Study on Pre-Weakening Pattern and Behavior of ¼ Scale Steel Structure under Blasting Demolition

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Abstract : Blasting demolition which is the method to raze buildings with small amount of explosive is one of the most efficient methods to take down high rise structures. However, only limited research information is available at the moment while the demand for demolition is rising. Therefore, this study is aims to point out proper patterns of pre-weakening structural steel members and amount of C-4 and also study the behaviour of steel structures under blasting demolition. In the study, firstly several candidate plastic hinge sections are tested and compared to efficiently reduce structural strength in order to minimize the amount of the explosive consumption in the demolition. Then secondly, the appropriate amount of C-4 explosive is determined through blasting test. Finally, a purpose-build ¼ scale steel structure is applied the method. The collapse of the structure is designed using analysis program and actual tests are carried out. The results show that the steel structure can be demolished by C-4 explosive through appropriate pre-weakening pattern, amount of C-4 explosive and structure collapse design.

Keywords : Blasting Demolition, Steel Structure, Pre-weakening, Pre-treatment, C-4 Explosive

1. Introduction

During these recent years, demand for building demolition has been increasing due to end of service lifetime, change of purposes, etc. [1]. Blasting demolition, the method to initiate collapse of building using small amount of explosive, has become a popular method in many countries in Europe and America [2] because of its short period of operation, less required number of heavy machines, cost and time savings [1], [3].

However, there is only limited research on blasting demolition of steel frame structure which is one of most difficult structures to demolish [4]. This study therefore, aims at establishing basic data required in steel structure demolition. Concretely, the objectives are to find proper amount of C-4 explosive for H-beam, to propose proper preweakening pattern for H-beam and finally to propose the method to design structure collapse and demolish ¼ scale steel structure.

2. Test Program

2.1 Test Specimen

Sections and dimension of SS400 steel H-beams tested in this study are shown in Fig. 1 and Table 1.

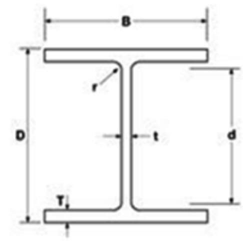


Fig. 1 H-Beam cross section

Table 1 Dimensions of H-beams

Section (mmxmm)	D (mm)	B (mm)	t (mm)	T (mm)	r (mm)
H 100 x 50	100	50	5	7	8

2.2 Explosive

Despite the popularity of commercial explosives such as dynamites and water-gels [4], C-4 explosive has been used in this study because of its stability, safety as C-4 is very stable to many sorts of physical impacts and barely explodes without explosive shocks. Another advantage of C-4 is its ease of forming as C-4 can be formed into required shapes easily. To sever steel structural members, the size of C4 explosive ribbon charge can be determined using the following equation. However, its thickness should not be less than half an inch [5].

$$C_T = 0.5S_T \qquad (1)$$

$$C_W = \mathrm{k}C_T \qquad (2)$$

$$C_L = \mathrm{S}_L \qquad (3)$$

where CT : charge thickness (mm), ST : target steel thickness (mm), CW : charge width (mm), k : Coefficient, CL : charge Length (mm), SL : target length (mm). The coefficient k is recommended by US Army Engineering School to be equal to 3 [5].

2.3 Blasting Test and Bending

Test In blasting test, Coefficient k was the varied from 1 to 3 with the same density of approximately 1.57 g/cm^3 as shown in Table 2. C-4 explosive charges were installed on one side in contact with the Hbeam. The beam's flanges on blasting side were cut off and ones on the other side were performed slit cuts in order to decline explosive amount. Fig. 2 shows the beam blasting test setup.

