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Experimental Investigations of Behavior of a Float-Type Power Unit Model under Operation of Natural Seismicity

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ABSTRACT.
Design floating power-generating unit must allow a possibility of its accommodation in different regions of Russia and for its limits. So seismic safety of installation must be ensured under high seismic load levels by the magnitude from 7 before 9. At concussion of soil is characterized by acceleration with peak values before 0.4-0.5g when displacing before 0.5м. Unlike overland objects on the floating block will be sent loads through lay liquid between the bottom and body of ship and from nodes of bracing system ship. Processes of floating object issue concussion at the action of seismic loads, with provision for the profile of bottom particularly, small depths and vicinity of coastline, highly complex. In this connection it took undertaking the model experiments for revealing the main regularities of these processes. Approach is stated in work to stating the test floating power generating unit model at 1:20 scale.

1. SIMULATION OF PROCESS OF SEISMIC INPUT TRANSFER TO THE HULL OF FLOATING POWER GENERATING UNIT

Let's consider special features of simulating the effect of earthquake seismic waves on the water area and floating power generating unit placed there. A system of parameters which determine the process of seismic waves propagation under the earthquake, can be presented by the list

$$\rho_s, K, G, \delta_{*}, \delta_{**}, l, \varepsilon, P_a, \rho_a, \gamma, x, y, z, t \qquad \text{(Eq.1)}$$

In (Eq. 1) the parameter group $\rho_s, K, G, \delta_{*}, \delta_{**}, l$ characterizes the properties of soil. Here ρ_s - initial soil density, K - a constant with dimensions of stress, for example, coefficient of elastic volumetric deformation, G - shear modulus, δ_{*}, δ_{**} - constant dimensions of stress, characterizing plastic and structural properties of soil, respectively, l - value with dimensions of length which describes inhomogeneity and anisotropy properties of the soil mass under consideration, ε - earthquake energy, which corresponds to the sizes of fault rupture, nature of motion etc. The parameters of pressure p0, density ρ0 and adiabatic curve indices γ characterize the state of gaseous atmosphere above the free surface of soil. The fourth group of parameters in (Eq. 1) includes coordinates x, y, z of soil mass point and current time t. When propagating the seismic waves will reach the contour of water area.

Seismic motions of water area bottom points depend on linear values - on the coordinates l1, l2, l3 of the water area geometrical centre and on its characteristic dimension L. Motion of water which fills the water area and related seismic shakings of the power unit hull as a braced rigid body can be characterized by the list of parameters

$$\rho_0, g, \Delta, J_x, J_y, J_z, m, c \qquad \text{(Eq.2)}$$

In (Eq.2) we have: ρ_0 - fluid density, g - acceleration of gravity, Δ - characteristic value of the gap between the floating body and the bottom of water area, m, Jx, Jy, Jz - mass and principal moments of inertia of the hull, - stiffness of elastic elements of the bracing system. Thus, the whole system of parameters which determine the process of interaction between seismic earthquake waves, water area bottom and floating power unit shakings related to them, is recorded in the following form:

$$\frac{G}{K}, \frac{\delta_{\cdot}}{K}, \frac{\delta_{\cdot\cdot}}{K}, \frac{P_0}{K}, \frac{\rho_0}{\rho_s}, \frac{\sqrt{(K/\rho_s)}t}{\sqrt[3]{\varepsilon/K}}, \gamma, \frac{l}{L}, \frac{l_1}{L}, \frac{l_2}{L},$$
$$\frac{l}{L}, \frac{m}{\rho_0 L^3}, \frac{J_x}{\rho_0 L^5}, \frac{J_y}{\rho_0 L^5}, \frac{J_z}{\rho_0 L^5}, \frac{\Delta}{L} \cdot \frac{\rho_0}{\rho_s}, t\sqrt{\frac{c}{m}}, t\sqrt{\frac{g}{L}}. \qquad \text{(Eq.3)}$$

