Control of seismic effect of mass explosions using low-speed means of initiation

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Abstract
The results on the development and use of methods of calculation of parameters of seismic explosion in blasting operations in the quarries, using the low-speed means of initiation are presented. The calculation of the parameters of seismic blasting using detonating waveguide type "Nonel" and detonating cords is given. The results were the basis for the development of the algorithm for the calculation of seismic safe parameters of industrial explosions.
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In recent years in Ukraine non-electric initiation systems of explosive charges of type "Nonel" are widely used for blasting operations [1-4]. The last one, due to the broad technical capabilities and security, allows to realize fully the effect of interaction of explosive charges, and hence to improve considerably the quality of crushing of rocks and elaborate soles ledge. However existing in Uniform safety rules [5] norms for calculating of seismic safety distances (separately exploded groups are considered the groups that are separated by intervals of delay of at least 20 ms) restrict the use of deceleration intervals of 17 ms, which are effective from the point of crushing and safety lining of wells on the blocks using the borehole charges with diameter of 100-150 mm. Furthermore, while using non-electric initiation systems of explosive charges, the time of development of the explosion do not only depend on intervals of deceleration of devices of various systems of non-electric initiation of charges (SNEIC), and on the actual additional delay intervals due to surface networks (waveguide) that is not taken into account in existing seismic assessments.

Currently before shotsmen there set a task to achieve high quality of crushing of rock mass, elaboration of the bottom at acceptable seismic effect that with larger scale of mass explosion and approach of works to protected objects assumes importance for ensuring both earthquake resistance of buildings and normal psychological atmosphere of near living people.

In industrial mass explosions with limited mass charge in quarries of Ukraine using SNEIC there was found out that their seismic impact is lower than during mass explosions performed by the same schemes and mass of explosives but using detonation cord (DC) and retarders (short-delay blasting by detonating cord). In this regard, on the one hand, there is an opportunity to increase mass explosion, the other hand, to improve the seismic assessment methodology during blasting operations using non-electric initiation systems of explosive charges [6-7].

Let solve the propagation time of the entire mass explosion.

The slowdowns between groups of explode charges is a sequence of numbers, since the distance between boreholes remains unchanged. According to definition of numerical sequence to each natural number *n* there corresponds a real number a_n, then the complex:

$$a_n = f(n),\ n = 1,2,\ldots$$

is called a numeric sequence (or sequence). Here, a_n is the element (or a member of the sequence); f (n) - the correspondence law; n - number of elements.

A sequence of numbers

$$a_1,\ a_1+d, a_1+2d, \ldots\ldots, a_1+d\cdot(n-1),$$

each of them is equal to the previous one, plus constant value *d* is called an arithmetic progression, where a_1 is the first member of progression, *d* is the difference arithmetic progression.

The n-th member of the arithmetic progression is equal to:

$$a_n = a_1 + d\cdot(n-1),$$

where *n* is the number of members of the progression.

Since the distances between boreholes are equal (they depend on the scheme of initiation, where the charges join the borehole at a diagonal, or otherwise), the deceleration rate L/D between neighboring boreholes also remains the same for all groups, where L is the length of waveguide, which connects two adjacent boreholes, D = 2000-2100 m /s - the speed of the shock wave in the waveguide. In this case, the sequence of slowdowns corresponds to properties:

- any member of the sequence, starting with the second one is equal to the average of its neighboring members:

$$a_\kappa = \frac{a_{\kappa-1} + a_{\kappa+1}}{2} (\kappa \geq 2)$$

- the sums of sequence members, equidistant to its ends are equal to each other.

Taking in consideration the above, it is possible to determine the sequence of delay as an arithmetic progression, for which the value of n-th deceleration is equal to:

$$t_n = t_1 + (\Delta t + L/D\cdot 1000)\cdot(n-1),$$

where *n* - is the number of deceleration rate, *Δt* - is delay between the last pair of adjacent wells.

This formula is valid for the schemes with the same degree of deceleration in the whole block. If the degree of deceleration is different, the formulas wil look as follows:

$$t_n = t_1 + (\Delta t + L/D\cdot 1000)\cdot(n-1) + \delta,$$

where *δ* – the sum of decelerations to the element, the value of which determines deceleration rate in the scheme.

Let us give an example of calculations based on the scheme of initiation applied to Kubachevsky limestone quarry.

For the combined scheme (deceleration - electrodetonators delayed action, wells are initiated by detonation cords) the length of all the connecting initiating detonation cord is 105 m, there initiated similar segments of DC 8 meters each, so one should only consider general slowdown, which is created by DC. Since the speed of detonation of DC is D = 6000 m/s, then t = L / D = 105/6000 = 17.5 ms.

