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CONSIDERING THE PERFORMANCE OF THE CONXL CONNECTION USING ADDED T-STUBS

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Abstract

Among the existing ideas to provide a column section, the box section accounted as a suitable idea for both gravity and lateral loading. Although the box-columns section pertains to a considerable advantage such as low slenderness ratio (increase the bucking strength) and post-buckling strength, and high ductility, providing continued plate for moment resisting frame is complicated. Accordingly, several ideas have been proposed to solve this problem, among them, the use of ConXL connection has better performance and more acceptance. In this paper, the ConXL connection and an idea to improve its performance were studied numerically and parametrically. Results indicated that all types of ConXL pertain to a suitable performance that has a capacity of more than 80% plastic moment of the beam and greater than the rotation of 0.04 rad. Moreover, adding a T-stub increases the energy dissipation and ultimate strength of the connection. This was noted that an unfilled column could be effectively utilized, provided that the thickness of the column is appropriately increased.

Keywords: ConXL; connections; steel; strength; MRF.

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1. Introduction

The design and implementation of steel connections are critical aspects of structural engineering, particularly in the construction of steel structures. Among the various connection types, ConXL steel connections have gained attention for their enhanced performance and efficiency. In Fig. 1, the schematic view of the connection is shown. The ConXL connection has attracted much attention because it is a standardized, cost-efficient, special moment biaxial connection for building applications. This connection comprises wide flange beams, concrete-filled square HSS or built-up columns, high-strength bolts, collar flange assembly, and collar corner assembly, and it has been pre-qualified and codified by the AISC-360-22 [1]. Utilizing the conventional beam-to-column connection for the MRF system, a lot of high-strength bolts are required because they are based on high-strength bolt friction bonding resistance. Ineffective in material cost (overplate, high-strength bolt), construction cost, and construction period. This shortcoming is complexly solved by the ConXL connection. This literature review explores the development, advantages, and applications of ConXL steel connections, highlighting key studies and findings in the field. ConXL steel connections are characterized by their innovative design that optimizes load transfer and structural integrity.

According to Smith and Jones [2] report, the development of ConXL connections stems from the need for more efficient and reliable connection methods in modern steel structures. They emphasize that traditional connection methods often lead to increased material usage and construction time, whereas ConXL connections promote a more streamlined approach. Wang et al. (2022) [3]

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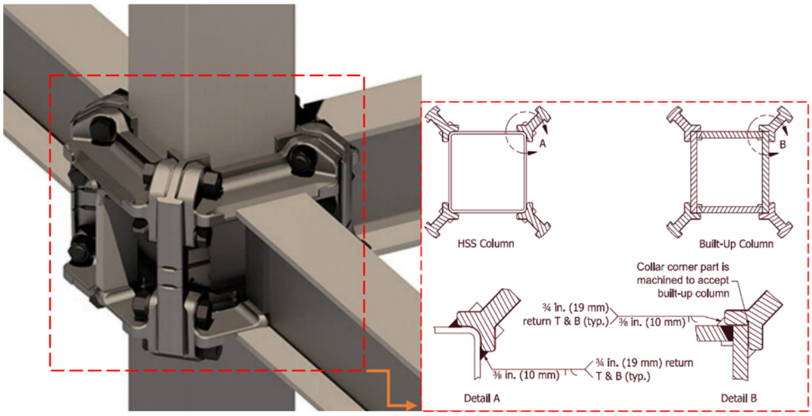


