International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Response of Steel Beam-to-Column Bolted Connections to Blast Loading

Alireza Bahrami, Sina Matinrad

Abstract*: In this research, response of steel beam-to-column bolted connections to blast loading is investigated. Nonlinear analyses of the connections are performed using the finite element software ABAQUS. In order to demonstrate the accuracy of the finite element modelling, an experimental test of a steel beam-to-column bolted connection is modelled. Comparison of the obtained result from the modelling with that of the corresponding experimental test verifies the modelling. Then, a 5-storey steel building is designed using ETABS software from which a beam-to-column connection of the ground floor is selected for the nonlinear analysis in ABAQUS. Thereafter, the components of the selected connection are designed. Finally, the connection is nonlinearly analysed considering parameters as the distance from the blast centre (2.5 m, 5 m, and 10 m) and blast power (500 kg, 1000 kg, and 2000 kg TNT equivalent mass of explosive). Effects of these parameters on the response of the connection are evaluated. Failure modes of the connections are assessed, too.

***Keywords*: connection, steel, blast loading, beam, nonlinear analysis.**

I. INTRODUCTION

Today, due to the increasing number of terrorist attacks around the world and the possibility of bombing in different parts of the world, the impact of the blast loads on various structures (both surface and underground structures) has received special attention. Blasting is a phenomenon with random nature that in addition to causing effects such as sudden shock, it creates compressive and tensile waves in the environment and influences structures and existing obstacles in its path. Blasting in or near a structure may occur for a variety of reasons, such as wars, terrorist attacks, or gas leaks. The blast can cause local structural damages to buildings, which most probably propagate into the structures and damage the buildings. It is clear that the occurrence of the local damages and their resulting progressive collapses will cause considerable life injuries and financial losses. A review of the incidence of wars and accidental blasts in structures and their consequences, as well as the increasing growth of the terrorist attacks, illustrate the importance of investigating the response of structural elements to the blast loading. Code-based design of connections can improve the overall behaviour of the structures by contributing in the nonlinear behaviour of the steel frames. The proper rotational capacity of the steel bolted connections allows them to prevent further lateral displacement of the frame and reduces the need for ductility in beams and columns by the inelastic deformation and energy absorption rather than making cracks. This illustrates the need for a detailed analysis and design of the connections. Prior to the Northridge earthquake, the welded frame was thought to be the best system to withstand vertical and lateral loads. The collapse of these frames was expected to be limited to yielding and local buckling in beams and columns as well as to the small permanent drift. The Northridge earthquake mostly caused damage to the weld area of the connections and cracks in the steel area of the connection members. On the other hand, due to the possibility of manufacturing the bolted connections, high safety, low running cost, high assembly speed, and easy quality control, the bolted connections have become increasingly attractive to designers. Some studies have been carried out on the behaviour of connections and on the blast loading [1-10], however, research on the response of steel beam-to-column bolted (SBTCB) connections to blast loading is limited which has been done herein.

This research focuses on the blast load response of SBTCB connections. The connections are nonlinearly analysed applying the finite element software ABAQUS. An experimental test of a SBTCB connection is modelled to uncover the accuracy of the modelling. The modelling is verified by the comparison of the modelling and test results. Thereafter, a 5-storey steel building is designed using ETABS software and a beam-to-column connection of the ground floor is selected for further modelling analysis in ABAQUS. The distance from the blast centre and blast power are considered as parameters in the analyses. Effects of these parameters on the connection response are assessed.

II. EXPERIMENTAL TESTING AND FINITE ELEMENT MODELLING VERIFICATION

An experimental test done on a SBTCB connection [11] was chosen for the modelling verification. Details of the specimen are illustrated in Fig. 1 and its material properties are presented in Table 1. The connection shown in the figure has components such as beam, column, T-sections, screws, steel plates, and stiffeners.

Manuscript published on 30 September 2019
* Correspondence Author
Alireza Bahrami*, Department of Building Engineering, Energy Systems, and Sustainability Science, Faculty of Engineering and Sustainable Development, University of Gävle, 801 76 Gävle, Sweden.
Department of Civil Engineering, Abadan Branch, Islamic Azad University, Abadan, Iran.
Sina Matinrad, Department of Civil Engineering, Abadan Branch, Islamic Azad University, Abadan, Iran.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

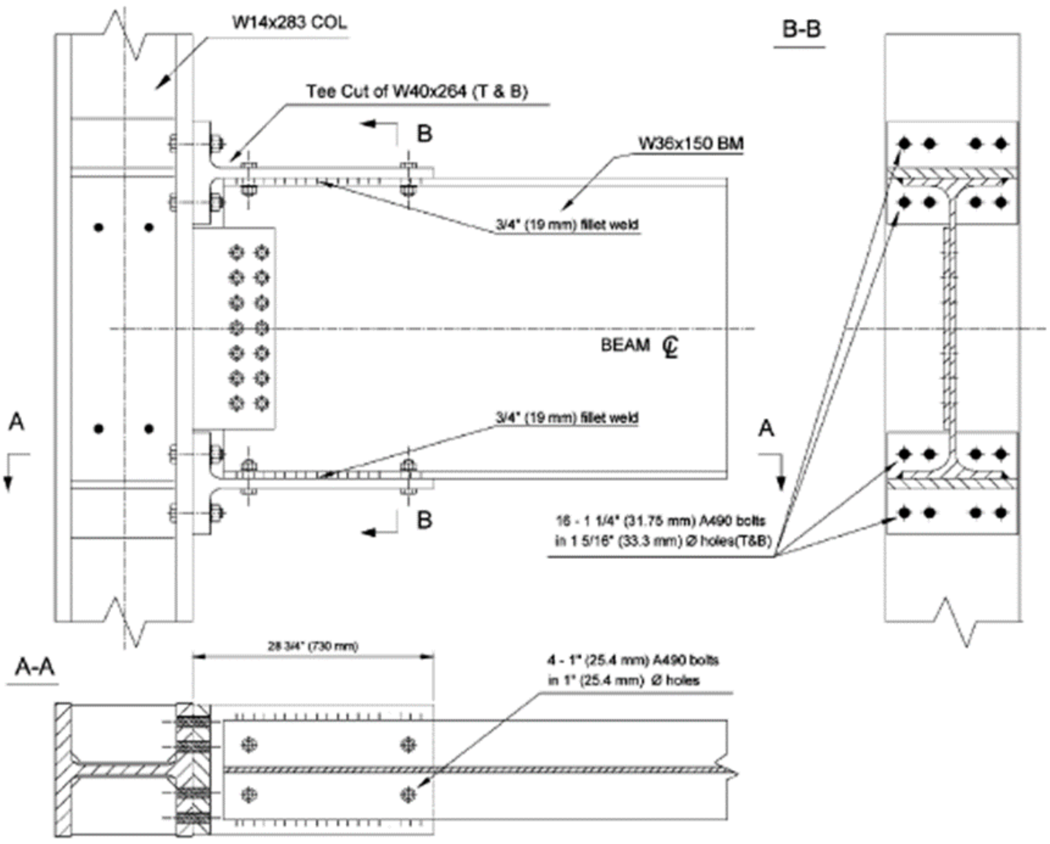

Fig. 1 Details of tested specimen [11]

