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Research paper

Seismic Protection of Buildings in Areas Adjacent to Open-Pit Mining

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Abstract

Purpose of the present research is the analysis of the seismic loadings on buildings in areas adjacent to open-pit mining, depending on the patterns of the spatial concentration of explosive energy in the rock massif, which have a complicated structure and its acoustic anisotropy; the justification for the general approach to technological solutions for the protection of buildings and structures and determination of the limits for parameters of mass explosions in open-pits due to the parameters of their seismic influence on these objects. The main factors of anthropogenic seismic regime of mining towns under conditions of application of exploding geo-technologies are analysed. The analysis of the change of the stress state of rock massifs with respect to their structure and lithological composition; the concept of the simulation model for the propagation of seismic waves in anisotropic medium and the formation of waveguides and shielding fractures in it; statistical analysis of surveying observations and mathematical treatment of their results are considered. As a result of the carried out researches, methods of calculating seismic safe restrictions for the parameters of blasting operations in the open pit and the protection of the built-up areas by shielding fractures have been developed.

Keywords: *anisotropy; explosion; rock massif; seismic waves; open pit;*

1. Statement of the problem

Despite numerous scientific studies devoted to the seismic safety of buildings and structures in the areas adjoining open pit, the problem of minimizing the wave manifestations of technological mass explosions remains almost unresolved in areas adjacent to open-cast mining, as evidenced by the excessively high costs of maintaining and repairing adjacent buildings and structures. Therefore, the **task** of finding ways to avoid these negative consequences of the explosion is very **relevant**, as it in turn contributes to **solving the problem** of rational subsurface management, resource and energy conservation.

The analysis of research and practice of exploitation of structures exposed to blasting operations shows [1, 2] that one of **the least studied theoretically and unresolved virtually questions** is the uneven formation under the influence of the explosion of a stress-strain state of rock massif with a complex regular structure and its acoustic anisotropy due to it, which azimuthally determines mainly the periodic functional dependence (epicycloid) of the elastic-mechanical characteristics in the front of the wave around the burst explosive charge. **The hypothesis** that the optimization of a stressed state becomes possible by differentiated energy absorption of the rock massif, as well as the creation of actually working additional reflecting elastic waves and shielding fractures for it [3, 4] has been adopted. In connection with this, **the idea** of using for the formation in the acoustically anisotropic massif of spatially complex forms of surfaces of different stressed states, as well as the deepening of this differentiation was laid down in the study, in order to solve it **the problems of the research** provide the justification for the optimal forms of zones of destruction and their mutual arrangement thereby creating conditions for the symmetrical action of explosions between two reflective surfaces - the vertical brace of the pit bank on one and created with a short-term advance of the "back" fracture – on the other. It is advisable to protect spacious zones with buildings on the surface by shielding fractures.

2. Presentation of the research material

It is known that the method of preliminary presplitting is the most effective in crystalline soils while simultaneously blasting of adjacent explosives, which specified the determination of the maximum possible mass of explosives in one explosion stage in the open pit taking into account the requirements of seismic safety that requires:

1. Determination of characteristics and properties of soils.
2. Investigation of the stability of the brace of the pit banks.
3. Localization of the limits of possible application of the developed measures.
4. Analysis of the seismic manifestations intensity of blasting explosive groups.

Characteristics of soils were determined by tested hardware and calculation methods [5, 6]. To obtain the values of physical and mechanical properties with a high degree of reliability the most typical samples were selected in the characteristic locations of their occurrence. The results of measurements and calculations are summarized in Table 1-7.

The velocity of longitudinal waves was determined with the help of a defect detector UKB-1 with direct sounding from the ratio $V_p = L/t \cdot 10^6$, m/s, where L – sample length, m; t – time of passage of a sound wave through a sample, μs. The results in the Table 2 indicate a significant difference in the velocity indicators depending on the direction relating to the lamination. Since Kryvyi Rih rocks were often crushed into high degree folds, the average velocity was taken: determined in the open pit "Pivnichnyi" was – 1300 m/s, and on the samples with the help of defect detector UKB-1 – 1308 m/s, practically coincided. Determination of the velocity of the transverse wave was also performed with the use of a concrete detector UKB-1. The samples were sounded through with short packets of ultrasonic impulses. During the damping of oscillations, the values of the critical angle α_{cr} were fixed, after that its sinus was determined, and then using the formula $V_s = 1550/\sin\alpha_{cr}$, m/s determined the velocity of the transverse wave. The results of calculations are given in Table 3

