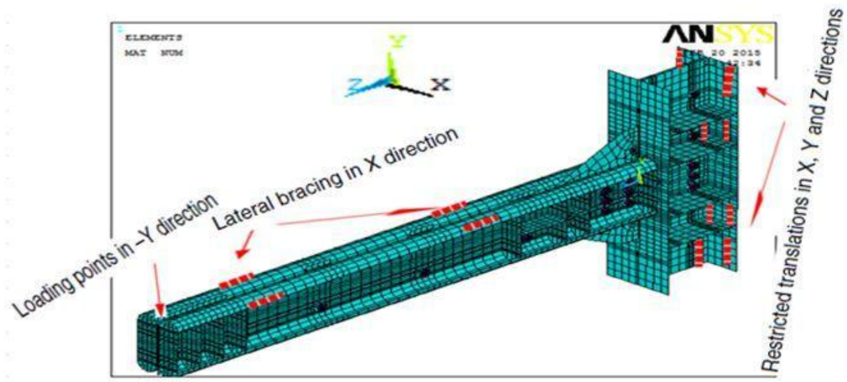

Figure 3: The manner of applying the support constraints in the analytical specimen

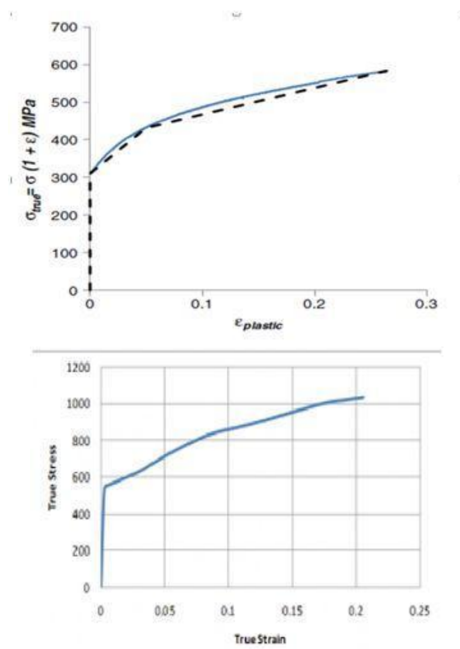

Figure (4 - A): The stress-strain curve of the cold -formed steel profiles sections (Figure 4 - B): the stress-strain curve of the bolts

Then the loading has been used as displacement using the protocol given in Figure (5) that is in accordance with AISC seismic regulations (AISC, 2005).
After the support constraints, as shown in figure (3), the loading was applied as displacement during 38 cycles to beam-head in line with the Y.

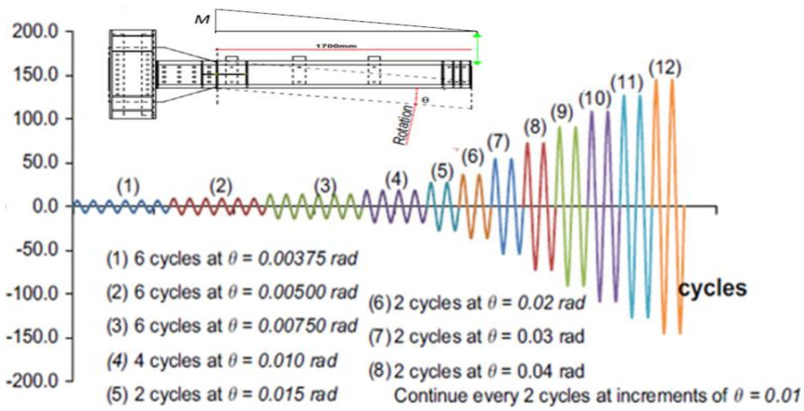

Figure 5: Cyclic loading protocol in accordance with the AISC Seismic regulations

Table 1: The number of loading cycles

The number ofcycles	$\Delta(y)=\theta*L_0$ L_0=1700mm	θ
6 cycles	±6.375	0.00375
6 cycles	±8.5	0.005
6 cycles	±12.75	0.0075
4 cycles	±17	0.01
2 cycles	±25.5	0.15
2 cycles	±34	0.02
2 cycles	±51	0.03
2 cycles	±68	0.04
2 cycles	±85	0.05
2 cycles	±102	0.06
2 cycles	±119	0.07
2 cycles	±136	0.08

