# A Phased Splitting off from the High-Strength Concrete by an Electro-Blasting Method

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**Abstract.** A phased splitting off from the monolith concrete block via electro-blasting method have been described. The results of experiments using the high-current pulse generator with operating voltage up to 15 kV and maximum stored energy of 126 kJ with initiation of the discharge in two boreholes were presented. The step by step electro-blast were produced simultaneous within boreholes drilled in the cast in the ground concrete monolith. Each subsequent electro-blast was performed in the boreholes pair situated farther from the free surface. Boreholes in each pair were drilled at a distance of 30-40 cm from each other, and of 25 cm apart from line of previous pair. It is shown that the electro-blasts leads to formation of main cracks at the predefined direction via boreholes line as well as main cracks lead to creation of a new free surface that help to form the desirable wave interference at the next step of the electro-blast.

## INTRODUCTION

Nowadays, there is an intensive urban growth and significant increasing of building density. In building sector the dismantling and recycling of various objects are often required, such as monolithic concrete structures, large solid blocks, old basements, etc. For solving such problems mechanical and explosive methods of fracture are widely used. However, there are some difficulties related to implementation of blasting in dense urban areas and environmental consequences of explosives usage. Substantial vibration from the mechanical and hydraulic hammers could lead to negative impacts on the surrounding infrastructure [1]. The development of new, effective, environmentally friendly technologies and methods for dismantling of the high-strength concrete structures, construction and expansion of tunnels, destruction and fragmentation of massive monolithic blocks of rocks is an actual problem in present days [1,2]. The electric-discharge technologies are promising methods for destruction, disintegration, demolition, splitting off and drilling of solid non-conductive materials. These technologies allows carrying out works in dense urban areas near communications, pipelines, waterworks, architectural monuments etc. without damaging them. There are no negative effects inherent to explosives as well [2-4]. In present paper the method of phased splitting off by electro-blast are presented, and experimental results are given and discussed.

## EXPERIMENTAL PART

### Electric-Discharge Destruction Principles

The electric-discharge blasting method is based on using the energy produced by an expanding electric discharge plasma channel when a powerful current pulse flows through it [1,5]. The discharge channel initiation can be implemented simultaneously in several boreholes allowing to split off the object in a predefined direction [6]. It should be noted that the phased electro-blasting is required for an effective crack propagation and destruction large objects. It is also essential to begin the destruction near the free surface paralleled to the axis of boreholes. It is well known that the free surface provides a wave interference which in turn creates the tensile stresses inside a solid

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material [5-7]. The coefficient of electrical energy conversion into the shock-wave disturbances is an important characteristic of electro-explosion. Its value depends on the energy stored in the capacitor bank, discharge channel length, characteristics of wave transmission medium, as well as properties of the destructible material. In most cases, the coefficient of energy conversion does not exceed 15% [8]. To improve the energy conversion efficiency, in Tomsk Polytechnic University the special electro-explosive cartridges (EC), acting as a shock wave transmission medium, was developed. EC is a coaxial system, in axis of which, in the moment of capacitor bank commutation, due to the explosion of thin copper wire, an electrical discharge is developed. EC is made of plastic material which have the acoustic stiffness close to that of destructible material, such as polyethylene or paraffin[5]. It was shown in [9] that application of polyethylene allows to increase the wave energy by 20–25 % in comparison with electrical discharge in water. As a result, the pressure amplitude of the generated wave increases by 25–30 %. The choice of the elastic materials as the surrounding the exploding wire material is also caused by the absence of crush zone in the vicinity of the channel that allows to avoid considerable loss of energy in this zone.