Table 1: Values of soils characteristics

Number of sample	Sizes, m			$V \cdot 10^{-4}$, m^3	$m \cdot 10^{-3}$, kg	ρ, kg/m^3
	$a \cdot 10^{-3}$	$в \cdot 10^{-3}$	$h \cdot 10^{-3}$			
1	39,55	39,5	42,4	0,662	246	3607
2	40,75	41,5	41,5	0,702	251	3580
3	40,5	41,85	41,3	0,700	255	3643
4	41,0	41,35	40,8	0,692	247	3569
Average						3600
5	41,5	41,25	41,75	0,715	265	3708
6	42,0	41,10	40,75	0,703	263	3739
7	40,95	40,00	41,35	0,677	235	3470
8	42,10	40,80	41,20	0,707	253	3579
Average						3624
9	39,40	39,20	41,50	0,641	224	3495
10	40,50	40,75	41,80	0,690	240	3478
11	40,00	40,10	42,10	0,675	229	3393
12	41,80	40,75	41,45	0,706	241	3414
Average						3445

Table 2: The velocity of longitudinal waves parallel and perpendicular to the lamination of samples: 1-4 and 5-8, selected in the open pit «Pivnichnyi» of VAT "Ukrmekhanobr", and 9-12 in the open pit "Pershotravnevyi" of PJSC "NORTHERN GOK"

Number of sample	The velocity of longitudinal waves relating to the lamination, м/c		
	parallel	perpendicular	average
1	1410	1215	1313
2	1395	1240	1318
3	1380	1220	1300
4	1375	1230	1303
Average	1390	1226	1308
5	4025	3795	3910
6	4010	3784	3897
7	3980	3769	3875
8	3995	3774	3885
Average	4003	3776	3890
9	4800	3810	4305
10	4700	3720	4210
11	4785	3790	4288
12	4750	3740	4245
Average	4759	3765	4262

Table 3: The velocity of longitudinal waves parallel and perpendicular to the lamination of samples

Number of sample	The velocity of cross wave relating to the lamination, m/s	
	parallel	perpendicular
1	1157	1043
2	1169	1056
3	1164	1051
4	1181	1068
Average	1168	1055
5	2425	2219
6	2460	2239
7	2456	2191
8	2378	2260
Average	2430	2227
9	2662	2330
10	2374	2282
11	2658	2321
12	2714	2289
Average	2602	2306

Table 4: Values of Poisson ratio (μ), Young's modulus (E) and displacement modulus (G)

Number of sample	Poisson ratio (μ)	Young's modulus, E	Displacement modulus, G
1	0,1928	$6,8365 \cdot 10^{9}$	$2,8657 \cdot 10^{9}$
2	0,1830	$5,7091 \cdot 10^{9}$	$2,4130 \cdot 10^{9}$
3	0,1642	$5,7595 \cdot 10^{9}$	$2,4730 \cdot 10^{9}$
4	0,1600	$5,6901 \cdot 10^{9}$	$2,4526 \cdot 10^{9}$
Average	0,1750	$5,9988 \cdot 10^{9}$	$2,5512 \cdot 10^{9}$
5	0,2276	$6,2324 \cdot 10^{10}$	$2,5384 \cdot 10^{10}$
6	0,2143	$5,0420 \cdot 10^{10}$	$2,0761 \cdot 10^{10}$
7	0,2191	$4,5698 \cdot 10^{10}$	$1,8343 \cdot 10^{10}$
8	0,2205	$4,7385 \cdot 10^{10}$	$1,9369 \cdot 10^{10}$
Average	0,2211	$5,1452 \cdot 10^{10}$	$2,1064 \cdot 10^{10}$
9	0,2468	$5,4297 \cdot 10^{10}$	$2,1775 \cdot 10^{10}$
10	0,2798	$4,8243 \cdot 10^{10}$	$1,8848 \cdot 10^{10}$
11	0,2456	$5,2410 \cdot 10^{10}$	$2,1038 \cdot 10^{10}$
12	0,2338	$5,2742 \cdot 10^{10}$	$2,1374 \cdot 10^{10}$
Average	0,2515	$5,1943 \cdot 10^{10}$	$2,0759 \cdot 10^{10}$

