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Development Behavior for Post-Tensioned Self-Centering Steel Connection under Cyclic Loading

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Abstract

One of the newest steel beam-column joints to replace conventional welded connections, post-tensioned connection steel is with the upper and lower angles. In this connection are high-strength steel strands that parallel beam web and angles between beams and column. Actually high resistance strands and upper and lower angles respectively are provider centralization properties and energy dissipation capacity of the connection. The benefits of post-tensioned steel can be used in connection with the centralization and lack of relative displacement (drift) persistent, stay elastic core components such as connecting beams, columns and fountains connection, appropriate initial stiffness and joint manufacture with materials and traditional skills. . In this study, numerical modelling in Abaqus software, the results of the analysis were compared with the results of laboratory samples and the results showed that the two together are a perfect match. After validation, parameters influential centrist connection then pulled the thick angles in three numerical models were evaluated. The results show that by increasing the thickness of the angles, increase energy dissipation capacity and ductility connection and the β_1 value does not experience tangible changes with changes in angle thickness.

Keywords: Post-Tensioned Connection; Centralized Bending-Resistant Frame; Sensitivity Analysis.

1. Introduction

Since the 1994 Northridge and 1995 Kobe earthquake, many efforts to improve seismic design, strength and performance steel building was carried out. When the earthquake affected buildings are large and powerful forces that are building these forces would enter the field of non-linear behaviour in the area of nonlinear behaviour. Today, the new framework is expected moment frames with non-elastic deformation large pile of Weston to withstand major earthquakes. Non-elastic deformations in structures oriented center of attention remains Drift are in connection with the opening of the beam can be removed Weston so it seems structures oriented center can be no harm in main structural members after earthquake is restored the initial position. Unlike conventional steel frame structural members based on ductility materials, behaviour-oriented center ductility with high strength is based on the behaviour of post-tensioned strands with bars. In general these strands and connectivity junctions foot of the column is in Weston Mercury application of steel structures for the construction. In this connection property to maintain its centralization post-tensioned strands and main components must remain elastically connection.

Another form of post-tensioned connections by Christopoulos et al. [3] was examined experimental and numerical analysis. This circuit consists of high-strength steel bars and rods enclosed for energy dissipation by submission in tension and compression, respectively. The results showed that the relative movement of the top floor, the frame has this connection to its original position without causing damage to the beams and columns, returns. Once again Christopoulos et al. [4] it has drawn seismic behaviour of connections after centralization with hysteretic behaviour flag shape compared with conventional seismic behaviour of welded joints. This comparison was made only for a

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single degree of freedom. For this study were used 20 record earthquakes and in the end it was observed that hysteretic response hysteretic elastic flag shaped like an even better response is achieved.

Garlock and colleagues [5] of the angles of the upper and lower fittings published in the lab under cyclic loading. The aim of the present study, the size and spacing of the holes on the corners to heel stiffness, strength and energy dissipation capacity of the connection. The results showed that corners even after the surrender, their efficiency are preserved. Also, much of the energy dissipation mechanism connecting the corners of performance and surrendered linked. Garlock et al [6] 6 examples of rigid beam to column connections under cyclic loading post-tensioned steel with 4% drift to simulate the effects of the earthquake.

In this connection the upper and lower corners bolted to beams and columns and also are used resister strands parallel to web beam. Bending moment resistant strands for service loads, high beam to column flange pressure the day. The parameters in this study were strengthened that consists of the initial strain, the number of post-tensioned strands and the sheets. The results showed that the binding post-tensioned steel has good ductility and energy dissipation capacity and are also subject to drift beam and column 4% remain elastic and will not have any harm. Only members of the upper and lower angles were damaged, causing energy dissipation as well. Garlock [7] a series of studies on the cyclic behaviour of a limited number of components of the proposed post-tensioned connections Ricles [1], carried out. They laboratory sample results with the results of the numerical model and found that the results were compared and validated numerical models corresponded with the results of laboratory samples.

