Research paper

Influence of obstacles on the precursor air shock wave progression

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Abstract

A dead-pressing phenomenon by the precursor air shock wave (PAS) going in an air channel, is commonly known as the channel effect. We have been investigated the mechanism of the channel effect in emulsion explosives in the case of smooth blasting, some experimental work has been carried out in laboratory. Hence, it is concluded that decreasing PAS velocity would be effective for the prevention of occurrence of channel effect. In this study, the obstacles in an air channel were applied to inhibit the PAS progression. Some experimental works have been made to investigate the influence of obstacles. It is found that an insertion of obstacles into an air channel is one of the effective methods for the inhibition of the PAS progression.

Keywords: Emulsion explosive, Channel effect, Precursor air shock wave (PAS), Obstacles

1. Introduction

Smooth blasting technique is widely applied for tunneling road or railway construction. Smooth blasting is one of the controlled blasting techniques to reduce the damage and overbreak beyond the intended excavation. The unexpected falling rocks are attributed to this damage at the perimeters of the excavation, and are undesirable and fatal from the view point of safety operation. In economic aspects, smooth blasting technique as a contour blasting makes it possible to minimize the cost of concrete lining for refilling the overbreak area. In case that the conventional blasting technique is applied, undoubtedly an excess overbreak must be expected comparing to the smooth blasting technique.

However, smooth blasting technique has some disadvantage. Smooth blasting technique often causes problem related to detonation failure in explosive column. When explosives placed in the decoupled charge hole are detonated, a precursor air shock wave (PAS) is generated between the explosive columns and the inner wall of charge hole. The PAS, progressing ahead of detonation front in explosive columns, precompresses and desensitizes the explosive columns. When detonation wave reaches this precompressed point, detonation wave ceases to propagate regularly. Thus, detonation velocity decreases and detonation failure occurs. This phenomenon is well known as the channel effect. Several works on the channel effect have been conducted under various conditions, using some kinds of explosives [1)-9)].

In our previous work [10)], we concluded that the time lag between the PAS progression and the detonation propagation was the primary factor in the detonation failure. The time lag means the precompression time for dead-pressing on emulsion explosives. It was proved on another work [11)] that the surface roughness of inner wall of borehole gives an influence on the PAS progression. And decreasing PAS velocity was one of the effective methods for the prevention of occurrence of channel effect in the charge hole.

In this study, main purpose is to explore realistic means of prevention for channel effect on actual blasting scene. The obstacles in an air channel were applied to delay PAS progression. Some experimental works have been made to investigate the influence of obstacles. In test series A, photographic observation has been carried out using high-

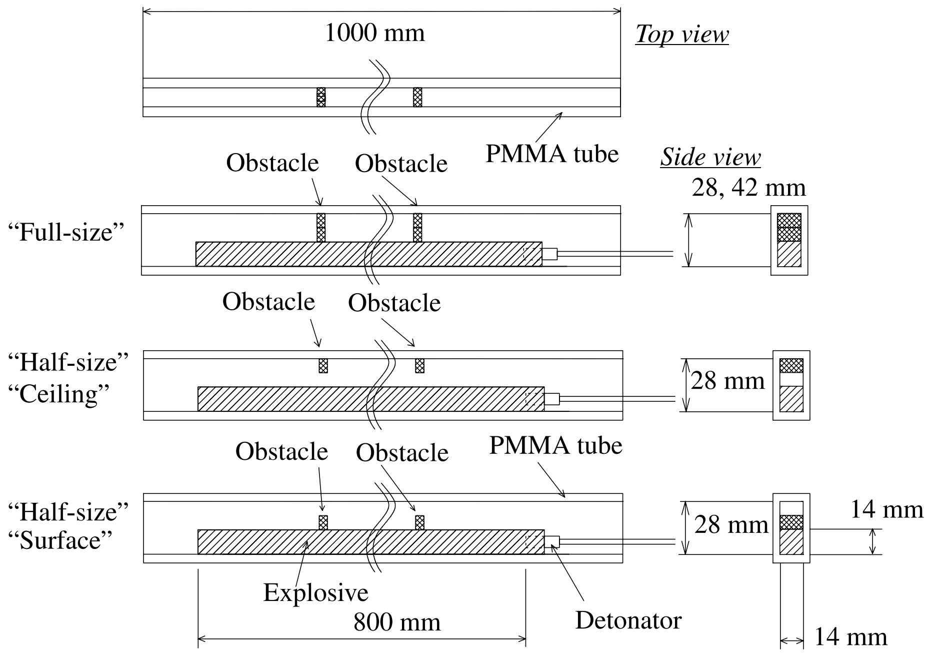


Fig. 1 Experimental arrangement used in test series A.

