



FINITE ELEMENT MODELING OF T-STUB CONNECTIONS REINFORCED WITH THREADED BARS

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The objective of study relates to steel structures which are mostly using bolted end plate connections as pinned or rigid connections joints between structural members. With these form of connections the beam tension force is transferred, through the bolts, to the column. The prospective complexity is that the column may be not strong to develop the required force for satisfying strength and stability checks. A new mean of providing local column reinforcement, using a system of threaded bars, were analysed. A finite element analysis of eight t-stub connection were undertaken in order to check the behaviour of connections reinforced in that manner. A finite element code ABAQUS was used to develop the various connections models. A finite element representing un-reinforced end plate connection was validated against an experimental test data by comparing force-displacement curves of both finite element model and test data. Adjustments were done on the finite element model to reflect test experimental data curve. To the un-reinforced finite element model, different non welded stiffeners such as backing plate, channel reinforcement to threaded bars etc. were added to improve connection strength. Connection strength improvements in order of 231% were observed when the model threaded bars compared to the un-reinforced model and 251% when using threaded bars with channels.

Introduction

Bolted connections are primarily used to connect a beam to a column or to splice two beams together, they are also used to transfer the forces supported by a structural member to other parts of a structure or to the supports. End plate connections are increasingly used as moment resistant connections in steel structures because of their simple fabrication techniques and speedy site erections. The end plate connections consist of a plate welded in the fabrication shop to the end of the beam, the plate is predrilled and then bolted at the site in the column flange using rows of high strength bolts. For this connection type, the tension zone is formed by the deformation of the column flange and end plate under tension and elongation of bolts, this zone can be represented using a T-stub model. Although simple in their use, bolted endplates are extremely complex in their analysis and behavior. The most accurate method of analysis is of course, to fabricate full scale connections and test these to destruction, which requires a wide range of experimental studies. Unfortunately this is time consuming and expensive to undertake. On the other hand, conducting experiments is a compulsion for the research to progress. The problem gets enormously simplified with the use of a general purpose finite element analysis programs such ABAQUS and ANSYS.....etc. ABAQUS has several features which are readily applicable to the problem of connection characterization.

Statement of problem

The column flange thickness necessary to resist the force from the bolts frequently conducted to a column section heavier than would be required to satisfy strength and stability checks. So as to reduce the column section, the column flange is usually reinforced by a plate welded between opposing column flanges at beam tension flange level. Conventional welded plate stiffening is difficult

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to fabricate by automatic processes and is particularly expensive when used on site. A more recently suggested form of reinforcement consists of backing plates in form of channel which have been investigated by different researches. This paper present another mean of providing local column reinforcement by using a system of threaded bars locked against inner flange faces of the column in tension zones of bolted end plate moment connections. The t-stub to column connections was the focus of this research. The ABAQUS finite element program was used to model the connections. The dimensions of the validation connection were the same as the dimensions of the model tested in the laboratory by Sethi [11]. The finite element results were compared to the laboratory test results. A series of nine tests were undertaken based on that test to investigate the use of threaded bars on overall behaviour of a connection.

Finite element modeling

Structural idealization of the tension zone

To investigate the behavior of the tension zone of beam to column connection as shown in the next figure, the column flange and the end plate can be considered to act as an equivalent t-stub with an effective length.

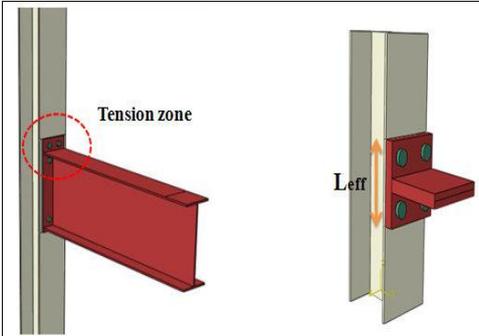


Figure 1: representation for tension zone of end plate moment connections.

Type of element

All the parts were modeled using C3D8R witch refer to continuum three dimensional 8-noded brick element with reduced order integration. This element has three degrees of freedom at each node. The solid (or continuum) elements in Abaqus can be used for linear analysis and for complex nonlinear analyses involving contact, plasticity, and large deformations. Reduced integration reduces running time, especially in three dimensions.

Materiel properties

The material properties for the various components of the numerical tests are presented in table 1 and 2.

Table 1: Column and t-stub material proprieties.

	column		T-stub	
	flange	web	flange	web
Yield stress B (N/mm ²)	319	326	260	240
Young's Modulus E (N/mm ²)	205*10 ³	205*10 ³	205*10 ³	205*10 ³

Table 2: Stiffeners and bolts material properties.

	Yield stress (N/mm ²)	Ultimate stress (N/mm ²)	Young's modulus (N/mm ²)	Poisson ratio
S355	355	550	205*10 ³	0.3
M20	640	800	205*10 ³	0.3

Contact modelling and boundary condition

Small sliding surface-to-surface contact was considered for all the contacts in the connection. Frictional contact using penalty stiffness formulation was considered for the tangential contact between the end-plate to and the column flange whereas the tangential contact between the bolt hole and the bolt shank is considered to be frictionless. The normal contact was considered as hard using augmented Lagrange formulation. Tie constraint is used for the connection of bolt head/nut to the t-stub/column. Master surfaces represent the surfaces of column and beam flanges, bolt head, bolt shank, whereas the surfaces interacting master surfaces are defined as slave surfaces. Both the ends of the column are fully restrained.