Rojas et al [18] studied a PT connection for a steel moment resisting frame with post-tensioned friction damped connections (PFDC) to increase the energy dissipation capacity. The results represented that the response of a PT frame exceeds that of a frame with a rigid connection and also good strength, ductility and energy dissipation observed. Wolski et al. [19] performed an experimental study on connections with top and seat angles combined with post-tensioned strands which indicated that such post-tensioning concentrates inelastic deformation on angles. They concluded that the combination of post-tensioned strands and energy dissipating devices results in self-centering behaviour by eliminating residual drifts of system. Hadianfard et al. [20] made numerical studies on the effects of angle geometry on a PT connection behaviour. The results showed that the energy dissipation capacity and post-yielding stiffness of a PT connection increase by increasing the angle thickness or decreasing the angle gage length.

Shiravand [9] the development of centralized post-tensioned connections, stiffeners to the upper and lower corners for improved energy dissipation capacity of the connection, were added. They are using numerical analysis, a series of theory to predict the behaviour of post-tensioned connections with the upper and lower corners reinforced with stiffeners have suggested. Finally, by adding hardware to connect the corners of increased resistance against high drift (4%). This paper is to model the experimental sample and then to validate the results of the numerical simulation of the laboratory samples deals. Then, the numerical modelling of principal and interest, explains. Number ۳is investigated numerically. The characteristics of the three models are post-tensioned connection with three thick steel angles (17.5, 22 and 25.5 mm).

2. Numerical Simulation

Sample name is 36S-20-P. Sample is consist of the two beams and a column crosswise, high-strength strand, beam flange reinforcement sheets, plates and sheets continuity forehead. Sample 36S-20-P simulated in Abaqus finite element software [10]. This section summarizes the modelling centralized connection point is then drawn.

All the models in this paper have been made in SIMULIA Abaqus FEA software. Figure 1. shows the three-dimensional solid model springs mode. Because of the complexity of the model and the massive computing, assumptions have been considered in order to solve these problems. Due to the symmetrical shape of sections and connecting components such as beams, columns, plates and sheets of strengthening the beams, the conditions and numerical simulation is used in the symmetry properties, in other words, half the beam-column connection is made in the application [7, 11].

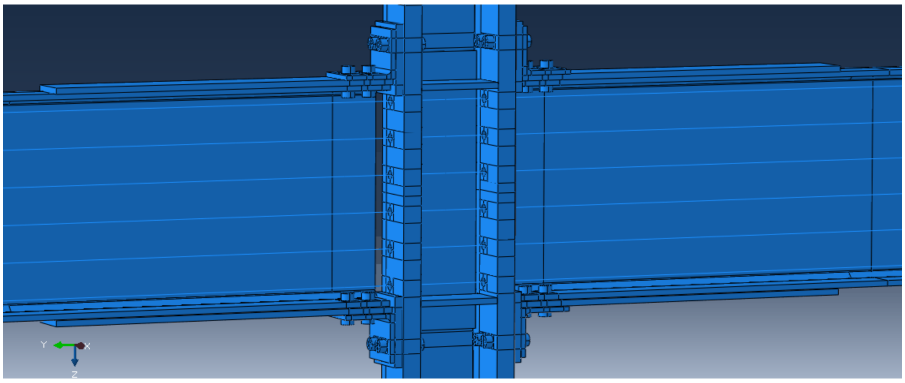

Figure 1. The placement of components in the springs' area

2.1. Specification Materials

Steel material properties connectivity components are given in Table 1. The values of tensile testing in the laboratory components are calculated in accordance with ASTM standard [12]. All of the components except the angles in the analysis are just a stretch, but for material properties angles are loaded on a cross. Materials have been tested twice and values of yield stress and ultimate been achieved of average tensions. For all materials is considered the behaviour of stress - strain that approximated as bilinear (Isotropic). For bilinear stress-strain curve definition is need to yield and ultimate stress and strain failure. Also, Young modulus, and thermal expansion coefficient strands and respectively is 199 GPA, 12e-6, 266 KN is considered of according to the force-displacement curve of strand 85% yield stress and tensile stress [13].