Table 2 Blasting Test Case Details

Case	Coeff. k	Explosive Thickness (mm)	Explosive Length (mm)	Explosive Width (mm)	Density (g/cm^3)
1	1	13	152	12.7	1.57
2	2	13	152	25.4	1.57

To reduce the amount of explosive in blasting demolition, which leads to decreasing disturbance to surroundings, proper pre-weakening patterns should be employed. Therefore here, 2 types of pre-weakening are applied on the beams to compare their effectiveness. Firstly, type 1 has V- cut on one side of its flange and slit cuts on the flanges on the other side. The V-cut has 90 degree with its trench bottom on beam web. V-cut height is 22.5 mm. Slit cut on the other side of beam flange is 22.5 mm long as shown in Fig. 3 (a). Moreover, in type 2 to further reduce beam strength, a 6.5 mm slit cut was placed on beam web in between above two cuts as shown in Fig. 3 (b).

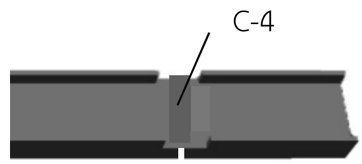
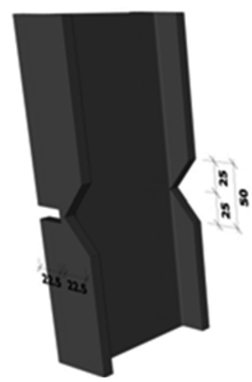
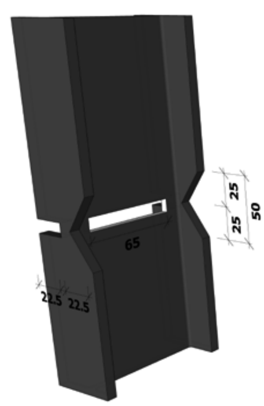


Fig. 2 Blasting test setup



(a) Type 1 V-cut on one side and slit cut on the other side of the beam



(b) Type 2 V-cut on one side, slit cut on the other side of beam and slit cut on web

Fig. 3 Pre-weakened Sections of H-beams

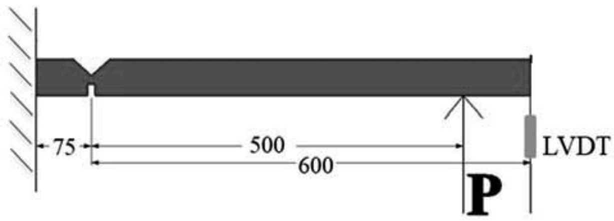


Fig. 4 Cantilever bending test (Unit: mm)

To evaluate patterns of pre-weakening assuming actual conditions, each pattern was performed cantilever bending test as depicted in Fig. 4. Then the bending strength of each pattern was compared to select the most appropriate pre-weakening pattern for structure blasting test.

3. Test result and discussion

3.1 Minimum Required Explosive Amount

Figure 5 shows the damage of the H-beams with coefficient k value of 1 and 2. When the k equaled to 1, the beam had a dent on it without severe damage as shown in Fig. 5 (a). However, when k equaled to 2 the beam was severed into 2 pieces completely. The damage when k equaled to 2 is shown in Figure 5 (b). As a result, it could be concluded that the coefficient k can be reduced to 2 to reduced required amount of C-4 explosive.

(a) When k=1

(b) When k=2

Fig. 5 Damage of H-Beams with different k Values

3.2 Pre-weakened section analytic estimation

Table 3 shows flexural resistance of each preweakening pattern and non-weakening one. Preweakening Type-1 and Type-2 had flexural resistance of 41.6 and 35.1 kN.m, respectively. It can be seen that both Type-1 and 2 of pre-weakening pattern could reduce flexural resistance of H-beam from none pre-weakening significantly to 21.3% and 18.0% as shown in Table 3.

