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СЕЙСМИЧЕСКИЕ ЭФФЕКТЫ, ВЫЗВАННЫЕ ПРОПУСКОМ ПАВОДКОВ ЧЕРЕЗ ГИДРОУЗЛЫ

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Рассматриваются результаты натурных наблюдений за вибрациями водосливной плотины Жигулевского гидроузла, поверхности грунта и жилых домов, расположенных на окружающей территории, при различных расходах и различных схемах пропуска паводка. Амплитуда вибраций каждой секции плотины прямо пропорциональна удельному расходу воды, сбрасываемой через секцию плотины, и слабо зависит от режима пропуска паводка. Обнаружен факт самосинхронизации колебаний отдельных секций плотины. При этом плотина начинает двигаться как единый жесткий штамп на упругом основании, а колебания поверхности грунта на фиксированном расстоянии от плотины резко усиливаются. Представлены результаты измерений вибраций домов разной конструкции на разном расстоянии от плотины. Выявлена зависимость параметров вибрации от режима пропуска паводков. Даны рекомендации по снижению вибраций домов. Определены параметры паводков, при которых вибрации домов превысят санитарные нормы.

Ключевые слова: сейсмические эффекты, самосинхронизация колебаний, вибрации, водосливная плотина, Жигулёвский гидроузел, санитарные нормы.

SEISMIC EFFECTS CAUSED BY DISCHARGED WATER THROUGH THE WATERWORKS

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The paper discusses the field observation results of the vibration of the spillway dam Zhiguli hydroelectric station, the ground surface and residential buildings located in the surrounding area at various flood discharges and various schemes of flood evacuation. The amplitude of vibration of each section of the dam is directly proportional to the specific consumption of water discharged through the section of the dam and weakly depends on the mode flood evacuation. It is discovered the fact of self-synchronization of the oscillations of the individual sections of the dam. The dam begins to move as a single rigid stamp on the elastic foundation. Oscillations of the ground surface grow sharply at a fixed distance from the dam. The paper presents the results of measurements of the different designs houses vibration at different distances from the dam and the dependence of vibration parameters from the floods skip mode. There are recommendations for reducing houses vibration. The research defines flood parameters, in which homes vibration will exceed health standards.

Key words: seismic effects, self-synchronization of oscillations, vibrations, spillway, Zhiguli waterworks, sanitary norms.

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1. Introduction

Significant houses vibration in the left region of town Tolliatti (Samara area, Russia), adjacent to the dam Zhigulevskaya HPP on the river Volga (Fig. 1) was found in the spring flood of 1979. The tenants of the upper floors of the 9- and 14-storey houses, separated from the dam for 2–4 km, were the first who felt this vibration. It was also suggested that vibration of buildings and cracks in the cladding of buildings associated with passage through the hydro system high flooding. In order to test this assumption and search measures to eliminate or reduce the observed vibrations there have been conducted field, laboratory and computational research, reflecting conditions floods 1979, 1980, 2005 and 2006 years. The main result of these studies is that under certain conditions the fluctuations in the individual sections of the dam on the General soil Foundation synchronized the dam begins to move as a single stamp with a large characteristic size equal to the length of the dam [1]. The radius of the attenuation vibrations zone from a vibration source is proportional to the size of the stamp, so increasing the current size of the stamp area perceptible vibrations propagating from the hydro system, growing and covering many houses. Choosing the scheme of maneuver gates of the dam, you can reduce the danger of oscillations synchronization in the low pass floods.

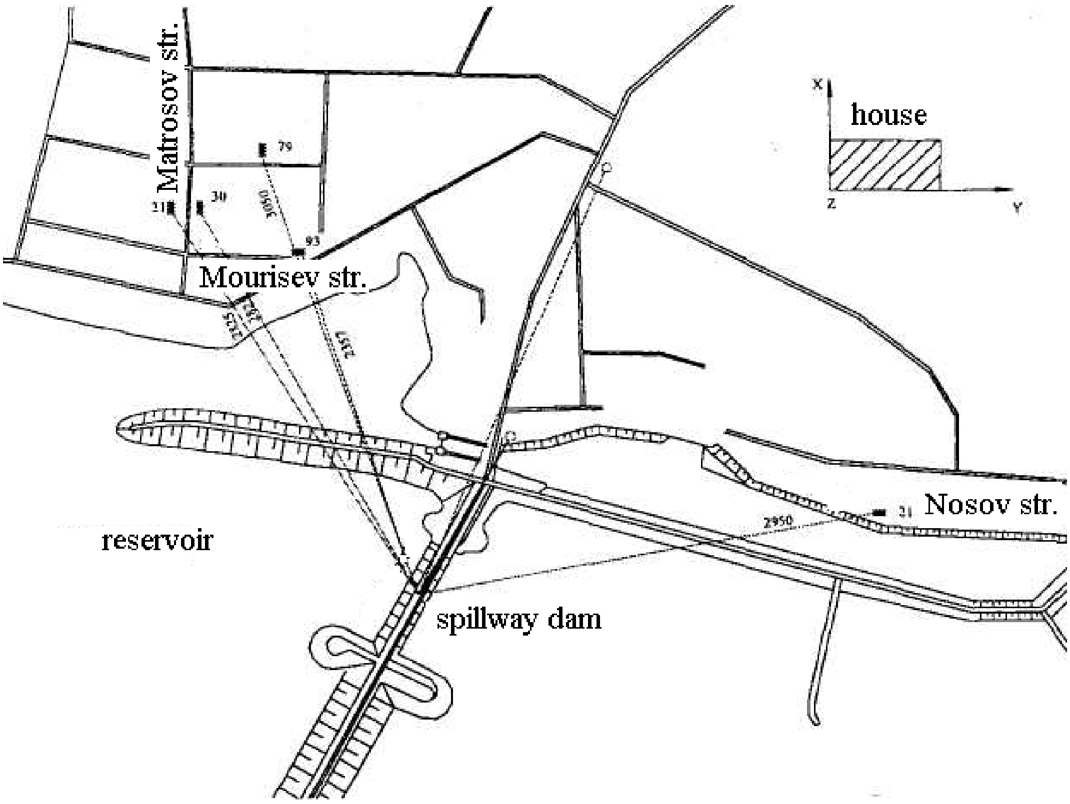

Fig. 1. The scheme of the waterworks and left surveyed houses

The composition of the basic structures Zhigulevskaya HPP includes Spillway Dam (SD); power house with Trash Construction (TC); groundwater dam and levees; shipping gateways. The power house is located on the right Bank and consists of 10 sections. In each section there are two units and four bottom of the spillway. The concrete spillway dam (SD) is located on the left Bank floodplain of the river Volga. Alluvial Sands with layers of clay and loam is overlain at the base of the dam. Alluvial deposits are underlain by indigenous clays. The concrete spillway dam Zhiguli hydroelectric station has a spread profile. The length of the dam is about 1009.2 m. Spillway front of the dam consists of 19 sections (38 spans of 20 m) and designed to permit 40300 m^3/s when the level in the reservoir at elevation 53.0 m. Section of the dam has a length of 52 m (the length of the side sections 62.6 m), the width of the sections 58 m. Weight of standard section is 98000 t. The main energy of the flow is extinguished on tread water fight, which consists of two parts. The first water fight is a reinforced concrete slab size 52 x 26 x 5,6 m. Two rows of power dissipaters and water power dissipater in form wall with trapezoidal cross-section are located on the stove. The second water fight is made in the form of plates with a thickness of 4.5 m at the end of which the second water wall is located. Expansion joints are located across 26 m in length plate.