Table 1. Profile of steel materials [7]

Components	Yield Stress	Ultimate Stress
Beam Flange	362	498
Beam Web	414	527
Reinforce Plate	397	574
Column Flange	356	499
Column Web	345	496
Angle	383	545
Strand	1620	1900

2.2. Meshing

main components of connection such as beams, columns, plates, sheets strengthened, screws and sheet forehead of elements volumetric 3D solid 8 node with integral dropped (C3D8R) have been made, but to simulate cable, Germans beam (B31) been selected. Nearby areas Springs has a grid (mesh) smaller than other places like between the sheets are strengthening to the free end. Figure 2. shows the meshed model is assembled. Beams in areas adjacent columns, elements smaller markets. Also column in areas adjacent angles elements smaller markets and in other areas is elements elder. About strand and pitch can be notice that in areas adjacent holes are elements smaller and others area elements elder. (Table 2)

Table 2. Number elements for components

Components	Number elements
beam	4008
column	5567
Reinforce beam	611
Plate double	812
angle	828
strand	1579
Column pitch	1728
Beam pitch	1288

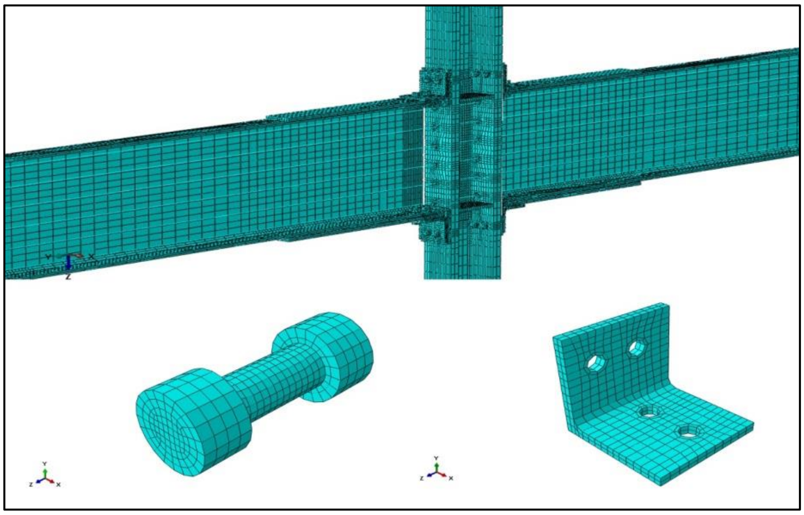

Figure 2. Details meshing simulation model

2.3. Interaction

The interaction between the main components of structural surfaces that are in contact with each other, have a huge impact on the accuracy of numerical model nonlinear analysis. In order to model the behaviour of welded components is used from the TIE. The interaction between other components (not boiling), is defined in two directions tangential and vertical. In a vertical direction, for all parts, components influence each other to prevent interaction is determined into HARD CONTACT. Two types of contact defined without friction and friction tangential to the characteristics. In order to simulate have been used forehead frictionless contact and friction contact between the body of the screw and strand holes in walls and head of bolts with angles, beams and columns angles with sheets and sheets of strengthening the beams. The coefficient of friction between steel surfaces is selected 0.33 [14].

2.4. Boundary Conditions

Connecting the boundary conditions, such as low-articular bearing columns, beams and maintenance support roller end side (side controls) connection, accurately modelled in the software. Fulcrum joint to simulate the coupling beam and columns, the points under the wing of the beam vertically and move around the bottom of the column were bound in three directions.

2.5. Pattern Cyclic Load

The load on the model of displacement such as displacement or relocation of the number and size of each load cycle under the Protocol SAC is shown in Table 3.

Table 3. Drift and the number of cycles loading protocol [15]

Load Step	1	2	3	4	5	6	7	8
Number of Cycles	0.00375	0.005	0.0075	0.01	0.015	0.02	0.03	0.04
θ (rad)	0.005	6	6	4	2	2	2	2

3. Verification of Finite Element Model

Solver of choice to simulate the performance cycle post-tensioned connections called Static-General. In this analysis to considered the effect of large deformations and nonlinear geometric. According to Moradi [7] and Shiravand [9] found that the use of finite element method in assessing the cyclical behaviour of post-tensioned connections is very convenient and accurate. For validation, the results of finite element model post-tensioned connection were compared with the results of laboratory samples Garlock [2 and 6]. Built-in software model is simulated exactly like laboratory specimens.

