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SAFETY GUIDE IN THE USE OF ATOMIC ENERGY

"DETERMINATION OF INITIAL SEISMIC SOIL VIBRATIONS FOR DESIGN BASES"

(RB-006-98)

The Guide contains general provisions and recommendations on Determination of initial seismic soils vibrations for design bases.

ABBREVIATIONS

PES - potential earthquake source

DSZ - detailed seismic zoning

IAEA - International Atomic Energy Agency

SSE - safe shutdown earthquake

DBE - design-basis earthquake

SNiP – Construction Rules and Regulations

SZ - seismic zoning;

GENERAL TERMS AND DEFINITIONS

Hypo-center - a point in the source, where the process of moving across the fault is started during an earthquake; it is characterized by geographical coordinates and depth of the source.

Instrumental hypo-center - a point of the source, where the process of moving across the fault is started; it is determined by seismic stations.

Macro-seismic hypo-center - a point of the source that is related to max. density of allocated seismic power; it is determined by macro-seismic observations.

Safe Shutdown Earthquake (SSE) - an earthquake that causes vibration at the site with max. intensity for the period of 10000 years.

Design Basis Earthquake (DBE) - an earthquake that causes vibration with max. intensity at the site for the period of 100 years.

Seismic intensity (J) - integral macro-seismic measure of seismic impact, determined by statistics of damage to reference buildings and structures, reaction of objects, reaction of people, parameters of soil movement, parameters of the earthquake source and distance to the observation point as well as any changes on daylight surface.

Seismic vibration of soil for design bases - seismic records and reaction spectrum (X accelerograms, X velocigrams, X displograms), corresponding to the specific impacts on the site when DBE and SSE or 50% and 84% of levels of occurrence are happened.

Source - area located inside the earth's crust, where the process of inedruous destruction of rocks due to "instant" discharge of tectonic stresses ia taken place.

Parameterization of the soil seismic movement - description of the seismic record by a set of numerical characteristics. There are three independent seismic vibration parameters, each of which can be scaled without changing the values of the other parameters. These parameters are the level of impact, prevailing frequency of vibrations and duration of vibrations. All the rest characteristics are closely correlated with the main parameters.

Bed rocks - hard rocks or other rocks, characterized by the velocity of distribution of transverse (shift) waves which is at least 700 m/s.

Duration of seismic vibrations - period during which the amplitudes of vibrations exceed the background vibrations by more than 10%.

Design bases - raw data and postulated events for designing the nuclear facilities, manufacture of equipment, systems and devices, their installation and adjustment, construction, ensuring its normal operation during the prescribed operating life.

Hypo-centric distance - distance from the hypo-center to the observation point.

The shortest distance to the fault surface is a widespread measure of distance. According to the practice, it gives the min. variance of empirical data.

Epicenteric distance - distance from the epicenter to the observation point.

Scattered or background earthquake activity - background earthquakes are considered to be low-magnitude earthquakes (usually M <= 4), which are difficult to associate with known seismic-generating structures. When a conservative approach is used, it is believed that background earthquakes can occur anywhere in the area in question. Recurrence of earthquakes, defined for the entire territory, is on average 5 times lower than a real one. Thus, assessment of the seismic hazard associated with background earthquakes is to establish presence of micro-earthquake epicenters in the immediate vicinity of the site.

Seismic records synthesis is mathematical simulation of seismic records (accelerograms, bicycles, velocigrams), satisfying the expected values of the main parameters of vibrations (impulse level and width) and spectrum (prevailing frequency and logarithmic width).

Spectrum of reaction (response) - a set of absolute values of max. amplitude, respectively, accelerations (y), velocities (y), displacements (ay) of linear-elastic system of oscillators with one degree of freedom, depending on its own oscillator frequency and damping 1%, 2%, 5%, 10% of the critical. Typical range of reaction, given in the Standards, is enveloping of sets rationed in the level of spectrum and therefore much wider than the spectrum of vibrations in a single earthquake.

Normal spectra - have a logarithmic width that is close to the average value: Rs =0.5 - 0.8 and it is 1/3 of the total sampling of the global data.

Narrow spectrum - has a width which is less than Rs =0.5 and make up 1/3 of the entire sample of the global data.

Spread spectrum - has a width which is more than Rs = 0.8 and make up 1/3 of the entire sample of the global data.

Acceleration (velocity, movement) of the soil for the design bases - peak acceleration (velocity, movement) of the given occurrence on the free surface.

Acceleration of zero period - acceleration of the response spectrum in asymptotic (solid) region of the spectrum, which usually is placed in the frequency range that is more than 33 Hz.

Phase characteristics - phase angles (phase spectrum) that may characterize phase shifts of seismic vibrations for different frequencies.

Spectrum width (Rs) - difference of the frequencies of the right and left slopes of the spectrum at 0.5 from the max. value. Logarithmic width of the spectrum is poorly dependent on magnitude of the earthquake and is in average it is close to Rs =0.65. This property reduces the extrapolation of weak impacts to the strong area.

Epicenter - projection of a point of the hypo-center of the earthquake on the earth's surface; is characterized by geographical coordinates.

1. PURPOSE AND SCOPE

1.1. Determination of initial seismic soils vibrations for design bases is designed to determine the parameters of seismic soil vibrations for the design bases in order to justify the seismic resistance of the nuclear facilities.

1.2. Aim of this Guide is to describe the possible approaches to determine initial seismic soils vibrations for design bases, to assess acceptability and to state priorities to use these approaches in appendices to the nuclear facilities of different types and particular goals of safety analysis.

1.3. Selection of approaches, completeness of the information used, austerity of analysis - is the responsibility of the operating organization. Correctness of the applied approach is assessed in relation to a specific object located in particular engineering and geological conditions.

1.4. The guide can be used to analyze existed, designed and constructed nuclear facilities.

2. SEISMIC VIBRATIONS OF SOIL METHODS AND APPROACHES

2.1. Seismic impacts can be subdivided into standard and local.

2.1.1. Standard impacts (max. accelerations, dynamic coefficient curves and their corresponding synthesized accelerograms) are defined regulatory for different types of soil conditions and scaled to reflect the intensity or max. acceleration of soil vibrations at the site.

2.1.2. Local impacts are determined with due regard to specific seismotectonic and soil conditions of the site using empirical, semi-empirical and analytical methods.

2.2. Seismic vibrations of soil at the site shall depend on the following main factors:

- position of active faults and their parameters (length, depth, direction of movement, velocity of movement);

- provisions of PES zones and their parameters (max. magnitude, depth of the source, mechanism of the source, parameters of seismic mode);

- transfer the site from the active fault centre or PES area;

- characteristics of damping intensity of seismic waves and changes in the spectral composition of vibrations in the way of the vibrations spread from a potential earthquake to the site;

- seismic characteristics of soil conditions at the site (velocity of spread of transverse seismic waves, their damping velocity, density and power of soil layers).

2.3. Any of the following methods (approaches) or combinations, which can be combined into three main groups, can be united into the main three groups to determine seismic impacts:

I. Methods that use recordings of strong earthquakes of the max. calculated level that occurred at the site (Approach 1), or available analog records of strong earthquakes (Approach 2).

II. Methods based on fault models:

- theoretical method (Approach 3);

- semi-empirical method (Approach 4).

III. Methods using standard spectrum:

- methods of synthesis (simulation, generation) of estimated accelerograms and action of spectrum with established estimates of soil movement parameters at calculated impacts in time or/and spectral form (Approach 5).

Seismic impacts, depending on the degree of study of seismic and soil conditions of the site, can be determined by any of the methods or several methods at the same time: regulatory, empirical, semi-empirical and analytical. The most likely parameters of seismic impacts and assessment of their uncertainties should be obtained. Applicability of each of the used methods shall be duly justified.

2.4. When choosing approaches to determine seismic variations of soil for design bases, the following information should be considered:

a) Approach 1, which uses records of strong movements from earthquakes at the maximum calculated level shall be preferred, i meets the requirements of the real site in the best way;

b) use of the semi-empirical method is preferable when there are no records of strong movements, but there is data on parameters of the fault and distributions of velocities between the fault and the site. Using Approach 4 allows you to get fairly reliable results;

c) if there are recordings of movements on the site when the earthquakes are weak, as well as known parameters of fault generating safe shutdown earthquake, you can apply Approach 3. This approach is very useful and practical for assessing short-period vibrations, as records of weak vibrations contain information not only about the local conditions of the site and heterogeneities in the way of waves spread, but also about the complex mechanism of destruction in the fault;

d) If only magnitude of the safe shutdown earthquake and distance to the source are known, Approach 5 shall be used. In this approach, seismic impacts are synthesized according to the standard reaction spectrum or spectral density, duration and enveloping, time-dependent (or phases defined from the records). This data is determined by mathematical analysis of a large number of records related to strong movements;

e) if using Approach 2 (when specific information about the site is not available ) requires a proper selection of data. It is required to follow the range of periods in which records are reliable. The approach cannot take into account the local conditions, the characteristics of the source or the area of wave propagation. It is recommended for limited use to obtain some preliminary assessments.