RESULTS AND DISCUSSION

Research Findings

Evaluation and Comparison of Results Obtained from the Analysis and Testing

Figure (6-A and 6-B) shows the manner of the stress concentration in the twentieth cycle and thirty-eighth cycle. Additionally, the Comparison between the analytical and laboratory results of the moment-rotation cyclic curve extracted from the analytical specimen and the laboratory specimen is observed in Figure (7-A and 7-B). There is a relatively desirable compliance between the laboratory and analytical results, and the difference between the results of the analysis and testing is justifiable for some reason. 1. It is obvious that in laboratory conditions, the consumption steel blurts out its real properties. But in analytical conditions, it will act according to the behavior defined in the model that some errors may be exist in the definition of materials, thickness and residual stresses in the materials.
2. The analytics software, no matter how accurate, again has some limitations and uses approximation in making numbers round that it can cause some errors in the process of analysis (Forooghi, 2006). So we can conclude that the compliance of the results obtained from the laboratory analysis is relatively desirable. Therefore, with its documents, the finite element modeling logic in this specimen can be used

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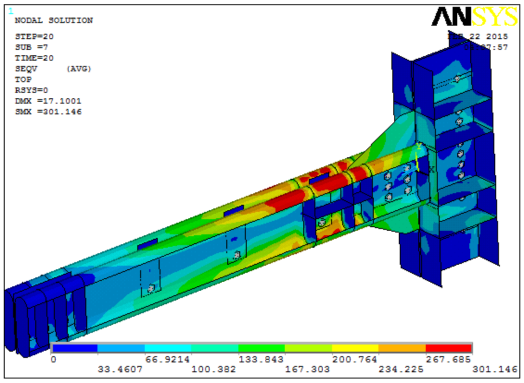
for the similar cases on the connections of suggested specimens. So the same model is used to continue the work.



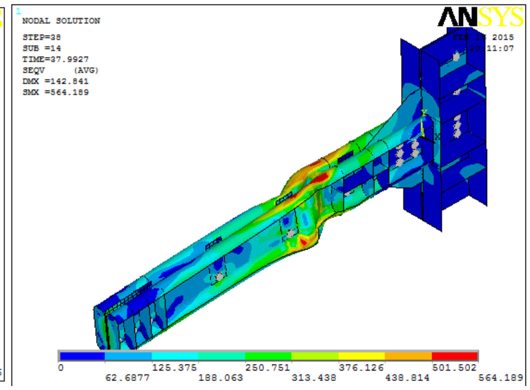
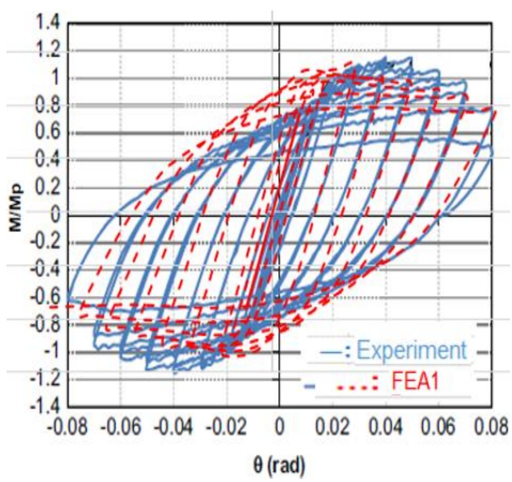


Figure (6A): The stress concentration in the twentieth cycle in the specimen A1
Figure (6B): The stress concentration in the thirty eighth cycle in the specimen A1



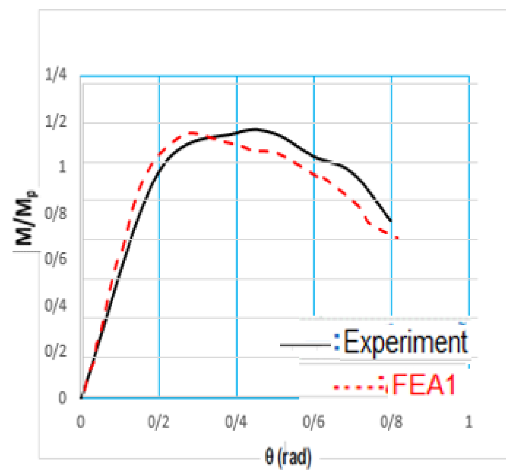


Figure (7-A): The moment-rotation push diagrams
Figure (7-B): The moment-rotation curve diagrams

The study of Stress Concentration in the Range of Holes in the Proposed Models
At this stage of the research, we investigated the five end-bearing and friction connections
The Washerless Loaded Specimens
The specimen A1 connection: in the head of bolts, no prestressed force is applied and the friction coefficient between the surfaces in contact was considered equal to zero. In the specimen A2, the prestressed force was applied to the head of bolts using table (2) retrieved from AISC regulation (Kulak and Grondin, 2001).