Steps of modelling

A series of nine t-stub end plate connections are undertaken. To achieve the objectives of this work, the modeling of these tests were divided into two steps.

First series of tests

For this step three aims were to be met the first is to develop a finite element model identified test V1, based on the specimen test of the experimental study presented by Sethi []; then to find a force-displacement curve characteristics and mode of failure for the finite element model; lastly is to validate the finite element model by comparing the results to the experiment test.

Second series of tests

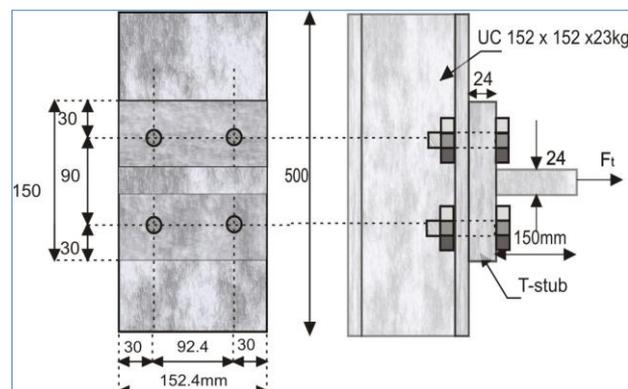
These tests are a combination of a reference test T1 and different element of reinforcement added as shown in table 3.

Table 3: Second series tests list.

Test identification	Stiffening element
T1	Without
T2	Welded plates
T3	Backing plates
T4	Channels
T5	Threaded bars
T6	Threaded bars + Welded plate
T7	Threaded bars + Backing plate
T8	Threaded bars + Channels

Dimensions and geometry of the models

For all the tests, the size of the column used is UC 152×152×23 kg where its dimensions are illustrated in next figures. The thickness of the t-stub is 24 mm. The flange of the t-stub is bolted to the flange of the column by two rows of high strength bolts, two bolts by row. The size of the bolts is M20 grade 8.8.