speed framing camera to confirm the state of PAS progression. In test series B, experiments were performed using plate-shaped obstacles in the polyvinyl chloride (PVC) pipe to simulate actual blasting configuration. The influence of materials, sizes and number of obstacles on detonation propagation length was investigated. We made a comprehensive assessment of the effect of obstacles on the prevention of PAS progression.

2. Experimental

2.1 Explosives

Only one kind of typical water-in-oil emulsion explosive was applied for this work. It is just an emulsion explosive named "explosive 3" in our previous work [10]. This explosive was cap sensitive, and its critical diameter was 6-8 mm. The detonation velocity of the unconfined emulsion explosive was 3000 – 3300 $m \cdot s^{-1}$ in the case of a rectangular cross section of 14 × 14 mm, and 3600 – 3900 $m \cdot s^{-1}$ in the case of a circular cross section of 20 mm in diameter.

2.2 Experimental arrangements

Test series A ; The emulsion explosive was charged in a transparent tube with rectangular cross section, which was made of 4 mm thick polymethylmethacrylate (PMMA) plates. The length of rectangular PMMA tube was 1000 mm. The inner width of the tube was maintained to be 14 mm. The inner height was changed to modify the decoupling coefficients in the experiments "full-size" obstacles were used. However, the inner height was maintained to be 28 mm in the experiments "half-size" obstacles were used. The explosive was charged in the form of rectangular cross section of 14 by 14 mm and 800 mm in length. PMMA plates with same thickness were chosen as obstacles. Two types of obstacle shape were used in this experiment. One was "full-size" obstacle, and the other was "half-size" obstacle. The full-size obstacle could reach from the explosive surface to the ceiling of wall in an air channel, and can completely separate each compartment. The height of half-size obstacle was just a half of full-size obstacle. The configuration of obstacles was varied in three ways. In the first experiment, two full-size obstacles were used. In the second experiment, two half-size obstacles were attached to the ceiling of wall. In the third experiment, two half-size obstacles were put on the explosive surface. The obstacles were placed at 300 and 600 mm from the tip of the precision electric detonator respectively. Figure 1 shows the experimental arrangement used in test series A.

A photographic observation system was just the same as our previous work [10] too. In this investigation, two picture framing rates of 1.0×10^5 and 5.0×10^5 frames per second (FPS) were applied and the interframe time were 2 and 10 μs . The positions of the PAS and the detonation wave were determined from the sequential photographs taken.

Test series B ; Sample emulsion explosive was packaged into polyethylene tubes made by thin film of inner diameter 20 mm and 550 mm in length. Three cartridges of explosives were connected by two "SB joints" made of Polycarbonate (PC) resin pipe with length of 150 mm. Polyvinyl chloride (PVC) pipe of 2000 mm in length was used to simulate the actual charge hole. The inner diameter and wall thickness of the PVC pipe were varied to evaluate the effects of decoupling coefficient and the degree of pipe confinement. Table 1 presents the specification of the PVC pipe and corresponding decoupling coefficient.

Three kinds of material shown in Table 2 were chosen for

Table 1 PVC pipe specification.