Figure 1. Column with attached collar corner assemblies [1]

conducted experimental tests on ConXL connections, demonstrating that they exhibit superior performance under both static and dynamic loads compared to conventional connections. The findings indicate that ConXL connections can reduce the risk of failure and enhance the overall safety of steel structures. Additionally, ConXL connections can lead to significant cost savings in construction. Johnson and Lee [4] analyzed the economic implications of using ConXL connections in high-rise buildings. Their research found that the integration of these connections not only reduced material costs but also minimized labor expenses due to faster assembly times. This efficiency is particularly beneficial in large-scale projects where time and budget constraints are critical. Nguyen and Tran [5] further support these findings by evaluating the performance of ConXL connections in seismic applications, demonstrating their resilience and effectiveness under dynamic loading conditions, which is crucial for ensuring safety in earthquake-prone areas. ConXL connections have been successfully implemented in various types of steel structures, including bridges, industrial facilities, and residential buildings. A case study by Patel [6] showcased the use of ConXL connections in a major bridge project, highlighting their effectiveness in enhancing load distribution and reducing stress concentrations. The study concluded that ConXL connections are a viable option for improving the longevity and durability of steel structures subjected to dynamic forces. Moreover, the adaptability of ConXL connections makes them suitable for retrofitting existing structures. Garcia [7] reported that the application of ConXL connections in retrofitting projects has shown promising results, allowing older buildings to meet modern safety standards without extensive reconstruction. This flexibility is particularly valuable in urban environments where preserving historical architecture is essential. Hernandez and Martinez [8] also emphasize the sustainability aspects of using ConXL connections in steel construction, highlighting their potential to reduce material waste and environmental impact, thus contributing to more sustainable building practices. In line with the research, O'Connor, [9] proposed a design Guideline for ConXL Steel Connections in High-Rise Buildings. After the report, the Impact of ConXL on Structural Performance was studied by Zhao [10] in good agreement with the Guidelines. Then, the capability of the connection was considered by Kim [11] based on the Finite Element (FE) approach. This connection also can be used in the retrofit aspect [12]. In summary, ConXL steel connections represent a significant advancement in the field of structural engineering, offering enhanced performance, cost efficiency, and adaptability for various applications. The literature highlights the benefits of these connections in improving the safety and longevity of steel structures while also addressing economic and sustainability considerations. As research continues to evolve, ConXL connections are likely to play an increasingly important role in the future of steel construction.

2. Proposed ConXL

Fig. 2 illustrates the proposed ConXL connection. Based on the figure, to make the proposed conXL, the T-stub is added to the top and bottom of the collar flange. So, by adding the T-stub, it is expected that a plastic hinge is formed at the end of the T-stub. It is suggested to use the thickness of the T-stub as the same as the flange beam thickness. Also, the length of the T-stub is determined as $S_1 = d/2$. Based on the AISC/ANSI 341-22 [1] the connections are designed based on the computed probable maximum moment, M_{pr}, and shear, V_h, at the location of the expected plastic hinge formation presented in Eqs. (1) and (2).

$$M_{pr} = C_{pr} R_y F_y Z_e \tag{1}$$

$$V_h = \frac{M_{pr}}{L_h} + V_{gravity} \tag{2}$$

where F_y is the specified minimum yield stress of the yielding element, Z_e is the effective plastic section modulus of the section at the location of the plastic hinge. Also, R_y and C_{pr} are defined as

