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Investigation of Vulnerability of Concrete Filled Steel Column Connections under Different Blast Scenarios

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ABSTRACT: Considering the increasing hostile and terroristic threats in the country, it is important to consider the passive defence criteria in structures. The desirable properties of steel and concrete can be used simultaneously to increase the strength of structural members. Concrete-filled steel tube columns (CFSTs) have been proposed as an efficient system in previous years. The main problem with using this type of column is how to connect the beam to such a column and extensive research has been done for seismic load scenarios. Despite the excellent resistance of these types of columns to the blast load, no comprehensive investigation has yet been conducted on the performance of beam-to-column joints under blast load. In this paper, the behavior of three types of beam-to-column connections under 5 blast scenarios is investigated. ABAQUS software was used to conduct the research. Verification was first performed using the results of an experimental study and a good agreement was observed. The behavior of beam-to-column blast-loaded connections was investigated using 16 different models using explicit nonlinear dynamic analysis. The results were compared in terms of stress, strain and damage contour as well as force, energy absorption, displacement, rotation and torsion diagrams. It was observed that the optimal connection where the connection was carried out as an extension of the beam inside the column, all parts of the column contributed to the load carrying and energy absorption and very good behavior was observed. In this case, the plastic joint in the beam is formed away from the column face.

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1- Introduction

Steel-concrete composite structures have been considered by engineers for decades due to the proper cooperation of these two materials in providing the tensile and compressive strength required for structural members. One of the composite member types is Concrete Filled Steel Tube columns (CFST). In these columns, the steel wall plays the role of longitudinal reinforcement and stirrups and also provides desirable confinement for the concrete core. The concrete core also delays the bending deformation and buckling of the steel wall. As a result, these columns have high stiffness, strength and ductility, all of which are very desirable to reduce the vulnerability of the structure to explosion load. Consequently, it can be expected that the use of CFST columns, due to the confinement of concrete inside the steel tube and prevention of local buckling of the steel wall, will reduce the damages caused by the explosion in the vicinity of the structure to some extent.

The connections of steel beams to CFST columns can be designed to be pinned or fixed connections. Since the behavior of joints in the structure is very important and strongly affects the overall behavior of the structure, the connections of steel beams to such columns have been studied by many researchers under earthquake loading [1-4]. However, the behavior of the connections in this type of columns has been less studied under blast loading.

The explosion causes a shock wave whose front pressure gradually decreases as it moves away from the blast center. The wave front is necessarily vertical due to the sudden increase in pressure caused by the explosion. The maximum pressure caused by the explosion is at the end of this initial phase. The propagation speed decreases with time and distance, but is usually greater than the speed of sound in the environment.

Since in the forced vibration phase induced by explosion load, the response of the structure is localized and in the area close to the explosion [5], the vulnerability is judged by controlling the amount of equivalent plastic strain in steel and tensile and compressive damage in concrete. In the free vibration phase, where the response of the structure is a displacement response [5], the vulnerability of the structure is judged according to the amount of rotation of the beam and the displacement of its end, as well as the deformation of the connection members.

2- Methodology

Finite element simulation is employed to investigate the behavior of steel beam to CFST column connections.

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To ensure the accuracy of the predictions of finite element models, validation was carried out using the results of an experimental blast test on CFST columns [6].

The finite element model was developed according to the details reported in the experiment. Eight-node three-dimensional elements were used to simulate the specimen. The behavior of steel was defined with a bilinear model by defining the yield stress and the ultimate stress. The behavior of concrete was defined using the concrete damaged plasticity model. This model is used for different loads and simulates the behavior of concrete by expressing separate behavior of concrete in pressure and tension. In this model, damage states are defined by a numerical variable called damage (D).

The CONWEP method was used to simulate the explosion load. In this method, the center of the explosive and its weight as well as the surface affected by the explosion charge, are determined in the model.

The specimen selected for validation is specimen C1, in which the weight of the explosive is 5 kg, the height of the explosive is 50 cm and its distance from the perimeter of the column is 20 cm. The analysis is of explicit nonlinear dynamic type. The size of the solution increments is automatically selected by the software. The size of the meshes, according to the sensitivity analysis of the mesh, is equal to 4 cm. The time considered in the analysis is 50 milliseconds. The effect of strain rate on the behavior of steel and concrete is considered by applying the relevant coefficients in the behavior of materials.

After ensuring the accuracy of the finite element model simulation, the response of the beam connection to the trapped CFST column under various explosion loading scenarios has been investigated. The geometry of the beams and columns is taken from the design done in the research of reference [7]. The cross-section of the box column is 40 x 40 cm with a thickness of 10 mm and the cross-section of the beam is IPE330. The yield stress and the ultimate stress of the steel are 240 and 400 MPa. The compressive strength of concrete is 25 MPa. The welding material used between the beam and the column is also simulated differently from the base steel. The height of the floor is 3.2 meters and the length of the opening is 5 meters, which is simulated due to the symmetry of half of the opening.

In the research, it is assumed that the walls and roof of the structure were destroyed by the explosion in the initial moments, and the transfer of the explosion pressure to the beams and columns and the connection is done directly. According to the table provided in FEMA-453 [8], the weight of the explosive is estimated at 454 kg of TNT.

Three connection specimens are considered for conducting research, which are the connection of the beam to the column with full penetration welding, the connection with the reinforcement plate and the connection with the extension of the beam inside the column. The third connection was suggested in the literature as a connection with very good seismic load behavior [1].

All three connections were analyzed under five explosion scenarios at different distances from the structure. In the first scenario, the explosive is placed on the ground and exactly on the beam axis. In subsequent scenarios, the distance outside the frame plane on the ground is increased by 0.5 m in each scenario to examine the impact of the blast center location.

3- Results and discussion

The difference in permanent deformation in the experiment and numerical analysis is equal to 10%. Given the observed agreement and the degree of difference, the accuracy of the modeling predictions in estimating the response of the CFST structure to the explosion can be assured.

In the first scenario, no torsion was observed in the beam because the explosion occurred exactly in the direction of the center of the beam. In other scenarios, with the explosive moving away from the center of the beam, in addition to the rotation that occurred in the beam, significant torsion has also occurred in the beam. Most of the concrete core of the column was severely damaged by the explosion. However, due to the surrounding steel wall and the confinement of the concrete core, the deformation of the concrete core is not significant.

4- Conclusion

According to the results, the use of haunch plates, as well as the extension of the beam inside the column, has caused the connection resistance to the blast load to increase significantly and the frame behavior is desirable under the blast weighing 454 kg (1000 lbs.) of TNT in a close distance that is a strong explosion. Comparing the maximum amount of rotation and torsion in the three connections under the most severe explosion scenario, it is observed that the third connection, especially in the case of more severe explosion, has a better performance and the amount of rotation is reduced by about 30% compared to the other two connections. In terms of the equivalent plastic strain index, the performance of the third connection was also more appropriate. The maximum amount of plastic strain in the first, second and third joints is 0.55, 0.249 and 0.217, respectively, which indicates that the beam in the first connection in the first scenario is damaged in the area of the bottom flange connection to the column.

It is also observed that by increasing the horizontal distance of the center of the explosive from the axis of the beam, the amount of force applied to the frame in the horizontal and vertical direction has decreased. The effect of the type of connection on the amount of force applied horizontally and vertically is not a regular trend.

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