The bottom of the concrete dam and left the village are alluvial sandy sediments with gravel-pebble layers. Confining bed lies at a depth of 40-50 m; groundwater level in the residential district is located at a depth of 15-20 m from the ground surface. In the Nosov Street it is significantly higher at a depth of ~ 1.0 m.

Each section combines two spillway span of the light 20 meters. The head on the crest of the Weir at normal reservoir level (NL) is equal to 9.5 m. Throughput of a single span with NL depending on the shutter:

Opening, m 0.5; 1.0;1.5; 2.0; 2.5; 3.0; 3.5; Full.

Flow rate, m^3/s 81;165; 252; 335; 420; 500; 579; 1000.

The water fight dams are devices for absorbing energy in the form of checkers against medium spans and low wall against extreme. Specific consumption of water on the apron in the estimated flood is 40 m^2/s, the local maximum up to 52 m^2/s. To ensure reliable energy dissipation and flood hydraulic jump downstream of the dam under all operating conditions schema damping in the form of two rows of checkerboard are applied.

Plate water fight, lying on the wet ground, is narrow resonance system and can draw energy fluctuations with relatively small effects. Due to these fluctuations, the surface elastic waves arise and spread in the Foundation soil. These waves are involved in the oscillations of the other water boards, the spillway section of the dam, earth structures and coastal samples. Elastic waves propagating from the base of the dam cause fluctuations in residential buildings, situated on the left Bank of the Volga in 2-3 km from the dam (Fig.1).

In 1979-80 flood passage was carried out according to the following schemes.

Scheme 1. Even the opening of 3.5 m; 2,5 m; 1.0 m and 0.5 m – modes No. 2, 6, 13 and 14, the flow through the dam Q = 25200, 11200, 3900 and 1920 m^3/s). The numbering of the sections is from the right Bank.

Scheme 2. The concentration of spending on the narrow front of the dam near the right Bank (subject to the current instructions for maneuvering valves, developed from the condition of minimum deformation of the riverbed downstream) – modes No. 3, 7, 10 (Q= 17500, 11066, 5730 m^3/s).

Scheme 3. Water discharge private jets, spaced across the width of the spillway front – modes № 4, 5, 8, 9, 11 (Q= 15980, 16690, 7900 and 5730 m^3/s). The distance between the jets in these modes varied from 2 to 10 spans (from 52 to 260 m).

The distribution of expenditures on the front of the dam in the experimental schemes 2 and No. 3 aims to reduce vibration of the dam and its influence on the left Bank of the buildings either due to the distance of the main source of vibration or due to the differences of the oscillations phases of the dam sections and the water fight, loaded uncorrelated jets.

The vibration of the dam was measured mainly in the postern. Vertical component of movement is recorded. In mode No. 2-5 measurements were carried out in two basic points (sections # 3 and # 10) and one variable, the following successively the numbers of sections (numbering from the right Bank). In mode No. 8-14 the oscillations were recorded simultaneously in seven points (three elementary and four variables). Account of the free soil fluctuations was carried out along the cross-section of the dam at distances of 1.5; 4.0 and 5.5 km from its center. On the open ground and in the postern of the dam the simultaneous recording of vertical displacements for mode No. 5. 10-15 m from buildings was carried out and on the upper floors three components of velocity shifts in modes No. 2 - 5 and No. 14 were recorded.

When skipping floods of 2005 and 2006 vibration studies conducted for eight schemes open spans SD from 0.5 to 3.5 m, the relative costs of the sections ranged from 6.1 to 29.7 m^2/s. Total expenditure SD was within 10660-16096 m^3/s

Check of SD vibration was carried out on sections 1, 5, 10 and 15, at three points along the height of the section (Fig. 2):

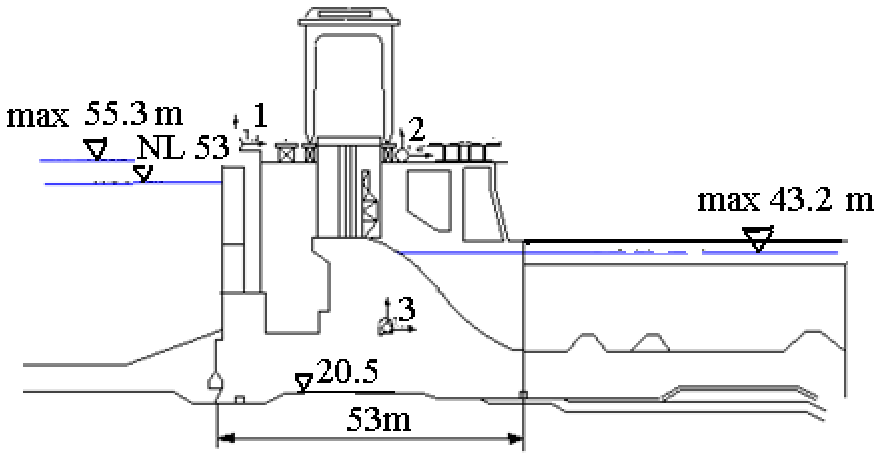

Fig. 2. The point of vibration measurements on sections of the spillway dam

Fluctuations houses were recorded synchronously in three points: 1 - on the first floor, 2 - on the last floor; 3 - on the ground 10 meters from the house.

Fluctuations houses were recorded in three main areas: X is along the short side of the house (the lowest hardness), Y - along the long side of the house (maximum rigidity), Z - vertical vibrations.

Ground vibration outside the SD was recorded five points in the direction of the investigated houses residential area (Fig. 1):

So 1 - 600 m from the middle of the SD; So 2 - 1300 m from the middle of the SD ; So 3 - 3260 m from the middle of the SD; So 4 - 2360 m from the middle of the SD ; So 5 - 1900 m from the middle of the SD.

The order and size of the gate opening SD were assigned according to the results of previous studies - field (2005, 1979-1980 years), model and calculation at constant flow rate SD16000 m^3/s.

In option 1, the concentrated discharge was performed three fronts with a maximum opening at 3.0 m spans in sections 7, 8, 11, 12, 15, 16. The flights left sections 2 and 3 are open at 2.0 m section 1 - 1.5 m.

In option 2, the discharge was carried out three fronts, but the spans of sections 8, 12 and 16 opened at 3.5 m.

In option 3, the concentrated discharge was carried out four fronts with a maximum open span 3.0 m. Spans sections 4, 5 and 6 were opened at 2.5 m, and sections 1 and 2 by 1.5 meters. This option is open bays of the spillway of the dam closest to the uniform scheme opening.

In all three embodiments, the spans of the left Bank of the sections, in accordance with the recommendations, were opened at a lower value.

