Development of Protection Techniques for Explosive Demolition of RC Pillar

철근콘크리트 기둥 발파해체를 위한 방호기술 연구

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ABSTRACT. Safety concern is one of the most important parameters in the design of building demolition by explosive blasting. Accidents were sometimes reported due to the flying chips of fragmented materials in building demolition work in urban area. Laboratory experiments were performed to investigate the failure behavior of reinforced concrete pillars under blast loading and to develop an effective protection technique. Sixteen reinforced concrete pillars were constructed. The failure behavior and the flying chip velocities were observed by means of a high-speed camera. Protection scheme was designed and the effects of several protection materials were investigated. Two kinds of non-woven fabrics and wire net were tested as protection materials. The results showed that reinforcing bar was one of the important factors to determine specific charges, and that mesh size of wire net and tied-up method affected the protection of flying chips. Control of gas effects is also a key to the control of flying chips. It was recommended to use both wire net and non-woven fabrics as primary and secondary protection materials. Such protection scheme was successfully applied to the explosive demolition of apartment buildings.

Key Words: explosive demolition, building demolition, control of flying chips, high speed camera, protection technique

초 록. 화약발파를 이용한 건물해체 설계에서 고려해야할 중요한 인자중 하나는 안전문제이다. 도심지에서 수행된 건물발파해체 사례에 의하면 부재 폭파시 발생한 파쇄물이 비산되어 인접한 건물이나 인명에 피해를 주어 심각한 문제를 야기시킨 사례들이 보고 된 바 있다. 본 논문에서는 건물발파해체시 발파로 제거하는 주요 부재중 하나로서 철근콘크리트 기둥에 대한 적절한 방호기법을 개발하기 위해 수행된 실험적 연구 결과를 제시한다. 기둥은 실제 규모로 제작되었으며 몇 가지 재료들에 대하여 고속카메라를 이용한 관찰 및 파괴 특성을 고찰하고 방호 특성을 분석하였다. 주요 결과의 하나로써 비산을 제어하는 핵심 기술은 기둥 발파시 발생하는 가스압을 제어하는 기술임이 확인되었으며 이를 위한 방호재 설치 기법이 제시되었다, 이 기술은 실제 발파해체시 성공적으로 적용되었다.

핵심어 : 발파해체, 건물해체, 비산제어, 고속카메라, 방호기법

1. INTRODUCTION

The use of explosives for demolition of structures has advantages over the conventional methods accomplished by mechanical tools, especially for high story buildings. In urban areas, safety concern is one of the most important parameters in the design of building demolition by explosive blasting. Flying chips from blasting columns may have serious impact on both personnel and the environment. Some accidents occurred due to the flying chips of fragmented materials in demolition projects in a block of large buildings in urban area. Laboratory experiments were performed to investigate the failure behavior of reinforced concrete pillars under blast loading and to develop an effective protection technique. The failure behavior and the flying chip velocities were observed by means of a high-speed camera. A protection scheme was designed and the effects of several protection materials were investigated.

2. EXPERIMENT

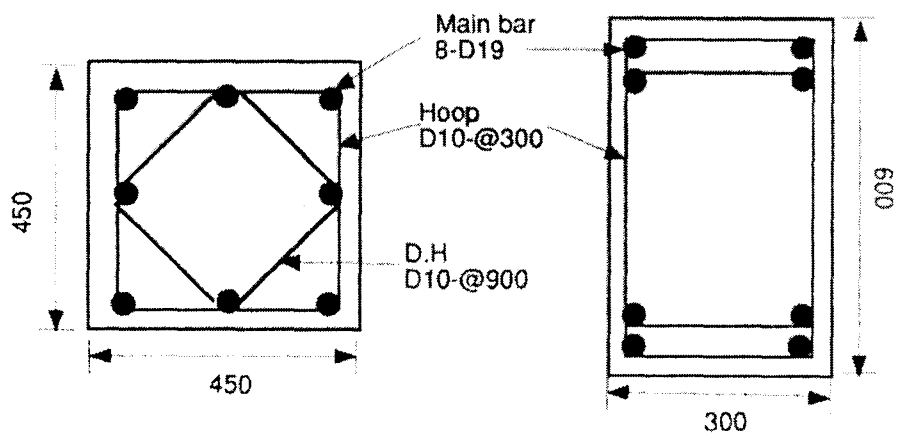
2.1 Preparation of Specimen

Sixteen reinforced concrete pillars were constructed with two sizes of which dimensions are: 450×450×180 mm, designated as column I, and 600×300×1800 mm, designated as column II. The columns were provided with plane face at both ends and hooks for lifting on one side.

