Effects of Constrictions on Blast-Hazard Areas

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ABSTRACT

A series of model tests were conducted with small-scale steel magazines to study the blast reduction effectiveness of constrictions placed in the access tunnel of underground ammunition storage magazines.

We changed the loading density of storage chamber, location and number of constrictions. We measured side-on pressures in the free field as well as in the access tunnel.

Constriction is very effective in reducing peak pressure and, consequently, blast hazard area within the range of our tests, and seems to be effective in reducing impulse in the free field. The double-constriction magazine was the most effective one in reducing hazard area among the magazines tested in this study, but was not the most effective one for reduction of impulse.

1. INTRODUCTION

The ROK and the US are jointly developing new designs for underground ammunition storage facilities that will significantly reduce the hazard areas surrounding ammunition storage sites. One of the potential design concepts is a multi-chamber facility equipped with hazard control features. Among the hazard control features that is being investigated are constrictions, chamber/tunnel closing devices, expansion chambers, external barricade and so on.

Fredrikson and Jenssen found that constrictions in the main tunnel were very effective blast attenuators in their tests with a very small-scale model magazine[1]. We wanted to investigate the blast reduction effectiveness of constrictions in a magazine larger than theirs for smaller cross-sectional area ratios.

A series of model tests were conducted with small-scale steel magazines to study the blast reduction effectiveness of constrictions placed in the access tunnel of underground ammunition storage magazines.

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We changed the loading density of storage chamber, the location and the number of constrictions. We measured side-on pressures in the free field as well as in the access tunnel. Pressure-time histories measured in the free field were analyzed to obtain the blast-hazard area relative to the one without constriction and the one caculated according to the procedures of the DoD safety regulation[2]

2. THE MODEL MAGAZINES

A magazine consisted of a storage chamber and an access tunnel. The storage chamber was made of steel and its inside dimension was L100 x W50 x H23 cm^3. The top, bottom and rear walls were made of 20.3 cm thick steel plate and the rest of the walls were made of 10.2 cm thick steel plate. The volume of the chamber was 0.115 m^3.

The access tunnel of the reference magazine consisted of a main tunnel, a blast-trap, a T-connector and a branch tunnel as shown in Fig. 1. The access tunnel was made of steel pipe of 20 cm inside diameter. The lengths of main tunnel and branch tunnel were 400 cm and 50 cm respectively. Parts of access tunnels were replaced by constrictions as shown in Figs. 2-4 to make the portal-constriction magazine, the middle-constriction magazine and the double-constriction magazine respectively. Each constriction has an inside diameter of 10 cm. The reference magazine has no constriction, the middle- and the portal-constriction magazine have one 80 cm constriction at the middle and portal part of the main tunnel respectively, and the double constriction has two 40 cm constrictions at the middle part of the main tunnel. Therefore each magazine has the same length of constriction in total, except the
reference magazine.

3. EXPERIMENTAL MEASUREMENTS

The explosive detonated for each test was 0.46 kg or 1.9 kg Comp. C-4 which gives a chamber loading density of 4.0 kg/m^3 or 16.5 kg/m^3 and a total loading density of 1.78 kg/m^3 or 7.37 kg/m^3 respectvely.

Pressure-time histories of blastwaves travelling down the tunnel and in the free field were recorded at locations shown by circular dots in Figs. 1-5 by using piezo-electric or piezo-resistive gauges. The instrumentation system consisted of pressure gauges, signal conditioning amplifiers (PCB 464A), a multi-channel waveform digitizing system (Nic 500) and a personal computer as shown in Fig. 6.

Pressure-time histories in the access tunnel at locations just before and after the constriction of the middle-constriction magazine are compared in Fig. 7. The high-frequency curve and the low-frequency curve represent the pressure-time history and the impulse-time history respectvely. It can be seen that peak pressure and impulse before the constriction are much higher than those after the constriction due to reflection and expansion of blastwave before and after the constriction respectively. Pressure-time histories in the free field are compared in Fig. 8 for the middle-constriction magazine and the double-constriction magazine. The pressure-time histories were obtained from gauges located at the distance of 12m along the zero-degree lines in the free field.

The peak pressure for double-constriction magazine was smaller than that for single-constriction magazine, but the peak impulse for single constriction magazine was slightly smaller than that for double constriction magazine.

4. DATA ANALYSIS AND DISCUSSIONS

Peak-pressures in the tunnels are shown as functions of distances in Figs. 9-12 for the reference magazine, the portal-constriction magazine, the middle-constriction magazine and the double constriction magazine respectively. The distances were measured from the exits of storage chambers along the centerline of the tunnels. Peak-pressures before the constrictions are much higher than those after the constriction, and decrease very rapidly after the constrictions. Peak-pressures at the entrances are listed in Table 1 in the unit of bars.

Table 1. Peak-pressures at the entrances

Magazine / Entrance Pressure(Bar)	Reference	Middle Constriction	Double Constriction
Experiment	23.3 (1.0)	13.6 (0.58)	5.0 (0.22)
Calculation (HULL 122)	13.6 (1.0)	8.8 (0.65)	3.9 (0.29)

Table 1. Peak-pressures at the entrances

The numbers in the parentheses are relative pressures compared with the entrance pressures of the reference magazine. It can be seen that the relative pressures of the experiment are very similar to those of the calculation with HULL 122 hydrocode. Since the double-constriction magazine has the lowest entrance pressure, it can be estimated that the double constriction reduces the hazard area most effectively.

The scaled blast pressures, P_w/P, measured in the free field along the zero degree lines are shown as functions of the scaled distances, R/D_t, in Figs. 13-16, where the solid and the empty circles represent the experimental data for 1.9 kg tests and 0.46 kg tests respectively. The test data for each type of magazine are fitted to

EQUATION

$$P_w / P = a(R / D_t)^{1.35} \quad \cdots\cdots \quad (1)$$

and represented by solid lines or dotted lines in the figures. R: D_t, P, P_w and “a” in Eq.(1) represent distance from the entrance along the zero degree line, effective hydraulic diameter at tunnel regions without constriction, peak-pressure at distance R along the zero degree line, effective overpressure at the entrance defined in the DoD regulation, and proportional constant respectively. The fitted equations are shown in the right bottom corners of Figs. 13-16 and summarized in Table 2.

Table 2. Fitted Equations for Peak-pressure in the free field.

Magazine	Explosive	Fitted Equation
Reference	1.9Kg	$P_w/P=1.18(R/D_t)^{1.35}$
Middle-Constriction	1.9Kg 0.46Kg	$P_w/P=1.80(R/D_t)^{1.35}$ $P_w/P=2.77(R/D_t)^{1.35}$
Portal-Constriction	1.9Kg	$P_w/P=2.22(R/D_t)^{1.35}$
Double-Constriction	1.9Kg 0.46Kg	$P_w/P=2.39(R/D_t)^{1.35}$ $P_w/P=3.45(R/D_t)^{1.35}$

Table 2. Fitted Equations for Peak-pressure in the free field.

The relative hazard area can be reasonably assumed to he proportional to the squared realtive hazard distance in the zero-degree direction. Expected from Eq. (1), the hazard distance is approximately proportional to $(1/a)^{1/1.35}$ and relative hazard area is approximately proportional to $(1/a)^{1/1.35}$. Table 3 summarizes hazard distances and hazard areas relative to the reference magazine, hazard areas relative to the DoD safety regulation for magazines tested in this study. Hazard areas relative to reference magazine are absent for 0.46 kg tests since we didn't conduct 0.46 kg-test for reference magazine.

We can see from Table 3 that the double-constriction magazine was the most effective one in reducing hazard area and thus, peak-pressure among the magazines tested in this study, and was more effective in reducing hazard area than the single constriction with the same total length of constriction at similar position.

Table 3. Relative hazard areas.

Magazine	Explosive	Constant "a"	Hazard Area rel. to Reference	Hazard Area rel. to DoD
Reference	1.9Kg	1.18	1.00	0.78
Middle-Constriction	1.9Kg	1.80	0.53	0.42
	0.46Kg	2.77	-	0.22
Portal-Constriction	1.9Kg	2.22	0.39	0.31
Double-Constriction	1.9Kg	2.39	0.35	0.28
	0.46Kg	3.45	-	0.16

Table 3. Relative hazard areas.