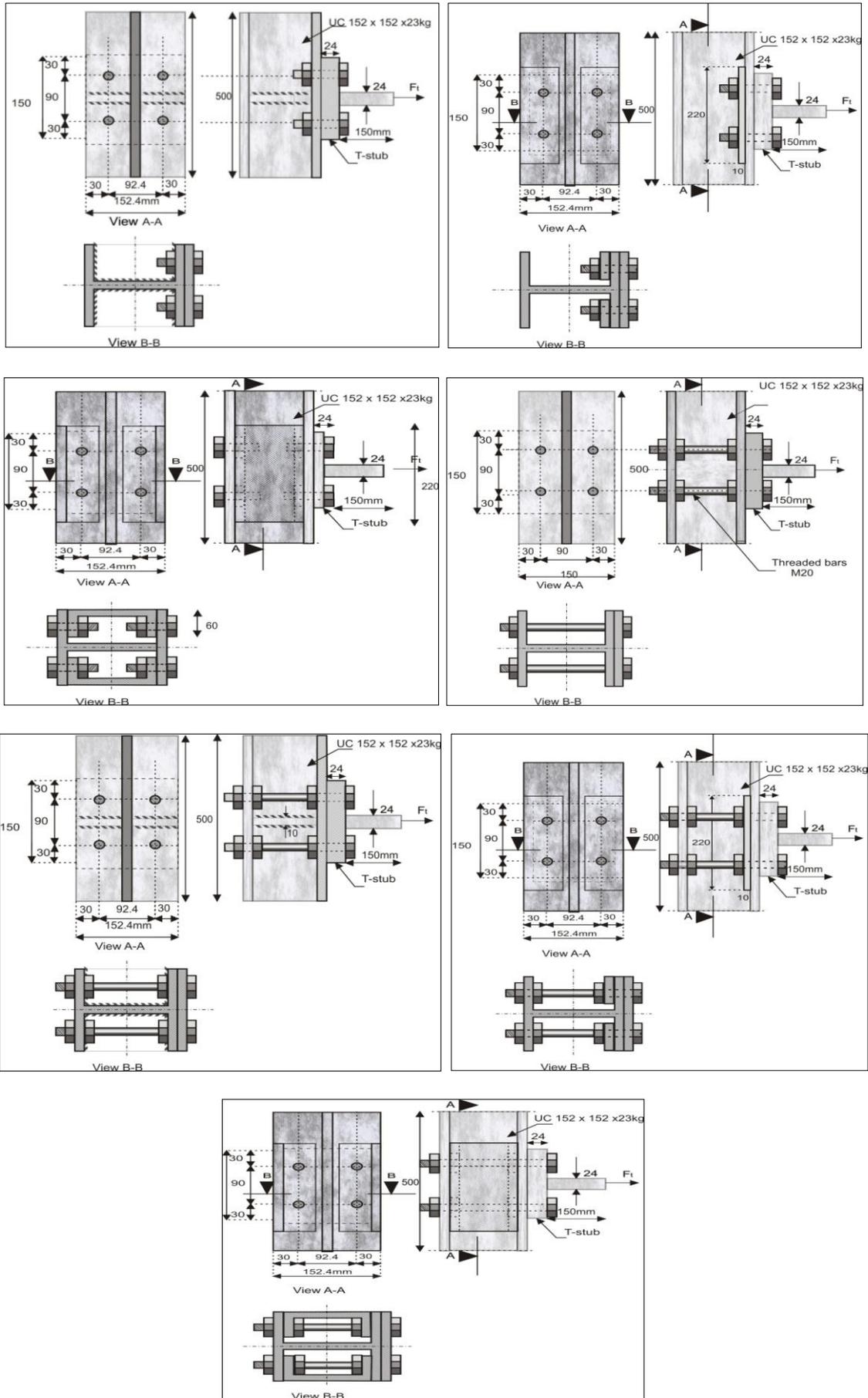


Figure 2: Typical geometry for tests T1 to T8 respectively.

Results discussion and comparisons

Comparison between the experimental test and ABAQUS (First series of tests)

Figure 3 shows non-linear response curve obtained from the laboratory compared with the load-displacement curve obtained from ABAQUS. It is apparent that the performance of the FE model was found to be in close agreement with the experimental test. The trends of both the curves are similar although there was some difference in the initial elastic stage; the experimental test has lower displacement than the finite element model at the same load, which signifies that FE model is less stiffer than the experimental test. This may be the results of an inexactitude of the input materials properties and boundary conditions for the model.

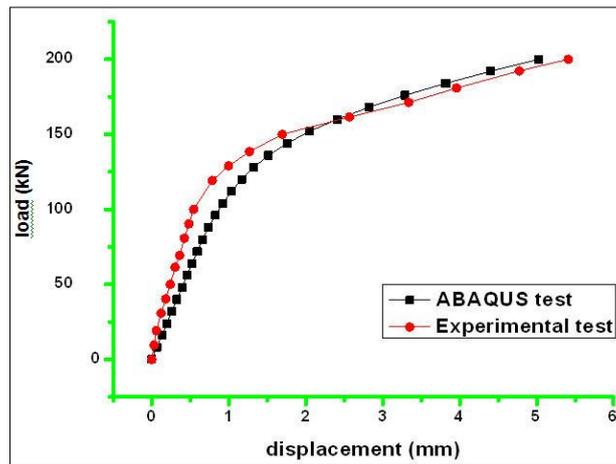


Figure 3: Load-Displacement curve for the test V1 and the test of Sethi [11].

Comparisons on the second series tests

The deformed shapes of the finite element models and the relationship load versus displacement for the models T1 to T8 are presented in the next figures.

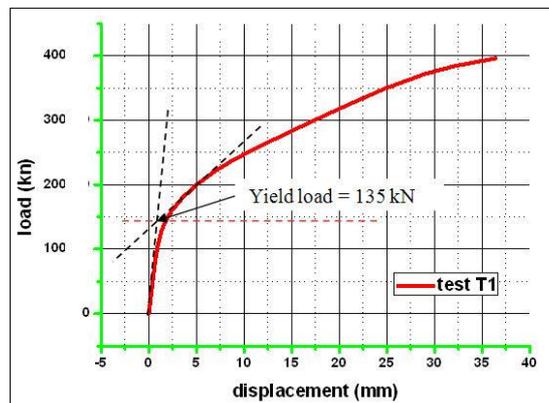


Figure 4: Load-Displacement plot for the numerical test T1.

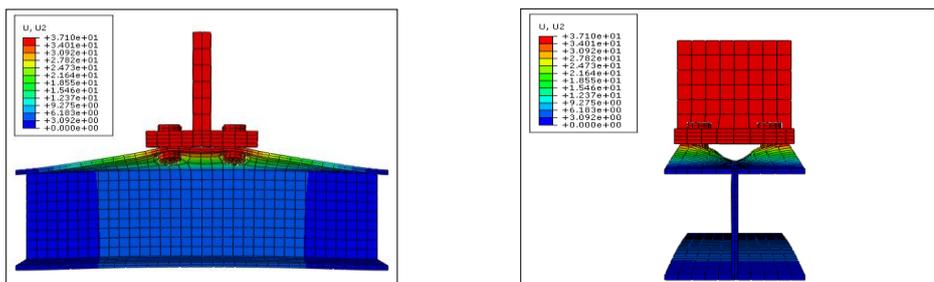


Figure 5 : Deformed shape for the numerical test T1.