3. GENERAL PROVISIONS ON DETERMINING SEISMIC VIBRATION OF SOIL FOR THE DESIGN BASES

3.1. Algorithm scheme of Determination of initial seismic soils vibrations for design bases is shown in Fig. 1

Site

Safe shutdown earthquake

Magnitude, epicenter distance, soil conditions at the site

Fault parameters, records of weak vibrations at the site

Fault parameters, velocity distribution

Records of strong movements at the site that are related to the level of safe shutdown earthquake

no

no

no

no

yes

yes

yes

yes

Application of other records of strong vibrations

Application of standard spectrum and duration

Semi-empirical approach, based on the fault model

Theoretical approach based on fault models

Application of records of strong vibrations at he site that are related to the level of safe shutdown earthquake

Method that uses strong vibrations records

Method that uses standard spectrum

Method based on fault models

Fig. 1. Algorithm scheme to determine input seismic impacts

Recommendations with the same titles are mentioned in Reference Appendices 1, 2, 3 respectively:

- determining the parameters of the initial seismic vibration of soil using records of strong movements;

- assessment and generation of estimated seismic impacts by methods based on the fault model;

- assessment and generation of estimated seismic impacts using standard spectra.

3.2. The task of determining soil vibrations for the design bases can be divided into two stages:

I. Determining the parameters of seismic vibrations of soil on the free surface of the soil (sections 3 - 5 of the Guide);

II. Determining the parameters of the calculated seismic vibrations of soil for the mark of the bed rock, blocked by the thickness of relatively weaker soils (section 6 of the Guide).

3.3. Solution of the task related to the stage I involves the following definition:

1) seismic vibrations of soil in the free field at the site of the facility;

2) frequency characteristics of soil vibrations;

3) max. amplitude (acceleration, velocity, movement) of soil vibrations;

4) accelerograms and response spectrum.

3.4. In order to solve the tasks of the Stage II, assessment of changes in the characteristics of soil vibrations shall be carried out in the form of parameters in the soil column, the same as for the bed rock.

3.5. If two levels of design basis earthquakes DBE and SSE are used for seismic resistance analysis, seismic vibrations of soil shall be determined in each case individually and directly for each level. In this case, they shall correspond to different sets of vibrations.

It is allowed to take the level of seismic impacts for DBE two times lower than for SSE.

3.6. Initial seismic vibrations for the design bases should be obtained for free surface and bed rock, taking into account the specific seismotectonic conditions of the site.

3.7. Magnitude of the parameters of seismic vibrations of soil and assessments of their uncertainty should be duly determined. Reaction spectrum should be determined for damping 5%.

3.8. Response spectrum is recommended to be re-calculated for the purposes of seismic resistance analysis of the nuclear facilities for the values 1%, 2% and 10%, taking into account the impact of the weight and inertia characteristics of the structure located on the soil.

3.9. A set of accelerograms or accelerogram for the design bases shall be determined in accordance with the requirements and criteria of Section 5 of the Guide.

3.10. Two orthogonal horizontal and one vertical components of soil vibrations shall be identified.

4. DETERMINING THE PARAMETERS OF SEISMIC VIBRATIONS OF SOIL

4.1. General

4.1.1. Seismic magnitude of the site for natural and man-induced conditions shall be determined by macro-seismic intensity. Recommendations how to define it are given in Reference Appendix No 4 to the Guide.

4.1.2. Max. parameters of seismic vibrations of the soil for the design bases (max. horizontal and vertical acceleration, velocity and movement of soil) should be determined as a result of special surveys carried out on the site.

4.1.3. If seismic vibrations of soil are presented for the design bases with the help of response spectrum, its form can be both standard (not dependent on the site) and indicative (depending on the site). Both spectrum, reflecting the degree of uncertainty of the dominant frequencies of initial seismic vibration, and narrow spectrum can be used. When using narrow spectrum, the central frequency should be shifted (expanded) by 10% in both directions to consider the uncertainty of dominant frequencies. Narrow spectrum can be recommended for specific objects with specific geology if the necessary seismological information about the site is available. Spread spectrum should be used in development of the typical projects that can be referred to a wide variety of soil conditions.

4.1.4. Standard and spread response spectrum should be set for different types of soils in the form of a family of curves for a set of damping values 1%, 2%, 5%, 10%.

4.1.5. It is necessary to determine the resonant period of T0 spectrum, which coincides with the visible period T, corresponding to the max. amplitude of soil vibrations. It can be calculated according to Recommendations given in the Appendix 4 to the Guide.

4.1.6. Form of the response spectrum on double logarithmic scale at the first approximation can be considered as symmetrical relative to the resonant period.

4.2. Using standard response spectrum

4.2.1. Selection of response spectrum (its form) for the design bases depends on the stage of Project development (typical project for the specific site, etc.) and on the degree of completeness of seismological information available for the nuclear facility site. At the development stage of typical project, it is acceptable to use a form of standard response spectrum.

4.2.2. Standard response spectrum can be used for seismic analysis during the Project development phase for a specific site, provided that the requirements of item 4.1.3 Guide are duly met. Other response spectrum can be used provide that their suitability should be justified additionally.

4.3. Horizontal component

4.3.1. As a standard response spectrum horizontal component on a free surface for earthquake intensity 9 according to the scale MSK-64, it is allowed to take the spectrum given in the Fig. 2, provided its suitability should be justified for this case.

The diagarm is not available.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Frequency, Hz | Acceleration m /c2 at the relative damping, % | | | |
| 1 | 2 | 5 | 10 |
| 1 | 6.0 | 5.0 | 4.0 | 3.0 |
| 2 | 26.0 | 20.0 | 13.0 | 10.0 |
| 10 | 26.0 | 20.0 | 13.0 | 10.0 |
| 30 | 5.0 | 5.0 | 5.0 | 5.0 |

Fig. 2. Standard response spectrum of horizontal component on free surface for earthquake intensity 9 according to MSK-64

4.3.2. Response spectrum for both horizontal components in this case can be taken identical.

4.4. Vertical component

4.4.1. when max. amplitude on a horizontal component is less than 250 cm/sq., amplitude of vertical component shall be in average twice less.

At high amplitude values, they begin to converge and can be estimated according the Table. 1. Ratio between spectrum levels for vertical and horizontal components is the same as for the respective levels of soil vibration.

Table 1

RATIO BETWEEN ACCELERATION AMPLITUDES ON VERTICAL X V AND HORIZONTAL X H COMPONENTS

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| X H, cm/sq. s | 250 | 300 | 350 | 400 | 450 | 500 | 550 |
| X V, cm/sq. s | 125 | 155 | 185 | 225 | 275 | 335 | 400 |
| X H, cm/sq. s | 600 | 650 | 700 | 750 | 800 | 850 | 900 |
| X V, cm/sq. s | 470 | 470 | 625 | 710 | 800 | 895 | 1000 |

Standard response spectrum for the vertical component can be obtained by scaling the response spectrum for a horizontal component with 2/3 ratio throughout the whole frequency area.

When using the response spectrum that is typical for the site, its form should be developed separately for both vertical and horizontal components.

4.4.2. Ratio of levels related to two horizontal components is subject to the log-normal law with zero average value and standard deviation of 0.16 units of logarithm (if we take ratio that is more intense to the second horizontal component, amplitude ratio in 16% of cases does not exceed 1.15, in 50% of cases does not exceed 1.65).

5. CRITERIA AND METHODS TO DEFINE ACCELEROGRAMS

5.1. General

5.1.1. To synthesize accelerograms, the generalized spectrum of reaction (median or 84% occurrence) can be used, obtained as a result of statistical processing of a set of analog accelerograms, selected for similar seismotectonic and soil conditions.

If calculations are made only for one synthesized accelerogram, it is necessary to justify the conservatism of the results.

5.1.2. In the case of seismic vibrations in soil are presented as a response spectrum, the accelerograms shall meet the criteria contained in sections 5.2 and 5.3 of the Guide.

5.2. Determining the parameters of accelerograms associated with macro-seismic characteristics of the site

5.2.1. In addition to the other requirements mentioned below, the accelerograms should be selected, modified or obtained by numerical methods so that their time parameters (duration of the accelerograms, enveloping vibrations) and amplitude parameters (peak acceleration, peak velocity, peak movements) shall correspond to those values that are defined for the site by its macro-seismic characteristics.

5.2.2. Enveloping vibrations - smoothed function of the natural change of peak amplitude over time. A form of amplitude of enveloping vibrations is given in Fig.3.

The diagarm is not available.

|  |  |  |
| --- | --- | --- |
| Magnitude | Та/Тс | Тb/Tc |
| 8 | 0.08 | 0.46 |
| 7 | 0.12 | 0.50 |
| 6 | 0.16 | 0.54 |

(0,31М-0,774)

Тc = 10

Tc - duration dependent on magnitude of vibrations per second,

when Т > Тc amplitude of impact does not exceed 1/10 of max. amplitude;

Тa - accelerogram amplitude response time;

Тb - accelerogram amplitude decay time;

М - magnitude.

Fig. 3. Form of the amplitude of enveloping vibrations

5.2.3. Peak accelerations of accelerograms should correspond to the acceleration of zero response spectrum period adopted for the design bases.

5.2.4. Peak acceleration of the accelerograms is defined as:

a) max. value of acceleration;

b) absolute value of the vector amount of 2 horizontal and vertical components.

5.3. Criteria for the accelerograms sysnthesis

Accelerograms shall meet the following criteria:

5.3.1. Mathematical average acceleration of zero period of individual accelerograms should be more or equal to the value of peak acceleration; each subsequent frequency should defend from the previous interval, equal to 10% of the previous frequency.

