Amirkabir University of Technology
(Tehran Polytechnic)

Amirkabir Jounrnal of Science & Research
Civil and Enviromental Engineering (ASJR-CEE)

Vol. 48, No. 3, Fall 2016, pp. 103-106

Investigation on the Use of Composite Column and Synthetic Fiber Rope Brace on Blast Resistance of Portal Frame

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(Received 15 May 2013, Accepted 27 September, 2015)

ABSTRACT

In this research, behavior of portal frame with hollow section steel columns (box sections) is investigated against explosive loading. In order to increase the resistance of the frame, two strategies are suggested: First, using synthetic fiber ropes with initial slackness as *x* brace; second, filling the frame column on blast side with concrete which is referred to as composite column. The finite element analysis software used is the commercialized ABAQUS code and to analyze the finite element model, an explicit dynamic method was used in the numerical solution. This study indicates that the use of synthetic fiber rope brace, especially in large blasts that intense snap loads appears in the rope, improves the total displacement of the frame. However, it has not been capable of reducing the plastic deformation of the local points of the frame subjected to direct blast. This problem was rectified greatly using composite columns. Filling the frame column with concrete on blast side can reduce the total displacements and local deformations of the frame significantly. The remarkable thing in studying frames with composite columns is that by applying strain rate, concrete with lower strength behaves like stronger concrete.

KEYWORDS:

Blast Loading, Portal Frame, X-Brace, Synthetic Fiber Rope, Composite Column, ABAQUS/Explicit, Dynamics Non-Liner Analyses

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1- Introduction

When a body explodes, a sort of reaction appears in its environment, which results in a considerably high compressive wave. This wave travels from the center of explosion toward the outside with a very high velocity, and finally scatters when all the waves become diminished or collide with a body [1]. The compression that a body experiences during a collision is called “explosive load”. In this paper, the possibility of using brace made of artificial fiber ropes for improving the impulsive response of box-section portal frames is considered first. For this purpose, a single frame is analyzed in ABAQUS software for two different explosions and the results are compared with frame having brace made of artificial fiber rope under the same two explosions. Then, the effect of using composite columns on increasing the explosive strength of the frame is discussed. For this purpose, the column located on the explosion side is filled with two types of concrete and then explosion is applied, similar to previous analysis. The effect of material strain rate and utilizing artificial fiber brace are also investigated.

2- Finite element modeling and theories attributed to concrete

A view of the studied frame with related information is depicted in Fig. (1). The frame has 3.5 m height and 5 m width and steel with young modulus of 200 GPa, poisons ratio of 0.3, density of 7800 kg/m^3 and yield stress of 345 MPa is used. Box30x30 and IPE30 are used for column and beam, respectively and they are oriented so that their major axis is in the plane of the frame displacement. The stress-strain relation is assumed elastic plastic. The effect of strain rate is also considered in the analysis. The columns are fixed at base and the beam-column connections are assumed to be rigid. Damping caused by the frame members is assumed to be negligible. For geometric modeling, all of the frame members are modeled with Shell elements, so that the nonlinear effects caused by high shear from explosive loading would be considered more accurately. S4R meshes are used in all members, which is a four-node element with double curvature for integration. The nonlinear model is used for force-displacement behavior of fiber ropes. In this study, rope with linear stiffness of 35 kN/m and equivalent nonlinear stiffness of 11.9 kN/$cm^{1.3}$ is used. “Tie” interaction is used for connecting cable to frame and the cable is modeled as a spring without compression bearing. Also, a surface–to–surface hard contact with a friction coefficient of 0.88 for tangential behavior is used to model the contact between steel and concrete.

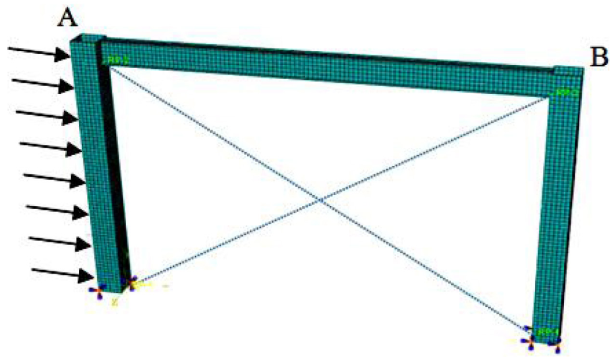

Fig. 1. View of the modeled portal frame, along with brace and applied explosive load

Loading is applied as a uniformly distributed compressive load that acts along the length of the column located at the left side of the frame. C3D8R, which is a solid, continuous and 8-node element with reduced integration, is used for the filled concrete in the column located on explosion side. Finally, the model developed by Nayal and Rasheed [2] and also the model developed by Hsu [3] are used for tensile and compressive behaviors of concrete, respectively and the well–known Drucker–Prager [4] criterion is considered for the yield surface of the concrete.