Name	Inner diameter (mm)	Thickness (mm)	Decoupling coefficient
VP40	40	3.6	2.00
VU40	44	1.8	2.20
VP50	51	4.1	2.55

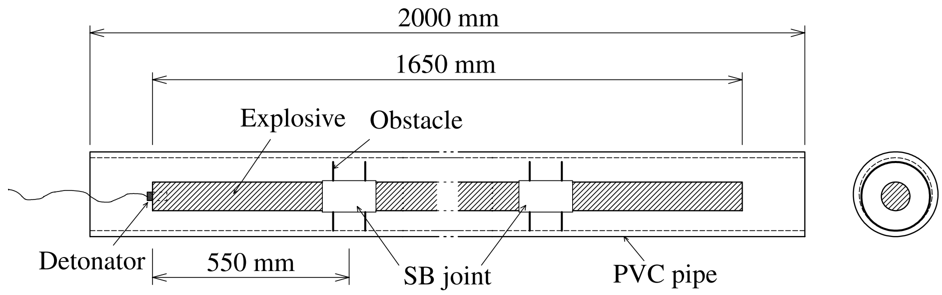


Fig. 2 Experimental arrangement used in test series B.

Table 2 Materials of obstacle.

Material	Thickness (mm)
Copper	0.3
Aluminum	0.3
PVC	1.0

Table 3 Obstacles size.

Applied pipe name	Obstacle diameter; mm (Occupied area ratio) Large-size	Small-size
VP40	36 (81 %)	30 (56 %)
VU40	40 (83 %)	32 (64 %)
VP50	48 (88 %)	44 (74 %)

※ Occupied area ratio : area ratio of obstacle / PVC cross-section

obstacles materials.

The obstacles used in this experiment are perforated disc just like a “flange”. One or two obstacles were attached to a SB joint. The size and number of obstacles were varied to study those effects on detonation propagation. Table 3 shows the obstacles size.

Three cartridges of explosives connected by SB joints with obstacles was placed inside PVC pipe, and was initiated by an electric detonator. Both ends of the pipe were opened not to be choked. So, initial pressure of air channel was kept at atmospheric conditions. Figure 2 shows the experimental arrangement used in test series B.

This figure shows the case in which four obstacles are applied. Detonation propagation length of the explosive was determined after test.

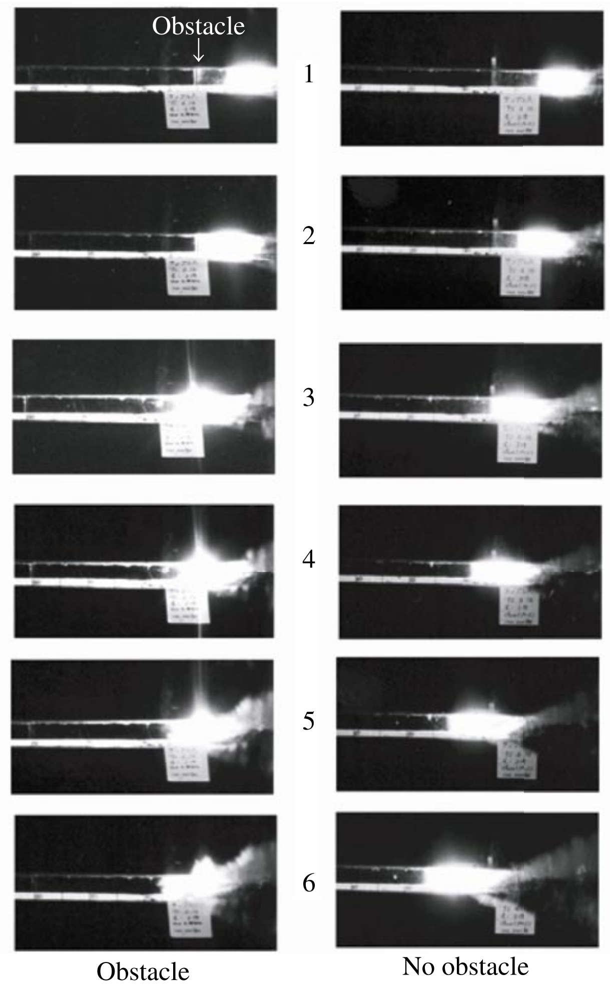


Fig. 3 PAS progression in PMMA tube.

3. Results and discussion

3.1 Test series A (PMMA tube)

Figure 3 shows sequential high speed framing photographs obtained in two different conditions. The photos on left row were obtained in the experiment PMMA tube with two full-size obstacles were used, and the photos on right row were obtained in the experiment PMMA tube with no obstacles were used. The interframe time of each photo was 10 μs.