It seems to be better in reducing hazard area to place the constriction near the portal as we can see by comparing the hazard area of middle-constriction with that of portal-constriction. The 0.46 kg tests showed much smaller "hazard area relative to DoD" value than the 1.9 kg tests, which fact means that the DoD regulation is more conservative or constrictions are more effective for low loading density explosions. We are going to do more analysis after conducting 0.46 kg test for reference magazine.

If we judge from our impulse data shown in Fig. 17, constrictions were effective in reducing peak-impulse in general. But peak impulses of the double constriction, which was most effective in reducing peak-pressures, were about the same as those of the middle constriction and larger than those of the portal constriction.

5. CONCLUSIONS

Constriction is very effective in reducing peak pressure and, consequently, blast hazard area within the range of our tests, and seems to be effective in reducing impulse in the free field.

The double-constriction magazine was the most effective one in reducing hazard area among the magazines tested in this study, and was more effective in reducing hazard area than the single constriction of the same total length at similar position. It seems to be better in reducing hazard area to place the constriction near the portal. The double constriction, which was most effective in reducing peak pressure, showed about the same impulse as the middle constriction and larger impulse than the portaI constriction.

REFERENCES

[1]. G. Fredrikson and A. Jenssen, "Underground Ammunition Storages : Model Test to Determine Air Blast Propagation from Accidental Explosions." Norwegian Defense Construction Service, Fortifikatorisk notat ~r 59/70, Oslo October 1970.

[2]. "DoD ammunition and explosives safety standards" DoD 6055.9-STD, Asst. Secretary of Defense, Washington, D.C., October 1992.

Fig. 1. The reference magazine.

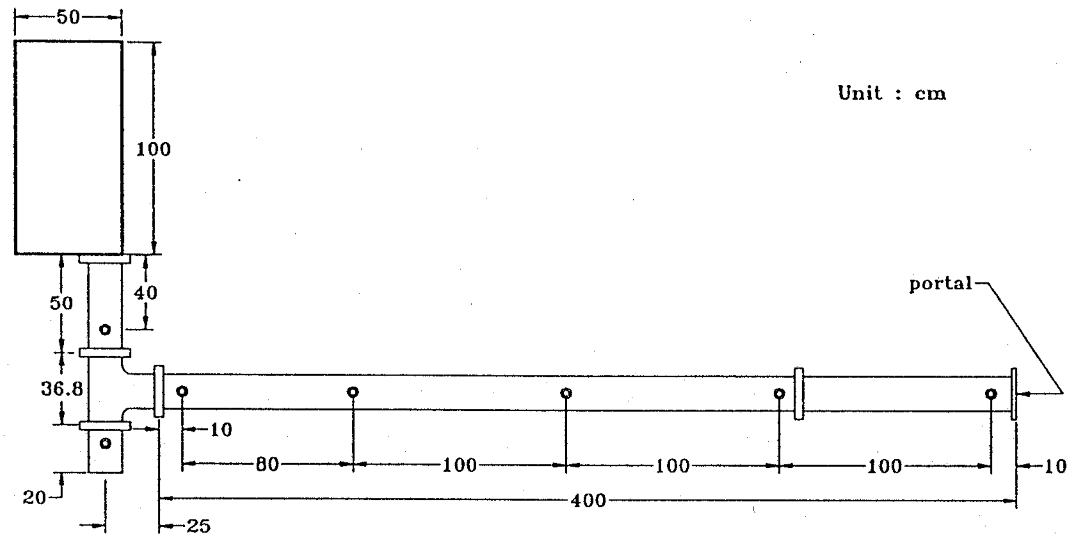


Fig. 1. The reference magazine.

Fig. 2. The middie-constriction magazine.

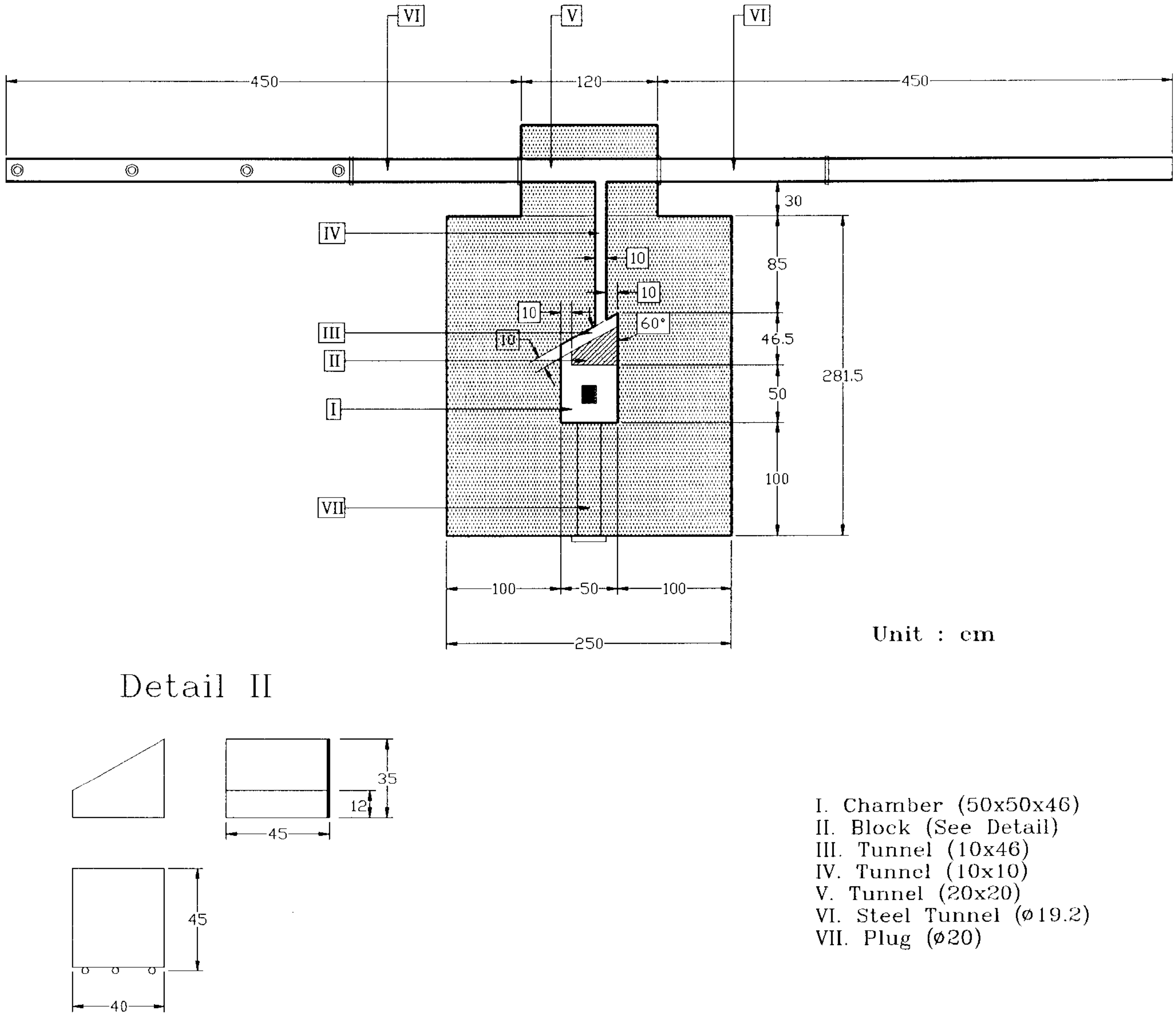


Fig.2. Small-scale magazine : Magazine S2

Fig. 3. The portal-constriction magazine.

