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FREQUENCY RESPONSE ANALYSIS OF NPP CONTAINMENT WITH WWER-1000 TYPE REACTOR

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ABSTRACT

Analysis of vibration load on the building structures of nuclear power plants (NPP) has come to the fore due to extension of their operational lifetime. Such analysis could be carried out if dynamic characteristics test (natural vibration frequency and natural mode) of NPP building structures is conducted in full-scale conditions.

In this paper we represent methods of frequency response analysis of the generating unit 1 (RO-1) reactor compartment at Kalininskaya NPP on the basis of technogenic vibration. Main vibration sources of RO-1 are turbine-type generators, main centrifugal pumps and pipelines of power generating units 1 and 2.

Vibration of RO-1 has been measured alternately at three points of RO-1 containment which is 76 m high and 47.4 m in diameter: top of the dome (76.0 m), holdout ring (70.3 m), point on the ground next to containment (0.0 m). Three components of vibration velocity have been measured simultaneously at each point: vertical Z-component, horizontal Y-component along the axis of the apparatus room and horizontal X-component across the room axis.

Magnetoelectric pendulum-type vibrometers have been used for measurement. They were modernized by ad hoc multiposition amplifier card installed into the sensor body. Vibrometers were connected to the recorder by vibration protected and jam resistant cables.

The results of present researches testified that dominant frequencies of X- and Y-oscillation spectra at RO-1 of Kalininskaya NPP (1.7 and 1.9 Hz correspondingly) correspond to the first vibration mode of RO-1 as a rigid construction on elastic foundation.

High peaks of spectra at 16.7 and 25 Hz result from vibrations caused by main centrifugal pumps and turbine-type generators and coincide with the number of their revolutions per minute (1000 and 1500 rpm). Other peaks of spectra are related to the vibration of pipelines of primary and secondary circuits.

Keywords: Frequency response, analysis of vibration, main vibration, vibrometer, NPP.

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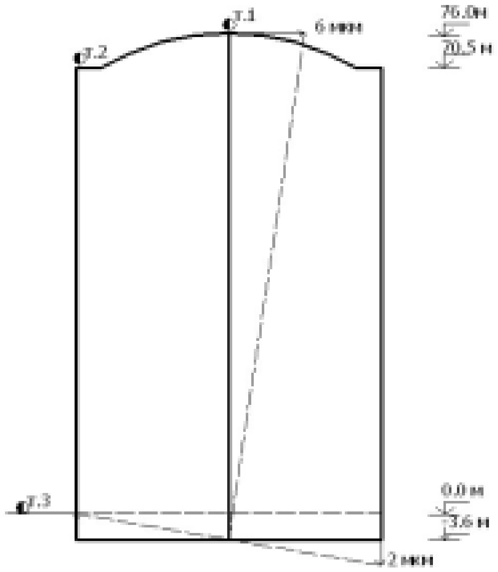

Fig.1. Containment outline with equipment layout and first vibration mode of RO-1 within the range of 1.7-1.8 Hz.

SM-3 magnetoelectric pendulum-type vibrometers have been used for measurement. They were modernized by ad hoc multiposition amplifier card installed into the sensor body. Vibrometers were connected to the recorder by vibration protected and jam resistant cables.

Personal computer (notebook-type) with multichannel analog-digital converter was used as a recorder. Specially configured software made it possible to record and process vibrometer signals. Vibration stress in the vibrometer operating coil is directly proportional to vibration velocity. In particular, the software allows to carry out integration and differentiation operations of velocity function in order to estimate displacement and acceleration correspondingly. Duration of each complete record is about 40 sec (6 complete records at each point).

Figures 2 and 3 show correspondingly segments of velocity records (mm/sec) of Z- and X-oscillations of the dome and related spectral intensity (spectra) of complete records.

Z-oscillations of the dome are characterized by maximum amplitude of 0.16 mm/sec and beatings. The spectrum of dome Z-oscillations is distinguished by frequencies of 16.7, 18 and 25 Hz. One may also note oscillations with frequencies of 9, 23.5 and 33 Hz (Fig.2).

Beating at the dome X-oscillation record indicates presence of two closely spaced frequencies, which is proved by complete spectrum record where 1.7 Hz oscillations dominate and 2 Hz oscillations are present (Fig.3). Oscillations in the range of 5-7 Hz are also apparent.

