APPLICATION OF NON-DETONATING CHARGES FOR CAUTIOUS BLASTING OF CONCRETES

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ABSTRACT. Usually, when carrying out special blasting works for demolition of concrete elements and structures in construction, the so-called "Small Charges Method" is applied. Traditionally, explosives with higher brisance and a shorter period of increasing the rate of explosive conversion are preferred. This ensures the completeness of the detonation and the optimal size of the "sphere of destruction" around each charge. In some specific situations, the shattering effect of explosives provides more damages to the surroundings, than benefits from blasting treatment of the concrete element. It often happens, that there are existing protected objects next to the demolited element or structure, even in the immediate vicinity. There are cases when, despite expensive measures to protect against the harmful effects of the explosion, some damages from the effects of detonation are unavoidable. In such situations, two approaches are applied in practice: non-explosive destruction or use of "low-energy" charges. The report discusses a real task for explosive crushing of hardened concrete in the body of a self-propelled concrete mixer, without deforming or damaging the technical means. Non-detonating metal-containing pyrotechnic mixtures have been used for explosive charges with reduced energy.

Keywords: non-detonating blasting cartridges, propellants, cautious blasting, blasting demolition

ПРИЛОЖЕНИЕ НА НЕДЕТОНИРАЩИ ЗАРЯДИ ЗА ПРЕЦИЗНО РАЗДРОБЯВАНЕ НА БЕТОНИ

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РЕЗЮМЕ. Обикновено, при провеждане на специални взривни работи за разрушаване на бетонни елементи и конструкции в строителството се прилага така наречения "Метод на малките заряди". Традиционно се предпочитат експлозиви с повишена бризантност и по-кратък период на нарастване на скоростта на взривно превръщане. Така се гарантира пълнотата на детонация и оптимален размер на "сферата на разрушение" около всеки заряд. В някои специфични ситуации, бризантното действие на взривните вещества нанася повече вреди по окръжаващата среда, отколкото са ползите от взривното третиране на бетонния елемент. Често се случва до подлежащия на разрушаване елемент или конструкция да има охраняем(и) обект(и), дори в непосредствена близост. Има случаи, когато въпреки скъпите мероприятия по защита от вредните въздействия на взрива, пораженията от ефектите на детонацията се оказват неизбежни. При такива ситуации, в практиката се прилагат два подхода: безвзривно разрушаване или използване на "нискоенергийни" заряди. В доклада е разгледана реална задача за взривно раздробяване на втвърден бетон в корпуса на самоходен бетонов миксер, без техническото средство да се деформира или поврежда. За заряди с понижена енергия са използвани недетониращи метало-съдържащи пиротехнически смеси.

Ключови думи: недетониращи взривни патрони, метателни взривни вещества, предпазливо взривяване, взривно разрушаване

Introduction

Modern industrial and civil construction is associated with an increasing need of demolishing of parts of buildings and entire facilities for reconstruction or complete clearing of terrains. Explosion is the fastest and most cost-effective way, but it is often accompanied by inconveniences, caused by the harmful effects of detonation. Carrying out blasting operations in urban areas, close to sensitive industries and critical infrastructure requires a specific approach for protection against seismicity, vibrations, shock wave and fly-rocks. The blasting technique is placed in an unfavorable competitive race with various non-explosive methods of destruction. Complicated working conditions are a prerequisite for developing a new generation of explosives and technological approaches for their application. They can be based on non-detonating energetic compositions. The processes for crushing of consolidated cement mixtures and ordinary concrete are identical to those in the fragmentation of rocks. In them, intense cracking can be caused even only under the influence of rapidly expanding gaseous products. The destruction of reinforced concrete and composite materials is complicated by the presence of reinforcement of different nature, spatial location and degree of crosslinking. The rupture of the reinforcing elements requires a brizant action of the explosion, which is inevitably associated with the detonation. The main purpose of this study is to research the possibilities of using pyrotechnic compositions for the destruction of concrete elements and structures in construction, without the risk of side effects caused by detonation of charges. Experiments for blasting of hardened concrete with non-detonating charges are the next step in the study of the potential of low-speed energetic compositions for delicate blasting not only in the extraction of dimension stones, but also for special blasting works.

Knowledge of the theoretical basis of explosive action in a solid medium, about the differences between the action of high-explosives and low-explosives, as well as the processes of crack formation in metamorphic rocks, plays a leading role in scientific and experimental activities.