$$R_y = \frac{F_u}{F_y} \tag{3}$$

$$C_{pr} = \frac{F_y + F_u}{2F_y} \tag{4}$$

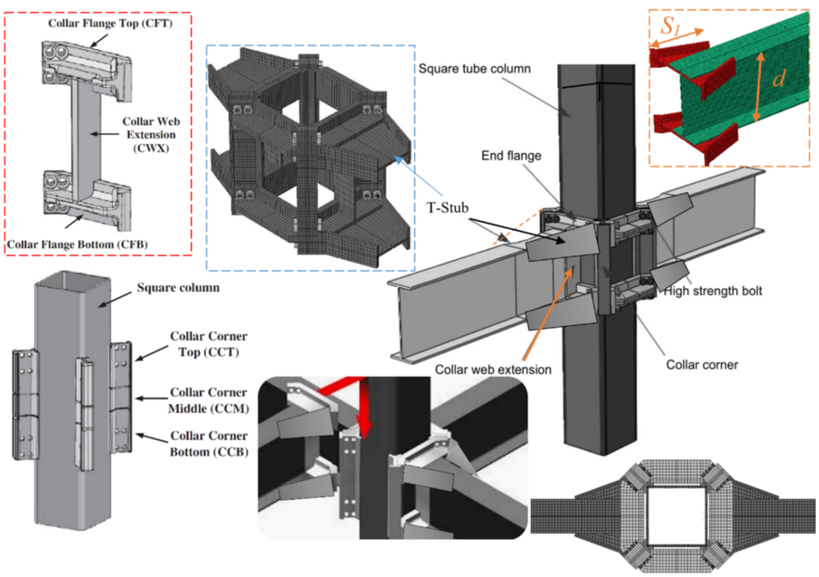


Figure 2. The proposed ConXL

3. Numerical study

3.1. Numerical models

To consider the behavior of the ConXL connection, a numerical study based on the finite element (FE) method was carried out. Accordingly, ABAQUS software was used for modeling the FE models.

To simulate the FE models, all parts of the FE models were simulated using Solid C3D20. Although shell elements (e.g., S4R) are generally recommended to reduce computational time since the solid element shows the stress on the thickness of the elements, the solid element was used. For the analysis of the FE models, the structural mesh type was used. Accordingly, mesh refinement process was used. All parts of FE models were designed based on the AISC/ANSI 341-22 [1].

The variable with expected impact on the system was considered that the variables are the effect of T-sub, columns properties (thinness and CFT column), RBS connection. Therefore, the section of $W24 \times 68$ was used for beams. Also, a box section of 406×406 mm was used for columns. Based on the defined variables, two different thicknesses of 12 mm and 20 mm for columns. For each model, the first part, C, represents the ConXL. The second and third letters stand for the model with (R) and without (NR) RBS; with (T) and (NT) without T-sub, respectively. Moreover, the numbers at the end of a name represent the columns' thickness. The A36 steel materials including yield stress of 240 MPa, ultimate stress of 370 MPa, and modulus of elasticity equal to 200 GPa were used. Also, bolts with high-strength steel including an ultimate strength of 590 MPa were used.

After the simulation of the FE models, they were analyzed (using the Static-General technique in ABAQUS) under boundary conditions as illustrated in Fig. 3. These boundary conditions were selected as the same as the experimental test used for verification of the FE results. Also, Fig. 4 illustrates the applied loading to the FE models.

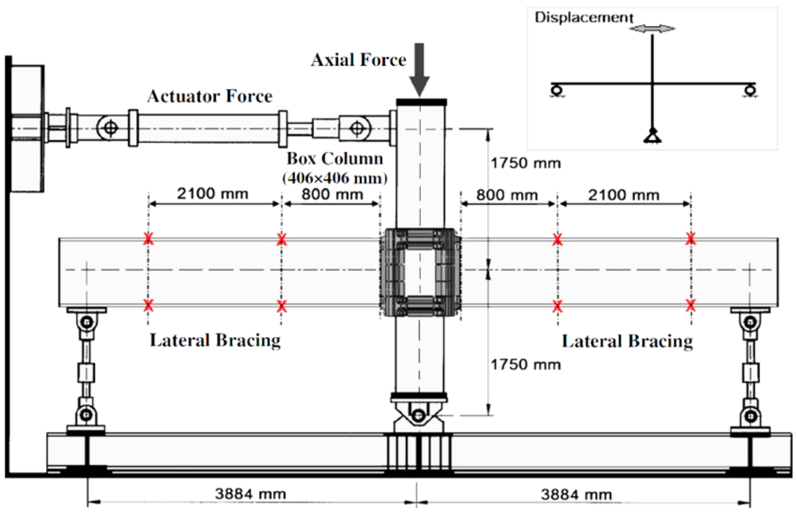


Figure 3. The boundary condition

3.2. Verification of the FE results

To verify the numerical results, an experimental test reported in Ref [12] was selected and simulated using the FE method. The material, boundary condition, and other required definitions were used as the same test. Subsequently, the test results and FE results are compared in Fig. 5. As realized in this figure, the two hysteretic curves are in good agreement. By achieving an acceptable error (less than 10%) in this modeling, other FE models will be considered with confidence in the accuracy of the results.