If geometrical similarity rules are observed for the model of water area, the relations

$$\frac{l_M}{l_H} = \frac{l_{1M}}{l_{1H}} = \frac{l_{2M}}{l_{2H}} = \frac{l_{3M}}{l_{3H}} = \frac{L_M}{L_H} = \frac{1}{\lambda}. \qquad \text{(Eq.4)}$$

where λ - linear scale factor, subscript "M" relates to the model, subscript "H" - to the prototype, are adequate. If at the same time for experimental simulation of earthquake effect we use explosive charge, energy ε_M of which is determined by the dependence

$$\varepsilon_M = \frac{\varepsilon_H}{\lambda^3}, \qquad \text{(Eq.5)}$$

Then parameters of the motion of water area bottom points (displacement $\overline{\alpha}_i$, velocity $\overline{v}_i$, acceleration $\overline{w}_i$, i = 1, 2, 3) at the instants of time

$$\frac{t_M}{t_H} = \frac{1}{\lambda} \qquad \text{(Eq.6)}$$

will be related as follows:

$$\frac{\overline{\alpha}_{iM}}{\overline{\alpha}_{iH}} = \frac{1}{\lambda}, \quad \frac{\overline{V}_{iM}}{\overline{V}_{iH}} = 1, \quad \frac{\overline{W}_{iM}}{\overline{W}_{iH}} = \lambda \qquad \text{(Eq.7)}$$

When manufacturing a model of power unit and bracing system which satisfies the requirements

$$\frac{\Delta_M}{\Delta_H} = \frac{1}{\lambda}, \quad \frac{m_M}{m_H} = \frac{1}{\lambda^3}, \quad \frac{J_{xM}}{J_{xH}} = \frac{J_{yM}}{J_{yH}} = \frac{J_{zM}}{J_{zH}} = \frac{1}{\lambda^5}, \quad \frac{C_M}{C_H} = \lambda^5, \qquad \text{(Eq.8)}$$

and preserving the type of fluid the equality of all dimensionless combinations in (Eq.3) is ensured, aside from the last one, since usually acceleration of gravity g is equal in field and on the model with the exception of centrifugal machine experiments.

Analysis of earthquake seismic input in solid grounds indicates that in a ground motion two characteristic periods can be distinguished. On the first one, which is relatively high-frequency, maximum accelerations act, on the second one (low-frequency) maximum ground displacements are reached. Accelerations which correspond to the accepted periods differ in 5-10 times. If while simulating the first period of seismic input to water area the influence of gravity on the fluid-unit system motion can be neglected so it is allowable to exclude the expression $t\sqrt{g/L}$ from the list of dimensionless combinations (Eq.3). Then fulfillment of the conditions of geometrical similarity will allow for full simulation of seismic motions of a power unit hull, and experimentally-fixed values of acceleration wi, velocity vi, displacement αi and characteristic time T of motion of a unit model hull can be transferred to full-scale conditions according to the relations

$$W_{iH} = \frac{1}{\lambda} W_{iM}, V_{iH} = V_{iM} \alpha_{iH} = \lambda \alpha_{iM}, T_H = \lambda T_M. \qquad \text{(Eq.9)}$$

It should be noted, that condition of equality of fluid density ρ_0 and soil ρ_s ratio in (Eq.3) is equivalent to the condition of equality of the ratio of disturbance spreading velocities in water and soil. In case the amplitudes of pressure are relatively low for describing the deformation pattern it is sufficient to consider medium compressibility in acoustic approximation. As a result we can write

$$\frac{\rho_{0P}}{\rho_{sH}} = \frac{\rho_{0M}}{\rho_{sH}} = \frac{C_0}{C_s}, \qquad \text{(Eq.10)}$$

where C_0 - sound velocity in water, C_s - speed of longitudinal elastic waves in soil.

At the second period the seismic motions of water area bottom can be characterized with initial speed V_0 and characteristic time of its proceeding t_0. Laws of motions of water area bottom are entirely determined by soil properties, i.e.

$$V_0 = \sqrt{\frac{P_*}{g_*}} V\left(\frac{\delta_*}{P_*}\right), t_0 = t_* T\left(\frac{\delta_*}{P_*}\right)$$

where V, T - dimensionless functions. System of basic parameters when studying this period of seismic vibrations of a power unit hull and water is presented by the list

$$V_0, t_0, g, g_0, m, J_x, J_y, J_z, P_a, L, C \qquad \text{(Eq.11)}$$

From (Eq.11) dimensionless combinations can be composed

$$\frac{m}{g_0 L^3}, \frac{J_x}{g_0 L^5}, \frac{J_y}{g_0 L^5}, \frac{J_z}{g_0 L^5}, \frac{V_0 t_0}{L} . t\sqrt{\frac{c}{m}}, t_0\sqrt{\frac{g}{L}}, \frac{P_a}{\rho_0 g L}. \qquad \text{(Eq.12)}$$

As $t_{0M} = \frac{1}{\lambda} t_{0H}$ according to (Eq.12), then from the condition of equality of combinations $t_0\sqrt{\frac{g}{L}}$ it follows that $L_M = \frac{1}{\lambda^2} L_H$. However in accordance with (Eq.4) $L_M = \frac{1}{\lambda} L_H$, i.e. full simulation of the whole process of seismic vibrations under the conditions of explosive charge explosion taking into account the influence of gravity is impossible due to necessity to change the geometrical scale of system simulation at various periods of motion.