Reinforcement of column I (see Fig. 1a): 8 main bars of Φ(diameter) 18 mm, hoops of Φ10 mm, spaced by 300 mm;

Reinforcement of column II (see Fig. 1b): 8 main bars of Φ18 mm, hoops of Φ10 mm, spaced by 300 mm, cross hoops of Φ10 mm spaced by 900 mm.

In order to ensure the compressive strength of the concrete to be over 210 kg/cm^2, it was designed to use No 325 slag cement. The job mixture proportion was: cement/sand/aggregate = 1/1.6/3.0 and the water/cement ratio of 0.52 was adopted. When the specimens were produced, test samples were made and



(a) Reinforcement of Column I (b) Reinforcement of Column II

Fig. 1. Diagram Showing Reinforced Test Specimen Column

kept for compression test after a standard curing of 28 days. The whole lot of specimens (16 columns in all) was prepared in two batches, each batch provided with 12 test sample cubes of 15×15×15 cm. These test sample cubes for each batch were put to compression tests individually and the compressive strength values obtained from these tests were 344 kg/cm^2 and 324 kg/cm^2, respectively, thus the compressive strength of the specimens for this test being acceptable with the average value of 334 kg/cm^2.

2.2 Design of Blast Parameters

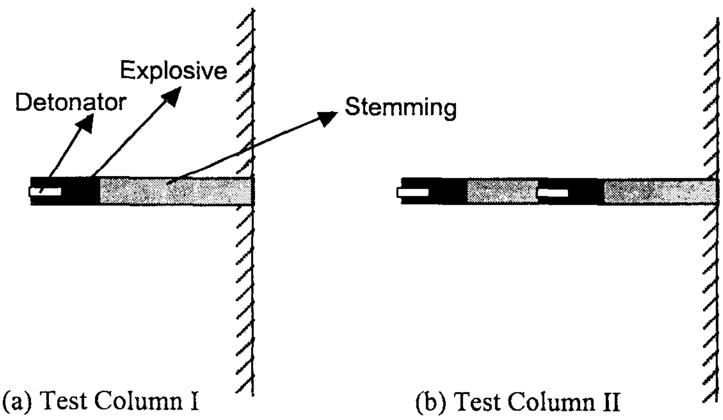
(1) Explosives

The #2 ammonia-antimony rock explosive of high safety and power was selected. The detonation velocity is 3,286 m/sec, density of 0.95 - 1.10 g/cm^3 and 32 mm in dia. According to the method proposed by U. Langefors that the power of the explosive, S, shall be calculated to the standard of Dynamite 35% NG explosive (calculated power S=1), with 5/6 for the explosion heat Q_v and 1/6 for the specific volume V_o, the power S of the explosive for the corresponding calculated weight is 0.833 [1].

(2) Drilling and charging

When the specimens were prepared, blast holes were also prepared in them so as to ensure soundness of the holes free from any damages on the specimen due to drilling. With regard to column I, as there was a main bar passing through the blast hole, the main bar was bent in an arc at the place of the hole to bypass it. The blast holes were precast on the central axis of each column with a hole diameter of 36 mm. On column I, the holes had a depth of 400 mm spaced by 300 mm, 4 holes on each column.

