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# New method of bench dynamic testings of NPP seismic isolation systems and equipment

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ABSTRACT: Development of seismic explosive tables for testing NPP large-sized objects are being continued in Russia. Seismic explosive technology for seismic testings permits to enhance essentially the capabilities of reprodicing the parameters of destructive earthquake effects, especially for high building marks comparing with motor-driven seismic platforms.

## 1. MAIN PRINCIPLES OF SEISMIC EXPLOSIVE TECHNOLOGY FOR THE SEISMIC TESTINGS.

Within the recent years the problems of experimental check of operation and stability evaluation of diverse NPP objects and their elements (structures, building constructions, systems, components etc.) under the conditions of destructive-earthquake-type effects have assumed great importance. On the complex of ground shake tables (these tables are under operation in Russia for more than 20 years) the reproduction of the dynamic loads, caused by such effects, is realized using the explosive technology. The complex incorporates a set of stands with load-carrying capacity up to 300 tons, the largest seismic platform dimensions make up 30 x 12 m. According to the technology developed such reproduction of the necessary loading conditions of the objects under study is carried out due to

energy effect of firing the explosive charges on the bearing structures of the test stands and further transformation of the kinematic processes with the help of special forming devices. In order to set the necessary direction of the test stand structures movement the explosive charges firing can be carried out both in the soil (directly under the test stand or on the side of it), and in the special load actuators, which are installed on the test stand and creat jet power (recoil force). As forming devices for transformation of the test stand kinematic processes to the required test parameters the elements of various type and design (pneumatic, hydraulic, pneumo-hydraulic, mechanical etc) are used. Chosing the weight and the quantity of the explosive charges, conditions of their arrangement (placement distance and depth, installation in the actuators, etc), setting the firing sequence, as well as application of the forming devices with certain characteristics, changing the devices layout and operation mode etc. ensure forming the loads of the required type, rate and frequency content.

## 2. ADVANCEMENT OF THE SEISMIC EXPLOSIVE TECHNOLOGY METHODS.

In 1995 the complex was incorporated with the CC500/300 test stand, designed for testing the structures (seismic isolated structures included) and the equipment of various designation. This stand includes a rectangular steel fragment of a building with dimension 22 x 6 x 7 m and weight 400 tons, supported with the help of the removable support elements or the seismic isolators on the movable supports. Fig. 1 presents a schematic diagram of the test stand CC500/300. Simulation of seismic vibrations, which are similar to the earthquakes effects, is produced with the help of two forming cascades. The first of them includes two support platforms (rigid steel beam structures), which are installed on the base slabs with the help of the rollers. With the help of lateral forming pneumatic elements, located on the ends, and fixing (hammer) device the support platforms

move in the horizontal direction. The first test stand cascade introduces to the system the major low-frequency component within the range between 1 and 2.5 Hz. The second cascade consists of two intermediate platforms which include bearing areas for the test stand table supports. They are located above the first forming cascade on the pneumatic elements. Energy input to the system is provided by application of the powder load actuators which are installed in pairs on the sides of the intermediate platforms. Attachment of the actuators provides for the capability to change the slope angle to control the vertical and horizontal movement component.

The Ir pulse, obtained from the powder load actuators, is calculated according to the following dependences:

$$Ir = \int_0^{tu} Qr(t) \cdot dt \qquad (1)$$

where tu - pulse time;

$$Qr(t) = Pr(t) \cdot Sr,$$

here Pr(t) - pressure of gases, acting on the working medium;

Sr - cross sectional area of the actuator barrel;

$$Pr(t) = \begin{cases} 0 & , \text{ at } t=t0=0; \\ Prmax \cdot t/tn & , \text{ at } t<tn; \\ Prmax \cdot (hk/(hk+Zb))^{j} & , \text{ at } tn<t<tb; \\ Prmax \cdot (hk/(hk+htp))^{j} \cdot (tu-t)/(tu-tb) & , \text{ at } tn<t<tb; \end{cases} \qquad (2)$$

where hk - length of the explosive chamber;

htp - length of the actuator operating compartment;

j - adiabatic curve index;

$Prmax = 125.5 \cdot \nabla^{0.753}$, [kPa]

$\nabla = wr/wk$, [kPa]

here wr - weight of the powder charge;

wk - initial volume of the explosive chamber.