In studies of mechanism of transferring the seismic shaking to power unit and fields of hydrodynamic pressures in water area liquid medium the main parameter of disturbance is acceleration of water area bottom points. This condition makes it possible to distinguish the first period of seismic explosive effect as the most dangerous for the unit safety and therefore the most interesting for investigation. Thus, during experiments with models of both water area and unit which has been performed in compliance with the rules of geometrical similarity at 1:λ scale with the observance of criteria (Eq.4), (Eq.8), it is required to reproduce the motion parameters of water area contour points which satisfy the relations (Eq.6), (Eq.7), (Eq.10).

The most expedient is the use of special stands, where due to internal energy sources the bottom of water area model could be set in motion with the parameters which satisfy the relations (Eq.6), (Eq.7), (Eq.10). It is allowable, since exactly seismic motions of water area bottom create external disturbance when studying the response of water-unit model system.

In our case the setting of experiments is substantially complicated due to necessity to simulate both actual outlines of the power unit hull and conditions of its bracing, to reproduce non-stationary motions of water area bottom at simulation of its seismic waves loading, that is, due to simultaneous fulfillment of the conditions (Eq.6), (Eq.7), (Eq.10). This situation had required to create a new unique seismic explosive stand.

Opportunity to enhance studying the second period of the effect under some practically appropriate requirements to water area bottom motion which are reproducible on the stand is to be specially noted. If under experiments with geometrically similar models of water area and power unit hull (relation (Eq.4), (Eq.8)) the bottom motion parameters at some phase will meet the conditions

$$\frac{V_{0M}}{V_{0H}}=\frac{1}{\sqrt{\lambda}}, \quad \frac{t_{0M}}{t_{0H}}=\frac{1}{\sqrt{\lambda}} \qquad \text{(Eq.13)}$$

then in the list (Eq.12) equality of all dimensionless combinations, aside from the last one, is performed. Recalculation of testing results for the field conditions is to be accomplished according to the rules

$$W_{iH}=W_{iM}, \; V_{iH}=\sqrt{\lambda}\,V_{iM}, \alpha_{iH}=\lambda\alpha_{iM}, T_H=\sqrt{\lambda}\,T_M . \qquad \text{(Eq.14)}$$

Full simulation with due regard to the equality of combination $\frac{P_a}{\rho_0 g L}$ is possible if air pressure above the free water surface in the water area model ($P_{aM}=\frac{1}{\lambda}P_{aH}$) is reduced, resulting in technical problems when carrying out the experiments. At the same time our experience in solving the hydrodynamics problems shows, that influence of barometric pressure on free fluid surface vibration is small (except when contribution of surface tension forces is substantial). Usually its value is set equal to a constant, and when considering impulsive problems it is set equal to zero. Such conclusion permits to preserve air barometric pressure in the model at experiment setting.

2. EXPERIMENTS SETTING

In the course of researches experimental analysis of shaking of the power unit floating model under the effects equivalent to earthquakes of 8-9 magnitude (as per MSK-64 scale) taking into account actual layout of unit bracing had been conducted. The main aims of these testing were: to evaluate dynamic loads on the unit model at various locations relative to the walls of pool and depths under bottom, to determine the influence of dumping braces on the floating unit dynamics. In this condition possibility of siting a floating power unit in various regions of the country and abroad was taken into account. The choice of simulation scale was substantially affected (apart from economical reasons) by methodology of reproducing seismic motions of water area bottom with required parameters (see relations (Eq.6), (Eq.7), (Eq.10), (Eq.14)). It is to be noted, that range of amplitude-frequency parameters of simulated effect appeared to be rather wide. The experience acquired permits to generalize on expediency in this very case to apply seismic explosive technology for reproduction of seismic motions of water area bottom. The method in question implies the use of programmed camouphlet blasting of small distributed explosive charges in soil under the foundation and on the side of the seismic platform. Special feature of setting an experiment with floating unit model is necessity to reproduce reaction of bracing system at a required scale. This system consists of two or three mooring posts and connecting hinged rods with built-in dumping inserts. Therefore it is preferable to lay out mooring posts models on separate movable sites as to simulate really possible seismic motions of mooring posts and water area bottom under the power unit bottom according to different laws.