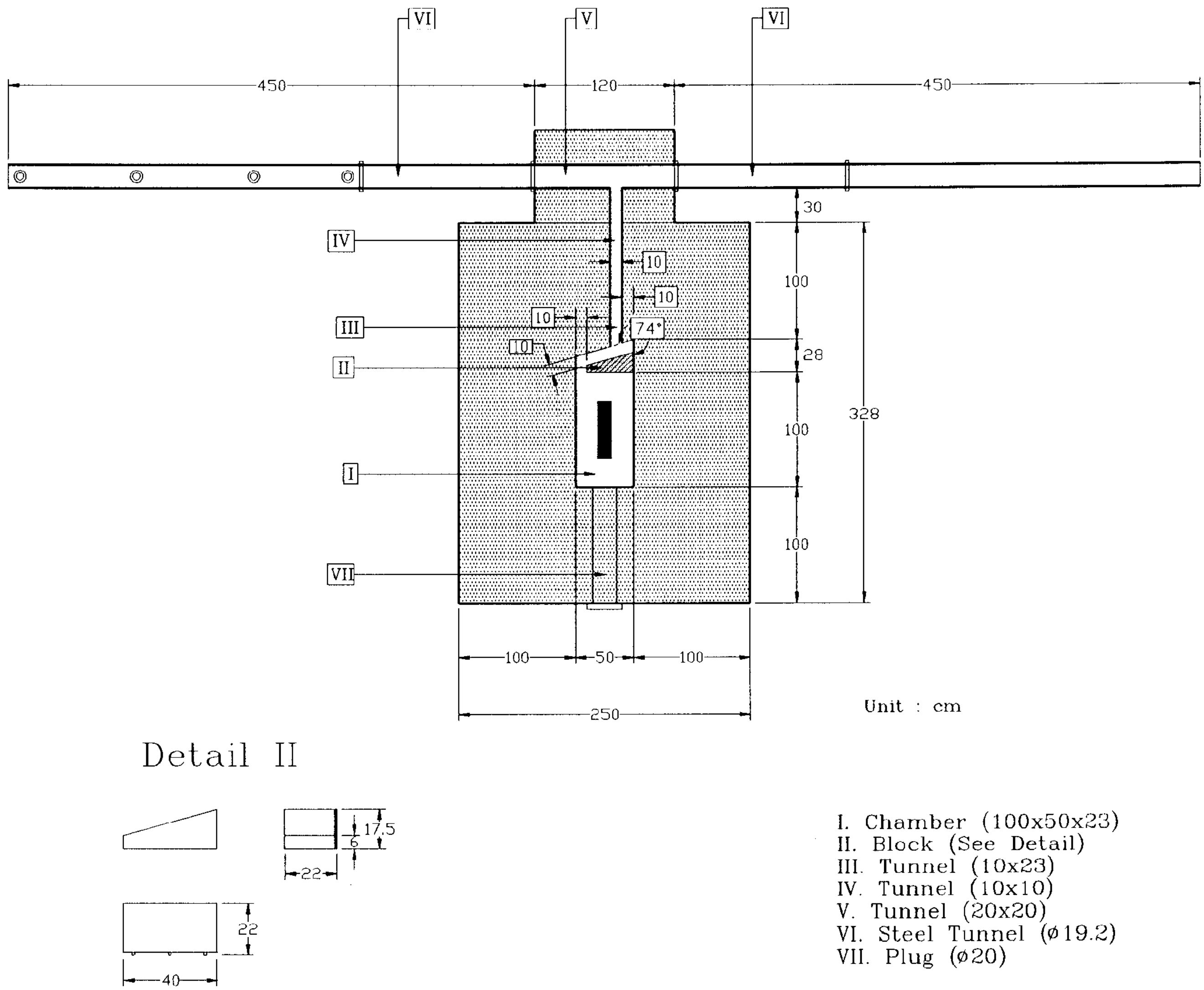


Fig.3. Small–scale magazine : Magazine S3

Fig. 4. The doubie-constriction magazine.

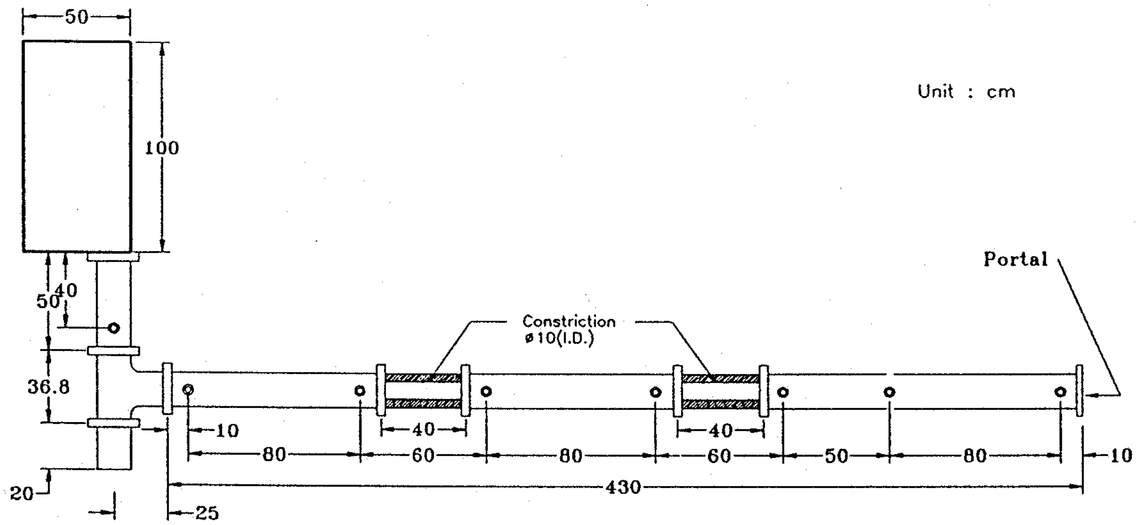


Fig. 4. The double-constriction magazine.

Fig. 5. Gauge locations in the free field.

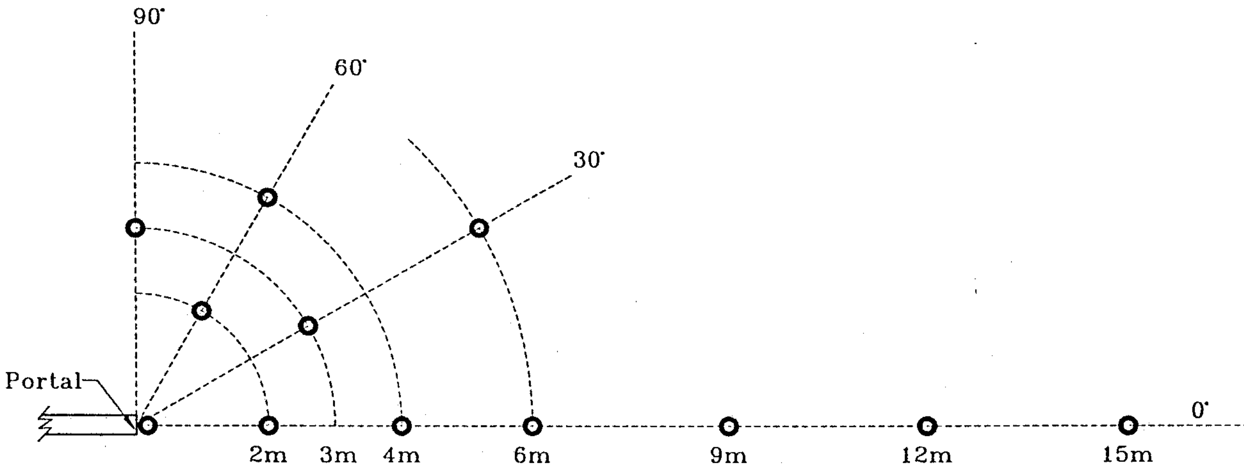


Fig. 5. Gauge locations in the free field.

Fig. 6. The instrumentation system.