2. The Vibration of the Dam

When water flow pass through SD basic hydrodynamic loads associated with exposure to turbulent flow occur on the plates of the water fight due to pressure fluctuations on the surface of the plates. Changes in pressure pulsations along the length of the water fight are such that the main share of the pulsating load is concentrated on the first plate of the water fight. Due to the averaging of the load on square plate range of total load is significantly lower dominant frequency of the pressure pulsations in the points. Major fluctuations in the spillway section of the dam are associated with the passage of ground waves from the water boards and the adjacent sections. Consideration of the waveform and correlation analysis showed that the vibration separate section combines the features of a random stationary process and unsteady beating with an almost constant period. Fluctuations beats due to the fact that the plates of the water fight and sections of the dam are connected through the subgrade and have similar natural frequencies. Displacement of vibration any section is closely associated with a specific flow rate discharged through this section. The open mode of the remaining sections of the dam has relatively small effect on the oscillations of the considered section. Influence of the mode of opening of the dam gates maximum at the highest unit costs, however, in the considered range of cost changes it in any case does not exceed 15 % (Fig. 3).

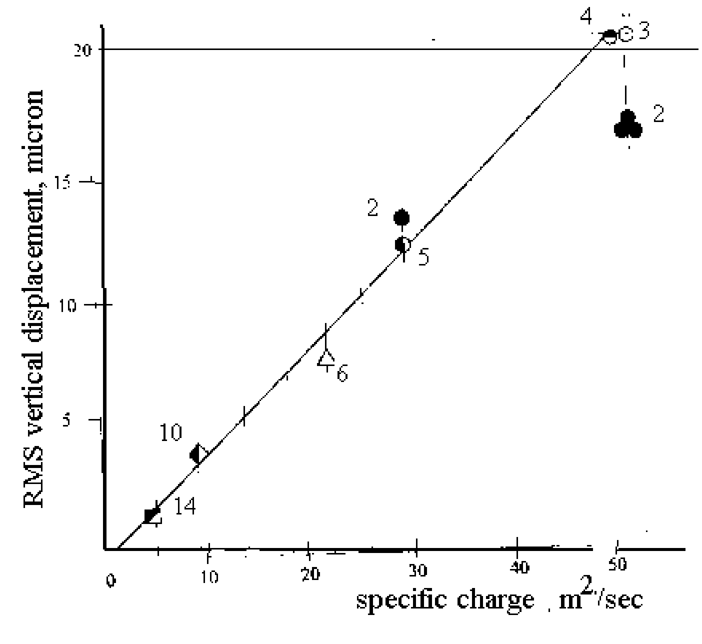

Fig. 3. The impact of specific consumption standards vertical vibration of the dam Measuring 1979-60. The numbers of points - number of modes

A straight line on Fig. 3 is described by the formula

$$Z' = -1{,}9 + 0{,}8\,q\,,$$

here Z' is the root mean square value of the vertical displacement of the sections (μk), q is measured in m^2/s. The highest standards of vertical vibrations of the dam sections during the initial period of operation were recorded in 1957 and amounted to: Z' = 25,8 μk at q = 36,2 m^2/s and the coefficient of flooding hydraulic jump downstream of the dam = 1,1. The results of the RMS estimates vibration of section No. 10 research 1957-60 and 1979-1980 years are shown in Fig. 4.

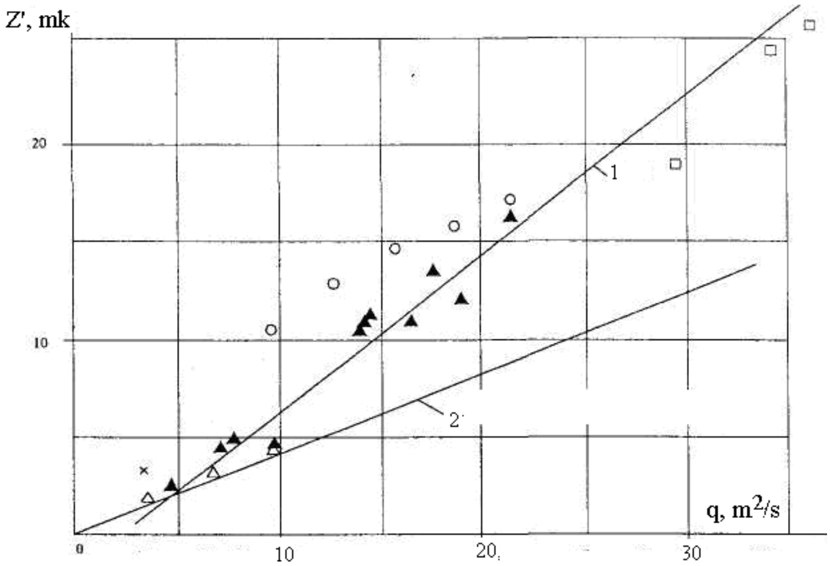

Fig. 4. The dependence of the standard vertical vibration section 10 of SD from specific consumption on the crest
1 – early measurements (1957-60), 2 – results from 1979-80 years

Standards of vibration of each section are closely related to the magnitude of the flow discharged through the section. Figure 5 contains the results of all measurement standards vibration of the dam. As you can see in 25 years (after 1980) properties of the oscillating system "Dam-Foundation" almost has not changed.

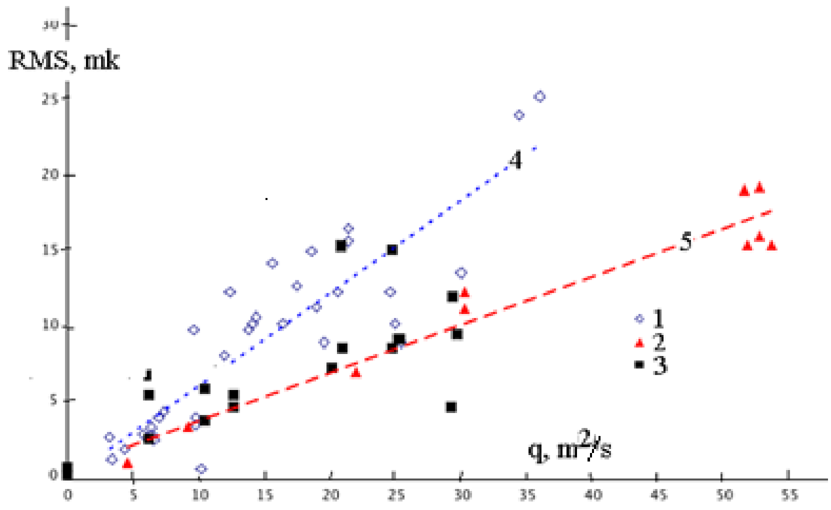

Fig. 5. The dependence of the standard deviations (RMS, μk) vertical displacement of the sections SD from specific consumption section. Summary of results.
1 - section 10 (1957-1960); 2 - sections 3, 10 (1979-1980); 3 - sections 1, 5, 10, 15 (2005); 4 - section 10 (1957-1960)%
5 - sections 3, 10 (1979-1980), 1, 5, 10, 15 (2005)

Comparison of measurements made for 20 years, in the previous period (1960-80), shows a slight increase in the effective stiffness of the system - standards vibration became significantly lower. The dependence of the maximum magnitude of vibration of the individual sections from the corresponding specific consumption is less stable (Fig. 6).