Table 5: Safety factors f, obtained for samples 1-4 and 5-8 from the open pit "Pivnichnyi» of VAT "Ukrmekhanobr", and 9-12 from the open pit "Pershotravnevyi" of PJSC "NORTHERN GOK"

Number of sample	The limit of compression strength, kg/sm^2		G_{cm}, kg/sm^2	f
	Parallel to lamination	Perpendicular to lamination		
1	445	610	637	6
2	416	578		
3	455	637		
4	428	590		
Average	436	604		
5	725	1087	1087	10
6	645	954		
7	705	1065		
8	658	980		
Average	683	1022		
9	910	1401	1463	14
10	905	1384		
11	944	1463		
12	901	1384		
Average	915	1407		

As it can be seen, the presented in the tables results of the researches complement each other. The advantage of the first method is the integrity of the obtained values. The velocities of waves are checked in two ways. The advantage of the experiments is the possibility of a high degree of measurement detailing which increases the reliability of the analysis of the explosive process. Precision of results is more than 0.9.

Further, seismic manifestations were studied and the dependence of the extremely safe mass of explosive in one stage from soils characteristics was defined in order to determine the regularity of the seismic waves propagation in a structurally exceptionally complex rock mass. Recording of seismic waves was carried out by the method of multichannel oscillation measurement [7] by electronic oscilloscope TPS2014 by "Tektronix" with built-in self-starting function for seismic wave approach, complete with electro-dynamic sensors SV-10TS and SG-10. To determine the velocity of propagation of a seismic wave in a rock massif two methods were adapted: a) direct measurement; b) Triangulation triangle (Figure 1).

Direct method. In this case, two seismic sensors are placed at a distance from each other in such a way that the connecting axis is perpendicular to the front of the seismic wave. The oscilloscope TPS2014 determines the time interval for which a seismic wave passes from one seismic sensor to another (Fig. 1, a).

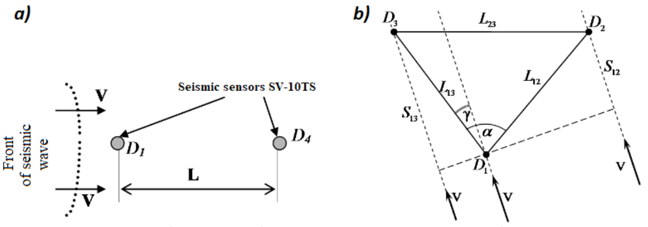


Fig. 1: Diagrams of methods for measuring the velocity of a seismic wave: *a* – direct, *b* – by means of a triangulation triangle

The velocity of propagation of the seismic wave V was determined [4] as $V=L/\Delta\tau$, where L – the distance between the sensors, m; $\Delta\tau$ – time of seismic wave passage between two seismic sensors, s.

The triangulation triangle method is characterized by the fact that the direction of approach of the seismic wave front to three seismic sensors does not affect the measurement results. Seismic sensors D_1, D_2 and D_3 were placed in the form of a triangle at a distance of 1÷2 m apart (Fig. 1, b). In this case, the distances L_{12}, L_{13} and L_{23} between each pair of sensors were measured with an accuracy of ±1 cm and fixed. The seismic wave first went to the sensor D_1, then D_2 and last to D_3. In this case, its direction was the angle γ relative to the segment L_{13}. At the seismogram of the oscilloscope TPS2014 when the waves pass through the sensors, the time intervals Δt_{12} and Δt_{13} are visualized – the delay with which the wave comes to the sensors D_2 and D_3 relative to D_1. The value of the angle α (Fig. 1, b) using the cosine theorem was determined from the expression $\alpha=arccos\ [(L^2_{12}+L^2_{13}+L^2_{23})/(2L_{12}L_{13})]$. As can be seen from Fig. 1, b, distance difference which the seismic wave passes from the sensor D_1 to the sensors D_2 and D_3 respectively equal to the levels $S_{12}=L_{12}\cos(\alpha–\gamma)$; $S_{13}=L_{13}\cos\gamma$. Since the wave velocity is constant, $V=S_{12}/t_{12} = S_{13}/t_{13}$, the ratio $L_{12}\cos(\alpha–\gamma)/t_{12} = L_{13}\cos\gamma/t_{13}$ was obtained, from which after trigonometric transformations follows the next.