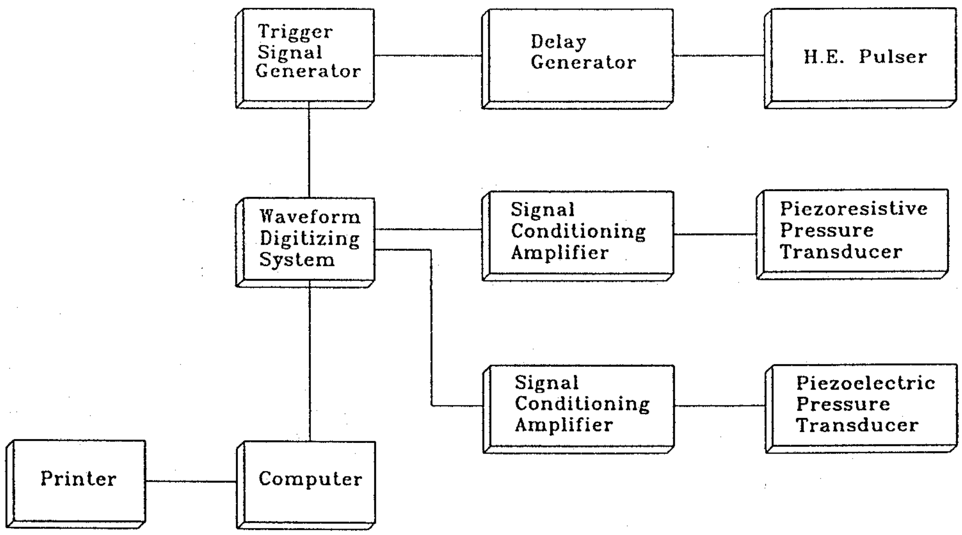
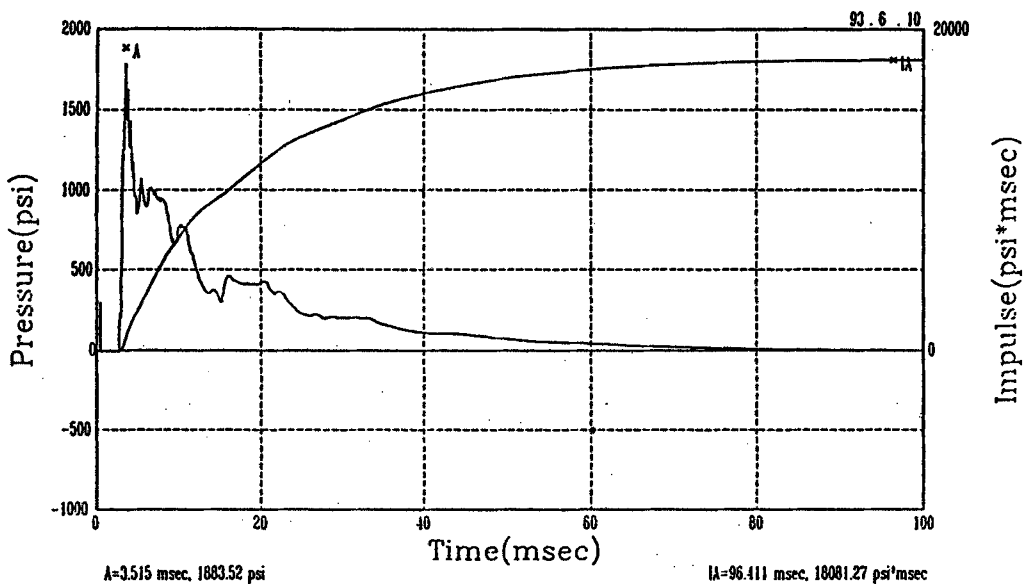


Fig. 6. The instrumentation system.

Fig. 7. Pressure-time histories in the access tunnel.



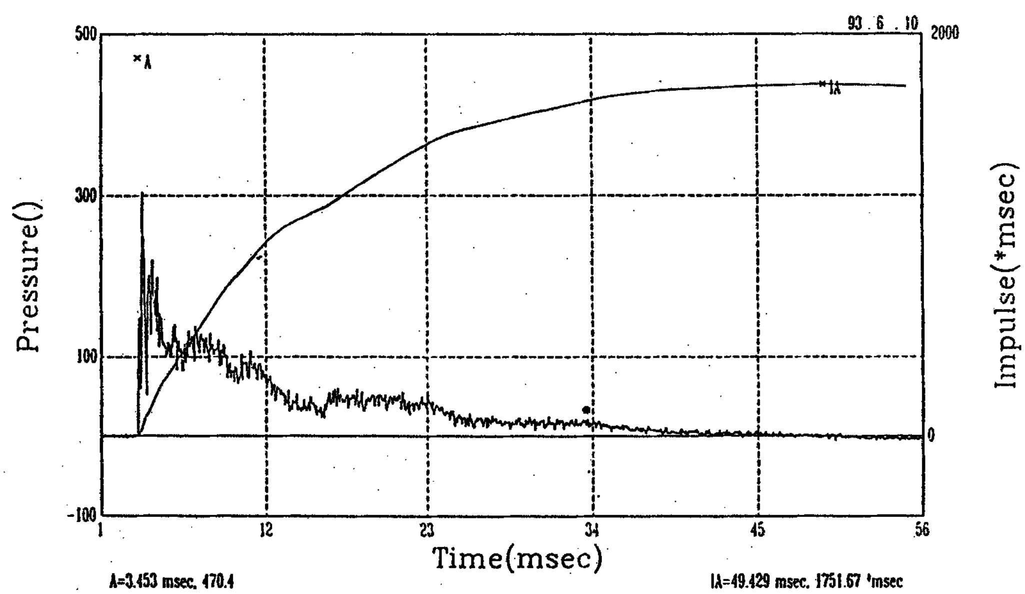
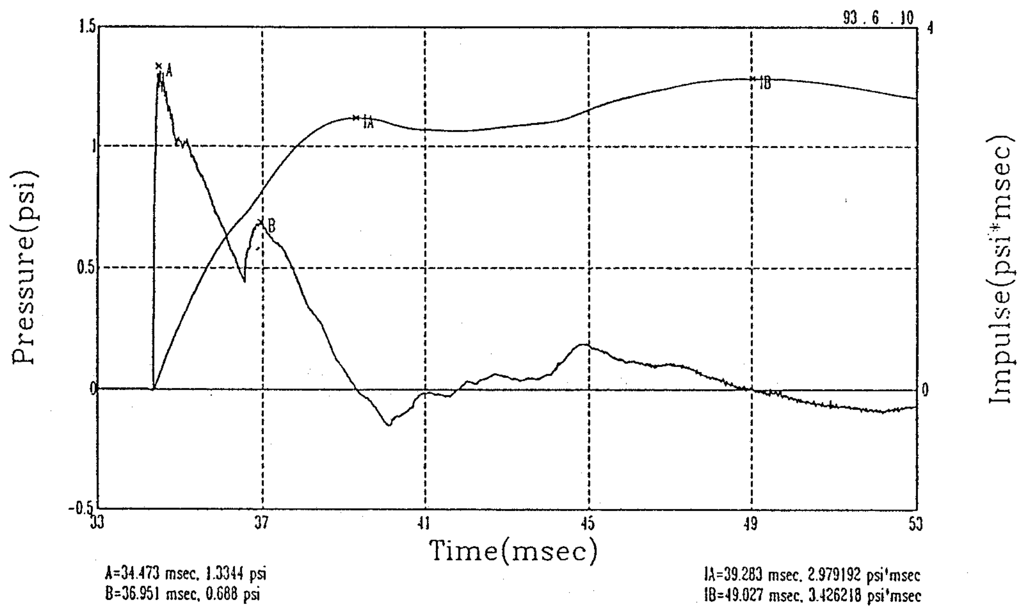


Fig. 7. Pressure-time histories in the access tunnel.

Fig. 8. Pressure-time histories in the free field.