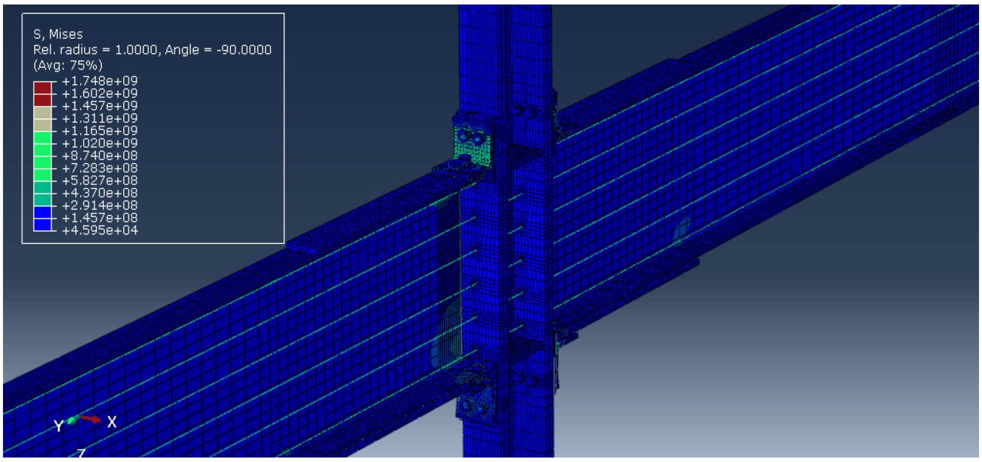

Figure 3. Typical stress distribution 36S-20-P

Compare the response force - displacement connection after laboratory sample drawn numerical example is shown in Figure 4. It turns out that the hysteresis curve as shown in laboratory samples hysteresis curve with a minimum number of errors matches.

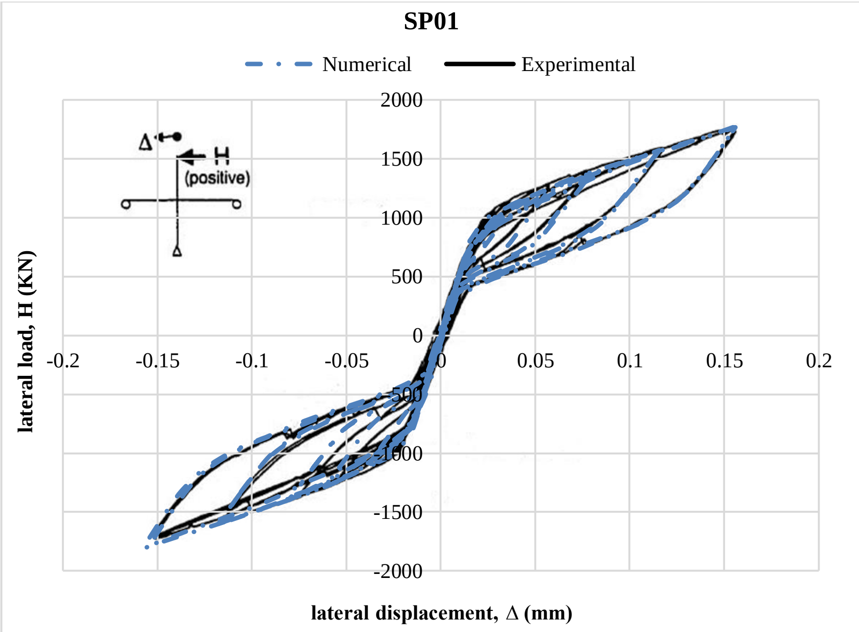

Figure 4. compares the response force - displacement experimental and numerical examples

The values in Table 4. is calculated that results of experimental and numerical analysis of the samples were compared with the percentage of error between two values, and observed that the maximum error between experimental and numerical results is less than 5%.

The values of this tables include of T_0 total initial post-tensioning force, T_u ultimate post-tensioned strands, T_{max} maximum post-tensioned strands in drift 4%, M_d moment or anchor detachment threshold, M_{max} maximum bending moment in the beam in drift 4% and have to say that plastic hinges is visible in the upper and lower angles.