Table 3 Flexural resistance of each pre-weakening pattern

Type	Flexural Resistance (kN.m)	Residual Flexural Resistance Ratio (%)
Control	195	100
1	41.6	21.3
2	35.1	18.0

As estimation of residual flexural resistance is essential when designing blasting collapse of steel structure, the ultimate flexural resistance of each pre-weakening pattern was analyzed through FEM. In the analysis, an elastic perfectly plastic model was used in stress-strain relationship of steel beam. The picture of the relationship is shown in Fig. 6. Here, the nominate yield strength of SS400 steel was used in the calculation. Calculation results and test results for each pre-weakening pattern are shown in Fig. 7 in Load-Displacement curves. The analysis results appear to have good agreement with the test results. Thus, it could be said that the flexural resistance of pre-weakened H-beam can be estimated using elastic perfectly plastic model.

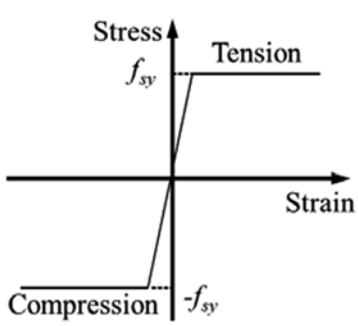
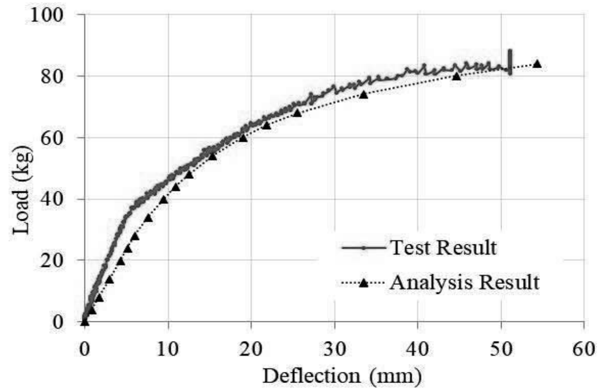
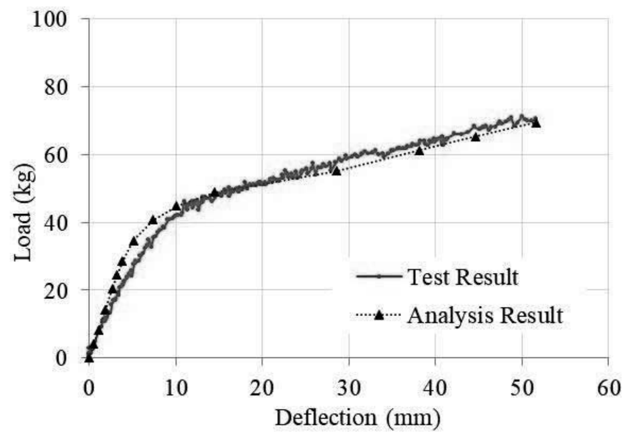


Fig. 6 Stress-strain relationship of SS400 H-beam



(a) Type-1



(b) Type-2

Fig. 7 Comparison of analysis results and test results

3.3 Steel Structure Blasting

To study the behavior of steel structure under blasting demolition, a ¼ scale steel structure was built of SS400 steel H-beams with the same section as blasting test specimens. The structure was threestory steel structure with 1 m width, 1 m length and 0.8 m height in each story. Each floor slab thickness was 10 cm. The picture of the purpose-build structure was as shown in Fig. 8. During determining of collapse pattern and locations of charge and pre-weakening, the design steps shown in Fig. 9 were followed.

Collapse pattern adopted in this study was a pancake type which is a straight down collapsing one. In calculation of required bending moments to initiate razing of the structure after blasting SAP2000 was used. Three candidate points of charging locations on columns, upper end, middle and lower end were compared.