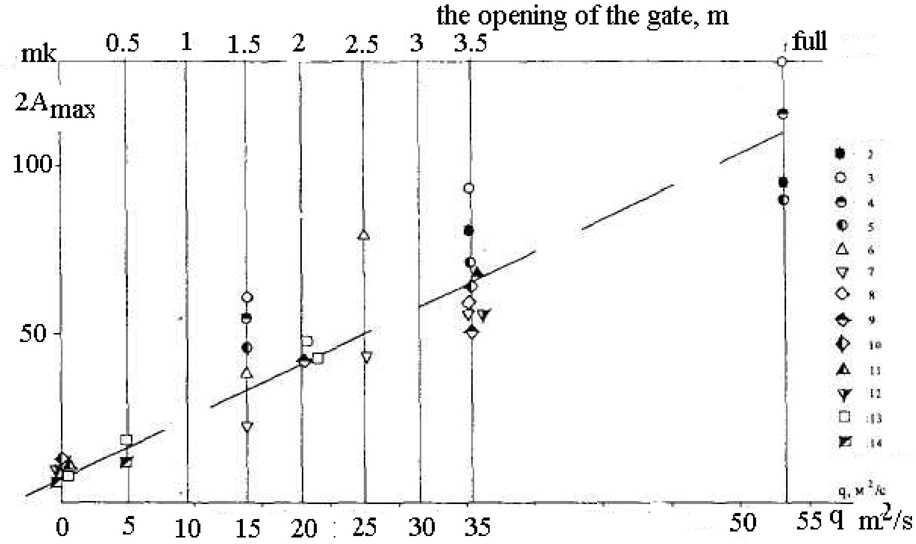

Fig. 6. The average value of the amplitude of the vibration ($2A_{max}$ - the difference between the maximum and minimum of vibration displacement) sections of the dam depending on the specific consumption of water through the section under different regimes of water passes through the dam. Non – label ingregimes

The scatter of results is significantly greater. This means that when the same specific discharge in the section, but with different modes of opening of the dam gates distribution functions of vibration (and fluctuations) can be significantly different. Figure 7 shows the results of calculations of the average ($2A_{max}$) and RMS ($2A_{max}$) the magnitude of oscillations of the dam depending on the total flow of water through the dam.

Here:

$2A_{max} = \Sigma\ (2A_{max})_i/N$,

$2A_{max} = \sqrt{\Sigma\ (2A_{max})^2_i/N}$,

where N is the number of blocks of the dam.

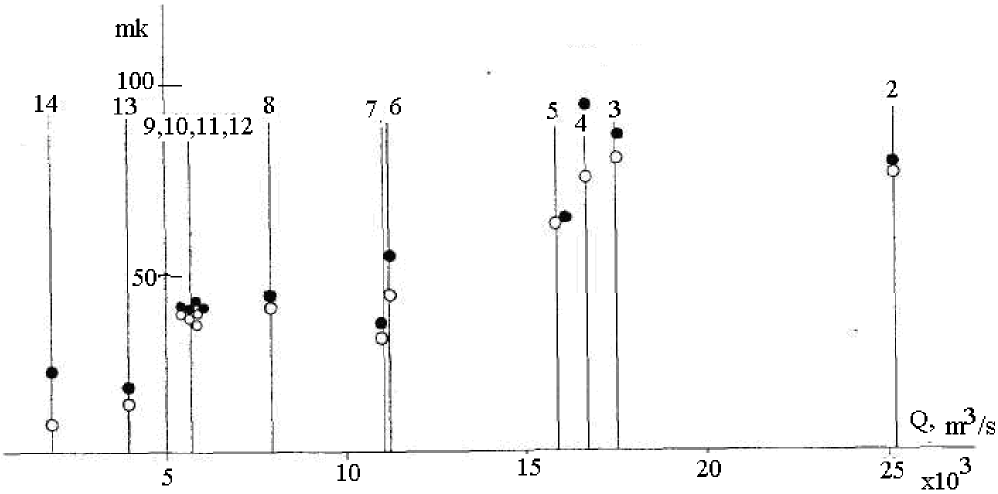

Fig. 7. The dependence of the averaged magnitudes of dam vibration $2A_{max}$ as the function of flow rate Q through the spillway dam: empty points - $2A_{max}$ the maximum magnitude of vibration taken by sections of the dam, averaged along the dam; black points - $2A_{max}$ RMS value of the maximum magnitude of vibration, averaged along the dam. Non – label in regimes

The amplitude of oscillations depends on the allocation of consumption across the front dam. Qualitatively this result is explained by the fact that various recognition modes of consumption change the correlation between fluctuations in different sections. Self-synchronization of the oscillations of the individual sections is often observed with a uniform distribution of flow (Fig. 8).

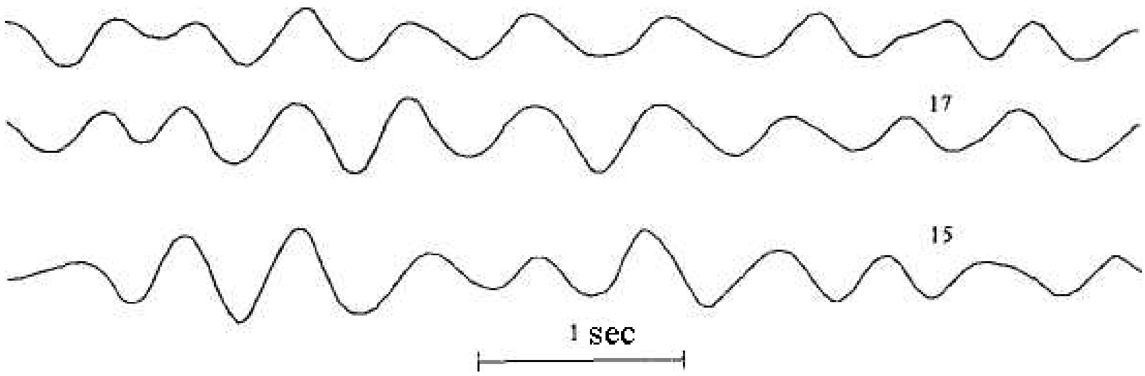

Fig. 8. Some examples of sin-phase oscillations of the dam sections

Uneven opening of the gates reduces this effect. In this case, the correlation between the fluctuations of the individual sections of the dam is relatively small. The correlation coefficient does not exceed 0.5 even for adjacent sections. On the mutual correlation function of the vibration sections No 9 and No 10 we can clearly see oscillations corresponding to the natural frequencies of the fundamental tone, and, most importantly, visible oscillations of the type of beats detected during visual analysis of the records (Fig. 9).

