The 2017 World Congress on
Advances in Structural Engineering and Mechanics (ASEM17)
28 August - 1 September, 2017, Ilsan(Seoul), Korea

Blast response simulation of Alfred Murrah building reinforced by use of HPFRCC

*Jung-Wuk Hong[1)] and Jae-Wook Jung[2)]

[1), 2)] *Department of Civil Engineering, KAIST, Daejeon 34141, Korea*
[1)] *j.hong@kaist.ac.kr*

ABSTRACT

In this study, the structural behavior against the blast load is evaluated for a structure reinforced by high-performance fiber-reinforced cementitious composite (HPFRCC). Blast analyses are carried out using the finite element method for the Alfred P. Murrah Federal Building which experienced a terrorist attack in 1995. The structural responses to the blast load are simulated, and the effectiveness is evaluated. To enhance the effectiveness, specific reinforcements according to the types of members are required. With the optimized reinforcement using high-performance fiber reinforced cementitious composites (HPFRCC), the resistance to blast load is significantly improved.

1. INTRODUCTION

Alfred Murrah building was the main target of the Oklahoma City Bombing that occurred in 1995. On April 19, 1995, a truck carrying 4000 pounds (1812 kg) of TNT exploded, which caused almost a third of the Alfred Murrah building to collapse. The attack on the building was the most destructive terrorist act in the United States before the 9/11 attacks in 2001 (Kazemi-Moghaddam and Sasani, 2015). Social infrastructures and civil facilities also have been exposed to blast loads. Therefore, the safety of concrete structures against accidents and blast loads is becoming an important social issue. Consequently, the demand for the structural resistance to impact and blast loads has increased, in addition to the compressional strength that a concrete structure must have (Choi *et al*., 2014). In order to improve this property, HPFRCC has been developed to enhance weak tensile strength, strain, and ductility.

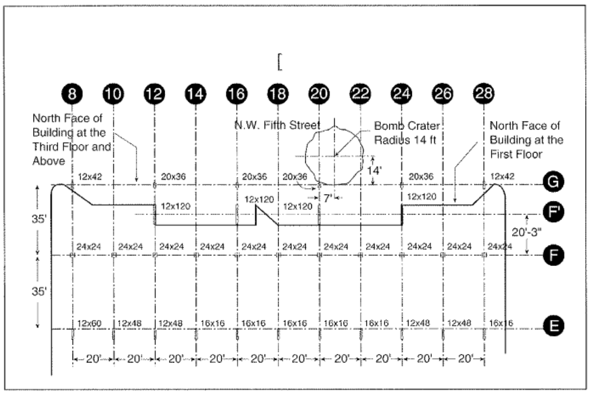
In this study, the blast resistance performance of a structure reinforced by HPFRCC is evaluated. Particularly, the RC structure of the north side of the Alfred Murrah building which was directly destroyed by the blast load is constructed, and numerical analyses are carried out using the finite element method. In Alfred Murrah

[1)] Associate Professor
[2)] Ph.D. Candidate

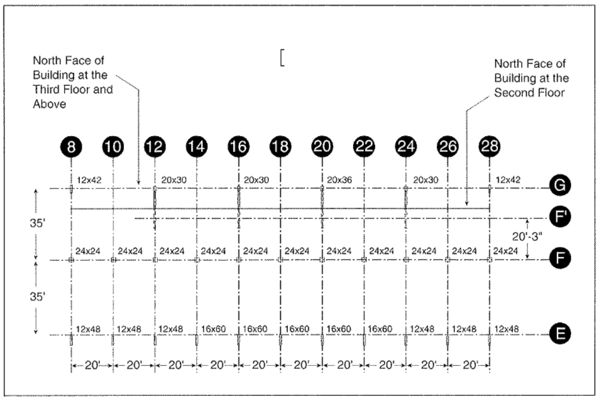
building, the RC structure, made of normal concrete, is reinforced by HPFRCC step by step to evaluate the efficiency of blast resistance. As a result, significant improvement of the blast resistance is achieved through the use of HPFRCC, and the reinforcement might be applicable to enhance the blast resistance of similar structures.

2. NUMERICAL MODEL

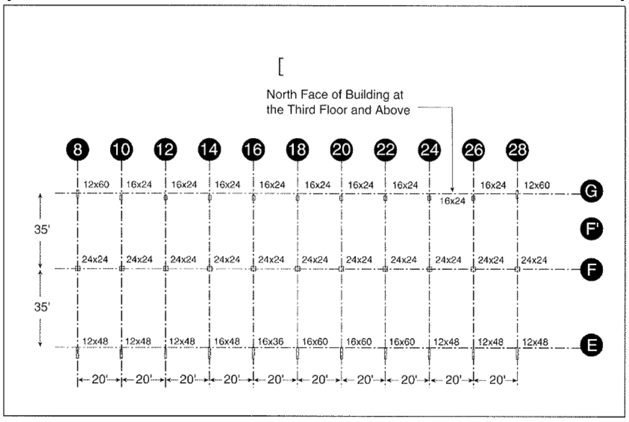
Numerical models are developed for response evaluation of blast load on the Alfred Murrah building. Of the north side frame structure of the building that was exposed to the blast load, the structure from the first to fifth floors between the column G16 and the column G24 is modeled. Details of structures are provided by FEMA 277 (FEMA, 1996) as shown in Fig. 1.



