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"IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE"

APPLIED GEOPHYSICS

lecture course

Recommended by the Methodological Council

of the Igor Sikorsky Kyiv Polytechnic Institute

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"Applied geophysics" lecture course this is the educational edition for students of specialty 184 "Mining" / V.G.Kravets, V.V.Boyko, Kovtun A.I., Han O.V. Igor Sikorsky Kyiv Polytechnic Institute – Electronic text data (1 file: 2,10 MB). – Kyiv : Igor Sikorsky Kyiv Polytechnic Institute, 2019. – 64 p.

"Applied geophysics" lecture course – considers a complex of issues related to seismic safety of industrial explosives in the mountain spas, in geotechnical, industrial and civil construction. The lecture course is designed for use by foreign students and may be useful for full-time and part-time students of specialty 184 "Mining" in the course of completion of graduate and postgraduate projects, as well as for mining engineers in designing and organizing subcontracting works.

The lecture course contains information that corresponds to the current achievements of science and technology in the field of seismic security during blasting operations of mining and construction, highlights the features of shaping the forms and sizes of seismic boundaries.

"Applied geophysics" lecture course – recommended for students of specialty 184 "Mining" specializations "Geotechnical and urban underground construction", "Development of deposits and extraction of minerals".

CONTENT

Definition of terms and concepts

The following terms are used in this sense.

– **acceptable speed of seismic fluctuations** of the ground is the speed at which the conservation of buildings and structures is fully guaranteed, and probable local deformations will not exceed the projected ones;

– **protected objects** - buildings, buildings, engineering, natural and others. Objects, which should be fully guaranteed preservation, and the probability of local deformation does not exceed the permissible standards;

– **mass explosion** (in open work) - an explosion of two or more well bore holes, boiler or chamber charges mounted in the general explosive network, as well as single charges in charging workings exceeding 10 m in length;

– **explosive substance** (ES) is a chemical compound or mixture capable under certain conditions to a very fast self-propagating chemical transformation with the release of heat and a large number of gaseous products;

– **seismic wave** (seismic explosive wave (SEW)) - transverse, elongated, volumetric, superficial (Rayleigh) waves formed in the environment from explosion charges of explosive substances;

– **explosive materials** (EM) - materials, means of initiating an explosion, articles and devices containing explosives;

- **blasting works** - a complex of organizational and technical measures related to the preparation and conduct of explosions;
- **ball** - a standard unit of measurement that characterizes the intensity of the seismic effect of a charge explosion with certain quantitative and qualitative indicators on the building, engineering structures, natural objects, living creatures, etc.;

– **seismic stability** - the ability of buildings and structures to withstand seismic effects without loss of operational qualities;

– **seismic equipment complexes** - a set of basic devices for recording and reproduction of seismic information and auxiliary devices, which is intended to determine the parameters of soil seismic fluctuations or structures construction;

– **security zone** (seismic security zone) - a zone planned by results of calculation during the design of blasting operations, in which there is no excess of the limit values of elastic waves intensity;

– **seismic zone** - zone around the source of an explosion in which the boundary norms of the intensity of elastic waves are exceeded;

– **seismic boundary** - the boundary, determined by the results of calculations during the design of explosive works, beyond which there is no exceeding the limit values of the intensity of elastic waves, or the isolation of permissible limit values of the intensity of elastic waves;

– **soil displacement** - the distance to which a part of the soil has moved under the influence of elastic oscillations;

– **mass velocity** or **rate of soil displacement** - the rate of displacement of the soil particle in a seismic wave;

– **acceleration of soil displacement -** change in time of mass velosity in a seismic wave;

– **period of oscillation -** the time for which the part of the soil undergoes a complete cycle of oscillation;

– **frequency of oscillations -** the number of total oscillations of the soil particles (periods) in one second;

– **isoseysm -** a line around the source of the explosion with the same values of mass velocity or acceleration of oscillation, built on the results of calculations or equipment measurements.

Theme 1 NORMATIVE AND METHODOLOGICAL ISSUES OF SEISMICSAFETY BY EXPLOSIVE WORKS

Lecture 1. Preface. Classification of the territory of ukraine by tectonic structure

The territory of our country undergoes significant technological мan-made loads, especially in industrialized regions. A large number of industrial sites, in particular mining enterprises, pose a threat to the environment and human health.

In mining, one of the main processes that have a negative influence on the environment is blasting. The explosion spends considerable energy on the destruction of rocks to a certain extent. At the same time, it pollutes the air with toxic gases, creates a dust cloud and generates a system of seismic waves threatening surrounding structures and violates the stability of mining, natural and man-made elements of relief.

The proposed course "Applied Geophysics" covers a number of problematic issues related to the study of the state of seismic security in the quarry of Ukraine, advanced achievements in the industrial seismic, seismic protection of various types of security objects. It includes the following areas of research in industrial seismic:

- studying the geological-tectonic structure of the granite terrains of the Ukrainian Crystalline Shield (UKSh) and limestones of the Precarpathian Trench and conducting their classification for forecasting the seismic intensity of the explosion;
- studying the nature of the distribution around the explosion of seismic waves in arrays, where anisotropy manifests itself in the form of a logical system of parallel cracks;
- studying the fluctuations of the "soil-structure" system and determining the influence of the frequency characteristics of buildings on their seismic stability with the estimation of the change in the intensity of seismic oscillations when they move from the ground to the foundation of the building and further to the building itself;
- determination of the features of the spread of the seismic explosive wave in a multi layer array of rocks;
- determination of seismic resistance of soft rock ramps and elaboration of methods for recalculation of slope steepness depending on physical and mechanical properties of overburden;
- estimation of the seismic effect of multiblock mass explosions with a non-electric system of initiating charges of ES for the determination of seismically safe scales of blasting operations.

The main volume of building materials in Ukraine is mined in quarries located within the boundaries of the Ukrainian Crystalline Shield (UCSh) and the Limestone of the Carpathian Trench. As a result of seismic events caused by industrial explosions, a number of problems arise in densely populated areas. To solve them, it is necessary to identify seismic zones on the basis of geological and tectonic analysis of the territory of Ukraine by determining the parameters of tectonic disturbances in places designated for the development of rocks.

To assess the heterogeneity of granite UCSh, where the quarries of building materials are located, the geological-tectonic characteristic of the territory of Ukraine has been studied(Fig.1.1)

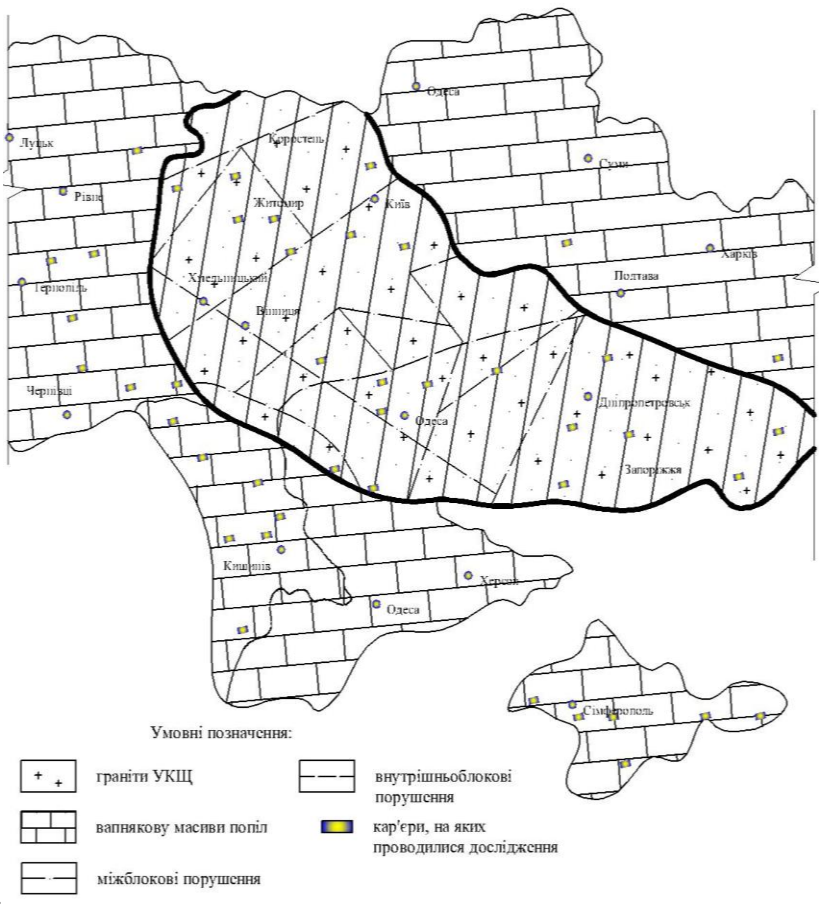


Fig.1.1. Geological and tectonic map of the territory of Ukraine

The study of the geological-tectonic map during long-term research in quarries, determination of the structure of the arrays of the UCSh allowed to determine the nature of the anisotropy of the arrays, to identify interblock and intra-block disorders. Data of measurements and results of their processing are given in Table 1.1.

Table 1.1.
Parameters of granite breakdown of UCHCH

Область	Granite Area S, ths. км2	Total length of interblock violations Lbl, ths km	Total length of intra-block disorders, L, thousand km	*S/L*, thousand km
Zhytomyr	29,9	0,45	0,583	51,29
Khmelnitsky	4,55	0,21	0,225	20,22
Vinnitsa	26,5	0,469	0,918	28,87
Kievskaya	26,3	0,3	0,325	80,92
Cherkassy	18,65	0,2	0,27	69,07
Kirovograd	24,6	0,112	0,14	175,71
Nikolaev	11,3	0,135	–	-
Odesa	4,5	0,12	–	-

On the basis of the complex of scientific researches, the classification of UCSh and limestones of the Precarpathian bend is developed on the basis of the presence of anisotropic properties in the area where the quarry and the adjoining territory of the living population are located. Classification contains three classes and two subclasses (Fig. 1.2).

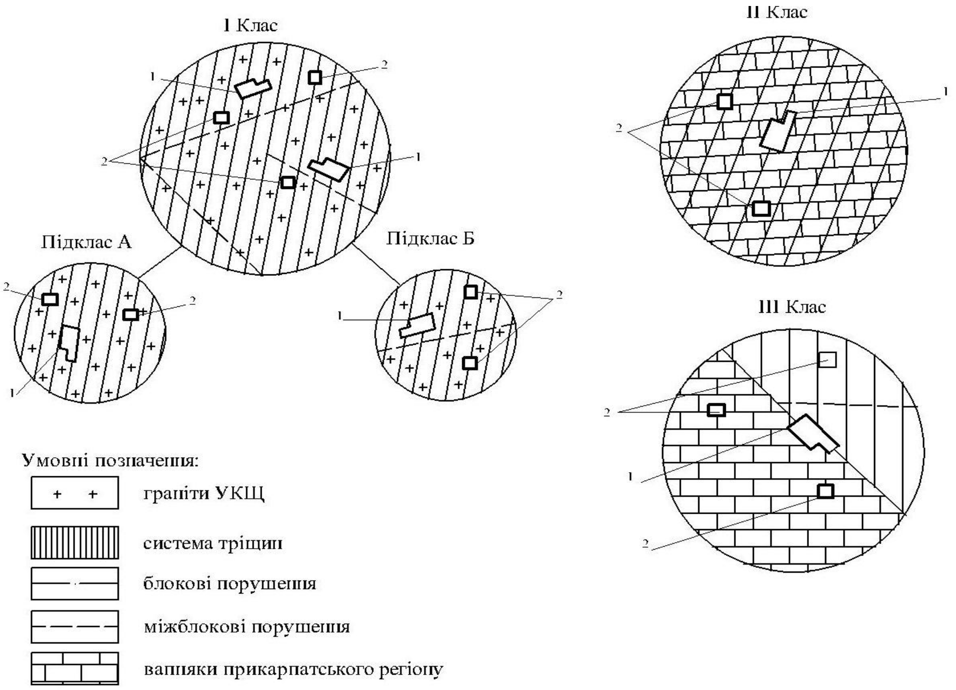


Fig. 1.2. Scheme of classification of territory of Ukraine into classes and subclasses: 1 - career field; 2 - protected object

1 class- granites of the Ukrainian Crystal Shield:
subclass Ais territory with a regularly oriented system of parallel cracks in the zone of the mining enterprise and adjacent guarded objects;

subclass B is a subclass A with block and interlock faults.
II class is the territory of the limestone of the Precarpathian trough with a system of vertical and stratum cracks, which has a quarry and an adjoining area with protected objects.
Class III - the territory located in the region at the boundary of the 1st and 2nd classes.

From the given classification, the direction of investigation of the nature of the spread of seismic waves around the source of an explosion in arrays, where the anisotropy manifests itself in the form of a regular system of parallel cracks, is established.The obtained research results can be used in the development of seismic engineering equipment for industrial and special blasting operations in areas with engineering and natural objects requiring seismic protection.

Control questions

1. *Dangerous factors of explosion in mining*
2. *Explain the term "seismic security"*
3. *Justify the need to study the tectonics of the mountain regions of Ukraine*
4. *What does the term "anisotropy" mean?*
5. *Define the concept of a "seismic-safe zone"*
6. *Class of rocks for anisotropy*
7. *Subclasses of granite by tectonics.*

Lecture 2. METHOD OF SEISMIC WAVES PARAMETERS MEASUREMENT

Instrumental recordings of seismic waves in an industrial seismic system are conducted in the explosion of individual and system of charges. The equipment used to study the seismic properties of the rock mass must provide not only the measurement of the velocity of oscillations, but also the program of spectral analysis of the oscillatory process of the system "source of explosion - a rock mass - an object" in connection with its seismic stability, technical condition, etc.

The main purpose of seismic measurements is to establish the patterns of interaction of seismic waves in the system, taking into account the frequency characteristics of soil oscillations. The results of these measurements are determined in different ranges of the frequency of massive oscillation velocities.

Measurement tasks:

a) operational control of the impact of seismic waves on security objects;

b) statistical accumulation of data on the parameters of oscillation (speed and frequency) and their use when adjusting the existing scale of the explosion;

c) the choice of safe levels of oscillation for objects;

d) the use of seismic parameters of the short-wave explosion of the BP system of boreholes for the development of recommendations for the determination of seismic-hazardous parameters of blasting operations at different parts of the quarry field and the transfer of these data to areas with similar mining-geological and technical conditions.

Seismic observations provide an opportunity to quantify the level of oscillations, and then develop recommendations for the safe operation of objects that are protected in the course of blasting operations. The value of the seismic safety criterion should not exceed the permissible values according to the standards.

The data of instrumental measurements are unified in the uniform form and are divided into the following groups.*I. General Information.*

Characteristics of rocks at the site of installation of seismic detectors, parameters BP.

A. Characteristics of covering rocks.

B. The parameters of the explosion of each block and the characteristics of the breeds that are undermined.

B. Parameters of seismic waves.

Fig. 2.1 depicts the elements of the measuring system.

Fig. 2.1. Elements of the information channel

As a measuring element of an information channel, electromechanical sensors of the pendulum type are taken CM-3 and CM-3B.

The principle of operation of the device is as follows: the body of the device with a magnet rigidly attached to the object under study and repeats its movements. A pendulum with a coil fixed on it tends to stay calm. Because of the relative motion of a magnet and a coil in the latter, an electromotive force (EMF) is induced, or a voltage whose magnitude is proportional to the velocity of motion. Changing this EMF and fixing it at the registration node.

The next element of the information channel is an analog-to-digital converter ADA1406, which works with frequencies 400 KHz and 100 KHz.

The last element of the measuring channel is a PC.

To measure the parameters of the seismic waves, at least 7 seismic sensors are located on the profile. The satellite system is used to set the coordinates of the sensors.

The maximum influence from the oscillation process can be estimated by the module of the complete vector of oscillation velocity

$$|\bar{V}| = \sqrt{(V_x)^2 + (V_y)^2 + (V_z)^2}, \qquad (2.1)$$

if the oscillation rate of the particles of the soil in the component oscillations reaches a maximum at one time within the phase shift of 90□, which happens very rarely.
This is confirmed by the fragment of the oscillogram (Fig. 2.2), where the records of the velocity of soil displacement by the three components (X, Y, Z) in the joint observation point of the two apparatus complexes are presented.

From Fig. 2.2 it is evident that the difference in the time of entry of the maximum amplitudes by component of the oscillations is almost equal to the period of oscillations (T = 0.029 s), which corresponds to phase shift in 360□. Therefore, the module of the complete vector of velocity can not be determined by the formula (2.1). In this case, the module of the full speed vector is determined by the line 1-1 (Fig. 2.2), which corresponds to the time of the arrival of components of oscillations of 0.153 s, or along the line 2-2 (the arrival time of oscillations is 0.178 s). In this case, the maximum impact from the oscillation process according to the formula (2.1) is 1.9 cm / c and 1.66 cm / c, respectively.