As originally designed, the specific charge q for blasting of the reinforced concrete column was 1.0 - 1.25 kg/m^3 and consequently the explosive charge for each hole Q_i was 81 - 100g for column I and 54 - 67.5g for column II. After the preliminary tests, the specific charges for



(a) Test Column I (b) Test Column II

Fig. 2. Diagram Showing Charge Structure

the columns I and II had been adjusted to 0.7 kg/m^3 and 1.30 kg/m^3, respectively and the charge in each hole was adjusted to 57g and 70g accordingly. For column I, concentrated charge at hole bottom and inverse initiation were adopted; for column II, separated charge in two segments and inverse initiation were adopted so as to raise the blasting effect as the lateral resistance was less (W = 15 cm). The hole was deep and the charge length was short. The details are given in Fig. 2.

2.3 High Speed Photography Scheme

The system was composed of a LBS - 16A high-speed camera of compensator type, a synchronous controller for the blasting and the high-speed photography and a 3 way pulse-delay generator as shown in Fig. 3.

The main technical indices are given in Table 1. The frame frequency was determined to take 1000 - 2000 fps, the bigger value taken for the case of strong illumination and the smaller value taken for the case of weak illumination, in consideration of the film packing size of 30 m/case and the film consumption at the acceleration stage of the LBS-16A camera high speed operation.

In order to obtain the actual information about the lateral movement of the reinforced concrete column at the time of blasting (bulge and flying chip), the camera should be located in front of the test specimen column with the main beam axis perpendicular to the normal line of the column side (i.e. on the same plane of the precast blast hole center line) and at a

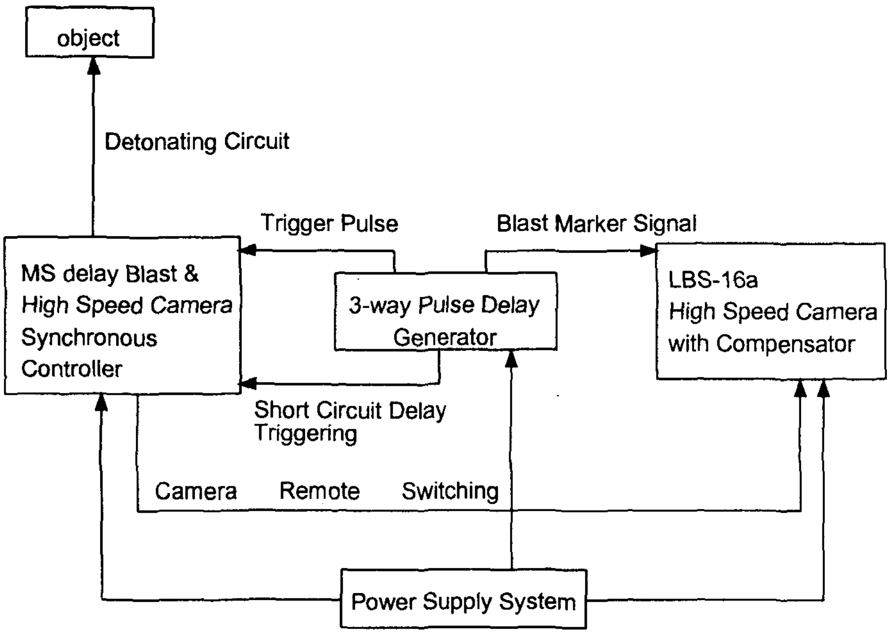


Fig. 3. Diagram of High Speed Photo Testing System

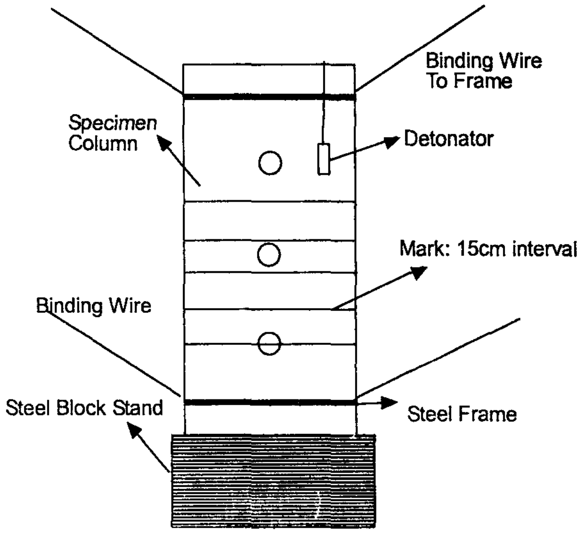
distance as short as possible. The camera should be protected by metallic wire net as a safety measure.