The experiment on determining the velocity of the seismic waves propagation in the rock massif of the open pit “Pivnichnyi” took place on February 21, 2013 at 14-00 while blasting of block number 4. The angle of lamination inclination was from 42° to 50°. The degree of moisture was low. Block number 4 was practically square shape, its size was 70 m. There were drilled 119 wells in the block with an angle of 90°, a network of 7×7 m, charged with Granulite CM. The total number of explosives is 28.2 tons. The weight of the explosives which fell to a degree of deceleration was 240÷260 kg, which was about 46% of the maximum allowed.

The design level of seismic waves during the blasting of block number 4 was less than 2 points on the international scale MKS-64 [7]. The design duration of the explosion is 1075 ms. The block was blasted with the help of the non-electric initiating system “Impulse”. Measuring equipment was located at a distance of 200 m north of the block at the bottom of the open pit. At the same time, the velocity of waves was determined by the two methods described above simultaneously. The axis of the seismic sensors D_1 and D_4 (the distance between which L_{14}=19.0 m) was oriented perpendicularly to the expected direction of the seismic wave propagation to determine its velocity by direct method. The sensor system D_1, D_2 and D_3 formed a triangulation triangle to determine the velocity of the seismic wave in a second way (the distance between the sensors in the triangle was: L_{12} = 1,42 m; L_{13} = 1,88 m; L_{23} = 1,78 m).

Taking into account the actual distance between the sensors, the angle α = 63.5° was determined. Copies of oscilloscope record of seismic waves recorded at the measuring point are shown in Fig. 2

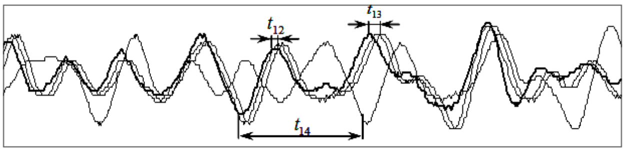


Fig. 2: The fragment of oscilloscope record of seismic waves recorded at the measuring point

The analysis of oscilloscope records allowed to set time intervals of seismic waves passing between the first and second seismic sensors – t_{12} = 0,0011 s; between the first and the third – t_{13} = 0,0006 s; between the first and the fourth – t_{14} = 0,0144 s. Using these experimental data, on the basis of the above methodology the actual velocity of seismic waves propagation was determined: $V=L_{14}/t_{14}$ = 19,0/0,0114 ≈ 1320 m/s; $V=L_{13}/t_{13}$=19,0/0,0114≈1320 m/s; $V=S_{13}/t_{13}=L_{13}\cos\gamma/t_{13}$ =1,88·0,412/0,0006≈1291 m/s. As a result of the performed experiments, it was established that the velocity of seismic waves propagation in the rock massif of open pit “Pivnichnyi” of VAT “Ukrmekhanobr” is within V_{sw} = 1291÷1320 m/s. These values are 12÷14% less than the theoretical (Vs = 1500 m/s) which was used in design. In development to the above mentioned we state that in the conditions of considerable distance to the sensors the asymmetric shape of the explosive waves was transformed into a symmetric one.

At the open pit of VAT “Ukrmehanobr” during one large explosion explodes 1÷2 blocks, 50÷150 m long, 15÷20 m wide. In the block there are 2 to 4 rows of wells with a depth of 7÷32 m, the diameter of 250 mm, network 7.0×7.0 m with rock strength f = 5÷7; 6.5×6.5 m at f = 8÷12; 6.0×6.0 m at f = 12÷14. The standard capacity of 1 running meter of a well with the diameter of 250 mm is 46 kg of granular explosive – compolite. As systems for initiating an explosion detonating cord (DC) and non-electric systems “Nonel”, “Prima-Era”, “Impulse” are used.