Table 1 Material properties

Part of connection	Yield stress (MPa)	Ultimate stress (MPa)	Section size
Beam	390	512.6	W36×150
Column	358.3	454.7	W14×283
T-section	441	544.3	WT40×264

The web of the T-sections was welded and connected to the beam flange by bolts. The flange of the T-sections was connected to the column flange by bolts. Steel plates were also welded to the column flange and connected to the beam web by bolts. Therefore, the two top and bottom T-sections and the steel plates have rigidly been connected to the beam and column which all together have made the SBTCB connection. Moreover, two stiffeners have been welded in the column web where the connection exists. The modulus of elasticity and the Poisson's ratio of the steel are 210000 MPa and 0.3, respectively.

In modelling, all the features considered in testing have also been taken into account. C3D8R solid element has been utilised for the model. It is an eight-node element that each node has three degrees of freedom. Material modelling of the steel is an important part of the modelling [12,13,14]. Herein, the steel has bilinear kinematic hardening behaviour to consider progressive hardening and softening effects [15,16]. The contact surface between the connection components was defined as tie. This constraint allows two areas with different meshes to be combined. The amount of the displacement was applied according to the loading code [17]. The support conditions of the experimental test have been simulated in the modelling, as well. At the top and bottom of the column, fixed supports have been considered and the translation in all directions has been set to zero. The out-of-plane translation of the beam has been set to zero while the translation is free in all other directions. To determine the mesh size, a number of models with different mesh sizes were examined and the mesh size that led to more accurate result was chosen for the modelling. Fig. 2 demonstrates the simulated model after meshing.

The force-displacement graph obtained from the nonlinear analysis of the finite element modelling is compared with that from the experimental test in order to verify the accuracy of the modelling (Fig. 3).

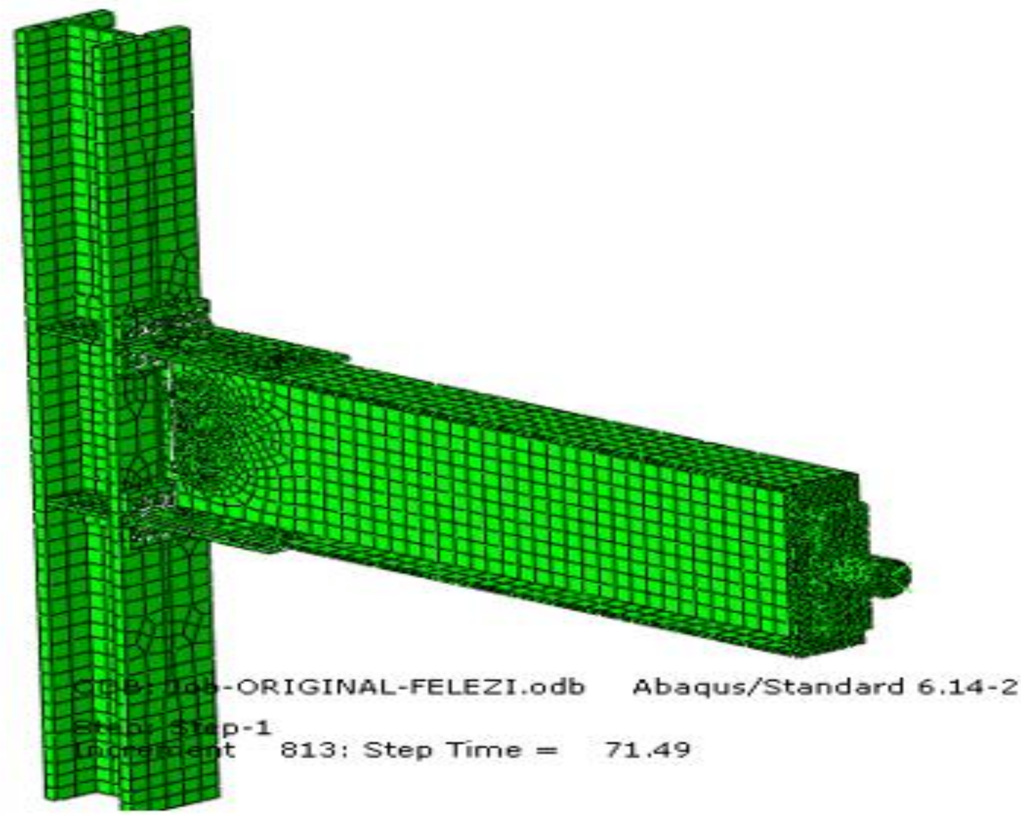

Fig. 2 Simulated model after meshing

As can be seen from the figure, the ultimate strength of the tested specimen is 1535 kN with the displacement of 132 mm. However, the ultimate strength of the simulated specimen is 1622 kN with the displacement of 129 mm. Comparison of the obtained ultimate strengths from the test and modelling indicates the difference of 5.4%. Also, by comparing the graphs it can be observed that they have many similarities. This issue illustrates the point that the tested and simulated specimens behave similarly under the load. Thus, the small difference between the results and moreover their similar behaviours uncover the modelling accuracy. Consequently, the proposed finite element modelling in this study has the ability to correctly predict the response of the connections.