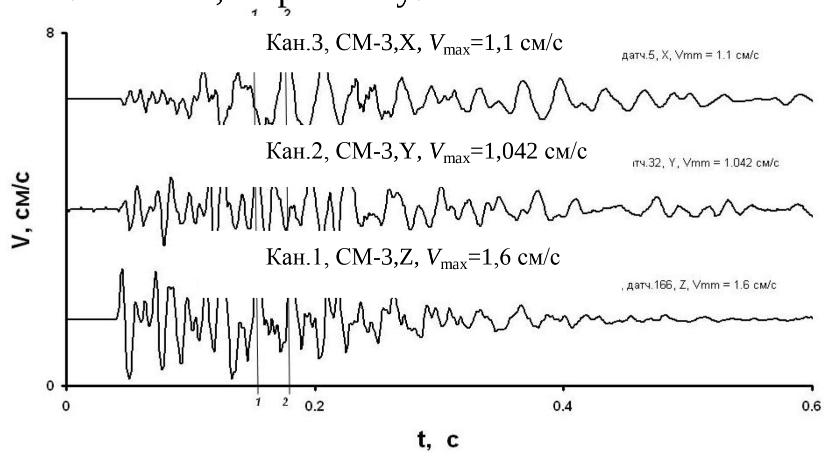


Fig. 2.2. Characteristic oscillogram of a mass explosion for seismic sensors in the direction of X, Y, Z

As an example of the capabilities of the hardware complex, we will conduct a study of the impact of mass explosions # 1 and # 2 on the supports of transmission lines, located at distances of 380 m and 440 m from the blast blocks, respectively, which are undermined. Seismic sensors SM-3 were installed on a soil basis of the power transmission line and its construction at an altitude of 1.5 m. In Table. 2.1 the maximum values of the displacement rate of soil particles are given.

Table 2.1

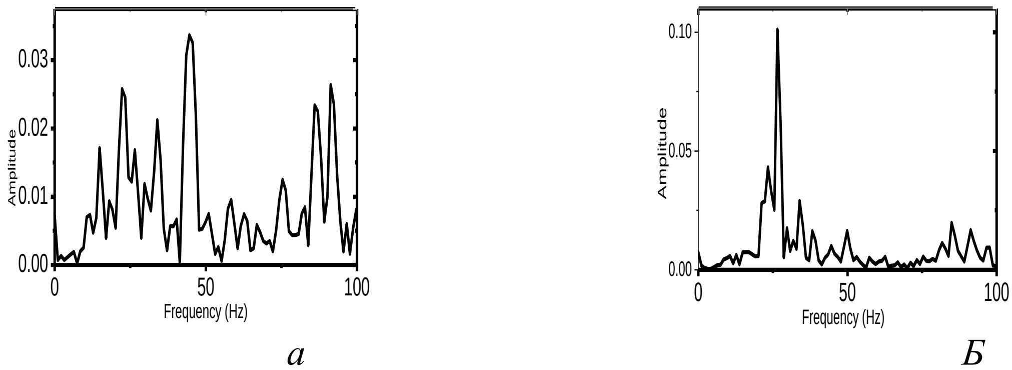
Maximum values of the displacement rate of soil particles (cm / c)

Seismic detector installation location	Explosion №1	Explosion №2
Support structure	0,64 cm/s	0,45 cm/s
Ground base support	0,85 cm/s	0,37 cm/s

Analyzing the data in the table. 2.1, it can be seen that during the explosion №1, the rate of oscillation of the soil is greater than the rate of fluctuation of the structure of the support. At explosion №2 - on the contrary.

a *Б*

Fig. 2.3. The frequency response of seismic oscillations recorded by seismic detectors installed on the ground (a) and on the support structure (b) during the explosion № 1



a *Б*

Fig. 2.4. The frequency response of seismic oscillations recorded by seismic detectors installed on the ground (a) and on the support structure (b) in the explosion №2

Analyzing the frequency response, are presented in Fig. 2.3, b and 2.4, b it should be noted that they have a pronounced peak of the amplitude of oscillations at a frequency of 26.5 Hz for the support structure in the explosions No.1 and No.2, which is the frequency of the eigenvalues of the structure of the transmission line. There was no pronounced amplitude peak at frequencies close to 26.5 Hz among seismic oscillations fixed on a ground support base during the explosion # 1 (Fig. 2.4, a). Therefore, the resonance phenomena did not occur at the interaction of the SOF with the ground base of the bearing with its construction, and the massive velocity of the elements of the construction of the support was less than the ground base, as a result of dissipative energy losses in the transmission of wave phenomena to the elements of the construction of the support.

In response №2 explosion seismic waves recorded in the dirt on a support (Fig. 2.4, a) contains a maximum amplitude at a frequency close to the natural oscillation frequency design support (22.5 Hz), so the effect of fire between the resonant elements and SVH design support, leading to increased rate fluctuations compared to the speed of the shift soil particles 1.22 times.

As a result of the studies received confirmation that the study SVH action on security facility is necessary to vibrational spectral analysis process, which all registered seymodatchyky. It was shown that the module full velocity displacement of soil particles from the values of the components of oscillation (X, Y, Z) is determined only at a time when there is an oscillatory process.

Control questions
1. Requirements for measuring equipment
2.The object of seismic measurements
3.The main task of measurements
4. Imagine the circuit of the measuring equipment
5. Principle of seismic sensor operation
6. The principle of determining the coordinates of the sensors
7.Formula of the module of the complete vector of oscillation velocity
8. Explain the reason for changing the vibration parameters when moving from the ground to the object

Lecture 3
DETERMINATION OF THE ACTUAL PARAMETERS OF THE SEISMABLE WAVE

– With the help of seismometric equipment, measure the velocity and the period of the fluctuations of the soil near the foundation of the building and compare them with the permissible speed of soil fluctuations for the building. Actual seismic stability of buildings that are to be preserved is determined by the ratio of periods of soil and building fluctuations.

– Registration of oscillations is primarily carried out at places of maximum approximation of blasting works to buildings and structures that are subject to protection. Measurements are carried out at the foundation of the building to determine the pattern of propagation of the seismic burst wave from the cell of the explosion to the object. Measurements are performed simultaneously with the use of two groups of seismic receivers (three per group) at each point, which fix the fluctuations in 3 directions: for two horizontal components (x, y) and one vertical (z). By the results of the processing of the received seismogram, the parameters of the seismic wave of the boom - the displacement or the rate of soil displacement, or the acceleration of the soil particles, the period of oscillation and the frequency of oscillations are determined.

Data processing includes:

- determination of parameters of seismic oscillations by seismograms;
- the velocity of oscillation (V) is calculated by the formula:

$$V = \frac{2\pi \cdot A}{T}, \qquad (3.1)$$

where A is the displacement amplitude, cm, T is the oscillation period, p.

The period of oscillation was determined with seismograms at the time marks between the peaks of maximum amplitudes of oscillations;

The velocity of oscillation for each component (Vx, Vy, Vz), in centimeters per second, was calculated according to the formulas:

$$V_x = \frac{2\pi A_x}{10T_x};\ V_y = \frac{2\pi A_y}{10T_y};\ V_Z = \frac{2\pi A_z}{10T_z}, \qquad (3.2)$$

where T_x, T_y, T_z– periods of oscillation for each component, s.

The resulting amplitude of the displacement of soil particles (A), oscillation velocity (V), acceleration (a), is calculated by the formulas:

$$A = \sqrt{A_x^2 + A_y^2 + A_z^2}; \qquad (3.3)$$

$$V = \sqrt{V_x^2 + V_y^2 + V_z^2}; \qquad (3.4)$$

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}. \qquad (3.5)$$

The seismic load (G), in kilograms, on the building is calculated by the formula:

$$G = P\ \frac{a}{g}\ K_с\eta_к, \qquad (3.6)$$

where P - weight of the building, kg
a - acceleration of fluctuations of the soil at the foundation of the structure, cm / s2;
g - acceleration of free fall, cm / s^2;
Кс - coefficient of dynamism (coefficient of perception of fluctuations in the building).
The coefficient of dynamism is determined from the seismogram of the fluctuations of the soil and the building or by the formula

$$K_c = 1 \Big/ \sqrt{\left(1 - T_0^2 / T^2\right) + \lambda^2 \cdot T_0^2 / T^2} \quad , \tag{3.7}$$

where T_0 - period of own fluctuations of the structure;
T - period of prevailing oscillations of the ground, which determine by seismogram,
λ - decrement of attenuation of own fluctuations of buildings and structures. The value of the decay of attenuation is shown in Table. 3.1;
η_k is the coefficient of deformation form, η_k = 0,96.

Table 3.1

The value of the decay rate for different types of buildings and structures

Type of building	T_0, c	*λ*	*H/b*
One-story brick house	0,20	0,25	0,28
Residential two-storey brick building	0,26	0,17	0,88
Residential four-story brick house	0,29	0,12	1,30
Three-story brick building with reinforced concrete frame	0,24	0,20	0,86
Residential five-story panel house	0,30	–	1,20
Garage for dump trucks (two-story, multi-pass, brick, reinforced)	0,50	–	0,985

Actual seismic stability of buildings and structures is determined by comparing the velocity of oscillation, which is calculated according to formula (2.3) with the permissible speed of soil fluctuations near the foundations of buildings and structures in accordance with existing norms.
The works are carried out in accordance with the measurement protocol, which contains the following information:

1) a reference to the methodology;
2) the name and address of the measuring laboratory;
3) date and place of measurement;
4) place of blasting operations;
5) date and number of the protocol of measurements;
6) results of measurements;
7) signature of the responsible for the results of measurements;
8) other indicators that may affect the measurement result;
9) any transaction or any conditions that occurred during the determination and not set out in this standard that could affect the measurement results.

It is necessary to regularly check the equipment for reliable results. The frequency of verification is determined by each organization that performs the measurements and is certified in accordance with the established procedure.

The inspection should be as follows:

a) seismographers;
b) multichannel digital recording oscilloscope;
c) equipment for processing seismograms (computer software).

Control questions

1. Measured oscillation parameters
2. Priority places of measurements of oscillation parameters
3. Explain the connection between the period and frequency of oscillations
4. Formula for determining the velocity of oscillations
5. How is the period of oscillation determined?
6. Give a form of formulas to determine the resulting oscillation parameters
7. Formula for determining seismic load
8. Formula for dynamic coefficient
9. What is a "decay of attenuation"?
10. How to determine the seismic stability of buildings?

Lecture 4NORMS OF SEISMIC SAFETY AND TYPES OF SEISMIC WAVES

The growth of the scale of construction necessitates an increase in the number of mining companies or the expansion of already existing territories. At the same time, the boundaries of quarries are gradually approaching civil and industrial buildings. The destructive impact of seismic waves from industrial explosions is increasing.

In these conditions it is necessary to constantly monitor the detrimental effect of explosions in order to preserve the integrity of buildings. Estimation of explosions and regulation of intensity of seismic action is carried out guided by the magnitude of the maximum speed of wave oscillations. The speed should be less than the permissible value taken from the existing standards. Experts try to construct such schemes of blasting, at which at the same mass of charge will be the minimum indicators of the intensity of seismic waves on buildings located nearby. But for the construction of seismic boundaries around the site of explosion it is necessary, along with a comparative analysis of the influence of various schemes of blasting, to carry out the analysis of seismograms by types of waves (surface, volumetric longitudinal and transverse, waves of Lyav). Dangers for a particular object are waves, which, in spectral composition, are close to the frequency characteristics of the structure.
Such work requires knowledge of the permissible level of seismic influences (the rate of fluctuations of the ground at the base of the object) on the surrounding industrial, civilian or natural objects. Determination of fluctuations in the state of buildings and structures during explosions is carried out according to the intensity scale of seismic oscillations, which is given in Table. 4.1 2.7.

Table 4.1.

Scale of intensity of seismic fluctuations during explosions

Characteristics of vibrations	Ball	Velocityof oscillation, cm/s
Fluctuations register only devices	1	less than 0.2
Fluctuations are felt in some cases in quiet weather	2	0,2–0,4
Fluctuations are felt by some people or who are aware of an explosion	3	0,4–0,8
Fluctuations are felt by many people, glass tempering	4	0,8–1,5
Loss of whitewashing, damage to old buildings	5	1,5–3,0
Thin cracks in plaster; damage to buildings that had deformations	6	3,0–6,0
Damage to buildings that were in satisfactory condition: cracks in plaster, falling pieces of plaster, thin cracks in walls, cracks in furnaces and pipes	7	6,0–12,0
Significant damage to buildings: cracks in the supporting structures and walls, large cracks in the partitions, fall of stove pipes, plaster coatings	8	12,0–24,0
Building destruction: large cracks in the walls, masonry bundle, falling of individual parts of walls	9	24,0–48,0
Large destruction and collapse of buildings and structures	10–12	>48,0

The most acceptable criterion for seismicity of buildings in explosive operations is the rate of displacement of soil particles in their basis [4,8,18]. Damage to structures occurs when the rate of displacement of soil particles (U, cm / s) exceeds its permissible value [U]. Particularly dangerous situation becomes, when the frequency of oscillations of the ground base of the building approaches its own. The use of this criterion in practice leads to an overestimation of the maximum permissible norms, when the determination of the permissible volatility of the soil in the basis of the construction is carried out without taking into account the technical condition of the buildings (weakening of the cracks) and the frequency spectrum of the "soil-building" system. Due to the overestimation of boundary norms, an error is assumed with regard to the definition of seismic parameters of mass explosions in quarries. This leads to the further development of existing and the formation of new cracks in the surrounding buildings.

Seismic stability of mountain ranges is determined by the absence of residual deformations during the passage of seismic explosive waves. The criterion for seismic resistance of a rock is the relative elastic deformation (E_0), which is calculated by the formula:

$$E_0 = U/V_p, \tag{4.1}$$

where U - velocity of oscillation of particles of soil of a seismic wave, m / s;Vp - velocity of seismic wave propagation, m / s.

The permissible relative elastic deformation of rocks for the engineering structures contained therein establishes the class of structures, their characteristics and the period of operation, respectively (Table 4.2).

Table 4.2

Permissible relative elastic deformation of rocks
for the engineering structures contained in them

Class of buildings	Characteristics of the structure and its period of operation	Permitted relative elastic deformation
1	Particularly responsible buildings of a long service life of 10 to 15 years: hydrotechnical tunnels, trenches of mines, capital tunnels, chambers of crushing, mines	0,0001
2	Responsible buildings with a lifetime of 5 to 10 years: bypass and transport tunnels of hydrotechnical structures, over-chamber helicopters, overheads, quays and dumps	0,0002
3	Buildings that are used for a short time (from 1 to 5 times): chambers, drifts, ledges	0,0003
4	Nonresponsive structures, which are used once: cleaning blocks, work benches, workbenches of quarries, etc.	0,0005

Згідно "Єдиних правил безпеки при вибухових роботах" [14] визначення безпечних відстаней при короткосповільненому вибухуN зарядів загальною масою Q з часом сповільнення між вибухами кожного заряду не менше 20 мс проводиться за формулою:

$$r_c = K_r K_c \frac{\alpha}{N^{1/4}} Q^{1/3}, \tag{4.2}$$

where Кr - coefficient, which depends on the soil properties in the basis of the protective structure;

Kc - coefficient, which depends on the type of security building;
α - coefficient, which depends on the performance of the explosion;
N - number of charge groups, units;
Q - total mass of charges, kg.
This calculation of the safe distance applies only to buildings that are in a satisfactory technical condition. In the presence of violations in buildings (cracks in walls, etc.), the safe distance, calculated by the formula (4.2), should be increased by at least twice.
Here are the results of calculations for the following conditions of use of the system of short-term initiation: explosions with a total mass of 12000-16000 kg of explosive, in the zone 300-700 m there is a factory for processing raw materials for crushed stone and settlement. Soils in the basis of houses - not watered sand and clay, depth of more than 10 m. Accordingly:
Kr = 12; Kc = 2; α = 1.
The safe distances for different numbers of charge groups N and total mass Q charges are calculated according to the formula (4.2), which is doubled as the houses are in unsatisfactory technical condition (Table 4.3).

Table *4.3*

Seismically safe distances

Q, кг	4000	6000	10000	12000	16000
$R_c \times 2$,м(*N*=6 шт.)	480	658	660	700	770
$R_c \times 2$,м(*N*=15 шт.)	398	440	526	550	614
$R_c \times 2$,м(*N*=20 шт.)	360	400	480	560	570

Data analysis of Table 4.2.2.11 indicates that for a 16,000 kg mass explosion with 6 degrees of deceleration, the minimum size of the dangerous distance will be 770 m, and with 20 degrees of deceleration - 570 m. Although the latter significantly reduces the size of the danger zone, but to mount the short-wave explosion scheme With 20 groups, when the total mass of BP is small, it is practically impossible. Such requirements can be fulfilled by a non-electric system of initiation such as "Nonel", which in recent years has been widely implemented in Ukrainian quarries. However, the influence of the method of initiating the prediction of the seismic effect of short-term blasting has not yet been reviewed by scientists in this area.

Therefore, it should be noted that the received dimensions of seismic distances are approximate.

From the analysis of existing literature data and normative documents, it is determined that the type of waves which is most closely related to the spectrum of the eigenvalues of the protected object is based on the frequency spectrum at the maximum values of the amplitude of the oscillations. It is erroneous to assess the seismic security of a security object only for one of the wave-surface types. Taking into account that during explosions of stress and relative deformations of objects directly proportional to the velocity of oscillations, the seismic hazard will create those types of waves in which these parameters will be maximal.

