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BLAST PROTECTION OF THE PERIMETER

SUMMARY: The article brings a different approach to the perimeter protection in comparison with current manuals. It explains the reaction of the fortification materials when high explosive detonates on of their surface. Fortification is assessed here as concrete or loose material. Based on acoustic rules it is a process of attenuation of transition waves while propagating the above mentioned materials. The article shows the false feeling of the security of persons standing behind concrete wall and vice versa the underestimating of the loose material efficiency. Further recommendations how to improve blast protection of perimeter walls are given on the conclusion of this article.

Keywords: Berm, blast protection, concrete wall, explosives, perimeter security

INTRODUCTION

Perimeter is a physically marked outer edge of a military facility. It clearly and distinctly encircles space forbidden for any unauthorized intrusion. Its design has to announce a strong visible sign not to approach illegally. Consequently, enemy consideration should be focused to penetrate a perimeter line. The purpose of penetration may be a nuisance or show of force action as well as an attempt to conquer the base. It is a spectacular action whose effect could be to inflict casualties or humiliation of troops. In any case, the successful attack reduces credibility of troops in minds of local residents. Recently, the concern is paid to the potential attack by bulk explosives on perimeter structure. Force protection measures applied on any military facility have to solve a perimeter security as paramount task. Commander is obliged to implement steps reducing implications and damages, when attack happens. He uses so called Risk Assessment, where the threat anticipated and the respective countermeasures applied are compared and assessed their proportionality. In this framework the reliability of the different design of the perimeter structures shall be evaluated.

BASIC DESIGN OF THE BLAST PROTECTION STRUCTURES

First of all, we have to classify basic structures, used for perimeter protection.

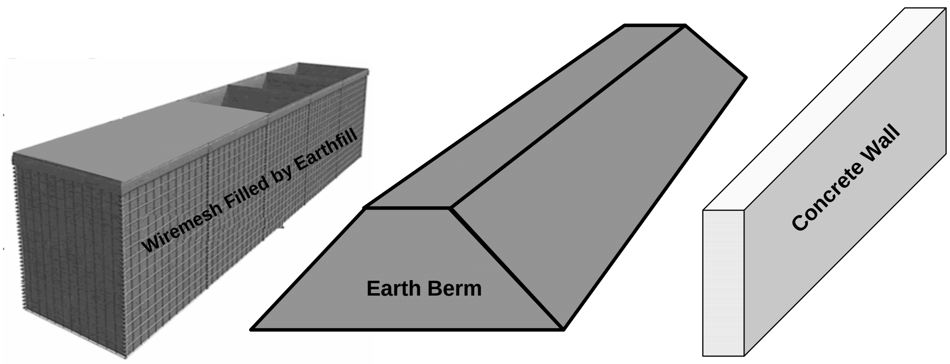

Fig. 1 Basic blast protection structures

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The picture contains three different structures: from left there are foldable wire mesh bags filled by earth fill (HESCO Bastions), earth berm and concrete wall. As a rule, strong solid structures like concrete walls are preferred. Their mass, size and strength can induce feeling of security inside of the perimeter. But is it the truth? Are they really impregnable for energy, released by explosives? Is it the best structure capable to withstand the detonation stress? The first impression could answer "yes, of course"; concrete is a hard solid stuff and the harder looks the better. But why the medieval engineers ceased the option to protect fortresses by masonry walls and changed their construction by lower berms made by soil, when artillery became decisive weapon for any siege? The answer can be obtained by the mechanism of blast effect on the solid structure.

ENERGY OF THE LONGITUDINAL WAVES

The detonation produces energy in the form of a shock wave. The surrounding environment determines where this energy loses its value and continues as acoustic energy producing elastic waves, by other words, sound. The propagation of acoustic energy can bring the first approach to this consideration. We will focus to elastic longitudinal waves, moving through the particular material. Their speed is a constant for each material.

The propagation of acoustic energy should be characterized by its intensity. It is defined acoustic energy output related to square unit. The formula is [1]

$$I_{\mathrm{elast}} = p_{\mathrm{elast}} v_{\mathrm{elast}} \qquad (1)$$

where I is intensity [W m–2], p is acoustic pressure [Pa] and v is acoustic speed (speed of the oscillation of particles around their fixed positions) [m s–1].