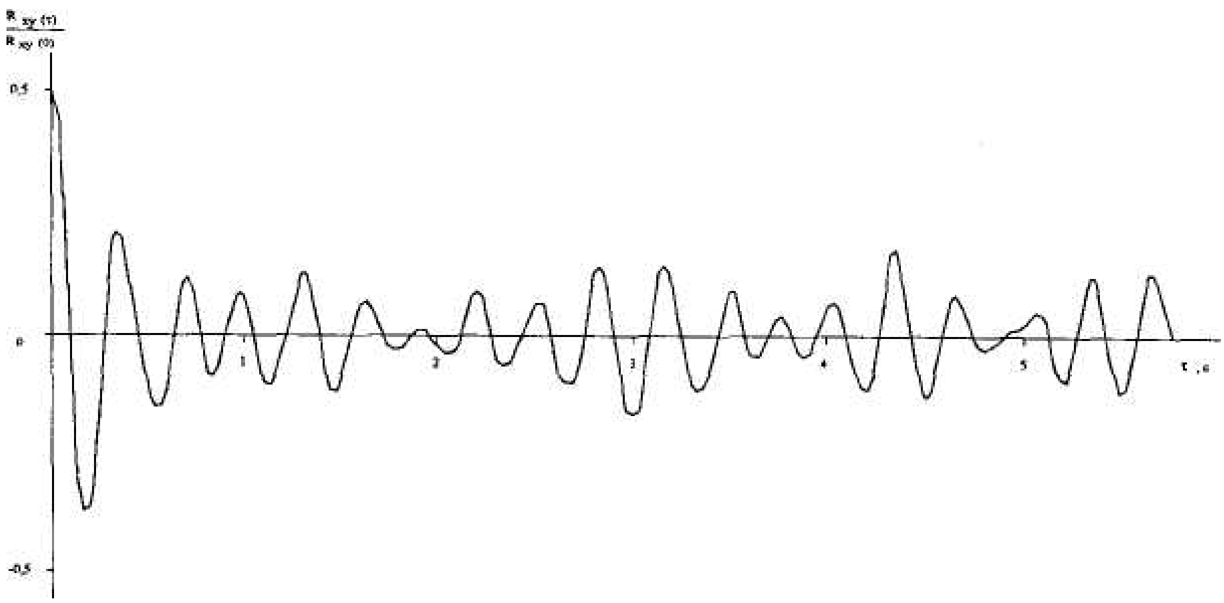

Fig. 9. Mutually correlation function of adjacent sections of dams No. 9, 10. Mode 2

These features of the movements were identified and the autocorrelation functions of the vibration section 10 in different modes (3 and 6). With a uniform opening of the dam (modes 2 and 6) the period of oscillations of the section is about 0.6 s (frequency about of 1.66 Hz). When a concentrated discharge through the spillway section (3), the period of oscillations of slightly increased (to 0.65). The appearance of the autocorrelation function does not change much, because the beats are saved due to fluctuations in the neighboring sections. Measurement of the vibration sections of the dam, completed in the spring of 2005, showed that the normalized vibration spectra of different sections of the dam have very similar form irrespective of the value of specific consumption of water discharged through the section (Fig. 10).

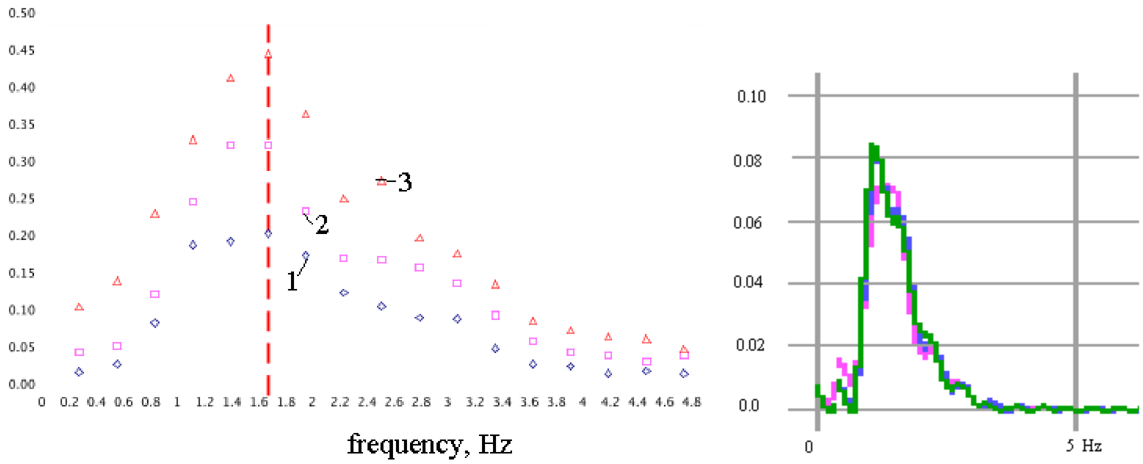

Fig. 10. The original (left) and normalized spectra of vertical oscillations of neighboring sections (1, 2 and 3) of the dam on the measurement at 2005 year. The normalized one was made by dispersion. Flow discharge throw SD 15400 m^3/s.
1 - section 1 (gates section open at 0.5 and 1.0 m), 2 - section 2 (gates section open at 1.5 and 2.5 m),
3 - section 3 (gates section open at 2.5 and 2.5 m)

Mode change flood evacuation little changes the shape of the vibrations spectra.

Studies conducted in 1957-1960 showed that when the water discharge through one span of the period of oscillations of the section corresponding to the maximum spectral density was about to 0.65, which corresponds to a frequency of about 1.5 Hz. Comparison of the frequencies shows that after 20 years of operation of the hydro system, the rigidity of the base has increased by about 20% (change frequency from 1.5 to 1.66 Hz (10%) is equivalent to the change in the elastic modulus at 20%). This trend is consistent with the results of the comparison of the standards of the vibrations shown in Fig. 4, 5. Over the past period of irreversible deformation structures were not observed. Therefore, a detectable increase in dynamic stiffness can be associated with an increase in stiffness of the pore fluid, for example, by dissolving gases available in the initial period.

The base of the sections moves predominantly in a vertical direction and may slightly rotate around a horizontal axis perpendicular to the flow. This can be judged by the trajectories of the movements of the characteristic points of the profile of the dam - dry tunnel in the dam (“poterny”) and the top of the calf (Fig. 11).

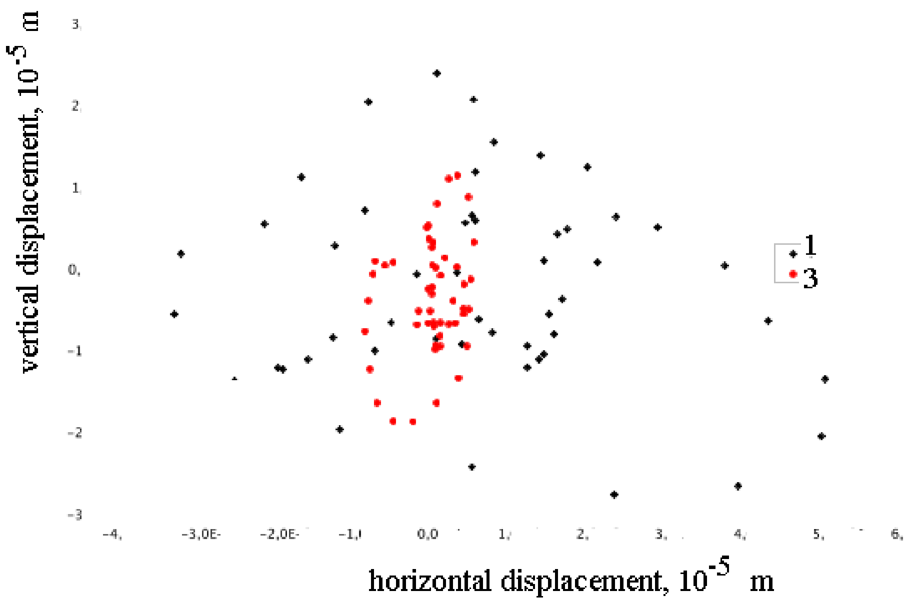

Fig. 11. Trajectory section 5 VSP. Motion 2 sec. Mode 6.Point 1 - on the bull at level 59.15 m, point 3 - in the dry tunnel at level 27.50 m. Gates section opened at 3.5 m

On the basis of the obtained materials, you can make the following conclusions.

