STUDYING SUPPORT-PENDULUM SEISMIC ISOLATION SYSTEM FOR LARGE NPP EQUIPMENT

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ABSTRACT

The paper presents the results of theoretical and experimental investigations of support-pendulum seismic isolation (SPSI) system, designed for protection of large NPP equipment against seismic, shock and vibration loads. SPSI is a set of separate supports, the composition of which includes pendulum bars with special fastener assemblies and plastic damper in the form of rod steel elements system.

Full-scale seismic SPSI testing had been conducted on the Russia's largest seismic platform BCC-300. The tested SPSI had three supports, on which a 40-ton mockupup of NPP equipment had been installed. Mockupup size was 4,6*3,7*6,8 m. The testing reproduced three-component load input which corresponds to seismic input, intensity of which exceeded 9 as per the scale MSK-64. Decreasing horizontal accelerations and speeds on the NPP equipment mockupup were approximately 2 times, the amplitude of horizontal displacement had increased on 20% approximately. Relative horizontal displacements of the mockupup were of quick-damped vibrations type that demonstrates the efficiency of using plastic dampers in the form of deformable rods.

The procedure for design and selection of rational damper structural parameters includes searching the optimal parameters of viscous damping for linear dynamic model on the basis of construction of spectral density of seismic input power and selection of force characteristic for the damper, ensuring damping, equivalent to optimal viscous damping. Purpose-oriented function of optimization is the minimum of dispersion of seismic isolated object accelerations. This experiment had confirmed the correctness of damper structure choice procedure for provision of the required dissipation level.

INTRODUCTION

Currently in Russia a variety of seismic isolation systems with plastic dampers has been developed, Belyaev et al. (2009). These constructions of seismic isolation systems relate to support or support- pendulum types.

The paper presents the results of theoretical and experimental investigations of support-pendulum seismic isolation (SPSI) system, designed for protection of large NPP equipment against seismic, shock and vibration loads. SPSI consists of a set of separate supports, the composition of which includes pendulum bars with special fastener assemblies and plastic damper in the form of rod steel elements system. SPSI does not incorporate rubber or elastomeric elements which ensures its application in the increased radioactivity zone.

Full-scale seismic SPSI testing had been conducted on the Russia's largest seismic platform BCC-300. The SPSI version under investigation consisted of three supports. 40-ton mockupup of NPP equipment had been installed on these supports. Dimensions of mockupup were 4,6*3,7*6,8 m. The testing reproduced three-component load input which corresponds to seismic input, rate of which exceeded 9 as per the scale MSK-64. Maximum horizontal accelerations of the seismic platform were 9,6

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m/s^2, vertical accelerations − 4,6 m/s^2, horizontal speeds and displacements − 0,69 m/s and 0,11 m respectively. These parameters can be considered as extreme for Russian territory. The decreasing horizontal accelerations and speeds on the NPP equipment mockupup were approximately 2 times, the amplitude of horizontal displacement had increased on 20% approximately. Relative horizontal displacements of the mockupup were of quick-damped vibrations type that demonstrates the efficiency of using plastic dampers in the form of deformable rods.

The procedure for design and selection of rational damper structural parameters includes searching the optimal parameters of viscous damping for linear dynamic model on the basis of construction of spectral density of seismic input power and selection of force characteristic for the damper, ensuring damping, equivalent to optimal viscous damping. Purpose-oriented function of optimization is the minimum of dispersion of seismic isolated object accelerations. This experiment had confirmed the correctness of damper structure selection procedure for provision of the required dissipation level.

DESIGN ANALYSIS

Efficiency of the alternate designs for seismic isolation bearings had been analyzed on the basis of numerous calculations, technological and economical analysis and reliability performance. Consequently for manufacturing and testing of experimental model we had chosen a construction of support-pendulum seismic isolation bearing (SIB), (Figure 1) as the most promising.

