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Effect of Dividing Concrete Target on Perforation Resistance

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Abstract:

Concrete has been widely used over many years by military and civil engineers in the design and construction of protective structures. One of the loading types that protective structures are designed to withstand, is the localized impact of missiles or projectiles. Parameters that affecting design process are the barrier or target geometry (mainly thickness), and concrete properties. In this paper, the effect of dividing concrete target on perforation resistance was studied through 23 specimens (37 concrete panels) with total different thicknesses (10, 15 and 60 cm). The thickness of the part of the divided target that faces the impacting missile was also studied. The study showed that dividing concrete target had positive effect on perforation resistance provided that the biggest divided mass faces the impact missile.

Keywords:

Concrete; Penetration; Perforation; Impact; Damage; Missile.

Nomenclature

- A the projectile maximum cross section area (in²).
- d the projectile diameter (in).
- C slenderness ratio factor of projectile [$C = 0.003$ for ($L/d < 10$); 0.002 ($L/d > 10$)]. Where (L) is the projectile length.
- e the perforation thickness (in), i.e. the maximum thickness of a target which a missile with a given impact velocity will completely penetrate and have a theoretical exit velocity equal zero.
- f_c the ultimate compressive strength of concrete (lb/in²).
- N the projectile shape factor ($N = 0.72$ for flat nosed bodies; 0.84 for blunt nosed bodies; 1.00 for spherical end bullet nose; and 1.14 for very sharp nose).
- s the scabbing thickness (in), i.e. the thickness of target required to prevent scabbing of material from rare face of the target for a missile with a given impact velocity.
- S_i soil penetration factor ($S_i = 5.0$ for medium dense sand).
- V the striking velocity of the projectile (ft/s).
- W the projectile total weight (lb).
- x the penetration depth (in), i.e. the depth which a missile will penetrate into an infinitely thick target.
- X_f final penetration value in soil (ft).

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1. Introduction

Concrete is a common material for protective structures to resist impact and explosive loads. The local effect phenomenon for hard missile impact to concrete target is shown in Fig . 1. In this figure it is clear that if a missile strikes a concrete target with high velocity, pieces of concrete will spall "eject" from the front face of the impacted target forming a crater that is greater than the cross section area of the impacting missile. As the velocity increases, the missile will penetrate the target to depths beyond the depth of the spall crater, forming a cylinder penetration hole with a diameter only slightly greater than the missile diameter. Further increase in velocity produces cracking of the concrete target back face followed by scabbing of concrete [1]. Many formulae were developed to determine the penetration depth (x), the perforation thickness (e) and the scabbing thickness (s) of a concrete target. Some of these formulae were conservative or underestimate penetration values. In 1984, Haldar and Hamieh [2] summarized most of the damage-predicting equations commonly used to estimate the local effect of non-deformable missiles on concrete. Haldar and his associates proposed a non-dimensional impact factor (I) which was defined as:

$$I = \frac{12}{32.2} \frac{N W V^2}{d^3 f_c} \tag{1}$$

The proposed functional relationship between the impact factor and both of the penetration depth (x), the scabbing thickness (s) were summarized as follows:

$$\frac{x}{d} = 0.6470 + 0.0567 I \tag{4.0 \leq I \leq 21.0} \tag{2}$$

$$\frac{x}{d} = 1.1875 + 0.0299 I \tag{21.0 \leq I \leq 455.0} \tag{3}$$

$$\frac{s}{d} = 3.3437 + 0.0342 I \tag{21.0 \leq I \leq 385.0} \tag{4}$$

According to Haldar and Hamieh [2], the predictability of these equations were found to be superior to the corresponding equations of penetration. As a conservative assumption, scabbing thickness (s) in Haldar formulae was taken as perforation thickness (e).

