Blasting strong rocks in the constrained conditions

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Abstract. The article deals with a new technology of blasting strong rocks in the constrained conditions of reconstructing railways by means of widening the recesses or shelves on the slope. Reliable no-fly stone rock blasting is provided by installing a transformable gas-permeable shelter on the blast block. The blast containment shelter includes upper frames placed on the surface of the blast block and side frames to shelter the side slope of the ledge. Special elastic elements that serve as a transformable gas-permeable shelter made from heavy-duty dump trucks worn-out tires are suspended on the frames. Shelter frames are installed on railway platforms. The use of a railway crane in hitch with cargo platforms provides the fold increase of the covered area of the explosive block as the time allocated to the technological “window” is taken only for installing and removing the shelter by a railway crane and the time for blasting the block. The time is not lost on moving the blasted rock debris left on the flooring sleepers in the existing railway track by the bulldozers to the excavating pit and for doing other work. A reliable no fly stone rock blasting when creating the secondary tracks of the railways is also provided by using decelerations when initiating explosives.

1. Introduction

The growth of traffic along the railways of the Russian Far East requires the construction of secondary tracks, the expansion of railway stations and junctions. Railway lines run mainly in mountainous areas (Figure 1), therefore the reconstruction of railways with a considerable length of excavations in rocks and permafrost is connected with the use of blasting [1]. In this regard, reconstruction of the eastern railway polygon requires large-scale use of explosive methods of work near the existing railway track.

Under such conditions, blasting operations are carried out in specially allocated “windows” - short time intervals between train movements. Presently, a special project is developed taking into account these specific conditions. The project should meet the requirements of regulatory documents, and include work and measures to ensure the safety and continuity of train traffic, as well as the safety of the existing track and structures during the construction of the secondary track [2].
The volume of preparatory work to ensure the safety of the main structures is quite large. It is necessary to provide the transfer of engineering networks outside the explosion hazard zone (at least 200 m from the explosion site), or provide for their protection from flying pieces of rock mass and the seismic effect of the explosion by special means. Protection of the upper structure of the track from explosion damage by special floorings should also be performed. It is recommended to cover bridges and overpasses with suspended protective shields.

After the explosion, 75-80% of the time of the allocated “window” is spent on cleaning up the exploded rock mass from the protective flooring on the existing railway track by the bulldozers and moving it to the excavator face at the site of the explosion. Cleaning the rock mass from the railway track occurs simultaneously; teams of installers eliminate possible damage done to the power transmission lines (contact network), communication lines and auto-locks that have been disconnected since the start of the “window” time. Such methods of blasting significantly complicate the work under the conditions of moving railway transport. The effectiveness of working in such conditions remains extremely low.

Flying rock fragments do a significant damage to the environment.

Therefore special blasting methods are used in which a good loosening quality is achieved with the least negative impact on the elements of the track, communication and structure, as well as natural environment. The main direction of increasing the efficiency of blasting in constrained conditions is the use of shelters of various designs. Shelters are placed above the blast rocks to reduce or even completely eliminate flying pieces of rock during the explosion. The Pacific State University researchers developed and tested [3] a method of explosive loosening of rocks in constrained conditions. It is based on the use of a combination of the design of borehole charges with an air cushion in the bulkhead with a gas-permeable transformable shelter made of elastic elements [4]. Worn tires from heavy-duty dump trucks are used as such elements [5, 6].

However, the disadvantage of the proposed scheme is the low productivity of the process of laying and forming a gas-permeable shelter of elastic elements. Installing such a shelter in the conditions of the existing railway required the development of a special technology described in this paper.

The above-mentioned conditions required a separate solution of the design of a crushing effect of blasting in rock environment. To date, the methodology for determining the optimal parameters of rock blasting includes a significant number of operations. Measurements are made of the specific energy intensity of rock drilling during the drilling of blast holes and the calculation of the parameters of
explosive charges, patterns and intervals of deceleration during their blasting, estimation of the results of the explosion by the energy intensity of excavation of rock mass and the selection of optimal parameters of the explosion based on statistics [7]. The disadvantage of this method is the need to collect a large amount of statistical material. The sequence of operations in the specific system “rock mass - explosive charge” is unknown due to the probabilistic nature of the explosion of a group of charges in time and space due to deviations from the nominal time of the operation of decelerators [8]. The authors propose a solution to the problem of determining the intensity of attenuation of rock mass in the area of each exploded well during the development of a mass explosion in a real rock mass. The method takes into account the size of the pre-destruction zones and is used in calculating the charge parameters of specific wells.