Table 2: The prestressed force in high strength A325 bolts taken from the AISC code

Prestressing force in ton	Bolt diameter in millimeter	Bolt diameter in inches
12	18	0.71 in
13	20	0.79 in

Additionally, the friction coefficient was considered equal to 0.2. The prestressed force was applied in the specimen A3. Additionally, the friction coefficient was considered equal to 0.3. The increase in the friction coefficient can be carried out using sandblasting method or cleaning by the flame that these operations are performed after piercing and the friction coefficient can be increased for steel up to 0.6 (Tahooni, 1996). Then the model was loaded in different specimens during 38 cycles. By selecting the area around the holes, the stress concentration was examined at the thirty-fifth cycle (Δ_y = 119). As seen in Figure (8), the stress concentration in the range of holes which are in contact with the head of bolts shows the connection A1 in the thirty-fifth cycle in the specimen. The highest stress which is equal to 323.406, occurred near the range of the nineteenth and twentieth holes. Since the place of applying the anchor is in this range, it seems natural. In Figure (9-A and 9-B), with magnification of the nineteenth and twentieth holes, you can see the manner of the stress concentration in this range.

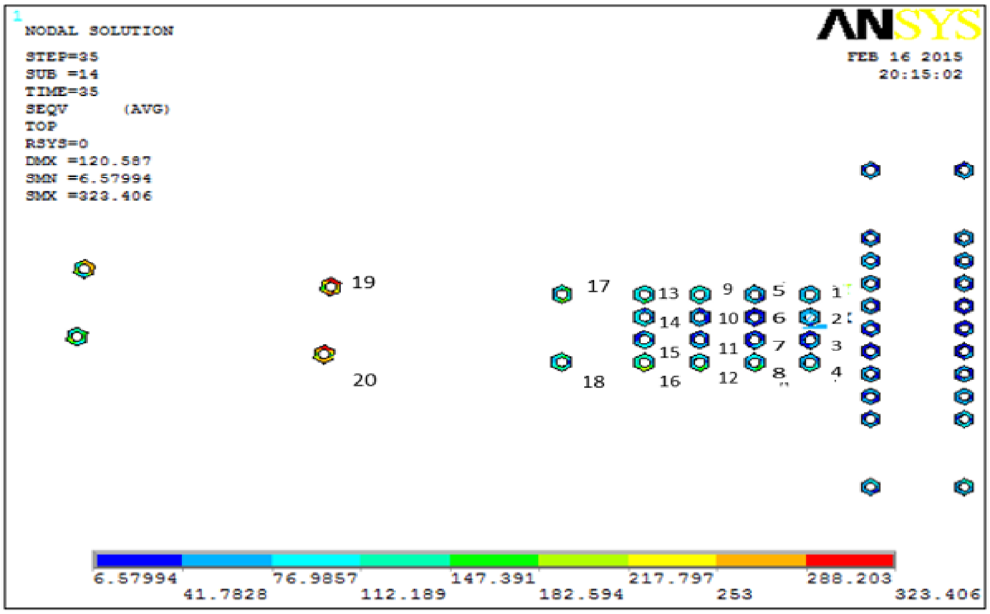
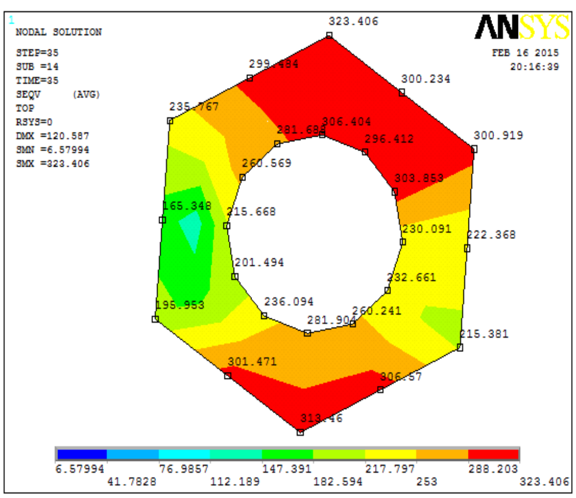


Figure 8: Stress concentration around the holes -the thirty-fifth cycle of loading in the specimen A1



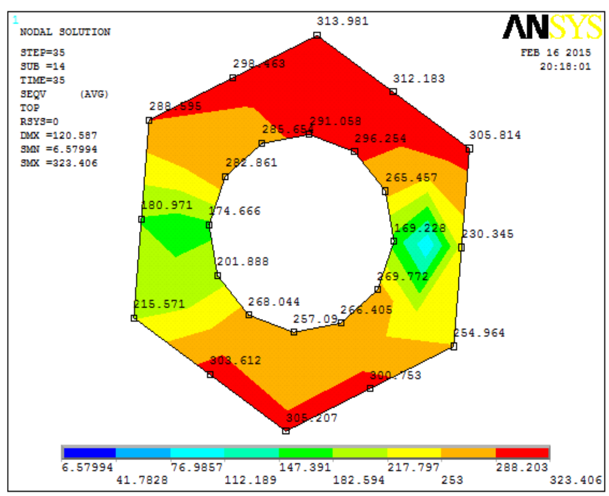


Figure 9-A: Stress concentration around the the nineteenth hole in the specimen A1
Figure 9-B: Stress concentration around the twentieth hole in the specimen A1

Figure (10) shows the stress concentration in the range of the holes in the connection specimenA2 in the thirty-fifth cycle in which the highest stress is equal to 323.393, that this amount has had a slight decrease compared to the specimen A1. Once more, the greatest stress has occurred in the range of the nineteenth and twentieth hole (Figure 11-A and 11-B).