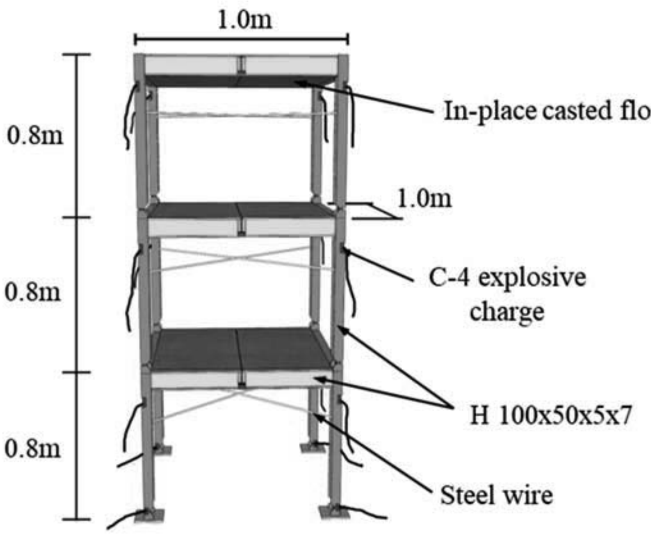


Fig. 8 Structure Blasting Setup

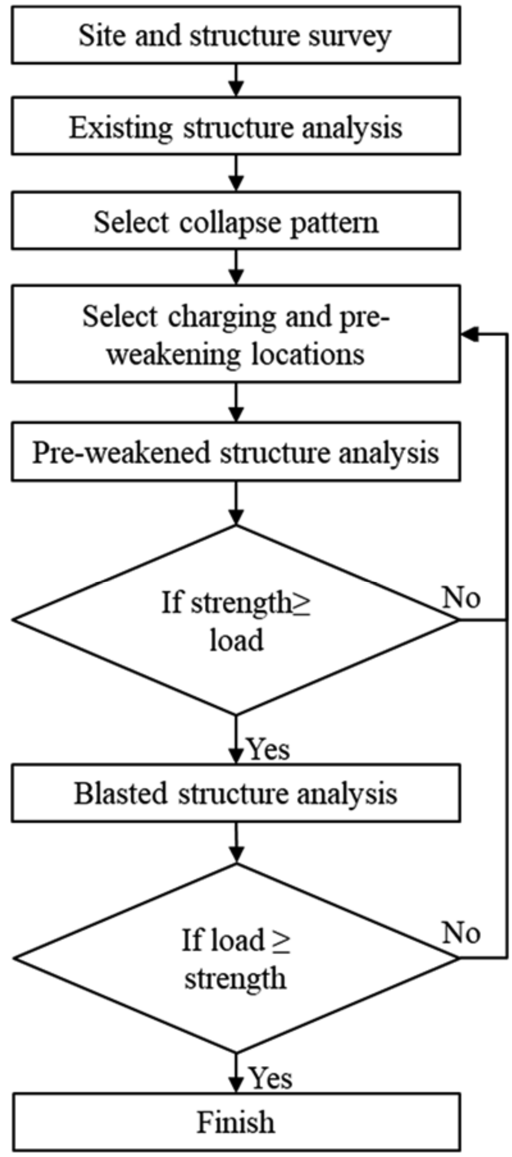
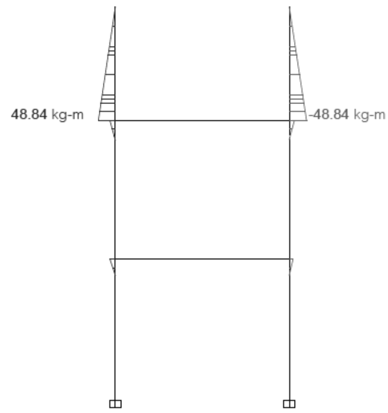
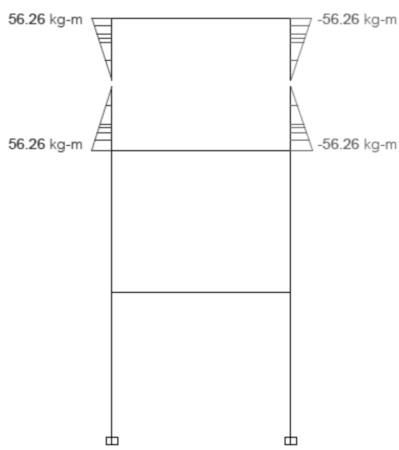