1-Support frame, connected with foundation
2- Support frame, connected with building
3- Pendulum link
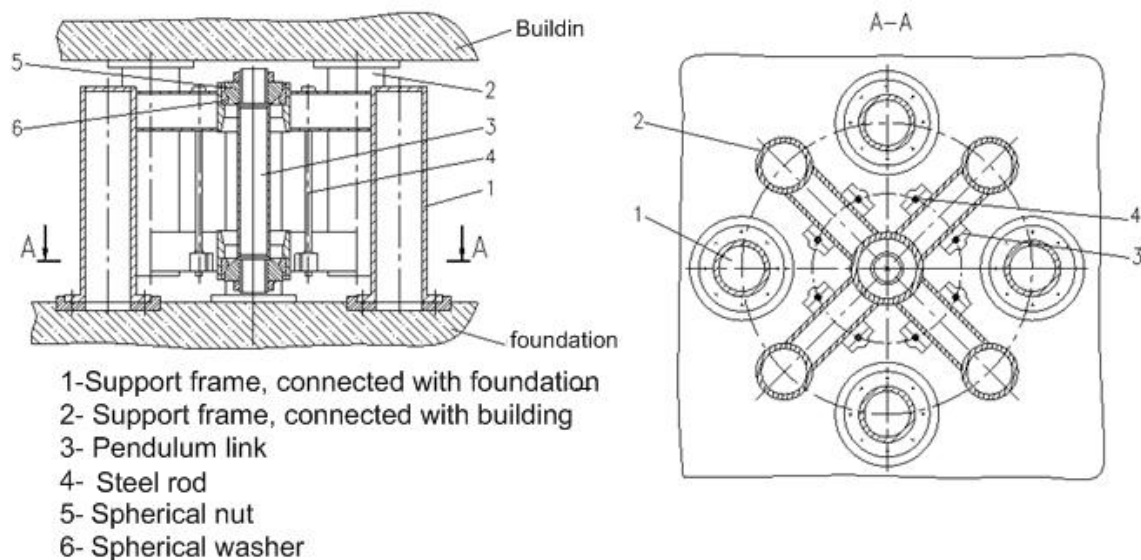4- Steel rod
5- Spherical nut
6- Spherical washer

Figure 1. Support-pendulum bearing with a hinged unit in the form of spherical nut and washer

In the construction under study plastic deformable rods had been used as dampers (Figure 2).
For choosing the efficient design values for these dampers a special technique had been suggested. The technique consists of three phases:
- searching the optimal parameters of viscous damping for linear dynamic model (LDM) with single degree of freedom;
- modelling the elastic plastic dampers force characteristic family corresponding to various design values;

22nd Conference on Structural Mechanics in Reactor Technology
San Francisco, California, USA - August 18-23, 2013
Division IX (include assigned division number from I to X)

- choosing the force characteristic of damper, ensuring the damping equivalent to optimal viscous damping.

Figure 2. Plastic deformable rods

As the optimality criterion we had taken the minimum of absolute accelerations for the object to be protected (OP). The boundary conditions were peak displacements of this object relatively the foundation. Now consider these phases.

Search the optimal damping for LDM was carried out on the basis of statistical manipulations with the dynamic problem solving results. Dynamic model was a linear single-degree-of-freedom system:

$$\ddot{x} + \alpha \cdot \dot{x} + \omega^2 \cdot x = -\ddot{y}_0(t),\qquad(1)$$

$$\omega = \sqrt{\frac{g}{l}},$$

$$\alpha = 2 \cdot \gamma \cdot \omega,$$

where $g = 9.8$ m/s^2 – gravity acceleration; l = 1.5 m - length of pendulum; γ - linear damping coefficient . In these calculations γ varied from 0 to 1; x - horizontal displacement of the object to be protected relatively the traveling foundation; $\ddot{y}o(t)$ - horizontal acceleration of the protected object foundation under seismic input.