The second cascade forms, mainly, the vibrations within the range between 2 and 5 Hz. On four support units of the

shock-absorbers, suported on the areas of the second forming cascade a two-storied building fragment which represents a test stand table is installed.

Changing the parameters of firing, reaction time, angle of inclination of the powder load actuator, value of the initial pressure in the vertical and lateral pneumoelements, on the intermediate platforms of the second forming cascade there are created non-stationary effects, equivalent to the earthquake loadings of severe earthquakes, with the required frequency content in the preset amplutude time domain. The type of characteristic test effect, formed by the stand, is shown on the Fig.2.

The test stand is designed for the following problems solution:

- testings of large-sized objects with the weight up to 500 tons, installed directly on the intermediate platforms. Testings objects with the weight up to 300 tons can also be placed on the first, second storey and the roof of the building fragment.
- integrated testings of the actual seismic isolation systems or their fragments with load-carrying capacity up to 500 tons. On the intermediate platforms of the second forming cascade there are provided positions for installation of the seismic isolation and damping devices. The test stand table structure gives the opportunity to reproduce both the changes of kinematic parameters on the various marks of the isolated object and their effect on the equipment.

## 3. METHODICAL BASES OF THE SEISMIC TESTINGS OF NPP SEISMIC ISOLATION SYSTEMS.

On the each unit of the seismic explosive stands complex there is ensured realization of three main test modes:

- "seismic shock" mode reproduces vibrations of the building constructions and equipment attachment units at the inputs, for example, of near industrial explosions;
- "rigid seismic" mode simulates, among the other things,

seismic vibrationson the high (12.0 m and higher) marks of buildings and structures, as well as model loads in accordance with the similarity laws;

- "soft seismic" mode simulates the ground motion and the motion of the building foundations under the conditions of various earthquake rates.

In this case the support blocks motion of the object under study in accordance with the testings purposes has a form of spatial, flat or one-dimensional non-stationary vibrations. Limits of the changes in the characteristic peak values of the loadings in the area of [0;200 Hz] frequencies are presented in the Table 1.

Table 1

| Type of loading mode | Acceleration (g) along the axes | | Velocities (m/c) along the axes | | Displacements (m) along the axes | | Durations of the load input, c |
|---|---|---|---|---|---|---|---|
| | oz | ox(oy) | oz | ox(oy) | oz | ox(oy) | |
| shock-seismic | +30/ -10 | 40 | +3/ -1 | 3 | +0.5/ -0.2 | 0.5 | to 1.0 |
| rigid-seismic | 10 | 10 | 2 | 2 | 0.5 | 0.5 | to 5.0 |
| soft-seismic | 2 | 2 | 1 | 1 | 0.7 | 1.0 | to 30.0 |

Thus far in the world practice a considerable volume of data on the seismic isolators simulation tests has been accumulated. In this circumstances a transfer to full-scale experiments with seismic isolators and, especially, with the fragments of NPP buildings seismic isolation systems is of special interest. Specifications of the seismic explosive stands complex ensure the opportunity to provide such seismic full-scale testings under the conditions of "soft seismic" (see table) mode. The technique of preparing and testing the the elements and fragments of the NPP full-scale seismic isolation systems provides for a series of measures, the basic of which are:

- development of technology of erection, starting-up and adjustment and repair jobs under the near-service conditions;

- determination of the seismic isolation facilities operability;
- determination of the dynamic efficiency of the seismic isolation facilities for the real operation conditions.

Development of erection and and adjustment technology of the shock seismic protection facilities on the test beds permits to improve the technological tools for execution of such operations under the real operation conditions. In each particular case the technology will be determined by the clearances for the transportation and erection areas of the seismic protection facility elements on the object, by the opportunity to use the lifting devices, by the sequence of operations etc. The test stand base presents unique opportunities for simulation and development of the erection technology.