About explosives and their impact on hard medium

The explosives are high-energetic chemical compounds or mixtures of chemical compounds that, when properly initiated, instantly turn into gaseous products with high temperature and pressure. This process is called "explosion". During that rapid decomposition, one kilogram of explosive turns into hot gases in just a part of milisecond, creating a pressure of about 10,000 MPa (1,450,000 psi) inside the blast hole. The explosion temperatures of the various explosives are between 1,500 °C to 4,500 °C. Detonation velocities for civil and military explosives varies in the range from 2,500 to 8,000 m/s.

The rate of explosive's chemical reaction (combustion, deflagration or detonation) is one of the parameters determining their classification. This parameter has a direct influence on the brizancy of the explosive, respectively for the fracture formation in the treated rock. The type of explosive decomposition is decisive for the choice of explosives and the appropriate explosive technology in special blasting works. The detonation velocity is the speed at which the shock wave travels through the length of the charge. The higher this speed, the greater is the strength of the explosive's shredding effect. High-speed explosives are suitable for blasting hard rocks and strong reinforced concrete. The blasting agents with a lower detonation rate are used to break up soft rocks and weak concrete. The propellants emits their gaseous products for a longer time and therefore exert a better throwing action.

The detonation pressure is the pressure in the reaction zone when the explosive decomposes at supersonic speed. It causes the primary shock wave of compression. That compression wave propagates in the environment and is an important indicator of the ability of the explosive to perform good fragmentation.

Deflagration is a subsonic reaction of chemical decomposition of explosives. It is typical for all types of gunpowder and other propellants, which work by means of the pressure, generated by the compressed gaseous products of the explosion. Practically, they haven't a brizant action.

Experimental part

The occasion for the experiment was a road accident with a concrete truck, overturning when driving off-road. The accident ended with uncontrolled hardening of the concrete solution in the mixer body (Fig. 1).

Fig. 1. Concrete truck

The task

Explosive fragmentation and crushing of hardened concrete solution inside the mixer's body of a concrete truck (Fig. 2 and 3) without allowing deformations of the metal housing.

Fig. 2. Concrete mixer exterior

Available concrete in the mixer - 6 m³. Brand of the concrete mixture - "B-20", with receipt according to BDS EN 206 - 1.

Standard containing for 1 m^3:

- Variegated river gravel or crushed stone - 1250 kg. ~ 1300 kg.
- Washed sand - 650 kg. ~ 700 kg;
- Portland cement brand M 250 - 465 kg .;
- Water - 180 l. ~ 200 l.

Approximate weight of 1 m³ of the described concrete solution = 2550 kg. Weight of 6 m³ concrete "B-20" = 15 300 kg.

Fig. 3. Concrete mixer interior

Site conditions

The steel body of the mixer (barrel) is made of wear-resistant steel sheets brand DILLIDUR 400/500 with a thickness of 12 mm. The individual sheets of the housing are welded with an automatic welding machine with internal and external welding seam. Inside the mixer are welded screw ribs made of wear-resistant steel sheets 4 mm., designed for mixing the concrete solution and for its unloading. There is an inspection hole with a diameter of 500 mm., which is covered with a removable cover, in the front compartment of the barrel (Fig. 4). Outlet diameter 900 mm.

Fig. 4. Concrete mixer revision hole

The available hardened concrete mixture was distributed along the entire length of the barrel, filling 37.2% of its total geometric volume. The remaining free volume of 62.8% was inconvenient, but sufficient to carry out the processes of preparation of special blasting works (Fig. 5). Due to the narrow space in the mixer housing for the preparatory processes for drilling and blasting works and the difficult access to the site, it is not possible to use perforators with compressed air. Another reason to avoid the pneumatic drilling technique is that a large amount of dust is released when working with a pneumatic perforator. Under these conditions (small free volume, lack of open space, poor ventilation, even with personal protective equipment) it was not appropriate to work with pneumatic tools. For this purpose, an electric drill BOSSH GBH 5-40 DCE was selected, with the necessary accessories to it (crushing awls and drill bits for boring of blast holes). The electric drill was powered by a portable gasoline single-phase generator model IMER EXPLORER 4010 - 3000W.

Coefficient of strength of the concrete mixture

The uniaxial compressive strength class of concrete is indicated by the letter "B" and numbers after it, showing the minimum strength in MPa. These indicators mean strength with a guararity of 95%.