External input for the system (1) were set by earthquake accelerogramms (Figure 3), characteristic for the seismic area, in which the object to be protected was located OP. System responses (absolute accelerations maxima) were averaged, that is, evaluation of the responses mean value was calculated.
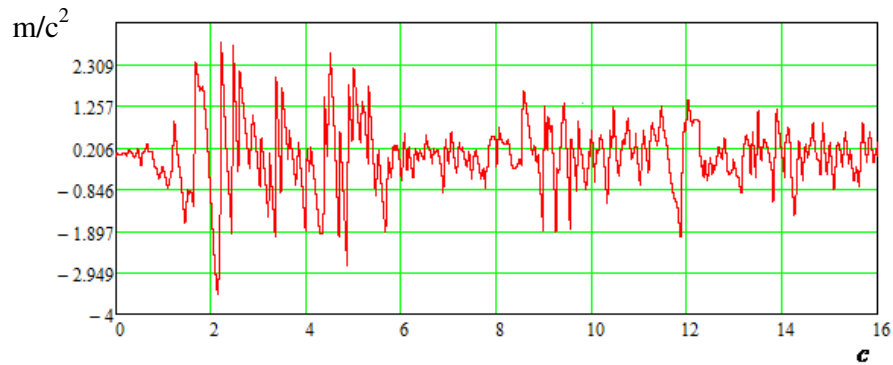
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Division IX (include assigned division number from I to X)

Figure 3. Typical accelerogramm

Mathematical model for the dynamics of the protected object, placed on the SIB, was the following equation:

$$\ddot{x} + 2\zeta\omega\dot{x} + \omega^2 \cdot x + f(u,\dot{u}) = -\ddot{y}_0(t) \qquad (2)$$

where $\zeta = \dfrac{\alpha}{2m\omega}$; u= x+y$_0$

$f(u,\dot{u}) = \dfrac{P(u,\dot{u})}{m}$ - force of plastic damper resistance reduced to unit mass, it is characterized by the

following parameters: $f_T = \dfrac{P_T}{m}$, $\omega_1 = \sqrt{\dfrac{c}{m}}$, $\omega_2 = \sqrt{\dfrac{c_{pl}}{m}}$, $P(u,\dot{u})$ - bilinear force characteristic of a
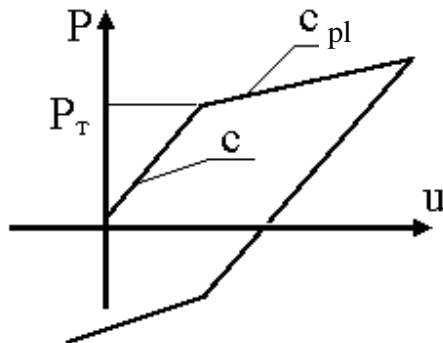
plastic damper (Figure 4).

Figure 4. Bilinear force characteristic of a plastic damper

Based on the analytical dependences] a family of nonlinear force characteristics of plastic dampers has been formed. As variable design values we considered configuration, dimensions and quantity of plastic dampers.

As an example Figure 5 presents various force characteristic of rod dampers, derived in the result of varying the length of rectilinear rods, being plastic deformable elements of plastic dampers. These characteristics were approximated by bilinear power diagram with elastic unloading.

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San Francisco, California, USA - August 18-23, 2013
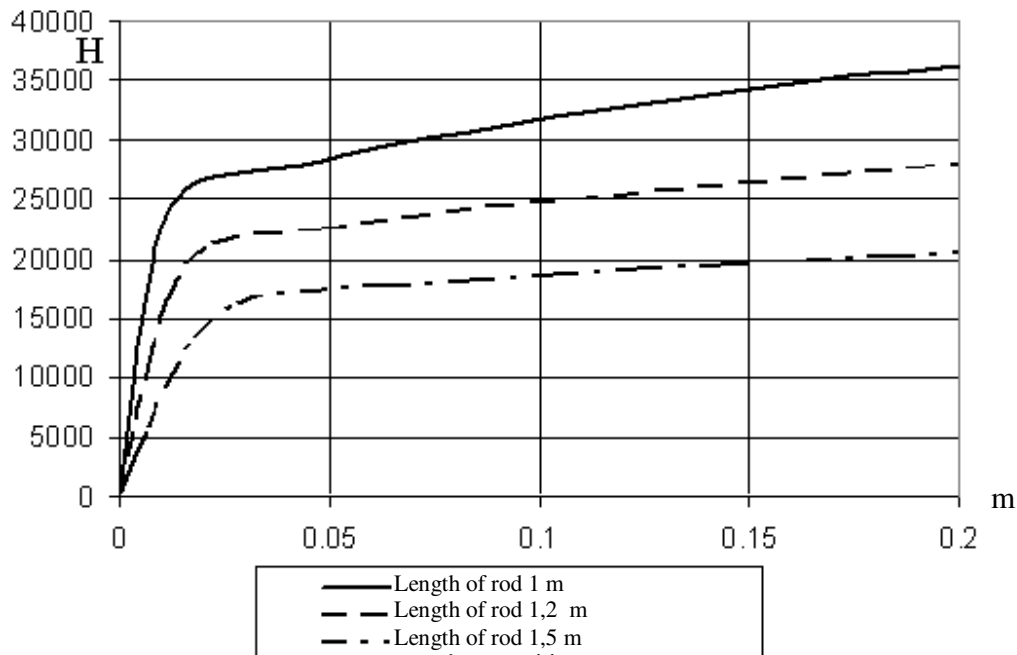Division IX (include assigned division number from I to X)