To predict penetration in soil layers, the Army Corps of Engineers (ACE) presented the following formula [3]:

$$X_f = C S_i N (W/A)^{0.5} (V - 100) \tag{5}$$

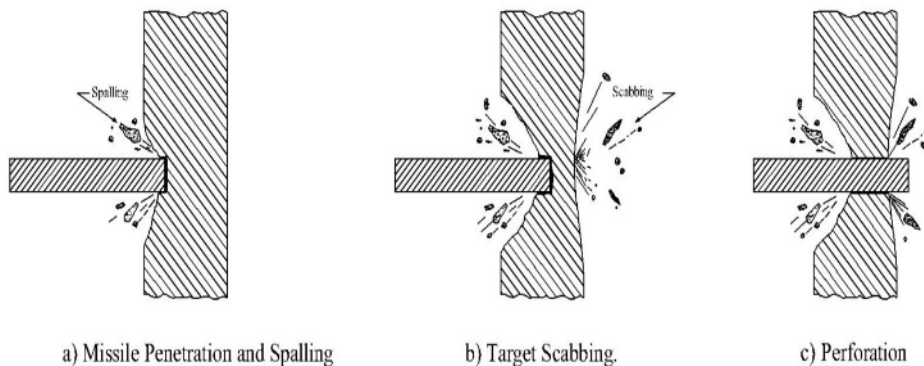


Fig. 1. Missile impact phenomena

2. Experiments

The impact tests were conducted in the laboratory using a gun that accelerated a blunt-nose projectile of yield strength (1726 MPa), Brinell hardness number (475) and mass (175 g). The projectile was 23 mm diameter and 64 mm length. Impact velocities were measured with electro optical velocity measurement device. The tested specimens were concrete panels with dimension of 50 cm x 50 cm and different thicknesses. The compressive strength of the used concrete was 250 kg/cm². Test specimens were mounted on stationary stiff steel frame at distance of 50 meters in front of the gun.

To study the effect of dividing concrete target on penetration resistance , number of 23 specimens (37 concrete panels) with total thickness of 10, 15 and 60 cm were tested. To identify the missile perforation velocity for undivided concrete s specimens, three specimens were tested for each thickness under different incremental projectile impact velocity until full perforation occurred. The front and back face crater area and depth were measured for each panel under different impact velocities.

2.1 10 cm specimens divided into two 5 cm panels.

The 10 cm specimen was divided into two equal panels of 5 cm thickness for each. The two 5 cm panels were tested first with 1cm empty space in between as shown in Fig. 2, and second using 1cm sand in between as shown in Fig. 3. Table 1 shows the test results for the divided 10 cm panels compared with that of the undivided panels .

2.2 15 cm specimens divided into 10 and 5 cm panels.

To study the variation effect of panel thickness that faces the impacted projectile on penetration resistance, the 15 cm specimens was divided into two panels of 10 cm and 5 cm thickness. The two panels were tested in two positions as follows:

- The 10 cm panel was in the front facing the impact projectile , and the 5 cm panel in the back.
- The 5 cm panel was in the front, and the 10 cm panel in the back.

The test results of the divided and undivided specimens are shown in Table 2 and Fig. 4.

2.3 60 cm specimens divided into 40 and 20 cm panels.

60 cm specimen was divided into two panels of 40 cm thickness as a front panel facing the impact projectile, and 20 cm as a back panel. The test results of the divided and undivided specimens are shown in Table 3 and Fig. 5.

Table 1. Results of 10 cm concrete specimens

Specimen	Impact velocity (m/s)	Front face crater area (cm ²)	Back face crater area (cm ²)	Notes
One 10 cm panel	275	144	563	- Full perforation. - Projectile found near the specimen.

Two 5 cm panels with 1 cm empty space in between	255	54	325	- Full perforation for both two panels.
Two 5 cm panels with 1 cm sand in between	285	63	320	- Projectile was captured by the panels.
	295	57	415	- Projectile was captured by the panels.

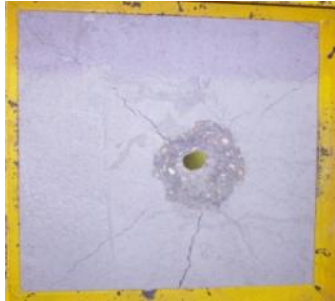
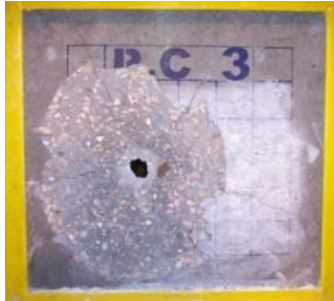



Table 2. Results of 15 cm concrete specimens

Sample type	Impact velocity (m/s)	Front face crater area (cm ²)	Back face crater area (cm ²)	Notes
One 15 cm panel	400	171	222	- Full perforation.
Two panels of 5 cm as front panel and 10 cm as back panel	410	230	720	- Full perforation - Damage for both panels.
	425	180	850	- Full perforation. - Severe damaged in the 10 cm panel.
Two panels of 10 cm as front panel and 5 cm as back panel	425	220	-	- Projectile was captured by the front panel. - The back panel totally cracked. - Small dent was found in the back panel front face.