Control questions

1. What parameter describes the intensity of the seismic wave?

2. What is the permissible level of seismic impact?

3. List the main types of seismic waves

4. Explain the concept of oscillation stability

5. Name a particularly dangerous situation for buildings

6. Explain why the indicators of seismic security are overestimated.

7. Demonstrate how the seismic stability of the rock mass is determined.

8. What parameters characterize the technical condition of the building?

9. How does the number of slowdown groups affect the seismic effect?

10. For which houses need to double the calculated radius of a safe area?

Theme 2 FEATURES OF THE SEISMIC ACTION OF EXPLOSION IN ROCK MASSIVE

Lecture 5 Effect of cilinder charge expression in anisotropic rocks

Theoretical investigations of the character of the distribution of the wave field from the explosion of charge BP are based on the model of the medium close to the real anisotropic array. The output model is a homogeneous infinite environment with a system of parallel cracks. The physical and mechanical properties of the filler are different from the properties of the medium itself. Detonation of the charge along its length is taken instantaneously, and the seismic wave is considered at a considerable distance from the place of the explosion.

Since all types of waves that are excited by the explosions of industrial BP are characterized by low amplitude, and the task is to establish only a qualitative picture of the distribution of seismic waves around the explosion, then the solution uses the theory of the sound wave [21].

Using the equations describing the propagation of seismic waves in a cracked rock, we obtain the character of the distribution of isoeism around the explosion(Fig.5.1).

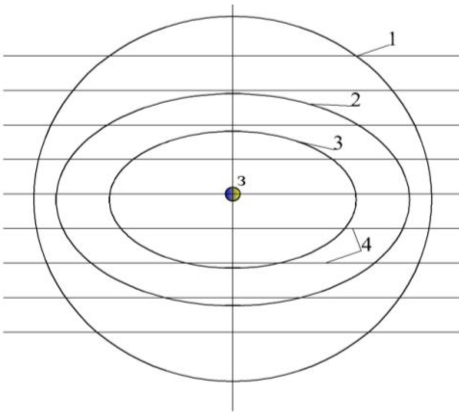


Fig.5.1. Results of calculation of isoeism in a cracked array around an explosion: 1-3 - isoeism; "O" - place of explosion; 4 - system of parallel cracks

Investigation of the destructive and seismic effects of the explosion of single cylindrical charges of BP was carried out within the array of granites of the 1st (subclass A) and limestone of the 2nd class, respectively, of the quarries classification. Theoretical and experimental investigations of the explosion were concentrated on granite and limestone massifs, where anisotropy was manifested as a system of naturally oriented cracks.

The laws characterizing the mechanical motion of anisotropic rock around the explosion were investigated in two areas: in the zone of irreversible deformations (parameters of the funnel of destruction) and in the following elastic region (parameters of seismic waves). With the first zone we associate the concept of a seismic emitter (a destroyed zone that is a source of seismic energy). In this case, seismic waves from the explosion arise as a result of the release of energy in the irreversible deformation of the rock.

The main source of information about the necessary destructive parameters, wave motion and their change from the distance around the explosion are the shape and size of the visible crater of destruction, as well as seismograms that record the fluctuations in various azimuthal points of seismic receivers installation. The processing of seismograms gives an opportunity to obtain a number of characteristic kinematic force, amplitude-frequency indices of oscillation of various types of anisotropic rocks for the establishment of forms of isoeism.

The first zone is interesting for the intensity and uniformity of destruction and the parameters of the isoeism on its outer boundary, which determine the uneven formation of oscillations in remote parts of the array. With this information, it is possible to establish the relationship of destructive and seismic action with the strength and elastic characteristics of rock massifs.

The diagram of installation of seismic sensors around the charge is shown in Fig. 5.2.

The radius of the destruction zone was determined at the location of the sensors, further in the plan the shape of the zone of destruction was built. The next stage is the registration of oscillations in different directions, which allows determining the maximum mass velocity in each type of seismic wave (longitudinal Pp, transverse Ps and surface R) depending on the directional angle.

The difference in the time of receiving the input signals at the points N1-N7 in waves, excited by the explosion of a single charge, determined the velocity of the spread of seismic waves in different azimuthal directions.

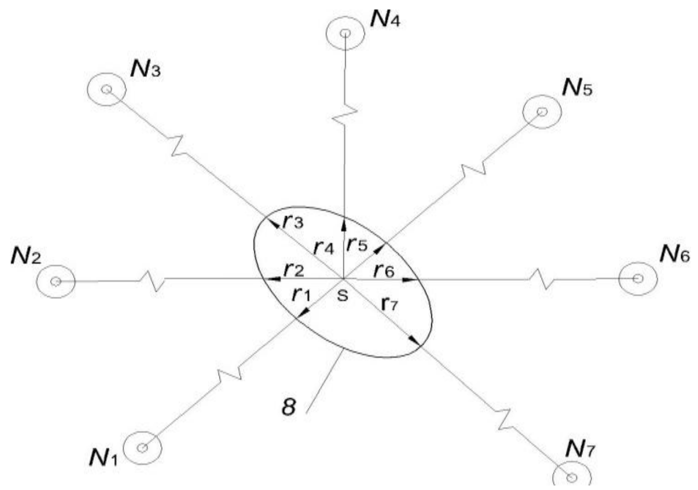


Fig.5.2 Scheme of installation of seismic detectors for determination of zones of destruction and isoeism: S - charge; N1 .... N7 - location of sensors; 8 - theoretical contour of the destruction zone; r1 ... r7 - value of the radii of the destruction zone;

According to the results of the measurements, the radii of the zone of destruction and isolation of the velocities of oscillations, frequencies and oscillation energies were constructed (Fig. 5.3-5.6).

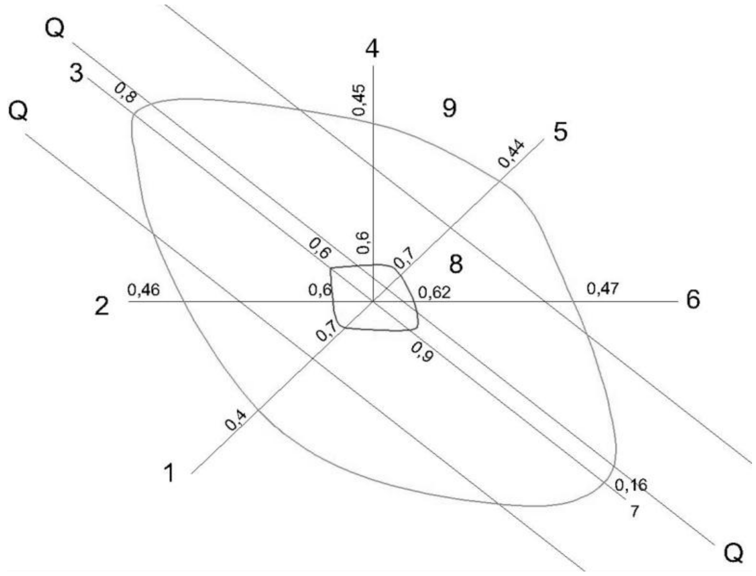


Fig.5.3 Interconnection of the crater of destruction (8) and the zone of isoeism (9). Q - Q - direction of the main system of cracks

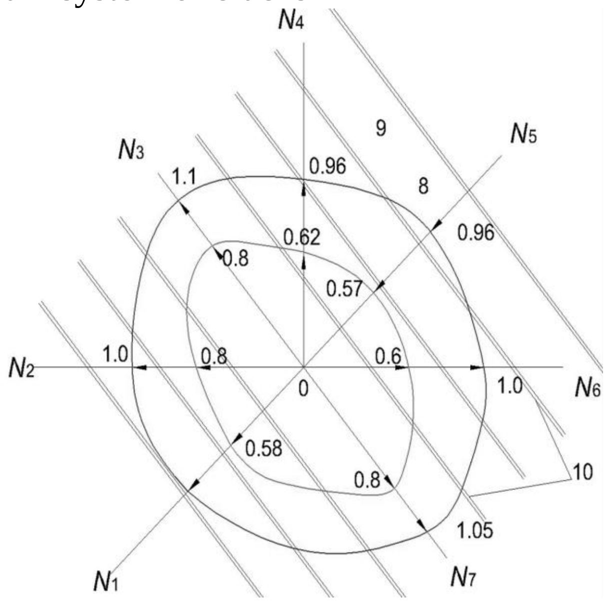


Fig.5.4 Parameters of the zone of destructionfrom an explosion of an extended charge of BP weighing 0.63 kg:
8- in granite of the first class of subclass A, 9 - in limestone of the II class; 10 - system of cracks; 0,57 ... 1,1 - numerical values of the radius of the destruction zone in meter

For each explosion of the borehole charge, the anisotropy coefficient of the rock strength ka equal to the ratio of the maximum length of the fracture funnel radius (rmax) to the minimum (rmin) was determined.
The processing of the results of the hardware measurements allowed to obtain data for each type of waves at the massive oscillation velocities in different profile

directions. According to these data, the deviation of the form of the isoeism from the circle was determined. It is characterized by a seismic anisotropy coefficient ksa equal to the ratio of the maximum values of massive oscillation velocities to the minimum obtained at identical distances from the cell of the explosion.

Analyzing Fig. 5.4, we see that the parameters of the destruction zone in the explosion of charge BP depend on the type of rock, acoustic rigidity and width of the cracks. In limestone, the size of the destruction zone is 1.3 times larger than in granite. The absorbing action of the crack in relation to the explosive wave leads to the fact that in the direction of greater frequency of cracks the radius of the destruction zone is smaller. Therefore, the geometry of the destruction zone has minimum dimensions along the main axis of anisotropy of fracture.

Analysis of the calculated values of the coefficient of anisotropy of rock solid properties shows that the value of ka, with increasing fracture, is increasing. For granites the value of ka is 1,2-1,4, for limestones - 1,05-1,16.

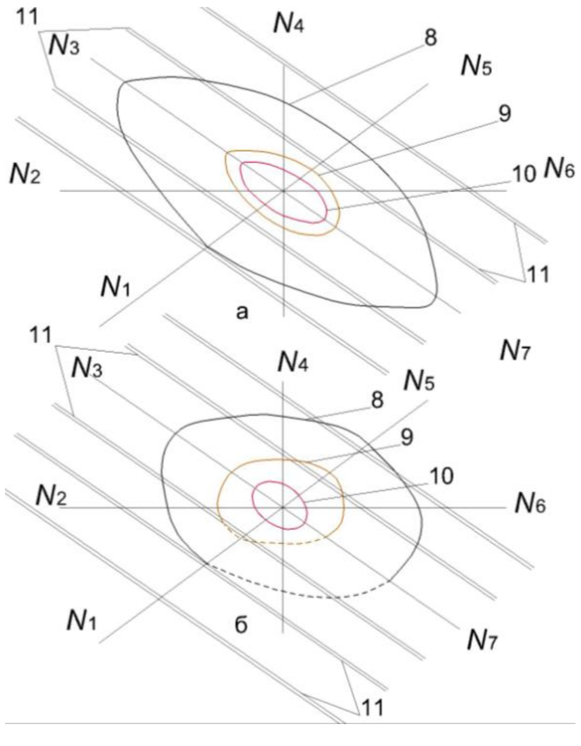


Fig. 5.5 Isotope zones 8, 9, 10 are obtained around the explosion of an extended charge VR, respectively, the indicated mass of charge is 0.089; 0.041 and 0.027 kg / m

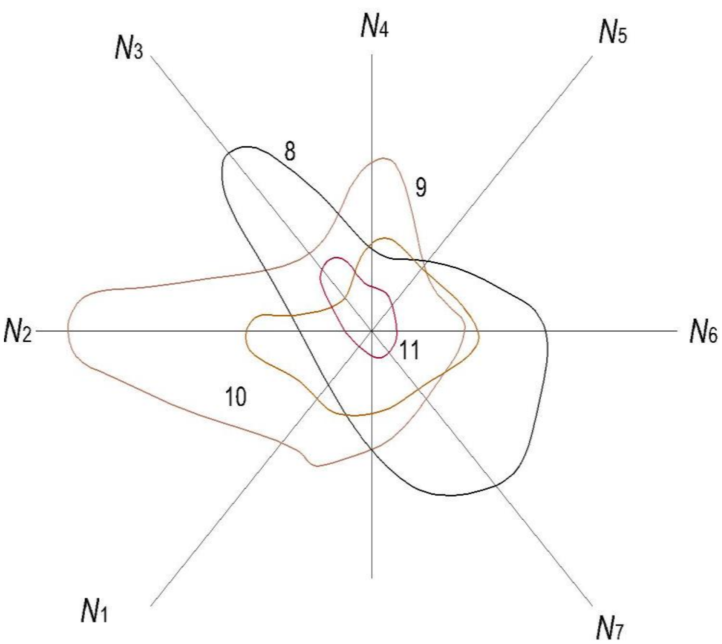


Fig. 5.6 Interconnection of isolated energy zones at different frequency ranges with a funicular funnel:

8-10 - energy isolation in the surface, longitudinal and transverse waves;

11 - Destruction funnel zone

The difference in the shape of the zone of destruction from the circle, obtained from the explosions of single charges of the BP, indicates the anisotropy of the rock mass with respect to its elastic properties. Therefore, we can assume that in such an array massive velocity of oscillations will be directional values, and each direction of anisotropic medium will need to be characterized by the indicative velocity - a spatial figure that outlines the shape of the isoeism.

Control questions

1. Give a description of the theoretical model of the array
2. Explain what you mean by "isoseism"
3. Explain what is meant by the anisotropy of the real array
4. Give an explanation of the term "seismic emitter"
5. What parameters characterize the shape and size of the funnel of the explosion?
6. Give the definition of the anisotropy coefficient
7. Explain the concept of seismic anisotropy
8. Name the approximate values of seismic anisotropy coefficient for granite and limestone

Lecture 6

Relationship of the seismic effect with the spectral composition of elastic oscillations

Subsequently, the analysis of the oscillation process was carried out in terms of its amplitude-frequency spectrum, which allows to determine the band of frequencies that bear the main energy of seismic oscillations.

In the spectral analysis of seismic waves from the explosion of a single cylindrical charge for the three types of waves, in each of the directions of the installation of the sensors, the amplitude-frequency spectrum and the mean mass velocity of oscillations were determined (Fig. 6.1).

Analysis of the amplitude-frequency characteristics in Fig. 3.11 shows that when the directional angle changes with respect to the direction of propagation of cracks in the range of 0-90^{O} harmonics in the direction along the cracks, the main peaks of the maximum amplitudes are shifted to the region of high values (longitudinal waves) perpendicular to the cracks (φ = 90^{O}) low harmonics (surface waves), and in the direction located at an angle (φ = 45^{O}) to the cracks, the maximum amplitudes in the spectrum occupy an intermediate value (transverse waves).

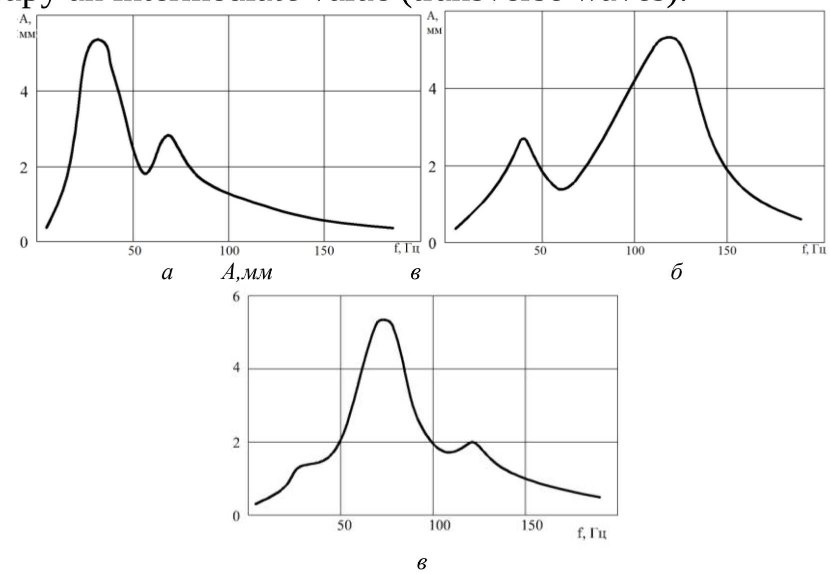


Fig. 6.1. Amplitude-frequency spectra of an explosion of an extended charge VR: a, b, c - perpendicularly, along and at an angle of 45 ° to cracks, respectively

Such a distribution of the frequency spectrum in the characteristic directions around the explosion suggests that each type of seismic waves in different ways reacts to the environment, where the anisotropy of the rock mass is manifested in the form of a system of parallel cracks. As a result, there is anisotropy of seismic detection around the explosion. According to theoretical and experimental studies, isoeism around the explosion has a form close to the elliptic asymmetry. This is due to the fact that in anisotropic array in different directions, the conductivity of each type of seismic waves is not the same and depends on the number of cracks in the way of propagation of oscillations, and on the width of the cracking.

In the direction of greater frequency of the cracks, their absorbing action in relation to the longitudinal and transverse waves with high frequency component oscillations leads to the fact that at the same distance around the explosion surface waves propagating in this direction, which carry low harmonics, and seismic oscillations are characterized by the lowest degree of attenuation.

It should be noted that although along the cracks there is the highest degree of damping of longitudinal and transverse seismic waves, in this direction the values of mass velocity are maximal and vary in the range of 0.7-1.15 cm / sec. The latter situation is explained by the best conductivity of seismic oscillations in the direction along the cracks with the advantage in the high-frequency component of the spectrum of oscillations.

The leading properties of anisotropic rock massif in different directions differ not only by the decay of the massive velocity of oscillations but also by the velocity and length of the seismic wave.