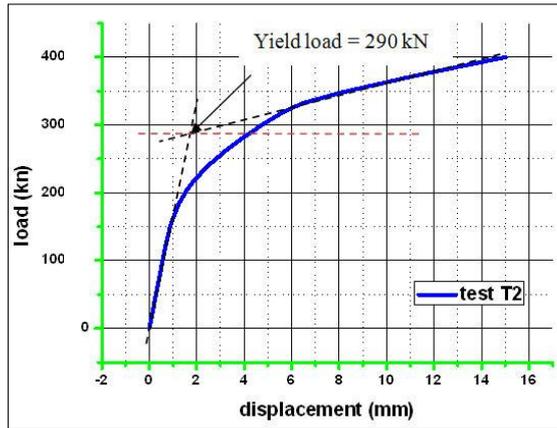


Figure 6: Load-Displacement plot for the numerical test T2.

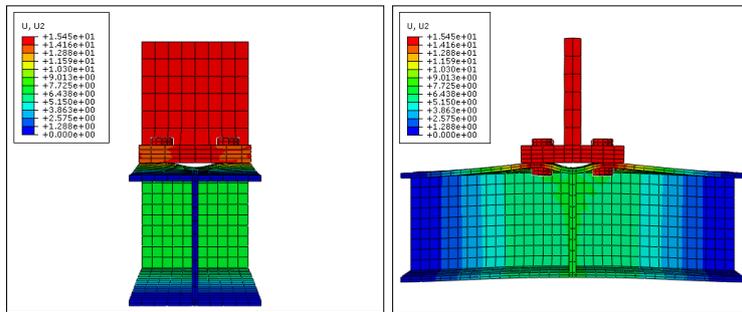


Figure 7 : Deformed shape for the numerical test T2.

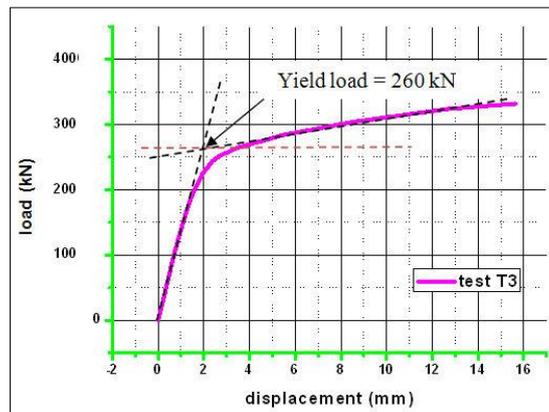


Figure 8: Load-Displacement plot for the numerical test T3.

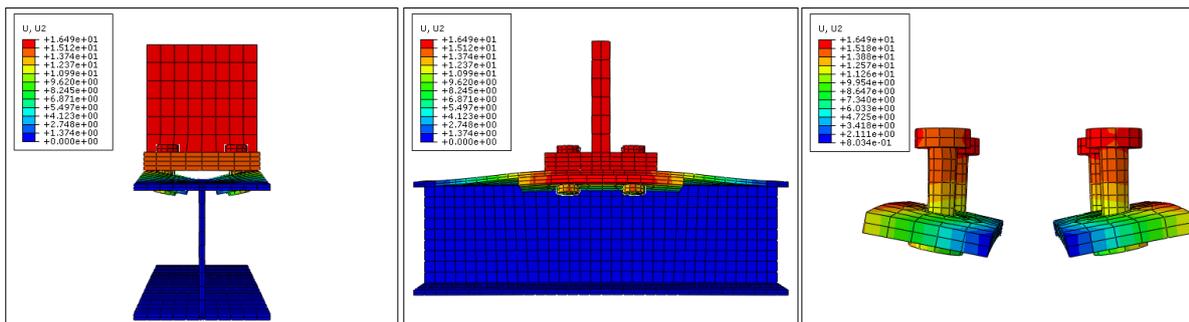


Figure 9 : Deformed shape for the numerical test T3.

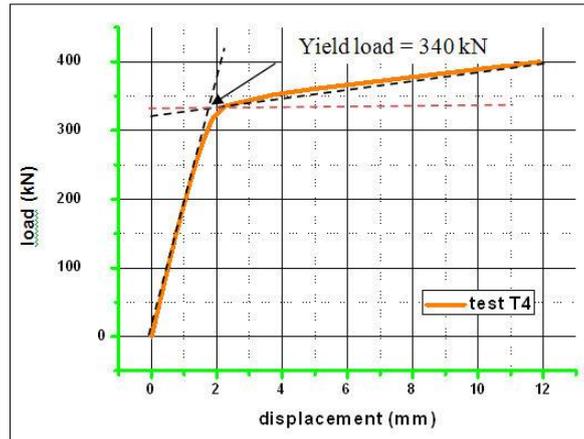


Figure 10: Load-Displacement plot for the numerical test T4.

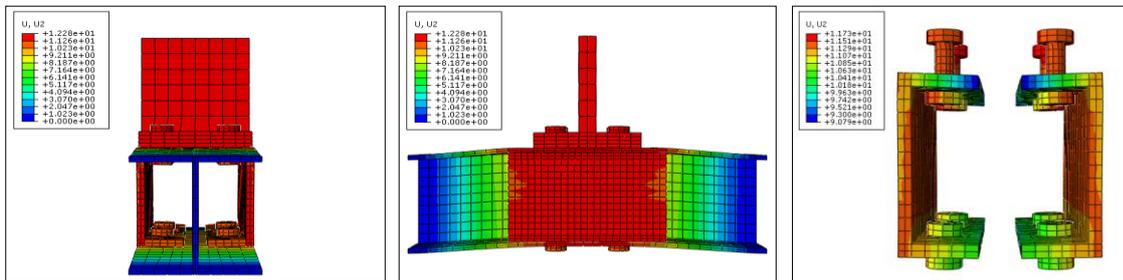


Figure 11 : Deformed shape for the numerical test T4.