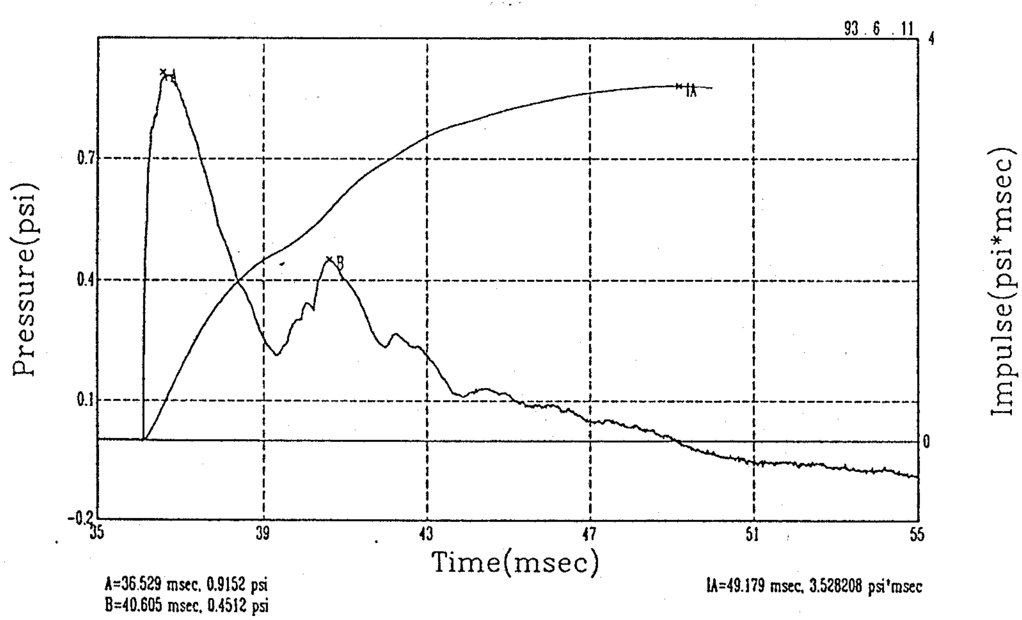


Fig. 8. Pressure-time histories in the free field.

Fig. 9. Pressure vs. Distance in the access tunnel for the reference magazine.

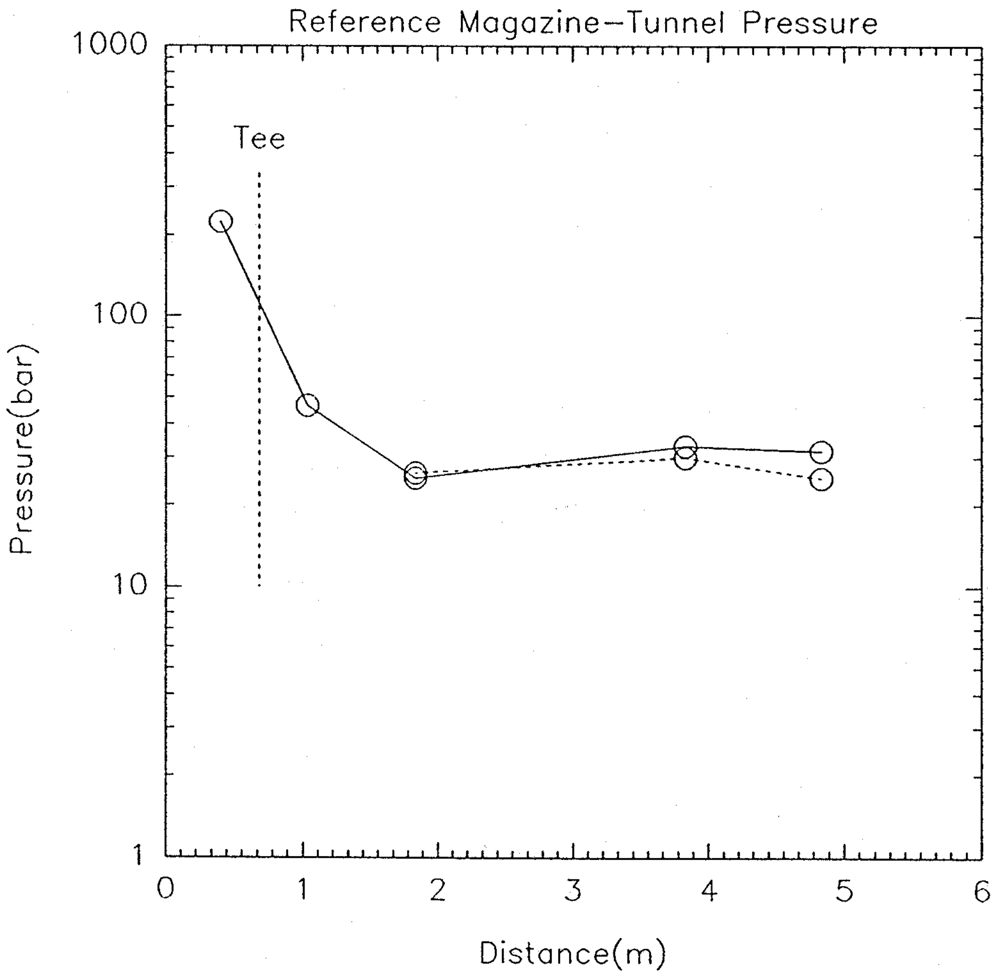


Fig. 9. Pressure vs. Distance in the access tunnel for the reference magazine.

Fig. 10.
Pressure vs. Distance in the access tunnel for the middle-constriction magazine.

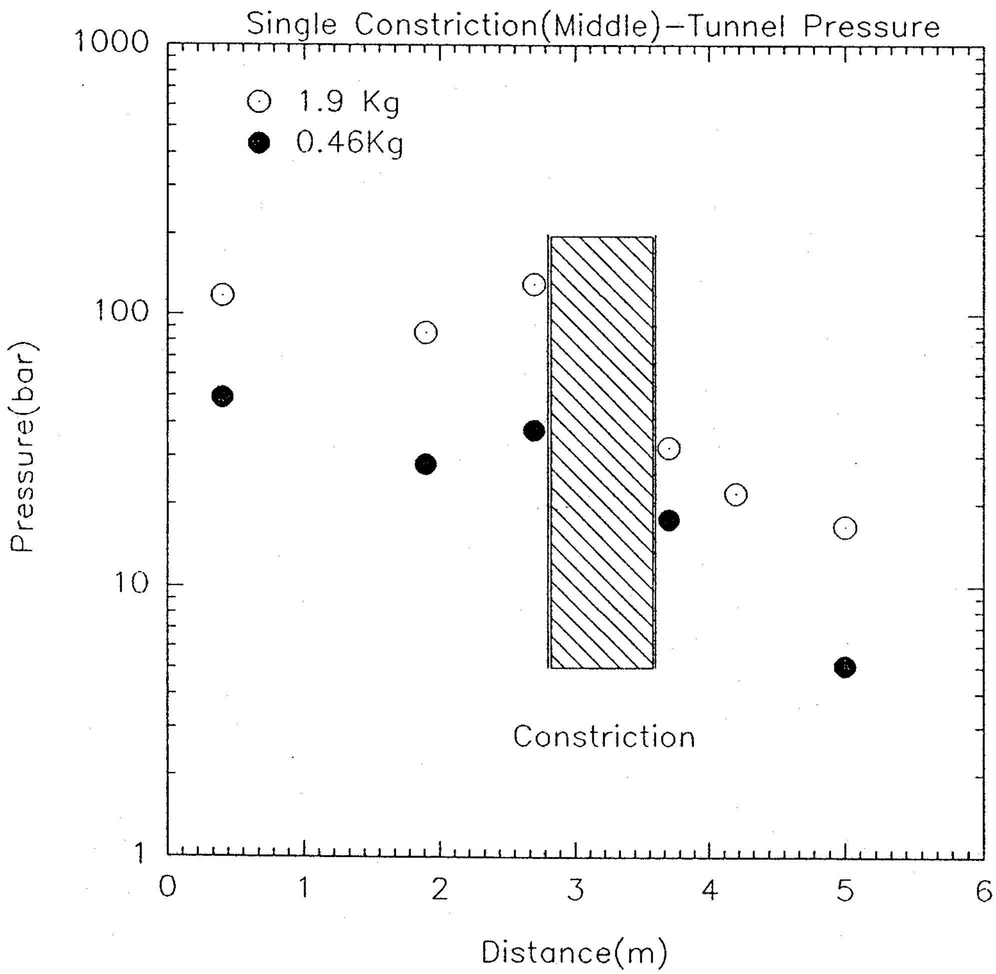


Fig. 10. Pressure vs. Distance in the access tunnel for the middle-constriction magazine.