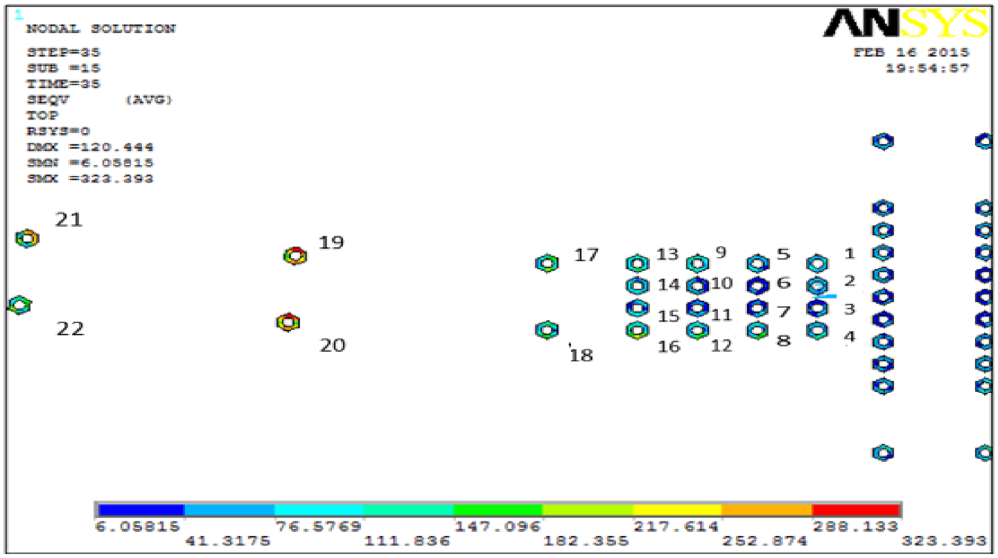
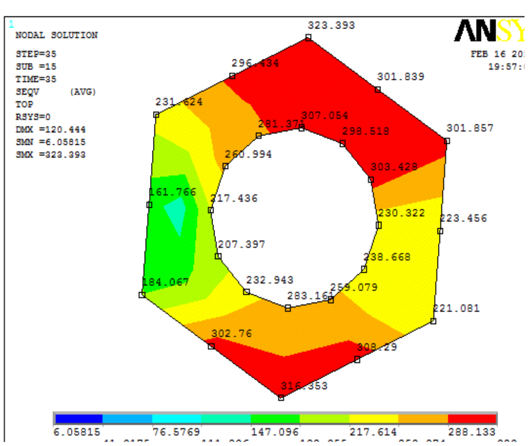


Figure 10: The stress concentration around the holes in the thirty-fifth connection of specimen A2



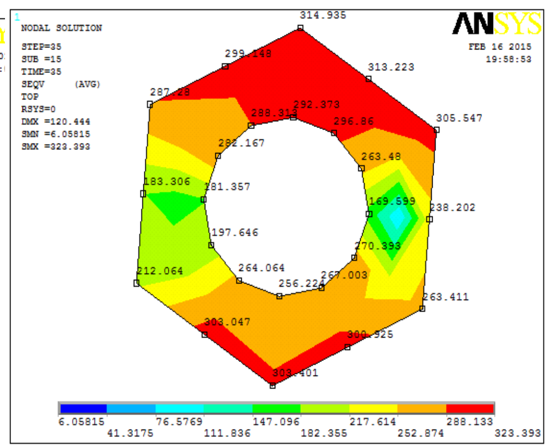


Figure (11-A): The stress concentration at the thirty-fifth stage in the nineteenth hole in the specimen A1

Figure (11-B): The stress concentration at the thirty-fifth stage in the twentieth hole in the specimen A2

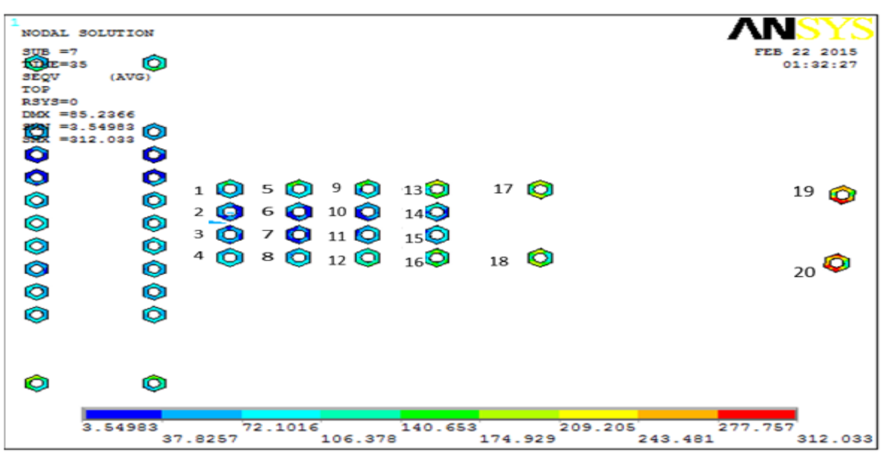


Figure 12: The stress concentration around the holes in the thirty-fifth cycle in the specimen A3

