Investigating the Cyclic Behaviour of Post-tensioned Steel Connections by Changing the Diameter and Arranging the Strands

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Article Info

Abstract

Failures of steel frames during Northridge 1994 earthquake prompted researchers to improve the behavior of beam-column connections where most of the fractures occurred. Therefore, various details have been proposed for moment connections. Post-tensioned connection is one of the new connections proposed by researchers. In this study, the numerical modeling of the post-tensioned connection was performed using ABAQUS finite element software. In addition to verifying the accuracy of the modeling with the experimental results, 4 samples of the connection were modeled and investigated the effect of some parameters on the connection behavior under cyclic loading. In the range of models of this paper, the results show that increasing the strand diameter by fixed post-tensioning force Increases the flexural strength and power in the lateral force bearing. Also, the increasing the strand diameter by fixed post-tensioning force does not affect the connection initial stiffness. In addition, increasing the number of strands from 4 to 6, leads to an increase connection power in the lateral force bearing to 11.6% and an increase in energy dissipation to 2.4%. Also, increasing the number of strands will increase the flexural capacity and decrease the maximum force of each strand. The use of less strand with equivalent diameter and equivalent post-tensioning force, and changing the strand spacing from the center of gravity of the beam does not affect the behavior of the connection.

1. Introduction

In Northridge earthquake in 1994, the connections in steel moment frames suffered a brittle fracture in beam to column connection zone. The connection fracture will be brittle and abrupt in beam to column connection zone due to the presence of thermal residual stresses cause of welding, the stress concentration and the presence of multi-axial stresses. In addition, the plastic hinge formation also will be possible in the column that causes the structure instability. Extensive researches were conducted into the subject to resolve the problem, and a new beam to column connection was introduced. One of these new connections is the post-tensioned connection. Ricles et al. [2] proposed a post-tensioned moment connection for use in steel moment frames in 2001 inspired by the idea of using post-tensioned energy dissipator connections in precast concrete frames. A post-tensioned steel moment connection includes top and seat angles, high-strength strands, reinforcing and shim plates. Various studies have been done on beam to column post-tensioned steel moment connection. Ricles et al. [2] presented an analytical model based on fiber elements using DRAIN-2DX software in 2001 for post-tensioned connection with top and seat angles. The results showed that the proposed model predicted the accuracy of experimental results. Ricles et al. (2002) [1] as well as Garlock et al. (2005) tested a beam to column post-tensioned connection system with top and seat angles, the results of the experiments showed that the size and geometry of the angles affect the connection flexural
capacity and energy dissipation capacity, and the strands must be designed to remain in the elastic range and to be sure of self-centering. Also, the more the number of the strands, the greater the connection stiffness. Azizi and Siahpoos [4] studied the effect of strength and angle specification on post-tensioned connection behavior in 2017. The results showed that the use of high-strength steel for an angle increases the lateral load bearing capacity and connection energy dissipation. Also, the use of stiffener for an angle increases the dissipation energy capacity of the connection significantly. Moradi et al. [5] presented the beam to column post-tensioned connection finite element model with bolted-angle using ANSYS software in 2015. Modeling results are in good agreement with experimental results and it was observed that increasing the amount of initial post-tensioning force leads to the higher initial stiffness, greater flexural capacity and higher energy dissipation. Gerami and Khatami [6] presented the proposed model of post-tensioned connection using OPENSEES software in 2011. The results of this study showed that the proposed model of post-tensioned connection by OPENSEES software simulates the connection behavior well. It was also observed that the connection with the higher initial post-tensioning force has higher force-displacement behavior and loading capacity than other samples. Sharbati et al. [7] simulated a sample of the post-tensioned connection using ABAQUS software in 2012. Verification results showed that the simulation has a correct prediction of the experimental results. Garlock et al. [8] compared the seismic performance of the steel moment frame with post-tensioned connections with the seismic performance of the steel moment frame with welded moment rigid connections through dynamic time history analysis in 2002. In this study, DRAIN-2DX software was used for modeling. The results show that the seismic performance of steel moment frame with post-tensioned connections is better than the seismic performance of the steel moment frame with welded moment rigid connections. In other words, the moment frame with post-tensioned connections reduces the seismic requirements of the structure. Christopoulos et al. [9] tested a post-tensioned energy dissipation moment connection for the structures with steel moment frame in 2002. In this connection, high strength post-tensioning steel bars and energy dissipating bars have been used instead of the strand. The results of the experiments show that the proposed connection is able to bear the great deformations with the energy dissipation specification, and the beam and the column remain non-damaging in this connection and there is no permanent displacement in the connection. Rojas et al. [10] introduced the post-tensioned friction damped connection (PFDC) in 2005, in which they used the installed friction dampers on the beam upper flange and under the beam lower flange for energy dissipation and control of the inelastic deformations. The results of the analytical studies show that PFDC frame is better than a special moment frame with welded connections. The seismic performance of PFDC frame was satisfactory in terms of the resistance, storey drift, local deformation, and self-centering. Rickels et al. (2006) proposed other friction tools for self-centered moment frames. These tools are only placed on the lower flange in order to prevent interaction with the floor diaphragm and if necessary, are replaced easily. Also, other researchers [12, 13, and 14] have had good studies about the connections with reciprocating loading. In this paper, numerical modeling of the post-tensioned connection has performed using ABAQUS Finite Element software [15] and the post-tensioned strand parameters have considered as a variable and the effect of these parameters has evaluated on the connection behavior, while controlling the accuracy of the modeling with Ricels et al. [1] experimental results. Due to the fact that the post-tensioned strand is one of the main components of the connection and there have not been enough studies on the strand's effect on the connection behavior, this paper has attempted to investigate the strand's effect on the connection behavior by considering some of the strand's parameters as a variable. Studied parameters include increasing the diameter of the strands by stability of the post-tensioning force, using less strands with cross section and equivalent force, the effect of strand distance from the beam center of gravity and increasing the number of strands. The results of the modeling are presented in two sections, including results in the form of charts and tables, as well as the graphical results.