2. The Main Part
A systematic study of design and technological solutions made by the authors [9] resulted in the development of design and technology of the equipment of the blasting unit with a transformable gas-permeable shelter, providing a fold increase in the volume of explosion in an allotted temporary “window”.

A transformable gas-permeable shelter for explosion containment includes upper frames for covering the surface of the explosive block and side frames for covering the side slope of the ledge (Figure 2).

![Figure 2. The scheme of the frame of a transformable gas-permeable shelter before the installation on the sheltered rock mass](image)

The frames include metal frame 1, inside of which on special rings (flexible elements) 2, made, for example, of chains, the resilient enclosing elements 3, made, for example, of heavy-duty dump trucks worn tires are suspended. All enclosing elements are interconnected by flexible connections 4 made, for example, of chains or ropes.

Figure 3 shows the layout of shelter elements on railway train. Upper frames 1 for sheltering the surface of the blasting block are installed on the front rail platform 3 attached to railway crane 4. Side frames 2 for sheltering the slope of the blasting block are on the rear rail platform 5. Frames 1 and 2 are made wide so that to fit into the railway gauge.
Figure 3. Railway jib crane coupled with railway platforms containing the elements of transformable gas-permeable shelter.

Railway crane 4 with platforms 3 and 5 is adjusted to the step of the ledge prepared for the explosion with charged blast holes and downhole conductors of the initiating pulse brought to the surface. Upper frame 1 of the shelter is captured by the slings of a railway crane, then moved and laid in the desired position on the covered section of the blasting block. The elastic enclosing elements hanging freely on special rings (flexible elements) lie on the surface of the ledge covering it (Figure 4). On top of upper frame 1, to prevent the flying of even small chippings the Rabitz grid is laid as a filter.

If it is necessary to increase the width of the shelter of the blasting unit, several upper frames are installed in parallel connecting them together with flexible connections. To shelter the side slope of the ledge with charged blast holes 6, side frame 2 of the shelter is grabbed by the slings of the railway crane with the help of sling brackets 3, then moved and laid in the desired position on the covered slope of the blasting unit. To connect side frame 2 with the upper frame previously installed on the surface of the block, carbines 4 pivotally installed on the side frame are fixed on brackets 5 of upper frame 1.

The conductors of the initiating pulse are passed through the holes in the upper frames and mount the explosive network. The device is ready to go.

In case of short-delayed blasting of loosening charges in wells 6 of the blasting unit with deceleration of 150-200 ms, pre-destruction of the blasting unit occurs. Due to the use of bulging charges in side wells, the first, strongest rock mass strike at the shelter is softened - rock mass is expanded with some movement, but without flying stones [10]. Together with the expanded rock mass, the shelter creates a buffer layer, damping the explosion of other rows of wells and preventing pieces from flying out through the gaps in the frames.
The elasticity of the shelter made from elastic enclosing elements due to their resilience during the expansion of the blasted rock does not allow individual pieces to break away from the total mass.

The inertial resistance of the compact rock mass reinforced by the mass of the shelter balances the force of the explosive shock. The height of the rock toss with shelter depends only on the thickness of the blasting layer and the coefficient of loosening the rock, since the amount of rock expanding after loosening depends on the latter.

After the explosion, side frames for sheltering the side slope of the ledge are installed one by one with a railway crane on the rear railway platform. Then, the upper frames are similarly laid on the railway platform.

Thus, the following results increasing the efficiency of the organization of blasting operations at the reconstruction site are achieved: multiple increase of covered explosive block area is provided; the time of the allocated “window” is spent on installing and lifting of the shelter by a railway crane, as well as the blasting of the block; there is no time lost on cleaning by bulldozers the blasted rock mass from a bed of sleepers and doing other work specified in paragraph 1.

It is known that the process of the crushing action of an explosion in the rock medium is an active component of the total destruction of rocks with discontinuity or separation (dispersion) of rocks as a result of various physical factors of the explosion influencing them. A shock wave from an explosive charge transforms into a stress wave in the form of an inelastic perturbation of a medium with a fairly smooth change in parameters and a propagation velocity equal to the speed of sound in a given medium, and the time removing a substance from a state of rest is always less than the time it returns to this state. In the process of propagation of compression waves, covering a volume of 120-150 radii of a charge,
the medium does not behave elastically; in it appear residual deformations leading to the disruption of the continuity of the medium’s structure [11].