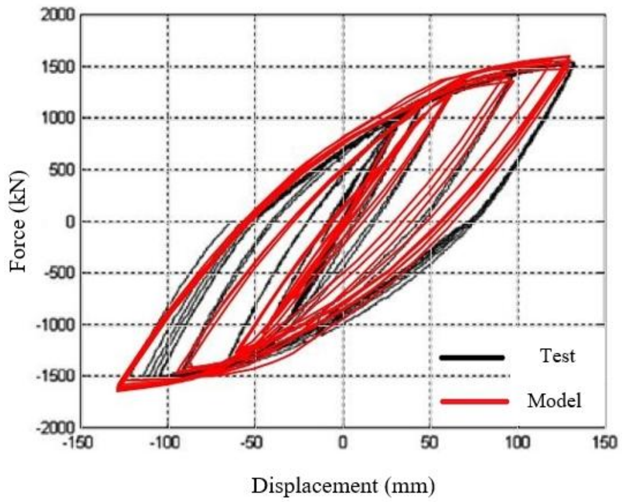

Fig. 3 Force-displacement graphs of model and tested specimen

III. STEEL BUILDING DESIGN USING ETABS SOFTWARE

In order to design SBTCB connections, a 5-storey steel building with the storey height of 3 m has been designed based on AISC360-10 using ETABS software. The plan and designed building are shown in Figs. 4 and 5.

The most critical floor of the building against the surface blast loading is the ground floor due to its proximity to the blast point, therefore, a SBTCB connection from the ground floor has been considered for the analyses.

IV. NONLINEAR ANALYSIS OF SBTCB CONNECTIONS UNDER BLAST LOADING USING ABAQUS SOFTWARE

To model the SBTCB connection of the ground floor of the building in ABAQUS, the components of the connection and the column stiffeners have been designed using ETABS results, as illustrated in Figs. 6-8. All the bolts comply with ASTM A490. Table 2 lists the profiles used for the beams and columns of the building. All the beams and columns were made of the steel type ST37 with the Poisson’s ratio of 0.3.

The above-mentioned details and specifications have been modelled in the SBTCB connection using the ABAQUS software. Fig. 9 presents the simulated model of the connection.