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Additionally, Figure (12) shows the stress concentration in the range of the holes in the connection specimen A3 in the thirty-fifth cycle in which the highest stress is equal to 312.033, that this amount has had a decrease compared to the specimen A1, A2. Again, the greatest stress has occurred in the range of the nineteenth and twentieth hole (Figure 13-A and 13-B).

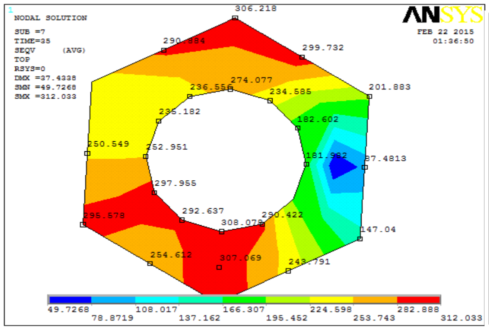
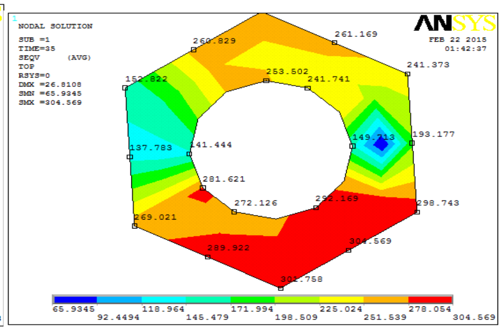

Figure 13-A: The stress concentration around the nineteenth hole in thespecimenA3
Figure 13-B: The stress concentration around the twentieth hole in the specimen A3

The Connections of the Loaded Specimen using Washers under Nuts and the Head of the Bolt
At this stage, modeling was performed by defining the washer under the head of bolts in which the thickness of the washer is 5mm and the washer diameter is equal to 50mm that is larger than the diameter of the head of bolts (American Iron and Steel Institute, 1999).

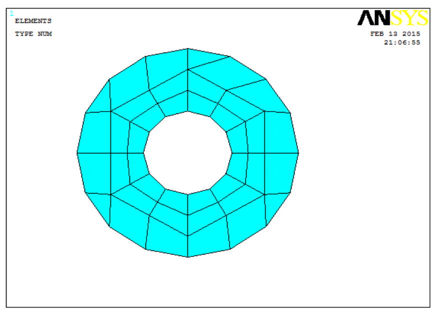

Figure 14: Washer grid using element shell181

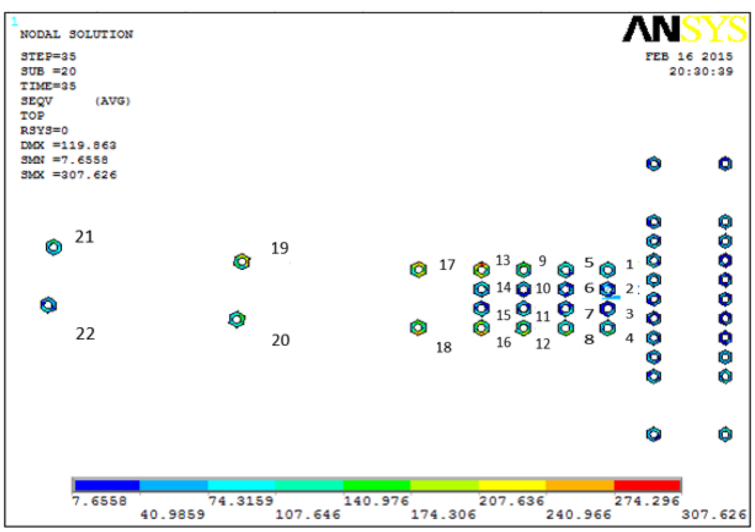

Figure 12: The stress concentration around the holes in the thirty-fifth cycle in the specimenA3