Using the interconnection of the velocity of propagation of waves with the frequency of oscillations f, we determine the wavelength (m) along the cracks ($\varphi = 0^{O}$) at an angle ($\varphi = 45^{O}$) and perediducular to the cracks ($\varphi = 90^{O}$) in the frequency bands that carry the maximum load.

Calculations for different quarries have shown that within the same type of rocks forming an array the values of the velocity of seismic waves propagation and the frequency of oscillations vary depending on the diffraction angle. In granites of the UkrSh, the values of the velocities of the spread of seismic waves along directions along the cracks and perpendicular to them vary 2-3.8 times, and for limestones of the Carpathian Trench - in 1.1-1.3 times.

The increase in the velocity of the spread of seismic waves in the direction along the cracks and a significant decrease of its perpendicular to the cracks once again convincingly confirms the difference in the conducting properties of the medium.

The screening effect of a crack in relation to the seismic wave leads to the fact that the wave propagation velocity is significantly reduced. This is the reason that the values of the velocity of oscillations in the indicated direction take the minimum values, and therefore the axis of the ellipse of the isoeism is the same as the main direction of anisotropy of fracture.

Since the parameters of the elastic wave vary with an increase in the distance from the explosion due to the non-uniform absorbing properties of the medium in different directions of the anisotropic array, the shape of the contour of the isoeism is due to the coefficient of seismic anisotropy (k_{sa}> 1), which depends on the magnitude of the wave length ratio λ to the width of the single cracks d in the system of a cracked array (Fig. 6.1).

As can be seen from Fig. 6.2, the functional dependence k_{sa} = f (λ/d) has a curvilinear form and decreases with increasing ratio of k_{sa} value.

k_{sa}

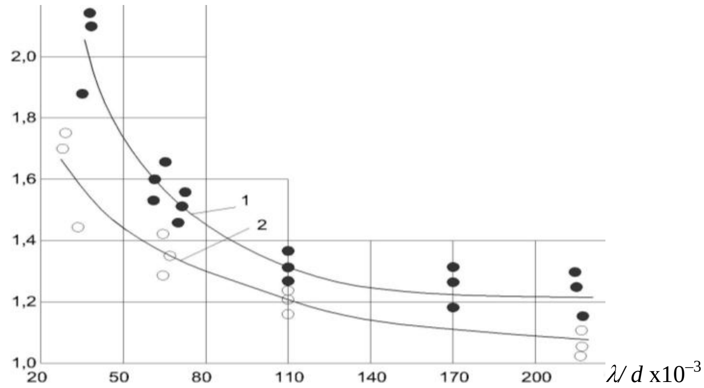


Fig. 6.2 Dependence of the coefficient of anisotropy on the ratio *λ/d*; *λ* - wavelength; *d* - average value of crack width in the system of cracks, 1, 2 - direction of measurement, respectively, in normal and at an angle of 45^O to the direction of propagation of cracks

The average ksa varies for this case in the range 1.8-1.1. However, in the direction perpendicular to the cracks (φ = 90^O), in comparison with the direction at an angle φ = 45^O, the value of k_{sa} is more than 1.3 times (at*λ/d* = 250-1100). In the range of *λ/d*=1100-2200, the value of k_{sa} decreases. For larger values, it approaches the unit, therefore, the elliptic form of the isoeism is converted to a circle.

Thus, the analysis of experimental data suggests that one of the main causes of the change in the shape of the isoeism is the uneven frequency oscillation in different directions, as well as a different rate of propagation of seismic waves. These results are well-compatible with theoretical studies, according to which the dimensionless parameter at d = λ is critical, in which the transition of the isoeism from elliptic to circular occurs only with a decrease in frequency.

The study of energy loads formed from the explosion of a wave packet was carried out using the equipment and techniques given in Section 2.

The curve, which combines the energy levels of oscillations in each of the directions of the sensor installation, allows us to describe the shape of the distribution of isomers of seismic waves in terms of anisotropic rock massif.

As we see from Fig. 5.6 (Lecture 5), the isolation of the energy of oscillations in all three types of waves is in the form of an oval. Comparing it with the form of isolines of equal mass velocity of oscillations allows to establish their coincidence in the surface wave in the range of low frequencies. Therefore, surface waves for security buildings and structures with low natural frequencies are the most dangerous, and the orientation of these forms with respect to fracture is a reliable basis for predicting seismic zones.

Therefore, surface waves for security buildings and structures with low natural frequencies are the most dangerous, and the orientation of these forms with respect to fracture is a reliable basis for predicting seismic zones.

Thus, established on the basis of the above studies in semi-industrial conditions, the relationship of seismic anisotropy with the anisotropy of the rock massif allows us to deepen knowledge in the study of the physico-technical foundations of the nature of the distribution of isoeism and subsequently use them in industrial conditions

Control questions

1. *Explain how you understand the concept of spectral analysis of seismic oscillations*
2. *How does the frequency spectrum of waves depend on the direction of measurement?*
3. *What is the relative conductivity of each type of seismic waves?*
4. *What is the absorbing environment?*
5. *In what direction is the highest conductivity relative to the system of the main cracks?*
6. *How are the wavelengths different depending on the direction of observation?*
7. *On what parameters depends seismic anisotropy coefficient?In what conditions the elliptic isoeism is circular?*
8. *Name the main cause of the danger of a surface wave*

Lecture 7

Transformation of the amplitude-frequency spectrum of mass explosions in conditions of geological and tectonic structures

When studying the interaction of an object with different types of seismic waves it is necessary to know the security criteria for objects with different constructive and functional features.

In a career, a source of seismic radiation in mass explosions is located in a rock mass, over which in most cases the sediment layer occurs. A seismic wave in the transition from a rock massif to this layer, reflected and refracted within its limits, can run several times in it. In this case, the following reflected and refracted waves are superimposed on the previous ones. This can lead to resonant phenomena. This interference effect depends on the combination of the thickness of the layer of sediment (h) and the wavelength (λ). Obviously, this motion can not be described analytically.

In the transition from the rock mass to the deposits even in the absence of the effect of interference, the parameters of the seismic wave change due to the refraction on the boundary. After its release on the earth's surface, the surface Rayleigh wave seismic wave (R) begins with other attenuation laws and parameters of motion than in volumetric waves (P and S). The interaction of this wave with the foundations of buildings (objects with a period of their own oscillations to 5-7s) causes them in the tension and deformation that determine the degree of seismic security of mass explosions.

In spite of the fact that in real conditions of conducting explosive work in the environment emitted a large number of waves of different types, usually researchers are limited to the consideration of three major. These are bulk waves (P and S) in the array and surface (R) propagating along the free surface.

Proceeding from this, in order to reduce the seismic effect with unchanged total mass of charge, it is necessary to apply such a technology of landing, in which the maximum value of the amplitudes of the seismic process will be formed in transverse or in longitudinal waves. This can be achieved by changing the slowing intervals, the mass of charges and their number in groups.

On an example of an oscillogram (Fig. 7.1), we consider the distribution of the vibrational process on the phase by wave types. The superficial phase reflects the segment with the largest period of oscillation (Vr). The transverse phase has the so-called "core" (Vs), and the longitudinal phase corresponds to a segment with a high frequency (Vp). The safest phase for objects with a low frequency spectrum of proper oscillations will be those whose maximum amplitude will fall on areas with a maximum frequency.

On the contrary, in the case of obtaining maximum values of amplitudes of oscillations for a period with a maximum period, due to the fluctuations in the seismic wave, the process of its own fluctuation of buildings will cause the greatest danger.

Bulk waves are characterized by relatively high frequencies (10-40 Hz), the surface wave is characterized by weak attenuation with distance, large amplitudes and low (2-8 Hz) frequencies.

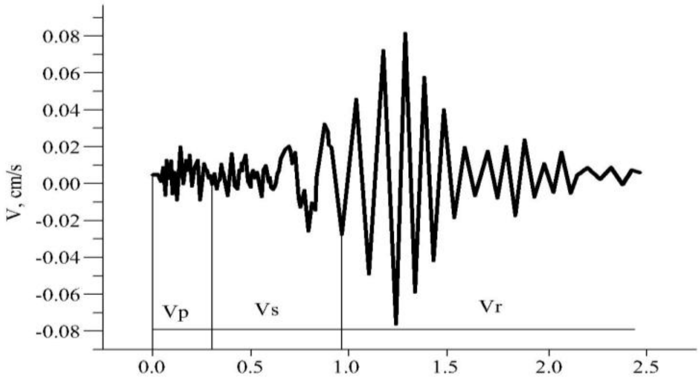


Fig. 7.1 Characteristic oscillograms with the distribution of the oscillatory process on segments that correspond to different types of waves

Surface types of waves are the greatest danger to buildings of mass development around active quarries. They are in the frequency spectrum and at the maximum value of the amplitudes of oscillations most closely related to the parameters of their own oscillations of these objects. Therefore, the object of research is taken by the surface waves of Relay.

When short-wave explosions of BP charges in various geological and tectonic models of anisotropic rock mass seismic oscillations are distorted and form a rather complicated wave picture. Differences in the periods of bulk and superficial waves occur both at the expense of heterogeneity of rocks, and because of the spillage of waves from adjacent charges, which are broken shortly slowly. To compare such very important characteristics of the explosion as the spectral composition, the energy of different frequencies, the form of the spectrum and other possible only by operating the spectral density of seismic flows.

The graphic representation of seismic oscillations in the form of spectra allows to analyze the seismic manifestations of a short-wave explosion, when the velocity of oscillations is described by a more complex form compared with the extinct sinusoid. It is supposed that the finite or infinite number of components of oscillations propagates in an anisotropic medium independently of each other.

In fig. 7.2, 7.3 depicts the spectra of oscillations obtained for identical schemes of short-term landing of charges, but in different rocks. For arrays of rocks, where anisotropy manifests itself in the form of naturally oriented cracking, only one maximum is observed in the oscillation spectrum. In arrays of blocks with block structure, two maxima are observed: in the range of low and high frequencies.

This peculiarity in the formation of spectral characteristics is explained by the fact that:

a) the presence of rocks in the system of parallel cracks for surface waves is not a source of additional reflection of oscillations. Therefore, the wave freely extends over the medium, only with the distance loses the magnitude of its amplitude;

b) in the massifs of the block structure (geological-tectonic structure of the 1st class of subclass B) in the spectrum of oscillations two maximum values of density are observed. From Fig. 7.3 it is evident that the maximum amplitudes of ground oscillations include both bulky high-frequency (40-100 Hz) and surface surface low-frequency (10-15 Hz) waves. The displacement rate of soil particles for bulk and surface waves is almost the same. Consequently, the amplitude-frequency characteristics of the wave process are unfavorable for objects with both low and high harmonics of proper oscillations.

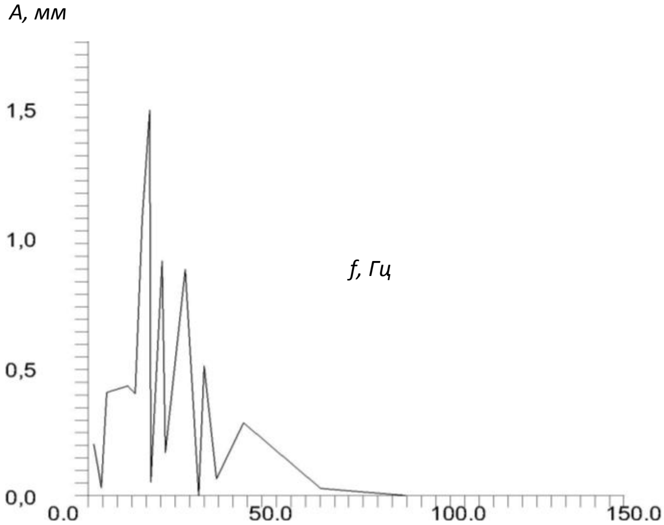


Fig. 7.2 Spectrum of oscillations in rock masses with a system of parallel cracks. Career in the I class - subclass A (mass of charge 7200 kg, distance 150 m)

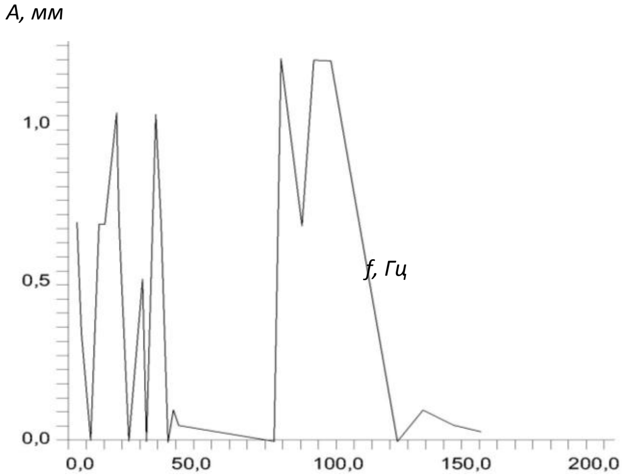


Fig.7.3 Spectrum of oscillations in an array with a system of parallel cracks and interblock violations. Career of the I-th class - subclass B (mass of charge 7200 kg, distance of 250 m)

Consequently, the influence of technological factors on the seismic security of objects located in various geological and tectonic structures of Ukraine's territory can be predicted by studying the spectral density relative to each type of seismic waves. Such a factor may be the slowness interval in the charge plan. If the interval of deceleration is carried out by regular means, for example, with the help of pyrotechnic means of the KSDP-69 relay at intervals of 10; 20; 35; 50; 75; 100 ms, it is possible to obtain resultant oscillations at different distances and in different azimuthal directions from the epicenter of the explosion, in the spectrum of which will be observed both the minimum and maximum values in different frequency ranges.

In fig. 7.4 shows spectrograms of short-wave explosion of charges with a delay of 20; 35; 50 ms in array rocks with cracking and block structure.

From the above spectra it can be seen that as the velocity interval increases, the spectrum changes. With an increase in the slower interval, the maximum value of the spectral density decreases. The reduction of seismic hazard is due to the absence of fluctuations after each subsequent burst charge in the CSR scheme and the creation of a monotonic decrease in the spectral density at the frequency of the main maximum.

For a block structure, when an explosion occurs on one block, and protected objects are located on another block divided by tectonic disturbances, the reduction of seismic hazard is provided by a slowing interval, which reduces both the spectral density of the main maximum and the energy-intensity of the frequencies of the resonant range.

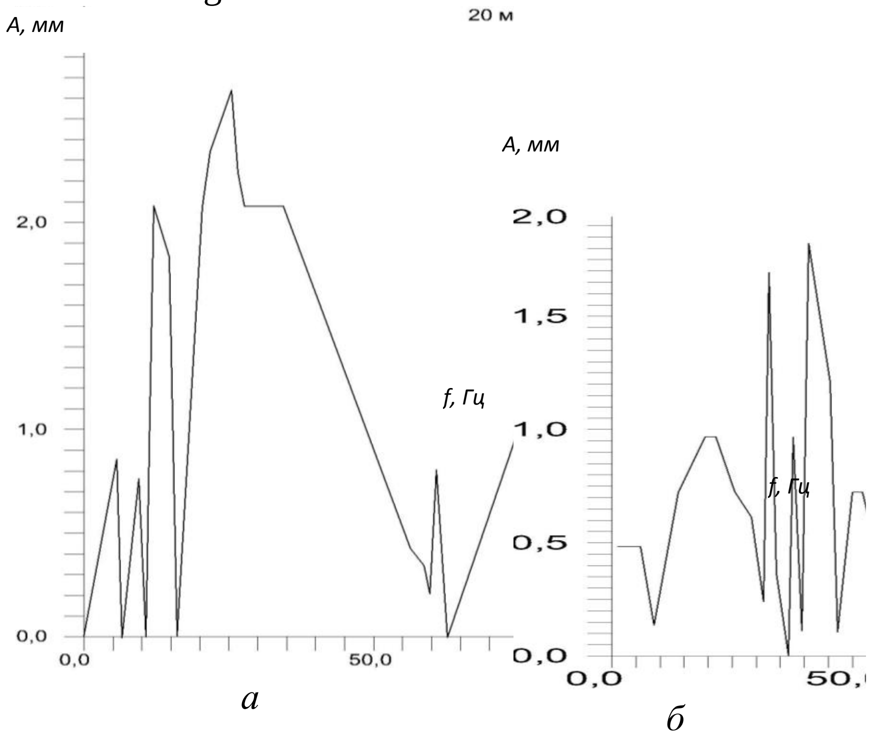


Fig. 7.4 Characteristic spectrograms of short-wave explosion of BP charges with slowing intervals: a - 20 ms; b - 35 ms respectively

In this regard, in order to ensure seismic safety, it is always advisable to increase the slowness to the magnitude equal to the duration of fluctuations from one wellbore charge.

However, the value of the slower interval is limited by the factor of the mechanical summing up of neighboring charges, and also by the fact that, at larger slip intervals, a significant part of the energy of seismic radiation from neighboring charges has time to dissipate.

Control questions

1. Describe the real picture of the passage of waves in a layered environment

2. What are the phenomena of interference of waves?

3. Give the frequency characteristics of different types of seismic waves.

4. Explain the peculiarities of wave propagation with short-term undermining.

5. Explain whether the components of the oscillation depend on each other

6. How does the deceleration period affect the spectral composition of the oscillation process?

7. Explain the features of the spectrum of oscillations in block structures

8. Why can not arbitrarily increase the slowing interval?

Lecture 8
Seismic stability of the career side by acceleration criterion

To calculate the stability of slopes and career sides by acceleration criterion we will use the method of the circular cylindrical surface of the slide. Taking into account that this method is developed for homogeneous rocks, we first make calculations within the ledges with homogeneous rocks. In the future we will take into account all types of rocks that make up the board of a career.