Thus, the process of destruction of a rock mass confined by an open surface does not occur instantaneously, it occurs during a certain time, when the system of forces and stresses involved in the destruction changes significantly in space. The process of brittle fracture of rocks by an explosion is characterized from a physical point of view by a certain type of fracture, namely, separation from the action of a compression wave by tensile stresses in the rarefaction phase. This leads to the formation of systems of cracks dissecting the rock mass [12-14].

The design of the explosive loosening the rock mass has also been improved. As mentioned above, determining the optimal parameters for explosive destruction of rocks includes measuring the specific energy intensity of drilling blast rock holes and calculating explosive charge parameters, patterns and deceleration intervals during their blasting, evaluating the results of an explosion with the energy intensity of rock excavation, and choosing the optimal explosion parameters based on the data. On test blocks with the same mass properties, several explosions are carried out with the exact time of initiation of each explosive charge being fixed. Then there built a model of the actual development of a mass explosion in real time and space for a specific blasting scheme and charge design. When rational explosion results are achieved, the combination of specific indicators of the properties of the rock mass, the parameters of the charges and the sequence of their initiation in time and space is considered to be the optimal parameters of explosive destruction for the rock mass with similar properties which are then accumulated in the database. Work blocks are divided into sections with similar properties of the mass and for each of them optimal parameters of explosive destruction from the accumulated data bank are selected.

The disadvantage of this method is the need to collect a large amount of statistical material because of the principle of the “black box” incorporated in it: only the input properties of the system “rock mass - explosive charge - rock mass” are measured (solidity of rock mass, charge parameters). The only output measured property is energy consumption in excavation. The sequence of operations of the specific system “rock mass - explosive charge” is unknown due to the probabilistic nature of the explosion of a group of charges in time and space due to deviations from the nominal time of the operation of decelerators [8].

Therefore the task is set to determine the intensity of mass attenuation in the area of each blasted well in the process of developing mass explosion in a real rock mass based on the size of pre-destruction zones and using it to calculate the charge parameters of specific wells.

The authors propose to determine the intensity of attenuation of the mass in the area of each blasted well by differentially calculating the magnitude of the borehole charges for different zones of mass weakening occurring during the development of the blast. A preliminary graphical analysis of the intended blasting scheme for the drilled and next blocks determines the parameters of the stress waves passing through the vicinity of specific wells covered by the pre-destruction zones from explosions of previous borehole charges. These parameters include: the number of waves, the direction of approach and the distance to the explosion of previous charges.

The possibility of determining rational parameters of explosive destruction of rocks taking into account pre-fracture zones will be considered using the example of blasting with a diagonal block scheme for wells having a diameter of 140 mm located on a $4 \times 4$ m grid (Figure 5). Blasting is carried out using a non-electric system, for example, RIONEL. Deceleration between the wells of the surface network was performed by RIONEL X device: in the row - 200 ms, between the rows - 150 ms. The downhole network was initiated by RIONEL MS-30 device with a deceleration of 750 ms.
Radius of the destruction zone $r$ can reach a limit of 40 charge radii ($R_3$) [15], and radius of fracture zone $R$ can reach a value of (200-250) $R_3$ [16-19]. For graphical construction of the interaction of pre-destruction zones, the radius of the destruction zone is taken to be $r = 2.8$ m, and the pre-destruction zone is $R = 14.0$ m. The initiation of the surface network of the borehole charges of the block is carried out in the direction "from well 1".

Figure 5a shows the zone of preliminary destruction from the explosion of well 1, bounded by radius $R$. Figure 5b shows the same process from the explosion of well 7. It can be seen that the pre-destruction zone of the block with diagonal downhole blasting is limited only by radius $R$.

![Diagrams showing pre-destruction zones](image)

**Figure 5.** Schemes for the development of a block pre-destruction zone with diagonal downhole blasting and initiation of a surface network from the side well in the first row of the block: a - after the explosion of Well 1; b - after the explosion of Well 7.

