Numerical investigation of effective parameters on behavior of concrete-filled steel tubular gusset plate connections

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ABSTRACT

Concrete-filled steel tubular (CFST) gusset plate connection is a commonly used method in which the plates are welded directly to the columns. Due to the importance of stress distribution and energy absorption capacity on the behavior of the mentioned connections, in the present study, numerical analysis of the behavior of these connections under different loadings has been investigated. The studied variables include the thickness of the gusset plate, the compressive strength of the concrete, the D/t (diameter to thickness) ratio of CFST, and the type of loading. The results show that although filling hollow tubular sections with concrete prevents the local buckling of the steel wall, the use of concrete with higher compressive strength does not always lead to increased load capacity and energy absorption, so that in many of the studied models, the energy absorption capacity decreases by 18% to 30%. On the other hand, the results showed that the diameter-to-thickness ratio has a significant effect on the energy absorption capacity of the simulated connections, so that with increasing this ratio, the energy absorption capacity has decreased in the range of 76% to 91%. Also, the loading condition is effective in the load-bearing capacity and the energy absorption of the structure. So that in the case of eccentric tension and in-plane bending, the energy absorption capacity is reduced by 53% and 86%, respectively, compared to axial tension loading.

KEYWORDS

Concrete-filled steel tube (CFST), Gusset plate, Finite Element Method, Failure

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1. Introduction

Nowadays, the use of Concrete Filled Steel Tubular Sections (CFST) has received much attention due to their performance in improving the behavior of the structure. This is due to the efficiency of the concrete in the steel profiles, which significantly increases the local buckling strength of the thin-walled hollow sections. One of the influencing factors affecting the behavior of CFST columns is the behavior of the brace connections to these members. Extensive research has been done in this field, and it has been shown that the CFST profile can increase connection strength under compression or tension loading by bracing [1-3].

According to the previous investigations and the lack of design criteria for the CFST-to-gusset plate connection, in this investigation, the parameters affecting the behavior of these connections are investigated using finite element modeling. The variables studied include the thickness of the gusset plate, the compressive strength of the concrete, and the diameter-to-thickness ratio of the CFST. According to these variables, 12 finite element models are simulated and analyzed under axial tension loads. To investigate the influence of the type of loading, the next step is to select the best connection from the point of view of energy absorption and to examine its behavior under eccentric tension and in-plane bending again.

2. Methodology

The modeling is performed in ABAQUS finite element software using the C3D8R element, and a non-linear static method is used for analysis. The load is applied gradually to the models (displacement control) with a time step of 0.10 seconds until the failure. The specifications of steel and concrete members are shown in Table 1 and Table 2, respectively.

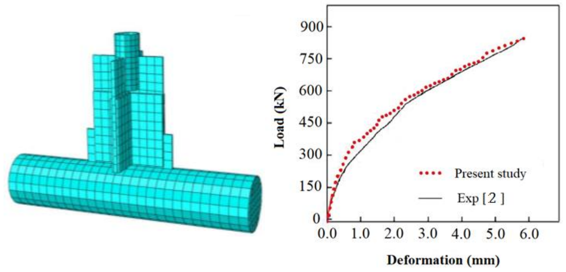
Table 1. Mechanical properties of T-300-4AX in Xu et al. research [2].

Member	Thickness (mm)	F_y (MPa)	F_u (MPa)	E (MPa)	ε_u (%)
Column	4	269	385	2.04e5	32.6
Brace	6	330	485	1.99e5	34
Gusset plate	12	405	505	2.04e5	34.9

Poisson's ratio and concrete density are selected as 0.2 and 2400 $^{kg}/_{m^3}$, respectively. The concrete damaged plasticity model (CDP) has been used to define this material. To model the steel-concrete interaction, surface-to-surface contact is created with tangential behavior (using the penalty method) and normal behavior with friction coefficients of 0.25 and 0.5, respectively. In the present study, the numerical results have been verified with the results of the T-300-4AX sample in the experimental study conducted by Xu et al. [2], as shown in Fig. 1-(a).

Table 2. Specifications of concrete material introduced to the software.

Dilation Angle	Eccentricity	Fb0/Fc0	K	Viscosity Parameter
30.5	0.1	1.16	0.666	0.001



(a) **(b)**

Fig. 1. Model verification; (a) Meshing the studied model, (b) Comparison of load-deformation curves obtained from experimental and numerical works..

According to the load-displacement curve shown in Fig.1-(b), it can be seen that there is an acceptable agreement between the numerical modeling and the experimental results. In the following, a parametric study is carried out to investigate the influencing factors on the connection behavior of the CFST column to the gusset plate connection. The investigated models have been presented in Table 3.

Table 3. Introducing the models investigated in the present study.

Model	D/t	Compressive strength of concrete (MPa)	Gusset plate's thickness (mm)
Dt50 f40 t11	50	40	11
Dt50 f40 t14		40	14
Dt50 f45 t11		45	11
Dt50 f45 t14		45	14
Dt50 f50 t11		50	11
Dt50 f50 t14		50	14
Dt70 f40 t11	70	40	11
Dt70 f40 t14		40	14
Dt70 f45 t11		45	11
Dt70 f45 t14		45	14
Dt70 f50 t11		50	11
Dt70 f50 t14		50	14

3. Discussion and Results

According to the results, it can be seen that in all the models examined in this study, the cracks are initially created between the end of the gusset plate and the tube wall. After increasing the load, when this reaches 85 to 90% of the ultimate strength, a yield line appears on the tube and around the connection to the gusset plate, and finally, a sudden failure occurs with the formation of rupture cracks along the gusset plate.