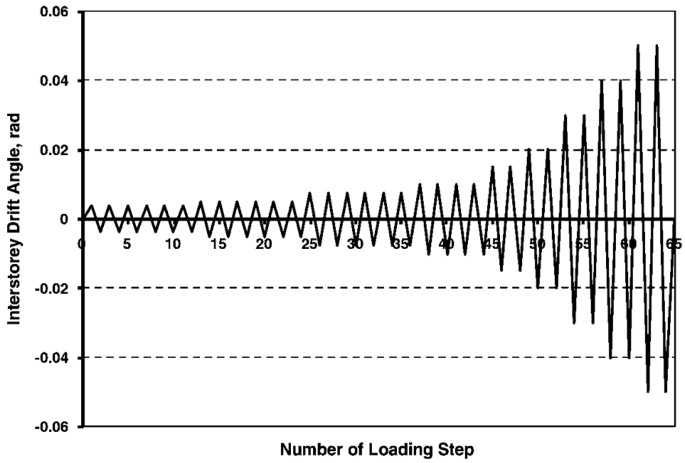


Figure 4. Cyclic loading diagram based on AISC 341-22 [1]

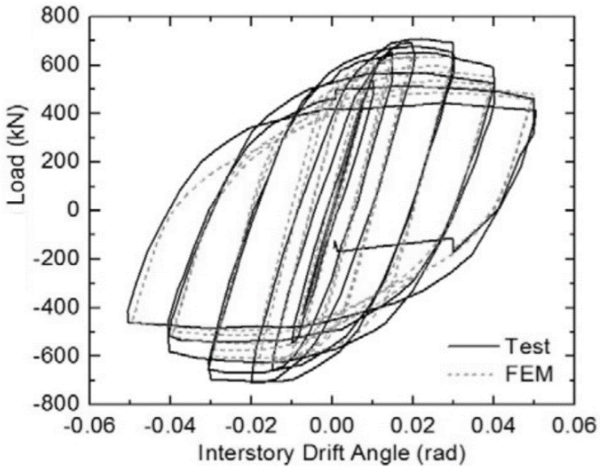


Figure 5. Comparing the FE results with the experimental test [12]

4. Discussion and results

4.1. Response curves

Fig. 6 illustrates the hysteresis curves of the FE models. This figure shows that all models pertain to stable hysteresis loops without degradation. The red dotted line in this figure represents the 0.8 Mp of the beam. All models have a moment capacity greater than 0.8Mp while rotation is 0.04 rad (or 4%). Accordingly, based on the AISC, all the connections have acceptable rotation capacities that are categorized as special moment resisting frames. Fig. 4 confirms that except model C-NR-NT-12.5, all types of elements pertain to a suitable plastic hinge formation on the beams outside of the connections as expected. So, it is expected that imposed seismic energy be adsorbed through the plastic hinge formed at the two ends of the beams. Comparing the results confirms that removing the RBS without any new consideration of the connection causes to increase in the stress on the panel zone as well as on the columns at the top and bottom of the ConXL connections. In this situation, adding T-stub increases the stress that yields the flanges of the columns whereas columns with increased thickness are used (C-NR-T-20), a suitable performance is observed. It should be noted the model CF-NR-T-12.5, C-NR-T-20, and CW-NR-T-20 reveals a similar performance in the case of suitable confined yielding (plastic hinge formation) on the beams.

