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Blast Protection of the Perimeter

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Abstract:

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

1. 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

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countermeasures applied are compared and assessed their proportionality. In this framework the reliability of the different design of the perimeter structures shall be evaluated.

2. Basic Design of the Blast Protection Structures

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

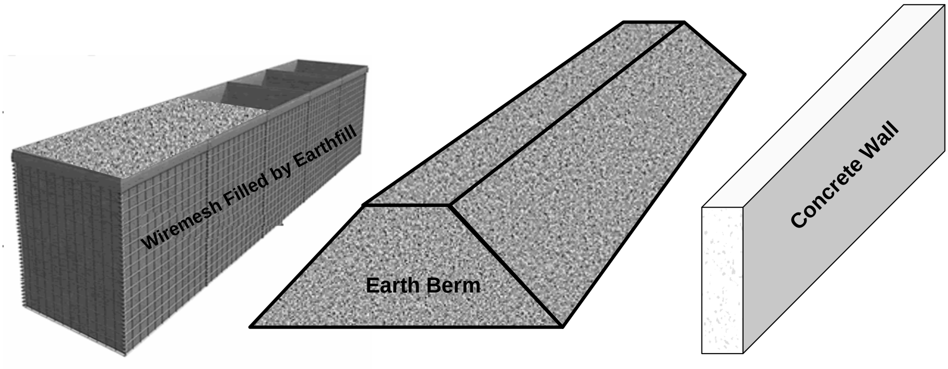

Fig. 1 Basic blast protection structures

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.

3. 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]

$$I_{\mathrm{elast}} = p_{\mathrm{elast}} v_{\mathrm{elast}} \tag{1}$$

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

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

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)

$$p_{\mathrm{elast}} = v_{\mathrm{elast}}\,r\,c \qquad (3)$$

then

$$I = v_{\mathrm{elast}}^{2}\,r\,c = wc \qquad (4)$$

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. Heavy materials characterized by high speed of sound can transfer acoustic energy with minimum loses. When we turn back to our consideration on the barrier construction, the last formula indicates that we need just the opposite effect, when materials restrain the transfer of energy. The lower density and lower speed of sound should be preferable.

4. The Density and Sound Speed in Materials

Let us see the picture below related to potential construction materials the both natural (soil, rocks) and artificial (concrete) [2]. The potential construction materials have approximately the identical density except of dry arenaceous ones (sand/gravel) which are partly lower. There is not remarkable difference among wet arenaceous, argillaceous (silt, clay), sandstones or concrete in their density ρ. While the speed of sound of dry arenaceous is comparable with the sound in air, the respective speed of the rest of the construction materials differs substantially. The moisture brings changes in the transfer of acoustic energy. Wet arenaceous has almost three times bigger speed of sound than dry arenaceous. The speed of sound c of concrete is comparable with detonation speed of ANFO explosives and c of crystalline rocks is close to detonation speed of TNT. We can conclude preliminary that dry arenaceous material is presumably the worst for transfer of acoustic energy, which is desirable for us. This allows us to define formally the transient speed making use of above mentioned formulas.

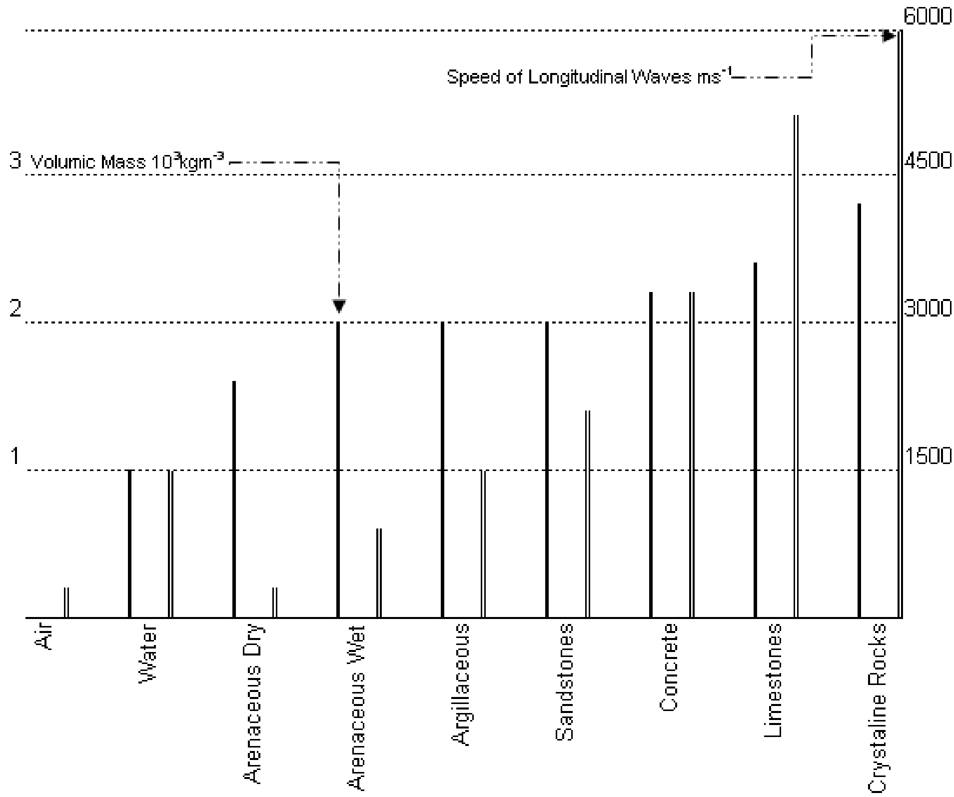

Fig. 2 Volumic mass (density) and sound speed in potential construction materials

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

$$r_{\text{det}} \approx \frac{4}{3} r_0 \tag{5}$$

where ρ_0 is the density of the intact explosive (before detonation) [kg m^{-3}], ρ_{det} is the density of the detonated explosive [kg m^{-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]

$$R_{\text{lim}} \approx 3-10r \tag{6}$$

where R_{lim} 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.