(a)



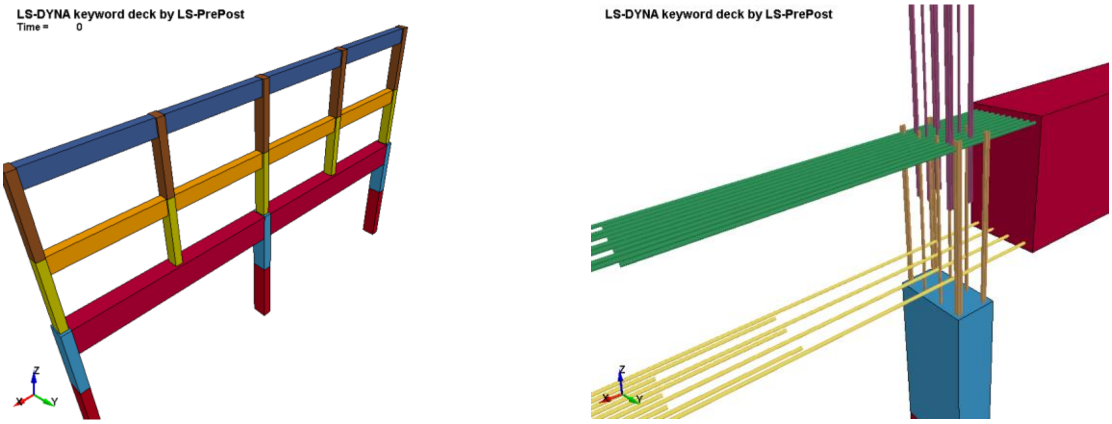
(b)



(c)

Fig. 1. Column locations and dimensions – (a) first floor, (b) second floor, and (c) third floor through roof (FEMA, 1996)

The CSCM material model is used to describe both the normal concrete (27 MPa) and HPFRCC (180 MPa). As for steel rebars, a plastic kinematic material model is used with the keyword MAT_PLASTIC_KINEMATIC. The concrete part is discretized with solid elements of size 10 cm, and the rebar is composed of the beam elements as shown in Fig. 2. In order to evaluate the blast response of the reinforced structure, parts of the structure are replaced with HPFRCC parts as described in Table 1.



(a) (b)

Fig. 2. Numerical models of (a) frame structure and (b) reinforcement bar

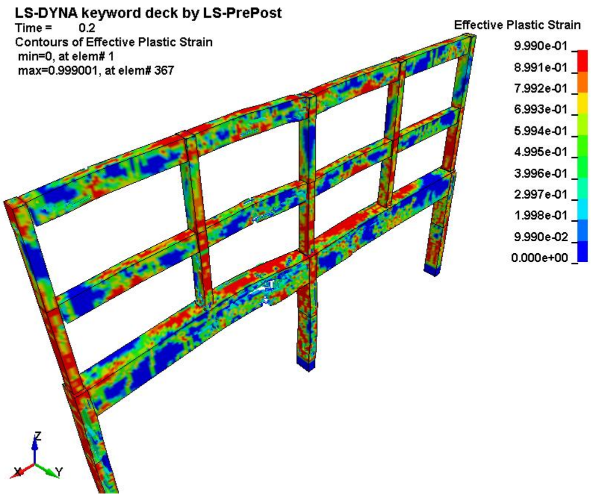
Table 1. Locations of reinforcement using HPFRCC.

Model number	**Location of HPFRCC**	
	Column	Girder
1	None	None
2	1st floor	None
3	1st and 2nd floors	None
4	1st and 2nd floors	3rd floor
5	1st, 2nd, and 3rd floors	3rd floor
6	1st, 2nd, and 3rd floors	3rd and 4th floors
7	1st, 2nd, 3rd, and 4th floors	3rd and 4th floors
8	1st, 2nd, 3rd, and 4th floors	3rd, 4th, and 5th floors