2. Post-tensioned connection behavior

A post-tensioned steel connection includes top and seat angles and high-strength strands. Strands running parallel to the beam and along its length and are anchored out of the connection. The strands with their post-tensioning force cause the beam flanges compress against the column flanges and thus resist against the moment, while the two angles and the friction at the beam and column interface resist shear. In fact, the angles are energy dissipation tools in this connection, so the initial purpose of the angles is to dissipate energy. The beam flanges are reinforced with reinforcing plates to prevent beam yielding. Also, shim plates are placed between the beam flanges and the column flange so that only the beam flanges and reinforcing plates are in contact with the column [1, 3]. Garlock et al. (2002) [3] have shown that in an tension angle, a mechanism is formed with the formation of three plastic hinges as shown in Fig. 1, in which two plastic hinges are formed on the muscle of each angle leg and the third hinge is formed near the bolts that connect the angle to the column. Moment behavior is a post-tensioned connection with a top angle and seat angle under cyclic loading like Fig. 1.
The relative rotation of the connection is zero before the gap opens and the beam tension flange separates from the column, so that the initial stiffness of the connection under the applied moment is similar to a welded moment connection [1]. The moment is known as the decompression moment at the moment of gap opening, point 1 in Fig. 1 represents the decompression moment of the connection. With continued loading, the angles yield (point 2) until the angles suffer full plastic yielding in point 3. Between points 3 and 5, the stiffness of the connection includes the stiffness of the elastic strands and the stiffness of the angle strain. If loading continues at point 5, the post-tensioned strands will begin to yield, and upon unloading at point 4 and before yielding of the strands, the angles dissipate energy among points 4 to 8 until the gap closes between the beam-column.

3. Specifications of models
3.1. Reference experimental model

A cruciform-shaped analytical connections specimen has been made of two beams on either side of a column, strand, angle and reinforcing and shim plates by Ricels et al. [1] in the laboratory, that is a specimen of frames’ inter-connection. The beams have a roller support at the free end and the column has a hinged support at the bottom and is free at the top to apply the lateral displacement. The height of the column used in the connection specimens is 3658 mm and the total length of the samples is 6096 mm, including two beams and the height of the column section. The intended specimen for verification is specimen PC6 among the tested specimens by Ricels. Beam section is W24 × 62. Concrete filled tube (CFT) with dimensions of 406 × 406 × 13 mm has been used for the column. Details of the connection specimen and specification of the used bolts are shown in Fig. 2.
Shim plates are placed between the angles and the beam flange with the column flange. The dimensions of this plate are 275 × 254 × 19 mm. Beam flanges are armed with reinforcing plates to yield with least amount. Reinforcing plates have been used for specimen PC6 with dimensions of 603 × 203 × 12.7 mm. The specimen has 4 post-tensioned strands with high strength on each side of the beam web, which are placed with equal distance at the height of the beam [1]. The column has been made of ASTM A500 GR.B steel with a 379 MPa yield strength. HSLA-100 steel has been used for reinforcing and shim plates and A36 steel has been used for other steel materials. Specification of the steel materials used in the laboratory model and the numerical model are shown in Table 1 for verification.