The main factors that characterize the seismic impact of massive blasts in the open-pit were taken: the mass of explosives to the degree of deceleration in the explosive blocks - Q; the distance from the block to the observation point – R. The main parameter characterizing the intensity is proposed to consider the module of the vector of the maximum velocity (displacement) of the soil in the basis of structures: $\upsilon=\sqrt{\upsilon_x^2+\upsilon_y^2+\upsilon_z^2}$, where $\upsilon_x^2;\ \upsilon_y^2;\upsilon_z^2$ – horizontal and vertical projections of the velocity on the coordinate axes respectively. It has been experimentally proved that this parameter in a momentary explosion is better than the displacement amplitude, acceleration and the period of oscillations correlates with the explosive mass and the distance to the observation point. To determine the proportionality between the level of seismic vibrations of the soil at a given point and the mass of explosives during massive blasts in open-pits, it is necessary to use the relation $Q=\upsilon^2R^3K^{-2}{}_f$, where υ – the maximum permissible velocity of seismic vibrations of the soil near the protected object, cm/s ; K_f is seismicity factor for a given area. When calculating the boundary value of the explosive mass K_f is determined experimentally during the monitoring of seismic security of mass explosions, the maximum permissible speed of seismic fluctuations.

Since 2006 and to date more than 70 experimental measurements of seismic waves have been made during the explosions in the open pit “Pivnichnyi” of VAT “Ukrmekhanobr”, the results of which are given in Table. 6, 7

Table 6: The system of initiating explosion “DC”

№ of block		Q, kg	R, m	υ, sm/s	K_f
2006	3	900	740	0,17	112,1
	4	780	800	0,13	108,3
	7	900	700	0,13	82,5
	9	860	750	0,13	93,6
	11	800	750	0,17	121,3
	13	840	700	0,23	149,4
	17	900	1200	0,07	92,6
2007	1	880	1100	0,07	82,2
	2	900	1200	0,08	115,7
	10	560	700	0,15	117,6
	16	560	650	0,18	128,7
	17	840	1000	0,10	109,3
Average values		810 ± 75 ε = 10 %	856 ± 126 ε = 15 %	0,14 ± 0,03 ε = 23 %	110 ± 12 ε = 11 %

Table 7: The system of initiating explosion “Prima-Era”, “Nonel”

№ of block		*Q*, kg	*R*, m	*υ*, sm/s	K_f
2007	6	280	800	0,09	126,1
	20	280	650	0,13	130,2
	24	460	850	0,16	189,1
	28	480	900	0,13	162,1
	32	520	900	0,13	152,5
	37	400	1350	0,05	121,6
	38	260	1000	0,06	118,4
2008	4	500	900	0,11	137,3
	5	280	700	0,09	101,9
	8	230	850	0,09	147,1
	11	250	600	0,14	129,5
	12	180	800	0,08	137,2
	19	260	700	0,08	89,2
	21	260	600	0,21	190,2
Average values		331 ± 41 *ε* = 12 %	829 ± 68 *ε* = 9 %	0,11 ± 0,02 *ε* = 16 %	138 ± 11 *ε* = 8 %

On the basis of monitoring data during the period of 2007-2017 on the open-pit “Pivnichnyi” of VAT “Ukrmekhanobr” with the use of the initiation system “Prima-Era”, the experimental value of the seismic coefficient K_f = 138±11 was obtained; in the case of the application of DC – K_f =110±12. The obtained value of K_f in accordance with the method described above allows to establish the dependence between the limit value of the explosive mass and the level of seismic vibrations that may occur as a result of the simultaneous initiation of the corresponding explosive mass. The results of calculations of the seismic safe explosive mass under the condition of the use of DC are given in Table 8, and for non-electric systems “Prima-Era” and “Nonel” in Table 9. In the case when the distance to the object is not equal to the value given in the tables, the seismic-safe explosive mass is taken on the basis of the graphs depicted in Fig. 3, 4, which are offered for practical use at designing at the open pit “Pivnichnyi” of VAT “Ukrmekhanobr”.