Using this graphical method it is possible to determine the number of pre-destructions in the vicinity of all the wells of the blasting block (Figure 6, a).
Figure 6. Pre-destruction of the vicinity of the wells of the block with diagonal downhole blasting and initiation of the surface network from the well in the first row of the block: a - number of pre-fractures; b - the value of the coefficient $K_i$.

However, it is impossible to determine exactly the intensity of pre-destruction in the vicinity of blastholes by the number of these pre-destructions, since this intensity largely depends on the distance to the blast hole.

The value of deformation $\varepsilon_{pr}$ of the explosive cavity bounded by radius $r$ can be determined by the formula (1) [20]

$$\varepsilon_{pr} = \sqrt{\frac{\rho_o D^2}{E(k^2-1)(1+\frac{4\pi\nu}{k^2})}},$$

where $\rho_o$ is the density of explosives, kg/m$^3$; $D$ is the detonation velocity, m/s; $E$ is Young's modulus, Pa; $E_0$ is the energy release of explosives per unit mass of the substance; $K$ is the indicator of polytropy; $\nu$ - Poisson's ratio, Pa.

However, the stress wave propagates beyond the boundaries of the blast cavity carrying out preliminary destruction of the area surrounding wells. The magnitude of the deformation (pre-destruction) of the vicinity of these wells is determined by the formula (2)

$$\varepsilon_i = \varepsilon_{pr}K_i = \varepsilon_{pr}\left(\frac{r}{R_i}\right)^2,$$

where $\varepsilon_i$ is the magnitude of the deformation of the vicinity of the $i$-th well; $K_i$ is the coefficient of pre-destruction intensity, taking into account the change in the magnitude of the deformation as it moves away from the axis of the blasted well; $R_i$ is the distance from the axis of the $i$-th well to the blast.

The $K_i$ coefficient when reaching the maximum deformation of the blast hole of the well $\varepsilon_{pr}$ is equal to 1, i.e. the blast cavity of the well is completely destroyed. The change in the magnitude of the deformation of the vicinity of the wells will be shown on the considered example of the development of the pre-destruction zone of the block with diagonal downhole blasting and the initiation of the surface network from the well in the first row of the block. For graphical construction of the interaction of pre-destruction zones, the radius of the destruction zone is taken to be $r = 2.8$ m, the surface network of borehole charges of the block is initiated from well 1. Figure 6b shows the values of the coefficient $K_i$. 
which takes into account the change in the strain in the zone of wells 3, 6, 10, 14 with increasing distance from the explosion of well 1. As can be seen from the graph, the pre-destruction rate decreases quite rapidly with increasing distance of the action of stress waves. As subsequent wells explode, the amount of deformation in the vicinity of neighboring wells continues to accumulate.

Figure 7 shows a diagram of the distribution of the coefficient of intensity of pre-destruction in the vicinity of the wells of a block during the sequential blasting of all wells with a calculated explosive charge.

![Figure 7. Scheme of distribution pattern of the coefficient of intensity of pre-destruction of the vicinity of the wells of the block during the sequential blasting of all wells with a calculated explosive charge.](image)

It can be seen that the total preliminary deformation of the vicinity of the wells over the entire block before the blasting of almost every well exceeds the maximum value, which leads to over-regrinding of the material and excessive consumption of explosives.

For using the positive effect accumulated by the preliminary destruction of the vicinity of the wells, the following solution is possible.

Given that after the explosion of the 7th well, the relative deformation of the explosive cavity of wells 5, 8, and 9 exceeds the ultimate value \( \varepsilon_{pr} \), the rock in the vicinity of these wells will be destroyed and no additional blasting will be required. The total preliminary deformation of the rocks of the vicinity of the wells throughout the block before blasting practically every well exceeds the limit strain. Therefore, it is proposed to charge the unit in the following way. A full charge of explosives only charges wells 1-7 and 23-28 - a total of 14 wells (Figure 7). The deformation of the rocks in the vicinity of the remaining wells exceeds the maximum strain, therefore to achieve complete deformation it is enough to charge them with a half explosive charge. Such a decrease in the explosive charge significantly reduces the shock impulse from the explosion on the elastic elements of the shelter and ensures the localization of the explosion.

3. Conclusions

For large-scale use of explosive methods of work close to the existing railway track, a new technology of specially allocated temporary “windows” has been developed. The duration of work under the conditions of the working movement of railway transport is reduced to 75-80% of the time of the allocated “window”. This is achieved through the elimination of preparatory and other related work inherent in traditional technologies.