## High Voltage Equipment

For conducting the experiments, destruction and splitting off the rocks and high-strength concrete structures by using the electro-blasting method, the pulse power system was designed and constructed in High Voltage Electro-Physics and High Current Electronics Department of Tomsk Polytechnic University. The main part of pulse power system is the high-current pulse generator with operating voltage up to 15 kV, the maximum stored energy 126 kJ and maximum current pulse exceeded to 300 kA. The power supply consists of industrial frequency step-up transformer with single-stage voltage doubling circuit and protective inductor in output. During charging, the energy storage power consumption is up to 3kW. After the charging of capacitive energy storage, the remote pulse is applied to high-voltage switch which encourages the expansion of the conducting plasma channel in the borehole. The joule heating of the plasma increases the temperature in the channel of up to $2{\cdot}10^4$ K resulting in the extremely rapid channel pressure rise and its fast expansion. Short lifetime of the plasma allows developing very high power in the discharge channel. The maximum power value generated in the plasma channel is typically in the tens and hundreds of MW [5,7,9].

The transmission of the stored energy to a load is provided by the cable line consisting of eight coaxial cables. It gives an opportunity to connect simultaneously up to four electrode systems and realize the electro-blast in four boreholes. For registration of electrical characteristics of high-current pulse generator during operation the measuring system was used. The current pulse measurement was provided by Rogowski coil CWT-1500. The voltage measurements were provided by compensated resistive divider DNV-25. Signals from these devices were transferred to a oscilloscope Tektronix TDS-2024B.

## Experimental Field

Investigation of the phased splitting off from concrete monolith by the electro-blasting method was carried out with a sample of the concrete block immersed in the ground. The dimensions of the specimen were 300x150x120 cm. The concrete compressive strength was 40 MPa. The scheme of experiments is presented in Figure 1.

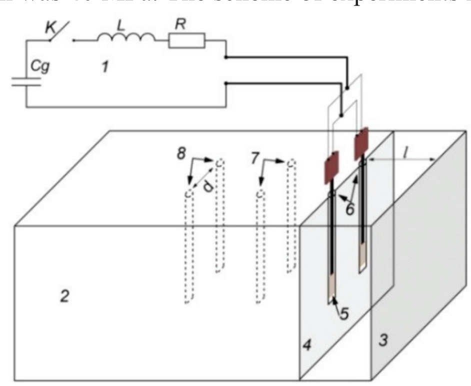


**FIGURE 1.** Scheme of experiments of the phased splitting off by electro-blasting method. 1 – high-current pulse generator, 2 – concrete block, 3 – free surface, 4 – created free surface after electro-blast, 5 – electrode with electro-explosive cartridge, 6-8 – borehole pairs.

The experiments were carried out with initiation of the discharge in two boreholes at the same time. The electro-blasts were produced three times. Each subsequent electro-blast was performed in the boreholes pair situated farther from the free surface. Boreholes in the pair were drilled at a distance of 40 cm from each other, and of 25 cm apart from the previous borehole pair. The depth of the boreholes was 70 cm. The high-current pulse generator was operated at the charging voltage of 12 kV. As it was already mentioned, to increase the amplitude of shock waves and step up the efficiency of its transfer to the destructible material, the polyethylene cylinder with copper wire in its axis was used as an electro-explosive cartridge. The outer diameter of the cartridge is equal to the inner diameter of the borehole in the destructible material and is equal to 26 mm.

## RESULTS AND DISCUSSION

The photographs of the concrete block immersed in the ground are shown in Figure 2. As experiments have shown in comparison with natural rocks, concrete is split off by the electro-blast with significant difficulties. This is due to heterogeneity and the high viscosity of the concrete as well as its acoustic stiffness that much lower than at rocks. All this factors increases the shock-wave dissipation, and therefore the distance from the boreholes to the free surface under splitting off concrete must be less than the same distance under the splitting off rocks, otherwise the main cracks will not occur.