Table 8: Seismic-safe explosive mass (the system of initiating explosion DC)

Distance *R*, m	Explosive mass *Q*, kg						
	Seismic stability, points						
	1	2	3	4	5	6	7
20							95
30						80	321
40					48	190	762
50					93	372	1488
60					161	643	2571
70				64	255	1020	4082
80				95	381	1523	
90				136	542	2169	
100			53	186	744	2975	
125			103	363	1453		
150			179	628	2510		
175		71	283	997	3986		
200		106	423	1488			
250	52	207	826	2905			
300	89	357	1428				
350	142	567	2268				
400	212	846	3385				
450	301	1205					
500	413	1653					
600	714	2856					
700	1134	4536					
800	1693						
900	2410						
1000	3306						

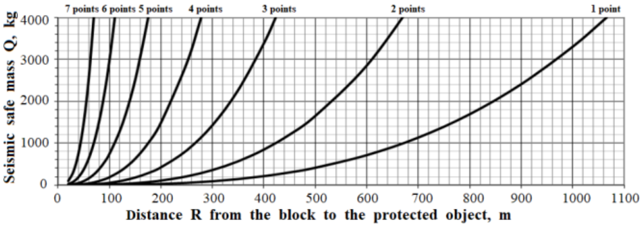


Fig. 3: Dependences of seismic safe explosive mass from the distance to the protected object (for the system of initiating explosion DC)

Table 9: Seismic safe explosive mass **(**the systems of initiating explosion “Prima-Era”, “Nonel”)

Distance *R*, m	Explosive mass *Q*, kg						
	Seismic stability, points						
	1	2	3	4	5	6	7
20							60
30						51	204
40					30	121	484
50					59	236	945
60				26	102	408	1633
70				41	162	648	
80				60	242	968	
90				86	345	1378	
100			34	118	473		
125			66	231	923		
150		28	113	399	1595		
175		45	180	633			
200		67	269	945			
250	33	131	525	1846			
300	57	227	907				
350	90	360	1441				
400	134	538					
450	191	766					
500	263	1050					
600	454						
700	720						
800	1075						

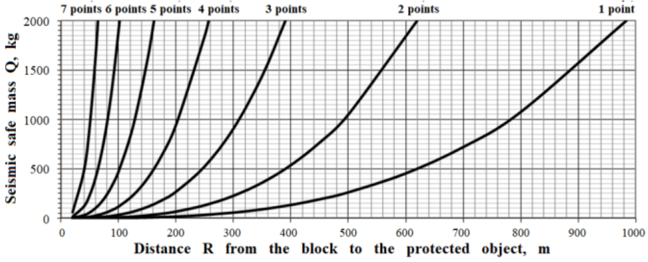


Fig. 4: Dependences of seismic safe explosive mass from the distance to the protected object (for the systems of initiating explosion “Prima-Era”, “Nonel”)

The method of their use allows to quickly evaluate the seismic safe parameters of the blasting that ensure the stability of the sides, braces of the slopes, structures at a given permissible vibrations velocity and is an important condition for the improvement of the drilling and blasting operations and the implementation of the developed technology.

As a result of the carried out researches calculation methods of seismic parameters of blasting operations in the open pit “Pivnichnyi” of VAT “Ukrmekhanobr” were developed taking into account modern explosives and explosive devices. It takes into account the acoustic anisotropy of rocky soils.

At the same time, experimental explosions with the registration of real deformations and stresses in the rock massif around the explosive charges revealed somewhat lower indicators than the idealized calculated ones. Having investigated the stress state and massif structure we established the main reason for this difference – the effect of system macro fracture which divide the massif into separate blocks. And after performing a comparative analysis of the values of the above deviations with the values of fracture opening we developed a simplified method of compensating for it in calculations by introducing a corresponding coefficient K_{st} which differs from the proposed in [8] so that it takes into account not only the level of filling fractures with mineral fines but also the explosion kinetics and an inertial factor for passing an elastic wave through a macro fracture. The physical meaning of this coefficient consists in the “graduated” cutting of the elastic wave amplitude when it is propagated through the blocks or layers of the rock (Fig. 5), in combination with plastic deformations of near-surface zones of macro fractures caused by the movement of rock masses when considering the behaviour of a destructive rock mass as a set of elastic rods. Taking into account these factors it is proposed to determine this coefficient within the zones of intense explosive loads as