The following scheme of gentle blasting when loosening rock slopes during the construction of the secondary railways is suggested:
- sheltering places of explosion with gas-permeable mats;
- use of blast holes of a special design;
- use of downhole blasting with large decelerations.
The use of a railway crane in conjunction with cargo platforms provides a multiple increase of the area of the covered blasting block, since the time of the allocated “window” is taken up by laying and removing the shelter by the railway crane, as well as the time for blasting the block; The time is not lost on moving the blasted rock mass left on the flooring sleepers on the existing railway track by the bulldozers and doing other work.

An improved methodology for designing the process of explosive loosening of the rock will allow more rational preparation of work in difficult conditions of the existing railway. The combination of an elastic shelter design using a buffer layer of expanded rock mass ensures no-fly stone blasting. As a result, the shock impulse from the explosion on the elastic elements of the shelter is significantly reduced. This ensures the localization of the explosion and more effective operation of the shelter. Application of the described method allows to reduce explosive charge by 2 times in more than 55% of wells. The additional benefits of saving explosives should also be considered.

References
[1] Shevkun, E, Leshchinsky A, Piotrovich A 2014 Vestnik TOGU (Pacific National University, Khabarovsk) 2 33 pp 93-102
[2] 2000 VSN 178-91. Design and production standards for drilling and blasting operations in the roadbed construction (Moscow: State Unitary Enterprise of the Central Prudential Center)
[3] Shevkun E, Leshchinsky A, Piotrovich A 2018 International Multi-Conference on Industrial Engineering and Modern technologies. IOP Conf. Series: Materials Science and Engineering 463 022081). doi: 10.1088/1757-899X/463/2/022081
[4] Shevkun E, Leshchinsky A 2008 The method of blasting ledges in cramped conditions. Patent of the Russia Federation No. 2006121285/03 Bull. No. 5
[5] Leshchinsky A, Shevkun E, Urenev I 2008 Shelter of explosion sites with worn-out automobile tires. Patent of the Russian Federation No. 2006109907/03 Bull. No. 1
[6] Leshchinsky A, Shevkun E 2009 The method of cyclic-stream mining of rocky rocks. Patent of the Russian Federation No. 2008103889/03 Bull. No. 21
[7] Haeri H, Shahriar K, Fatehi M, Moarefvand P 2014 International Journal of Rock Mechanics and Mining Sciences 67 pp 20–28
[8] Piotrovich Yu 2015 Mining information-analytical bulletin 4 pp 341-348
[9] Piotrovich A 2018 International Multi-Conference on Industrial Engineering and Modern Technologies. IOP Conf. Series: Materials of Science and Engineering 463 022059 doi: 10.1088/1757-899X/463/2/022059
[10] Demidyuk G 1967 Explosive business 62 19 pp 36-51 (Moscow, Nedra)
[11] Kutuzov B 1988 Directory of the fuse (Moscow: Nedra)
[12] Momeni A, Karakus M, Khanlari G, Heidari M 2015 International Journal of Rock Mechanics and Mining Sciences 77 pp 89–96
[13] Fu X, Sheng Q, Zhang Y, Chen J 2015 International Journal of Rock Mechanics and Mining Sciences 80 pp 155–170
[14] Liu T, Cao P, Lin H 2014 Theoretical and Applied Fracture Mechanics 74 pp 55–63
[15] Yurovskikh A 2003 Development of a model of rock destruction at the quasistatic stage of the explosion: Dis. cand. tech. Sciences (St. Petersburg)
[16] Alexandrov V, Kochanov A, Levin B 1987 FTPRPI Moscow 4 pp 24-32
[17] Sadowsky M, Adushkin V, Spivak A 1994 About the size of zones of irreversible deformation during an explosion in a block medium. Dynamic processes in geospheres. Geophysics of strong disturbances (Moscow: Science)
[18] Seinov N 1997 *Contribution of V.E. Alexandrov in the development of blasting. Explosion destruction and irreversible deformation of rocks* (Moscow)

[19] Shemyakin E, Kochanov A, Dengina N 1997 *Parameters of stress waves and pre-fracture of solid rocks during an explosion. Explosion failure and irreversible deformation of rocks* (Moscow)

[20] Shtukarin N 2010 *Explosion physics in applied problems* (Krasnoyarsk: Sitall)