The distance between wells L_i = 3 m, the delay time between the wells due to DC is $t_i = L_i / D = 3/6000 = 0.5$ ms.

Duration of the explosion will be equal to:

$$T = 7 \cdot 15 + t = 105 + 17.5 = 122.5 \text{ ms},$$

where 7 - is the number of groups of deceleration used in the explosion at the west open-pit side of Kubachevsky limestone quarry with the 15 ms delay time.

The seismic effect of the explosion:

$$K_{seism} = Q/T = 2100/122.5 = 17.14,$$

where Q = 2100 kg, is the weight of explosives.

Let us define seismic blast effect at the same switching pattern but using DC in all the chains, using the above mentioned method of calculation. The length of all connecting initiating DC is 132 m. Let us use the standard deceleration between the groups of 20 ms.

$$t_n = t_1 + (\Delta t + L/D)(n-1) = 20 + (20 + 132/6000)(7-1) = 272 \text{ ms},$$

The seismic effect of the explosion:

$$K_{seism} = Q/T = 2100/272 = 7.72$$

Let us use in the scheme of initiating system of "Nonel" type and carry out similar calculations. The degree of deceleration in accordance with the production range is 17 ms. The length of waveguide will be 132 m.

$$t_n = t_1 + (\Delta t + L/D)(n-1) = 17 + (17 + 132/2000)(7-1) = 515 \text{ ms},$$

The seismic effects of the explosion:

$$K_{seism} = Q/T = 2100/515 = 4{,}077.$$

Thus, the rate of explosion seismicity using detonating waveguide is reduced by 1.9 times as compared with traditional means of short-delay blasting.

Calculations show that non-electric scheme of "Nonel" is the most safe scheme of initiation of borehole charges at mass explosion, without considering its other benefits, including lower initiating of charge in the borehole, which is so technologically important. In fact, the use of combined scheme with electric deceleration means between groups of charges of 15 ms during initiation of DC is the violation of Unified explosive safety regulations, according to which certain groups are those delay between which makes at least 20 ms. This causes dangerous explosion seismic action, as indicated by the above mentioned calculations.

The calculations showed that the scheme of initiation of "Nonel" type with deceleration of 17 ms is not inferior according to the parameters of seismic safety of initiating scheme of DC 20 ms due to slower passage of shock wave in the waveguide.

Let's calculate the safe radius for 3 mentioned above schemes using the formula of Sadowsky.

$$R_c = k_r \times k_c \times a \frac{Q^{\frac{1}{3}}}{N^{\frac{1}{4}}}$$

where:

k_r is the coefficient, which depends on the properties of the soil at the base of the protected object;

k_c- is the coefficient, which depends on the state of the protected object;

a - is the coefficient, which depends on the action of explosion indicator;

N –is number of groups of charges pcs;

Q - is the total weight of the charge, kg;

Let us assume $k_r = 12$, $k_c = 2$, a = 1.

For the combined scheme (deceleration - electrodetonators delayed action, wells are initiated by DC) the number of groups in calculations will be 4 instead of 7, because according to Unified explosive safety regulations, separated groups are those, between which the delays are 20 ms. That is why, as the group we may take the charges with delay of 30ms (two groups of 15 ms).Here the safe radius will be:

$$R_c = 2 \cdot 12 \cdot 1 \cdot \sqrt[3]{Q} \; / \sqrt[4]{N} \; = 217.3 \text{ m}.$$

According to Uniform safety rules for blasting operations, the obtained distance should be multiplied by 2. We obtain:

$$R_c = 217.3 \cdot 2 = 434.6 \text{ m}.$$

For initiating scheme of "Nonel" type with deceleration of 17 m/sec, radius of seismic safety parameters will be $R_c = 188.9484 \cdot 2 = 377.9$ m.

Thus, according to calculations, more secure scheme of initiation is the system of "Nonel" type.

The seismic effect of the explosion is determined by the seismicity:

1) Maximum weight of the explosive charge in the group, which accounts for one deceleration, upon the condition of separation of all groups (more than 20 sec.):

$$Q_{max} = \Sigma Q_{well}, \text{ kg};$$

2) Maximum weight of charge that blows per one millisecond:

$$K_C = Q/T, \text{ kg/ms},$$

where Q is the total mass of the explosive, T is the duration of the entire blast.

Acceptable rate of seismicity:

$$K_{extra} = Q_{max}/T_{gr}, \text{ kg/ms},$$

Q_{max} is permissible mass of explosive in the maximum group,

T_{gr} is time delay in the maximum group.

Terms of seismic explosion:

$$K_C \le K_{extra} \le [V]/(\sqrt[3]{Q}^{\,r})$$

The presented method and the results of the analysis were the basis for the development of the algorithm for the calculation of seismic safe parameters of industrial explosions.

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