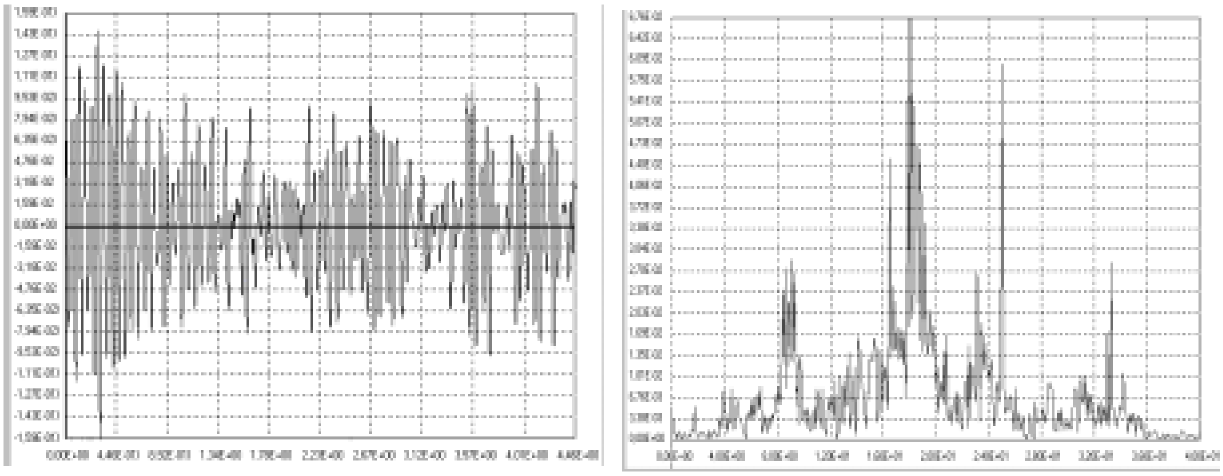

Fig.2. Segment of velocity record of the dome Z-oscillations and complete record spectrum.

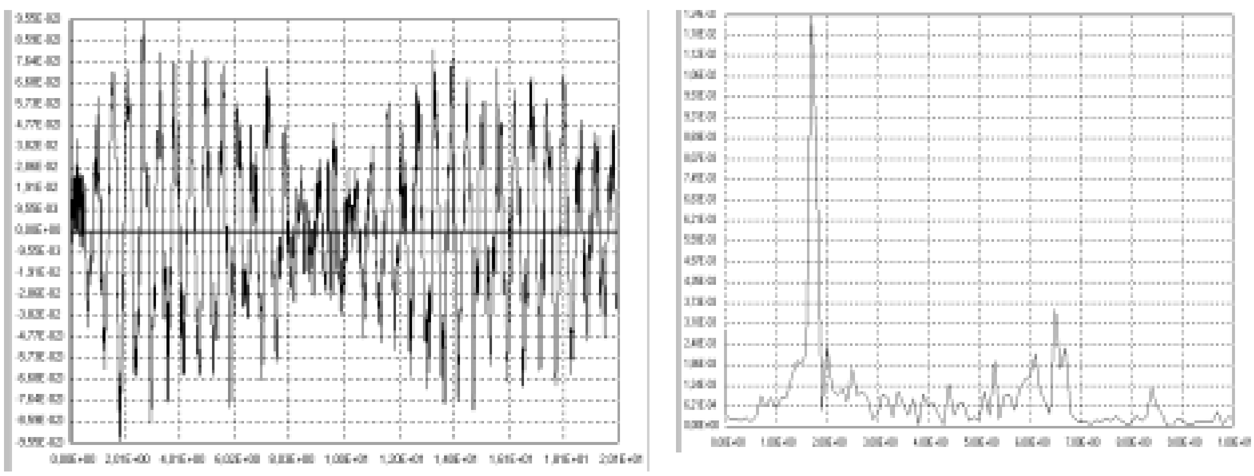

Fig.3. Segment of velocity record of the dome X-oscillations and complete record spectrum.

Figures 4 and 5 show correspondingly segments of velocity records of Z- and Y- oscillations of the holdout ring and related spectra of complete records.

Amplitude level of the holdout ring Z-oscillations is 1.5 time lower than that of the dome (Fig.2 and 4). Velocity peaks of Z-oscillations of the holdout ring increased significantly at 1.9 and 6 Hz.