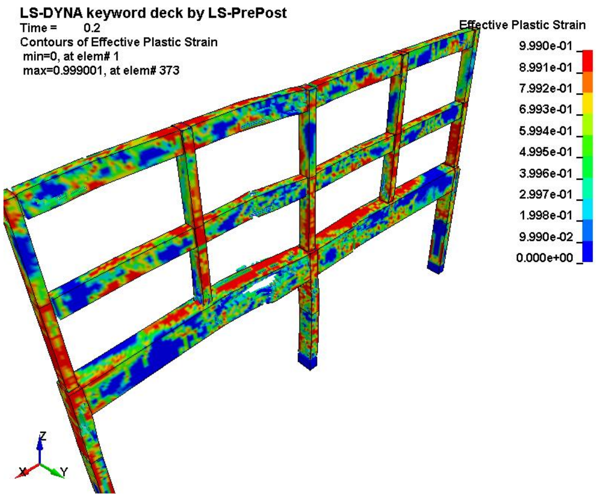
Using LS-dyna capable of describing the blast loads based on Conventional Weapon Effects Programs (ConWep) with parameters of TNT mass, coordinates of the detonation point, characteristics of explosion load (hemisphere, spherical shape, and ground reflection), blast loads are applied to the structure (Hallquist, 2007). Specifically, two tons of equivalent TNT mass is used and the ground reflection is assumed for the analysis.

3. NUMERICAL RESULTS

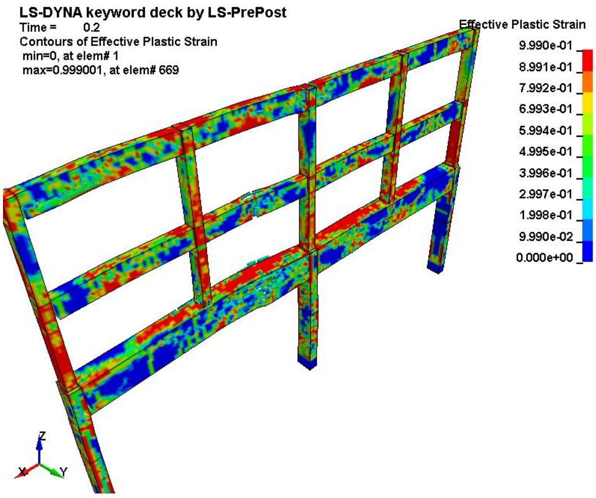
Blast analyses of the eight numerical models are performed by the detonation of 2 tons of TNT, which is equivalent to the amount used in the Oklahoma City bombing. The damage distributions and the deformed shapes are presented in Fig. 3.