Table 1. Specification of High Speed Camera Model LBS-16A

Frame Rate	100 8,000 frame/sec		
Image Size	7.5 x 10.4 mm		
Film Capacity	Max. 120 m/case		
Dynamic Resolution	40-55 line pair/mm		
Shutter Factor	1/2.9		
Time Scale	5 settings of 100, 500, 1000, 5000, and 10,000 Hz		
Technical Features			
Focal Distance	38	100	500
Relative Aperture	1:3	1:3	1:3
Field Angle	19o 7′	7o 24′	1o 30′

2.4 Fixation of Test Specimen Column

For the tests, the specimen column was fixed at both ends as it was a slender long column, not stable if just placed upright and it easily toppled and fell during test due to vibrations from the blast, thus affecting the test results. The detailed fixation was: As shown in Fig. 4, a metallic trestle was provided and wooden blocks were stacked on the ground to from a stand; a chain block was used to lift the test specimen column and place it on the stand, assuring column center line and the main optical axis of the camera to be on the same horizontal plane so as to remove any interpretation error due to camera inclination. Then a #8 steel wire with 4.06 mm in diameter was used to bind the two column ends by 2 to 4 turns, this measure being helpful for stability of the column and also removing part of the end effects, and finally to fasten the column tightly onto the four supports of the trestle, respectively.



fabric 2.1×2.1 m; (C) metallic wire net 2.2×1.8 m having 3.25 mm in wire diameter and grid of 5×5 cm. The gray non-woven fabric is a cheap texture, which is 5 mm thick. It is generally used as covering material for heat insulation. The white non-woven fabric is made from polyester long fiber having 15 kgf/cm^2 in tensile strength, 10 kgf in tear strength, and 70-100% in elongation.

The tests consist of four preliminary tests and twelve formal tests. In the case of using single protective material, it was in close contact with the column and tied by five turns of wire spaced at 0.36 m. In the case of using non-woven fabric and wire net for the protection, the wire net was first applied to the column and the joint was tightly fastened and then over the wire net the non-woven fabric was wrapped and tied. At the 11th and 12th tests, the protection method was to hang gray non-woven fabric at two layers of fabric at the other side, and at the same time, at the side with blast hole openings, at a distance of 0.8 - 1 m from the column face, a layer of white non-woven fabric was hung.

2.6 Preliminary Test

The preliminary tests were carried out in a tunnel for blasting in order to find the proper blast parameters, adjust the high-speed photography parameters and modify the test plan. The test results are given in Table 2. The first preliminary test was carried out on column I with no protection. According to the original test scheme, the specific charge for blasting of the reinforced concrete column, i.e. q = 1.0 - 1.25 kg/m^3 was taken and the charge in one hole of column I was Q_i = 80 - 100g. The larger value, i.e. 100g for one hole and total charge of 300g, was taken for the test. After blasting, the reinforced concrete column was shattered, the 8 bars were pulled out and the hoops were thrown away, the results showing too much charge.

Table 2. Results of Preliminary Test

Test Column	Protection Material & Method	Charge Weight per Hole(g)	Specific Charge (kg/m^3)	Description of Test Results	Remarks
Column I	Non	100	1.23	Shattered column bars pulled out; too much charge	
Column I	C+blue fabric	57	0.7	Broken hole area bars bulged at sides good result	W/ wire mesh
Column II	Non	38	0.7	Local hole area broken but not all too small charge	Specific charge adjusted to 1.1 kg/m^3
Column II	C+blue fabric	60	1.1	Broken hole area in large lumps; insufficient charge	Specific charge adjusted to 1.31 kg/m^3

On the basis of the first test, with reduced charge to q = 0.7 kg/m^3, the second test was still conducted on column I with the charge of 57g. The whole column was wrapped with a metallic wire net (1.8×2.2 m) as protection and the net joint was secured at 8 points with wire and metallic wire was used to bind the column end and the middle with 2 or 3 turns; in addition, blue protective fabric was hung at both sides of the column with parallel to the side faces, in close contact on one face and at a distance of 35 cm to the other face to see how the protection was. The test results: No damage of the net only with net joint forced apart, some broken chips thrown out, middle portion of reinforced concrete column in the blast hole area completely shattered and thrown away, main bars at column sides bulged, a part of about 45 cm in height at the ends not shattered, blue protective fabric not damaged (see Fig. 5). These results indicated that the charge adopted was appropriate.