For example, for the most used concrete B-20, this means that when testing a reference cube of this brand of concrete, its strength is good at 95% of the results with a pressure of 20 MPa. The compressive strength of the concrete is determined on reference (test bodies) cubes with size 150 x 150 mm, which harden at the prescribed technological time.

According to the European standard to which the Bulgarian BDS EN 206 - 1 is synchronized, the strength classes are marked with "C" and two groups of numbers after it. For the most used concrete C - 20/25 this means that its minimum strength determined on test specimens (cylinders with a diameter of 150 mm and a height of 300 mm) is with a pressure of 20 MPa, and the minimum strength determined on cubes) with a size of 150 x 150 mm. is 25 MPa.

In the present case, the concrete mix had not reached its standard strength, but was still brittle and with high moisture content. The strength coefficient according to M.M. Protodyakonov was accepted: f = 10 - 12.

Selection of technological method of blasting and construction of the charges

Given the specific conditions of the site and the irregular shape of the concrete body, which is located in the lower part of the steel barrel of the mixer, the blasting for swelling the concrete was carried out in stages in several sectors in order to preserve the structural integrity of the mixer. In the design of blasting, the concrete body was considered as similar to a dug foundation of non-reinforced concrete. In order to achieve a more gentle blasting effect with successive opening of free surfaces, a model of bench blasting by the method of small charges was provided.

Selection of the explosive

Having into accpount the delicate technical conditions of the site, an opportunity was sought for a choice between explosives that do not detonate. In selecting the appropriate formulations, as a starting point were used the results of the laboratory tests of explosive mixtures published in „*Innovative formulations for a new generation of low-speed explosive compositions, designed for blasting in tender conditions and for extraction of rock-cladding materials*" – Journal of Mining and Geological Sciences, p.94 – 99, vol.62, Nr.2, 2019.

Fig. 5. Blasting field

In this particular case, a pyrolant explosive was chosen - a pyrotechnic mixture with a working form of chemical reaction "combustion". The so-called "Sound-light gas-generating pyrotechnic composition" provides a relatively large volume of gaseous products per kilogram of explosive and a sufficiently short period of rate increase to deflagration. During the ongoing chemical process, the contained metal powder fuel raises the temperature, which contributes to the greater expansion of the gaseous products (Table 1). Charge construction – continuous type.

Table 1. *Non-detonating explosive mixtures*

Characteristics	Black powder	Flash powder for SFX	Noise-light gas generating mixture
1. Ingredients, %:			
- KNO_3	75	-	-
- $KClO_4$	-	-	50
- $Ba(NO_3)_2$	-	50	20
- charcoal	15	-	-
- S	10	-	10
- Al/Mg powder	-	50	20
2. Estimated characteristics:			
- oxygen balance, %	- 20,3	- 23,4	- 8,5
- heat of blast, MJ/kg	3	4,5	4
- volume of gases, l/kg	280	260	340
3. Experimental characteristics:			
- moisture & volatile[3], %	-	-	-
- bulk density, kg/m^3	0,4 ÷ 0,5	0,5 ÷ 0,7	0,6 ÷ 0,8
- efficiency, cm^3	30	28	35
- brizance[1], mm	-	-	-
- critical diameter in bulk density[1], mm	-	-	-
- stable diameter in bulk density[1], mm	-	-	-
- velocity of chemical decomposition, m/s	300÷600	600÷900	400÷700
- optimal loading density[2], kg/m^3	Does not compact	Does not compact	Does not compact

Notes:

1. Brizance, critical diameter and stable diameter are not determined because the charges are not initiated by a detonator and do not detonate in the site conditions.

2. The charges are not sealed in the blast holes in order not to create preconditions for their explosive combustion to pass into detonation.

3. Moisture and volatile components reduce the burning rate and performance of the described pyrotechnic compositions.

Type of the the blast pattern

The decision for application of non-detonating charges deprives from the convenience of relying on the brizance action of the blasting. Respectively, the typical "spheres of explosive destruction" around the charges become practically unattainable. The expansion of the heated gaseous products causes only a few single radial cracks from the point of explosion, without areas of grinding and active fragmentation. In order to achieve sufficient cracking of the concrete body, it was necessary most of the cracks from the individual charges to be crossed. For this reason, the relative distance between the individual blast-holes should have been the same. A staggered layout of the blasting pattern was chosen.