Peak velocities of the holdout ring Y-oscillations are much the same as peak velocities of the dome X-oscillations (about 0.09 mm/sec). At the velocity spectrum of Y-oscillations the peak at 1.9 Hz dominates. Peaks at 6, 16.7, 17.8 and 25 Hz should also be noted (Fig.5).

Ground vibration at the point next to RO-1 is close to harmonic with prevailing frequency of 25 Hz for all components and maximum amplitude of Z-acceleration of 1.3 cm/sec^2.

Earlier comprehensive frequency response analysis of facilities similar to RO has been carried out by MGSU (MISI) using models [1] and in full-scale conditions at the incomplete Krymskaya NNP [2, 3]. During the researches diverse ad hoc methods of vibration excitation were applied, which allowed to specify natural vibration frequency and natural mode of the facilities.

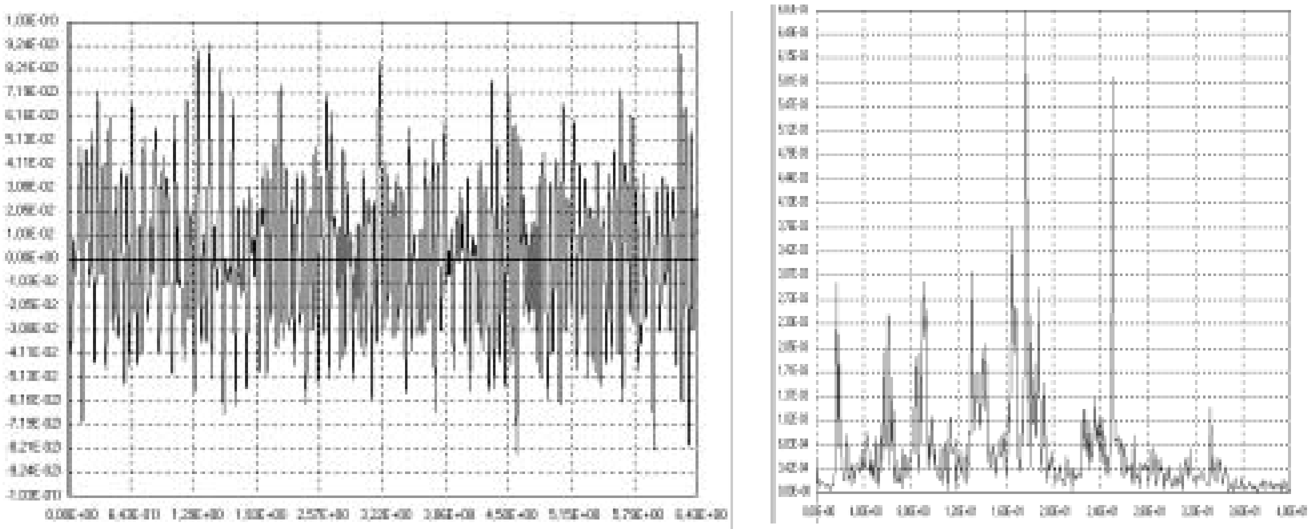

Fig.4. Segment of velocity record of the holdout ring Z-oscillations and complete record spectrum.