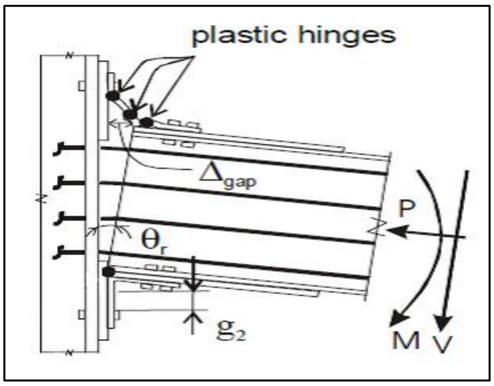

Figure 5. Plastic hinges and the final transformation of post-tensioned steel connection [16]

Table 4. Comparison of experimental and numerical analysis

Sample Model	T_0 (KN)	θ_{max} (rad)	$\frac{M_d}{M_{pn}}$	$\frac{M_{max}}{M_{pn}}$	$\frac{T_{max}}{T_u}$	θ_{rmax} (rad)
Experimental Model	3194	4%	0.47	0.96	0.55	0.033
Numerical Model (SP1)	3123	4%	0.487	0.995	0.0551	0.0325
Error Percent	2%	0	3.62%	3.65%	0.18%	1.5%

4. Numerical Models

Numerical simulation model validation is named SP1. After validation of 36S-20-P, turn to build three other models to assess the effect of the thickness of the angles, the behaviour of post-tensioned steel connection arrives. Specifications models are given in Table 5. where T_0 = total initial post-tensioning force, N_s = Number of PT strands, L_{rp} = length of the beam flange reinforcing plates, g_2 = distance from the fillet to the washer plate edge.

Table 5. Profile models

Sample Model	T_0 (mm)	N_s	L_{rp} (mm)	g_2 (mm)	Angle Thickness (mm)
SP01	3123	36	1372	137	19.05
SP02	3123	36	1372	137	17.5
SP03	3123	36	1372	137	22
SP04	3123	36	1372	137	25.5

5. The Results of the Analysis of Numerical Models

$M - \theta$ Curves are obtained from the force-displacement of each connection, by increasing the thickness of angles in connection, the induced initial stiffness from post-tensioned strands decrease. Also by increasing the thickness of angles, energy dissipation of connections increases.