3- Analysis and discussion on results

In this section, the frame is analyzed in three cases: single, equipped with brace and with composite column (using two different concrete strengths of 20 and 32 MPa). The results from all of these cases are compared. Time history plots for the displacement of joints A and B (their locations are determined in Fig. (1)) are shown in Figs. (2) through (5) for different cases.

Results indicate that using composite column, with either 20 or 32 MPa concrete strengths, reduces the peak displacement of both joints A and B and utilizing composite column and brace together would be more effective in reducing the displacements. Nearly same results are obtained for both values of concrete strengths. The brace has greater effect on joint B; while composite column is more effective on joint A. The Von-Mises stress contours are depicted in Fig. (6) for a single frame and in Fig. (7) for a frame with a composite column, both at time t=10 m.sec. Fig. (6) shows that the stress in a frame with

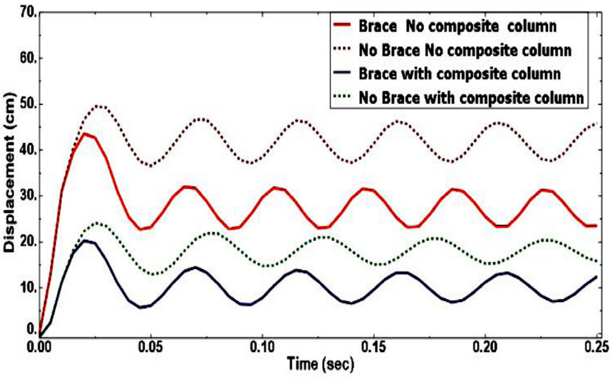

Fig. 2. Time history plot for displacement of joint A for four different cases (Concrete strength of 20 MPa)

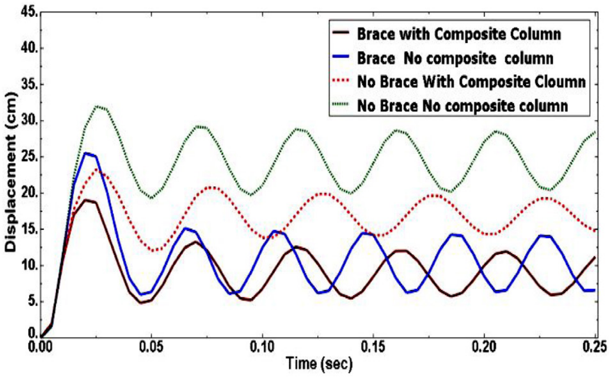

Fig. 3. Time history plot for displacement of joint B for four different cases (Concrete strength of 20 MPa)

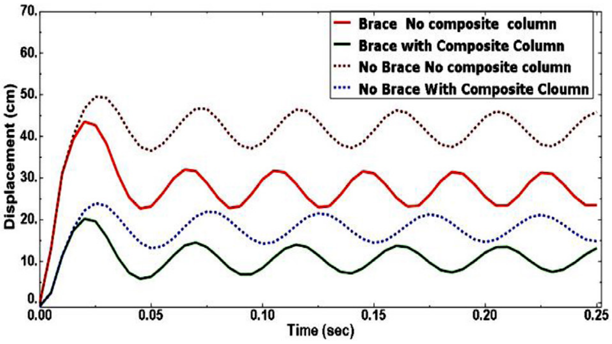

Fig. 4. Time history plot for displacement of joint A for four different cases (Concrete strength of 32 MPa)

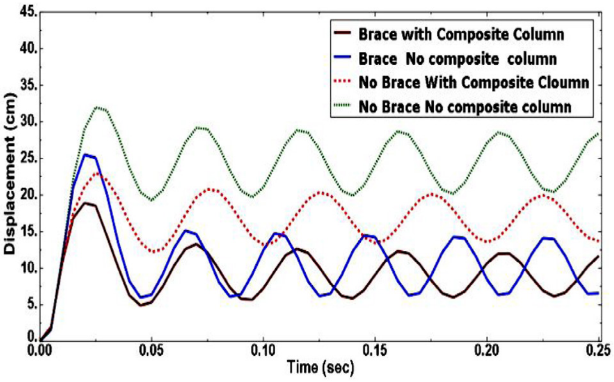

Fig. 5. Time history plot for displacement of joint A for four different cases (Concrete strength of 32 MPa)