The detonation pressure is defined [3]

$$p_{\text{det}} = r_0 v_{\text{det}} v_{\text{flow}} \tag{7}$$

Where p_{det} is detonation pressure [Pa], ρ_0 is volumic mass of non detonated explosive [kg m^{-3}], v_{det} is detonation speed [m s^{-1}] v_{flow} is a speed of detonation products, reaching approximately $v_{\text{det}}/4$, then

$$p_{\text{det}} = \frac{1}{4} r_0 v_{\text{det}}^2 \tag{8}$$

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.

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

$$w_{\text{trans}} = AN\frac{1}{R} \tag{9}$$

Where A is a function of the specific exothermic volume of the explosive Q_{exotherm} [J kg^{-1}], N is the mass of explosive charge [kg] and R is the distance from the explosion site [m], then

$$w_{\text{trans}} = f\left(Q_{\text{exotherm}}\right)N\frac{1}{R} \Rightarrow I = f\left(Q_{\text{exotherm}}\right)N\frac{1}{R}c \tag{10}$$

Analogically to (4) we can formulate

$$f\left(Q_{\text{exotherm}}\right)N\frac{1}{R} \approx w \tag{11}$$

The final expression may be

$$w_{trans} \approx wc \tag{12}$$

This formula shows the fact that energy of longitudinal waves propagating certain material is proportional its speed of sound. "Slow" material (argillaceous) can transfer less energy than solid rock or concrete. In the case of "slow" material we can make use of formulas (6) or (7), where this status is valid. In the case of rigid materials this could be just on the contact with the detonating explosive (compare detonation speed of explosives and speed of sound of those materials, see Fig. 2).

5. 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 ($\rho \cdot c$) than propagated originally. This compression wave is reflected as a tensile wave. When opposite case "B" happens, the reflected wave keeps its original nature.

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.

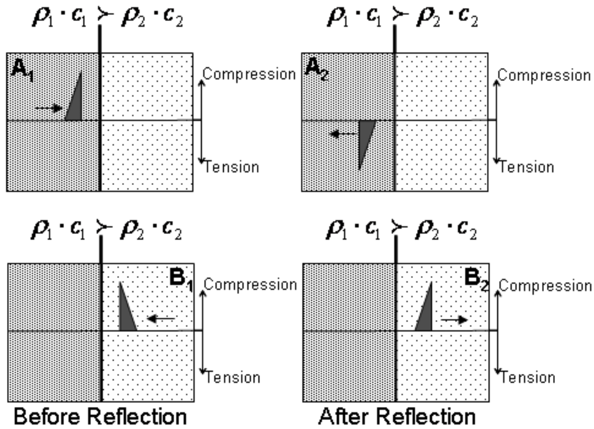

Fig. 3 Character of longitudinal waves after reflection in different materials

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. This feature is characterized by coefficient of absorption of seismic energy [2]:

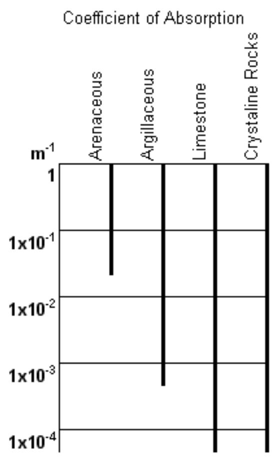

Fig. 4 Energy of longitudinal waves – coefficient of absorption

This picture makes visible the fact, that arenaceous materials absorb the energy of waves more than 100 times 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.

Fig. 5 Comparison of damages on rigid and loose protection structures (archive of the author)

Further evidence can be proposed, when one calculates charge dimension for the loose material comparing black powder and TNT (Fig. 6) [3]. The picture is organized in such way that all basic features of TNT are expressed as multiplication of the basic features of black powder. We can see that exothermic feature is more or less comparable in the both explosives but detonation speed of TNT is more than ten times higher. The simple example of dimensioning of the charge in the identical materials confirms the fact, that the energy of TNT is wasted, when TNT is used in the loose materials. We have to overcharge 2-3 times when we want to achieve the respective effect [4]. It is good to emphasize, that black powder has comparable detonation speed as speed of the sound in loose materials.

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.

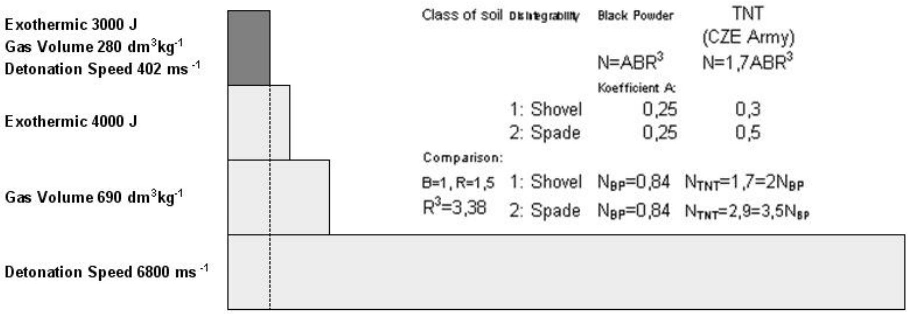

Fig. 6 Comparison of the efficiency of the black powder and TNT

6. 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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