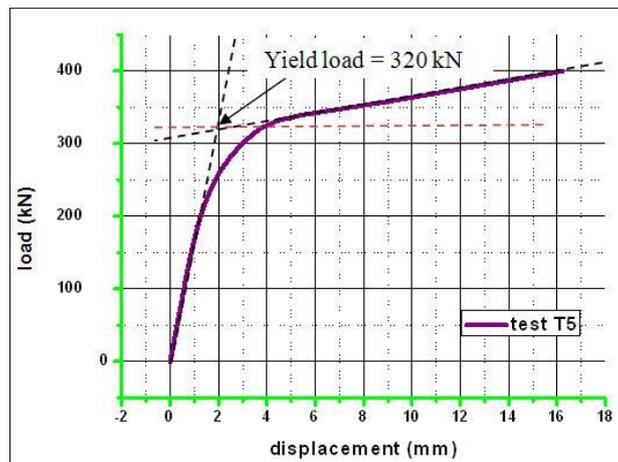


Figure 12: Load-Displacement plot for the numerical test T5.

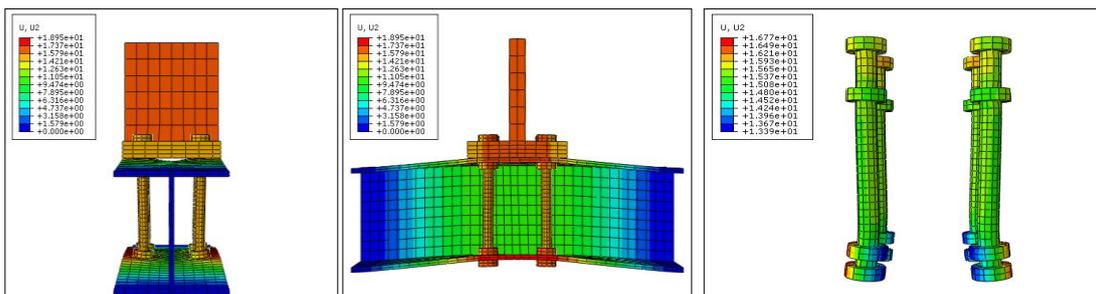


Figure 13 : Deformed shape for the numerical test T5.

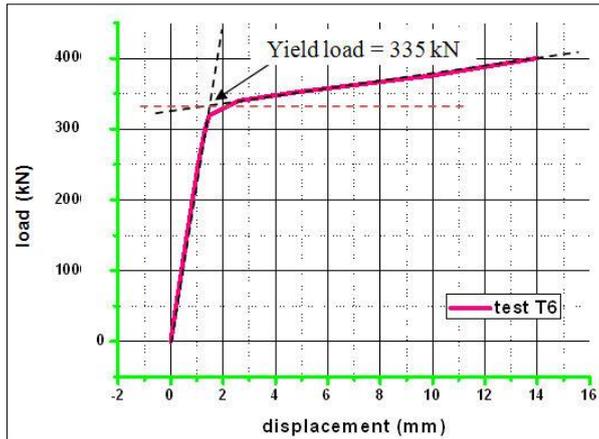


Figure 14: Load-Displacement plot for the numerical test T6.

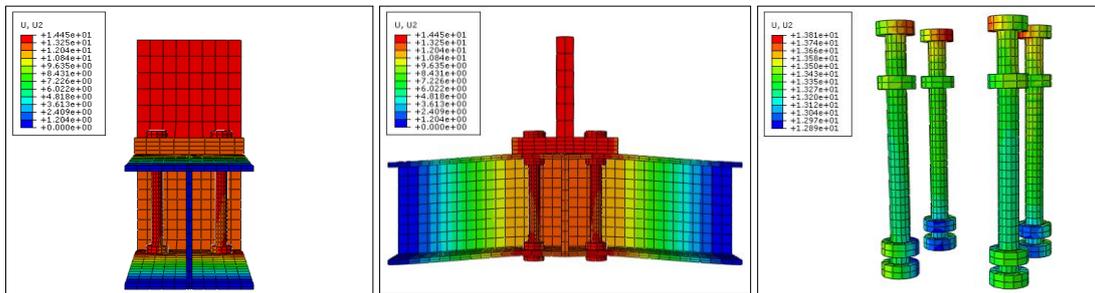


Figure 15 : Deformed shape for the numerical test T6.