5.3.2. In the area of frequencies from 0.5 to 33 Hz, the mathematical average ratio of the response spectrum values (calculated on the basis of individual accelerograms) and response spectrum for the design bases (ratio should be calculated for all frequencies specified in Table 1) and it should be <= 1.

5.3.3. No point of mathematical mean response spectrum value calculated for individual accelerograms should be below 10% of the design basis response spectrum. The response spectrums should be calculated at a relatively small step in frequency. The recommended frequencies and intervals are given in Table 2.

Response spectrum values should be calculated for frequencies at specified interval limits and intermediate points within each interval with the appropriate incremental step.

Table 2

FREQUENCIES RECOMMENDED FOR CALCULATING RESPONSE SPECTRUM

|  |  |
| --- | --- |
| Frequency range, Hz | Increment, Hz |
| 0,5 - 3,0 | 0.10 |
| 3,0 - 3,6 | 0.15 |
| 3,6 - 5,0 | 0.20 |
| 5.0 - 8.0 | 0.25 |
| 8.0 - 15.0 | 0.50 |
| 15,0 - 18,0 | 1.0 |
| 18,0 - 22,0 | 2.0 |
| 22,0 - 34,0 | 3.0 |

5.3.4. When synthesizing of three-component accelerograms is performed, it is necessary to ensure their statistical independence. When using analogue accelerograms, it is not allowed to use a single accelerograms to characterize three-component movement. The start time of shift in one time implementation should not be considered as a way to obtain other accelerograms.

Statistical independence of two a1 (t) and a2 (t) accelerograms is confirmed by the correlation ratio calculation:

where:

Е - mathematical expectation;

m1 , m2 - average values a1 (t) and a2 (t);

- standard deviations.

Two accelerograms are considered statistically independent if the absolute correlation ratio is less than 0.3.

6. ESTIMATED SEISMIC VIBRATIONS OF SOIL FOR THE MARK IN THE BED ROCK

6.1. Seismic vibrations of soil for the mark of the bed rock shall be determined by the analysis of interaction of the soil and the structure.

6.2. Estimated seismic vibration of soil obtained for the bed rock should be in conjunction with the seismic vibration of soil on free surface of soil.

6.3. Estimated vibration of soil for the rock should be determined depending on the soil model, the type of waves propagating in the soil during an earthquake, and the type of boundary chosen for the "soil - structure" model.

6.4. In the analysis of dynamic behavior of "soil -structure" system, it is allowed to adopt hypothesis of verticality of the wave propagation of displacement and compression in the event that simulation of the structure introduces (accidental) additional eccentricity (5% of the characteristic size of the structure in the plan), which allows to conduct an engineering accounting of the impacts of the amplification of reactions associated with the possible actually non-vertical propagation of seismic waves.

6.5. Calculations that determine boundary vibrations in accordance with 6.2 and 6.3 of the Guide should be carried out using mathematical models and procedures that are collaborative with those used in the analysis of the "soil - structure" system.

6.6. In the case of partially buried structures, calculations should be made to change the amplitude and frequency composition of seismic oscillations in the depth of foundation. Amplitudes of acceleration of the response spectrum, calculated in free semi-space at the depth of the foundation, should not be below 60% of the corresponding design basis response spectrum on the surface of the soil.

7. DETERMINING THE CHARACTERISTICS OF SEISMIC SOIL VIBRATIONS OF THE GIVEN PROBABILITY OF EXCESS

In absence of a representative amount of experimental data on dynamic parameters of soil vibrations during earthquakes (for prospective construction sites, these data are usually not available and cannot be obtained during the engineering survey period), it is possible to use a technique to map out ways of determining for a specific site the seismic impact of a given probability of excess in incomplete seismological information, without using the records of seismic earthquakes [33]. The method is described in Appendix No 5 to the Guide.

Appendix No 6 of the Guide shall provide a list of materials on the deep structure of the earth's subsoil, which should be taken into account when determining the initial seismic soils vibrations for design bases

Appendix No 1   
(reference) "Determination of initial seismic soils vibrations for design bases"

DETERMINING THE PARAMETERS OF INITIAL SEISMIC VIBRATIONS OF SOIL USING RECORDS OF STRONG MOVEMENTS

This method is used in two cases (see Fig. 1 of the Guide):

1) when records of strong earthquakes at the site or near it are known and are related to the level DBE or SSE;

2) when there are no suitable records about the site or near it and then other records of strong earthquakes are used, rationing them to peak values (similar records of strong soil movements can be used).

Flow diagram how to determine the parameters of seismic soil vibrations using records of strong movements is presented on Fig. 1.1.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | Relevant SSE/ accelerograms /velocigrams/ seismic records at the site |  |  |  |  |  | Seismic impacts parameters | |  |
|  | Mechnism of sources |
|  |  |  |  |  |  |  |  | |  |
| Estimate  amax, 2/a, Vmax, dmax, Tmax | |
|  |  |  | S (omega) - frequency characteristic of seimic channel |  |  |  |  |  |  |
|  |  |  |  |  |  |  | Calculating accelerogram duration | |  |
| 2 | Relevant SSE/ accelerograms /velocigrams/ seismic records outside the site |  | Solution of the integral equation of I kind by the type of collapse |  | Relevant SSE accelerograms, re-calculated for the particular site |  | Calculating reaction spectrum SA(t), SV(t) SD(t) | |  |
|  |  |  |  |  |  |  |  |  |  |
|  | Records of average and weak earthquakes on the site and outside the site |  | Calculating the empirical transit functions of the environment |  |  |  | Calculating PS power spectrum | |  |
|  |  |  |  |  |  |  |  |  |  |
| 3 | Global or regional banks data of strong movements |  | Sampling accelerograms by magnitude and distances |  | Appropriate SSE accelerograms, matched to the conditions of the site |  | Calculation of I intensity | |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  | Selection criteria: similarity of depth and mechanisms of source, similarity of soil conditions |  |  |  | Calculating beta dynamic ratio | |  |

Fig. 1.1. Flow diagram how to determine the parameters of seismic soil vibrations using records of strong movements

USING RECORDS OF STRONG EARTHQUAKES ON THE SITE

If there are records of strong movements (earthquakes) on the site (e.g. accelerograms) corresponding to the level of SSE, then this method should be preferred, as they (in these records) take into account all the information that determines the initial seismic vibrations of the soil for design bases.

1.1. Accelerogram is categorized with the following data:

a) designation of constituents; b) scale of time; c) accelerations in the form of segments corresponding to the length of 1 s and 0.1 g; d) the line is presented as follows : seismic magnitude, date of earthquake, epicenter distance in kilometers and number of seismic station (Figure 1.2 is not given).

To indicate three constituents of vibrations, it is accepted that the letter B means the vertical component, and the letter G - horizontal, indicating the angle in degree placed between direction of the recorded vibrations and the direction to the epicenter (Figure 1.2).

Vibration process is non-periodic vibration with variable amplitude and period. The period is considered to be a double interval between adjacent zero acceleration values.

1.1.1. The initial length of time usually has relatively smaller amplitudes. It refers to longitudinal seismic waves. The longer interval is, the greater epicenter distance is. At short distances from the source, the initial segment is 1 - 3 s. Periods of vibrations in the initial area are relatively smaller.

1.1.2. The average section of record has the greatest amplitude of accelerations. It refers to transverse waves, complicated by the introductions of exchange and surface waves. Periods of vibrations on the average area are slightly larger or the same as in the initial site. The transition from the initial site to the middle is clearly expressed on the record.

1.1.3. The final section is characterized by longer periods. Amplitude of accelerations gradually and irregularly is reduced in such a way that it is difficult to record the end of vibrations. Transition from the medium section to the final section is not clearly expressed.

1.1.4. Total duration of the vibration process is not the same and the greater the seismic magnitude is, the longer the epicenter distance is. Vibration shall last approximately 10 - 40 s.

1.1.5. Number of deviations (amplitude) on the record is very high (more than 100), which is taken into account in spectral analysis.

1.1.6. The vertical component of acceleration usually has slightly smaller amplitudes than horizontal ones (about 60 - 70%).

1.1.7. Both horizontal components are usually commensurate and there is no sharp dependence of the amplitude on the angle between the direction of vibration and the direction to epicenter.

1.2. Using the accelerograms, you can determine the following:

- amplitude level of vibrations;

- duration of vibrations;

- spectral content of vibrations.

1.2.1. Amplitude level of vibrations

Amplitude level of vibrations can be set using accelerograms:

- max. amplitude;

- max. amplitude of vibrations;

- root mean square amplitude of vibrations that is equal to the root square of the amplitude on the representative section of the record;

- spectral level on fixed periods.

For the vast majority of accelerograms, the ratio , where a max is the amplitude of max. acceleration and is the magnitude of root mean square acceleration, is placed in the interval of values 2.41 - 2.47 [13].

It should taken into account that from an engineering point of view, the value of amax may not be representative in the case of a single emission of large amplitude, or when the period of vibration with maximum amplitude is outside the maximum frequency characteristics of the structures vibrations. As a result of these, as well as some other factors, the correlation between amax and intensity is accompanied by a significant variation value that is close to the average (delta аa -> 100%). However, in combination with duration of the maximum phase, the value of amax x tay has a closer correlation with the seismic magnitude [14]. The amplitude parameter of seismic impacts also uses amplitudes of spectral accelerations of SA vibration of the oscillator with 5% damping at fixed periods of T 0.2 s and T 1.0 s, describing the impacts in the short and long-period areas of the spectrum [15].