The main reason for selecting a simulation scale was refusal to reproduce a configuration of water area line of power unit placement. Under this condition we took into account not only power unit installation options and seismic input parameters of 8-9 magnitude, but also evaluation results of decrease of horizontal hydrodynamic loads when a floating body moves away from vibrating wall of a tank (pool). According to the calculation data at a 4-5h (h - floating body drift) distance from the vertical wall hydrodynamic pressure of fluid is negligibly small, hence the unit hull shakings induced by their operation are small as well. Thus, at the distance of 30-40 m from a shore line the only source of horizontal unit hull shakings under the earthquake is response of connections between the unit and the mooring posts. In view of all this when setting the experiment it is possible to be limited to simulation of a fragment of water area, immediately adjacent to the unit installation place. As a fragment of water area we had accepted a pool of rectangular shape, rigidly fixed on the seismic platform. Dimensions of the pool allowed to install a unit model at a distance from its walls. It made it possible to choose a large scale of geometrical similarity and to produce a unit model which satisfied the relations (Eq.8). Parameters of test inputs has been specified from the condition of their conformity, according to (Eq.9), with typical earthquakes of 8-9 magnitude. The criterion of conformity, apart from the relation (Eq.9), was filling the seismic input response spectrum within the range of frequencies, characteristic for internal equipment of power unit. Thus all the factors which determine special features of setting the experiments with a power unit model on seismic explosive stand had been determined.

3. OBJECTS AND CONDITIONS OF TESTING

As a testing object a floating power generating unit model at 1: 20 scale was chosen, the model was located in a pool on one of the platforms of a ground shake table, the layout of which is presented in Fig. 1. The stand is of modular structure. On the large test platform (overall dimensions are 10,2×5,2×0,5 m) with a water-filled pool (Ref. No 1) a model of power unit was located (Ref. No 2). The model was connected with the help of hinged braces (Ref. No 3) to dumping inserts (Ref. No 4). These inserts were located on the models (simulators) of mooring posts (Ref. No 5), installed on individual small platforms (Ref. No 6), which overall dimensions are 3,0×3,0×0,2 m. To create a rocking motion and compensate the weight load all platforms of the stand were located on two-line pillow-type pneumoelements (Ref. No 7). For imitation (simulation) of a soft layer on the bottom a sandy interlayer (Ref. No 8) was spreaded on the platform (Ref. No 1). Actions on platforms which simulate seismic input from earthquakes were created by blasting explosive charges (Ref. No 9), which were located at the platforms side and under them and were covered with soil.

During testings the weight of large platform with a model of unit was 45-70 t depending on the amount of water in the pool, the weight of small platforms with mooring posts simulators (models) was 4t approximately.

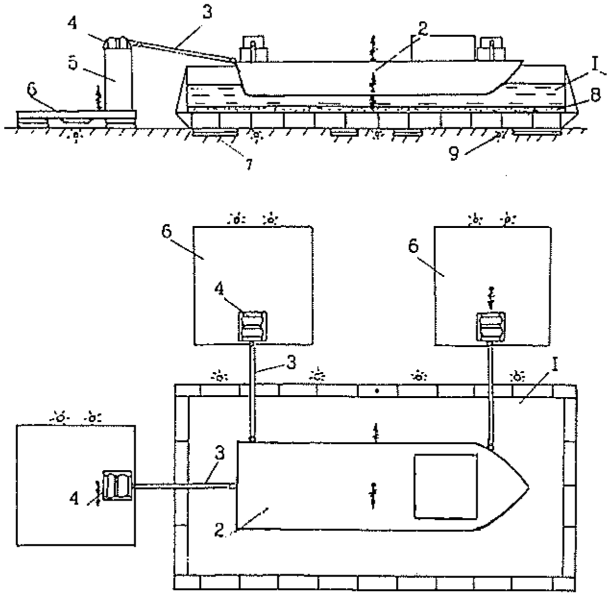

Fig. 1. The layout of a ground shake table

During testings vertical inputs or both horizontal and vertical inputs together with various rate and frequency content in each of the directions were formed in experiments.

4. MAIN TESTING RESULTS

During the testings inputs on the stand had been realized (on pool bottom and bottom sand layer, on small platforms) which were equivalent to loadings from earthquakes of magnitude 8-9.