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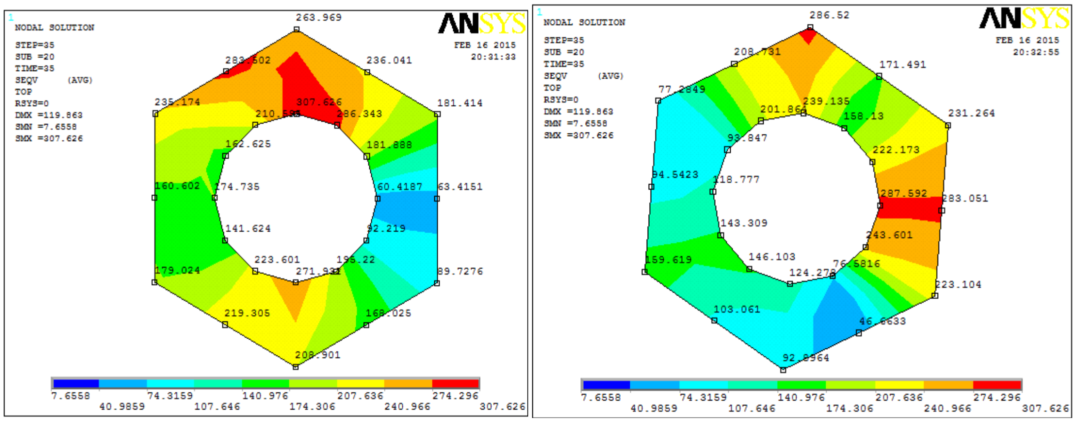

Figure 16-A: The stress concentration around the sixteenth hole in the specimen B1
Figure 16-B: The stress concentration around the nineteenth hole in the specimen B1

Then, as shown in Figure (14), the washer was meshed using the elements shell181. Then, the two specimens namely B1 and B2 were investigated that the loading steps were performed like the previous specimens during the 38 cycles.
In the specimen B1, we defined a washer under the head of bolts and the friction coefficient is considered equal to 0.2. Additionally, in the connection of specimen B2, the friction coefficient was considered equal to 0.3, despite the definition of a washer under the head of bolts.

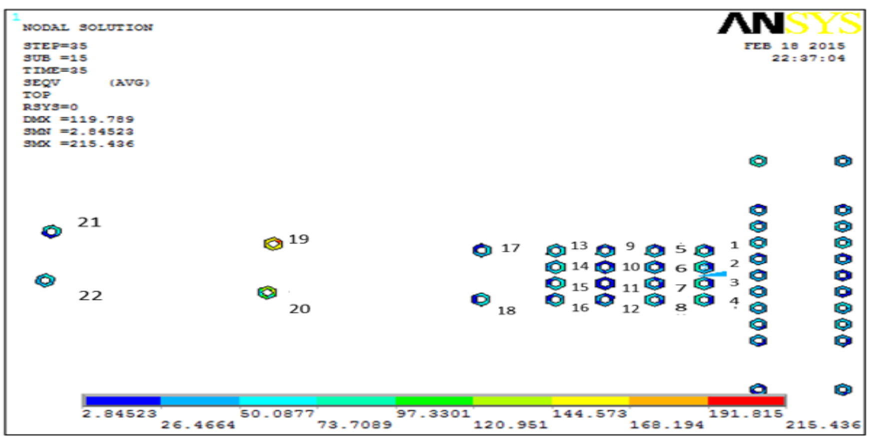

Figure 17: The stress concentration in the area around the holes in the thirty-fifth cycle of specimen B2

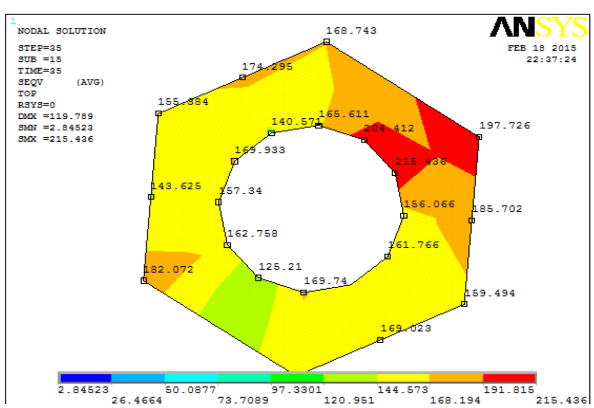

Figure 18: The stress concentration around the nineteenth hole in the specimen B2

Figure (15) shows the stress concentration in the range of the holes in the connection specimen A3 in the thirty-fifth cycle in which the highest stress is equal to 307.626, that this amount has had a decrease compared to the previous specimens. The greatest stress has occurred in the range of the nineteenth and sixteenth hole (Figure 16-A and 16-B).

Figure (17) shows the stress concentration in the range of the holes in the connection specimen B2 in the thirty-fifth cycle in which the highest stress is equal to 215.436, that this amount has had a significant decrease compared to the previous connection specimens. Additionally, the Figure (18) shows the stress concentration in the range of the nineteenth hole in the specimen connection B2.

And another method is the manner of the stress concentration by choosing a path (Path) in the Ansys program on the holes like figure (19) diagramming in all specimens and you see the manner of stress concentration in (Figure 20).