Figure 5. Dependence of force in plastic dampers on the relative horizontal displacements
of plastic deformable rod ends

Further, as in the linear model case, a representative sample of accelerogramms was used as system input and maxima of the absolute OP accelerations were averaged. As the efficient one we considered the force characteristic of plastic dampers, which gave the mean value of maximum which was close to its optimal value, received in LDM.

As a methodical example for calculation of the protected object, located on the SIB shown above had been performed. The plot of the mean values of absolute OP accelerations maxima versus dimensionless damping factor γ is presented in the Figure 6. The Figure shows that minimum of the parameter is reached for $\gamma = 0.25$. This parameter corresponds with the mean value of the absolute acceleration maximum 1.23 m/s^2.

For nonlinear problem the maxima are summarized in Table 1. Based on the results received we had chosen the efficient characteristic and design values corresponding to it. In this condition operability of dampers with the chosen parameters under the conditions of cyclic load input was tested.

FULL-SCALE TESTING RESULTS

Present means and technique of carrying out the dynamic testing of the above structure were described in Belyaev et al (2009). Seismic testing of the building to be tested (building mockupup) with isolation system on the basis of pendulum bearings took place on the seismic platform BCC-300. The seismic platform reproduces 3D seismic load inputs with the intensity level up to 10 as per MSK-64 scale. It is located on the opened test site near the city of Vyborg (Leningrad region) and is designed for full-scale tests of seismic stability of building construction, techware and equipment. With the aid of seismic platform it was possible to can be create the required conditions for testing the seismic object the mass of which exeeds 40 tn, the height is more than 9 meters and with dimensions up to 30*14 meters.
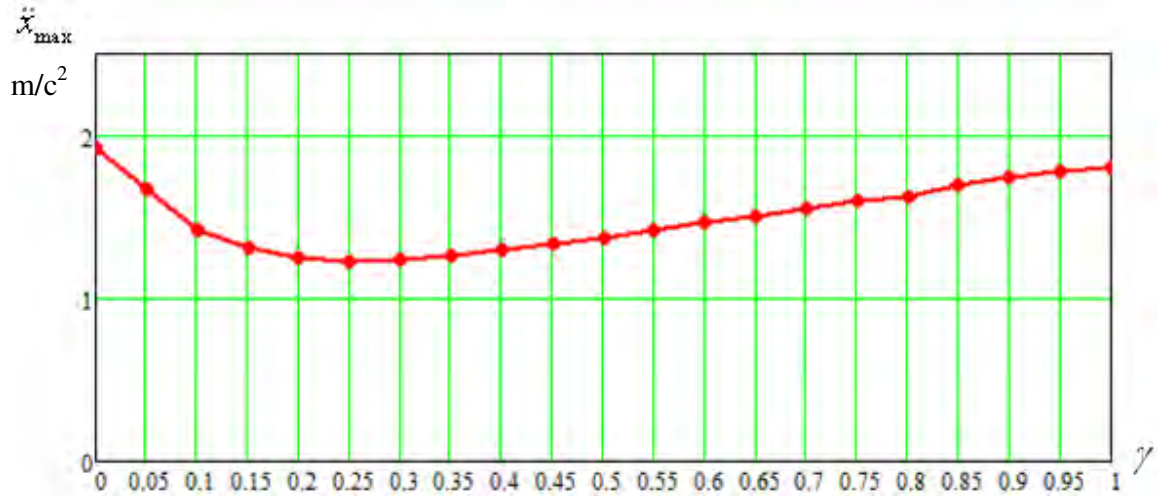
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Figure 6. Plot of the mean values of absolute OP accelerations maxima versus
dimensionless damping factor γ