$$K_{fr} = \sqrt{f \cdot \rho_{fr}} \left(1 - \frac{r_{wf} \cdot g_{fr}}{A}\right)^{(1-\rho_{fr})} ,$$

where f – strength of the rock; ρ_{fr} – the level of filling fractures with rock fines, is determined by the ratio of the filler volume V_3 to the fracture volume V_{fr} ($\rho_{fr} = V_3 / V_{fr}$); r_{wf} – distance from charge to wave front; g_{fr} – the index of specific fracture of the rock massif, is determined by the ratio of the average width of systemic fractures, normal with respect to the direction of waves propagation (g_{fr} = □$_{fr} / l_{fr}$).

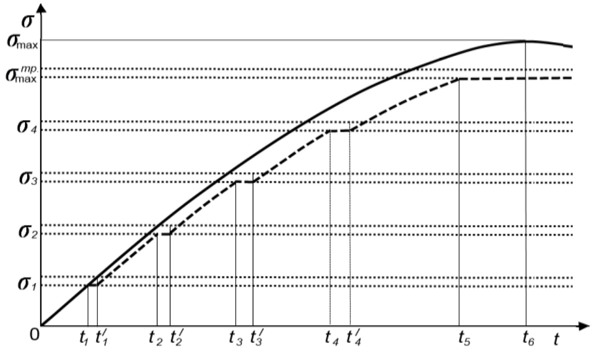


Fig. 5: Modification of the stress dependence graph (deformation) at the front of the elastic wave due to the system fracture of the rock massif

The introduction of this coefficient significantly improves the precision of the results of theoretical calculations and experimental registrations to determine the interaction of the explosion energy with the rock massif. Fig. 5 shows how different the theoretical and the real calculations are, represented by the modified curve, the contours of the stresses development (deformations) in the front of the elastic wave for the system fracture of the rock massif. Accordingly, it is proposed to determine the limits of the zones of minimum and maximum loads of the block rock massif by the explosive wave not by a theoretical but modified trochoidal curve (Fig. 6).

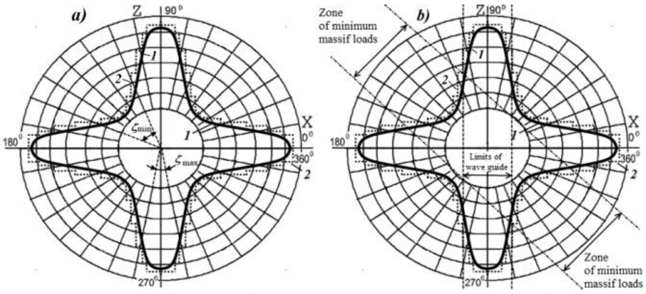


Fig. 6: The limits of zones of minimum and maximum loads of block rock massif by blast wave: *1* – theoretical trochoidal curve, *2* – modified trochoidal curve

As for the experimental recordings of rock mass loading levels parallel ($R_\|$) and perpendicular to ($R_\perp$) sub-orthogonal systemic fracture of rocks, they clearly demonstrated how different the stress fields are formed depending on the degree of “development” of system fractures and caused as the result acoustic anisotropy (Fig. 7): coherent by a natural mineral material close to the rock and with incoherently closely spaced longitudinal (a) and “developed” fractures of both systems (b).

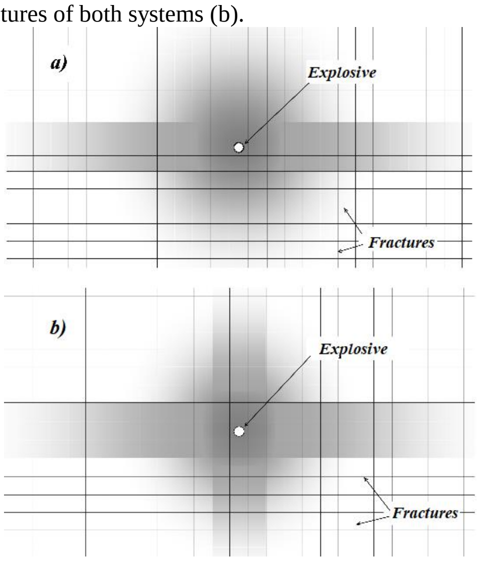
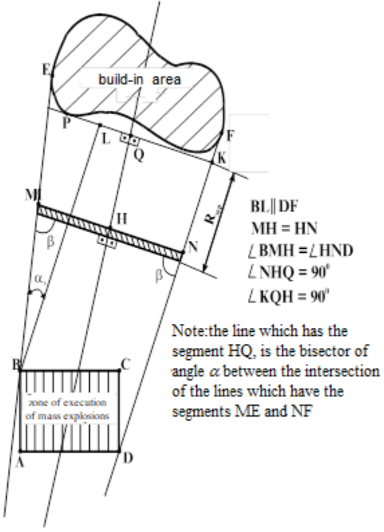