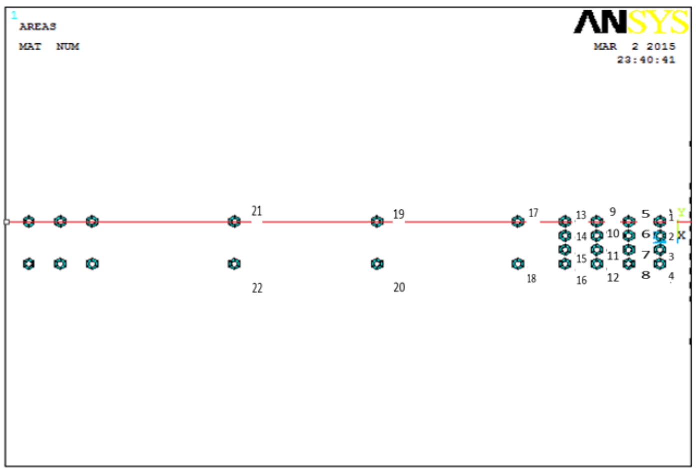

Figure 19: The defined path in Ansys program

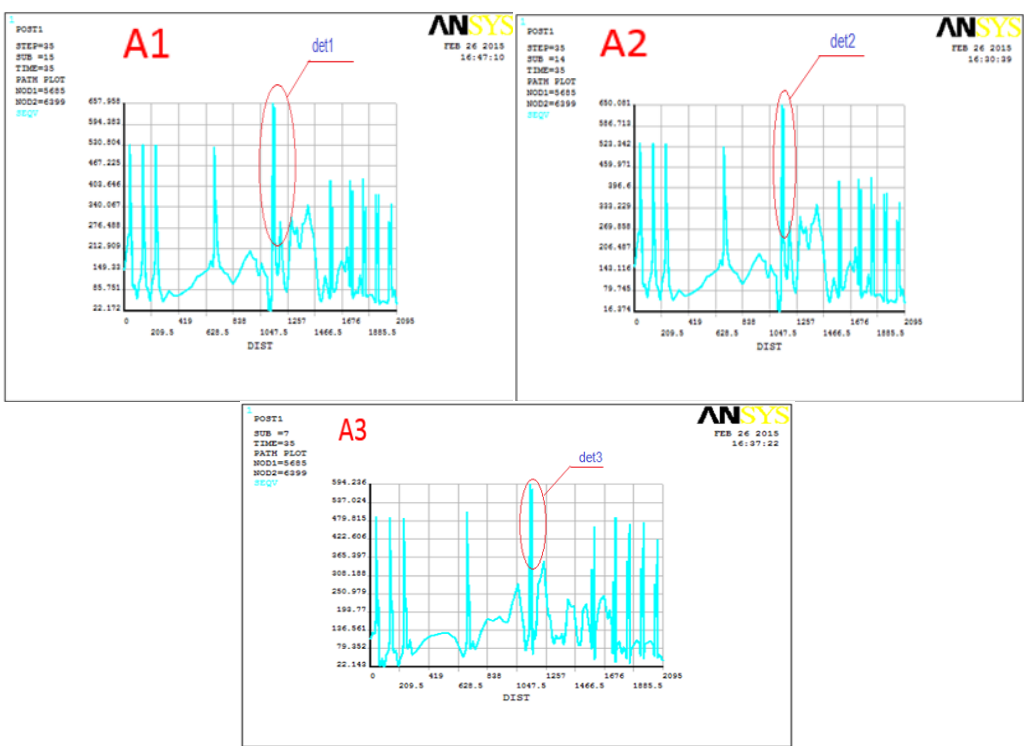

Figure 20-A: Chart of stress concentration around the defined path holes(using no washers)

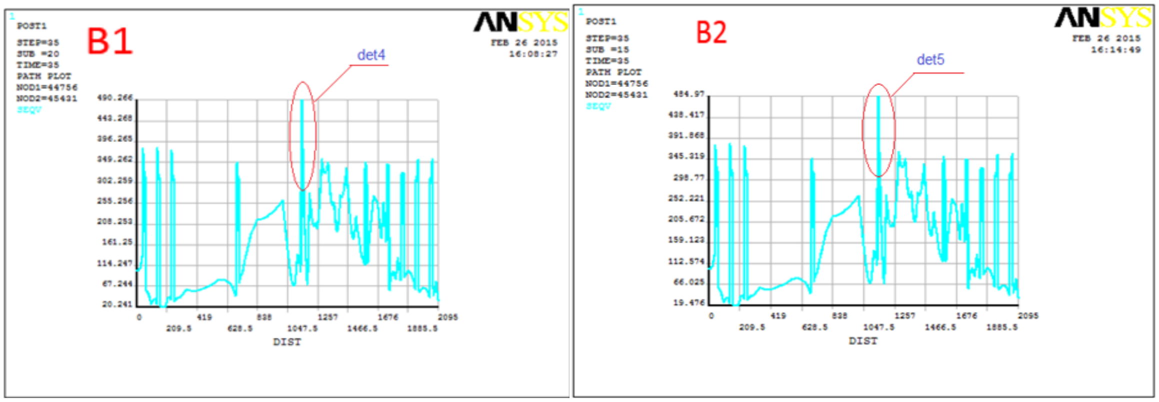

Figure 20-B: Chart of stress concentration around the defined path holes (using washers)