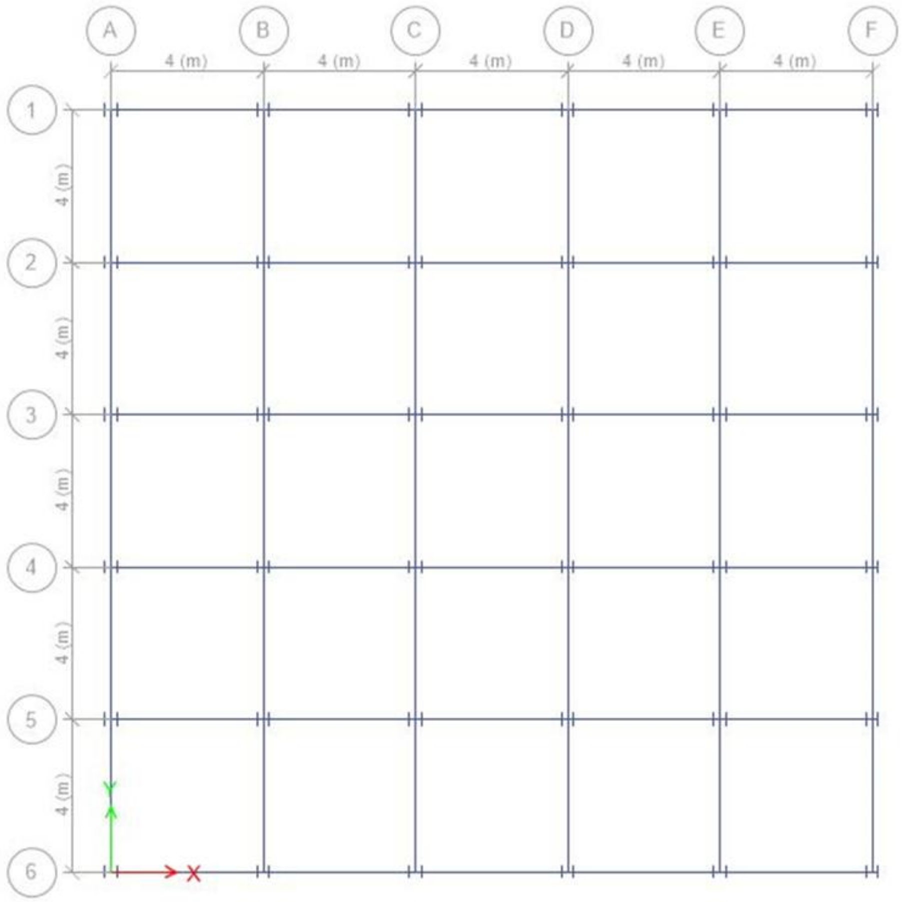

Fig. 4 Plan of 5-storey steel building

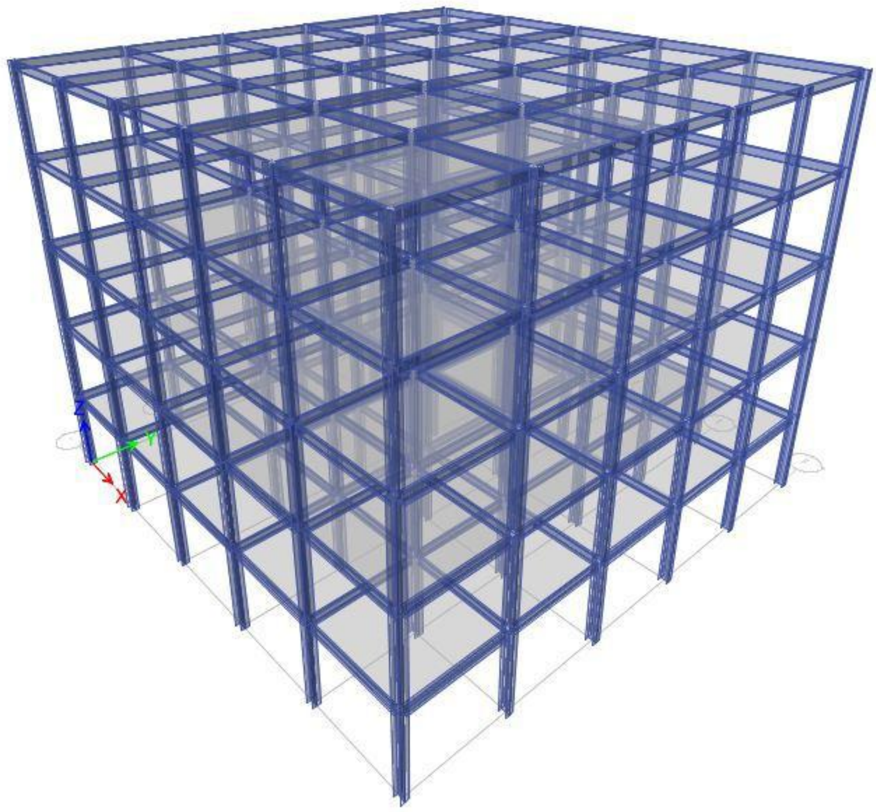

Fig. 5 Designed 5-storey steel building using ETABS

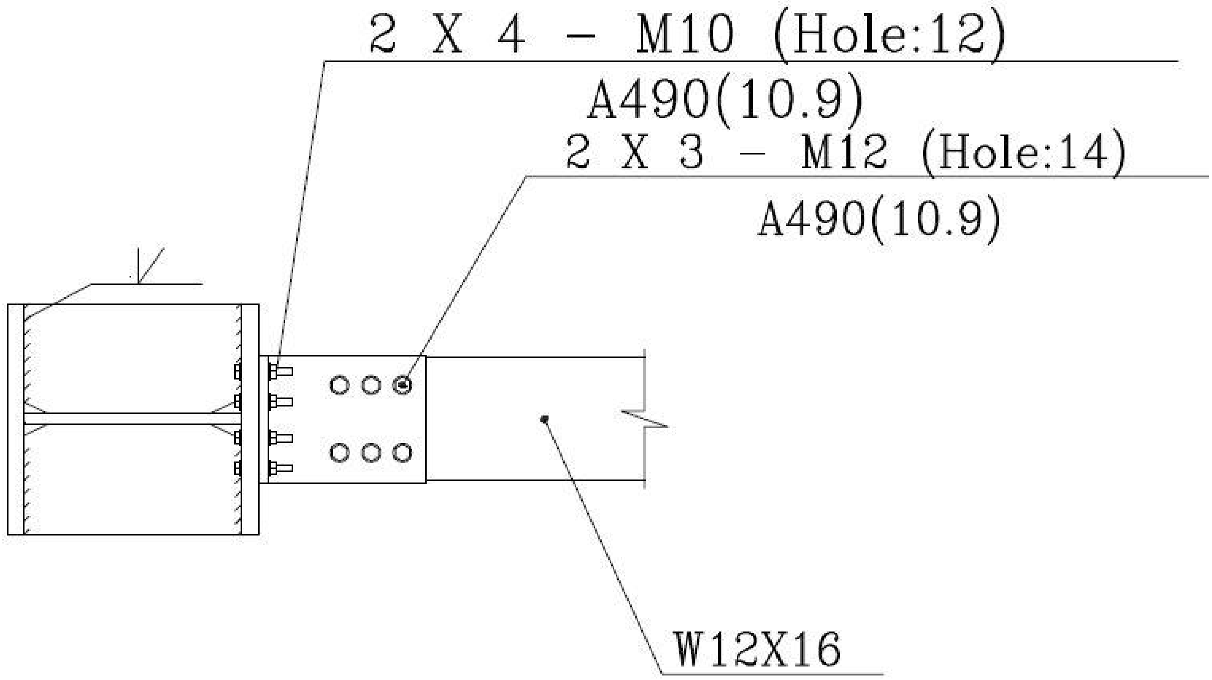

Fig. 6 Plan view of SBTCB connection (All dimensions are in mm)