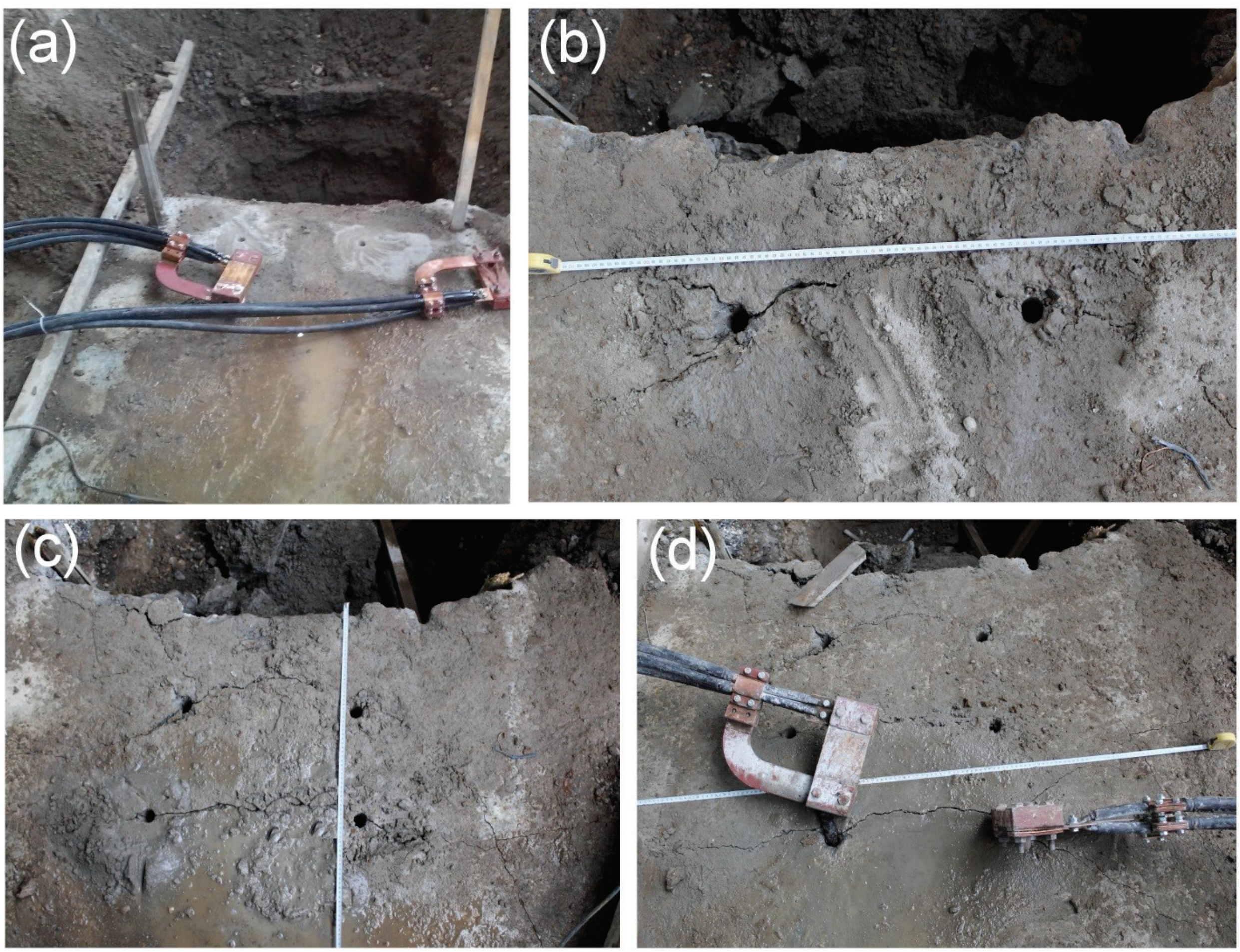


**FIGURE 2.** The experimental results of phased splitting off from the concrete monolith block.

First electro-blasting experiment was produced in the boreholes (6) (fig. 1). The distance to the free surface (3) equals to 25 cm. During the electrical discharge, the wire explosion and plasma channel formation occurred, expanding channel generated the pressure wave which propagated in the polyethylene cartridge and then in the concrete block. The shock wave, being propagated, reflects from the free surface of the monolith and then turns back to the borehole. As a result of direct and reflected waves superposition the tensely deformed state and formation of the mechanical compressive, tensile and shear stresses are caused, which ultimately leads to the growth of cracks. Overall, due to the electro-blast the main cracks were formed (fig. 2(b)) and reached the free surface indicating of splitting off the block fragment and creation of a new free surface (4) (fig. 1). The second experiment was performed in boreholes (7) (fig. 1) which located at the distance of 50 cm from the edge of the monolith. After the electro-blast the main cracks were also produced, due to the waves reflection from the new free surface, created on the previous step (fig. 2(c)). It led to formation of another free surface. The same result was obtained in the third electro-blast that was performed in boreholes located at the distance of 75 cm from the edge of the block. Thus, after three electro-blasts, the numerous cracks were created (fig. 2(d)). The summary of the experimental results are given in Table 1.