By examining the von Mises stress contours, it can be said that, generally, for the models under axial tension, the failure occurred due to the steel tube punch shear and appears as a rupture of the steel tube along the connection with the gusset plate. Of course, in the models with a D/t ratio equal to 70 (e.g., Fig. 2), the rupture is mainly concentrated at the two ends of the gusset plate, while the middle parts experience less stress. Also, for the models with a D/t ratio equal to 50 (e.g., Fig. 3), in addition to yielding at the connection point of the gusset plate with the steel tube, the yielding effects on the steel tube (along the endpoints of the gusset plate) are observed.

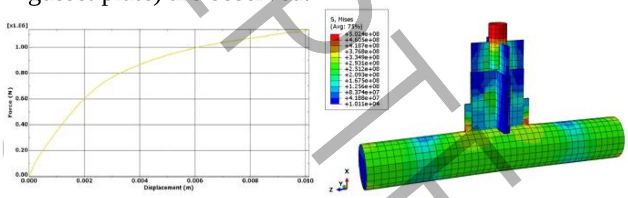


Fig. 2. Results of Dt70 f40 t11 model.

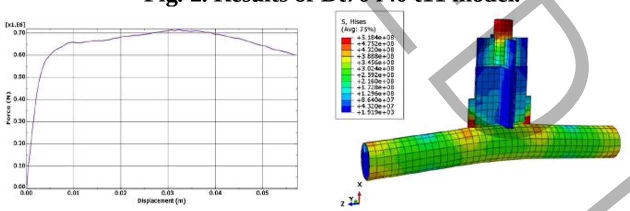


Fig. 3. Results of Dt50 f40 t14 model.

In the following, a comparison is made between different models according to the amount of energy absorption of the CFST column to the gusset plate connection.

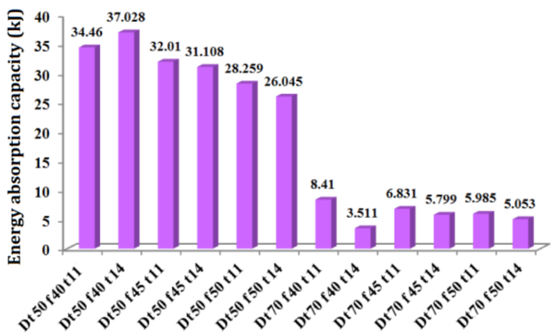


Fig. 4. The energy absorption results in the studied models.

As can be seen in Fig. 4, among the 12 finite element models of the CSFT to the gusset plate connection that have been subjected to axial tension, in the case where the thickness of the gusset plate is 14 mm, the compressive strength of concrete is 40 MPa and the D/t ratio is equal to 50 (model Dt50 f40 t14), the energy absorption capacity has increased compared to other cases. This amount is more than ten times the energy absorption in the weakest model, in which the thickness of the connecting plate is 14 mm, the compressive strength of concrete is 40 MPa, and the D/t is 70 (model Dt70 f40 t14).

Due to the possibility of creating unexpected loads, it is necessary to study the behavior of the investigated models under eccentric tension and in-plane bending. For this reason, the model Dt50 f40 t14, which has the best behavior in terms of energy absorption capacity, is subjected to the mentioned loads and analyzed. In the case of eccentric tension loading and in-plane bending, the energy absorption capacity has decreased by 53% and 86%, respectively, compared to axial tensile loading. According to the obtained values in Fig. 5, it can be concluded that how to apply the load affects the energy absorption capacity of the CSFT to gusset plate connection.

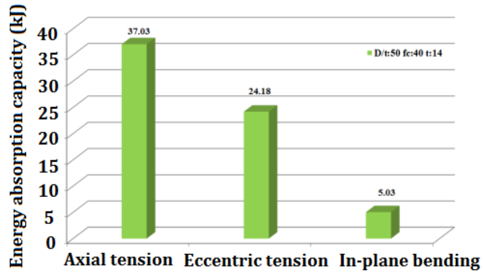


Fig. 5. Comparison of the effects of different loadings on the connection behavior in the studied CSFT columns.

4. Conclusions

The most important results of the research are briefly stated as follows:

- Changing the thickness of the gusset plate has a more considerable effect on the energy absorption capacity of models with a diameter-to-thickness ratio of 70.
- Using concrete with higher compressive strength does not always increase the load-bearing capacity and energy absorption. However, filling tube sections with concrete postpones the local buckling of the steel wall.
- The diameter-to-thickness ratio is the most important compared to other investigated parameters, and with the increase of this ratio, the energy absorption capacity has decreased significantly.

5. References

[1] R. Feng, B. Young, Behaviour of concrete-filled stainless steel tubular X-joints subjected to compression, Thin-Walled Structures, 47(4) (2009) 365-374.

[2] F. Xu, J. Chen, W.-l. Jin, Experimental investigation of concrete-filled steel tubular longitudinal gusset plate connections, Journal of Constructional Steel Research, 124 (2016) 163-172.

[3] J. Chen, J.-h. Zhu, F. Xu, and W. Xue, 02.05: Design of concrete-filled steel tubular longitudinal gusset plate connections, ce/papers, 1 (2017) 471-478.