At the third test, column II was tested with no protection. The specific charge was 0.7 kg/m^3, a charge of 38 g packed and filled in two rolls for one hole with the charge structure as shown in Fig. 2b. The test results: Column partially broken in the hole area with exposed bars, obviously insufficient charge resulting from more and dense hoops of column II requiring increased explosive charge (see Fig. 6).

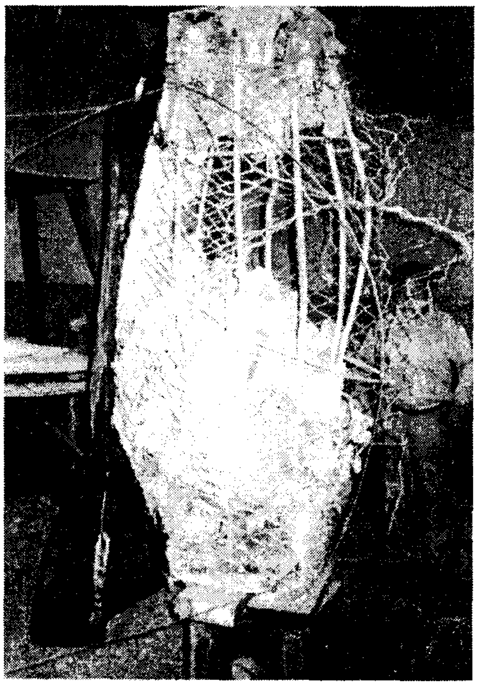


Fig. 5. View after 2nd Test Blasting, Column I.

Fig. 6. View after 4th Test Blasting, Column II.

Hence, at the fourth preliminary test, the specific charge was raised to 1.1 kg/m^3, that is, 60 g in each hole filled in two segments. It was protected by metallic wire net in the same way as in the second preliminary test. The test results: Column shattered in the hole area, net not damaged with only open joint, showing still insufficient charge. As a result, it was decided that the specific charge for column II in the formal tests should be increased to 1.3 kg/m^3, 70 g for one hole. Through the above four preliminary tests, it was found that the specific charge for the columns of two size, as the hoop structure and resistance line were different, should be modified to have a bigger difference. It was appropriate to take 0.7 kg/m^3 as the specific charge for column I while for column II it should be increased to 1.3 kg/m^3, all these two values being out of the original range of the design scheme.

3. RESULTS AND DISCUSSION

3.1 Effects of Protection Methods

The blast charge and unit consumption for the formal tests were taken from the preliminary test results: 0.7 kg/m^3 as the specific charge for column I, 57 g in one hole; 1.3 kg/m^3 as the specific charge for column II, 70 g in one hole. In the course of the tests, in order to accurately know the distance and distribution of the flying chips in the blast, a piece of white non-woven fabric marked with scale was placed beforehand on the ground to the direction of the blast hole opening and one side where there might be most flying chips, so that such data as distance and size of some flying chips could be obtained at the blast test. Summary of test results are shown in Table 3. The results of the 1st to 4th test showed that gray non-woven fabric did not play a role of protection material at all, while white non-woven fabric had some controlling effects depending on the arrangement. The parts around charge hole was torn or partly thrown away and the torn holes around the charges imply that it is especially weak against heat. But white fabric seems be effective to relieve the gas pressure and thus control the acceleration of fragment movement.

The 5th and 6th test results showed that wire net was very effective to control the fragments. Large size of fragments occurred near free surfaces and smaller toward the charge, making most of fragments being captured inside a net even if the size of the fragments was smaller than that of wire grid. However, flying chips escaped from the net accelerated much more resulting in greater flying distance. Thus, without additional protection, use of wire net only is not enough for safety.