1. The amplitude of the individual sections of the dam is almost determined by the specific consumption discharged through the section;

2. When the maximum specific consumption of standard vibration section can reach 20 MK; a reset of the flood affects the phase relation of the oscillation sections: under uniform discharge flow possible self-synchronization of oscillations, uneven reset possible mutual damping of the oscillations. These effects can cause variation in the standard vibration separate sections, not exceeding 30% of the maximum assessment standard (± from the mean). Increase (or decrease) standard vibration by matching or mismatch fluctuation will not exceed 6 MK;

3. A more important result of self-synchronization of oscillations may be changing the conditions of propagation of the disturbances from the dam. When non-synchronous vibrations sections of these perturbations decay at a distance of 4÷5 characteristic size of the partition, i.e. at a distance of about 0.3 km In the case of self-synchronization of oscillations corresponding distance will increase 19÷20 times!

The same form of the spectra of the different sections can mean the following:

- each section is a linear dynamical system and has the same dynamic characteristics (the same sharply-resonant transfer function);
- all sections move as a single unit with a single dynamic characteristic;
- each of the previous option are not constantly, and in some periods, the relative duration of which depends on the mode of admission of water through the dam as a whole (from the schematic maneuvering gates).

Considering the distribution of fluctuations outside of the dam, torsional vibrations of the base sections can be ignored. Thus, we can restrict the study of the vertical motion of the rigid stamps on the elastic of saturated base.

3. Soil Vibration Outside of the Dam

The emergence of in-phase oscillations of the dam with a maximum amplitude means, in certain intervals of time duration of 1 ÷4 period of oscillation of the dam (section and the water fight) varies as a single stamp; while the length of such a stamp depends on the nature and form of elastic waves. With a uniform opening of the gates at the front of the dam in the soil the intermittently plane wave may occur, which is not reborn in spherical up approach to residential homes. As is known [2] that is, if the distance from the source of disturbance does not exceed three lengths of the stamp. With the decrease in front of the big discoveries of the waves in the paddles ground up approach to residential homes acquire a spherical shape and heavily damped. When discoveries in mode 3 (a private jet), the two ones go three sources creates a two (or three) basic spherical waves, interfering respectively phase states at the point of the meeting. Measuring oscillations of the ground surface are produced about houses and free undeveloped territory.

The nature of the process fluctuations in soil with distance from the spillway of the dam varies from quasi-stationary random until sinusoidal fragments. Spectral analysis of the speed fluctuation of the soil showed that the spectrum is quite wide from 1.1 to 2.5 Hz. However, the main vibrations are at a frequency of 1.5 to 1.6 Hz. At distances from 1.5 km to 5.5 km from the dam (on its axis) transversal and longitudinal components of ground displacement are almost the same. 1.5 km from the dam standard velocity of the soil amounted to 0.06 mm/sec. In the area of residential houses intensity of ground vibrations decreases in 2 times - up to a 0.035 mm/s. The highest vibration levels are recorded here for mode 2 (scheme 1) - V ' = 0.042 mm/sec, at least pass flow scheme 3 mode 5 - V ' = 0,016 mm/s. Here V' is the standard *(RMS)* horizontal components of the velocities vibration of the soil. Vibration spectra of soil at different distances from the dam is very similar to the spectra of fluctuations of the dam (Fig. 12).

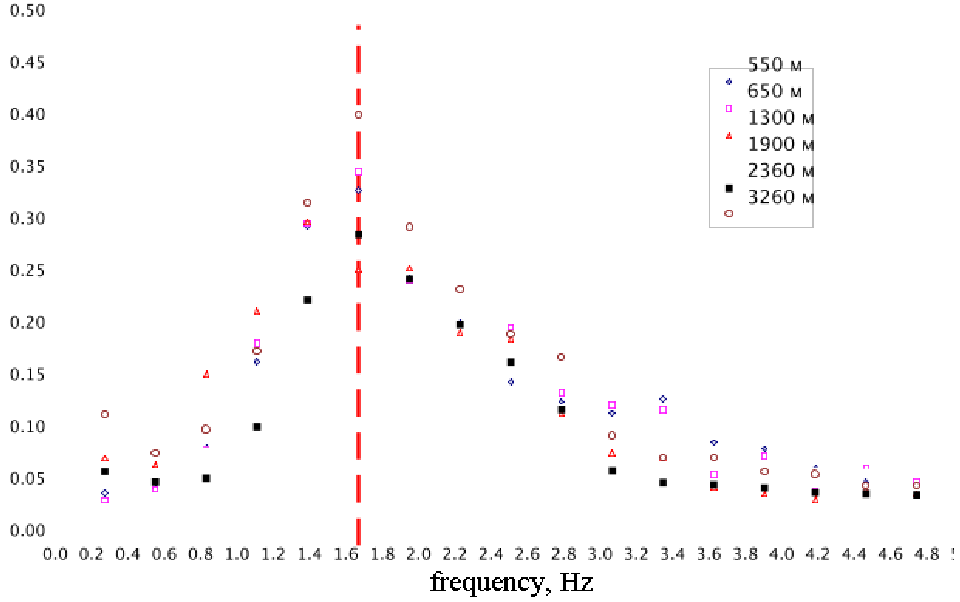

Fig. 12. Vibration spectra of the soil at different distances from the dam on the measurement 2005

The damping of the surface of an elastic half-space fluctuations hard (and flexible) dies of various shapes has been studied in detail both theoretically and experimentally [2]. It is established that the decrease in the amplitude of oscillations of the surface of the pound as the distance from the stamp can be described as

$$\frac{z'}{z'_0} = \left(\frac{x}{2l}\right)^{-\psi} \quad \text{or} \quad \log z' = C - \psi \log x,$$

where $2l$ is the width (or length) of the stamp, x is the distance from the center of the stamp; the exponent ψ depends on the form of a stamp in the plan and spectral composition fluctuations, remaining in the range $0{,}5<\psi\leq 2$.

Figure 13 presents the results of measurements of standard oscillations of the ground surface speed, held at distances of 1.5 and 4 km from the centre of the oscillating four sections of the dam along its axis in mode 3 (empty points) scale I. It is also shown the results of measurements published in [3], in the propagation of vibrations from one section of the dam (black points scale II). For line I (synchronous oscillations partition groups) ψ is a little more than 0.5, and for the line II (oscillations of one section) ψ is close to 1.