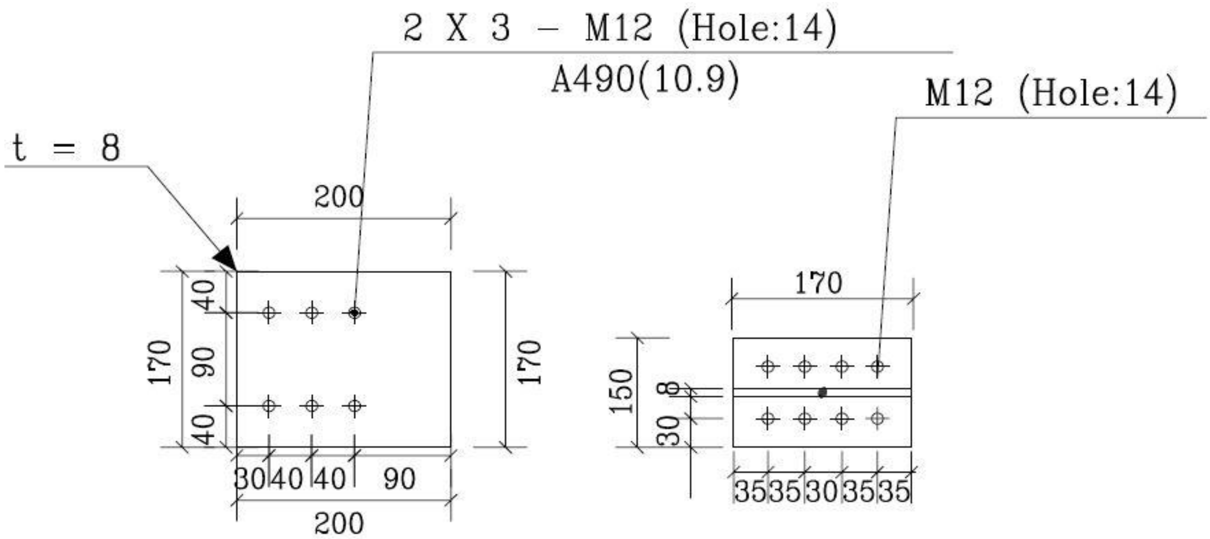

Fig. 7 Details of T-section connecting beam-column (All dimensions are in mm)

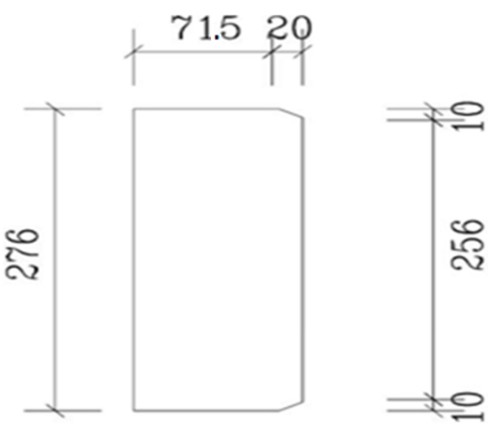

Fig. 8 Column stiffener with thickness of 20 mm (All dimensions are in mm)