Fig. 9 Blasting demolition design procedure

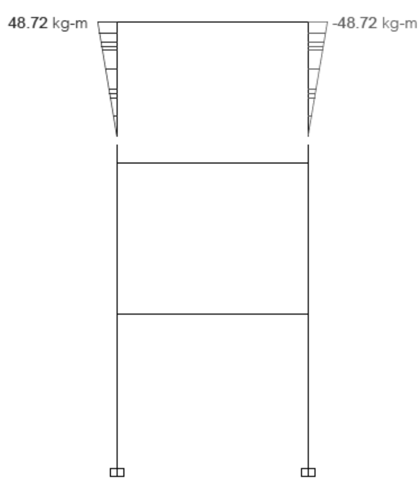
Pre-weakening pattern used in the analysis was the Type-2, the weakest one. V-cuts on inner side, slit cut on outer side and web at column lower ends were applied on each level to allow bending of columns. The analysis results shown in Fig. 10 elucidated that blasting at upper or lower ends of columns required similarly small bending moment of around 49 kgf.m to bend each columns.



(a) When blasting at the upper ends



(b) When blasting at the middle



(c) When blasting at the lower ends

Fig. 10 Analytic results of each blasting point

Nonetheless, blasting at the middle of columns needs more than two times larger force to bend columns. In ¼ scale steel structure blasting here, beside applying Type-2 of pre-weakening pattern on the structure, the upper end of each column was cut its flanges at outer side, the same pattern as blasting test. Moreover, steel wires were installed at the upper end of columns in each level and floor slabs were cut into two pieces at the middle to utilize floor slab weight in generating sufficient bending moments. To initiate collapse of the structure, a dozen of C-4 explosive charges are placed on column upper ends in each level. However, the lower ends of columns at level 1 are also placed the charges to ensure the collapse of the structure. In order to create sufficient bending moments on columns lower ends, additional 6 charges are placed at the middle of each front and back beam to release the potential energy of floor weight to pull the steel wires.

The blasting setup is already shown in Fig. 8. After placing 22 C-4 explosive charges at each location, the charges were fired in three steps from top level down to ground level with detonation caps. Firstly, upper ends of columns in level 3 and both front and back upper ceiling beams were fired. Then the same pattern was repeated in level 2. Finally, in level 1 addition to the same pattern as level 2 and 3 the charges at lower ends of 4 columns were also detonated at the same time.

(a) Level 3 detonation

(b) Level 1 detonation

(c) Steel structure after blasting demolition

Fig. 11 Steel structure blasting demolition

Detonation interval time between each level was set at 0.3 second. Fig. 11 (a) to (c) shows detonation in level 3, level 1 and the result after blasting demolition. Although all charges in level 2 and some other charges were not detonated due to malfunction of the detonators, the structure toppled down and the columns that had been blasted were severed from the ground completely with plastic hinges created at pre-weakened point as shown in Fig. 12.

Fig. 12 Bended column with a plastic hinge at lower end

4. Conclusion

1. Pre-weakening of H-beam steel structure with Vcut on inner side, slit cut on outer side with or without beam web slit cut can significantly reduce beam's flexural resistance.

2. Proper amount of C-4 explosive ribbon charge to sever SS400 steel beam completely can be derived by equation (1)-(3) in which k value can be reduced to 2 in case of relatively thin steel plate.

3. Residual flexural resistance of steel columns using H-beams can be calculated using FEM and elastic perfectly plastic model.

4. H-beam steel structure collapse designing procedures were proposed in 3.3 and the steel structure can be demolished using C-4 explosives charges placed in contact to its members along with pre-weakening pattern mentioned in 2.

5. Reference

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