Fig. 7: Vector-geometric graphs to determine the orientation of the shielding fracture

The built-up areas for which seismic protection by these measures becomes impossible, are proposed to protect with shielding fractures, the parameters calculating method of which is as follows.

When creating shielding fractures, its main parameters are spatial orientation and width. These parameters depend first of all on the mutual alignment of the buildings and the explosive operations front, the distances between them, the spatial orientation of the systems of abruptly falling and primary-layer fractures and their characteristics, the watering degree, as well as the physical and mechanical characteristics of the massif, separating it from the zones of mass explosion. In this case, the most rational is the location of the fracture when it is oriented parallel to the elastic waves front. The area and configuration of the fracture are determined in such a way that its acoustic shadow while explosive waves spreading completely covers the projection of the medial section of the protected massif on a plane perpendicular to the direction of propagation of their front. This problem is easily accomplished by vector-geometric constructions (Fig. 8).



$BL \| DF$
$MH = HN$
$\angle BMH = \angle HND$
$\angle NHQ = 90^\circ$
$\angle KQH = 90^\circ$

Note:the line which has the segment HQ, is the bisector of angle α between the intersection of the lines which have the segments ME and NF

Fig. 8: Vector-geometric constructions to determination of shielding fracture orientation

The following operations are performed:

1. Boundaries of existing and perspective build-in sites and areas of mass explosions are described.
2. The extreme points of the selected areas are connected by tangent BE and DF (Fig. 6).

3. The angle α between the tangent BE and DF (BL – parallel to DF) is determined.

4. A bisector of angle α is constructed (in figure 6 the segment HQ belongs to it).

5. Perpendicular to the bisector of the angle α a tangent to the contour of the built-up area PK is constructed.

6. From the intersection point Q of the tangential PK with the bisector of the angle α the distance HQ is set aside as safe for the built-up area under the conditions of the explosion performance by the shielding fracture arrangement.

7. From the point H a line is formed perpendicular to the bisector of the angle α to the intersection of it with the lines BE and DF.

On the line of the MN segment it is more rational to dispose the shielding fracture, as it has the smallest length and completely “shadows” the protected massif.

The authors developed a method for calculating the parameters of blasting for the shielding fracture device is close to the calculation of blasting by presplitting method in construction [3]. This completely solves the elastic-plastic problem.

3. Conclusions

Analysis of the data given in Table. 6, 7 allows to assert that:

- the level of seismic waves from explosions in the open pit “Pivnichyi” of VAT “Ukrmekhanobr” has never exceeded the normative level;
- the system for initiating explosion significantly affects the seismicity of mass explosions – with the use of the systems “Prima-Era”, “Nonel”, the seismic effect of the explosion is almost 30% lower than in the case of the use of DC;
- the seismicity of the explosion is influenced not by the system of initiation itself, but the maximum explosives mass to the degree of deceleration in the application of the initiation system: in the application of DC – 810 kg, and systems “Nonel”, “Prima-Era” – 331 kg;
- significant influence on the massif power load of systemic macro fractures requires the introduction of a compensating factor K_{cm} into the calculations.
- the azimuthal stresses of the massif around the charge differ significantly not so much depending on the acoustic anisotropy of rocky soils, as a result of the fracture formation of waveguides.

As a result of the carried out researches, methods of calculating seismic safe restrictions for the parameters of blasting operations in the open pit of VAT “Ukrmekhanobr” and the protection of the built-up areas by shielding fractures have been developed.

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