Fig. 11.
Pressure vs. Distance in the access tunnel for the portal-constriction magazine.

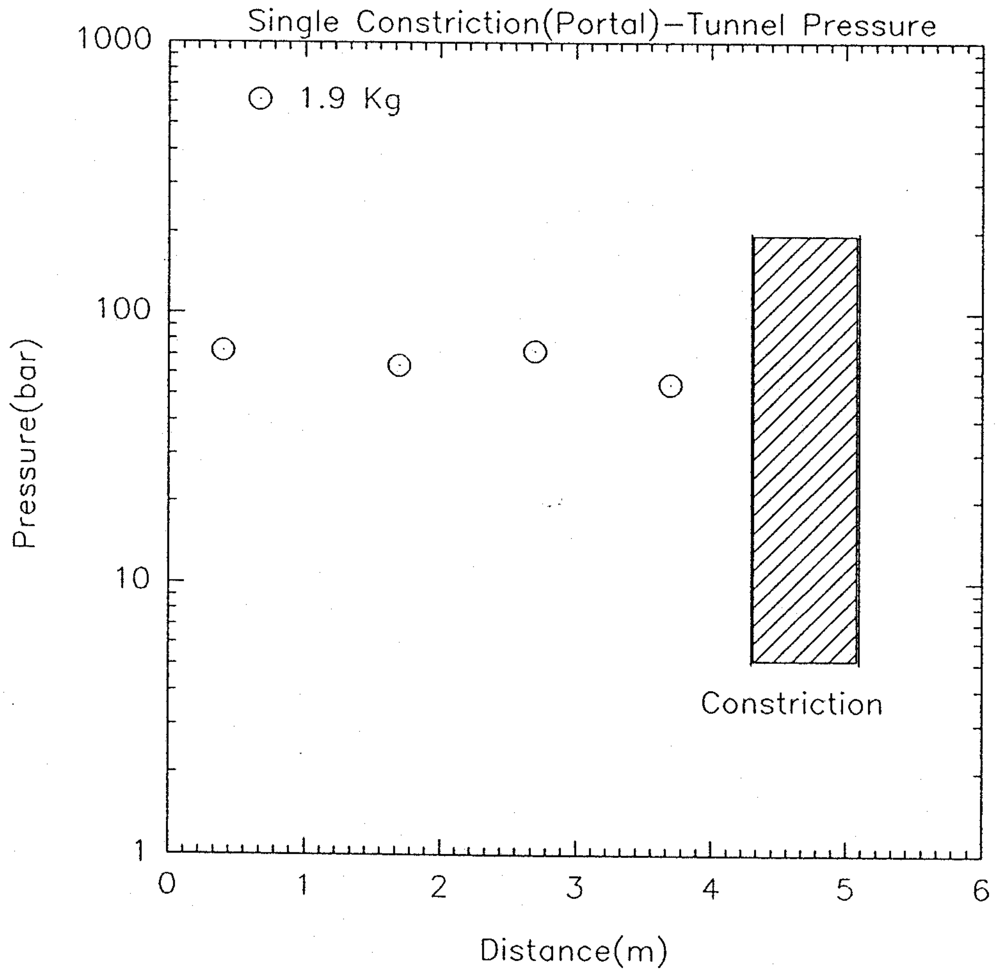


Fig. 11. Pressure vs. Distance in the access tunnel for the portal-constriction magazine.

Fig. 12. Pressure vs. Distance in the access tunnel for the double-constriction magazine.

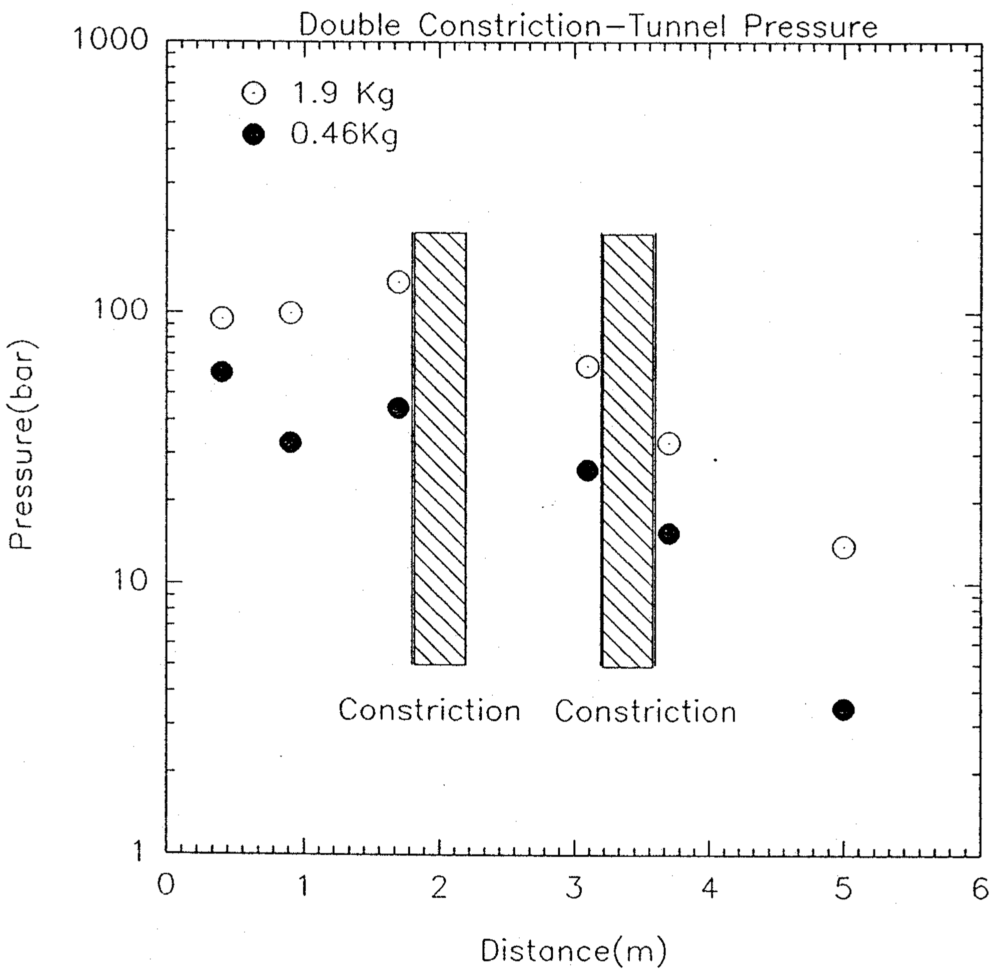


Fig. 12. Pressure vs. Distance in the access tunnel for the double-constriction magazine.

Fig. 13. Scaled Pressure, Pw/P vs. Scaled distancd, R/D_t in the free field for the reference magazine.