1.2.2. Duration of vibrations

The parameter of duration (period) of vibrations in practice uses the width of the tay impulse, i.e. the period of time during which the vibrations level exceeds amax /2. The diagram of measuring the amplitude and impulse width is shown in Fig. 1.3 (it is not given). Cases of simple in shape vibrations (Figure 1.3, "a") and a records of a wave group separated by a period DELTA t, during which а <= аmax / 2 (Fig. 1.3, "b"). In the case of complex type vibrations (b) the impulse is considered to be the same at DELTA t q 2 s. Then t = DELTA t1 + DELTA t + DELTA t2 . Otherwise (DELTA t > 2 s) two separate impulses shall be considered.

1.2.3. Spectral content of vibrations

The parameters of seismic impacts, which characterize the spectral composition of vibrations, shall be considered:

- a period corresponding to maximum amplitude;

- Fourier S spectrum (omega);

- reaction spectrum, i.e. SA (T acceleration spectrum), SV/T velocity and displacements of SD(T) oscillators with 5% damping.

Expressions for Fourier's spectra are recorded in the form of [16]:

(1.1)

where:

f(t) - vibration process;.

omega - cyclic frequency;

S(omega) - complex function of circle frequency shall be defined

completely by amplitude │S(omega)│ and phase spectrum:

S(omega) = │S(omega)│ (1.2)

In its turn, amplitude and phase spectra are determined by the coefficients A(omega) and B(omega):

│S(omega)│ = [A2 (omega) + B2 (omega)-1/2;

(1.3)

where:

In engineering assessments, most of the operations are carried out using the spectrum module |S(omega)|, i.e. Fourier's amplitude spectrum.

1.2.4. Reaction spectra

The equation of movement of y(t) of linear oscillator with one degree of freedom and damping of x when moving the basement (t) can be expressed by the following ratio:

y(t) + 2 omegai x(t) + omega y(t) = -x(t), (1.4)

where:

omegai - frequency of its own vibrations of undamped oscillator. The relative displacement y in such oscillator can be recorded in the following form:

- omega x (t-tay)

1 t .. i 2 1/2

y = - -------------------- integral х(тау) е sin omega (1 - x) (t - тау) dtау. (1.5)

2 1/2 0

omega i (1 - x)

Relative velocity y:

-omega (t-тау)

. t .. i 2 1/2

y = -integral х(тау) е cos omega (1 - x) (t - тау) dтау +

0

- omega x (t-tay)

x t .. i 2 1/2

+ ------------- integral х(тау) е sin omega (1 - x) (t - тау) dтау. (1.6)

2 1/2 0

(1 - x)

.. ..

Absolute acceleration (y + х):

omega (1 - 2 x) -omega x(t-тау)

.. .. i t .. i 2 1/2

(y + х) = ------------------ integral х(тау) е sin omega (1 - x) (t - тау) dтау +

2 1/2 0

(1 - x)

- omega x (t-tay)

t .. i 2 1/2

+ 2 omega x integral х(тау) е соs omega (1 - кси ) (t - тау) dтау. (1.7)

0

The reaction spectrum is enveloping of maximum response of oscillators. At small amounts of damping x element (1 - x2)1/2 and expression for maximum relative displacement of the oscillator y = SD can be recorded in the following form (see 1.5):

- omega x (t-tay)

t .. i 2 1/2

S = [integral х(тау) е sin omega (1 - x) (t - тау) dтау] . (1.8)

D 0 maх

Then form max. relative velocity (see 1.6):

SV = omegai SD. (1.9)

Reaction spectra are built in double logarithmic scale (Figure 1.4 - not given).

They can be calculated by direct method of solving the equation (1.4) and recalculating from one spectrum to another. For example, the velocity spectrum, calculated by multiplying omega spectrum offsets or dividing into omega spectrum accelerations, is called the pseudo-velocity spectrum. It differs from a certain straight spectrum by less, the less damping is occurred. The damping values of most of the civil structures are in the interval x = 0.02 - 0.2 [17].

1.2.5. Dynamic coefficient

Dynamic coefficient is equal to [18]:

, (1.10)

where - an amplitude (enveloping) record of acceleration of vibrations of the linear oscillator with a given frequency of omega0 and damping x when vibrations x(t) are occurred.

In engineering calculations, the greatest interest is maximum value of betatmax = beta', which is called the dynamic factor and characterizes the effect of seismic impact on the structure.

The value of beta' depends on the period of T vibrations and x damping.

The amplitude level, i.e. the scale of beta coefficient, shall be set by the dividing beta' by the value of max. acceleration of the vibrations amax of the oscillator basement (acceleration of soil vibrations).

The curves of dynamic coefficient dependence on the period of beta vibrations (T) are also used for fixed damping (usually x is taken equal to 5%) [4]. Beta curves are much less common in velocities and displacements. In combination with reaction spectra, dynamic acceleration betaa, velocity betav and displacements betad shall be determined as follows:

betaa = SA / amax ; betav = SV / Vmax ; betad = SD / dmax . (1.11)

2. USING ANALOG RECORDS OF STRONG SOIL MOVEMENTS

In the case of analog earthquake records for the site conditions, these records must be re-calculated. The recalculation method is based on the theory of f flat waves propagation in horizontally layered and linear-nonelastic grounds (environment) [20, 21].

]Calculation of the accelerogram vibration for the site a(t) according to the record u(t) obtained outside of the seismic station is limited to solving the integral equation of the first type of collapse [22]:

К(t - тау) а(тау) dтау = u(t), (1.12)

where core of the integral K(t) describes the impact of the structure of environment on the path of "source - station," "source - site," as well as impact of the recording equipment. K(t) spectral area is described by the following ratio:

K (omega) = F K(t) = epsilon of this S (omega) TETA (omega), (1.13)

where:

F - Fourier's conversion operator;

S (omega) - frequency characteristic of seismograph;

TETA (omega) - ratio of frequency characteristics of environment on the path of waves propagation along the route "source - station" Gi (omega) and to the site G2 (omega);

Epsilon - coefficient, depending on the type of recording device,

Omega2 - seismograph;

i omega - velocigraph;

I - accelerograph;

this = PSI1/ PSI2, where PSI1 - direction of radiation from the source to the station, PSI2 - from the source to the site.

If the mechanism of the source is known, this value can be estimated. Otherwise, the value of K (omega) is determined up to the value of this factor. To reduce impact of this factor, you should select records as close to the object site as possible.

Definition of the accelerator vibrations on the site according to the station's recordings is referred to the class of incorrectly set tasks, and search for any solution shall be carried out in a regular form. A special regularization procedure shall be used to select coefficients to provide a regularized solution of the equation (1.12). Mathematical support in the form of ready-made computational programs is given in the document [23]. The problem connected with differences in the conditions of seismic waves is reduced to the definition of values of the complex function of TETA (omega) of the expression (1.11). Practical interest is implemented by the way to build empirical transition functions of the environment (ground) using earthquakes and explosions. These transition characteristics shall be built in the form of a relationship of spectrum of seismic vibrations.

The spectrum of seismic vibrations in the point with the number i can be roughly presented in the following form:

Ui (omega) = fi W(a) Gi (omega) Si (omega), (1.14)

where W(omega) - spectrum of source. Ratio of spectra related to synchronous records of one seismic event at two stations i 1.2 shall be equal to:

(1.15)

This expression shows that the value of transfer function of environment:

(1.16)

can be determined by records of weak and medium-sized seismic events in the frequencies at which U1 (omega) and U2 (omega) are represented in a proper way.

If in the point with the conditional number i =1, which can make a record of strong earthquake from dangerous seismic zone, and in the point i = 2 at the construction site there are synchronous records U(t) of several weaker seismic events (n = 1, 2,... N) from the same source zone, the formal link between the relevant records can be expressed as a system of equations:

*,* (1.17)

where recoil spectrum R1.2 (omega) is given by (1.15). The solution of each of the system equations (1.17) relative to q1.2 (t) can be implemented in the same way as solution of the equation (1.12), i.e. to be obtained it in the following form:

*,* (1.18)

where f1,2 (omega, alfa) - regularizing function. Considering that

and by taking M(omega) = omega2p, choosing the specific value of the parameter p, it is possible to build a regulatory function f1.2 (omega, alpha).

Deviations in positions of the hypo-centers of earthquakes, therefore, and some differences in the ways of seismic vibrations propagation, non-linearity effects and other causes may cause such situations when individual values q(t) are slightly different from each other. The resulting value of transit function shall be defined as mean value of all implementations:

(1.19)

When using the records of engineering and seismo-metric stations, sometimes it is difficult to make their accurate positioning over time. In such cases, as shown in [24], the averaging should be followed after the shifts of functions q (t) for the periods of tay (m), at which max. values of the function of mutual correlation for each of the implementations q (t) are relative to one of them.

The way in which transition functions described above are built shall impose a number of restrictions on them. Functions can only be defined in a class of absolutely integrated and shall only describe impacts of the environment parts, compared by linear dimensions with wave lengths from the frequency range, in which with sufficient accuracy and detail it is possible to obtain spectrum of synchronized records of earthquakes from the seismic zone that is interesting for us. Accuracy of description of the impacts of different parts of structure related to the environment shall depend on how the level of useful signal at the appropriate frequencies shall exceed the level of interference. The algorithm described in detail and the example of its use are presented in the document [21].