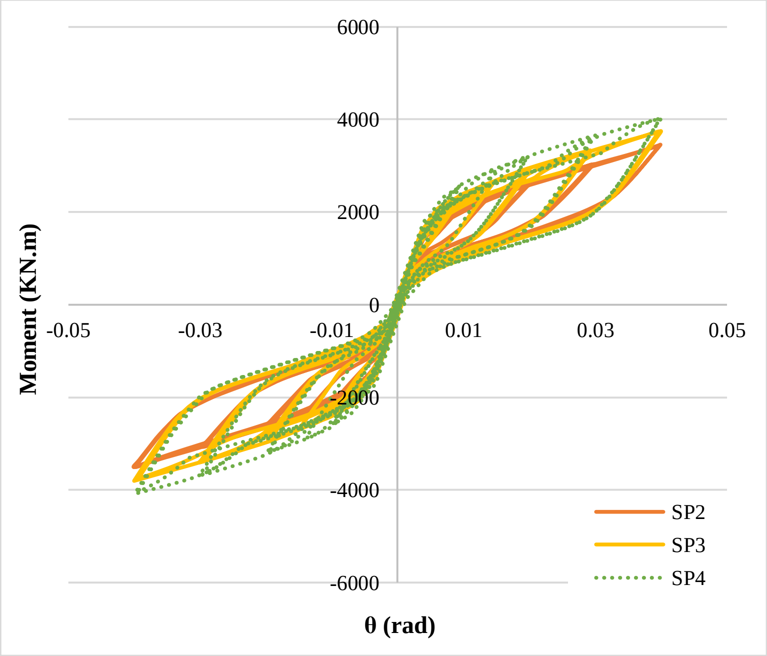

Figure 6. Curves $M - \theta$ samples SP2, SP3 and SP4

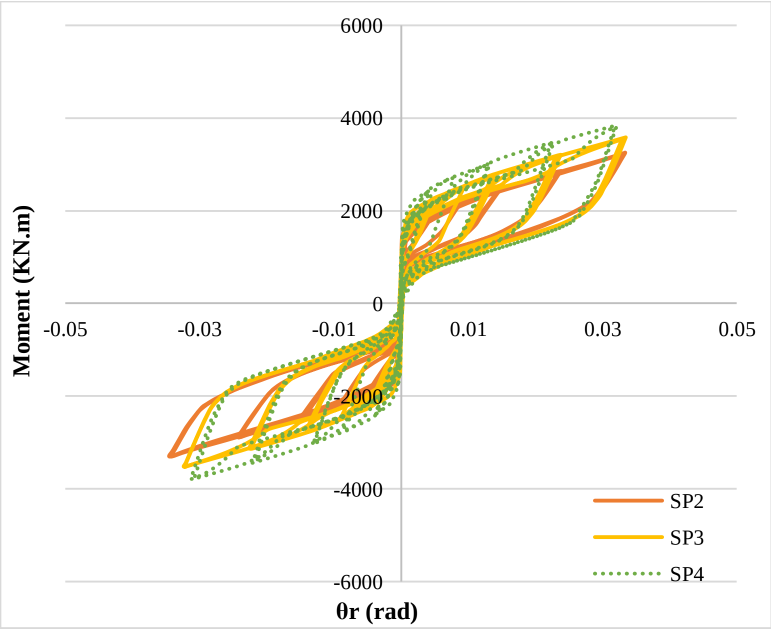

Figure 6. Curves $M - \theta r$ samples SP2, SP3 and SP4

6. Ductility

To determine the seismic design standards of steel structures, the ductility of the connection is of great importance. The ductility of connection is, indeed, the ability of the connection in tolerating non-resilient transformations so that the connections in the changes do not show considerable resistance reduction. The requirements of ductility in average and special frames must be considered. The moment-rotation curve has been used to express the ductility. The angles of relative and absolute rotation of the connections are considered as an important quantity in ductility classification. For example, final rotation of θ_u connection or relative ductility index $\frac{\theta_u}{\theta_y}$ with elastic rotation limit of θ_y is often used. T_0 Compute the elastic rotation limit, the M_y yield moment is calculated by $M_y = C_y \times M_u$ [17], where M_u is ultimate connection moment (Table 6).

Table 6. Form factor of the modelled sample

Sample Model	Ductility Factor
SP01	1.99
SP02	2.25
SP03	2.06
SP04	1.85

7. Analysis of Sensitivity

Shiravand [13] provided equations for calculating the coefficients. The values of this article have been calculated using the proposed equations. In fact, it is only dependent on the geometry of the angles. Table 7. is displayed Correction factors for all models.

Table 7. Values β_1

Sample Model	β_1
SP01	0.497
SP02	0.494
SP03	0.496
SP04	0.495

Table 7. by analysing samples SP01 to SP04 values obtained from the analysis as shown are available in Table 8. Δ_{gap} Parameter which it shows the gap opening and closing at the beam-column interface under cyclic loading. By increasing the thickness of angles, tolerate the bending moment in beam, 4.5 to 13.8 percent .maximum the opening connections SP02 (angles connection with a thickness of 17.5) and the lowest is belong to SP04.

Table 8. The numerical values of the analysed samples

Sample Model	$\frac{M_{max}}{M_u}$	$\frac{T_{max}}{T_u}$	θ_{rmax} (mm)	Δ_{gap} (mm)
SP01	0.995	0.551	0.0325	28.71
SP02	1.006	0.54	0.0334	29.5
SP03	1.07	0.53	0.03226	28.5
SP04	1.2	0.53	0.03192	28.2

8. Conclusion

In this study, a connection with the real dimensions of post-tensioned steel beams, columns, upper and lower angles, strands resistance and stiffeners examined and analysed under cyclic loading cyclic connect SAC to assess response (curve M-θ and M-θ_r) and location of plastic hinges forming the desired connection, M-θ Curves is obtained from the force-displacement of each connection, The results showed that by increasing the thickness of angles in connection, the induced initial stiffness from post-tensioned strands decrease. Also by increasing the thickness of angles, energy dissipation of connections increases. By increasing the thickness of the angles bear the bending moment in beam, 4.5 to 13.8% increase. The β_1 value does not experience tangible changes with changes in angle thickness. And also values of the opening distance between beams and column (Δ_{gap}) in 4 models are near to 28.5 mm.

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