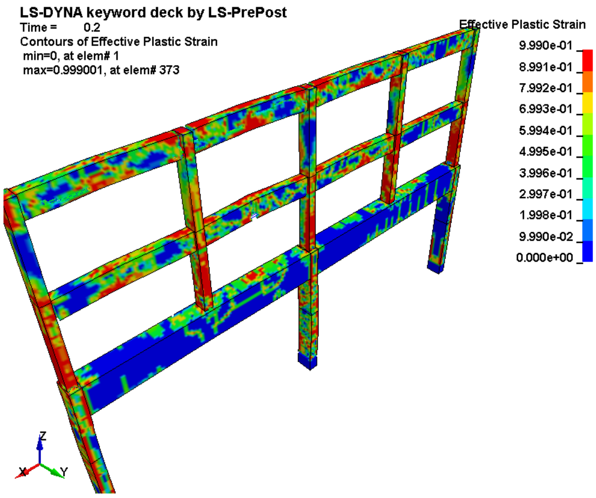
Model 1



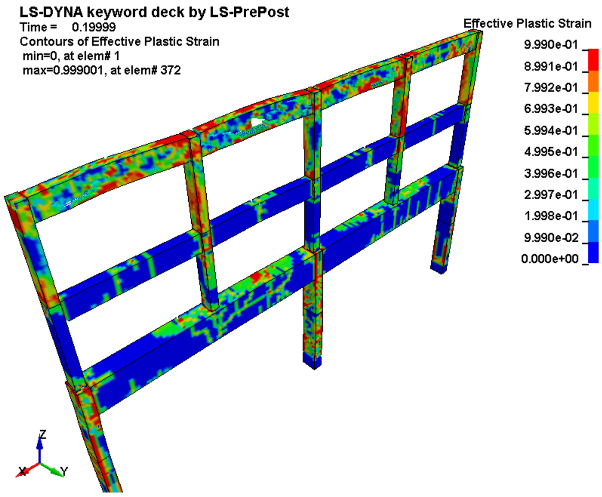
Model 2



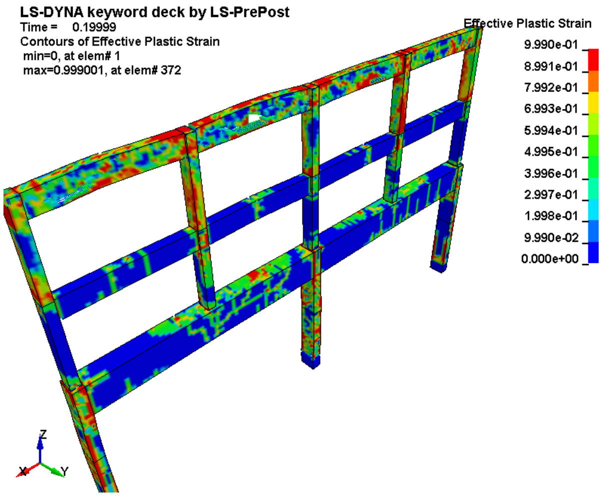
Model 3



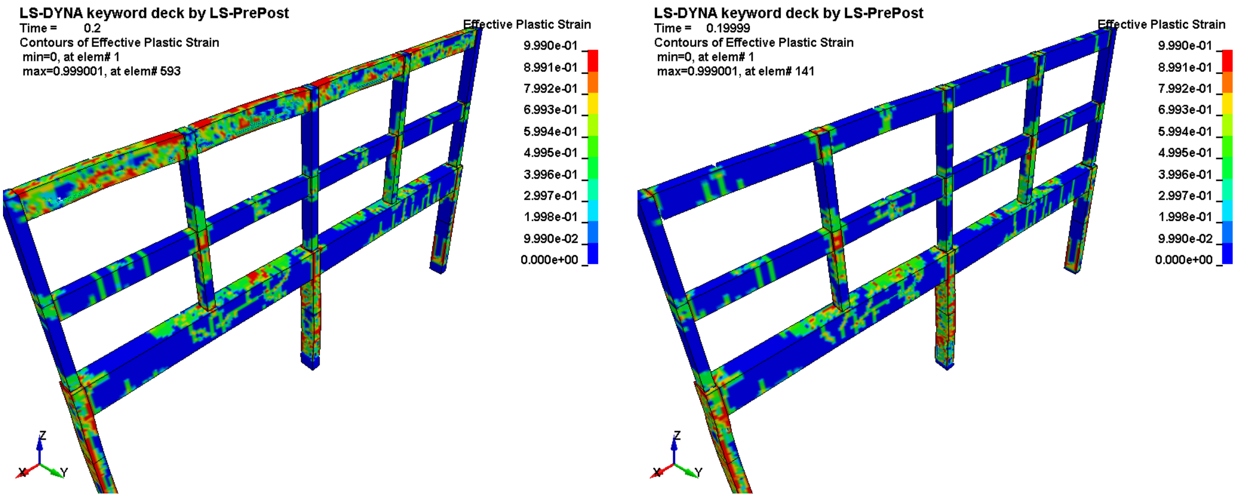
Model 4



Model 5



Model 6



Model 7 Model 8

Fig. 3 Damage patterns of numerical models

Based on the deformed shape and damage pattern, Model 1, which is composed of normal concrete, is destroyed with the largest damage in the girder at the 3rd floor between G20 column and G24 column. In the case of reinforcement with HPFRCC only on the first floor column (Model 2), there is no significant difference from the normal concrete structure (Model 1). When the columns on the 1st and 2nd floor are reinforced with HPFRCC (Model 3), the damages on the 1st and 2nd floor columns are greatly reduced compared with that of the normal concrete structure and only local damage is observed. However, the girder at the 3rd floor is destroyed. When the columns on the 1st and 2nd floors, and the 3rd floor girders are reinforced (Model 4), eminent destruction is not observed, but considerable damage exists on the 3rd floor columns. In the numerical model where the first to third floor columns and the third floor girder are reinforced (Model 5), the destruction of the 3rd floor girder does not occur and the damage to the columns on the 3rd floor is also considerably reduced. However, as the lower floors become stiffer, the blast energy is not absorbed by the deformation energy of the lower floors, and rather the girder of the upper floor (5th floor) fails. This phenomenon might be prevented by reinforcing the girders of the 4th and 5th floors (Models 6-8). In conclusion, the reinforcement of the girder is more important than the reinforcement of columns in 3rd and higher floors, and at least columns of the 1st to 3rd floors and girders of 3rd to 5th floors should be reinforced to prevent structural destruction.

4. CONCLUSIONS

In this research, we evaluate the blast resistance of the Alfred Murrah building reinforced by HPFRCC, particularly, the RC structure on the north side directly affected by the blast load. Blast analyses are performed using eight numerical models with different HPFRCC reinforcements, and the effectiveness of the reinforcement is evaluated. In conclusion, it is required to reinforce the columns and girders for the lower floors exposed to large blast load. On the other hand, in the high-rise part, the girders should be reinforced rather than the columns to effectively resist the blast load.

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