Table 2 Specifications of beams and columns

Member	Specification
Beam	W12×16
Column	W12×87

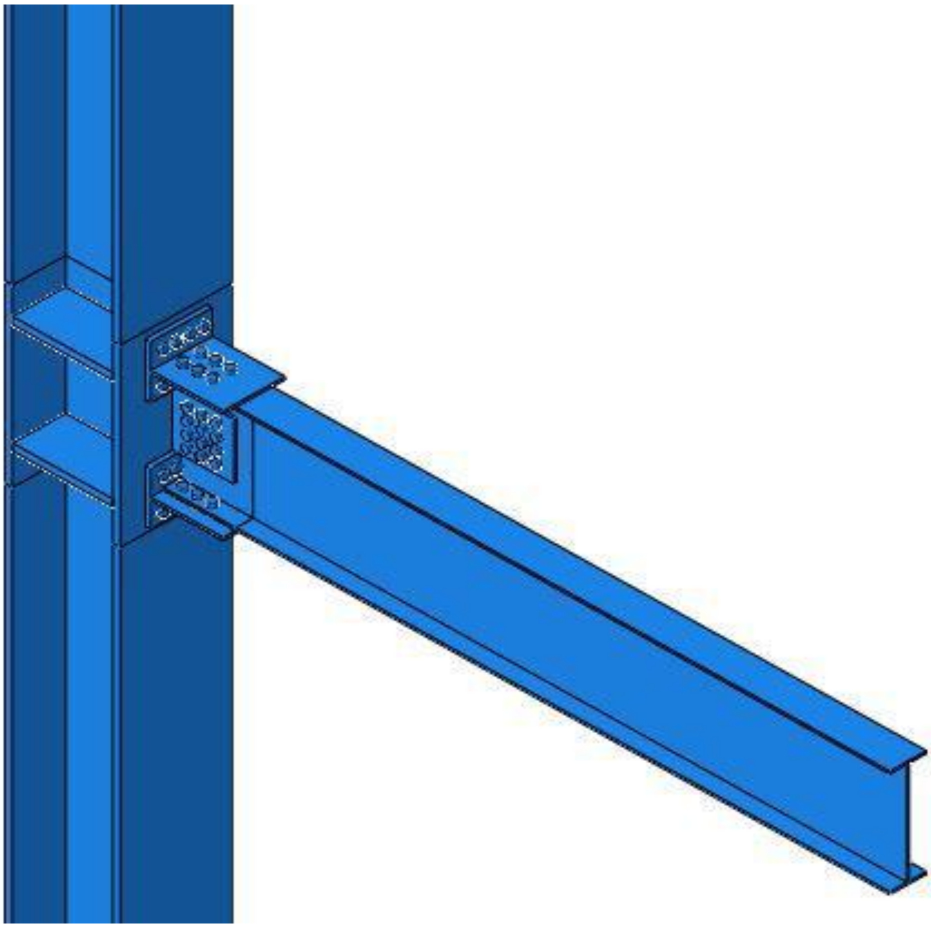

Fig. 9 Simulated model of connection in ABAQUS

One of the most commonly used explosives in blasts is TNT. TNT is generally considered to be the reference for other explosives. It means that when a strong explosive is other than TNT, its equivalent energy is obtained using the explosive coefficient. Generally, the coefficient of an explosive to convert to the equivalent TNT is defined as following:

$$C.F = \frac{explosive\ mass}{TNT\ equivalent\ mass}$$

Conwep is a method of calculating the effect of an explosion on a target based on the distance between them and the mass equivalent to the explosive. This is one of the numerical methods for analysis. The ABAQUS software has the ability to apply blast loads by Conwep. To use it, it is necessary to introduce the software the point where the explosion occurs, the surface on which the explosion pressure should be applied, and the weight of the explosive as the TNT equivalent mass. Considering the high accuracy of Conwep, it has been utilised in this study to model the blast loading on the building.

V. RESULTS AND DISCUSSIONS

This section examines the response of the modelled SBTCB connection to the blast load with the consideration of different parameters.

A. *Effect of Distance from Blast Centre on Connection*

In order to investigate the effect of blast centre distance on the connection response, the connection was modelled against 1000 kg TNT blast load at 2.5 m, 5 m, and 10 m distances. Then, the applied compressive forces to the column support due to the blast have been obtained. The obtained forces are demonstrated in Fig. 10. As the distance from the blast centre to the connection increases, a sharp decrease of the forces is noticed that is due to the short impact of the blast load, which appears as a sudden drop with increasing distance.

Retrieval Number: C5347098319/2019©BEIESP
DOI:10.35940/ijrte.C5347.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

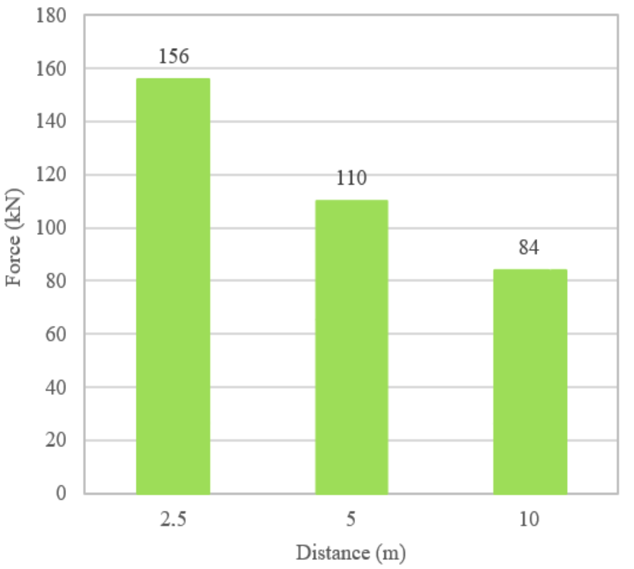

Fig. 10 Comparison of applied forces on connection due to blasting at different distances

The maximum stresses in the connection due to the change of the blast centre distances are listed in Table 3. The table represents that by increasing the distance between the blast centre and the connection, a decrease of the connection stress is experienced. The maximum stress created at a distance of 10 m indicates a reduction of 34.6% compared to that at a distance of 2.5 m. This decrease of the stress results in the reduction of the possibility of the connection failure.

Table 3 Maximum applied stresses in connection due to blast load at different distances

Distance (m)	Maximum stress (MPa)
2.5	425
5	410
10	278

Figs. 11-13 show the failure modes of the connection for the blasting 1000 kg TNT at distances of 2.5 m, 5 m, and 10 m, respectively.

As the distance from the blasting centre increases, the stress in the connection significantly decreases, as well as the stress concentration on the connection area decreases which finally reduces the risk of the connection complete failure. Also, increasing the distance reduces the displacement of the beam in perpendicular direction on the connection plane.

B. ***Effect of Blast Power on Connection***

To investigate the effect of the blast power on the SBTCB connection, the connection was modelled against 500 kg, 1000 kg, and 2000 kg TNT at 5 m distance to the connection. The applied forces to the connection due to the mentioned explosives have been obtained as illustrated in Fig. 14. The maximum stresses in the connection are summarised in Table 4.