Table 1. Specification of steel materials in line with reference [1].

<table>
<thead>
<tr>
<th>Connection components</th>
<th>Tension (MPa)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>σ_y</td>
<td>σ_u</td>
<td></td>
</tr>
<tr>
<td>beam flange</td>
<td>230</td>
<td>421</td>
<td></td>
</tr>
<tr>
<td>beam web</td>
<td>266</td>
<td>455</td>
<td></td>
</tr>
<tr>
<td>angle</td>
<td>230</td>
<td>465</td>
<td></td>
</tr>
<tr>
<td>reinforcement plate</td>
<td>843</td>
<td>895</td>
<td></td>
</tr>
<tr>
<td>shim plate</td>
<td>843</td>
<td>895</td>
<td></td>
</tr>
<tr>
<td>Post-tensioned strand</td>
<td>1305</td>
<td>1864</td>
<td></td>
</tr>
</tbody>
</table>

3.1.1. Loading experimental model

Test equipment and their form of placement are shown in Fig. 3. Each specimen is tested using a series of lateral displacement cycles corresponding to the multiplier amplitude. These displacements include two cycles that each storey relative drift angle has ranges of 0.1, 0.2, 0.3, 0.4, 0.5 and 0.7, followed by three cycles with relative drift angle with ranges of 1, 1.5, 2, 2.5 and 3 percent [1].

Fig. 3: Post-tensioned connection test equipment [1]

3.2. Numerical models

Made specimen in this paper is based on PC6 laboratory model made by reference [1] in the term of geometry, material specification and connection boundary conditions. Each specimen is tested using a series of lateral displacement cycles in line with the multiplier amplitude. These displacements are applied in each storey relative drift angle with ranges of 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 1, 1.5, 2, 2.5 and 3 percent. Also, the initial post-tensioning force and strands' diameter amounts are 90 kN and 15 mm, respectively. The parameters studied in the numerical models are as follows: (1) increasing the diameter of the strands by stability of the post-tensioning force, (2) using less strands with cross section and equivalent force, (3) the effect of strand distance from the beam center of gravity and (4) increasing the number of strands. Specification of the studied models have been presented in Table 2. To use the table, it should be noted that the terms PC6, D, ST, SST and N are the reference model name, the strand diameter, the post-tensioned strand, the strand distance from the beam center of gravity and the number of the strands.
Table 2. Specification of the studied models.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Strand diameter (mm)</th>
<th>Number of strand with equivalent diameter and force</th>
<th>Strand distance from beam center of gravity (mm)</th>
<th>Number of strands</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC6</td>
<td>15</td>
<td>x</td>
<td>125</td>
<td>4</td>
</tr>
<tr>
<td>PC6 − D18.75</td>
<td>18.75</td>
<td>x</td>
<td>125</td>
<td>4</td>
</tr>
<tr>
<td>PC6 − D22.5</td>
<td>22.5</td>
<td>x</td>
<td>125</td>
<td>4</td>
</tr>
<tr>
<td>PC6 − 2ST</td>
<td>15</td>
<td>2</td>
<td>125</td>
<td>x</td>
</tr>
<tr>
<td>PC6 − 1ST</td>
<td>15</td>
<td>1</td>
<td>125</td>
<td>x</td>
</tr>
<tr>
<td>PC6 − 2ST − SST250</td>
<td>15</td>
<td>x</td>
<td>250</td>
<td>4</td>
</tr>
<tr>
<td>PC6 − N6</td>
<td>15</td>
<td>x</td>
<td>125</td>
<td>6</td>
</tr>
</tbody>
</table>

4. Modeling and verification

4.1. Modeling

ABAQUS finite element software has been used for numerical modeling of this study. The components have created for this connection in Part module include an angle, a beam, a composite column (including 2 sections of steel and the concrete), bolts, reinforcing plates, shim plates, strands, a washer plate, and supports which each has been modeled in line with the real size. Bilinear stress-strain behavior and also, isotropic steel material behavior have been considered for all the materials. Specification of the defined materials in Property module have been presented in line with the laboratory model. There is a great deal of interaction between the components in this connection, and ABAQUS Analyst has been used to get the connection response to the lateral displacement since the Implicit ABAQUS Analyst has a high ability to simulate the nonlinear behaviors. Surface to surface connection has been used to define the surfaces connection that interact with each other. Also, Tie Constraint has been used to tie members that have been welded together. Bolt Load software has been used for pre-stressing and post-tensioning. In the second stage, lateral loading has been applied to the top of the column as literal displacement. All components have been arranged using continuum volume elements, at first and using ABAQUS C3D8R reduced integration. Modeled connection in ABAQUS is shown in Fig. 4.