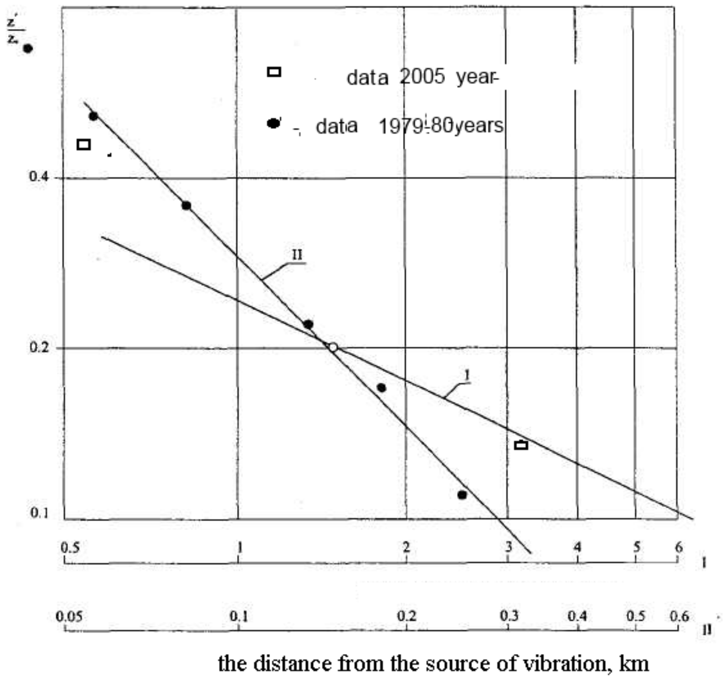

Fig. 13. Relative values of displacements RMS at different distances from the source

The reduction of vibrations on the order of magnitude (10 times) fluctuations in one section takes place at distances of ~ 0.3 km, and with variations of the dam as a whole (or large part) - at distances up to 6 ÷ 7 km. Figure 14 shows the spectral density of fluctuations in the speed of the ground at a distance of 1.5 km from the dam from measurements of 1979-80. The maximum of the spectrum is observed at a frequency of about 1.5-n 1,6 Hz, which corresponds to the frequency of natural oscillations of the sections of the dam.

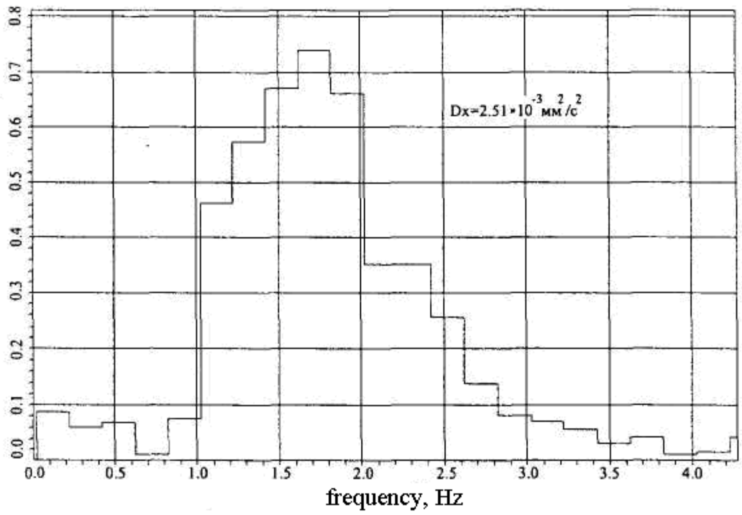

Fig. 14. The normalized spectrum of the vibration of the "free" ground 1.5 km from the centre of the dam. Mode 3 in 1979-80 years

4. Houses Vibration

In 1979-80 the researchers surveyed four 9-storey panel building and one 14-storey frame-panel house in the area of residential development, located on the left Bank of the Volga in the 2 and 4 km from the dam. In 2005-2006 they surveyed four houses, two houses are located upstream of the hydroelectric station and two houses in the downstream. The main characteristics of the surveyed houses are shown in table 1.

Table1

The main characteristics of the surveyed houses

Address	Distance from the middle of VSP, m	Arrangement relatively water-engineering system	Type houses	Quantity floors	Size in the planм^2
21, 30 Matrosov Street, 92 Murysev Street	2825 2357	top pool	Largely the panel	9	158.5x11.5 133x11.5 153.5x11.5
73, 79 Chaykina Street	3050	top pool	Brick	14	38.0x16.0
32 Kuibyshev street	2340	lower pool	The panel	16	45.6x17.6
21 Nosov Street	2950	lower pool	Brick	14	60.0x18.0

The source of houses vibration is intense fluctuation structures spillway of the dam. This conclusion is made on the basis of the following observations:

- the occurrence of vibration of the houses and the greatest movement of the upper floors coincide with the beginning of the flood and its peak;
- the reduction of the homes vibration level coincides with the reduction of the flow through the dam; fluctuations in soil attenuate with distance from the dam;
- synchronous recording of the vibrations of the dam and soil (about the house on the Nosov Street) showed that in periods of self-synchronization of oscillations sections of the dam dramatically amplify the vibrations of the soil around houses (with some phase shift corresponding to the time lag of surface waves).

Fibro epithelial buildings in areas of higher seismicity showed that the elastic line of the vertical cross sections in most cases either does not have any distinct patterns, approaching straight, or is characterized by the presence of double curvature with the concavity at the bottom and convex at the top of the building.

House No 30 on the Matrosov Street was examined in detail. In this house, and a 9-storey house on the Nosov Street the researchers registered the speed of oscillation of the first and ninth floors and ground 10 m from the building on all three components - vertical Z and horizontal, the length and breadth of the building, Y and

X. the Vertical oscillations are virtually unchanged from the first to the ninth floor. The greatest move makes the 9th floor in the plane of least rigidity home - XY. The fluctuations are kind of beating with the main frequency of 2.1 Hz and the period of the beating 3-6 sec.

The oscillation in the plane of least stiffness ratio of the maximum amplitudes on the top floor and at the base was about 5. House No 30 on the Matrosov Street, due to the low damping, had the highest ratio of dynamic to 9.5. The magnitude of the movements in this house on the 9th floor was reached 165 μk (Fig. 15). On the records of the fluctuations of the ninth floor, it can be seen that the vertical tremor with a frequency of 1.4 Hz precedes by the resonant buildup of the building in the direction of least rigidity.

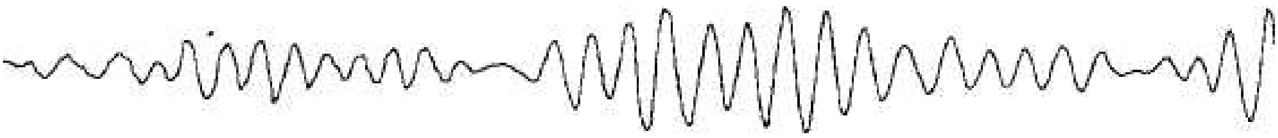

Fig. 15. Horizontal oscillations of the 9th floor of a residential building: street Matrosov

Analysis of the oscillations of the first and last floors of surveyed houses showed that the construction of the houses is a narrow resonance system, oscillating on its own bending frequency in the plane of least rigidity. These frequencies for the 9-storey houses were 2.2÷2 Hz (Fig. 16), 14-storey house of 1.35 Hz. In addition, there is a large contribution to the variance of the displacements at frequencies of 1.5 and 1.8 Hz. Can assume that 1.5 Hz is the predominant frequency of ground vibrations, and 1.8 Hz is one of the frequencies of torsional vibrations in the house.