With analogy to electric circuits p corresponds to voltage and v corresponds to the electric current. Without deriving it is possible to formulate the relation p/v

$$\frac{p_{\mathrm{elast}}}{v_{\mathrm{elast}}} = \rho c \qquad (2)$$

where p/v is acoustic resistance of the surrounding material, ρ is the density (volumic mass) of the surrounding material, c is the speed of the longitudinal waves (sound). Whereas indicated from (2)

$$p_{\mathrm{elast}} = v_{\mathrm{elast}} \rho c$$

Then $$I = v_{\mathrm{elast}}^2 \rho c$$

And finally $$I = w \cdot c \qquad (3)$$

where w is defined as the density of acoustic energy [J m–3]. As visible from the above mentioned formulas, the intensity depends on the density of the acoustic energy and the speed of the longitudinal waves.

Now, we have to make use of method of analogy for determination, whether detonation energy could be characterized by the intensity as defined in Formulas (1) and (3).

Detonation wave affects its surrounding by shock, accompanied by destruction effect on all surrounded materials. Generally, the transient speed will achieve its maximum on the contact with detonating explosive, where possesses the maximum of energy. But at a distance [3]

Where Rlim is the distance from the centre of the detonating explosive [m], r is the radius of the intact explosive [m], the wave loses its energy and is transformed regressively into longitudinal elastic wave.

$$R_{\lim} \approx 3 - 10r \qquad (4)$$

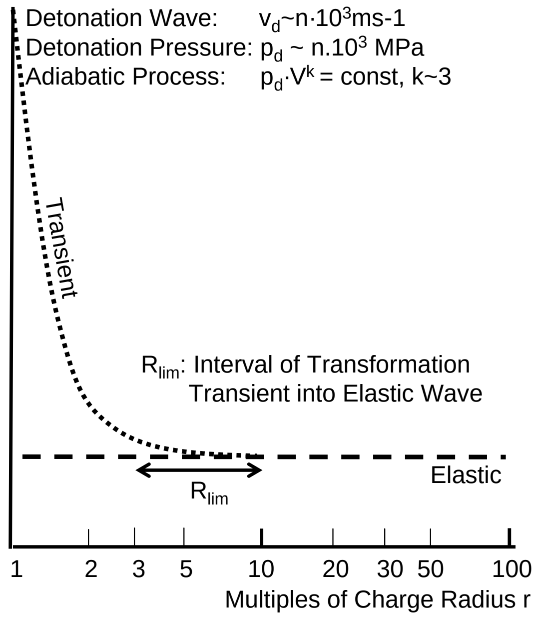

Fig. 2 Transformation of detonation wave into elastic wave at distance Rlim

Now, we have to derive the density of the detonation energy:

While detonating the explosive is transformed into gas products, the density of them is approximately [3]

$$\rho_{\det} \approx \frac{4}{3}\rho_0 \qquad (5)$$

where ρ0 is the density of the intact explosive (before detonation) [kg m–3], ρdet is the density of the detonated explosive [kg m–3].

The detonation pressure is defined [3]

$$p_{\det} = \rho_0 v_{\det} v_{\text{flow}}$$

Where pdet is detonation pressure [Pa], ρ0 is volumic mass of intact explosive [kg m–3], vdet is detonation speed [m s–1] vflow is a speed of detonation products, reaching approximately $v_{\det}/4$, then

$$p_{\det} = \frac{1}{4}\rho_0 v_{\det}^2 \qquad (7)$$

From (8) is obvious, that any material on the contact of explosive will be affected by detonation pressure, which is proportional to quadratic detonation speed, which constitutes brisance.

Thermal energy of explosion could be derived from adiabatic process indicated on Figure 2:

$$Q = \frac{1}{2\left(k^2 - 1\right)} \cdot v_{\det}^2 = \frac{1}{16} \cdot v_{\det}^2 \qquad (8)$$

Comparing formulas (7) and (8) we obtain:

$$Q = \frac{p_{\det}}{4 \cdot \rho} \qquad (9)$$

The flow of energy of the transient wave is defined as [3]

$$w = Q\frac{N}{R} \qquad (10)$$

Where A is a function of the specific exothermic volume of the explosive Q [J kg–1], N is the mass of explosive charge [kg] and R is the distance from the explosion site [m], then

$$R \geq R_{\lim} : \left(v_{\det} \rightarrow c\right) \Rightarrow I = w.c \qquad (11)$$

Comparing this formula with (3) it is obvious that we are allowed to make use of analogy with acoustic formulas to describe an explosion process, which could make the further considerations easier.