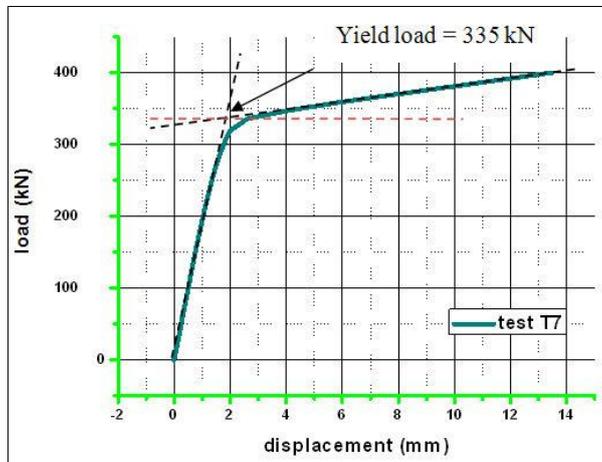


Figure 16: Load-Displacement plot for the numerical test T7.

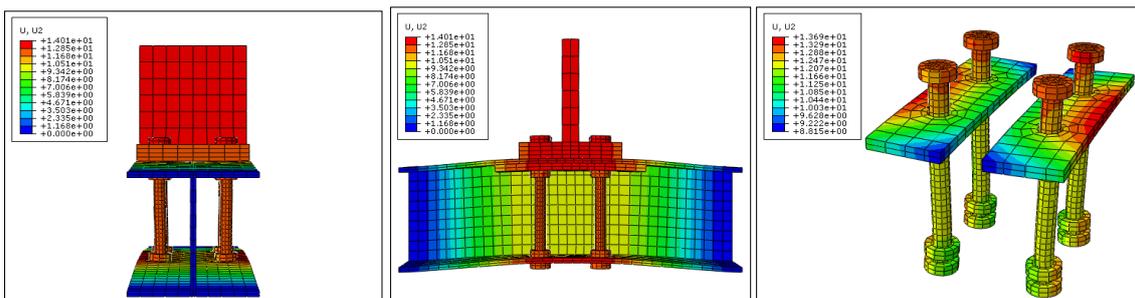


Figure 17 : Deformed shape for the numerical test T7.

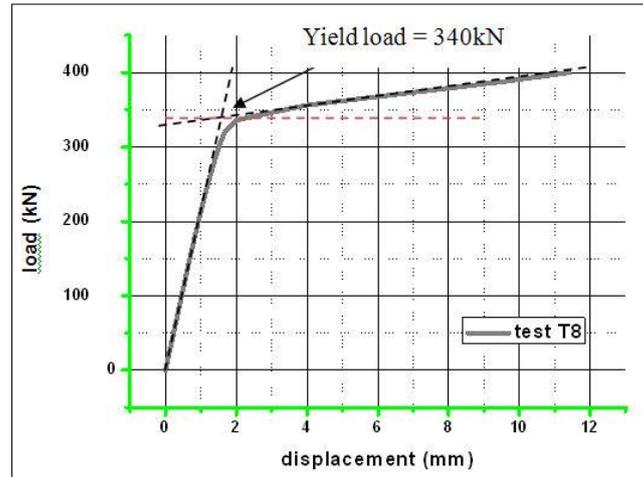


Figure 18: Load-Displacement plot for the numerical test T8.

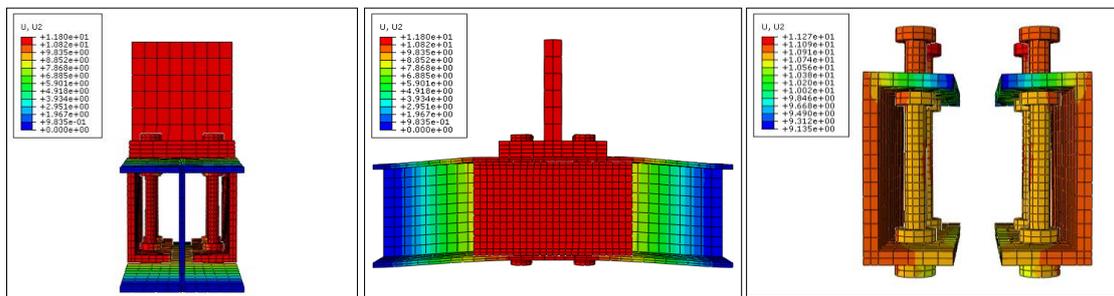


Figure 19 : Deformed shape for the numerical test T8.

From the graphs illustrated earlier, it can be observed that all the tests respond in the same way with increasing loads and have two dissimilar regions. At the beginning the curves are linear and while the load attain to a certain point become non-linear which give an idea that initially the connections behave elastically and when they achieve a resistance load the connection gradually lost stiffness and act as plastic.