In the case that PMMA tube with 28 mm in height, corresponding to the decoupling coefficients ; 2.0, with no obstacle was used, detonation wave could propagate to 490 mm in length. However, in the case that PMMA tube of same height with full-size obstacles was used, detonation propagation length was decreased to 330 mm. The effect of obstacle was not found in this experiment

Figure 4 presents the relation between propagation length and time of detonation wave and PAS determined from the sequential photographs.

The broken line with symbols of triangle indicates PAS propagation length in the case of “No obstacle”. And the solid line with symbols of circle indicates the length in the case of “Obstacles”. It is clearly shown that the addition of obstacles hinders PAS from progressing at the point where obstacle is positioned. However, the propagation of detonation wave was stopped near the point where obstacle is positioned.

As mentioned previously in “Experimental arrangement”

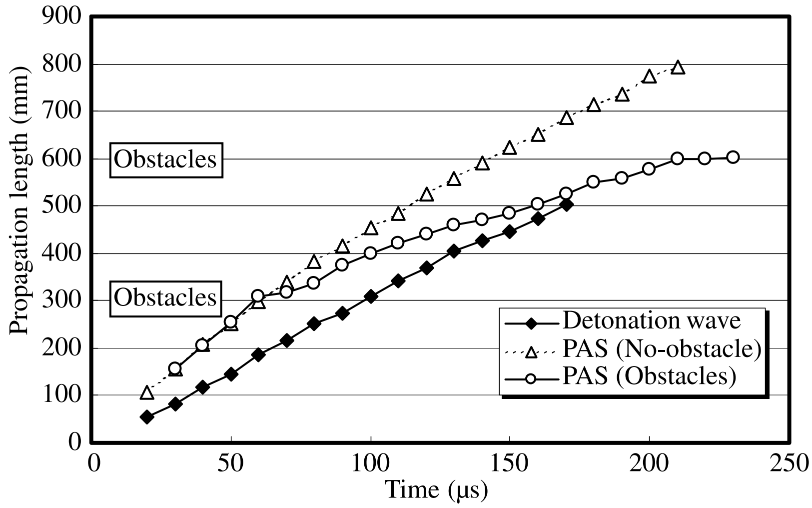


Fig. 4 Propagation length of detonation wave and PAS (Deco ; 2.0).

section, the obstacle could completely separate each compartment. Therefore, it can be assumed that PAS delayed by obstacle may be reflected on the surface of obstacle, and travel to opposite direction. This PAS progressing in opposite direction and the initial PAS may be concentrated at the point close to its obstacle in an air channel. Consequently, the air pressure rises at this area. And this high-pressure air compresses the explosive column. If this assumption is correct, it is concluded that detonation failure attributes to this air compression.

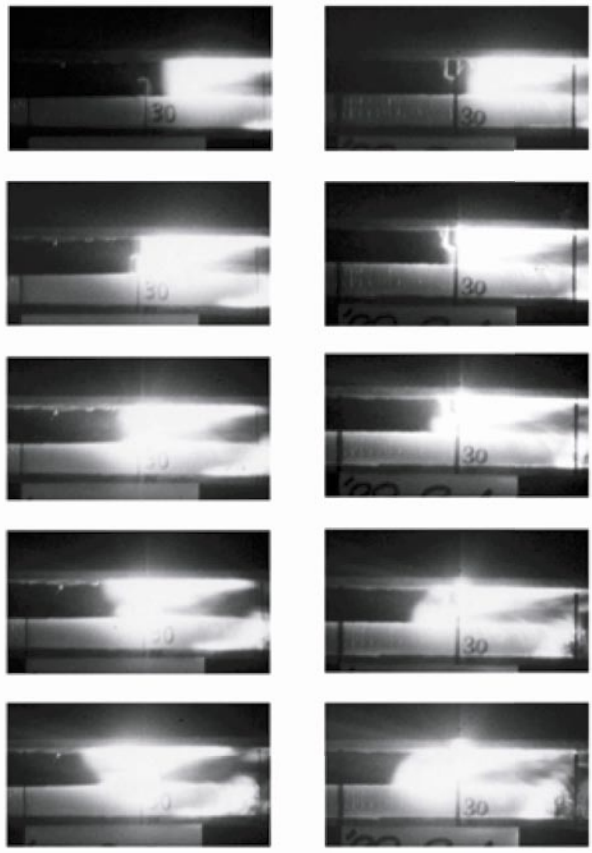
In our previous work [11], we performed photographic observation of channel effect in the experiment PMMA tube with sandpaper was used. Sandpaper was glued on the ceiling of PMMA tube. Sandpaper could decrease the PAS velocity, and could improve the ability of detonation propagation. In other words, it is not necessary to stop PAS progression completely, and it is only necessary to delay the PAS progression. Therefore, half-size obstacle was applied in the next experiments