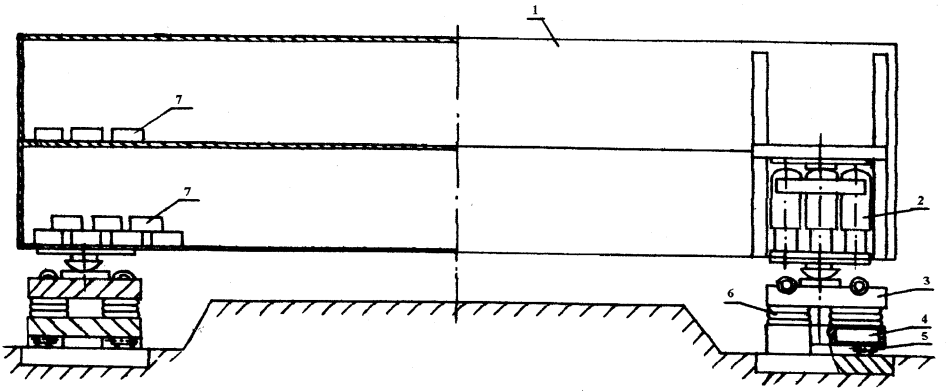
Determination of operability and efficiency of the seismic isolation facilities includes a set of investigations of both the separate elements and a fragment of the system for various operation conditions. Such operations shall include the testings of single seismic isolation facilities on the various static loads, impacts, parameters of the seismic isolators characteristics (pressure, initial height, damping property etc), kinematic parameters (maximum deformation and deformation rate) under various temperature condition. Realization of the testings on the test stands is carried out by way of fixing one side of the test platform to the stand body with the help of cylindrical or ball hinges. Under the center position of the opposite side a seismic isolator to be tested is installed, and the platform is loaded in this position with ballast weights up to the required force in the shock-absorber. Explosive charges under the stand body or on the side of it actuate the platform, causing the seismic isolator deformation in the necessary direction.

The most complicated and labour-consuming are the testings of a fragment of the seismic isolation system. The total scope of the modes to be tried-out for all operation conditions and occurrence of possible emergency situations shall provide for the following seismic testings conditions.

1. Testings on the earthquake-equivalent effects, specified by the response spectra (standard spectra, spectra of specific accelerogramms for the object siting area, integrated spectra for the accelerogramm set).
2. Testings having regard to the azimuth and (or) angular rotations of a seismic isolated structure, induced either by the time delay in the waves arrival to the support seismic isolator elements, or caused by the initial angular rotations of the seismic isolated structure because of the base slab inclination or nonuniform permanent deformation of the supports.
3. Testings on the equivalent effects which are different because of the angular motion of the support foundation or due to different modes of motion of the foundation points in the positions of the seismic isolators placement.
4. Initiation of a motion with required or maximum conceivable deformations and rates of the seismic isolators and damping devices deformation. Such test conditions would be required also when checking the influence of the attached cable and engineering communications on the protected object motion and when checking their structural behaviour.
5. Testing of the seismic isolation systems when the seismic isolators specifications depart from the rated ones due to long-term operation, partial loss of tightness, slipping or partial destruction of the connections, caused by previous earthquake, etc.
6. Testings of the seismic isolated structure at the system centre of mass eccentricity (preset or appeared while in service) for the conditions of non-adjusted position of the structure or during the recovery of its setting position due to redistribution of forces in the seismic isolators.

## 4. CONCLUSION.

This approach is realized during the testings with the help of the seismic explosive stands of the full-scale fragment of multicomponent low-frequency seismic isolation of the NPP reactor building with VVER-640. Testing is to be completed in 1997.




1 - testing construction (fragment of a building)
2 - support elements
3 - movable supports
4 - support platforms
5 - rollers
6 - pneumatic elements
7 - testing equipment

Fig. 1. Shematic diagram of the test stand.

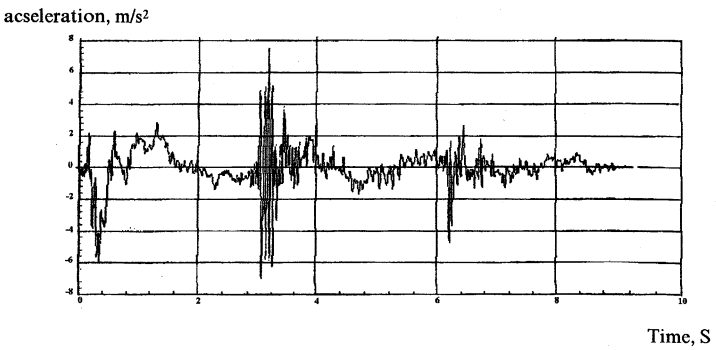



Fig. 2. The process of the stand motion.