THE SOUND SPEED AND ATTENUATION IN CONSTRUCTION MATERIALS

Turning back to Figure 2 we have to emphasize another fact. The transient area of the graph (R<Rlim) indicates the loss of energy inversely proportional to speed of sound. Detonation energy affecting materials possessing low speed of sound will be consumed just close to explosion site unlike materials possessing high speed of sound, closer to detonation speed. This fact is justified by equation (11)

Let us see the Figure 3 below related to potential construction materials the both natural (arenaceous) and artificial (concrete) origin [2].

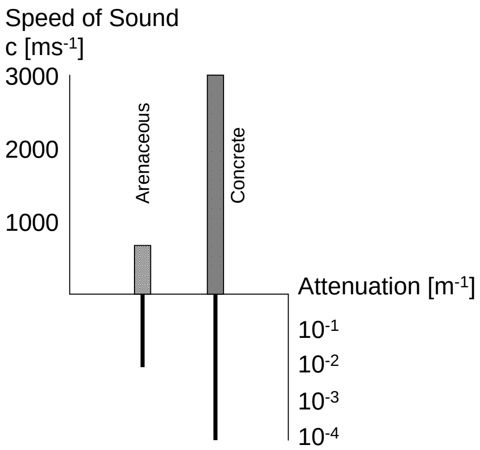

Fig.3 Speed of sound and attenuation of arenaceous and concrete materials

It describes features of materials of our interest – arenaceous (sand, gravel) and concrete. The speed of sound is compared as well as coefficient of absorption, which cause attenuation of elastic waves. This is supplemental factor affecting energy propagation trough materials.

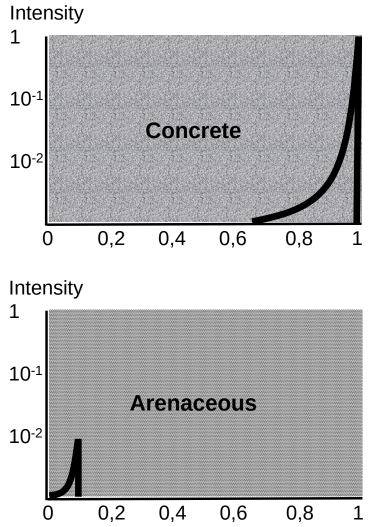

Fig. 4 Comparison of wavy features of concrete (on top) and arenaceous (on bottom)

Applying this recognition we can compare the situation inside mass of concrete and of the sand, scaling by concrete. This indicates Figure 4: Grid 0 indicates the site of the same explosion at concrete and arenaceous mass. We can observe the position and amplitude of the wave propagating arenaceous material in the moment when the wave propagating concrete of the amplitude 1 reached grid 1. The difference in position is almost ten times, the difference in amplitude is hundred times.

MECHANISM OF THE DISINTEGRATION

The mechanism of the construction material disintegration indicates following picture. It explains the character of the longitudinal wave (sound) while reflecting from acoustic boundary [3]. The case "A" shows reflection of the sound from the environment of the lower acoustic resistance (ρ·c) than propagated originally. This compression wave is reflected as a tensile wave. When opposite case "B" happens, the reflected wave keeps its original nature.

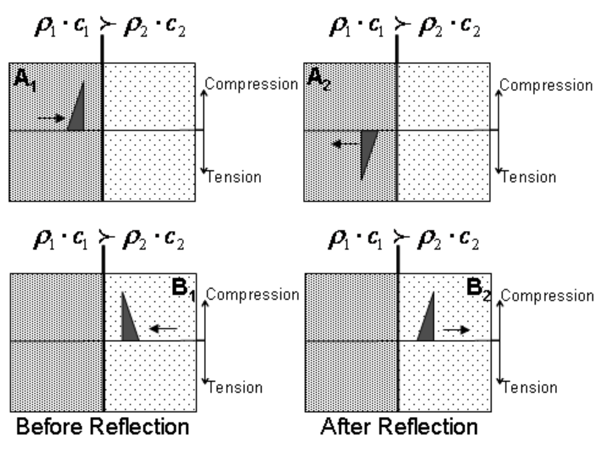

Fig. 5 Character of longitudinal waves after reflection in different materials

We can realize an important common sign – disintegration is propagated from the reverse surface toward the averse surface, where explosion occurs. The reason is the interference of the compression waves originated by explosion and its transformation into tensile wave reflected from the interface concrete (or soil) and air. The figure 6 justifies this statement.