When calculating the stability of a career breaker or a force vector, the slip prism is divided by vertical lines into a number of elements. Usually, these elements are taken in such a way that, without loss of accuracy, it is possible to take surface of the plane within the limits of the plane, and the contour of the slope, the action of external forces, etc., are practically homogeneous (Fig. 8.1).

Consider the equilibrium conditions of the th element. All external active forces (soil mass in the compartment, external load, etc.) acting on the i-th element are brought to the equatorialPi.

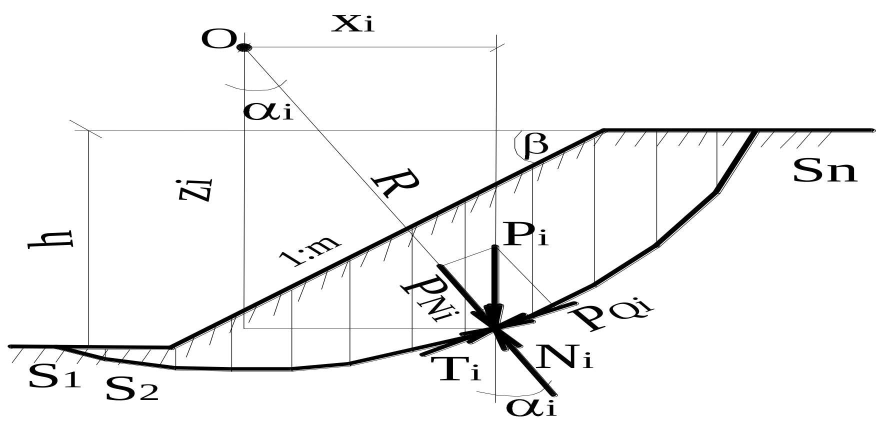


Fig. 8.1. Scheme of equivalent forces on the i-th bay of the slope of the career board

The latter is expanded at the point of its application into the components: the normal PNi and the tangent PQi to the plane of the element moving:

$$P_{Ni} = P_i \cos\alpha_i,$$
$$P_{Qi} = P_i \sin\alpha_i. \tag{8.1}$$

Assume that the center O and the radius of curvature R of the sliding surface are known to us. In this method, the forces of interaction between adjacent elements are not taken into account, based on the fact that the sum of these forces must be zero, and the total moment from them relative to the point O is small. The tangential force from all loads is a driving force that can cause landslides in the reach of a career.

The resistance of the movement of a loose body that lies beyond the surface of the slip (reaction) can be represented as the sum of friction and clutch forces:

$$T_i = N_i \tan\varphi_i + c_i s_i, \tag{8.2}$$

where Ni - normal reaction of the support;
s_i is the length of the arc of the surface of the slide;
φ_i - the angle of internal friction within the arc si;
c_i - specific gravity within the arc s_i.

From the equation of projection of all forces on the normal to the site of the element we obtain:

$$N_i = P_{N_i} = P_i \cos\alpha_i \tag{8.3}$$

The second equation of projection remains unsatisfactory, as the forces of interaction between the elements are not considered. The condition of the equilibrium of slopes is reduced to the equation of moments of all forces acting on a sliding prism relative to the center of the surface of the slide [7, 19].

But this approach does not take into account changes in the characteristics of the rocks in terms of strength (forces of clutch), which occur in dynamic (impulse) load mode.

Acceptance of seismic action in the calculation of anti-slip retaining structures is realized by adding to the design efforts of the so-called inertial seismic force S_{CI} [8].

The seismic force of Sci is approximately defined as the proportion of the earth's mass, which is subject to seismic influences, and has the form:

$$S_{c\,i} = \frac{a_c}{g} P_i \ , \tag{8.4}$$

where a_C - seismic acceleration;

g - acceleration of free fall.

Bearing in mind that the coefficient of dynamic seismicity $\mu = a_c/g$, we obtain:

$$S_{c\,i} = \pm\mu P_i \, . \tag{8.5}$$

The direction of the strength of S_{CI} is most unfavorable. In this regard, we assume that the seismic forces in each element of the shifting block are directed along the base of the element. The condition of the equilibrium of slopes is reduced to the equation of moments of all forces acting on a sliding prism relative to the center of the slip surface.

$$\sum P_i x_i + R\sum S_{ci} - \frac{R}{k}\sum T_i = 0, \tag{8.6}$$

where R is the radius that describes the surface of the prism of collapse.

In this case, the resistance forces of movement are reduced in K times, taking into account the need to provide a certain margin of stability slope against destruction:

$$K_c = \frac{R\sum T_i}{\sum P_i x_i + R\sum S_{ci}} \, .$$

Then the coefficient of Kc:

$$K_c = \frac{R\sum P_i \cos\alpha_i \tan\varphi_i + R\sum c_i s_i}{\sum P_i x_i + R\sum S_{ci}}. \qquad (8.7)$$

Given tha $\cos\alpha_i = x_i/R$, and the fact that seismic waves from massive explosions affect the system of slopes, composed of different breeds, we finally get the value of the coefficient of stability reserve:

$$K_c = \frac{\sum_1^j P_i \cos\alpha_i \tan\varphi_i + \sum_1^j c_i s_i}{\sum_1^j P_i \cos\alpha_i + \sum_1^j S_{ci}}. \qquad (8.8)$$

The value of the coefficient of dynamic seismicity μ for the calculation of natural slopes is recommended to take for tabl. 8.1. When calculating artificial slopes (embankment roads, dams, etc.), the value of the coefficient from Table. 8.1 should be increased by approximately 1.5 times.

Table 8.1

Coefficient of dynamic seismicity

Seismicity of the area	6	7	8	9	10	11	12
μ	0,00	0,025	0,05	0,1	0,25	0,50	>0,75

To calculate the coefficient of dynamic seismicity μ for the steps and sides of a career it will be more correct to express it using the equation of the method of the circular cylindrical surface of the slide. To do this, we will decompose inertial seismic force on rice. 8.2 on the vertical and horizontal components respectively.

$$S_{C.B.\ i} = \pm S_{c\ i} \sin\xi;$$

$$S_{C.\Gamma.\ i} = \pm S_{c\ i} \cos\xi,$$

where ξ is the angle of the output of the seismic momentum to the horizon.

The influence of vertical and horizontal components of seismic acceleration on the degree of stability is different. Composite Sc.в.i at certain moments of oscillation is able to unload a mass of prisms of collapse. The component of Sc.r.i can increase the shear forces. Typically, Sc.b.i and S.c.r.i are taken as acting in the direction of reducing the degree of stability of the ledge and the board of a career.

We define the shoulder forces of the Sc.b.i and S.c.r.i relative to the center of rotation of the prisms of collapse, respectively, n and m. Using the method of a circular cylindrical surface of a slip, you can write:

$$\mu = \frac{\sum_1^j (P_i \cos\alpha_i tg\varphi + c_i l_i) R}{\sum_1^j (P_i \sin\alpha_i) R + S_{C.\Gamma.} m + S_{C.B.} n}. \qquad (8.9)$$

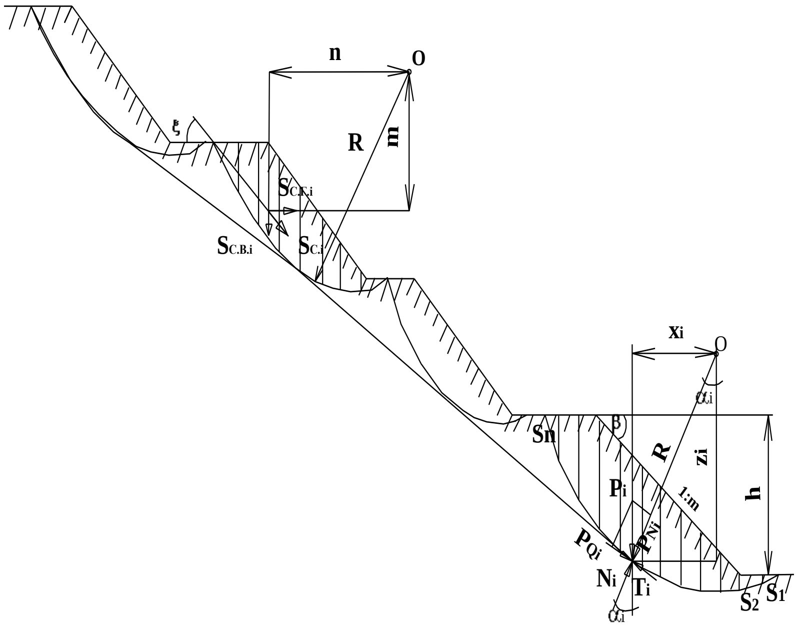


Fig. 8.2 Scheme of seismic force on individual ledges and a board of a career as a whole

The influence of inertia forces on the change in the stability of the ledge (board) [9] can be represented as an increase in its steepness at an angle

$$\delta_c = arctg\mu \; . \qquad (8.10)$$

From formula (8.10) it follows that when accelerating, the earth's surface undergoes a slope at the angle δc, and the degree of stability of the slope decreases [10]. Acceleration can be found due to the intensity of seismic oscillations (Table 8.2).

The unit of acceleration, as shown by the research [7,8,11-13], is an effective criterion for the stability of slopes when conducting explosive work in a career.

Table 8.3 presents the allowable value of the acceleration unit for mining objects composed of non-uniform mountain rocks

Table 8.2

Seismic acceleration

ΔB, points	6	7	8	9
a, мм/с^2	300–600	610–1200	1200–2400	2410–4800

Table 8.3

Values of acceleration units for slopes

Rocks	Acceptable value of acceleration unit, *g*
Soils	0,15
Rocks: - Strongly cracked with clay and high porosity	0,50
– strongly cracked	0,90
– moderately cracked	1,30
– weakly cracked	1,90
– very strong and monolithic, practically free of cracks	2,25

The above analytical calculations can be used to assess the stability of the career side by acceleration criterion after obtaining experimental data from oscillograms in real conditions of interaction of CVC with ledges.

Control questions

1. Explain the principle of constructing a scheme for calculating the slope stability using a circular cylindrical surface

2. Formulate the condition of equilibrium of the elemental volume of slope.

3. What forces relies on displacement?

4. Explain the essence of seismic force?

5. What force is added during impulse loading?

6. What is the coefficient of dynamic seismicity?

7. On what forces the inertial component decomposes?

8. How does the seismic affect the slope stability?

Lecture 9

Seismicity of the career side by criterion of massive oscillation velocity

To calculate the seismic stability of a multi-layered board career in a massive explosion, it is necessary to determine the correct way of spreading the seismic wave and the degree of its absorption by rocks.

There are similar works in the literature related to earthquakes. The starting point for investigating the spread of a seismic explosive wave (SEW) is most convenient to take the external boundary of the seismic cell of the explosion (SCE). On it, the mass velocity in a wave is a constant value for a certain type of soil irrespective of the mass of charge.

The boundary of the SCE on seismograms can be determined by the characteristic signs of oscillation. On the graphs, this limit is determined at the point where the degree of attenuation of amplitudes and periods of oscillations in the wave process varies depending on the distance, where the dependence of the intensity of the oscillations in a wave changes from the depth of the charge.

Research in the field of engineering seismology shows that the SCE is identified with the zone of irreversible deformations of the soil, and the outer boundary separates the zone of inelastic and elastic vibrations of the soil.

The distance to this limit from the charge of BP is called the radius of seismic emission. Thus, the boundary between the SCE and the elastic zone of soil oscillations is the zone of origin of the wave of elastic oscillations, and its distance to the charge of BP is the radius of seismic radiation R. The results of the investigations, including [7,14], have found that the SCE is proportional to the mass of the charged charge:

$$R_0 = K_0 Q^{1/3} = 5{,}5 \cdot 3945^{1/3} = 85\text{, м} \qquad (9.1)$$

where K_O is the coefficient of proportionality, which, based on the analysis of published data, varies depending on the type of rocks. For mass soils K_O = 2.5 m / kg$^{1/3}$, for rocks of coal deposits K_O = 4 m / kg$^{1/3}$, for most rock solid rockes K_O = 5.0-5.5 m/kg$^{1/3}$, for clay K_O = 7.5-8.0 m / kg$^{1/3}$, for loams K_O = 8.0-9.0 m / kg$^{1/3}$; Q is the mass of the bursting charge immediately, in kg. According to Japanese scientists $R_0 = 5{,}8Q^{0{,}38}$.

The given task was performed by measuring the intensity of the fluctuations of the soil (mass velocity) in a multilayer medium in conditions of mass explosions in the iron ore quarry of OJSC Poltavsky GOK. At each mass explosion several ore blocks were blown up with an interval of about 1 ÷ 5 seconds. Blocks were dispersed over the territory of the quarry, which allowed, at one blast, to register several acoustic waves from each block. The block was drunk through a grid of wells with a diameter of 250 mm and a length of 11-20 m in increments of about 6 m. At the same time, a group of 4 ÷ 8 holes was undermined. The following group was undermined by a delay of 50-300 ms. Number of groups in the block from 20 to 100. The mass of the explosive (anemix) in the group - 4 tons. Such a technology of explosive destruction can reduce the seismic impact of mass explosions.

The analysis of the propagation of the transverse wave S, as the most intense, from the point O (boundary SCE) to point B4 (free surface) was carried out according to the scheme in Fig. 9.1.

The algorithm for calculating seismic parameters of a mass explosion on the example of the propagation of the transverse wave S from point O to point B4 will be shown below. Mass of explosive 3945 kg.

The displacement rate of soil particles at the point O:

$$U_0 = \sqrt{\frac{V_p}{\gamma}\left(1-\frac{4}{3}\frac{V_S^2}{V_p^2}\right)^2 K_0^{-2}} = 12{,}5 \ \text{см}/\text{с}\,, \qquad (9.2)$$

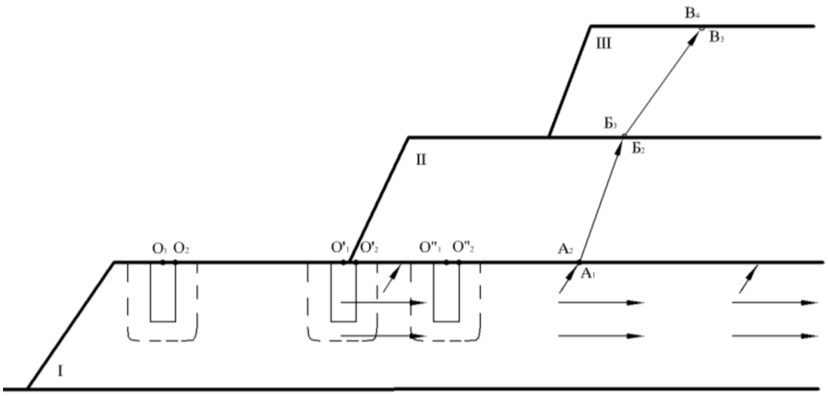


Fig. 9.1. The scheme for solving the direct problem of propagation of a seismic wave from the place of explosion to the free surface: I is the bedding rock layer (acoustic hardness N1 = 2.01x107kg / m^2.s), II - layer of rocky rocks (N2 = 1.51 · 107kg / m^2 · c), III - layer of soft rocks (N3 = 1,8 · 106kg / m^2 · s), O1, O'1, O "1 - place of laying charges BP; O_2, O'_2, O''_2 - boundaries of the zone SCE

If the wave breaks in the II layer of refraction, the refractive index will be equal

and the rate of variation of the soil at the point A2:

If the wave breaks in the II layer of the refraction, the refractive index will be equal

and the rate of variation of the soil at the point A2:

,

At point B2:

cm / s, absorption of wave energy in layer II

α2 (f) = 4.34 10-3 - r2 - thickness of layer II (r2 = 150 m).

When the wave breaks into layer III, the refractive index K2 is 1.79, and the rate of oscillation of the soil at the point B3 is 0.329 cm / sec.

In the soft layer III, the CVC will be distributed accordingly

cm / s

where α3 (f) = 0.465 - absorption of wave energy in the soft layer; r3 - thickness of layer III (r3 = 50 m).

As is known, when the wave reflects from the free surface of the amplitude, it doubles, therefore at the point B4, on the free surface of the layer of soft rocks, the velocity of soil oscillations will be 0.42 cm / c.

Thus, the intensity of oscillation on the free surface of a multilayered rock massif is determined [14].Аналогічним чином можливо розв’язати і обернену задачу. При розв’язанні оберненої задачі можливе визначення практичних питань. For example, you can determine the stability of a career tip. Let us demonstrate the solution to this question in the following example. It is necessary to determine the seismic mass of charge during a massive explosion in the quarry to provide a seismic stability of the yield of the quarry, composed of soft mosses (layer III in Fig. 9.1).

To solve this problem we use the same calculation data as for a direct problem.

According to the normative data, a quarry ledge, made up of overheads and a lifetime of more than 5-10 years, belongs to the second class of structures, and the permissible speed of its displacement is 8.2 cm / sec.