A close technique based on the same input data, which allow to perform re-calculation of accelerograms obtained in some soil conditions to sites with another near-deposition incision, is described in the document [20].

The task is to restore the signal that is suitable to the sole of the layered pack and receive the accelerograms on free surface of the platform. To do this, you need to know the spectrum of vibrations on the free surface in the area of the station (reference point) Fv (omega) and the spectral characteristics of the studied layered packs of Hv (omega) in the area of the station and Yv (omega) on the site. The input signal shall be calculated according to the following formula:

(1.20)

The related accelerogram on the site can be given as:

(1.21)

The spectral characteristics of the environment are calculated by the modified Thomson-Haskell formulas for the linearly inoupgue horizontal-layered model.

The method of recalculating accelerograms to other soil conditions can be applied only after careful analysis of experimental accelerograms, separation and identification of recorded waves and use of only the volume-wave part of the record. This recalculation should be treated with extreme caution, when sites are located in vastly different azimuths relative to the epicenters of possible earthquakes.

The method is particularly effective for determining seismic fluctuations at the mark of rock, if there are analog records obtained in similar seismotectonic conditions on loose soils. The obtained accelerograms are useful to be applied to obtain a generalized spectrum of reaction of the given occurrence and subsequent synthesis of the original accelerograms.

3. SELECTION OF ANALOGUE RECORDS OF STRONG MOVEMENTS

For the platform areas, selection of analog records of strong movements is the main method for obtaining initial seismic impacts (generalized spectrum of soil reaction of different occurrence) in conditions of incomplete seismological information.

To characterize the initial seismic impacts, a set of analog accelerograms recorded in similar seismic and soil conditions shall be selected from the database.

Analogue accelerograms are used to produce analogue reaction spectrum, which can be statistically processed in the future.

Based on the statistical processing of analog reaction spectrum, the median and 84% occurrence of the generalized spectrum of soil reaction are calculated, which correspond to the specific seismotectonic and soil conditions of the site where nuclear facilities are located. In addition, the most likely max. accelerations and periods are calculated and the degree of uncertainty is assessed.

Based on information on max. accelerations, generalized spectrum of soil response of specified occurrence and duration of vibrations, the accelerograms corresponding to specific seismic and soil conditions shall be synthesized.

The merit of this approach is its similarity to the approach used to determine standard seismic impacts.

Appendix No 2   
(reference)   
to the Guide "Determination  
 of initial seismic soils vibrations   
for design bases"

ASSESSMENT AND GENERATION OF ESTIMATED SEISMIC IMPACTS BY METHODS BASED ON THE FAULT MODEL

When assessing and generating estimated seismic impacts (solving a direct problem) it is necessary:

1. To simulate the process of any destructions in the fault ("fault model").

2. To simulate the radiation of seismic waves in the volume of the Earth's crust ("Green's function").

3. To consider local engineering and geological conditions.

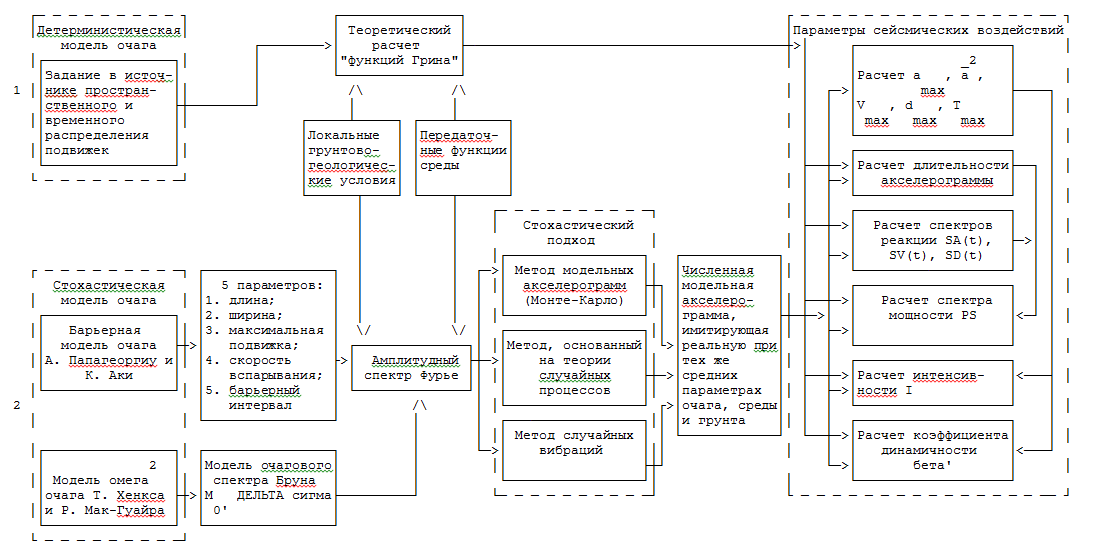
The problem can be solved by two methods: the first - purely theoretical, where all phenomena are described mathematically; the second is semi-empirical, where parts of the theory are replaced by experimental data.

1. THEORETICAL SIMULATION

There are two approaches to theoretical calculations.

The first, deterministic, requires a task in the source of spatial and temporal distribution of movement, as well as spatial distribution of the properties of the environment (geometry, physical and mechanical parameters) (Figure 2.1). In this case, a number of methods of calculating "Green functions" are used to assess the displacements in the point of observation. At the same time, radiation methods are used to calculate high-frequency vibrations in the near fiels and in the heterogeneous environment. However, consideration of models of homogeneous distribution of movement does not give good results in calculating high-frequency vibrations, as short-wave movements (high-frequency vibrations) shall be determined by the heterogeneous distribution of movement and local values related to source parameters. Since it is almost impossible to predict the detailed spatial and time distribution of movements in the sources of future earthquakes, stochastic source models shall be duly used.

Two types of stochastic models are used to calculate short-period movements of soil - the barrier model developed by A. Papageorgiou and K. Aki and the omega2 model of T. Hanks and R. Mc. Guire (Figure 2.1).



Computation amax, , Vmax, dmax, Tmax

Computation of spectrum reaction SA (t), SV (t), SD (t)

Calculating the dynamic ratio of beta '

Calculation of I intensity

Calculating PS power spectrum

Calculating accelerogram duration

Numerical model accelerogram, simulating the real at the same average parameters of the earthquake source, environment and soil

5 parameters:

1. Length;
2. Width;
3. Max. movement;
4. Opening velocity;
5. Barrier interval

Seismic impacts parameters

Random vibration method

Method based on random processes theory

Method of mode accelerogram (Monte-Karlo)

Stochastic approach

Fourier amplitude spectrum

Model of M. Braun source spectrum 0 DELTA sigma

Source omega 2 model Hanks and R. Mc.Guire

Source barrier model devloped by A. Papageorgiou and K. Aki

Source stochastic model

Local soil and geological conditions

Transformation functions of environment

Theoretical computation of Green's function

Building in the source of spatual and time distribution of movements

Source deterministic model

Fig. 2.1 Flow diagram how to determine the parameters of seismic soil vibrations by methods based on the "fault model"

Within the barrier model, the source shall be considered as a rectangular platform covered with cracks of a circular shape of the same diameter, separated by an undisturbed material. The cracks are placed independently and accidentally, radiation of seismic waves by this source is described by the expressions of T. Sato and T. Hirasawa. Fourier spectrum of the resulting movement has a random phase, which allows to refer the barrier model to varieties of stochastic models.

This barrier model can be described by five main parameters: length and width of the site (source), max. movement, rate of opening and barrier interval. In this model, the value of the high-frequency edge of the Fm spectrum shall depend on the size of the source and its other parameters.

In omega2 model, the value fm is determined by the effect of vibration damping in surface sediments. In omega2, vibration acceleration models shall be simulated by white noise in the frequency interval f0 - fm (where f0 is the angular frequency of the spectrum and form of the spectrum according to J. Brun). The model is characterized by the magnitudes of M0 moment, as well as power reset to DELTA sigma and fm. A proper adequacy between experimental and theoretical values amax and ̅2 in the magnitude interval 4.0 - 7.7 was obtained by this model. D. Boore developed both calculation models and used the random vibrations method, extending the range of magnitude from 1.0 to 7.0. Application

omega2  - models to calculate vibrations generated by the source from M 7.0 shall become incorrect due to violation of similarity, i.e. a noticeable increase in Kv = L / W form factor in the area of large magnitudes.

Two methods of calculations - Monte Carlo method and the method of random vibrations shall be used to calculate the vibrations from the source in the form of a barrier model and omega2 model.

In both methods, spectrum of R(F) vibrations shall be considered depending on the following factors:

R(f) = С S(f) A(f) D(f) I(f), (2.1)

where:

C - scale coefficient;

S - spectrum in source;

D - damping;

I - device reaction in the point of observation;

(2.2)

where:

R ТEТА,j - directivity function;

F- free surface effect;

v- part of energy referred to horizontal vibrations;

ро0 и vs0 - density and rate of secondary wave in source area;

R - geometrical divergence of waves.

Usually, F = 2 and v = 1/ are given. At distances of up to 100 km for body waves R q r (r - hypo-central distance). For distances of more than 100 km, where Lg waves can be dominated,

R ~= .