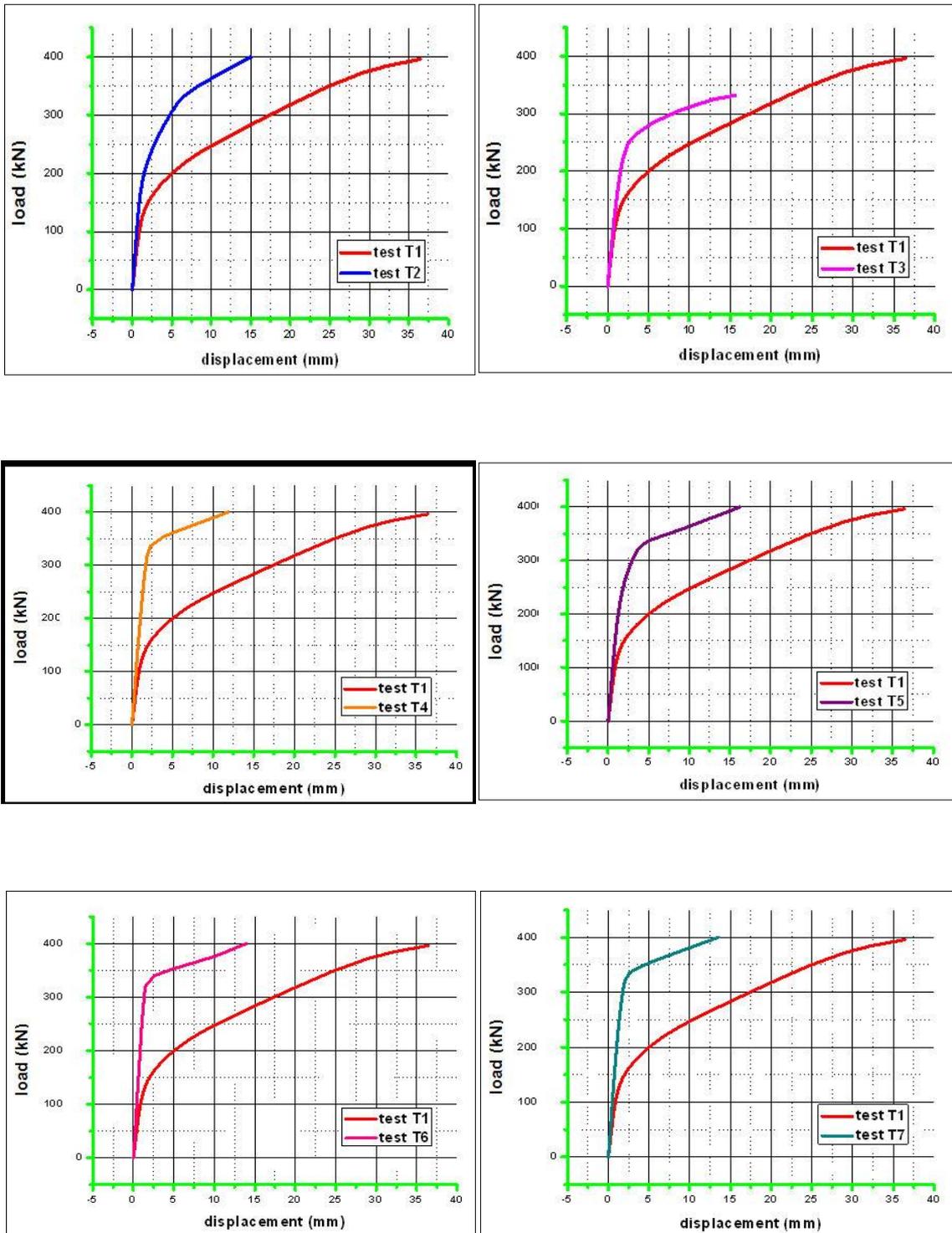
The resistance load, called also the yield load, is the minimal value of the applied traction force on which the plastic hinges start to produce ; its value can be obtained by the intersection of the tangent lines traced on both linear and non-linear ranges as shown in the previous figures. The results obtained are summarized in the next table.

Table 4: The connections resistance load.

Identification Test	Yield load (Kn)	Reinforcement element
Test T1	135	Without
Test T2	290	Welded plates
Test T3	260	Backing plates
Test T4	340	Channels
Test T5	320	Threaded bars
Test T6	335	Threaded bars + welded plates
Test T7	335	Threaded bars + backing plates
Test T8	340	Threaded bars + Channels

Comparison on the reinforced tests against the un-reinforced test

The numerical results comparisons can be exposed in the figure 20. Of the results examination, it seems to be reasonable to say that in term of the overall behavior, the load displacement curves were affected by the employing of the stiffeners. By increasing in the load the deformation capacity reduces for all stiffened connections. The initial stiffness increase. A remarkable improvement in the strength is necessary to cite and it is practically the same for the tests T4, T6, T7, T8.



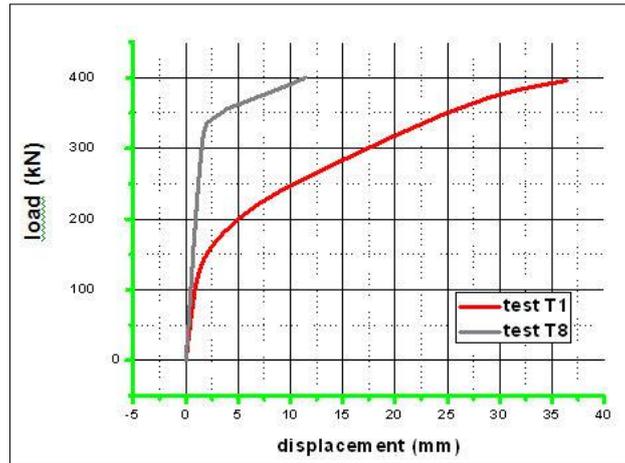


Figure 20: Comparison on the reinforced tests against the un-reinforced test.