According to Table 4, the increase of the TNT equivalent mass leads to the increase of the applied stress in the connection. However, with a 4-fold increase of the TNT equivalent mass from 500 kg to 2000 kg, 12.1% increase in the maximum stress applied to the connection occurred. Therefore, this large increase of the TNT equivalent mass does not lead to a large increase of stress in the connection.

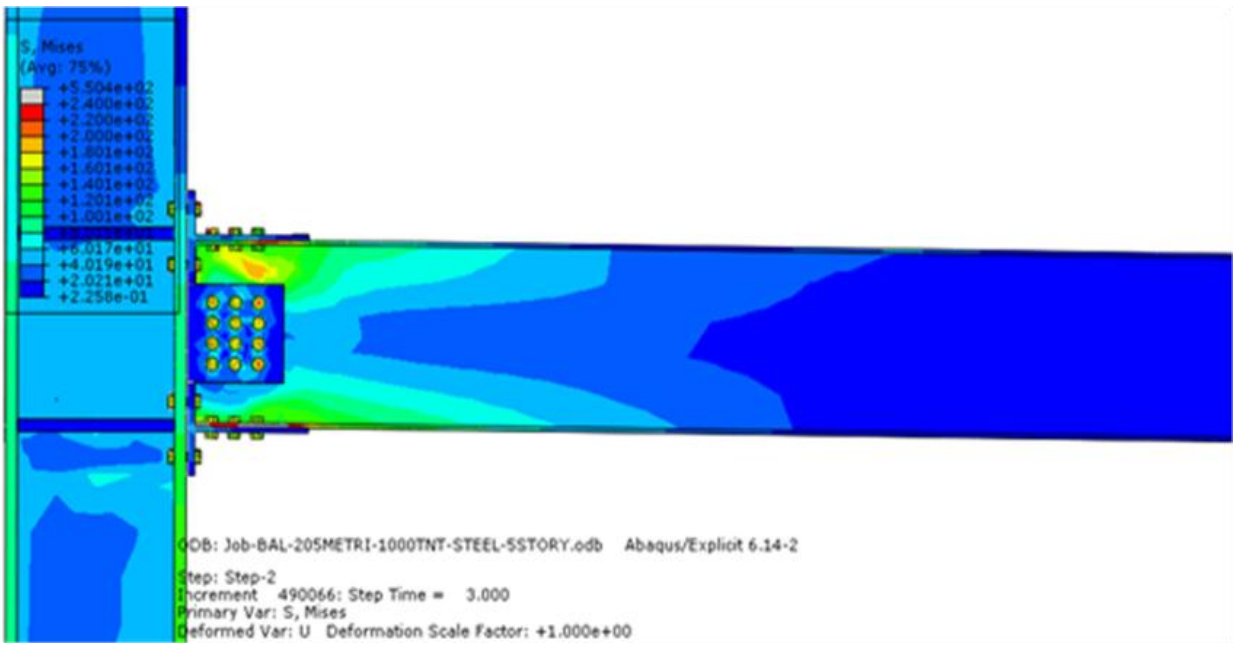

Fig. 11 Failure mode of connection due to 1000 kg TNT at distance of 2.5 m

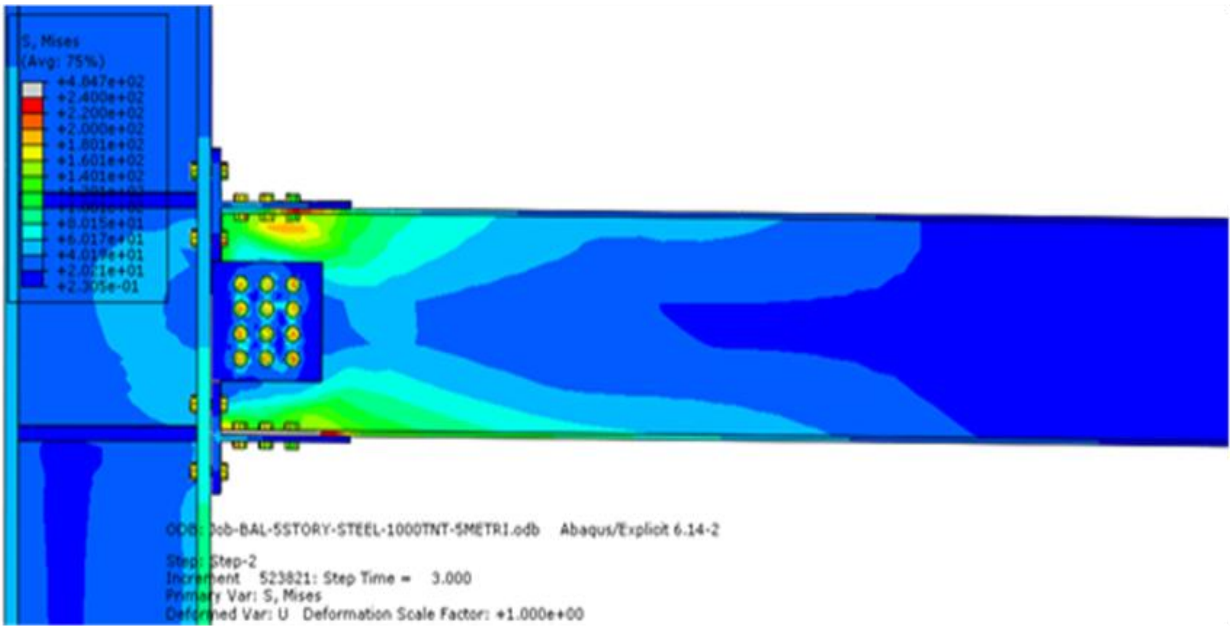

Fig. 12 Failure mode of connection due to 1000 kg TNT at distance of 5 m

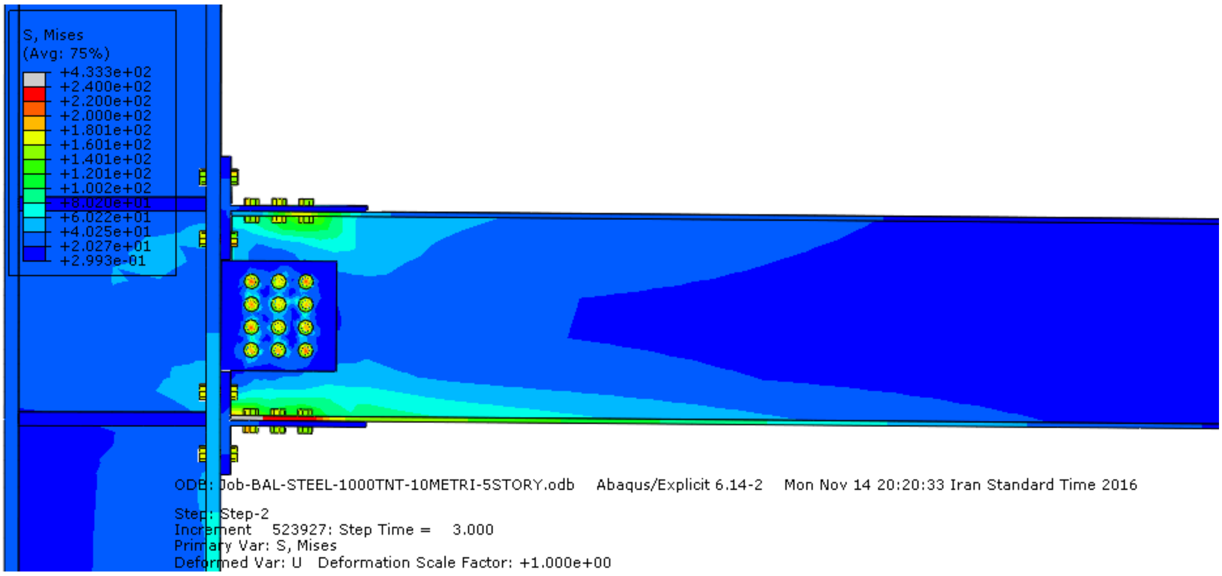

Fig. 13 Failure mode of connection due to 1000 kg TNT at distance of 10 m

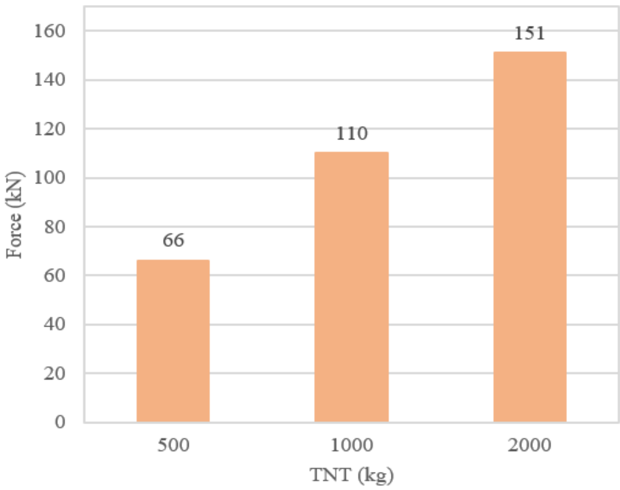

Fig. 14 Comparison of applied forces on connection due to blasting with different TNT equivalent masses

Table 4 Maximum applied stresses in connection due to blast load with different TNT equivalent masses

TNT equivalent mass of explosive (kg)	Maximum stress (MPa)
500	371
1000	410
2000	416

Figs. 15 and 16 illustrate the failure modes of the connection at a distance of 5 m for values of 500 kg and 2000 kg TNT. As the TNT equivalent mass of explosive increased, the stress in the connection area increased which may result in the failure of the connection. Moreover, by increasing the TNT equivalent mass of explosive, displacement of the beam in perpendicular direction on the connection plane increased, as well.