For the barrier model, the following expression is used for source spectrum S(f) [26]:

, (2.3)

where:

S0i (f) - spectrum of individual sub-source (circular crack);

N - total number of sub-sources;

T - duration of the whole fault opening

,

S0i (f) = f2 M0i, (2.4)

where M0i - sesmic moment of sub-source.

For omega2 - models:

S(f) = M0 / [1 + (f / f0 )2],

F0 = 4,9 х 106 vs0 (DELTA sigma / М0)1/3, (2.5)

DELTA sigma - in bar, f0 - in Hz, v s0 - in km/s and М0- in din. cm.

Taking into account violation of the principle of similarity for large earthquakes, it is necessary to use the following ratios for spectrum of the source [27]:

S(f) = M0 / (1 + i f / fB)1/2, f <= fA

S(f) = M0 (fa / f)3/2 / (1 + i f /fR)1/2, f >= fА, (2.6)

where:

fA = 4,9 х 106 Vsо K1/4 (DELTA sigma / М0)1/3, <= М0с,

fВ = 4,9 х 106 Vsо K3/4 (DELTA sigma / М0)1/3;

fА = 4,9 х 106 Vsо K1/4  DELTA sigma1/3 М0с М0-1/2, М0 >= М0с,

fВ = 4,9 х 106 Vsо K3/4 (DELTA sigma / М0) 1/3 (2.7)

Here M0c is a critical value of the moment starting from which the similarity is violated. It should be noted that in the area of maintenance of similarity for California earthquakes K was accepted equal to 4.

The factor of amplification of A (f) vibrations by the environment, i.e. so-called special characteristic of vibrations of layered thickness, can be calculated using Thomson-Haskell method under the L.I. Ratnikova Program.

Sometimes a corrective factor shall be used to determine A:

,

where 0 index is referred to source area, i - point of observation.

Damping factor D(f) with the distance can be written in the following:

D(f) = exp[-p f r / Q(f) V] P(f), (2.8)

where: Q - damping factor dependent on frequency in medium, that is different for different regions; P(f) - high-frequency filter slice;

P(f) = exp(-p K0 f). (2.9)

Finally, the I(f) filter depends on the terms of registration. For standard accelerographs, the expression should be for I(f):

, (2.10)

where fr = 25 Hz, x= 0,6, V = (2 p2 fr) .

Once R(f) spectrum is determined, the following calculation procedure shall be performed. Random number generator (Monte Carlo method) shall generate the Gaussian white noise with R(f) spectrum filtered through a box-shaped filter with a duration TW = 1 / fo + 0,05 for omega2 model or 1 / fA for the modified model. r - the distance from the source here.

Next, Fourier inverse transformation shall be done into a temporary area and the temporary functions a(t) shall be obtained, which are used to assess the values amax and. Not less than 20 generated (estimated) signals are required for proper assessment of amax. Spectrum that is average per mass of implementations is very close to the original estimated spectrum.

Random vibration method does not require use of random process generation. Spectrum R(f) of y value (acceleration, rate, displacement) shall be determined in accordance with the principle described by the expression (2.1).

Zero, second and fourth moments m0, m2, m4 power spectrum density shall be calculated by the following formula:

mk = -- / R(f)1/2 dоmega, (2.11)

where omega = 2 p f.

Root mean square value shall be defined by the following ratio:

, (2.12)

where Тr (period of vibrations) = Тomega.

The following ration is used to define reaction spectrum value:

, (2.13)

where T0 and X - period of their own vibrations and damping of the gamma oscillator - Tomega / T0.

The mathematical expectation E (ymax) of ymax value is calculated using precise or asymptomatic formulas that depend on the epsilon parameter and the number of N extremes, where:

epsilon = m2 / (m0 m4)1/2

*,* (2.14)

where С - bi-nominal coefficient that is equal N! / l! (N - l).

The expression (2.14) is used for small Ni 14.7, epsilon - 8.

For large N values, an asymptomatic solution is offered, but not the exact one:

E(ymax) = y2 {[2 ln(N)]1/2 + gamma [2 ln(N)]1/2}, (2.15)

where Euler constant is recommended as a gamma, equal to 0.557216.

After receiving spectrum of reaction, random vibrations shall be used to set stationary time implementations

with a given spectrum and the magnitude of ymax and .

The above mentioned stochastic methods can be used correctly outside the near field. For the near field, a modification of the above method was proposed using Monte Carlo method. However, this model contains a number of simplified assumptions, in particular, the assumption of a constant throughout the whole source of opening velocity. At the same time, it should be noted that the results of the calculations are more sensitive to changes in the velocity of opening [29].

In addition, a method based on the representation of vibrations from a large source as a sum of vibrations from small sources as sub-sources is used.

Essence of the method is that this sub-sources, together with start of their action, are randomly distributed with a homogeneous probability during the complete duration of T action and their emitted impulses have large-scale ratio v.

Sources begin to trigger with a delay as they move away from the hypo-center. At low frequencies, radiation of sub-sources is coherent with a spectrum level proportional to v multiplication.

High-frequency radiation is not coherent, and spectrum level is proportional to v. As part of Hanks and Mc. Guire model and representation of similarity of the spectrum by K. Aki and J. Aki and J. Bruno's spectrum of displacement at high frequencies is varied according to the law of f-alpha.

Then:

; (2.16)

where М0 - moment of the source; М0е - moment of the sub-source. For omega 2 - alpha model = 2 and delta = 3 [3].

vibrations are calculated as "Green's functions" and summarized at the point of observation. "Green's function" calculations are described in the fundamental work made by K. Aki and P. Richards [26]. The authors of the method postulated some random distributions of sub-sources across the surface of fault in accordance with the proposed fault geometry. Distribution of sub-sources should be related to the perceived heterogeneity of the source and of course, the result depends on adequacy of theoretical distribution of the real distribution of heterogeneities. Thus, when it is required to distribute sub-sources, you can take into account the results of the study of the distribution of distortion sites by their length and the amount of movement to take a proportional length of sub-distortion. Keep in mind, however, that in each case, distribution of parameters may differ from the average or characteristic in many cases. Thus, the results of theoretical and experimental studies allow us to conclude that maximum movement of Dmax to the center of the source is gravitated and that D values fall to zero at the edges of the fault. However, in some specific cases, the deviation from this trend can be quite significant, as it is determined by the spatial differences in the strength of rocks.

The perspectives of developed technology to estimate vibrations should be noted. However, at present, due to the lack of knowledge of the structure of sources of real earthquakes, methods of theoretical calculations described above are not widely used.

2. SEMI-EMPIRICAL METHOD

The semi-empirical method was proposed by Hartzel. This method uses records of weak earthquakes as "Green functions", avoiding the need to calculate these functions theoretically. This semi-empirical method is the most practical in determining the parameters of seismic impacts based on the fault model, but its application requires records of at least weak earthquakes. The key issue of the applicability of the semi-empirical method is presence in the available records some components corresponding to periods of their own vibrations of the designed structures.

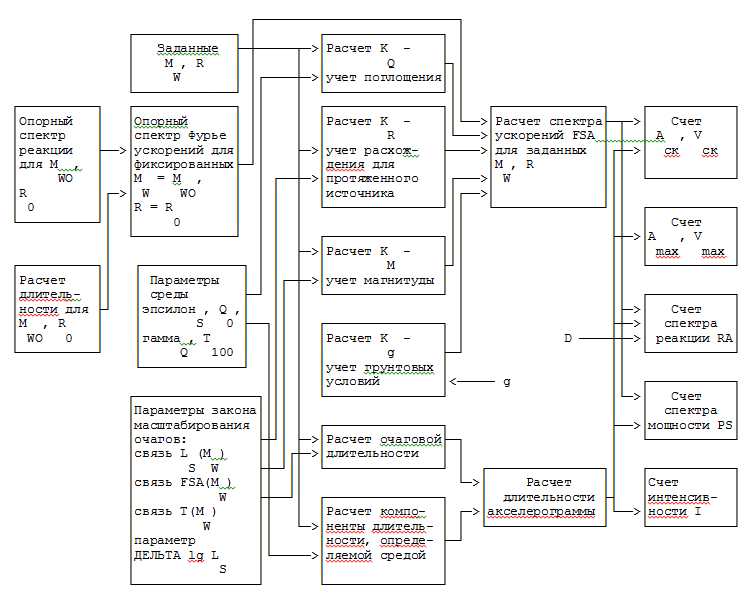
The method has proved to be very useful for assessment of short-period vibrations, as records of weak local earthquakes contain information not only about the local conditions of the site and spatial heterogeneities between the site and the source, but also about complex mechanism of destruction inside the source.

The semi-empirical method has been used and is currently being used in various variants. For example, Kanamori synthesized the Lav waves with periods from 2 to 10 s., taking into account the difference in seismic moments between weak and strong earthquakes.

Mr. Irikura proposed a method based on the coefficient of similarity for parameters of the source, arguing that the fault length, fault width and average dislocation are proportional to each other, and stress relief and sliding velocity do not depend on the size of the fault. He used his method to calculate vibration velocities with a predominant period of about 10 c. His method of super-positioning records from weak local earthquakes used as a factor in the ratio of seismic moments of strong and weak earthquakes.

Mr. Tanaka and other scientists synthesized accelerograms to simulate short-period vibrations and showed that the super-position factor should be as 2/3 ratio of seismic moments.