The results of the 7th to 10th test showed that combination of wire net and non-woven fabric might be a good protection method. The gray non-woven fabric could not control the fragments passing through the net (see Fig. 7) while the white gray non-woven fabric control them very effectively (see Fig. 8) It is recommended to use wire net as primary protection material and white non-woven fabrics as secondary one.

Inverse combination may be less effective in controlling the fragments around the charging area.

Table 3. Description of Test Results

Test Column (No.)	Protection Material & Method	After Tests		
		Protection Material	Test Column	Flying Chips
Column I (1)	A, tied by 5 turns of metallic wire	Completely torn, a great part thrown away with flying chips	Concrete completely shattered and thrown away in hole area, bars exposed, a part of 25-35cm thick at column ends not shattered but cracked not shattered but cracked	A chip of 146g thrown to a point 20.2m from hole opening; a chip of 1170g thrown to 23m to right side of column
Column II (2)	-ditto-	-ditto-	Concrete shattered in hole area, a great part thrown away, bars exposed, a part of 30-40cm thick at column ends	A chip of 350g thrown to a point 19m away from hole opening; a chip of 95g thrown to 20.5m to right side of column
Column I (3)	B, tied by 5 turns of metallic wire	Non-woven fabric torn, a part thrown away	Column toppled, 8 bars all pulled out; a part of 35-40cm thick not shattered but cracked	A chip of 21g thrown over 29m from hole opening; a chip of 83g to 22m and another of 15g to over 23.5m to right side
Column II (4)	-ditto-	Non-woven fabric joint forced apart, torn holes at some part, but still hung on column	Concrete shattered and thrown away in hole area, bars loosened, a part of 40-50cm thick at column ends not shattered but cracked	A chip of 46g thrown to a point of 32m from hole opening; a chip of 66g thrown to 23 m to right side of column
Column I (5)	C, joint secured and tied up by #8 wire	3 torn holes of about 100㎠, the rest in good condition	Concrete shattered in hole area, all fallen upon removal of wire net; a part of 33-41cm thick at ends not shattered	A chip of 24g thrown to 32m from hole opening; a chip of 17g thrown to 11m at right side
Column II (6)	-ditto-	A torn hole of 500x300 mm over column face with blast hole, the rest in good condition	Concrete in hole area shattered, all fallen upon removal of wire net; a part of 20-30 cm thick at ends not shattered but creaked	Chips of 25g thrown to 32m from hole opening; chips of 37g thrown to 21m at right side
Column I (7)	C + A, wrapped first by wire net then by fabric	Torn holes on both materials	Broken pieces all fallen upon removal of protective materials; a par of 35cm thick at ends not shattered	No flying chips at various places except some flying chips from torn holes

Table 3. Description of Test Results (Continued)

Test Column (No.)	Protection Material & Method	After Tests		
		Protection Material	Test Column	Flying Chips
Column II (8)	-ditto-	Grey fabric torn, wire net partially torn at blast holes and at right side	Concrete in hole area shattered, all fallen upon removal of protective materials; a part of 40-45cm thick at ends not shattered	A chip thrown to 27m from hole opening and to 22m at right side
Column I (9)	C+B, (tied in the same way as above)	Only lap joint of white fabric torn apart	All broken pieces fallen upon removal of protection; a part of 15-40cm thick at ends not shattered	No flying chip
Column II (10)	-ditto-	White fabric torn, wire net damaged with many torn holes	Concrete at blast hole area shattered; a part of 40-44cm thick at ends not shattered	3 chips of 20g, 29g and 46.5g thrown away 32m from hole opening; a chip of 129g thrown by 9m at right side
Column I (11)	A+B, gray fabric hung a both sides, white fabric at hole side, lower end fastened by wire	White fabric thrown by 7m; gray fabric at left side torn to strips, many torn holes at right side and shifted backwards over 1m	Concrete shattered and thrown away; a part of 45cm thick at ends not shattered but seriously cracked	A chip of 99g thrown to over 32m from hole opening; a chip of 129g thrown to 20.2m at right side
Column II (12)	-ditto-	All fabric torn	Concrete at hole area shattered and thrown away; a part of 27-35cm at ends not shattered	A chip of 143g thrown to 29m from hole opening; a chip of 78g at right side thrown to over 23.5m