**TABLE 1.** The experimental results summary of phased splitting off from the concrete monolith block

| # | $U_{ch}$, kV | $I_m$, kA | l, cm | d, cm | Result |
|---|---|---|---|---|---|
| 1 | 12 | 114 | 25 | 40 | Main cracks were formed and reached the free surface, splitting off fragment. |
| 2 | 12 | 113 | 50 | 40 | Main cracks were formed in the radial direction from the boreholes. |
| 3 | 12 | 110 | 75 | 40 | Main cracks were formed in the radial direction from the boreholes. |

The time interval, during which the wave covers the distance from the channel to the monolith boundary (free surface) and returns to the discharge channel, can serve as a an upper limit for the energy input duration when finding the most efficient mode of energy release. The speed of sound in the concrete is approximately 2300 m/s. So one can calculate that time needed for wave to cover 50 cm (double borehole-boundary distance) is 217 µs. Current curves in figure 3 shows that the energy release in present experiments is optimal. But it needs to mention that from the other point of view this mode limits the distance at which the crack is still generated (25 cm). And experiments prove it, cracks isn't propagate to the concrete boundary if the distance *l* in figure 1 is more than 30 cm. If one want to gain the distance of cracks grows and the destruction zone respectively, the period of energy input needs to be increased too. It definitely leads to the capacitance addition of the energy storage, that in turn leads to mass and dimensions enlargement.

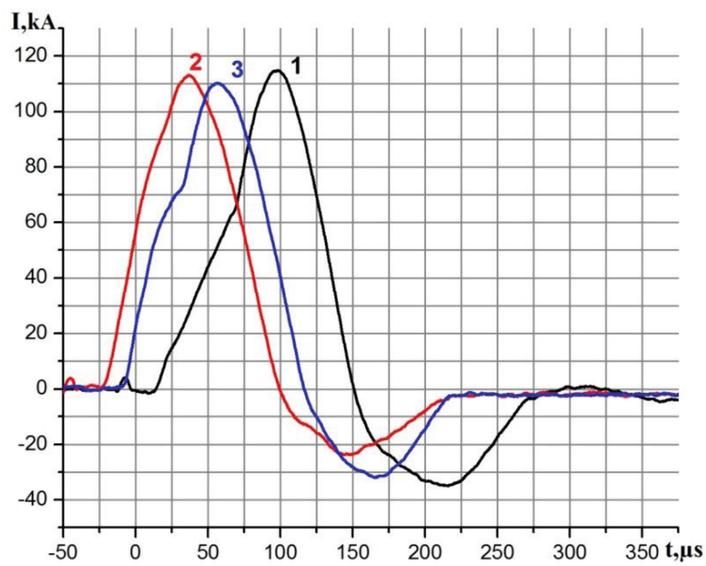


**FIGURE 3.** The average current waveforms of the discharge at the experiments of electro-blasting

## CONCLUSION

The experimental data have shown that under the following parameters of high-current pulse generator, stored energy of about 80 kJ, period of the energy release of about 200 microseconds and two electrode system, the distance between the boreholes of 40 cm and to the free surface of 25 cm, as well as depth of boreholes of 70 cm is satisfactory conditions for the phased concrete splitting off implementation. The way of increasing the splitting process efficiency is to increase the quantity of simultaneously triggered electrodes but this in turn needs increasing the capacity of the pulse generator and its mass and dimensions

The experimental investigation of the electro-blasting method have allowed to empirically create the approach of electrical discharge destruction and splitting off from concrete monolith. According to the experiments the electro-blasts leads to form main cracks at the predefined direction via boreholes line, as well as main cracks lead to create a new free surface that help to form the desirable wave interference at the next step of electro-blast. This scheme can find an application for weakening the monolith with its subsequent mechanical breakage.

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