In Russia, the semi-empirical method has recently been used in Kamchatka. Here, the limited number of records of strong movements was offset by the use of theoretical models, with some parameters of these models determined by weak local earthquakes (Figure 2.2). To this end, a simple approximate method of solving a direct problem of forecasting the parameters of vibrations, based on the method of random functions; model parameters are set based on the data available at the time and the newly received data.



Estimation of KM – counting of magnitude

I intensity calculation

PS power spectrum calculation

RA spectrum reaction counting

Counting Amax, Vmax

Counting ACK, VCK

Calculating accelerogram duration

Calculation of FSA spectrum acceleration for the stated MW, R

Estimation of component duration, defined by media

Source duration calculation

Kg estimation - soil conditions counting

Calculation of KR - estimation of defference for the extended source

Parameters of source scaling law:

correlation LS (MW)

correlation FSA(MW)

correlation T(MW)

parameter DELTA lg LS

Environment parameters epsilon S, Q0, gamma Q, T100

Calculation of duration for MWO, R0

Fourier support spectrum for the fixed MW = MWO, R = R0

Reaction support spectrum for MWO, R0

Calculation of KQ – counting of absorption

Set values MW, R

Fig. 2.2. Flow diagram the algorithm for parameters simulation related to soil vibrations

The first stage of algorithm for predicting the parameters of strong seismic vibrations of the soil is the calculation of Fourier spectrum (Figure 2.2). The original version of the algorithm is the source spectrum M0(f). FSA (f) Fourier Spectrum shall be calculated by the formula:

FSA(f / R, MW) = (2 пи f)2 С х М0(f / МW) х KR х KQ(f) х Kg(f) х KH(f), (2.17)

where:

C - scale coefficient;

M0(f / MW) - source spectrum (in particular, Brun's model can be used);

KR - element, that takes into account geometric divergence (spherical) adjusted for the size of source (depending on the magnitude);

КQ(f) - element, that takes into account losses due to absorption and scattering;

Kg(f) - a correction to spectrum, that takes into account soil category (as per SNiP: I, II or III; accordingly: Rock, medium hard or soft soil);

KH(f) is a low-frequency filter that defines the spectrum slice

at high frequencies (fmax parameter).

The second important element of calculation is assessment of the accelerogram duration. As a characteristic of duration in the method of random vibrations it is convenient to use "effective (rectangular)" duration of TP - duration of power equivalent signal with a rectangular envelope and root mean square amplitude, equal to the root mean square amplitude of the original signal in the area of maximum vibrations. To estimate the complete duration of "source -medium - soil" system, it is convenient to use the "Root mean square" duration of Tsk, which is defined as the second central point from the accelerogram square and is a combination of contributions made by source, environment and soil:

(2.18)

Transition from Тск to ТP is carried out by the formula:

ТP = КT х Тск.

KT factor can take values from 2 (for the accelerogram with Gauss enveloping) to 3.5 (for an accelerogram with rectangular enveloping).

Calculation of the whole "Root mean square" duration is based on the formula (2.18) as follows:

1) it is considered that the signal in the source has a rectangular envelope duration of TS, then: T Tск,s = TS / 3,5. Duration of the signal in TS source is proportional to the size of the source: TS = LS(MW) / vS. Coefficient vS has a sense as fault velocity in the source;

2) "root mean square" duration of pulse reaction of the environment is estimated by the empirical formula:

Тск,m = T100 х (R / 100). (2.19)

The T100 (duration at R q 100 km) is a customizable input parameter of the algorithm.

A record of a weak earthquake in rock soil can be considered as a "Green's function" of the environment. Therefore, study of the parameters of weak earthquakes allows to obtain the parameters of environment to be used in calculations of the parameters of strong movements.

Dependence of duration of weak earthquakes on distance can be used in calculating the complete duration of the accelerograms using the formulas (2.18) and (2.19). Mean enveloping weak earthquakes are used as encircling the "Green function" of the environment by power when constructing model accelerograms. "Root mean square" and "rectangular" duration can be calculated based on model accelerograms, as well as duration of T0.5 (according to Aptikaev) and T90 (according to Trifunak) and the transition rates from "Root mean square" duration can be determined in relation to duration in other definitions. Enveloping of weak earthquakes also have an independent interest as a form of impulse of scattered waves in actual environment.

According to the definition of "Root mean square" duration, calculation of Tck requires the integration of "tail" of the record (codes) with the weight t2. This results in a significant dependence of the result on random releases in the code, which is undesirable. To eliminate this effect, it is advisable to cut the code off from a group of straight waves. The simplest method proposed by T.G Rautian (in 1981), in which it is believed that the code begins at t = ts + k х (ts - tp). The value of k = 2 factor was determined by saturating the growth of the Tck,m values, with the growth of k.

Micro-seismic noise made significant contribution to the record and thus the result of the calculation of the "Root mean square" duration, respectively. Pattern of distortions is a fictitious increase in Tck,m. Dependence of Tck,m parameter, from R can be approximated by the following linear model: lg Тск,m = а + b lg R, separately for each component and each frequency interval.

When making mean enveloping, it is assumed that the envelope form is stable, i.e. the rationed envelope function has the form of F(t/Tck,m) and F(x) the same for all distances. With distance, only the scale of time that is set by the duration of Tck,m shall be changed. This view allows us to define the small sample as the average rationed enveloping, given to single distance.

Appendix No 3

(for reference)

to the Guide "Determination of initial seismic soil vibrations for design bases"

ASSESSMENT AND GENERATION OF ESTIMATED SEISMIC IMPACTS USING STANDARD SPECTRA

A single Accelerogram with a precisely defined spectrum of reaction can be generated with a view to [17]. There is a method of generating the estimated accelerogram, the spectrum of which SA (T, x = 0.05) in form shall correspond to the dynamic coefficient curve in the applicable SNiP 11-7-81 [4]. Accelerograms can be recorded in the following way:

*,* (3.1)

where:

A(t) - envelope, and the phase angles fi are evenly distributed in the interval from 0 to 2 p random values. A step in the frequency of DELTA omega is determined from smoothness of the reaction spectrum as (omegai - omegai-1) / omegai-1 = 0.06347. Estimations shall be made in periods range from 0.05 to 3 sec. As the first approximation for Vi.1, values directly taken from a given beta (T) curve are used for the corresponding omegai frequency values. Next approximation:

, (3.2)

where:

beta (T) - SNiP curves, and beta1 (T) - curve obtained at the first step of iteration.

The necessary accuracy of estimated spectrum compliance with the given value shall be obtained after a number of iterations. Application of the program in practice has shown that differences of the estimated spectrum from the specified on the periods of T > 0.05 sec. can reach 15% after 10 iterations. In the short-period area, due to systematic errors, the level of the estimated betai curve (T) at periods of Т -> 0 does not reach the values of beta (T = 0) =1. However, proximity of the estimated and preset curves in the engineering interval of periods allows practical applicability of the method.

To move from the base accelerogram a (T) to the estimated value of a (t) should be multiplied by K ratio:

(3.3)

According to SNiP, K shall be accepted at 0.1; 0,2; 0.4 for the estimated seismic amplitude of 7, 8, 9 intensity respectively;

0,12 <= К1 < 1 acceptable damages of structures shall be considered;

0,85 <= mкp <= 1,15 shall consider the recurrence of safe shutdown earthquake.

The selection of calculated spectral curves, acceleration levels and duration of vibrations should be based on the necessary occurrence (risk extent).

Appendix 4

(for reference)

to the Guide "Determination of initial seismic soil vibrations for design bases"

DETERMINATION OF SEISMIC MAGNITUDE TA THE SITE FOR NATURAL AND MAN-INDUCED CONDITIONS

1. Seismic magnitude shall be determined by the macro-seismic intensity of I according to MSK-64.

2. Assessment I uses regional ratios between I, magnitude M and distance to the source r. Assessments of I on empirical ratios relate to the base (level) soil. Intensity I can be defined by the following formula:

I = 1,5M - gamma lg r + c, (4.1)

where gamma, c - coefficients that characterize the damping of seismic magnitude depending on the direction of seismic radiation. For direction of the cross structures gamma =-3.5 - 4.2, c = 3.5 - 4.4 (depending on regional features); for direction along the structures, gamma = -3.0 - 3.4 s; =2.5 -3.3. For mean values, it is recommended to use gamma = -3,5, s = 3,0.

For M = 4.75 - 7.5 and r <= 150 km, the following formula can be used:

I = (0,0075М - 0,08) r + 1,35М. (4.2)

3. Change in the intensity of DELTA Ii due to hydro-geological conditions shall be estimated by the formula:

DELTA Ii = 1,67 lg(ро0 V0 / роi Vi) + Y e-0,04h, (4.3)

where:

ро - soil density;

V - displacement wave propagation velocity;

pо0 V0 and pоi Vi - seismic impedance of reference (0) and examined (i) soil;

h- depth of groundwater level;

Y - coefficient that takes into accounts its impact

Appendix No 5

(for reference)

to the Guide "Determination of initial seismic soil vibrations for design bases"

EXPRESS METHOD OF ASSESSING THE QUANTITATIVE CHARACTERISTICS OF SEISMIC VIBRATIONS OF SOIL OF THE SET PROBABILITY OF EXCESS

1. Input data to perform express assessments:

1.1. Results of the general seismic zoning of the territory of Russia, which establishes the intensity of vibrations at the construction area in points and average period of recurrence of vibrations.