Accelerations peak values were determined within the range of 0÷600 Hz, that corresponds the range of 0÷30 Hz for full-scale conditions. Durations of inputs and accelerations processes on the unit model structures during the testings varied within the range from 0,62 to 1,6 sec (13-32 sec in full-scale conditions). Characteristic records of the experiment-registered parameters of motions of unit model and pool (stand) bottom, as well as the results of their spectral processing are presented in Fig. 2÷3.

Analysis of the testing data permits to characterize processes of transferring earthquake loading to a unit at vertical and horizontal inputs, effects of changing the depth and the distance to waterfront, as well as loads transformation by absorbing braces.

Response spectra for these processes are presented in Fig. 2. Fig. 2 presents superposition of stand-simulated earthquake loading spectra with design earthquake spectrum (curve 1). Consideration of these curves testifies the sufficient completeness of excitation of seismic input components in frequency ranges of 0÷30 Hz, which is usually taken into consideration when assessing seismic danger for nuclear power engineering objects.

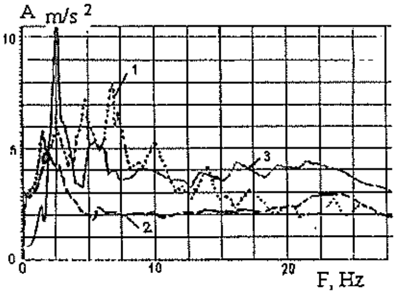

Fig. 2. Response spectrum of vertical accelerations: 1 - conventional spectrum, 2 - sand spectrum, 3 - spectrum of model bottom. Dimensions are brought to the real scale.

Consideration of the test-registered processes of loading the stand, soil and model of unit when the value of water layer under model bottom at vertical input is varying indicates that the load which had been transferred through water layer on the model bottom in its nature corresponds to bench test effects under reproduction, that is, the frequency content practically does not change. Taking into account spread in readings of some measuring transmitters, it is necessary to say that difference of rates in the processes of loading the stand and model under consideration is insignificant: difference in peak parameters is ≈10% in the most saturated part of spectrum (from 2 to 8 Hz in real scale). Under this condition when water depth under model vertical stabilizer is changing the load gain factors practically do not alter in frequencies.

The testing data had shown that reduction factor of earthquake loading, which is transferred through water layer to the model in horizontal direction is of order 4-5. Besides the data testify that the load transferred from mooring posts to model board is 7-20 times relieved and the influence of braces to its loading at earthquake loading transformation is quite small. It is illustrated by the data, presented on Fig. 3, where the processes of motion of waterside attachment of onboard brace, bottom and deck of the model are shown.

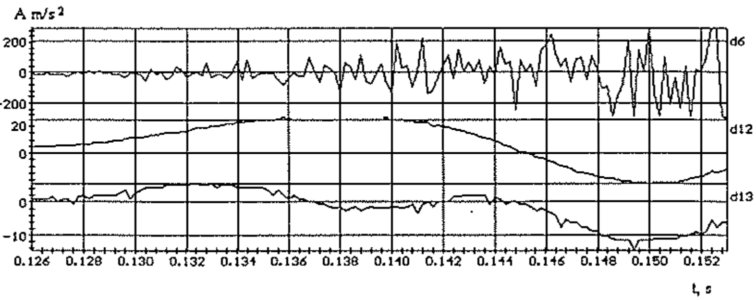

Fig. 3. Fragment of horizontal accelerations record: d6 - waterside attachment of onboard brace, d12 - deck of model, d13 - bottom of model.

Analysis of the results received has shown, that when the width of the gap between the unit and the bottom is changing more than four times (h = 0,36-1,57, h - power unit model drift, equal to 0,28 m) time characteristics of accelerations of soil surface and model bottom practically did not differ.

Power unit model hull vibration frequency under operation of elastic forces makes up 6.0 Hz, at full-scale condition the value of unit hull vibration frequency will be 0,3 Hz. From comparison of horizontal acceleration records of the sensors, installed on deck and power unit model bottom, one can see synchronism of process of vibrations along the model height. It testifies that power unit model hull move as rigid body at seismic input reproducible at the required scale.

As a whole, the amplitude of horizontal vibrations of the model is substantially lower, than the amplitude of vertical direction motion. This permits to use a set of experimentally justified simplifications when assessing the seismic shaking of a power unit hull under earthquakes effect.