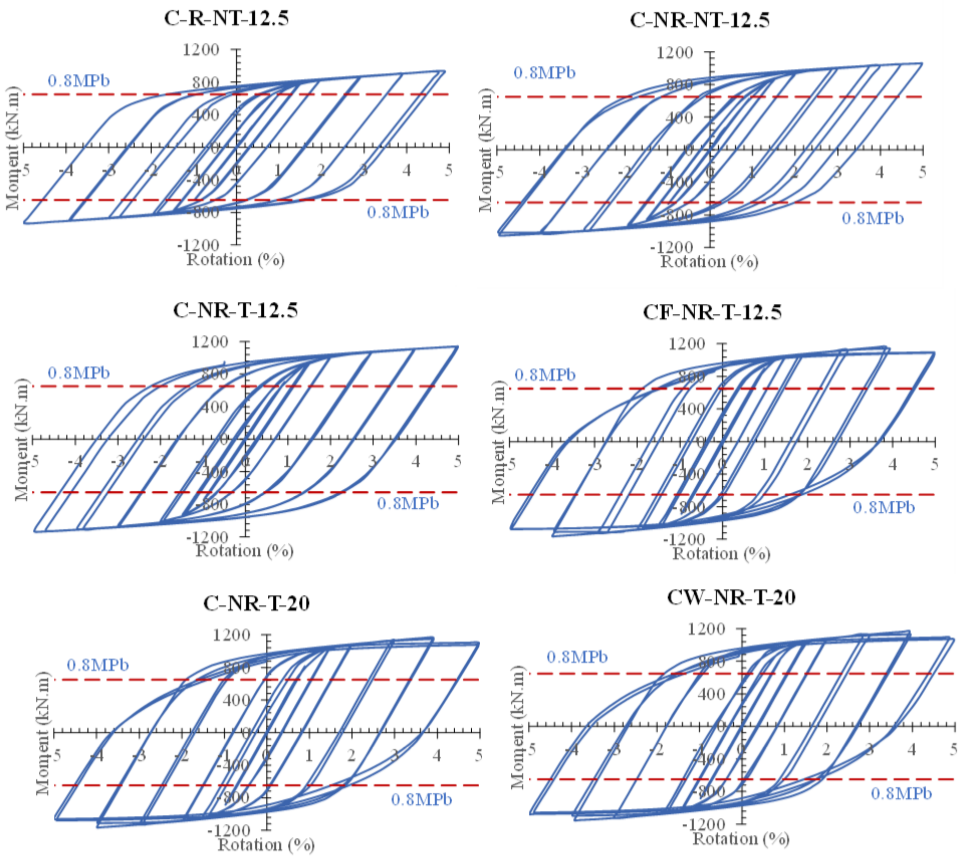


Figure 6. Hysteresis curves of the models

4.2. Energy dissipation

The energy dissipation (closed area of load-displacement hysteresis curve) is considered in Fig. 7. Energy dissipation of the system is started around the rotation of 0.7 rad (0.7%). Around the rotation of 0.03 rad the accumulated energy ratio is around 20% whereas between the rotation of 0.03 rad to 0.04 rad, this ratio reaches 80%. Comparing the results indicated the C-R-NT-12.5 has the lowest energy dissipation capacity and by changing the RBS to the conventional beam section, the energy dissipation is improved by 105. The noticeable finding is that energy dissipation improves by around 10% when the proposed connections are used. Also, the types of columns do not considerable effect

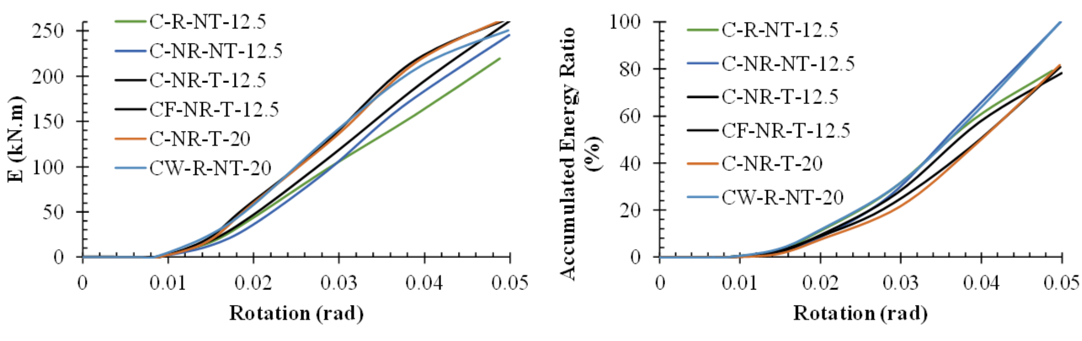


Figure 7. The energy dissipation of the models

on the energy dissipation capacity. But, when the collar web extension is connected to the columns, the energy dissipation as well as ductility is reduced. So, it is recommended to not connect between the collar web extension and columns for all types of ConXL connections.