We accept at the point B3 the rate of movement of soil U3 = 8.2 cm / s, and at the point B2 in the layer II rock rocks the speed of movement of soil particles will be:

$$U_2' = U_3' \frac{2N_3}{N_3 + N_2} = 1{,}75 \text{ см/с.} \qquad (9.4)$$

At the point A2 of the layer II, the soil movement speed (cm / s) will be equal to:

$$U_2'' = U_2' \exp[\alpha_2(f) r_2] \qquad (9.5)$$

At the point A1 of the bedding layer of rocky rocks, the speed of soil movement is:

$$U_1' = U_2'' \frac{2N_2}{N_2 + N_1} = 2{,}92 \text{ см/с.} \qquad (9.6)$$

Knowing the values of the velocity of oscillation at the point A1 and at the boundary of the SOW (the charge weight of the BP Q1 remains unchanged), we determine the distance r1 'between the point A1 and the new boundary of the SOW (point O2'), deciding the dependence:

$$U_0 = U_1' \exp[\alpha_1(f) r_1'], \text{ звідки } r_1' = 365, \text{ м.} \qquad (9.7)$$

Thus, with the preservation of the unchanging mass of charges in the group, one can find the minimum seismic-safe epicentral distance on a given horizon (between the points A1 and O1 '), in which the stability of the yield of soft rocks is maintained at 365 + 85 = 450 m.

For the calculation of other seismic distances (m) or masses of charges (kg), while conducting BP can use the method of dynamic similarity (for these conditions, the coefficient K = 450) and calculate the interesting parameter, according to one of the formulas:

$$Q_{доп} = \left(\frac{U_{доп}}{K}\right)^{\frac{3}{n}} r^3 \text{ або } \quad r_c = \left(\frac{K}{U_{доп}}\right)^{\frac{2}{3}} Q^{\frac{1}{3}}, \qquad (9.8)$$

where Udop is the rate of movement of soil particles at the point A1;
n - degree of attenuation (n = 1,5).
It is important to take into account the important circumstance associated with the change in the technology of BP in mass explosions due to the use of nonel non initiating agents in our time. These means provide the possibility of simultaneous landing of the charge mass of only one well, or its parts from the inside with a well-slower deceleration.

Control questions
1. From what boundary begins exploding seismic emission?
2. By what features is the boundary of the zone of seismic oscillation determined?
3. What is the radius of seismic oscillation zone identified?
4. By what parameter is the radius of COV determined?
5. Describe the algorithm of an elastic wave transition through a layered array.
6. Describe the inverse problem algorithm.
7. Point out the benefits of short-term blasting.
8. What are the benefits of the Nonel system when implementing anti-seizemic measures?

Lecture 10

Estimation of the type of elastic waves per permissible deformation of the sides of the quarries

The solution of various mining tasks is related to studies of deformation of rocks in the array, as well as to the determination and use of their deformation characteristics.

The permissible speed of displacement of soil particles UDOP, in which the ledge will remain stable, is related to the allowable value of the relative deformation D with the relations:

$$D = \frac{U_{доп}}{V_S}; \; U_{доп} = DV_S, \qquad (10.1)$$

where VS is the velocity of the transverse bulk wave.

Consider the rate of movement of soil particles for the point A2, which is located at the bottom of the sloping ledge (Figure 10.1), composed of sand and clay.

де V_S–швидкість поперечної об'ємної хвилі.

$$U'_{A2} = 0{,}0005 \cdot 660 = 0{,}33, \text{ м/с}. \qquad (10.2)$$

Minimum distances from the last row of wells to the foot of the ledge, folded loam, in which its steady state is maintained, are given in Table. 10.1.

The velocity of the transverse wave propagation is found in Table 10.2.

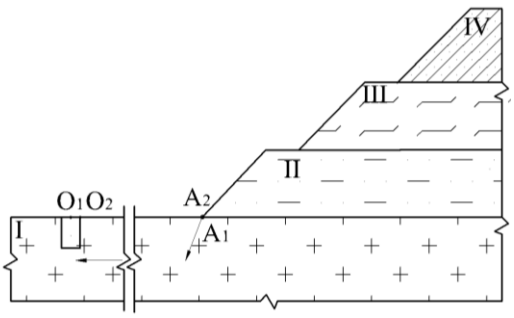


Fig. 10.1. Scheme for calculating the inverse problem in the rocks of OJSC "Poltavsky GOK"

Table10.1

Minimum distance from the last row of wells to the foot of the slope, provided that its stability is maintained.

Klass	II	III	IV
Slip service life	5–10 years	до 5 years	temporary
Permissible relative deformation	0,0002	0,0003	0,0005
Minimum distance at Vs, m	406	310	193
Minimum distance at Vp, m	283	193	72
Minimum distance at pseudo-Raleigh V_R wave, m	426	331	214

The displacement rate of soil particles for point A_1 is:

$$U'_{A1} = U'_{A2}\frac{2N_2}{N_2 + N_1} = 0{,}33 \cdot 0{,}237 = 7{,}8 \text{ см/с.} \qquad (10.3)$$

Table 10.2

Wave charakteristicks

Mountain rock	Longitudinal. waves speed, Vp, m / s	Transverse wave speed, Vs, m / s	Impedance, *N*, кг/м^2· с
Rock	4310	2590	$1{,}51 \cdot 10^7$
Send, clay	1100	660	$2{,}03 \cdot 10^6$
Alevrolites, clay, sandstones, marls	1800	1080	$4{,}32 \cdot 10^6$
Sands of fine-grained clay, loam	1000	600	$1{,}8 \cdot 10^6$

The rate of soil displacement at the point O_1:

$$U_0 = \sqrt{\frac{V_p}{\gamma}\left(1 - \frac{4}{3}\frac{V_S^2}{V_p^2}\right)^2 K_O^{-2}} = \sqrt{\frac{4310}{3500}\left(1 - \frac{4}{3}\frac{2590^2}{4310^2}\right)^2 K_O^{-2}} = 14{,}5 \qquad (10.4)$$

см/с.

Using formula (), we find seismic distance from the boundary of the SOW to the foot of the ledge, at which this ledge will maintain its stability:

$$r' = \frac{\lg U_0 - \lg U'_{A1}}{\lg e} \cdot \alpha_1 (f)^{-1} = 143 \text{ м.} \qquad (10.5)$$

Radius COW at a total mass of EM 1000 kg:

$$R_0 = K_0 Q^{1/3} = 5{,}0 \cdot 1000^{1/3} = 50 \text{ м.} \qquad (10.6)$$

We find the minimum seismic-safe epicentral distance on a given horizon (between the points A1 and O2), in which the stability of the dangling of the overlying rocks is maintained: 143 + 50 = 193m.

The value of the minimum seismic distance for the openings II, depending on the service life of the ledge, is given in Table. 10.1.

In the conditions of multi-blasting the influence of seismic waves irrespective of the horizon, their location is subject to all the objects in the quarry.

The research methodology was to determine the patterns of attenuation of seismic waves in the directions from the top down and from the bottom up to the side of the quarry.

In experiments an abnormal nature of the change in the displacement velocity during the propagation of seismic waves is observed, respectively, up and down the paths of a career. At a certain distance from the height of the quarry there are minimum displacement rates, after which they begin to rise. This can be explained by the passage of the wave through the rock with different acoustic rigidity.

Minimum displacement velocities are observed at a distance of 80 ÷ 100 m from the explosion irrespective of the horizon of the location of the blast block. Such a change in the rate of displacement with depth indicates the unevenness of its distribution on the board of a career. At a certain distance, it tends to increase.

In the formula for calculating the intensity of oscillations it is necessary to introduce a coefficient that will take into account the change in the displacement rate due to the lowering of the horizon of the location of the blown unit [7]:

$$K_H = e^{-\varsigma(H \pm H_1)}, \qquad (10.7)$$

where ς - empirical coefficient;

H ± H1 - difference of the markings of the horizons of placing of the explosion and object, m.

This equation is valid for H ± H1 ≤ 100m and is shown graphically in Fig. 10.2

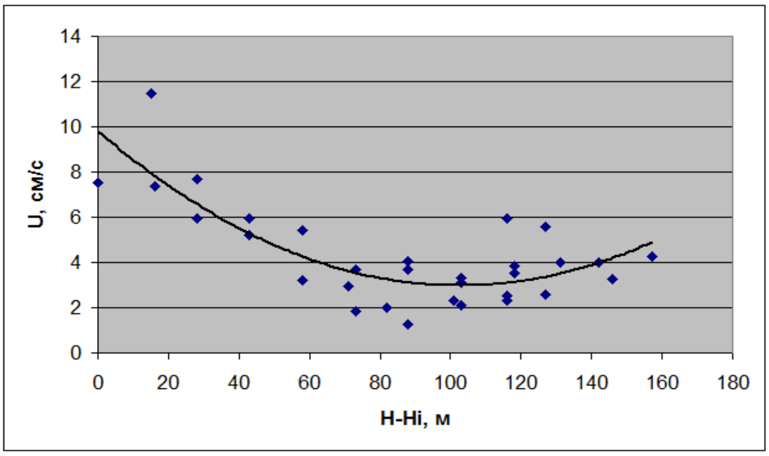


Fig. 10.2 Change of the rate of displacement of soil particles due to lowering the horizons of conducting BP

The power parameters of the transverse wave from the action of prolonged multiblock explosions can be determined by the formulas:

$$\sigma_{сж} = U_{A_2} V_R \rho, \ \tau_{сд} = C + \sigma_{сж} \tan\varphi, \ \tau_{раст} = \sigma_{сж} \frac{\mu}{1-\mu}. \qquad (10.8)$$

The dependence of the seismic-safe distance from the deformation in the slopes and the allowable rate of oscillation of the soil particles, under which the ground entrances will remain stable during multi-blast mass explosions, are given respectively in Fig. 3 for different types of bulk waves. 10.3, 10.4.

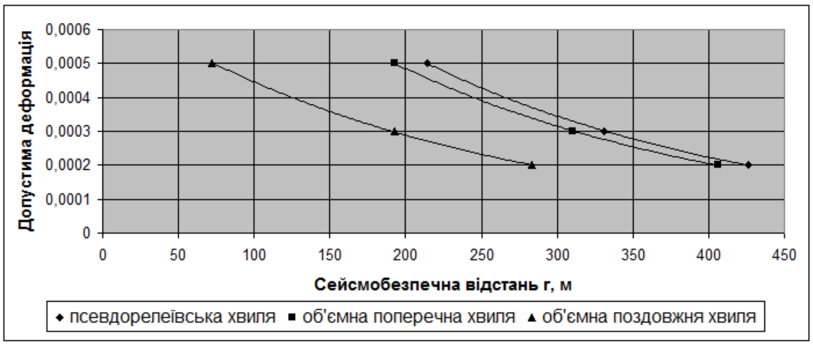


Рис. 10.3. Залежність сейсмобезпечної відстані від допустимої деформації в укосах для різних типів хвиль

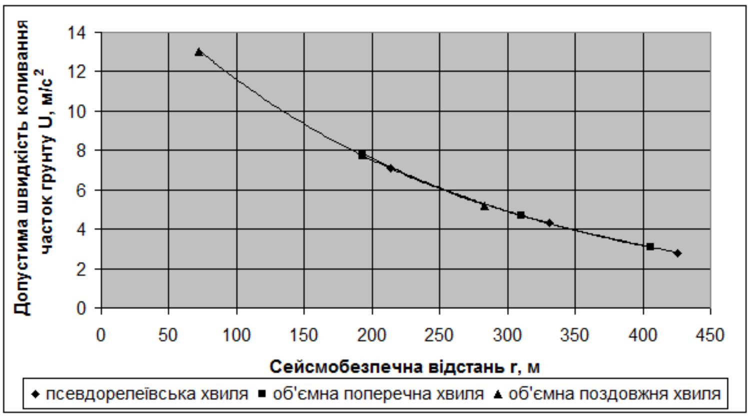


Fig. 10.4 Dependence of the seismic distance from the permissible velocity of the soil oscillations in slopes for different types of waves

From the charts shown in Fig. 10.2, 10.3 it is evident that the largest seismic distance is for the pseudo-Raleigh wave, that is, at long distances it will be dominant. But at the foot of the soil ledges, in the place of its origin, the pseudo-Rayleigh wave is still weaker than the transverse volumetric. Therefore, transverse waves are affected by the stability of soil ledges in many block blasting, which is confirmed by analytical dat

Control questions

1. What parameters determine the relative deformation of the medium in the seismic wave?

2. How does acoustic hardness depend on the type of rock?

3. Evaluate the tendency of changing the minimum distance between the wells of the last row and the lower reaches of the openings

4. What is an epicentral distance?

5. What is the abnormality of shifting the displacement rate on board the career?

6. Explain the cause of the abnormality of the change in the speed of displacement

7. How does the wave type affect the permissible deformation in the slopes?

Theme 3 SEISMICITY OF BUILDING OBJECTS

Lecture 11. Seismic safety of undamaged buildings

According to the existing regulations, the seismic impact assessment on the construction is carried out regardless of the amplitude-frequency characteristics of the "soil-building" system. In this regard, the primary importance of studying the parameters of seismic waves become not only in the criterion of mass velocity, but also taking into account the amplitude-frequency components of seismic oscillations.

Surface waves of Raleigh are subject to research, because they are the most dangerous for buildings of mass development of the territory of Ukraine in comparison with other (elongated and transverse).

The layer of soil on which the building is erected is shifted by the action of seismic waves, rocking the entire building and its separate parts. Together with the forced fluctuations of the effect of seismic forces in the building there are their own fluctuations, which depend on the shape and geometry of the structure, as well as on the physical properties of the building material. The imposition of these movements causes dynamic building efforts in the building, which can threaten its integrity. Depending on the position relative to the epicenter of the explosion (the distant distance), the propagation of different types of waves can be divided into three characteristic zones: the melee, the transitional and the distant.

Seismic security is important for two zones: transitional and distant. It is they are considered to justify the choice of the criterion of the impact of seismic waves on the building [15-17].

The transition zone of the explosion (relative distances from 6 to 16 m / kg1 / 3) is characterized by the presence of longitudinal, transverse and superficial waves and is presented as damped oscillations of type

$$a(t) = A_0 e^{-kt} \sin \omega t, \qquad (11.1)$$

where a - landslide; ω is the circular frequency.

The differential equation of building fluctuations will be

$$\ddot{x} + f_0^2 x = A_0[\omega^2 - k^2)\sin \omega t + 2k\omega \cos \omega t]e^{-kt}. \qquad (11.2)$$

Enter the designation:

$$\frac{k}{\omega} = \varepsilon, \ \frac{f_0}{\omega} = \eta;$$

$$A = \frac{(f_0 - \varepsilon^2)(\eta^2 - 1 + \varepsilon^2) + 4\varepsilon^2}{(\eta^2 - 1 + \varepsilon^2) + 4\varepsilon^2} A_0; \ \rho = \frac{2\varepsilon(\eta^2 - 2 - 2\varepsilon^2)}{(1 - \varepsilon^2)(\eta^2 - 1 + \varepsilon^2) + 4\varepsilon^2}.$$

The solution of equation (11.2) satisfying the initial conditions for,, will have the form:

$$x = -A[\frac{\rho\omega - k}{f_0} \sin f_0 t + \cos f_0 t - (\rho \sin \omega t + \cos \omega t)e^{-kt}]. \qquad (11.3)$$

Since usually the frequency of oscillations of the CVH is greater than the frequency of its own fluctuations in the building, it is small compared to the unit. If the decay factor of the perturbation is small compared with the frequency ω, i.e. $\varepsilon = 0$, in this case $A = A_0$, $\rho = 0$, and, consequently:

$$x = -A_0[\sqrt{16k^2 + 1}\sin(f_0 t + \varphi_0) - e^{-kt}\cos\omega t)], \qquad (11.4)$$

where $tg\ \varphi_0 = 4 f_0$.

If the value of the coefficient of attenuation of waves is proportional to the frequency of oscillations of the structure, then under the influence on the structure will occur predominantly own oscillations with amplitude:

$$A = \frac{4k}{f_0} A_0 . \qquad (11.5)$$

The magnitude of the force acting on the building, attributed to one unit of its mass, is:

$$\frac{F}{M} = \frac{4\psi}{g} A_0 f_0 = \frac{k}{g} U . \qquad (11.6)$$

Expression (11.6) shows that the fluctuations of the building and in the transition zone are directly proportional to the velocity of the particles of the soil.

In the zone of elastic deformations of soils, that is, at a great distance from the explosion where surface waves of the Rayleigh dominate (the zone begins with the indicated distances of 30 m / kg1 / 3), oscillations of the soils of the stable type

$$a(t) = A\sin\omega t . \qquad (11.7)$$

The differential equation of the system fluctuations taking into account the attenuation in it will be:

$$\ddot{x} + 2\lambda\dot{x} + f_0^2 x = A\omega^2 \sin\omega t$$

where λ – logarithmic decay of the attenuation of fluctuations in the house.
The general integral of it for a case where the attenuation is insignificant:

$$x = \frac{A\omega^2}{\sqrt{(f_0^2 - \omega^2)^2 + 4\lambda^2\ \omega^2}}[\frac{\omega}{f_{0_1}} e^{-\lambda t} \sin\ f_{0_1} t - \sin\omega t] . \qquad (11.8)$$

There $f_{0_1} = \sqrt{f_0^2 - \omega^2}$ – frequency of oscillations with allowance for attenuation. It is assumed that $f_0 >> \omega$, that is, approximately the frequency f is close to the value - $f_{0_1} = f_0$.