Table 3. Results of 60 cm specimens.

Sample type	Impact velocity (m/s)	Notes
One panel (60 cm)	980	- The panel was totally destroyed.

<p>Two panels (40 and 20 cm)</p>	<p>980</p>	<ul style="list-style-type: none"> - The 40 cm front panel was totally destroyed with slight effect on the back panel. - No cracks was found on front and back face of the back panel. only a dent of 1cm diameter and 0.5 cm depth was found at the front face of the back panel.
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Sample	Impact velocity (m/s)	Damage	
<p>One panel of 10 cm thickness.</p>	<p>275</p>	 <p style="text-align: center;">Front face.</p>	 <p style="text-align: center;">Back face.</p>
<p>Two panels of 5 cm thickness for each with 1cm air in between.</p>	<p>255</p>	 <p style="text-align: center;">Two panels of 5 cm each.</p>	
		 <p style="text-align: center;">Front face of front panel.</p>	 <p style="text-align: center;">Back face of back panel.</p>

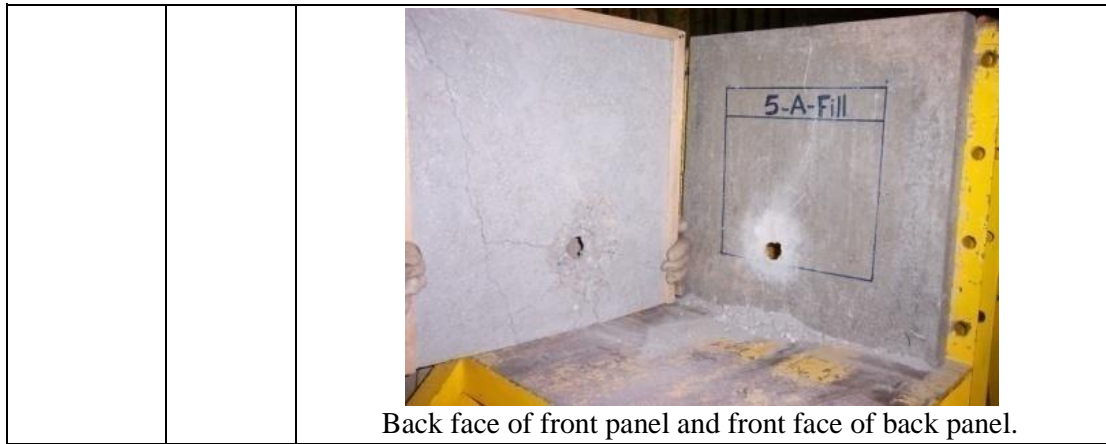
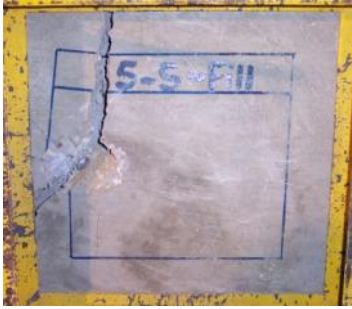


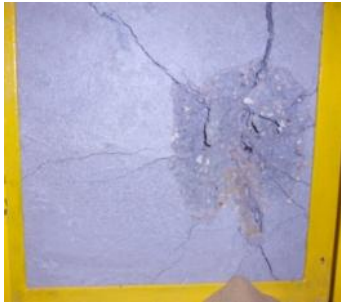


Fig. 2. 10 cm concrete specimens with 1 cm air in between.