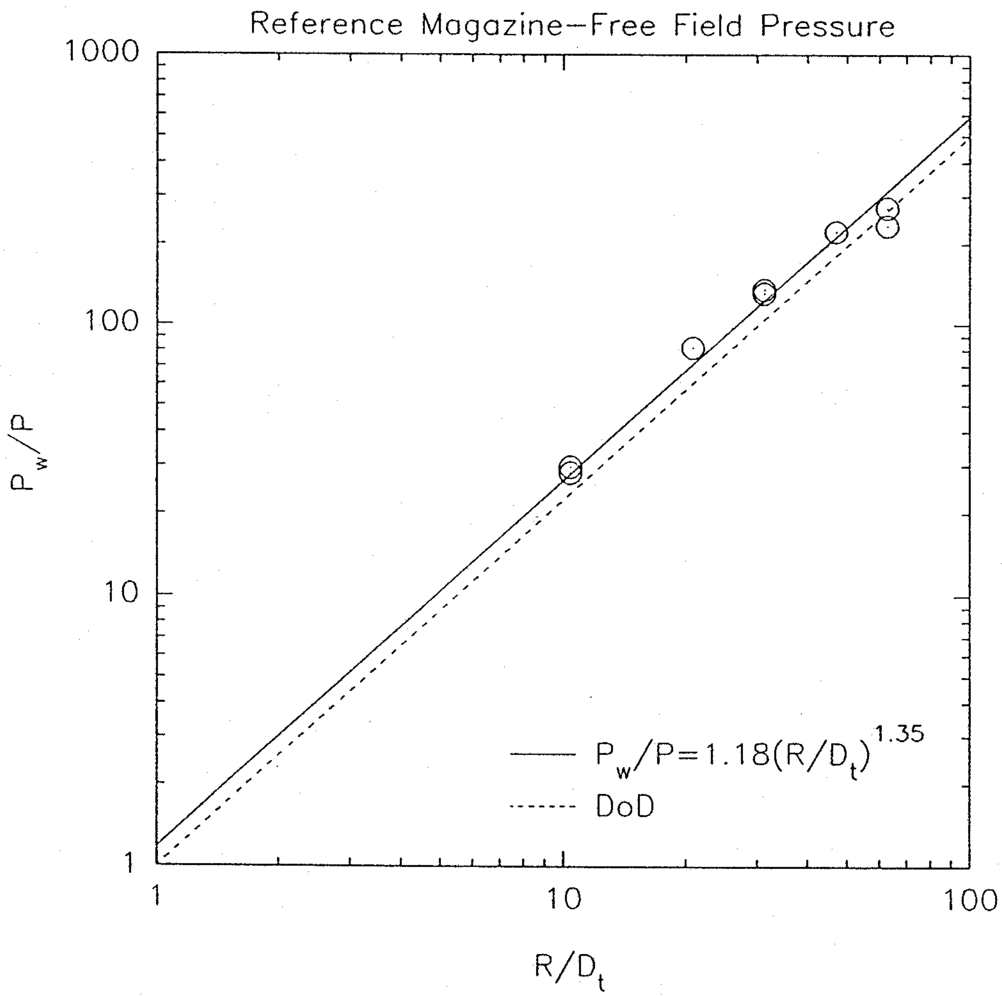


Fig. 13. Scaled Pressure, P_w/P vs. Scaled distancd, R/D_t in the free field for the reference magazine.

Fig. 14. Scaled Pressure, P_w/P vs. Scaled distancd, R/D_t in the free field for the middle-constriction magazine.

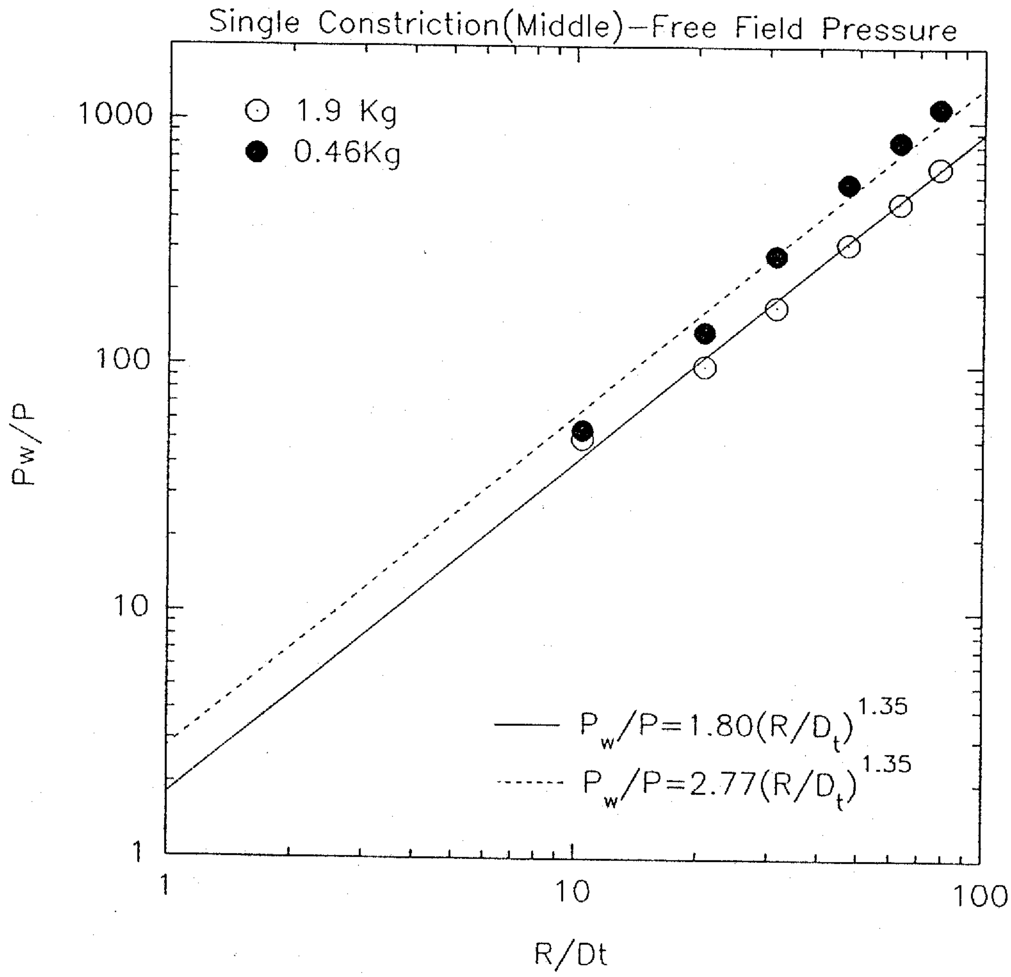


Fig. 14. Scaled Pressure, P_w/P vs. Scaled distancd, R/D_t in the free field for the middle-constriction magazine.

Fig. 15. Scaled Pressure, P_w/P vs. Scaled distancd, R/D_t in the free field for the portal-constriction magazine.