Note: A - gray non-woven fabric; B - white non - woven fabric; C - metallic wire net

Fig. 7. View after Blasting,
Column I (C+A)

Fig. 8. View after Blasting,
Column I (C+B)

3.2 Analysis of High Speed Photography Results

On the basis of the speed derived at different instant, several regions could be divided and by means of unary nonlinear regression analysis, the movement regularity of bulges and flying chips could be obtained. From the regression curve, the acceleration at different instant could be derived. The mathematical model for the regression curve is:

$$V = \sum_{i=0}^{m} A(i) X^{i}$$

where,

X = generalized time variable, selected as desired

V = speed of blasting movement on film

m = order of multinominal expression, usually 3 or 4 taken

As the camera was able to observe the two sides of the test column, two movement processes of bulge and flying chip from the column could be obtained. For the purpose of distinguishing them, the letter R (right side) and L (left side) were used as subscripts to represent the movement of the bulges and another two letters r and l as subscripts to represent the movement of the flying chips. The photographic test results are given in Table 4.

Table 4. High Speed Photographic Test Results

No.	Column & Protection	Bulging Movement						Flying Chip Movement					
		Forming Time (ms)		Initial Speed (m/s)		Initial Acceleration (m/s^2)		Occurrence Time (ms)		Mean Initial Speed (m/s)		Max. Size (cm)	
		t_R	t_L	V_R	V_L	a_R	a_L	t_r	t_l	V_r	V_l	s_r	s_l
1	C II, A	1.3	0.7	7.94	16.48	2.94	12.68	22	24	19.32	22.53	25.7	15.4
2	C I, A	4.0	3.0	3.20	9.0	0.64	2.25	22	37	14.40	14.11	14.4	8.8
3	C II, B	1.5	2.0	14.47	18.09	5.79	4.52	20	23	18.42	22.39	11.0	9.3
4	C I, B	2.0	1.0	16.10	12.10	5.37	6	19	28	15.70	25.40	12.8	19.2
5	C I, C	1.5	1.5	8.12	10.67	5.41	7.11	13	12	24.60	22.10	8.8	4.8
6	C II, C	1.5	1.5	21.82	13.64	14.55	9.09	9	11	16.43	19.70	4.1	3.3
7	C I, C+A	1.0	1.0	8.42	8.42	2.81	2.81	11	13	12.03	38.16	6.3	4.2
8	C II, C+A	1.5	1	21.42	16.07	14.28	8.04	16	19	41.79	33.75	4.8	4.8
9	C I, C+B	1.8	1.5	11.67	8.36	5.30	3.34	-	-	-	-	-	-
10	C II, C+B	2	1.5	16.07	23.57	16.07	15.71	15	14	21.52	29.47	6.5	4.7
11	C I, A hung	1.3	1.5	11.34	10.71	6.67	7.14	8	10	27.44	18.56	24.4	16.7
12	C II, A hung	1.0	1.0	24.11	24.11	24.11	24.11	5	3	42.86	21.43	17.71	43.4

Note: subscripts R and r - right side; L and l - left side.

4. CONCLUSION

Laboratory experiments were performed to develop an effective protection technique in blasting RC pillars. The results show that the unit explosive consumption depends on the reinforcing bar as well as material properties. Control of gas effects appears to be a key to the control of flying chips. In order to prevent the acceleration of flying chips, effective gas release is required. Wire net is shown to be very effective to hold most of fragments and white non-woven fabric to relieve gas pressure. In this regard, it is recommended to use both wire net and non-woven fabrics as primary and secondary protection materials.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Ni Shishan and Sha Wenjian at China Central Coal Mining Research Institute for support in the high-speed photographic test.

REFERENCES

1. Langefors, U. & B. Kihlstrm, 1978, The Modern Technique of Rock Blasting, John Wiley & Sons, 438 pp.