Sample	Impact velocity (m/s)	Damage	
Two panels of 5 cm thickness for each with 1cm sand in between.	285	 <p>Front face of front panel.</p>	 <p>Projectile was captured between the two panels.</p>
		 <p>Front face of back panel.</p>	 <p>Back face of back panel.</p>




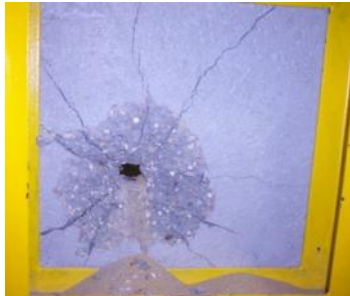

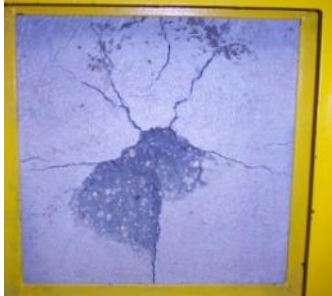


	295		
			
		Front face of front panel.	Back face of front panel
		Back face of front panel (projectile was captured).	Back face of back panel.

Fig. 3. 10 cm concrete specimens with 1 cm sand in between.

Sample type	Impact velocity (m/s)	Damage	
One panel of 15 cm thickness	400		
		Front face.	Back face.
Two panels of 5 cm as front panel and 10 cm as back panel.	410		
		Front face of front panel.	Back face of back panel.









Two panels of 10 cm as front panel and 5 cm as back panel.	425	 <p>Front face of front panel.</p>	 <p>Back face of back panel.</p>
		 <p>Back face of front panel and front face of back panel.</p>	 <p>The projectile was captured in the front panel.</p>

Fig. 4. 15 cm concrete specimen with 1cm sand in between.

Sample type	Impact velocity (m/s)	Damage	
One panel of 60cm thickness.	980	 <p>Before impact.</p>	 <p>After impact.</p>
Two panels of 40 cm as front panel and 20 cm as back panel.	980		

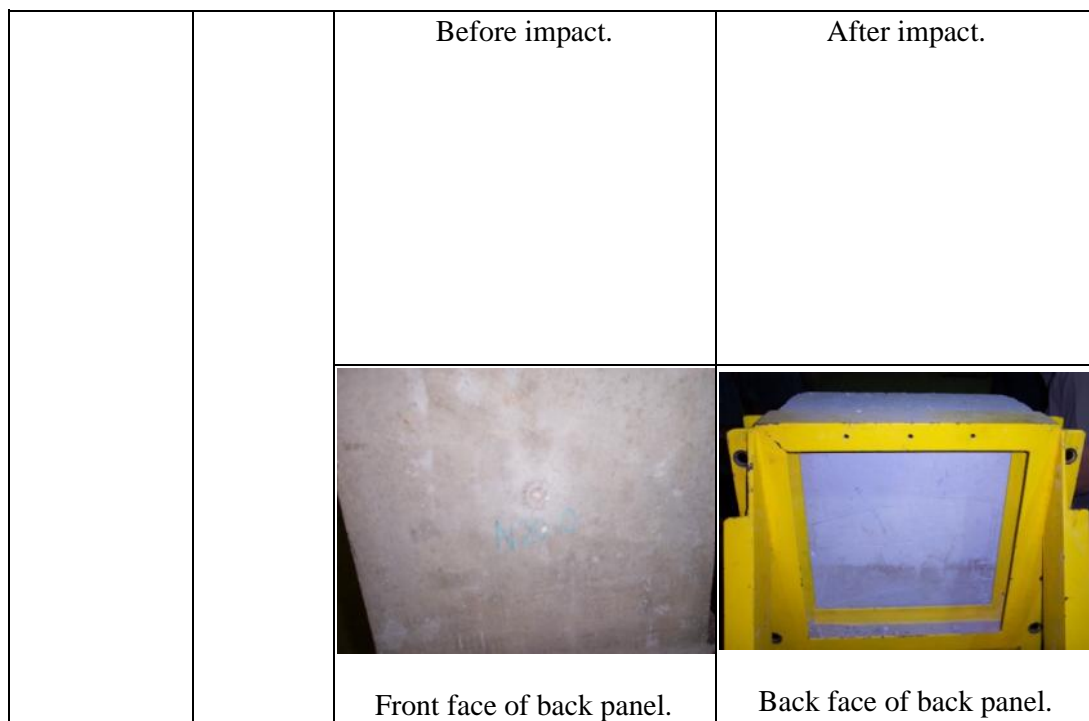


Fig. 5. 60 cm thickness concrete specimens.

3. Discussion

3.1 10 cm specimens (5cm + 5cm).