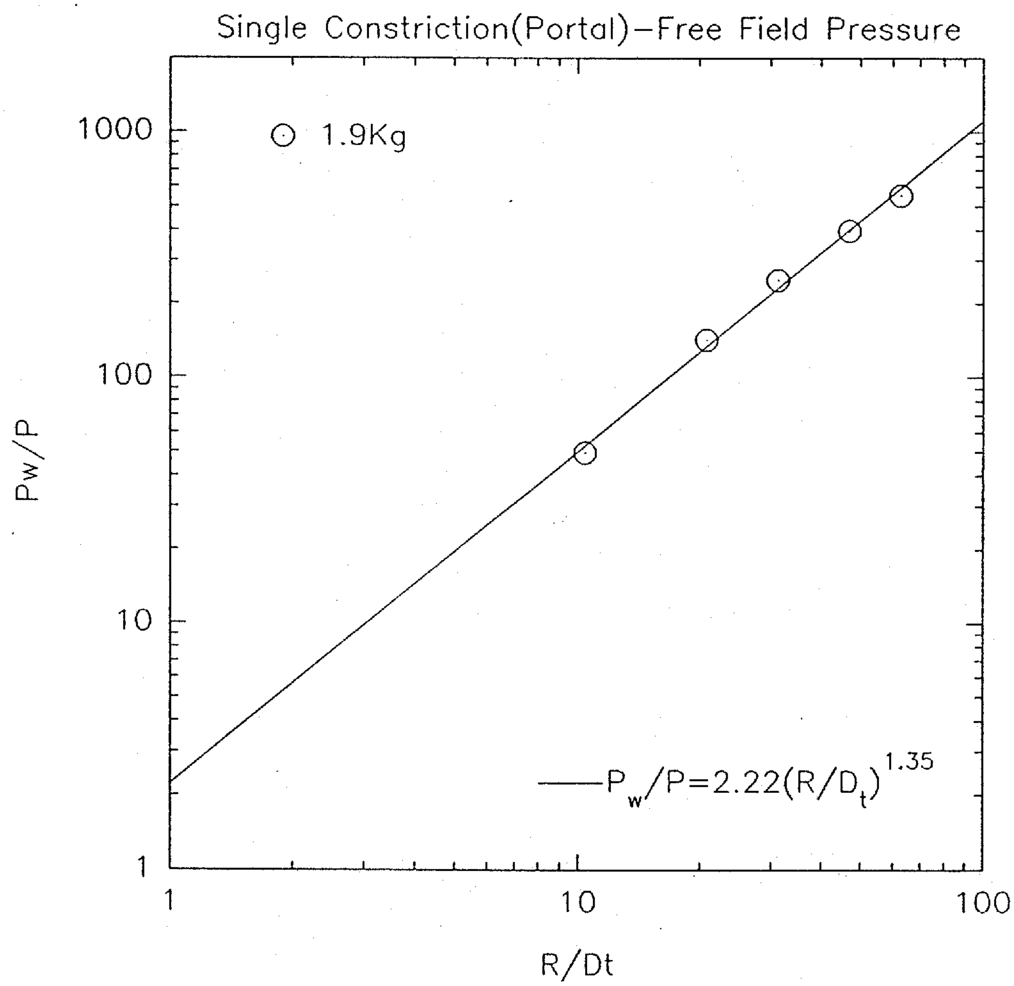


Fig. 15. Scaled Pressure, P_w/P vs. Scaled distancd, R/D_t in the free field for the portal-constriction magazine.

Fig. 16. Scaled Pressure, Pw/P vs. Scaled distancd, R/D_t in the free field for the doubie-constriction magazine.

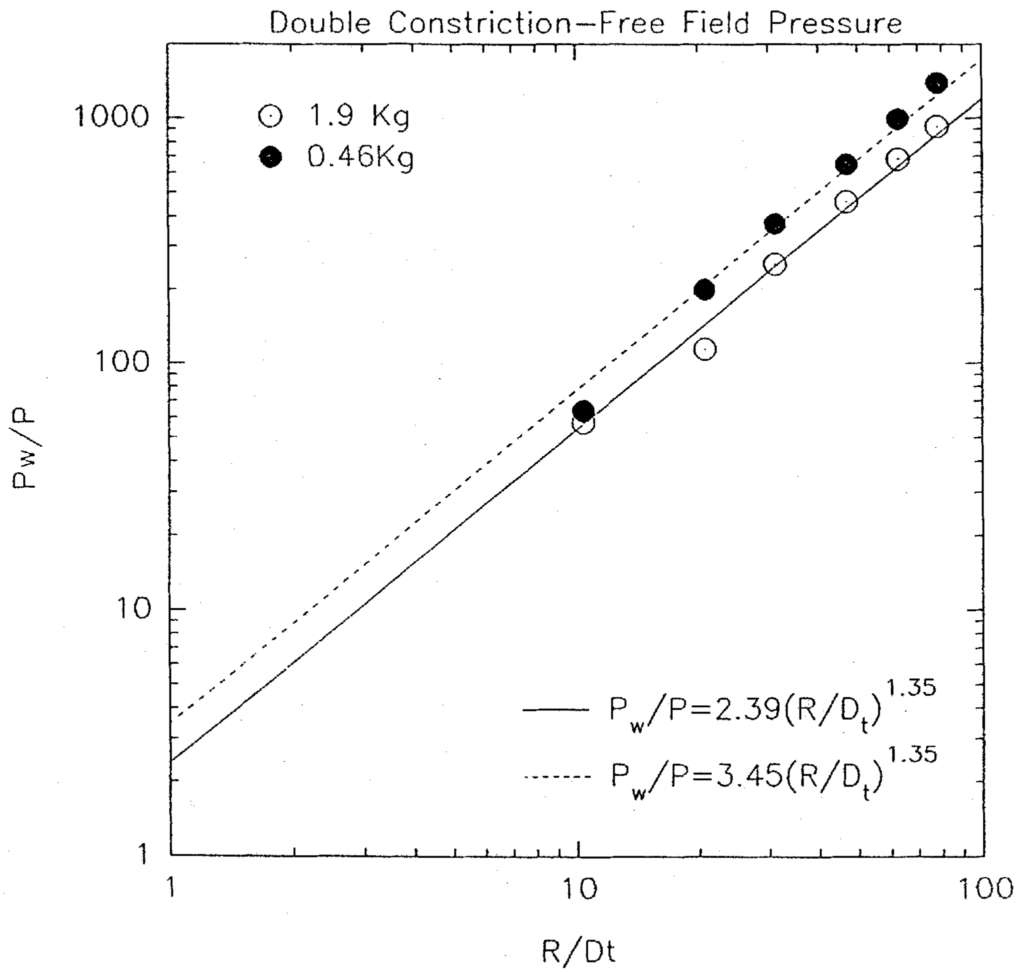


Fig. 16. Scaled Pressure, P_w/P vs. Scaled distancd, R/D_t in the free field for the double-constriction magazine.

Fig. 17. Impulse vs. Scaled distance, R/D_t, in the free field.

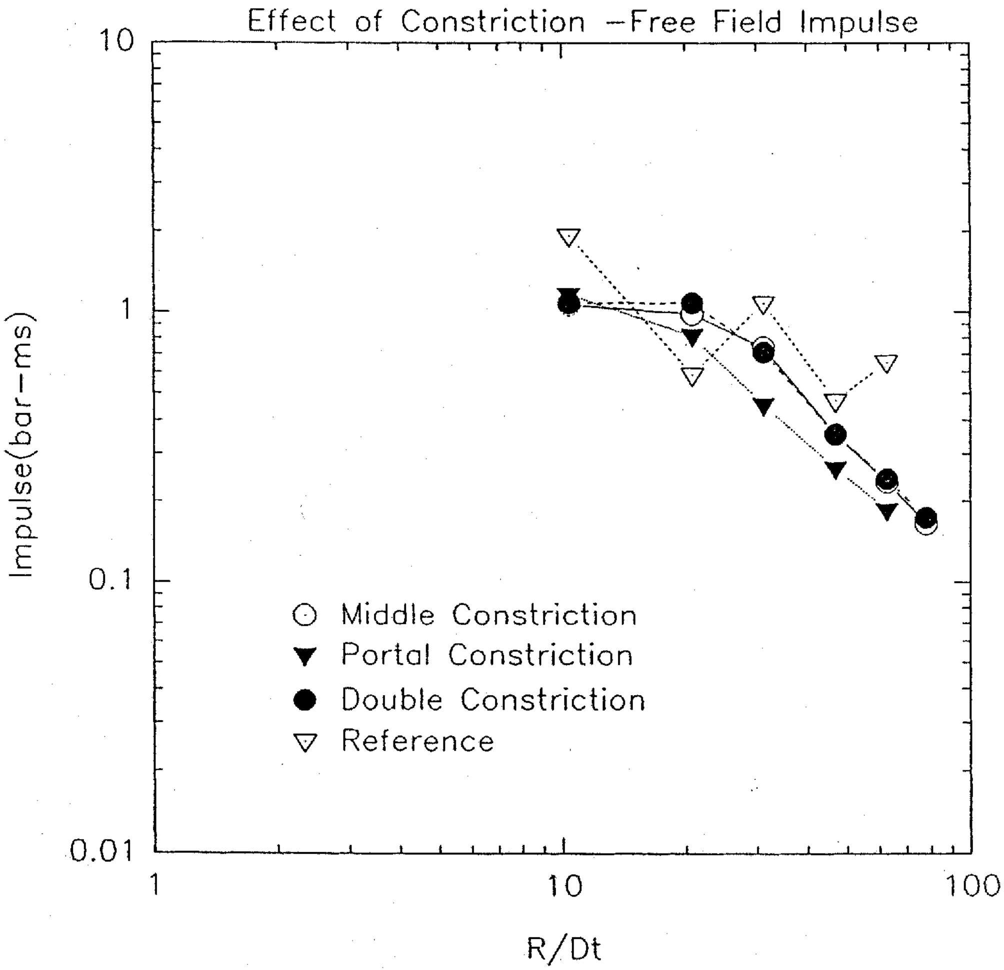


Fig. 17. Impulse vs. Scaled distance, R/D_t , in the free field.