![Fig. 4. Modeled connection in ABAQUS.](image)

4.2. Verification

Verification of the numerical model has been carried out by matching force-displacement diagram of this model with the force-displacement diagram of the model tested by Ricels et al. [1], which is shown in Fig. 5. As shown in Fig. 5, the numerical model diagram is in good agreement with the laboratory model diagram.
5. result discussion

5.1. The effect of increasing the diameter of the strands with the fix of the post-tension force

Two PC6-D18.75 and PC6-D22.5 models have been made with diameters of 18.75 and 22.5 mm respectively, to investigate the effect of strand diameter on the connection behavior, and the results of these connections are compared with PC6 model that has strands with a diameter of 15 mm.

5.1.1. Review results in the form of charts and tables

The force-displacement diagrams of the models have been compared with each other in Fig. 6. It is observed that the connection capacity is more in lateral force bearing in connectors with larger strand diameter, so that the connection capacity in the lateral force bearing of PC6-D22.5 connector (11.4%) is more than PC6 connector, and (3.6%) more than PC6-D18.75 connector. A summary of the models results has been presented in Table 3. In this table, $K_0$ is the connection initial stiffness at the relative drift angle of 3% before pressing, $K_{FR}$ is the rigid connection stiffness with dimensions of the same beam and column (equals to 14895 kN / m), $T_{\text{max,FEM}}$ is the most post-tensioning force of the strands and $\theta_r,\text{max}$ is the relative rotation between the beams and columns at a relative drift angle of 3%. Also, as shown in Table 3, the ratio of the decompress moment to the beams flexural capacity of the beams is ($\frac{M_{\text{max,FEM}}}{M_p}$), as well as the ratio of the connection moment capacity to the beam flexural capacity is ($\frac{M_{\text{max,FEM}}}{M_p}$), that has been calculated 3% at the relative drift angle. The amount of $T_U$ is based on the information of the strands manufacturer and $M_p$ is determined based on the beam materials and section specification [1]. It can be concluded from the amounts given in the table that by increasing the strands’ diameters, the relative rotation decreases between the beam and the column and the maximum entered force increases on the strands. It is also observed that the maximum connection anchor has increased with increasing the strands’ diameters, so that the maximum anchor in PC6-D22.5 connector is 13.5% higher than PC6 connector. It is clear from the amounts given in the table that the increase at the strands’ diameters by stability of the post-tensioning force has no effect on the initial stiffness and also, on the decompress anchor.

Figure 6. Force-displacement diagrams of PC6 and PC6-D18.75 and PC6-D22.5 specimens.
Table 3. Numerical results of PC6, PC6-D18.75 and PC6-D22.5 specimens.

<table>
<thead>
<tr>
<th>Model name</th>
<th>$K_0/K_{FR}$</th>
<th>$M_p$</th>
<th>$M_d$</th>
<th>$M_{max}/M_p$</th>
<th>$T_{max}/T_u$</th>
<th>$\theta_{r,\text{max}}$ (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PC6$</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.11</td>
<td>0.58</td>
</tr>
<tr>
<td>$PC6-D18.75$</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.21</td>
<td>0.66</td>
</tr>
<tr>
<td>$PC6-D22.5$</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.26</td>
<td>0.69</td>
</tr>
</tbody>
</table>

5.1.2. Check graphical results

In this section, the deformation and stress distribution of PC6-D22.5 connector have been shown based on Von Meyss criterion. Fig. 7 shows the simulated connection specimen at relative drift angle of 3%.