It is considered that the PAS is generated by the combination between shock wave caused by detonation of explosive and its reflection wave according to Mach reflection on ceiling surface. So, it is assumed that the configuration of obstacles will give an influence on PAS progression. The configuration of half-size obstacles was varied in two ways. One way was that two half-size obstacles were put on explosive surface. Another way was that two half-size obstacles were attached to ceiling of wall.

Figure 5 shows high speed framing photographs obtained in two different conditions. The photos on left row were obtained using PMMA tube with two half-size obstacles on explosive surface, and the photos on right row were obtained using PMMA tube with two half-size obstacles on ceiling of wall. The interframe time of each photo was 2 μs.

Photographs clearly indicate that the status to pass through the point of obstacle is different in both conditions. However, there was no difference of detonation propagation length, and detonation wave could completely propagate to 800 mm in length in both conditions.

Figure 6 presents the relation between propagation length and time of detonation wave and PAS determined from



Surface Ceiling

Fig. 5 PAS progression in PMMA tube.

each high speed-framing photograph. The solid line with the symbols of circle indicates PAS progression length in the case of "Surface". And the broken line with the symbols of triangle indicates the length in the case of "Ceiling". It is shown that the statuses of PAS progression are approximately same in these both conditions.

This figure also demonstrates that two PAS lines are approximately parallel with detonation wave line. It means that the time interval between the arriving time of PAS and that of detonation wave at the same point is constant. The time lag also means "compressed time" against explosive.

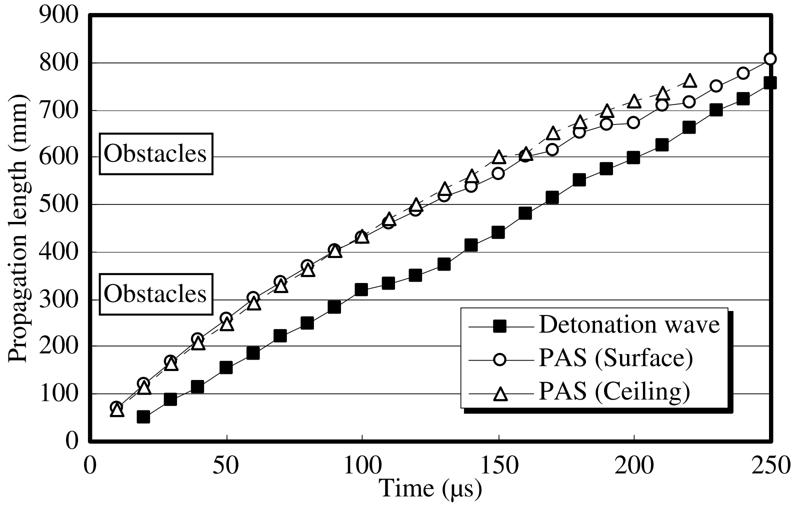


Fig. 6 Propagation length of detonation wave and PAS.

Table 4 Summary of detonation propagation length in various testing conditions.