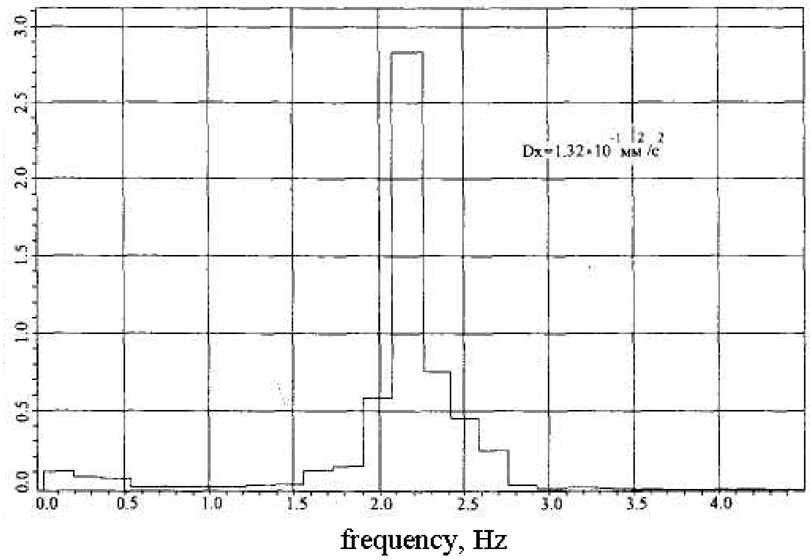

Fig. 16. The normalized spectrum of the vibration of a dwelling house (9th floor of 30 Matrosov Street)

The main several factors which affected the houses of on the level of vibration are:

- the total flow through the dam;
- diagram of the opening gates, which determines the size of the stamps, generating waves in the soil, different decaying with distance;
- the proximity of the frequency of exposure and the natural frequencies of the house.

The intensity of the vibration houses, as can be seen from Fig. 17, decreases with decreasing flow through the dam for different buildings in different ways. The highest bond vibration reducing consumption - the house number 30 on the street Matrosov.

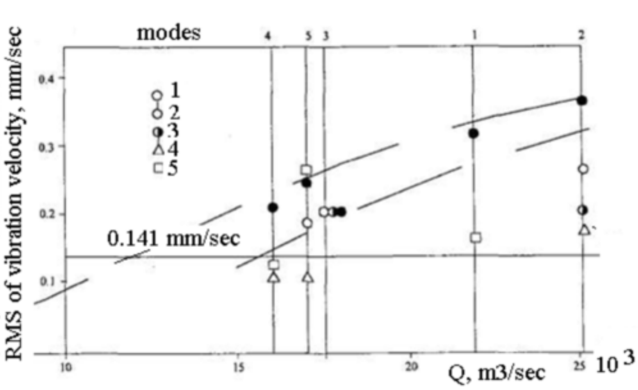

Fig. 17. Change in the vibration level of the upper floors of residential buildings with change of flow through the dam
1- Matrosov, 30; 2 - Matrosov, 21; 3 - Nosov, 21; 4 - Murysev, 91; 5 - Chaykina, 73

The most optimal variant of the water discharge is according to the scheme of mode 2 with the concentration of flow in 2÷4 spans, the most remote from the left coast.

According to the Sanitary standards of allowable vibration in residential buildings, which operated in the USSR, the level of vibration velocity on the average frequency of the active strip 2 Hz should not exceed 79 DB or 0.45 mm/s.

In the case of unstable vibrations, the amplitude of which varies by more than 40%, the acceptable level is reduced. Recording of houses vibrations shows that the vibration of the houses should be classified as unstable (changing over time) for which a valid RMS speed is 0.14 mm/s.

Figure 17 shows the standards of fluctuations in the speed of the upper floors movement of the various houses in various modes of operation of the dam. The top line estimates the value of standards in the most disadvantaged homes under unfavourable regimes, the bottom line is the same in optimized mode maneuvering valves. As can be seen from Fig. 17, the allowable vibration level will not be exceeded when the total flow through the dam, less than 12 000 m^3/s in almost any scheme of maneuver gates (to the extent permitted by the existing instructions for maneuvering).

When spending over the dam, large 16000 m^3/s, there will be houses in which fluctuations exceed the sanitary norm even with optimal maneuvering.

In the flow range from 12000 to 16000 m^3/s optimal maneuvering valves can enforce sanitary standards in almost all homes of Tolliatti.

When the size of the stamp modeling the dam is 1009x52 m^2, a forbidden area for the construction of a 9-storey buildings, located parallel to the target dam, *is* drawn from the center of the dam with a radius of 4.6 km. The restricted area for the construction of a 9-storey buildings, located perpendicular to the target dam, is drawn from the center of the dam with a radius of 3.7 km.

A similar zone for the construction of 5-storey houses are, respectively, the radius of 2.5 km and 2.0 km. Radius exclusion zone for the construction of a 14-storey building, square in plan, is 4.3 km.

5. Conclusion

Conducted systematic observations when skipping floods through the Zhiguli hydroelectric station on the Volga river permit to the following conclusions.

1. The vibration of each section of the dam when skipping floods contains two components is directly related to the flow of water discharged through the section and causing pulsating hydrodynamic load, and the component associated with the influence of neighboring sections, ranging in total elastic Foundation.

2. RMS (standard) vibration displacement of the individual sections of the dam is determined, mainly, specific consumption of water discharged through this section. Standard vertical vibration of the dam can reach 20 microns for the maximum specific consumption. The reset circuit of the flood affects the phase relation of the oscillation sections. With a uniform (or nearly uniform) distribution of consumption across the front dam is self-synchronization of oscillations at the frequency of 1.5 to 1.6 Hz. Uneven reset the optimized scheme of maneuver gates may cause mutual damping of the oscillations. These effects can cause variation in the standard vibration separate sections, not exceeding 6 μm, a noticeable change in the form of vibrations; a change in the ratio between the maximum and the mean-square displacements.

3. The most important consequence of self-synchronization of oscillations is the change in the conditions of propagation of the disturbances from the dam. When the synchronized oscillations noticeable vibration in excess of 0.1 from the vibration of the dam, may there be given to a distance of 6-7 km from the dam. Perturbations from fluctuations in individual sections fade at a distance of less than 0.5 km

4. Changing characteristics of oscillations of the sections of the dam and standards vertical vibrations compared with the data obtained in 1957-60, shows the increasing rigidity of the base of the dam.

5. The houses vibration in Tolliatti, was observed during the flood passage 1979, associated with the vibration of the dam. These houses vibrations do not go beyond the limits of sanitary norms, when the flow through the dam, less than 12000 m^3/s, in almost any scheme of maneuver gates (within the limits allowed by the current instruction).

6. When spending over the dam in the range from 12 to 16 m^3/s maneuvering valves can reduce the vibration level of the upper floors of residential buildings up to sanitary standards. Optimized circuit gate opening based on the following conditions:

- the opening of the gates over 2 m to start from the middle dam to the right Bank;
- reset costs in the discovery of more than 2 m should produce concentrated, with a maximum unevenness of discovery permitted under the current instruction for maneuvering. The number of bays with the largest opening on the site of concentrated reset should not be more than three;
- concentrated reset is done on two fronts: the first one is located in the middle span of the dam, the second one is after 10 flights in the direction of the right Bank.

7. When spending the dam over 16,000 m^3/s maneuvering valves is ineffective. So inevitably there will be houses in which the vibration level exceeds health standards.

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HYDRO 2015 – 22-я международная выставка и конференция по гидроэнергетике

26.10.2015 - 28.10.2015
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Издательство Hydropower & Dams ежегодно организовывает международную конференцию по гидроэнергетике, в которой участвуют ведущие специалисты отрасли, технический, финансовый персонал. Здесь обсуждаются вопросы, касающиеся всех направлений развития и аспектов эксплуатации гидроэнергетических сооружений.

В рамках конференции проводится выставка технологий, услуг и результатов научных исследований в гидроэнергетике с участием около 200 компаний.

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