As shown in Fig. 7, the compression flanges and beam web have high stress in this part, but the separated flanges from the beam-column common joint have low stress. It is seen in Fig. 7 that the lower flange of the right-side beam has been separated from the column flange and the gap has been made between the beam flange and the column flange. This causes a large deformation to occur in the angle of the beam flange separated from the column flange (strain angle). There is stress concentration on the strain angle muscle, and these points are the first points that enter the plastic stage. This is evident in Fig. 8 that shows the deformation and the distribution of the equivalent plastic strain at the strain angle. It is seen that the zone around the bolt hole connected to the column has also entered the plastic stage.
5.2. Effect of less strand usage with equivalent cross section and equivalent force

PC6-2ST and PC6-1ST models with 2 strands (the diameter and force of each strand are 21.2 mm and 180 kN, respectively) and 1 strand (with diameter of 30 mm and force of 360 kN) have been made and the results have been compared with PC6 model in order to investigate the effect of using less strands with an equivalent diameter and equivalent force to the connection behavior. In Fig. 9, the models’ force-displacement diagrams have been compared with each other. Also, the results of the models have been summarized in Table 4.

![Figure 9. Force-displacement diagrams of PC6 and PC6-1ST and PC6-2ST specimens.](image)

<table>
<thead>
<tr>
<th>Model name</th>
<th>$K_0/K_{FR}$</th>
<th>$M_f$ (KN.m)</th>
<th>$T_u$ (KN)</th>
<th>$M_d/M_f$</th>
<th>$M_{max}/M_f$</th>
<th>$T_{max}/T_u$</th>
<th>$\theta_{r,max}$ (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC6</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.11</td>
<td>0.58</td>
<td>0.0253</td>
</tr>
<tr>
<td>PC6 - 1ST</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.11</td>
<td>1.16</td>
<td>0.0253</td>
</tr>
<tr>
<td>PC6 - 2ST</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.11</td>
<td>2.32</td>
<td>0.0253</td>
</tr>
</tbody>
</table>

It is clear from the investigation of the results that the diagrams of the models are completely in line with each other. In fact, the use of less strands with cross section and equivalent force have had no effect on the connection behavior. Given the complete concordance of the diagrams, the numerical amounts are equal. Of course, as can be seen in table of amounts, the strand’s maximum force has increased to the same extent as the strands numbers have lessen and its diameter has increased. If necessary, less strands with cross section and equivalent force can be used due to the obtained results.

5.3. The effect of strand distance from beam center of gravity

PC6-2ST-SST250 model has been made to investigate the effect of strands’ distance from the beam center of gravity on connection behavior. This connection is similar to PC6-2ST connector. In PC6-2ST connector, 2 strands with equivalent diameter (21.21 mm) and equivalent force (180 kN) have been used instead of 4 strands, in which the distance of each strand from the center of gravity is 125 mm. The strands’ distance in PC6-2ST-SST250 connector has been increased from the center of gravity and equals to 250 mm. Results have been compared with PC6-2ST connector. The force-displacement and rotation-moment diagrams of the models have been compared with each other in Fig. 10. A summary of the models results has been given in Table 5. It is clear from the investigation of the results that the diagrams of the models are completely in line with each other. In fact, change in the strand distance from the center of gravity have had no effect on the connection behavior. Given the complete concordance of the diagrams, the numerical amounts are equal. Given the obtained results, it is possible to place the strands at a greater distance than the beam center of gravity and near the flanges for ease of access to the strands’ replacement due to damage (if necessary).
5.4. The effect of increasing the number of strands

PC6-N6 model with 6 strands has been made and the results have been compared with PC6 model, in which 4 strands have been used in order to investigate the effect of the increase in the number of the strands to the connection behavior.

5.4.1. Review results in the form of charts and tables

In Fig. 11, the models’ force-displacement diagrams have been compared with each other. As seen in the fig, the increase in the number of post-tensioning strands increases the strength and stiffness of the connection. In fact, by increasing the number of the strands, the total post-tensioning force has also increased, so the increase is observed in strength and stiffness of the connection. Also, it is clear that the connection capacity is greater in lateral force bearing in connectors with more strands, so that the connection capacity in the lateral force bearing in PC6-N6 connector, 11.6% is more than PC6 connector. Also, given the force-displacement diagram, the connection energy dissipation has increased slightly, so that the energy dissipation in PC6-N6 model, 2.4% is more than PC6 connector. Energy dissipation is obtained by calculating the total area of the hysteresis cycles. A summary of the models’ results has been presented in Table 6. It can be seen from table amounts that the increase in the number of the strands increases the flexural capacity and also, the maximum force of each strand decreases.