The effect corresponds with mechanical features. Rigid and brittle materials produce debris like secondary projectiles. We can make a tentative conclusion – the efficiency of the barrier occurs inversely in proportion to speed of elastic waves. Sandbags or HESCO Bastions represent higher level of security to space inside the perimeter than concrete or steel. There is a further argument supporting the above mentioned conclusion. The compact material can be considered closer to elastic stuff, while loose material cannot. Internal friction among grains of the loose materials absorbs energy of explosion.

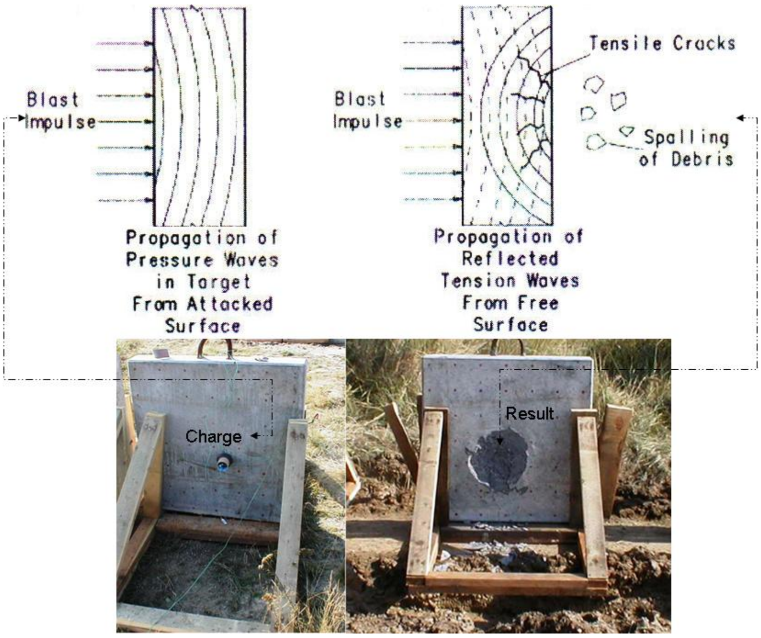

Fig. 6 Mechanism of disintegration - result

The indirect confirmation is presented on the figure 7. When charge exploded in the middle of the road, the solid wall on its side was seriously damaged but the HESCO barrier was almost intact.

Fig. 7 Comparison of damages on rigid and loose protection structures (archive of the author)

This picture makes visible the fact, that arenaceous materials absorb the energy of waves better than rigid materials, like limestone, which features are similar to concrete. Who wants to make an evidence of this theoretical conclusion, he can refer to history of the Egyptian assault on Sinai desert across Suez Canal: They breached a huge Israeli made sandy berm not by means of explosives which proved ineffective, but by flow of pressurized water.

Is any option available, how to diminish the splinter effect of the concrete wall? It is partly a hypothetical consideration. The solution could bring design similar like multi layered armour. The idea is to cover the reverse side of the concrete wall by ductile or plastic layer. We can suppose the speed of the sound approximately the same as in the argillaceous materials. In this case the interference occurs not on the brittle concrete surface, but in the ductile material, indicating slower deformation, resisting a loss of coherence. It may be plastic rubber based insulation material. The preliminary experiments have already been published, but without regulations. The inspiration can bring by the British company DYNASYSTEMS, which offers commercially reinforcement of buildings, cars, etc. The question is whether to buy the product or achieve similar effect by our means and assets. However, the functionality of this provision can be proved by our regulation. The charge, when we have on the reverse side of the object (steel) in water (for instance, penetration of the floating boat from inside), shall be four times bigger than we intent to penetrate the same material on dry surface.

CONCLUSION

The loose material composing a fill of HESCO Bastions or earth berm can give reliable protection of the reverse area behind perimeter line, when an attempt occurs to breach it by explosion. On the other hand, concrete wall may bring a false feeling of security. It can produce splinters as projectiles when the explosion occurs on the averse side of wall. The serious fact, that it is not necessary to penetrate this wall to induce this effect. The option how to reduce this effect is to cover it on the reverse side by plastic and ductile material. This provision is commercially available. It would be worth to examine expedient provisions, like rubber based insulation layers and check their efficiency.

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