As shown in Table 1 and Fig. 2, the dividing process "without using any filler between the panels" decreased penetration resistance. This is clear as the velocity that caused full perforation of the divided specimen was 255 m/s while the velocity that caused full perforation of the undivided 10 cm specimen was 275 m/s. The front panel of 5 cm thickness is considered thin, as the ratio of the panel thickness (t) to the projectile diameter (d) is less than 5.0 [1], ($t/d = 5.0/2.3 = 2.18 < 5$). For thin targets subjected to impact velocity higher than its penetration resistance, it was found that the penetration depth increased rapidly accompanied by wider scabbing area and larger fragments volume and velocity [1]. According to the this reason, the portion of impact energy absorbed by the front panel was too small to stop the projectile; and consequently the residual impact energy "after perforating the front panel" caused full perforation to the back 5 cm panel. The total impact energy in this case was lower than that required for perforating the undivided specimen. As shown in Table 1 and Fig. 3, using 1 cm of sand filler between the two panels improved perforation resistance. Although projectile impact velocity of 295 m/s caused damage for both panels, the projectile was captured in between them. In fact, 1 cm of sand filler did not significantly increase the concrete panel resistance from the thickness increase point of view due to the following reason:

Using equation (4) for projectile impact velocity of 275 m/s, it was found that the theoretical perforation thickness equal 11.2 cm. According to equation (5), the final penetration depth in dense sand equal 117 cm. This shows that, the penetration resistance in sand is about 10% of the concrete penetration resistance. This means that using 1 cm sand filler is equivalent (in resisting penetration) to about 1 mm of concrete, which is insignificant increase in target

thickness. The benefit of sand filler in this case is to prevent concrete scabbing at back face of the front panel and to preserve the continuity of the target.

3.2 15 cm specimens (10cm + 5cm).

As it can be seen from Table 2 and Fig. 4, using the 5 cm panel in front and 10 cm panel in the back; did not affect the specimen perforation resistance. In this case the two panels were totally perforated at approximately the same perforation velocity required for the undivided panel (410 m/s). In addition, the damage level represented by the front and back face crater area was found greater than that for undivided panel. This could refer "as explained before" to the fact that the absorbed energy by the front thin panel of 5 cm thickness was not significant enough and the residual energy caused full perforation of the back 10 cm panel.

When the 10 cm panel faced the impacting projectile and the 5 cm panel was in the back; the target resisted perforation up to projectile velocity 425 m/s. The projectile was captured by the front panel, while the back 5 cm panel was totally cracked. Small dent was found in the back panel front face. This behavior indicates that using front panel with higher thickness to projectile diameter ratio, improved perforation resistance; as most of the impact energy is absorbed by the front panel. The panel thickness (t) to projectile diameter (d) herein was ($t/d = 10/2.3 = 4.34$).

3.3 60 cm specimens (40cm front + 20cm back).

To have more investigation about the effect of front panel thickness to projectile diameter on penetration resistance, 60 cm thickness specimen was used. The specimen was tested first as undivided sample, and second the specimen was divided into two panels; 40 cm thickness as a front panel and 20 cm panel as a back one. In this case, the front panel thickness to projectile diameter was ($t/d = 40/2.3 = 17.4$). As shown in Table 3 and Fig. 5, the undivided 60 cm panel was totally destroyed at impact velocity of 980 m/s. When the divided specimen was subjected to the same impact velocity, the 40 cm front panel was totally destroyed while slight effect was found on the back panel. Only a dent of 1 cm diameter and 0.5 cm depth was found at the front face of the back panel, while no cracks were observed in either back panel faces. From the analysis, it is noticeable that increasing the ratio of front panel thickness to projectile diameter (t/d) increased the perforation resistance. More study is needed in this area to identify the optimum (t/d) ratio of front and back panel to improve perforation resistance. In this study, a ratio of (t/d) for front panel not less than 5 was recommended.

4. Conclusions

Regarding the behavior of concrete panels subjected to impact loads of hard projectile, the following conclusions were obtained by the present study:

1. Dividing concrete target could increase its perforation resistance .
2. A positive effect on perforation resistance was obtained by dividing concrete targets with setting the panel of bigger thickness in front of the impacting missile. The recommended front panel thickness (t) to projectile diameter (d) in this study was ($t/d \geq 5.0$).
3. For double-layer concrete wall target, putting sand filler in between layers improve s its perforation resistance.

5. References

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