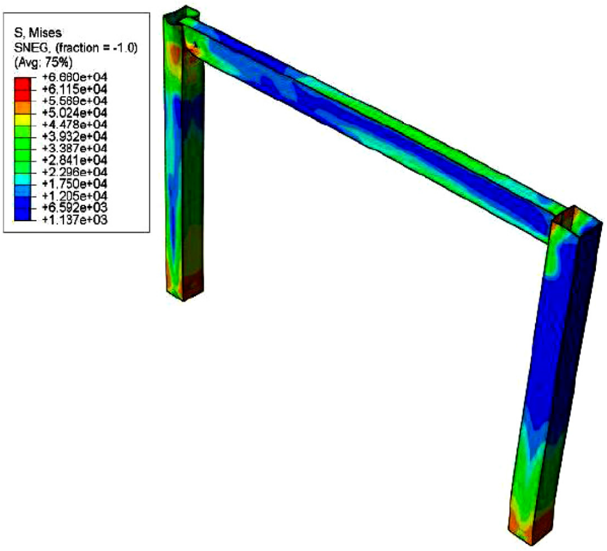

Fig. 6. Von-Mises stress contour for a single frame (without composite column) subjected to blast

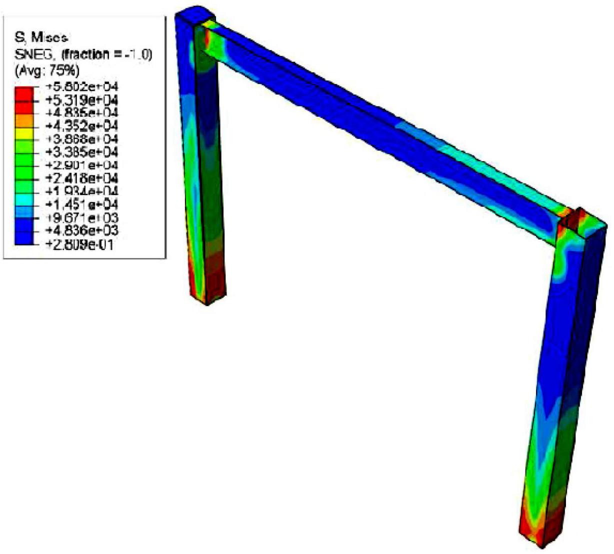

Fig. 7. Von-Mises stress contour for a frame with composite column (Concrete strength of 32 MPa)

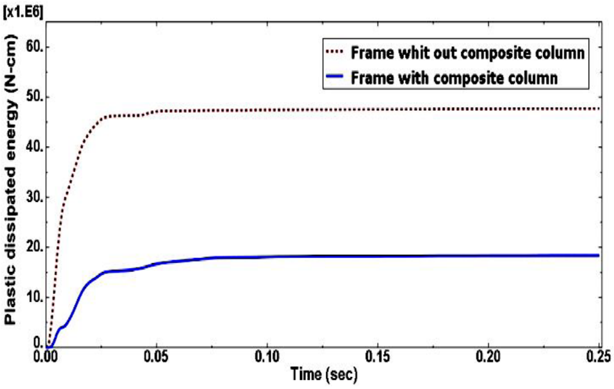

Fig. 8. Time history plot for plastic dissipated energy

composite column is reduced, compared to a frame without composite column.

The comparison of plastic energy dissipation (Fig. (8)) confirms the better performance of the frame with composite column relative to single frame, since using a composite column would result in about 63% reduction in plastic dissipative energy.

4- Conclusions

In this paper, two methods have been considered for strengthening portal frames against blast: First, making use of brace made of artificial fiber ropes and second, using composite columns. For this purpose, analysis has been done in four cases of single frame, frame equipped with brace, frame having composite column (two different values for concrete strength) and also brace and composite column together.

The following results have been outlined:

- Bracing is an efficient way for improving the blast response.
- Using composite column would significantly reduce the peak displacement of the frame, regardless of the concrete type. However, same results are obtained for two different concrete strengths.
- Using composite column would be more effective in reducing the top displacement of the column located on blast side. On the other hand, using brace is more effective in reducing the top displacement of the column located on opposite side.

5- Reference

[1] Fung, T. C. and Chow, S. K., “Responses of Blast Loading by Complex Time Step Method,” *Journal of Sound and Vibration*, Vol. 223, No. 1, pp. 23–48, 1999.

[2] Nayal, R. and Rasheed, H. A.; “Tension Stiffening Model for Concrete Beams Reinforced with Steel and FRP Bars,” *Journal of Materials in Civil Engineering*, Vol. 18, No. 6, pp. 831–841, 2006.

[3] Hsu, L. S. and Hsu, C. T.; “Complete Stress Strain Behavior of High Strength Concrete under Compression,” *Magazine of Concrete Research*, Vol. 46, No. 169, pp. 301–312, 1994.

[4] Zanganeh, K. A., “Shear Strength of the Reinforced Concrete Beams Subjected to Blast Loading,” *M.Sc. Thesis*, KTH Architecture and the Building Environment, Stockholm, Sweden, 2012.

[5] Hibbitt; Karlsson; Sorensen; “ABAQUS User’s Manual,” *Pawtucket*, 6th Edition, 2011.

[6] Ngo, T.; Mendis, P.; Gupta, A. and Ramsay, J.; “Blast Loading and Blast Effects on Structures,” *International Journal of Structural Engineering*, Vol. 7, pp. 76–91, 2007.