In Figure (20), in the five connection specimens, the greatest stress has occurred in the nineteenth hole and specimens have been reduced as before. In addition, with the magnification of the diagram, the nineteenth hole is observed in all specimens (det1, det2, ... det5) as shown in Figure (21).The washerless specimens have a different shape compared to the washered specimens. The fact is that the stress concentration around the hole in the specimens having washers differs with the washerless specimens which indicate that some of the stress has been controlled by the washer.

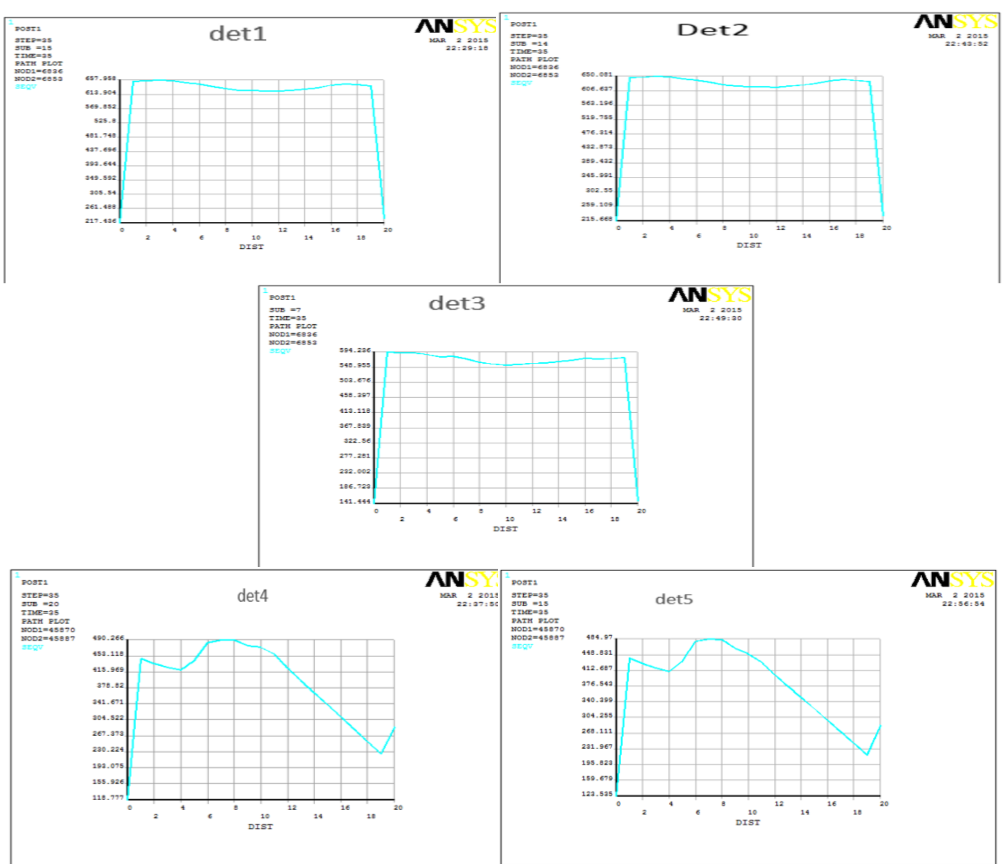

Figure 21: Graphs concerning the stress concentration around the nineteenth hole in all specimens

Discussion and Conclusion

In this study, the following results were obtained from the conducted studies:

1 – The creation of the prestressing force reduces the stress concentration and crushing in the range of holes under cyclic loading.
2. Raising the friction coefficient of the bolts reduces the stress concentration and crushing in the walls of holes under cyclic loading.
3 - Given that the other researchers had concluded that putting washers under the bolt head reduces the stress concentration and crushing in the range of holes, in this research too, by investigating the issue we endorsed the theory.
4- In general, in the friction connections, the stress concentration and crushing in walls of holes is lower in comparison to the end-bearing connections.
5 - Putting the washers under the bolts strengthens the beam web and delays the web buckling. Finally, it can be found that despite the prestressing force and increasing the coefficient of friction, considering that part of the force is tolerated by the friction before the hole position, stress around the holes is reduced. As a result, due to bolts further freight, the number of holes in the model can be reduced.

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