Determination of the face burden (average)

Due to the fact, that the construction of the barrel was complicated by internal screw ribs, the blasting was carried out in seven separate stages in order to prevent deformation of these elements. Therefore, in the first round, a preliminary manual breaking was made, in order to form an additional free face. In the sections of concrete, that were located immediately behind the auger fins, the charges worked in unfavorable conditions - with only one open surface (in the vertical direction). The construction of these charges was with a reduced concentration of explosive to prevent damage on the fin-ribbing. With the first cut holes in the mentioned stages, the effect of low explosive performance of "cracking charge" was sought. The burden of the next charges (second, third and fourth rows of blast-holes) appears in a horizontal direction to the newly discovered surface from the first cut-holes. According to the Method of the small blasting charges, when destroying a buried foundation, described on page 218 by N. Paunov and B. Barbulov "V pomosht na vzrivnika", burden was accepted in the range $W_b = 0.30 \div 0.85$ m. Due to the fact, that in the present case non-detonating pyrotechnic charges were used, the burden of the first cut-hole was determined to be 0.30 m.

Initiation technique

Electric ignters for professional pyrotechnic purposes with a resistance of 2.5 Ω and a guarantee amperage of 1 A connected in a series circuit, were preferred as the most suitable means for inflammation. The number of electric igniters was determined depending on the blasting rounds parameters. The main goal was to avoid overloading the structure of the concrete-mixer caused by instantaneous expansion of the solid material during blasting. Separated step blasting was chosen due to the impossibility of the electric igniters to work in series of delay.

Loading method

Manual loading with individual approach to the blast holes were preferred.

Fig. 6. Loading of the charge in the blast-hole

The drill-holes for phased loading were pre-checked for their design depth. Residual material from the drilling works was cleaned. The electric igniters were calibrated using an ohmmeter, with a difference in resistance values not exceeding 10%. During the preparation of the charges, the pyrotechnic composition was weighed with an electronic scale to correspond to the quantity set in the project. The electric igniter and the weighed pyrolant were wrapped and fastened in a thin polyethylene foil tube. The prepared charge was placed to the bottom of the blasthole with the help of a tamping-rod (Fig. 6). No excessive pressure was applied to the charge, so that it would not be deformed or dead-pressed. A sand stemming was applied. At each blasting round, the ends of the wires of the respective number of igniters were connected in a series to the firing cable.

Results and discussion

Excellent swelling fragmentation of treated concrete was performed after blasting with pyrolant charges (Fig. 7 and 8). No damages on the construction of the mixer were registered.

Fig. 7. Swelled concrete inside the mixer interior after blasting

The absence of seismic action is explained by the fact, that the blasting was carried out above the ground and no high explosives were used to cause supersonic shock waves and compressive stresses.

Due to the fact, that the blasting demolition was performed in a closed space, as well as due to the used pyrotechnic composition with a low deflagration rate (up to 400 m/s.), distributed in small charges (up to 50 g.), no air-blast with overpressure was formed.

The enclosed space and the well-calculated charges were a prerequisite for the lack of fly-rocks.

Fig. 8. Grain sizes of the fragmented concrete

The total used explosive weight was less than 5 kg. No dangerous amount of toxic gases and harmful chemical compounds were released.

Conclusions

It was made investigations for application of fast combusting pyrotechnic composition for obtaining of non-detonating explosive charges, suitable for blasting activities at tender and complicated conditions. Results from blast-splitting of consolidated concrete in the volume of the mixer was satisfactory. There was no fumes emission, air-blast or fly-rocks after explosion of pyrollant composition. The velocity of propagation of the reaction of chemical destruction of used high-energetic composition was between 400 and 700 m/sec. depending on the diameter of the charges, moisture and density. Usually, noise-light gas-generating mixture shows higher velocities of deflagration and in bigger diameters of the charges is inclined to pass from combustion to detonation. The authors doesn't noticed any tendency for transition from deflagration to detonation in case of ignition of 50 g. charges with soft burning electric fuse-head in drill-holes with diameter 38 mm.

Such energetic compositions could replace both the widely used industrial explosives and blasting gunpowder in cases of cautious blasting in tender conditions. One of the disadvantages is their increased sensitivity to external influences, which could be prevented by usage of suitable charge casings. Another drawback is relatively high cost, which can be compensated by the reliefs in the mode of acquisition, transportation, storage and use, resulting from the lower hazard class of the products.

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