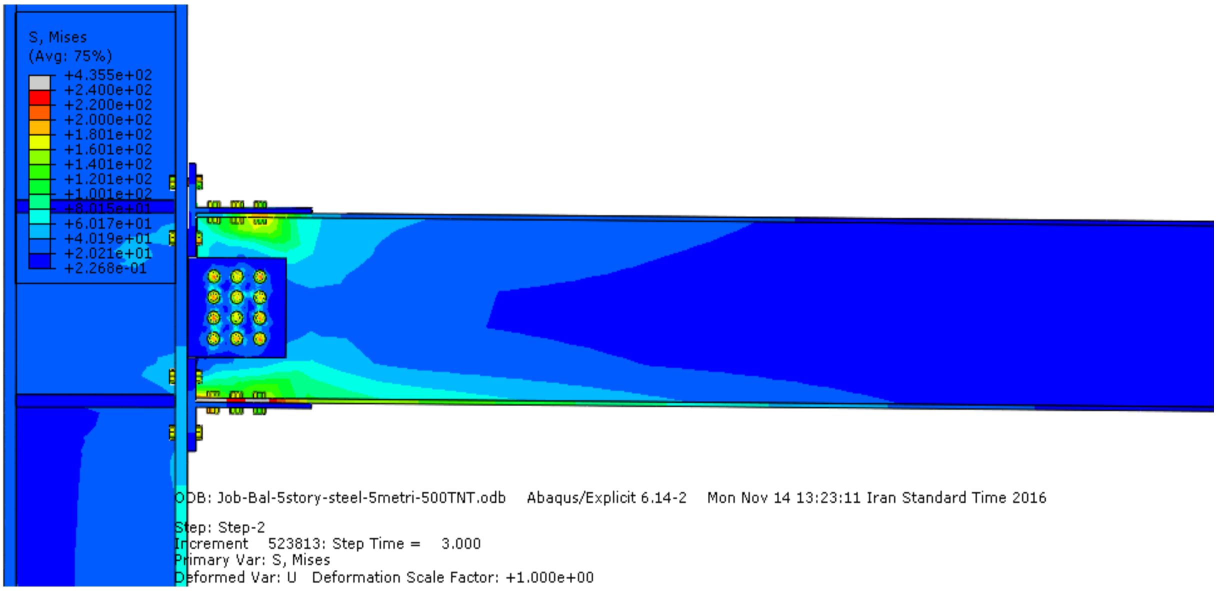

Fig. 15 Failure mode of connection due to 500 kg TNT at distance of 5 m

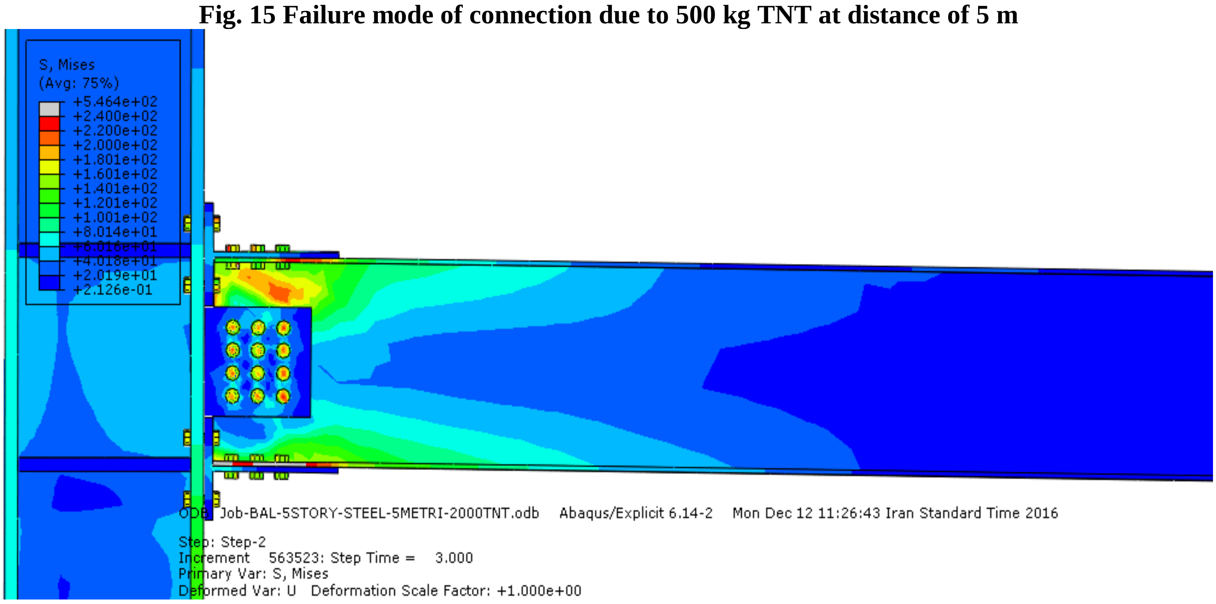

Fig. 16 Failure mode of connection due to 2000 kg TNT at distance of 5 m

VI. CONCLUSIONS

The response of the SBTCB connections to the blast loading was examined in this study. The connections were nonlinearly analysed using the finite element software ABAQUS. The accuracy of the modelling of the SBTCB connection was demonstrated by comparison of the modelling result with that of the corresponding test. Thereafter, a 5-storey steel building was designed using ETABS software and a SBTCB connection of the ground floor was chosen for the analysis in ABAQUS. The distance from the blast centre and blast power were considered as parameters in the analyses of the connection. Effects of these parameters on the response of the connection were assessed. It was found that decreasing the distance of the connection from the blast centre increases the force and stress applied to the connection. Also, increasing the TNT mass increases the force and stress applied to the connection. However, the large increase of the TNT equivalent mass does not result in a large increase of stress in the connection. The failure modes of the connections were evaluated, too.

REFERENCES

1. C. J. Oswald and E. J. Conarth, “A computer program for explosive damage assessment of conventional buildings”, U.S. Army Corps of Engineers, 1994.
2. T. Sabuwala, D. Linzell and T. Krauthammer, “Finite element analysis of steel beam to column connections subjected to blast loads”, International Journal of Impact Engineering, vol. 31, 2005, pp.861-876.
3. M. P. Byfield, “Behavior and design of commercial multistory buildings subjected to blast”, Journal of Performance of Constructed Facilities, ASCE, vol. 20, no. 4, 2006, pp.324-329.
4. H. C. Yim, “A study of steel moment connections for structures under blast and progressive collapse loading rates”, The Pennsylvania State University, Department of Civil and Environmental Engineering, 2007.
5. J. L. Liu, “Preventing progressive collapse through strengthening beam-to-column connection, part 1: theoretical analysis”, Journal of Constructional Steel Research, vol. 66, no. 2, 2010, pp.229-237.
6. A. Heidarpour and M. A. Bradford, “Beam-column element for non-linear dynamic analysis of steel members subjected to blast loading”, Engineering Structures, vol. 33, no. 4, 2011, pp.1259-1266.

7. S. Khalate and S. Kulkarni, "Finite element analysis of cold formed steel bolted connection", International Journal of Recent Technology and Engineering, vol. 4, no. 3, 2015, pp.23-28.
8. I. Faridmehr, Y. Ahmad, M. M. Tahir and M. H. Osman, "Cyclic and explosive evaluation of new proposed steel joint", Advances in Civil Engineering, vol. 2016, article ID 4975097, 2016.
9. B. Yang, H. Wang, Y. Yang, S-B Kang, X-H Zhou and L. Wang, "Numerical study of rigid steel beam-column joints under impact loading", Journal of Constructional Steel Research, vol. 147, 2018, pp.62-73.
10. F. F. Sun, X. Y. Xue, H. J. Jin, M. Sun, Z. M. Tang, Y. Xiao and G. Q. Li, "Hysteretic behavior and simplified simulation method of high-strength steel end-plate connections under cyclic loading", Journal of Constructional Steel Research, vol. 158, 2019, pp.429-442.
11. E. P. Popov and S. M. Takhirov, "Bolted large seismic steel beam-to-column connections part 1: experimental study", Engineering Structures, vol. 24, 2002, pp.1523-1534.
12. A. Bahrami, W. H. Wan Badaruzzaman and S. A. Osman, "Structural behaviour of tapered concrete-filled steel composite (TCFSC) columns subjected to eccentric loading", Computers and Concrete, vol. 9, no. 6, 2012, pp.403-426.
13. A. Bahrami, W. H. Wan Badaruzzaman and S. A. Osman, "Investigation of concrete-filled steel composite (CFSC) stub columns with bar stiffeners", Journal of Civil Engineering and Management, vol. 19, no. 3, 2013, pp.433-446.
14. A. Bahrami, W. H. Wan Badaruzzaman and S. A. Osman, "Numerical study of concrete-filled steel composite (CFSC) stub columns with steel stiffeners," Latin American Journal of Solids and Structures, vol. 11, 2014, pp.683-703.
15. A. Ucak and P. Tsopelas, "Constitutive model for cyclic response of structural steels with yield plateau," Journal of Structural Engineering, vol. 137, no. 2, 2011, pp.195–206.
16. A. Bahrami and M. Yavari, "Hysteretic assessment of steel-concrete composite shear walls," International Journal of Recent Technology and Engineering, vol. 8, no. 2, 2019, pp.5640-5645.
17. ATC-24, "Guidelines for seismic testing of components of steel structures," Report 24, Applied Technology Council, Redwood City: CA, 1992.