Comparison on the threaded bars stiffened tests

Numerical tests T2,T5,T6

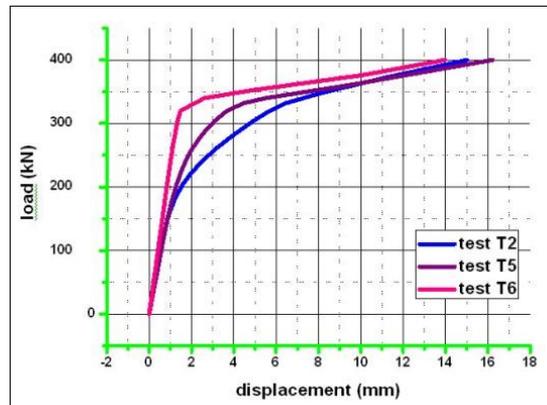


Figure 21: Load-displacement comparison for the numerical tests T2,T5,T6.

It is apparent from the figure that the using of the threaded bars and the welded plate together yields to more stiffer and strengthened connection. The improvement of the strength is 17.24 % compared to the test T2 and 6.25% compared to the test T5. The behaviour of the the test T2 and T5 is identical in term of stiffness, the difference arises in the strength . A negligeble difference in the deformation capacity is also observed for the three tests.

Numerical tests T3,T5,T7

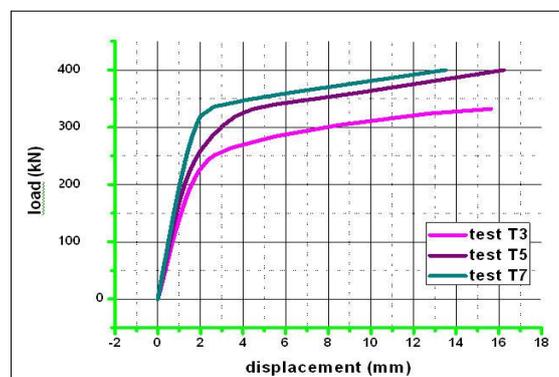


Figure 22: Load-displacement comparison for the numerical tests T3,T5,T7.

The tests clearly yield different responses. The comparison between the load-displacement curves of the connections shows that test T7 is stiffer than the test T5, which is by itself more stiffer than the test T3. Although the maximum applied load for the test T3 is 320 kN, but it is shown from the trend of the curve that the deformation capacity of the connections was reduced significantly from the test T3 to T7. It should be also noted that the resistance load of the test T7 is higher than both the other tests.

Numerical tests T4,T5,T8

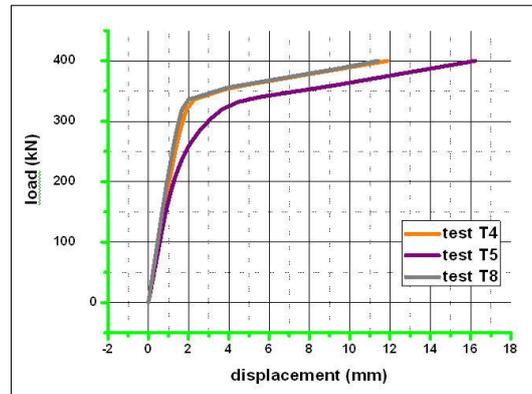


Figure 23: Load-displacement comparison for the numerical tests T2,T5,T6.

The numerical results plotted by the test T4 and those plotted by the test T8 are extremely coincident and they are similar in term of stiffness, strength and deformation capacity. Although the test T5 is less stiffer than both the tests T4 and T8 but it is still has the higher deformation capacity. The percentage of difference for the strength of the test T5 against the tests T4 and T8 is in order of 6.25%.

Conclusion

A series of nine t-stubs to column connections are studied in order to analyse the behavior of threaded bars in tension zone.

A t-stub to column connection experimentally tested by Sethi [] was undertaken .The experimental behaviour was compared with built up finite element model.

A finite element connection model was successfully constructed using the C3D8R element type

The load-displacement curve plotted from ABAQUS analysis results had shown a similar trend as that of the experimental load-displacement curve.

The different element of reinforcement added for the second series of tests were improved the strength and the stiffness of the connections but decrease the deformation capacity.

Resistance improvement was shown if using the threaded bars and the welded plate together and it was more important than using the welded plate alone. The same remark was noted for the use of the threaded bars and the backing plate together.

For the test T8, it wasn't useful to apply the threaded bars and the channels together because using these two reinforcement element didn't bring any improvement in term of overall behavior of the connection.

Finite element analysis can be used as analysis tool to predict the nonlinear behaviour of t-stub to column connections, it can also provide advantages in terms of time and expense over full scale tests.

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