Number of obstacles	Obstacle size	Material	Detonation propagation length (mm) VP40	VU40	VP50
4	Large	Copper	**1650**	**1650**	**1650**
		Aluminum	**1650**	**1650**	**1650**
		PVC	1200	**1650**	**1650**
	Small	Copper	800	**1650**	**1650**
		Aluminum	800	**1650**	**1650**
		PVC	800	**1650**	**1650**
2	Large	Copper	1100	**1650**	**1650**
		Aluminum	1100	1100	1150
		PVC	650	1150	1150
	Small	Copper	850	1100	**1650**
		Aluminum	850	1050	1150
		PVC	750	1050	1150
Nothing	—	—	700	850	850

“Critical compressed time” was estimated to be approximate 50 microseconds in our previous work under the condition of these experiments [10]. It is shown that the results of present work are consistent with that of previous work.

Kage et al. [12] conducted numerical simulation of shock waves propagating in a constricted duct. The purpose of their research was to clarify how the transmitted shock wave past the constricted duct is stabilized to the uniform shock. Numerical analysis was carried out by means of the parameters of incident shock wave, and constricted duct ratio. It is concluded that passing shock wave can not keep its homogeneity enough on pressure distribution, and the pressure level decreases compared to incident wave. It is considered that the same situation occurred in our experiments.

3.2 Test series B (PVC pipe)

It was described in the previous section that there was no difference of detonation propagation length independently from the viewpoint of configuration of obstacles. However, in the actual blasting scene of smooth blasting technique, the installation of obstacles to the inside wall of charge hole is impossible and unrealistic. In addition, generally a few explosives with small diameter are connected by joints for usage. This is the reason why the obstacles were attached on a SB joint. PVC pipe was used to simulate the actual charge hole. The choice of materials is based on the easiness to modify its shape.

Table 4 summarizes detonation propagation length of explosive in various testing conditions.

Taking these results into account, the following conclusions were obtained.

- Numbers of obstacle must keep or excess the minimum demand.
- Larger obstacle is more effective to improve the detonation propagation length.
- The choice of materials gives an influence on detonation propagation.
- The condition using PVC pipe named VP 40 (Deco. ; 2.0) is severer than the other condition.

As mentioned above, the choice of materials gives an influence on detonation propagation. However, it is not clear what property of material gives an influence.

Additional test is necessary to clarify the factor which influenced the results.

In this investigation, the shape of obstacle is simply circle. But, this shape will not be accepted in the actual blasting scene of smooth blasting technique. It is not easy to insert the explosive columns into charge hole, obstacles will be hindered from proceeding because of the surface roughness of inside wall in charge hole. Therefore, the shape of obstacle is the important factor from the point of actual handling in operation.

The obstacle called “Spider” in the actual blasting scene has some legs toward oblique direction against the axial direction of explosive column. It is considered that the explosive column with this type of obstacles can easily be inserted into the hole.

This obstacle is effective not only as a material to prevent detonation failure, but also as a sustainer of the explosive column to the center of charge hole. This sustainer can create some space that acts as an air cushion between the explosive columns and the inner wall of the charge hole. It enables to prevent the shock wave transferring into rock directly. As the damage to rocks is induced by shock wave, it seems to be effective to use obstacle as a sustainer to improve the smooth blasting effect.

4. Conclusion

From this investigation, it was concluded that the choice of material, position and shape of obstacles gave an influence on the PAS progression. It is not necessary to stop the PAS progression completely for the prevention of detonation failure, it is enough for the PAS progression to be delayed to achieve the improvement of detonation propagation.

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空隙内に置かれた障害物による，先行衝撃波進行に対する影響に関して

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爆薬薬包と穿孔内壁との間に空間が存在した場合，爆薬の爆轟によりその空間の中を先行衝撃波が進行して未反応の爆薬を死圧する。この現象はチャンネル効果として知られている。これまで我々はエマルション爆薬におけるチャンネル効果の発生機構を調べるため，研究室レベルで種々の実験を実施してきた。そして先行衝撃波の進行速度を低下させることがチャンネル効果発生を阻止するためには有効であることを結論づけた。

今回先行衝撃波の進行を抑制する目的で空隙内に障害物を置き，これによる先行衝撃波の進行への影響に関して検証した。

高速度カメラによる先行衝撃波の観察においても進行抑制が観察され，ある条件においてはチャンネル効果の発生を防ぐことができた。また，実穿孔を想定したパイプ内における爆薬の爆轟伝播性の検討においても，障害物を挿入することにより爆轟伝播長の向上が見られた。

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