When exposed to a seismic wave, whose frequency is much greater than the frequency of its own fluctuations in the building, the amplitude of the forced fluctuations of the building is small compared with the amplitude of its own oscillations and the solution (11.7) can be written in the form:

$$x = \frac{A\omega}{f_{0_1}} e^{-\lambda t} \sin\ f_{0_1} t , \qquad (11.9)$$

which indicates the direct proportionality of the displacement of the structure of the oscillation velocity in a seismic wave ($A\omega$ is the rate of fluctuation of the soil).
If the frequency of oscillations in the seismic wave is slightly different from the frequency of the own fluctuations of the building, i.e. $\omega/f_0 \approx 1$, then the solution (5.8) can be represented as:

$$x = \frac{A\omega}{2\lambda}(e^{-\lambda t} - 1)\sin f_0 t \, . \qquad (11.10)$$

In this case, the condition of resonance is fulfilled, the amplitude of oscillations with an increase in the time of action of the explosive waves increases and at a sufficiently large value reaches the largest value equal to $A\omega/2\lambda$.

It is seen that the amplitude of the fluctuations of the building under resonance conditions depends only on the velocity of oscillations in the wave and the coefficient of attenuation of the oscillations of the structure.

Considered cases of oscillations in a system with a single degree of will of SIH allow us to conclude that the deformations and dynamic forces acting on it are directly proportional to the velocity of the seismic wave and are inversely proportional to the frequencies of the system's own oscillations. The direct proportionality of the oscillation velocity of the soil particles near the building of the oscillation velocity in the seismic wave has been confirmed, since it represents the velocity of soil oscillation.

As a result of theoretical constructions, dependence was obtained for determining the permissible speed of soil oscillations near the foundation of a security structure and the nomogram of the calculation of the existing mass velocity in the permissible $U_{\partial on}$ in the soil basis of the security object, taking into account the relation T/T_0 shown in fig. 11.1

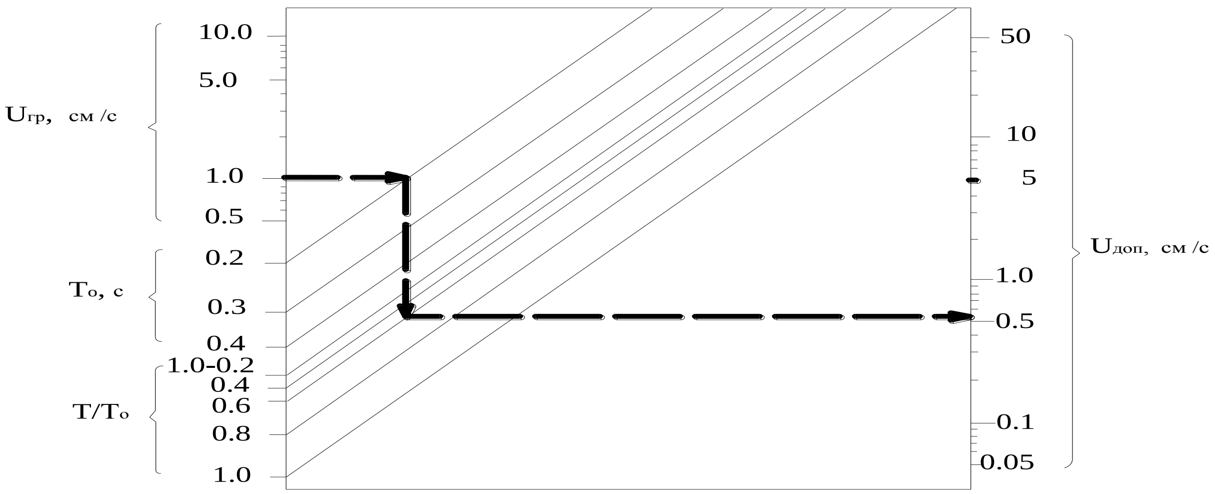


Fig. 11.1 The nomogram of the calculation of the permissible mass velocity in the soil basis of the security object by the spectral method of action

Control questions

1. What criteria are needed to determine the seismic safety of structures?

2. What type of elastic waves requires first-class study?

3. Name the parameters on which the level of internal fluctuations of the building depends

4. Name the characteristic zones of the propagation of elastic waves and their dimensions

5. What types of waves arise in the transition zone?

6. What types of waves are present in the remote zone?

7. Release the formula for recording damped oscillations in the transition zone

8. Restore the formula for recording the differential equation of the building fluctuations

9. Record the condition of resonance occurrence in the building

Lecture 12
The theoretical basis of seismic safety of exploited buildings

The analytical studies presented in the previous section are supplemented by industrial explosive events in the mining and extractive industries of Ukraine.

The study of the seismic effect of the explosion of BP charges on objects was carried out using the method of multichannel registration of oscillations given in L-2. For reliable results of measurements, various parameters of the seismic action of the explosion of the study were carried out using standard seismic receivers of type SM-3, designed for registration of vertical and horizontal oscillations, ADCs and PCs. By comparing the values of the measured oscillation velocities with the existing normative documents for this type of buildings, the permissible norms for the effect of seismic wave currents were determined, that is, the degree of seismic hazard of a mass explosion.

The use of measuring equipment allows us to calculate, with a sufficient degree of accuracy, the velocity of oscillation of the ground base on which the buildings are constructed, but it is difficult to establish their permissible value in this way. This is due to the fact that the seismic factor on the strength of its influence may be insignificant, but crucial in the general list of causes of the appearance of residual deformations (new cracks).

Systematic inspections of the condition of buildings and structures near the quarry were carried out in order to detect its change after mass explosions. Prior to measurements in each wall of the building, all the cracks were fixed and their parameters (total length and width) were determined. After each experimental explosion, changes in the parameters of existing cracks were controlled, and all new cracks were observed. In this way, the permissible speed of oscillation was established for the building, which allows you to calculate the maximum mass of the explosive for one slowing down.

As the results of experimental studies have shown, the rate of oscillation in the ground-based basis of buildings during explosions was about 1 cm / s, which according to SNiP-II-7-81 is an admissible value. But in the walls of many buildings there is an increase in cracks. Thus, in residential buildings of the village of Rokitne, located 500 m from the Rokitnyansky special circus, mass explosions with a permissible weight of 3000 kg on one slip cause slight damage. In some houses that are strongly weakened by cracks, located even at a distance of more than 750 m from the site of subversion, the damage is much larger. The survey of the technical condition of buildings and the study of engineering-geological characteristics of soils in their foundations determined that they have cracks both in epidemic and seismic origin. As a rule, such structures are found on constantly wet soils. The data collected during the observation period allowed to determine the number of newly formed cracks, depending on the parameters of the seismic explosive wave and the engineering-geological characteristics of the soils in the basements of buildings.

The practice of using existing criteria for assessing the effect of a seismic wave on the building also showed that its degree of danger is determined by a certain frequency range. For example, at the same rate of displacement of soil particles in the foundations of the building at the same distance there is a supposedly the same degree of danger at high (100 Hz) and low (10 Hz) frequency. However, these statements contradict the practice. In the first case, the danger for houses will be less (travel of a train or freight transport,), in the second - a bigger (the explosion of the charge of industrial BP).

The analysis of seismic action of massive bursts in quarries has shown that the existing criterion of the seismic wave hazard for buildings weakened by cracks is taken in such a way that it does not correlate completely with the level of damage to the object, depending on the resonance characteristics of the soil in its foundations and the object itself. Therefore, due to known methods for assessing the degree of seismic hazard, it is impossible to predict the permissible speeds of fluctuations of many types of buildings and structures. For a realistic assessment of the weakening of the walls of buildings, additional information is required on the degree of fracture damage, which is determined by the coefficient of weakening of the material strength of the capital walls of the building.

It follows that the assessment of the seismic stability of the building should be carried out at the permissible speed of oscillations of its soil base, since this indicator is most reliably correlated with the energy that violates the integrity of the building as a result of seismic action.

Thus, it is impossible to calculate the seismic safety of an explosion by the usual methods of statics of structures. The calculations should be carried out according to the dynamics methods - by the magnitude of the allowable velocity of the oscillations of the soil base particles of the building weakened by cracks. In addition, as shown by the study, the seismic effect of the explosion must be evaluated at the maximum amplitude of the velocity, selected from the oscillograms of the entire oscillation process, in the range of resonance frequencies close to this type of building weakened by cracks. In this case, the criterion for evaluating the buildings for the earthquake resistance of the explosion should be the allowable velocity of oscillations of its soil base, taking into account the coefficient of weakening of the material strength of the capital walls due to the presence of cracks. The calculated oscillation velocity allows to calculate seismic distances before the explosion.

In order to study the action of seismic waves from the short-wave explosion (CSR) of the BP's well borehole system in the building, including weakened by cracks, methods for assessing their technical state with the determination of the coefficients of fracture of bearing walls, the determination of the basic parameters of seismic waves, which according to the results of the research (Udop, cm / sec) are taken as a seismic safety criterion, as well as a method for calculating the permissible charge mass for simultaneous blasting.

Determination of the permissible rate of soil displacement (cm / s) at the foundations of buildings of different technical conditions takes into account the strength of the building material and the weakness of its cracks. At the same time, taking into account the frequency characteristics of the soil fluctuations, the internal fluctuations of the building, the allowable rate of displacement of the soil particles is determined by the formula:

$$U_{доп} = \frac{[\sigma] \cdot K_{осл} \cdot \psi \cdot K_{в}}{\rho \cdot V_p \cdot K_П}, \quad (12.1)$$

where $[\sigma]$ - the permissible stress for the building material or between the individual elements of the building, for which the permissible displacement rate is determined.

For brickwork on a cement M50 $[\sigma]$ is 7,0x10^5Па, for masonry from large sludge blocks - 23.10^5 Pa, for plaster - 0.9. 10^5 Pa;

$K_{осл}$ - coefficient of weakening of the cracking walls of the building;

ψ - coefficient of energy loss in the distribution of the structure of the oscillation process (for a brick building ψ = 0.6, for a building with large slag blocks ψ = 0.7);

ρ - the density of the soil in the basis of the building;

V_p - velocity of propagation of the longitudinal wave in the soil, cm / sec;

$K_в$ - coefficient of transmission of oscillations in a seismic wave from the ground to the building

$$K_в = (1{,}5 \cdot 10^{-2} r / Q^{1/3})^{1/5}, \quad (12.2)$$

where $r / Q^{1/3}$ – the distance from the explosion is given to the mass of charge, m / kg$^{1/3}$;

$K_П$ – coefficient of account of frequency characteristics $K_П = 2{,}4 f_0 / f + 0{,}9$;

f – frequency of oscillations of the soil;

f_0 – frequency of own fluctuations of the building.

The given distance in the formula (12.2) is selected on the seismic scale for explosions in accordance with the ballity, which does not cause disturbances and damage to those elements of the building for which the allowable velocity is determined by the formula (12.1).

The coefficient of weakening of the cracks of bearing structures is determined on the basis of the coefficient of cracking of the bearing walls [18]:

$$K_{осл} = (1 - A K_{Тр})^2, \quad (12.3)$$

where A – the coefficient taking into account the deformation form (for the deformation of the type of the crack A = 300);

$K_{Тр}$ – coefficient of the building fractures (determined on the basis of an inventory of a security building).

$$K_{Тр} = \frac{V_{Тр}}{V_0 + V_{Тр}}, \quad (12.4)$$

where $V_{Тр}$ – cracksvolume ($V_{Тр} = l \cdot d \cdot h$, де *l, d, h* – average length, width and depth of crack, respectively, m), m3

V_0 – об'єм носійноvolume of the carrier wall ї стіни, m^3.

The period of its own fluctuations in the building is determined by the formula:

$T_0 = 0{,}265(h/в)^{0{,}265}$, с, (12.5)

де h – building height, м; $в$ – buildingwidth, м.

The period of ground fluctuations, for different types of waves, is determined by the oscillogram, or by the following formulas:
during bursts of borehole charges in a longitudinal elastic wave

$$T_p = K_p Q_л^{1/6}(0{,}01l + 1), \text{ с}, \quad (12.6)$$

in the surface wave

$$T_R = K_R Q_л^{1/6}(0{,}015l + 1)(r/Q^{1/3})^{\nu}, \text{ с}, \quad (12.7)$$

де K_p, K_R, ν – experimental coefficients;

$Q_л$ – linear mass of borehole charge, kg / m;

l – length of the borehole charge, m;

r – distance from the place of the explosion to the observation point, m;

Q – mass of one well bore, kg.

Thus, it is important to assess the dynamic stability of the building, in contrast to the existing norms, when acting on it, the CVC has a relationship between the frequency characteristics of the building and the explosive wave, which was obtained on the basis of experimental studies.

control questions

1. Repeat the main components of the method of multichannel registration of oscillations

2. Explain how to determine the degree of seismic hazard

3. Characterize the complexity of linking the velocity of vibrations with residual deformations in the building

4. What types of cracks are present in buildings

5. Is there a correspondence between the level of danger and the rate of displacement of soil particles

6. Explain the concept of weakening factor

7. Determine the criterion of seismic stability of buildings in the presence of violations of strength

8. What is the method of assessing the technical condition of the building

9. Provide a formula for determining the permissible speed of fluctuations, taking into account the state of the building

10. Give a formula for the transfer coefficient in a seismic wave

11. What is the formula for recording the period of the house's own fluctuations?

12. Specify how to determine the period of fluctuations in the soil

Lecture 13 .Seismic stability of buildings weakened by cracks

The verification of the above analytical dependencies was made by means of hardware measurements directly in the buildings of the III-th class with their different technical state. In this case, the period T and the velocity of the soil fluctuations in the foundation of the building U cm / s, obtained from oscillograms, were used to determine the experimental coefficients Kp, KR in the formulas (9.6) - (9.7). The values of these parameters make 0,01 for granite, 0.012, 0.38 The periods of the own fluctuations of the building T0 were determined from the oscillograms or according to the formula (12.5) .The amplitude-frequency characteristics of the silicon-creep waves yielded the value of the period of maximum amplitudes.Analysis of these data showed that in the main periods of maximum amplitudes are in and a range of 0.025-0.2 s (at a frequency of 5 ... 40 Hz), the temporal fluctuations of the T0 buildings are 0.2-0.4 s (at a frequency of 2.5-5.0 Hz), and the decay of the attenuation varies from 0.3 to 0.5. These data correspond to most of the buildings of mass development of the territory of Ukraine.

Obtained from oscillograms the values of the rate of soil displacement in the foundation of the building and listed with the frequency characteristics of the fluctuations of objects according to analytical studies are shown in Fig. 13.1.

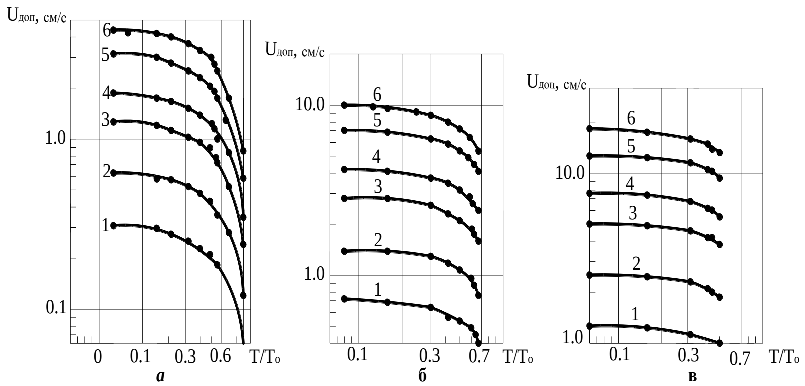


Fig. 13.1 Charts of determination of the normative allowable speed of fluctuations of the building of the III class, taking into account the ratio of T0 / T at □SB = 0,5: a - T0 = 0,2 s; b - T0 = 0.3 s; in - T0 = 0.4 s; 1-6 - corrected with T / T0 taking into account the value of Udop, respectively, 0.5; 1; 2; 3; 5; 7 cm / s, according to the standard documents for buildings of the III class

From the analysis of Fig. 13.1 it can be seen that these results (for example, in the resonant region of oscillations = 0,5 ... 1,0) differ significantly from the data of existing normative documents, which does not take into account the frequency factor. For example, for one and the same value = 1.0 cm / s, which is taken in accordance with the existing Scale (Fig. 13.1), depending on the magnitude and coefficient of damping 0.5, can vary 1.5 ... 5 times. This confirms the necessity of taking into account the amplitude-frequency characteristic of the "ground-base" oscillation system. For the operative determination of the permissible speed of fluctuations of the soil near the foundation of the buildings, depending on the frequency of the fluctuations of the soil near the foundation, a nomogram has been developed, shown in Fig. 11.1.

The analytical researches on the influence of silicon creep waves on the building have also been shown that, in addition to the magnitude of the relation (- the period of fluctuation of the ground, the period of the internal fluctuations of the building), the logarithmic decay of the attenuation is an important indicator in the joint oscillation process.

Using the values of the permissible speed of soil oscillations in the foundation of the building (cm / s), determined by the formula (12.1), seismic parameters of mass explosions in quarries are calculated. The maximum allowable mass value of borehole charges in a group (Qdp, kg) while simultaneously undermining them is determined by the formula:

$$Q_{доп} = \left(\frac{U_{доп}}{K}\right)^{\frac{3}{n}} r^3, \tag{13.1}$$

де K – a coefficient that takes into account the conditions of the explosion and the spread of seismic waves (CVW);

n – the rate of attenuation of the CVH at a distance;

r – distance of the explosion site to the protected object, m.