4.3. Hinge formation

For consideration of the stress on the main elements of the models, the list elastic stiffness of the models is listed in the Table 1, the von Misses stress as represented by the yield stress of the separate elements is shown in Fig. 8. While the T-stub is used, the yielding is started at the end of the T-stub that is far from the efface of collars. By changing the RBS to the general beam, the stress of the beam shows an ignorable change. Despite the maximum stress of the columns is reached to 0.98Fy in both types of beams, the area of the stress 0.98Fy on the columns is increased. Also, the lows low-distributed zone of stress close to yielding on the columns is obtained in models CF-NR-T-12.5 and C-NR-T-20. Also, as the collar web extension is connected to the column (model CW-NT-T-20) does not considerable effect on the distribution of the stress on the columns. By adding the T-stub, the

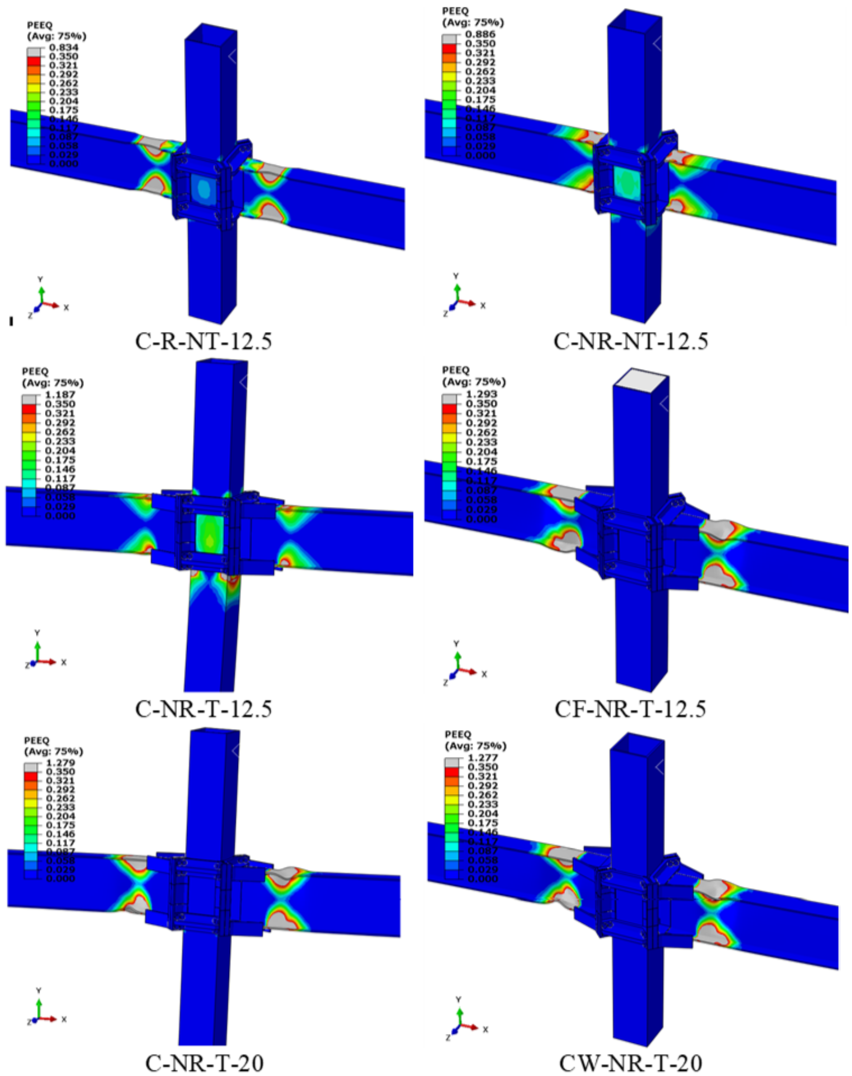
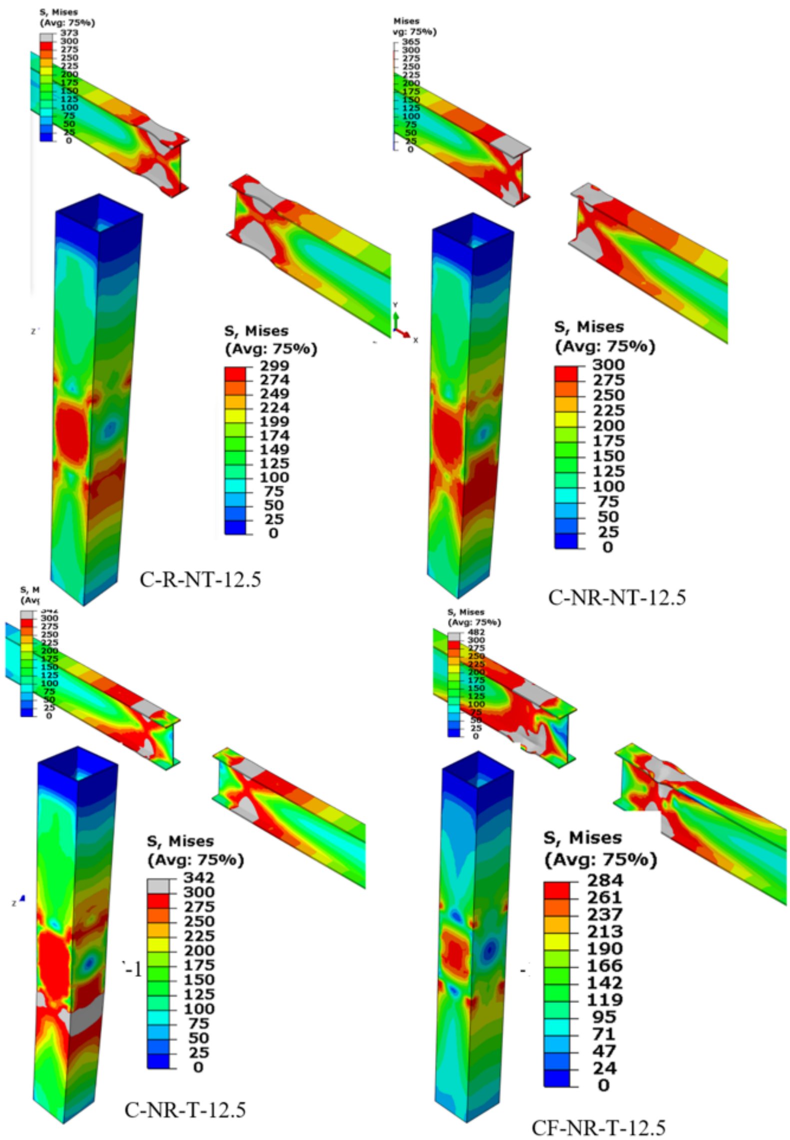


Figure 8. The hinges formation

yielding tends to start at the end of the T-stub. So, it acts as expected behavior as assumed. Therefore, the suggestions for the design of the T-stub are confirmed. Also, by connecting the web extension collar to the column, the stress on the column is increased which is not recommended to be used.