1.2. Research data on the refinement of seismic and tectonic conditions of the prospective construction area or Detailed Seismic Zone (DSZ), which establish location and depth of sources of possible earthquakes, their magnitude, repetition and minimum distance to epicenter.

1.3. Results of seismic micro-zoning of the site, determining the resonant properties of its soils, increment of intensity and amplitude of vibrations and velocity of transverse seismic waves propagation.

1.4. Sampling of max. accelerations of soil vibrations during earthquakes of specified intensity.

1.5. Dynamic and spectral features of the accelerograms of strong earthquakes and their reaction spectrum depending on the parameters of the earthquake center (magnitude M), epicenter distance of DELTA and the soil conditions at the point of dats registration.

2. Estimation of seismic vibrations of soil

Direct comparison of the accelerograms of different earthquakes is extremely difficult, so questions of predicting the level and form of the seismic impact of the specified probability of excess shall be considered in relation to the spectrum of soil reaction.

An advantage of this approach is in the ability to compare qualitative and quantitatively predictive and normative seismic impacts.

2.1. Normative seismic impact ̄ that is considered in the calculation of seismic resistance of buildings and structures according to spectral-dynamic theory, shall be determined by the formula:

, (5.1)

where:

T - period of free vibrations of buildings and structures;

- rated acceleration;

- dynamic coefficient;

2.2. The level of normative seismic impact shall be determined by the normative acceleration of soil vibrations 0.1; 0.2 and 0.4 g with the calculated seismic magnitude of the site respectively 7, 8 and 9. The effect of recurrence of vibrations in the standards is partly taken into account by the factor mkp.

2.3. The form of normative seismic impact is set by the beta (T) dynamic factor curve, which is independent on intensity of the earthquake and is fully determined by the type of soil conditions.

The normative seismic impacts established with the ratio (5.1) are close to average values and may differ significantly from the reaction spectrum of real accelerograms. This difference can be due to: the difference between real and normative levels of acceleration in an earthquake of a given intensity; the difference between ordinates of the real earthquake reaction spectrums and the normative beta (T) dynamic curve. Probability exceeding the normative acceleration above the actual PJ during an earthquake of the specified intensity J ~= 0.35; probability of exceeding the beta (T) curve above the level of the given reaction spectrum |Sа (T)| of the real earthquake is about 0.5.

2.4. Complete probability of exceeding the normative seismic impact at a given probability PJ of earthquake by the intensity J in the first approximation can be estimated by the following formula:

. (5.2)

2.5. It is possible to estimate the annual probability of PJ for the average period of recurrence of vibrations of the specified TJ intensity, assuming that the nature of propagation of earthquakes over time is subject to Poisson law:

PJ = 1 - exp(-1 / ТJ). (5.3)

When TJ values are fairly big, you can use a simpler ratio instead (5.3):

РJ = 1 / ТJ.

If you need to take into account the object operating life t0, the formula (5.3) can be presented as follows:

РJ = 1 - exp(-t0 / ТJ).

2.6. Probability of exceeding the normative seismic impacts for earthquake zones with a recurrence of vibration is equal 1 to 100, 1000 and 10,000 years and respectively they are equal:

;

The calculated probability of exceeding the normative seismic impacts below the level of probability of the design basis earthquake is commensurate with the level of probability of the safe shutdown earthquake and exceeds the reference level of probability of events Pkyv.

2.7. To determine the level of estimated seismic impacts, the probability of exceeding Pkyv<= 10 -6 year -1, shall be taken into account:

- the strongest earthquakes are characterized by more rare recurrence;

- increase in the level of estimated accelerations compared to normative accelerations;

- generalized curves of these reaction spectrum exceeding the level of normative curves.

2.8. Between the levels of max. acceleration of soil vibrations aPJ, probability of exceeding this acceleration and the normative estimated acceleration at the specified intensity of the earthquake J there is a correlation dependence in the form of [30]:

, (5.4)

where the expression in brackets is safety factor Ksaf, which ensures the transition from the normative seismic impact to the impact of aPJ of the specified probability related to the exceeding

2.9. Safety factor Ksaf, which provides a given level of probability of the seismic impact excess, are given in Table. 5.1, where the values Ksaf for ~= Рkyv = 10-6 when Рbeta (Т) ~= 0,5 for different periods of vibrations recurrence ТJ and the object operating life t0.

Table 5.1

SAFETY COEFFICIENTS VALUES

|  |  |  |  |
| --- | --- | --- | --- |
| t0, years | Values К without for Рk.y.b = 10-6 year-1 when betam ~= 0,5 | | |
| TJ | | |
| 100 | 1000 | 10000 (4545) <\*> |
| 1 | 3.1  (1,8) | 2.5  (1,2) | 1.8  (0,6) |
| 30 | 4 | 3.4 | 2.8 |
| 100 | 4.2 | 3.7 | 3.1 |
| 1000 | 4.4 | 4.2 | 3.7 |

----------------------------

<\*> The values of Ksaf calculated for the probability of exceeding ~= 10-4 for the recurrence of vibrations once every 100, 1000 and 4545 years are given in brackets.

2.10. Assessment of the shape of the soil reaction spectrum for specific seismic and geological conditions is based on:

- spectrum of reaction of analog accelerator, recommended for different zones of seismic magnitude of the territory [31];

- spectrum of reaction of California and other earthquakes.

The level of maximum reaction of linear oscillators in the low-frequency area (less than 4 Hz) - enveloping Senv (T, delta) of response spectrum of the real earthquakes, rationed to the max. acceleration of soil amax (Figure 5.1 - not given) [32].

Senv (Т0, delta) = 2,55Кdelta √Т0 , (5.5)

where Кdelta = 8 / (delta + 3,3) + 0,4.

2.11. Selective estimates of average dynamic and standard deviations, shall be made for different values of own periods of linear oscillators in the range of periods 0.2 - 4 s, allowed to establish the following:

- decrease in the average value of dynamic factor with the growth of its own period of linear oscillator;

- dependence of the standard sigma deviation on T0 linear oscillator period and the mean dynamic ratio for damping 5% critical vcan be presented in the form of:

sigma = (0,34 + 0,3Т0) . (5.6)

2.12. The average dynamic coefficients for the range of periods 0.2 to 4 sec. are shown in Fig. 5.1 (curve 6) and they are satisfactory consistent with the normative curves of beta (T) dynamic factor for the first, second and third categories per the seismic properties (curves 2, 3 and 4 in Figure 5.1, respectively). The same image shows the standard curve rationed to maximum acceleration of the response spectrum (curve 5), recommended by IAEA for the horizontal component when damping is 5% [2].

2.13. The curve of generalized spectrum of soil reaction depending on the characteristic period of Tmax can be recorded in the form of [33] :

, (5.7)

where:

Тi - soil vibration period;

d - damping value.

2.14. Effect of the velocity of the transverse seismic waves propagation vs, m/s, on the damping velocity shall be estimated by the formula:

d ~= -0,2 + 0,8 log vs. (5.8)

2.15. To assess the form (shape) of the generalized spectrum of ground reaction for specific conditions, it is necessary to have information about the characteristic period of Tmax reaction spectrum and the velocity of transverse seismic waves propagation on the site.

2.16. The specific period of reaction spectrum [33] Tmax is based on empirical dependence:

, (5.9)

where: Tres - a resonant period of vibrations in the site soil, shall be determined experimentally or by the following estimation:

Тres = 4h / vs, (5.10)

where:

h - power of layer, (м);

vs - transverse wave propagation velocity, m/sec;

2.17. The level of the predicted spectrum reaction Spre shall be determined by the value of safety factor Ksaf, maximum acceleration of soil , the level of the enveloping spectra of the Senv (T, delta), set for the characteristic period of Tmax reaction spectrum (at Тi = Тmax) by the formula (5.5), and the weakening factor Kweak, taking into account the difference in the level of spectrum Sa (T) at the same specific periods:

*,* (5.11)

where Кosl = -1,7 + 0,9 log vs where 100 m/s < vs < 1000 m/s.

If vs >= 1000 m/s Кosl = 1, and if vs <= 100 m/s = 0,1.

2.18. Average max. acceleration of soil , cm/sq.s, in an earthquake of a given intensity J can be estimated by the formula [31]:

; (5.12)

(5.13)

2.19. The average max. acceleration is almost identical to the normative estimated acceleration in the earthquake of the specified intensity of J when 0,1 с <= Тi <= 0,5 s.

2.20. Intensity of the earthquake J at the known parameters of the source (magnitude M, the depth of the source H) and the epicenter distance DELTA, as well as coefficients of the equation of the micro- seismic field a, b, c and soil conditions on the site can be estimated by the formula of the macro-seismic field [19].

Appendix No 6

(for reference)

to the Guide "Determination of initial seismic soil vibrations for design bases"

LIST OF INFORMATION SOURCES

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Appendix No 7

(for reference)

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LIST OF  
 MATERIALS ON THE DEEP STRUCTURE OF THE EARTH INTERRIOR

A set of maps on the geological structure and physical condition of the underground resources - Section 2 in the Geological Atlas of Russia 1:1000000, M. - S.-Pb., 1996.

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Director of Research and Development Center for Nuclear Radiation Safety

B.G. Gordon