### Table 5. Numerical results of PC6-2ST and PC6-2ST-SST250 specimens.

<table>
<thead>
<tr>
<th>Model name</th>
<th>$K_0/K_{FR}$</th>
<th>$M_P$ (K.N.m)</th>
<th>$T_u$ (K.N)</th>
<th>$M_d/M_P$</th>
<th>$M_{max}/M_P$</th>
<th>$T_{max}/T_u$</th>
<th>$\theta_{r, max}$ (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC6 – 2ST</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.11</td>
<td>0.58</td>
<td>0.0253</td>
</tr>
<tr>
<td>PC6 – 2ST – SST250</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.43</td>
<td>1.25</td>
<td>0.46</td>
<td>0.0248</td>
</tr>
</tbody>
</table>

### Table 6. Numerical results of PC6 and PC6-N6 specimens.

<table>
<thead>
<tr>
<th>Model name</th>
<th>$K_0/K_{FR}$</th>
<th>$M_P$ (K.N.m)</th>
<th>$T_u$ (K.N)</th>
<th>$M_d/M_P$</th>
<th>$M_{max}/M_P$</th>
<th>$T_{max}/T_u$</th>
<th>$\theta_{r, max}$ (rad)</th>
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</thead>
<tbody>
<tr>
<td>PC6</td>
<td>0.96</td>
<td>576</td>
<td>261</td>
<td>0.39</td>
<td>1.11</td>
<td>0.58</td>
<td>0.0253</td>
</tr>
<tr>
<td>PC6 – N6</td>
<td>0.97</td>
<td>576</td>
<td>261</td>
<td>0.43</td>
<td>1.25</td>
<td>0.46</td>
<td>0.0248</td>
</tr>
</tbody>
</table>
5.4.2. Check graphical results

The deformation and stress distribution of PC6-N6 connector can be seen at a relative drift angle of 3%, based on Von Mises criterion in Fig. 12-A.

![A. PC6-N6 Connection](image)

![b. PC6-N6 beam Connection](image)

**Figure 12. Von Mises Stress Distribution.**

Fig. 12-B shows the stress distribution in the connection left-side beam. The right side of the beam shown in the fig. is adjacent with the column, and its left side is free end of the beam. As shown in Fig. 12-B, parts of the flange and the beam web are yielded that are placed in the beam-column common joint and at the end of the reinforcing plate.

Fig. 13 shows the plastic strain distribution in the beam for PC6-N6 connector. As seen in the fig. most strains have been entered around the flange and the beam web and at the end of the reinforcing plate.

![Figure 13. Strain distribution in PC6-N6 connection beam](image)

**6. Conclusion**

The use of rigid moment connections is very common in steel buildings. New connections with different configurations were proposed and tested after Northridge earthquake and the collapses that were observed in the penetration weld between the beam flanges and column flanges. One of these new connections is the post-tensioned connection, in which the beam is installed to the column with steel strands with high strength and angle. Various experimental and numerical studies have been conducted on these connections, but further studies are needed in this regard due to the particular connection behavior and details that are in the connection configuration and in order to achieve the best structure performance. Regarding this subject, in this paper post-tensioned steel beam connection has been modeled to the composite column by applying changes to the diameter and arranging the strands using ABAQUS software. Therefore, the results obtained from this numerical study on post-tensioned connections are:

1- Regarding the conducted verification, it was found that the modeling of the post-tensioned
connection is capable of demonstrating the cyclic behavior of this connection well using the numerical method.

2- The connection capacity in the lateral force bearing was observed by increasing the strands' diameter and stability of the post-tensioning force. Also, it was observed that the connection moment capacity increased with the amount of 13.5%. However, it should be noted that the self-centering capacity of the connection decreases with the excessive increase in the strand diameter, if the post-tensioning force does not increase.

3- The increase in the number of strands will increase the connection capacity in the lateral force bearing with the amount of 11.6% and also, will affect the connection initial stiffness and will increase the initial stiffness slightly. This increase was also observed in Garlock et al. [3] experiment, which was conducted through increasing the number of strands in 2005. Also, more strands can be used with less post-tensioning force, so there is less likely that the strands yield, because the post-tensioning force of each strand is less.

4- Studies about the models of this paper showed that the use of less strands with equivalent diameter and equivalent force will not affect the connection behavior.

5- Investigating the connections showed that the strands' distance from the beam center of gravity does not affect the results. Therefore, it is possible to place the strands at a greater distance than the beam center of gravity and near the flanges for ease of access to the strands' replacement due to damage (if necessary).

7- Reference

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