The presence of cracks in buildings was taken into account by the use of dependencies (12.1), (12.3). The permissible speed of soil fluctuations near the foundation of the building was determined taking into account the coefficient of weakening of the material strength of the capital walls of the building. For the seismic assessment of the impact of technological explosions on the building requires knowledge of the strength of the material from which it is built. In the method, experimental seismic and frequency tachograms were used to determine the parameters of seismic wave currents: amplitudes, oscillation periods, velocities. Their values are related to damage to building constructions, and also depend on the scale of the explosion and distances.

For buildings of different technical state, the permissible speed, except for its evaluation in different frequency bands, was determined taking into account the coefficient of fracture of the constructions of the structure (12.4). It was determined by examining concrete buildings and taking into account the attenuation ratio calculated by the formula (12.3). The influence of the velocity of soil oscillations in the basis of buildings on their stability in various frequency ranges of oscillation frequencies obtained from oscillograms and spectrograms of short-acting explosion of a system of charges of different masses was experimentally investigated. On the basis of analytical and industrial research to determine the main criteria for the impact of seismic explosive waves on the object, norms of assessing the seismic safety of buildings with different technical conditions (Fig. 13.2) have been developed.

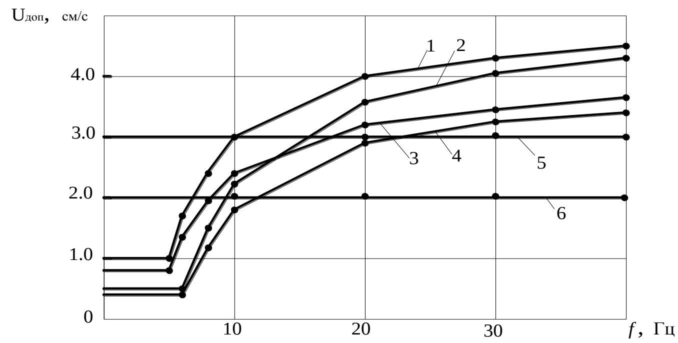


Fig. 13.2. Charts of determination of the norm of permissible speed of soil displacement in the basis of different types and technical condition of the building from the frequency of oscillations in the CVC:
1, 2 - from brick (f = 4 Hz) and samane (f = 5.5 Hz) respectively, which do not have residual deformations; 3, 4 - the same, weakened by cracks (Kolsk = 0,8); 5, 6 - the permissible level of intensity of oscillations for a brick
and stacked buildings in accordance with existing normative data, respectively

For the operative determination of the scale of industrial explosions with the permissible speed of soil fluctuations in the basis of a security building, taking into account the two estimation methods, a complex nomogram of rice has been developed. 13.3

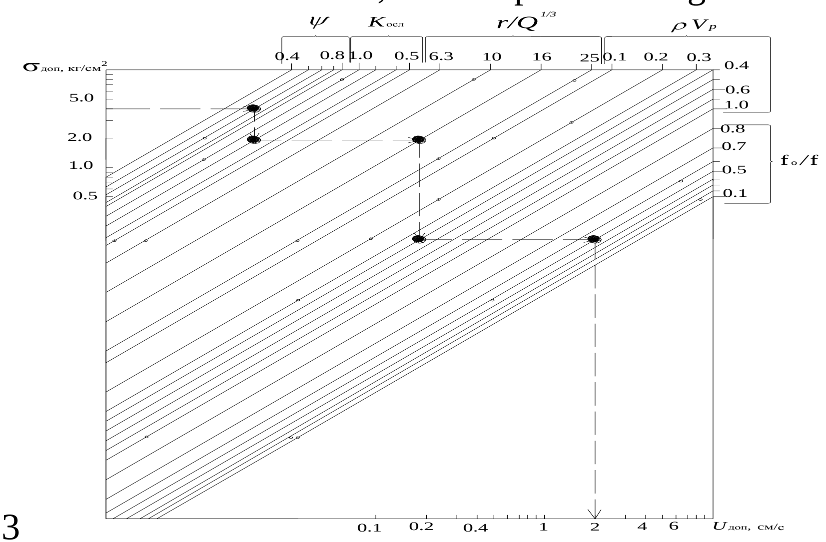


Fig. 13.3. Integrated nomogram for determining the magnitude of explosions and the allowable values of the velocity of the Udop, taking into account the frequency characteristics of the soil and building fluctuations and its weakening of the cracks

Experimental investigations of the influence of a seismic explosive wave on building of mass building (samanichni, brick, including cracked cracks) have allowed to obtain the following values of oscillation velocities in different frequency bands, which ensure the complete integrity of buildings of these types.

control questions

1. Name the numerical values of the amplitude-frequency characteristics of buildings of mass building in Ukraine

2. How much different and measured values of oscillation velocity can differ?

3. What is the characteristic ratio of oscillation periods in the resonance zone?

4. What parameter besides the relation of oscillation periods is decisive for the characteristic of oscillation process?

5. Submit and explain the formula for determining the mass of charges that are undermined at the same time

6. What are the constructive elements of the structure taken in the calculation of seismic resistance in the first place?

7. Compare the permissible fluctuation rates for brick and stacked buildings

8. On what factors a nomogram of permissible velocities of vibrations was constructed?

Lecture 14

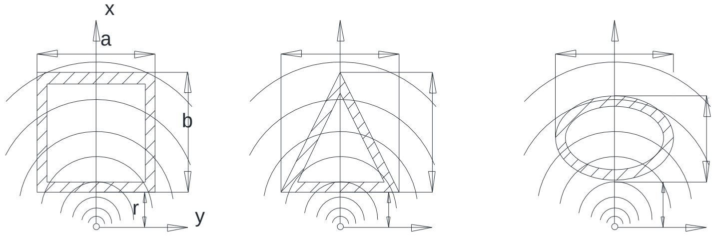
Forecast of seismic properties of objects with different configuration of foundations

In practice, subversion works often have problems in forecasting seismic resistance of security objects in the contour, depending on the configuration that has the foundation on which it is erected. The most erroneous is the definition of the maximum allowable charges in the near-range zone, the seismic resistance of security objects with different configuration of their foundations, when the methods of calculation are used are the same as for the long-range zone. In doing so, they get meaningless results from the point of view of practice. Of the known formulas, it follows that in case of need, at a distance of 10 m from the foundation of the building, only a charge of mass not more than 0,01 kg may be blown up. In fact, in the practice of drilling operations in this case, a charge of 30-50 times greater mass is applied.

The reason for this difference is that the mechanism of seismic action on the building in the near and far zones is different. The local nature of the explosion in the near zone is affected, as well as the dominant composition of volumetric waves, which makes it possible to ground on a soil basis with a high frequency and a small extent. As noted in the previous sections, if the rate of displacement is accepted as a seismic hazard criterion, then this should be the rate of displacement of the foundation throughout its configuration, since it is precisely the quantitative characteristic of energy that is transmitted through the soil basis to the entire building. This criterion does not depend on the configuration of the foundation and the type of construction of the structure, but depends only on the conditions of the explosion, the given distance and geological and geometric circumstances on the way of the spread of seismic waves.

In relation to the distant zone, where the rate of displacement of the soil and the foundation varies slightly (1.5 times) due to the pliability of the soil, as the criterion of seismic hazard, the rate of displacement at the base of the building is taken.

In the near zone, the displacement velocity on the foundation is much less than the displacement rate of the soil below it. This is due to the fact that, with close explosions, short waves of small length come to different parts of the foundation with significantly different amplitudes, since the latter fade in inverse proportion to the distance. For example, for the back wall, regardless of the configuration of the foundation, the amplitudes are much larger than for the near-point of the front wall



(Fig. 14.1).

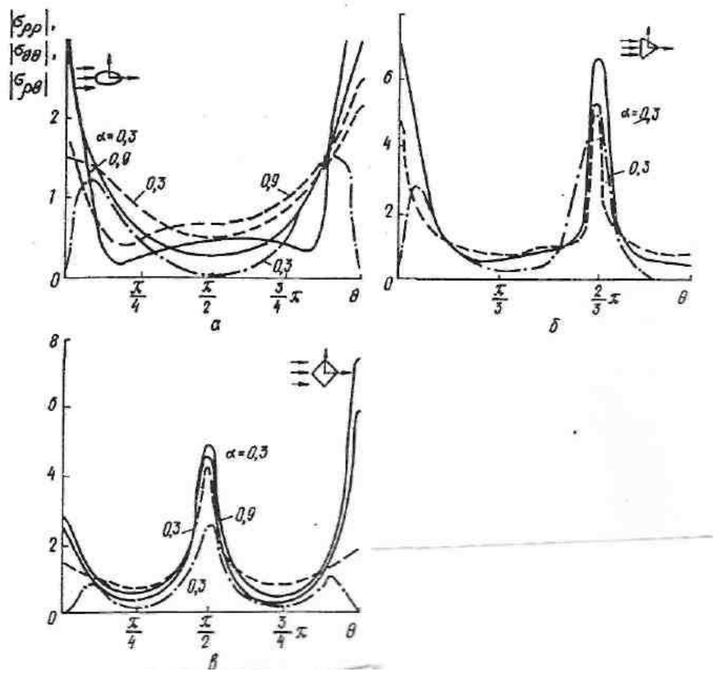
Fig.14.1. Seismic action scheme, in the near zone, charge through a soil basis on security objects with square, triangular and elliptic configuration of their foundations

If we consider the foundation of a building, for example, a square configuration, then under its separate parts (in corners) the soil remains practically immovable. Since all parts of the foundation and the walls are interconnected, most of the elements of this box structure are resistant to the fact that the building was involved in oscillatory motion, corresponding to the velocity of oscillation of the soil particles near the charge point. In the case when the structure (for example, a dam) is a foundation and all its parts are not interconnected, most of the elements of this construction will separately react to the oscillatory motion; accordingly, the velocity of the oscillations of the soil particles at different points to the charge will change. This leads to a significant increase in the seismic manifestation of the explosion through the soil basis in certain (dangerous), for a specific configuration of the foundation of the object, nodes. Therefore, there is a problem concerning the development of a method for calculating the stress fields (oscillation velocities) around the soil base, in which the foundation with elements of constructions of different configurations is located and which are affected by seismic waves from the explosion (especially in the near-field zone). In the distant zone, the methods of calculating earthquake resistance of buildings and constructions and other protected objects in the previous sections are based on the experimental determination of the velocity of soil oscillations only on its soil basis. At the same time, to assess the seismic stability, it is sufficient to measure the velocity of the soil fluctuations at any point of the soil basis around the foundation on which the building or structure is constructed. The assessment of seismic resistance using this technique does not take into account the wave pattern across the (configuration) of the contact boundary of the ground object and can be applied to objects of any configuration. That is, in existing methods for calculating seismic stability at a massive rate of oscillation of the ground base of the foundation, the different stability of the elements of its construction, depending on the configuration, is not taken into account. This is due to the lack of data on the distribution of dynamic stress fields (massive oscillation velocities) on the elements of structures of objects of different configurations.

When analyzing stresses in an array with an object, calculations were made for the most common configuration of dams, foundations of houses, etc.) elliptical, triangular and square sections. Voltage amplitudes are obtained $\sigma_{\rho\rho}$, $\sigma_{\rho\theta}$ i $\sigma_{\theta\theta}$attributed to $\sigma_{yy/\infty} = (\lambda+2\mu)\alpha^2$.

Figure 14.2 shows voltage dependencies σ_{pp},$\sigma_{p\theta}$,$\sigma_{\theta\theta}$from the corner θat fixed frequencies (numbers near curves - values α).On these graphs, the solid curve corresponds to the stress $\sigma_{\theta\theta}$,dashed–σ_{pp}i dotted dotted –$\sigma_{p\theta}$.

In the region of the smallest radius of curvature for objects having different shapes of the cross section, there are significant stress concentrations that are 3-8 times higher than the voltage in the incident wave. The greatest tension in the incident wave $\sigma_{pp}$are attained at the points of the least radius of curvature. At other points, the contour of the large can be like so$\sigma_{pp}$and so$\sigma_{\theta\theta}$. These theoretical calculations have found practical confirmation in practice, when the greatest violations (cracks) from seismic action are recorded in the corners of buildings with square and rectangular



foundations (Fig. 14.2).

Fig. 14.2. The dependence of the voltage amplitude on the angle at fixed frequencies along the contour of the foundation of the security object with an elliptic (a), triangular (b) and square (c) configuration.

The above suggests that in predicting the seismic effect of the explosion for objects of different configurations in the seismic stability calculations of security objects it is necessary to take data of measurements of the velocity of oscillations in the excited waves for the angular points.

Fig. 14.2 Characteristic cracks in the corners of buildings from the effects of seismic waves,

In case of blasting, the borehole charges that are exploded instantly should be oriented parallel to the flank walls (Figure 14.1) and prevent the occurrence of waves falling from the side of the angular points.

Control questions

1. How does the distance of the source of an explosion from an object affect the prediction of its seismic stability?

2. Name the factor affecting the prediction of seismic resistance in the near-range zone of the explosion.

3. Name a criterion that does not depend on measuring the velocity of the oscillation and the type of load.

4. Compare the rate of displacement of the foundation and the substrate at different distances from the source of the explosion.

5. How do structures of different configurations react to oscillatory motion?

6. Justify the need to take into account the configuration of the house when determining its seismic resistance

7. At what points of the design are concentrated intense tension?

8. In what places are the first violations of the house?

9. At what points of an object should first of all measure the biasing rate?

LITERATURE

1. Boyko V.V. Problems of seismic security of the explosive case in the quarries of Ukraine / BV. Boyko // - K .: LLC Publishing Steel »- 2012 -235p.

2. Boyko VV National standard of Ukraine. Carrying out industrial explosions. Standards of seismic security / Boyko VV, Vorotelyak V.E., Vorotelyak G.A. KuzmenkoA.O. // DSTU 4704: 2008. - To: Derzhspozhyvstandart of Ukraine. - 2009 - 11 p.

3. Zdeschits VM Measurement of the vector velocity of seismic oscillations using the TDS-2014 / VM memory digital oscilloscope. Zdeschits // Bulletin of Kryvy Rih Technical University. - Kryviy Rih, 2007. - Vip. 16. - p.191-196.

4.Explosive Directory. /BN N.Kutuzov, VMSkorobogatov, IEErofeev and.r. under commonly edit B.N. Kutuzov M .: Nedra, 1988.-511p.

5.Technical rules for conducting blasting operations on the daytime surface. - M.: Nedra, 1972. - 45 p.

6. Boiko V.V. Dynamic actions of seismic-explosive waves on the stability of soil slopes / T. Hlevnyuk, O. Chala / Problems of labor protection in Ukraine: Zb. sciences works - K .: NNIIPBOP, 2011. - Vip. 17. - P. 261-267.

7. Ismailov T.T. Rationale and development of blasting technology ensuring the stability of mining operations with combined processing of ore deposits: author's abstract. dis ... for the competition uh. Degree d. Tech. Sciences: specialty: 25.00.20 - "Geomechanics, rocks destruction, mine aerogas dynamics and mountain thermophysics" / T.T. Ismailov - M., 2010. - 35 p.

8Kuzmenko AA Seismic action of an explosion in rocks / AA Kuzmenko, V.D. Vorobiev, II Denisyuk, AA Daustas - M .: Nedra, 1990. - 173 p.

9.Zaurbekova ND The basis of the stability of the sides of quarries, taking into account the super-deformability of mountain rocks: author's abstract. discontinue sizz Student degree Candidate tech Sciences: special 25.00.22 "Geotechnology" / ND Zaurbekova - Almaty: 2010 -20s.

10. SNiP 2.05.06-85. Trunk pipelines. -M .: Stroyizdat, 1977.-59s.

11. Padukov VA Mining geomechanics: Textbook. allowance / Padukov VA - St. Petersburg Mining Institute. - Pb, 1997. – 134p.

12. A. s. (USSR), Method of explosive destruction of rocks / F.I. Kucheravyy, E.I. Yefremov, Yu.F. Kucheravyy, B.N. Myadelets / Goskom. USSR on affairs of images. and open 2476203, 1979.

13. A. s. USSR No. 1162969. A method for determining seismic hazardous areas in fractured mountainous masses / A.O. Vovk, VV Boyko, N.V. Krivtsov, F.I. Curly - No. 3623214; stated. 6.06.83; published 22.02.85. Bull No. 23. During the explosions. - Sat Swings of earth dams. - Moscow: Nauka, 1967.

14. Kucheryavyj F.I. Principles of compilation of a seismic canal and its tarification by various methods / F.I.Kucheryavy // "Development of non-metallic deposits", 1971, No. 12.-P.51-56

15. Brehovsky L.M. Waves in layered media / LM Brezhovskikh - M.: Science, 1978. - 343 p.

16. Boyko VV On criteria of seismic hazard of industrial explosions / VV

Boyko, AA Kuzmenko, T.V. Hlevnyuk // Bulletin of the National Technical University of Ukraine "KPI". Series "Mining": Zb. sciences works - 2005 - No. 12. - P. 45-52.

17. Kugel M. Development of methods of prediction and prevention of landslides in slopes on counterfeit territories: author's abstract. Dissertation for Science. Degree Candidate tech Sciences: special 05.15.09 - "Mechanics of soils and rocks" / Kugel M. - K., 2002. - 20 p.

18. DBN V.1.1-12: 2006 "Protection against dangerous geological processes, harmful operational influences, from a fire. Construction in seismic areas of Ukraine ".

19. Kravets VG Estimation of seismicity criteria in blasting operations and mountain blows / VG Karvets // Proceedings of the International. conf. "1X School of Geomechanics 2009", Poland, Gliwice: 2009.-P.113-137