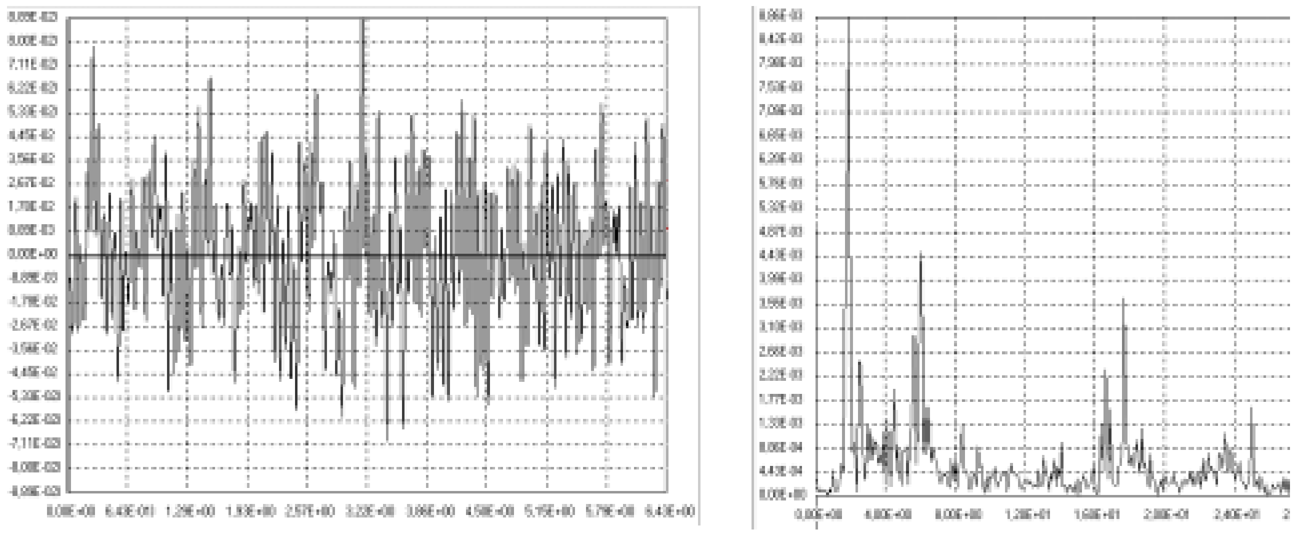

Fig.5. Segment of velocity record of the holdout ring Y-oscillations and complete record spectrum.

Comparison of earlier results with the results of present researches testified that dominant frequencies of X- and Y-oscillation spectra at RO-1 of Kalininskaya NPP (1.7 and 1.9 Hz correspondingly) correspond to the first vibration mode of RO-1 as a rigid construction on elastic foundation (Fig.1).

High peaks of Z-oscillation spectra at 17.8 Hz correspond to the first vibration mode of the dome. Figure 6 shows normalized vibration mode of containment at the same frequency with identified maximum displacement at the dome center.

High peaks of spectra at 16.7 and 25 Hz result from vibrations caused by main centrifugal pumps and turbine-type generators and coincide with the number of their revolutions per minute (1000 and 1500 rpm). Other peaks of spectra are related to the vibration of pipelines of primary and secondary circuits.

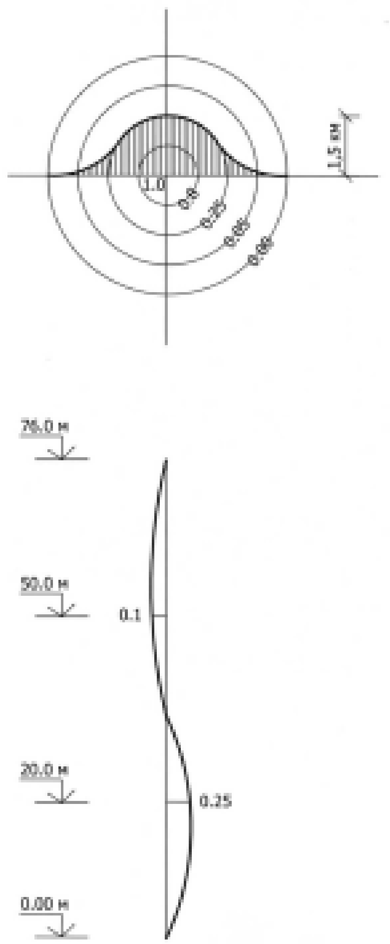

Fig. 6. RO vibration mode, coupled with the 1st vibration mode of the containment dome (f=17.8 Hz).

CONCLUSIONS

1. Analysis of vibration load caused by reactor compartment oscillations testified that dynamic stress makes 0.1% of static stress. But this moderate but permanent stress could cause soil "liquefaction" which result in differential settlement that occurs at RO-1 of Kalininskaya NPP.

2. Regular (each 3-4 years) instrumental inspection of building structures and foundation of facilities, important for the safe operation of nuclear power plants, should include vibromonitoring in order to provide control of dynamic characteristics that integrally reflect changes in the load bearing capacity of the main building structures and foundation soil. Such vibromonitoring is conducted at Kalininskaya NPP and Novo-Voronezhskaya NPP. In particular, frequency stability of the first vibration mode of Kalininskaya NPP RO-1 will denote stability of the foundation soil. Frequency stability of high-frequency oscillations of RO-1 will mean stable state of containment.

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