Table 1. The elastic stiffness of the models

Model	K (kN/mm)	Mu (kN.m)
C-R-NT-12.5	11.43	935.00
C-NR-NT-12.5	11.85	1059.54
C-NR-T-12.5	13.26	1141.58
CF-NR-T-12.5	15.35	1167.41
C-NR-T- 20	15.10	1166.78
CW-NR-T-20	15.12	1131.76



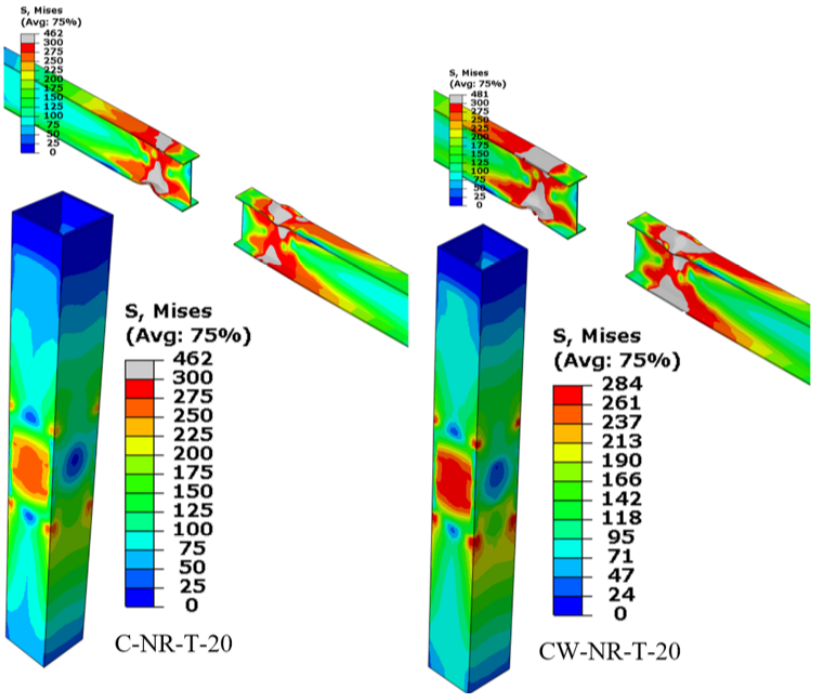


Figure 9. The yielding status of the main structural elements

A small yielding is seen around the hole of the bolts for all models and also on the collars of columns with thin thinness. But, by increasing the thickness of the columns, the stress of the collar is reduced as well. For the models with T-stub and thick columns, the collar is completely remaining elastic. Subsequently, they act as a reuse or replaced connection. The noticeable finding is that adding the T-stub cause to increase the stress of the bolts although all of the bolts experience stress lower than Fy.

In Fig. 9, the von Misses stress that represents the yielding of elements is shown. As illustrated in this figure, minimum stress occurred in column C-NR-T-20 without any hinge formation in columns. However, the column in model C-NR-T-20 is yielded so it confirms the finding in the previous sections that when the T-stub is added to the system, the thickness of the columns must be increased.

5. Conclusions

In this paper, the behavior of ConXL connection as a prequalified connection for moment resisting feme was investigated numerically and parametrically. Also, an innovative idea was proposed to improve the behavior of the conventional ConXL. Accordingly, the finding is summarized as follows:

- The hysteresis curves of the FE models confirmed that all models pertain to stable hysteresis loops without considerable degradation in stiffness and strength. All models pertain to a moment capacity greater than 0.8Mp while rotation is 0.04 rad (or 4%). Accordingly, based on the AISC, all the connections have acceptable rotation capacities that are categorized as special moment resisting frames.

- Comparing the state of plastic hinge formation was shown that except for model C-NR-NT-12.5, all types of elements pertain to a suitable plastic hinge formation on the beams outside of the connections as expected.

- Comparing the results confirms that removing the RBS without any new consideration of the connection causes to increase in the stress on the panel zone as well as on the columns at the top and bottom of the ConXL connections. In this situation, adding T-stub increases the stress that yields the flanges of the columns whereas columns with increased thickness are used (C-NR-T-20), a suitable performance is observed. It should be noted the model CF-NR-T-12.5, C-NR-T-20, and CW-NR-T-20 reveals a similar performance in the case of suitable confined yielding (plastic hinge formation) on the beams.

- Comparing the results indicated the C-R-NT-12.5 has the lowest energy dissipation capacity and by changing the RBS to the conventional beam section, the energy dissipation is improved by 105. The noticeable finding is that energy dissipation improves by around 10% when the proposed connections are used.

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