Table 1: Results for dynamic load calculation of SIB

No	f_T m/s^2	ω_1 1/c	ω_2 1/c	max $\ddot{u}$, m/s^2
1	0.75	8.15	1.25	1.8
2	0.65	6.35	1.05	1.7
3	0.5	5.2	0.85	1.65
4	0.25	2.25	0.55	1.6
5	0.1	1.25	0.25	1.75

For testing experimental samples of pendulum seismic isolation bearing and building mockupup had been made. Building mockupup installation on the bearings is shown in the Figure 7. Layout of sensors and their numbering is shown in the Figure 8. On the Figure the labels A162, A165, A166, A184, A187, A189, A192, A193 are used for acceleration sensors, P1÷P12 – for displacement sensors, arrows show the direction of measurements.

Experimentally received maximal acceleration values are listed in the Table 2, and the plot of relative horizontal displacements of the seismic platform and the mockupup is shown in the Figure 9.

Figure 9 shows that this process looks like vibrations which decay quickly due to elastic plastic dampers.

CONCLUSION

Maximum horizontal accelerations of the seismic platform were ~ 1g m/s^2, vertical accelerations of seismic platform ~ 0.5 g m/s^2, horizontal speed and displacement - 0.69 1g m/s^2 and 0.11 m respectively. These parameters can be considered as extreme for Russia's territory.

Reduction coefficient for horizontal accelerations on the mockupup as compared with similar parameters of the seismic platform motions, as it could be noted from the Table 1 is 2.

The test had shown that the dampers suggested permit to ensure the required dissipation level.

22nd Conference on Structural Mechanics in Reactor Technology
San Francisco, California, USA - August 18-23, 2013
Division IX (include assigned division number from I to X)

Figure 7. Seismic platform with mockupup of the seismic isolated building

Table 2: Extreme values of accelerations and time of their achievement in the test

sensor number	Peak value, m/s^2	Time maximum, s	Minimum value, m/ s^2	Time minimum, s
A16 5	8.34	16.07	-9.25	16.27
A18 9	8.05	16.07	-10.62	16.27
A19 2	5.0	16.11	-4.86	16.27
A19 3	3.96	16.52	-5.57	16.25

REFERENCES

Belyaev V., Guskov V., Routman Y. (2009). "NPP seismic protection against shock and vibration loads". *Proc., Structural Mechanics in Reactor Technology, SMiRT20,* (№ 2479)

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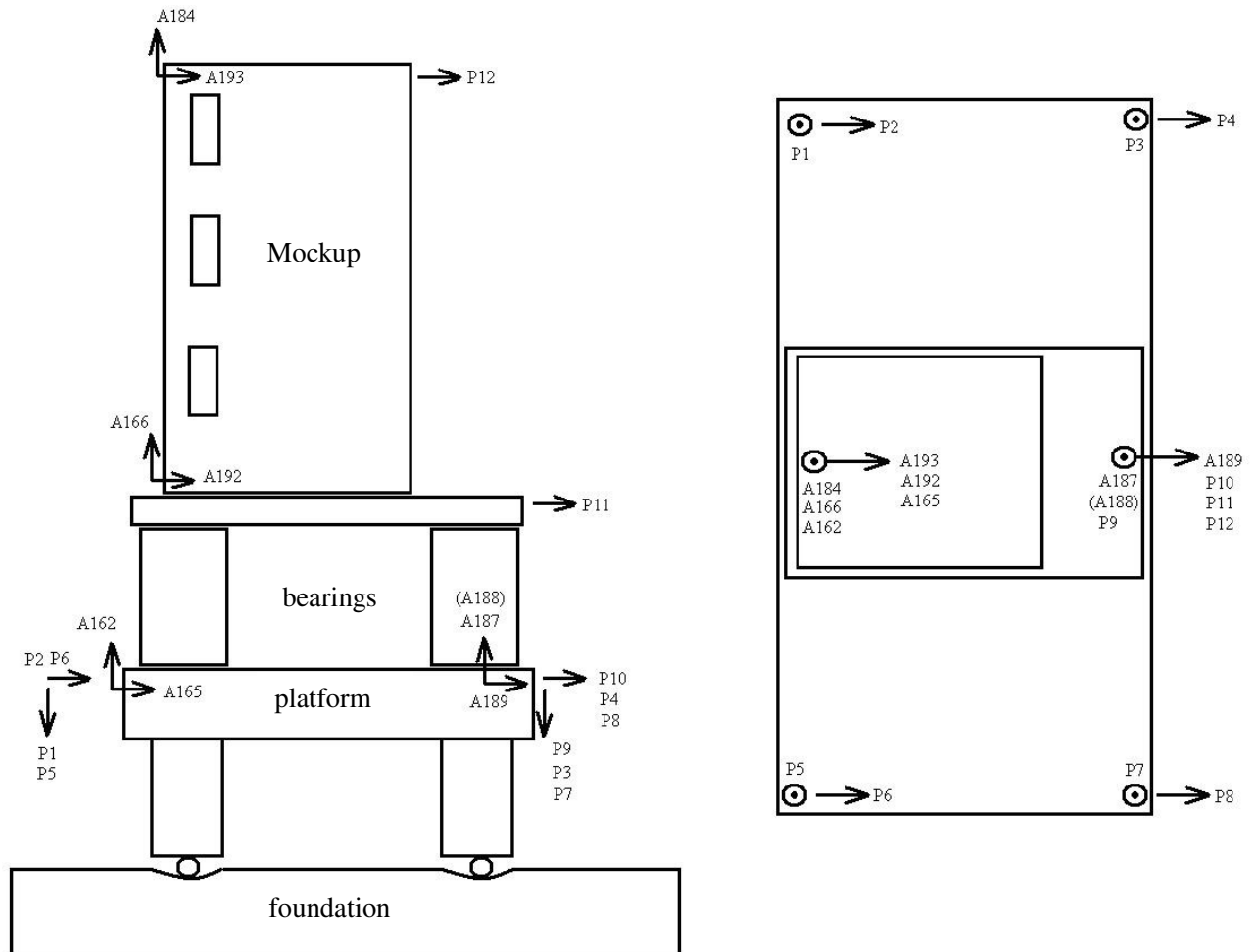Division IX (include assigned division number from I to X)

Figure 8. Layout of sensors and their numbering during the tests with mockup of seismic isolated building on the seismic platform BCC-300
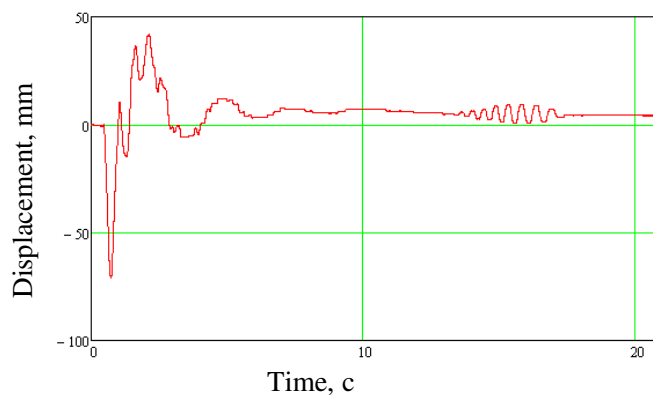

Figure 9 - Relative horizontal displacement of base of building mockup