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INFLUENCE OF THE DUCTILITY OF THE FOUNDATION AND STIFFNESS OF THE BUILDING BASE SLAB ON THE EFFICIENCY OF THE SEISMIC ISOLATION

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SUMMARY

For the regions with high seismicity level applying the seismic isolated foundations is considered as an effective means of buildings and constructions seismic protection. At present the foundations are used in which the seismic protection function is ensured by a set of discrete elements (flexible supports, rolling or sliding bearings) with low stiffness in both horizontal and vertical directions.

The problems of choosing the optimal layout of the seismic isolation devices for 3-D low-frequency seismic isolation system of a building are discussed in the paper. The influence of base slab deformability on the response values of the seismic isolators has been investigated. The results of numerical analysis illustrate distribution of the seismic isolators responses for the soils with various stiffness degree.

Three types of support elements has been studied, the experiments were performed in accordance with the following schemes: single-span struts with cross-sections rigidly embedded into the plates (basement and upper structure), the same struts except that with hinged support in one of the plates and the columns with curvilinear bearing surfaces, which are hinged-supported in the both plates. Number of supports were specified from the structural design of the building for the reasons of its strength provision. The seismic isolation system composes dry friction damping devices.

As a design model due to support elements type the boundary conditions were accepted for the adjoining nodes of each support as follows: rigid restraint, free adjoining and combination of these conditions, respectively. The building and base slab design models were based on the use of finite element method. Building-ground base isolation was simulated with a system of linear elastic and dissipative elements. Stress-strain modulus of ground base altered within the range of 16 Mpa (soft soil) and 1000 Mpa (hard rock).

Evaluation of seismic protection efficiency was carried out under the effect of magnitude 8 earthquake (as per MSK-64 scale) with the use of three-component seismic input, maximum response spectrum of which is within the range of 4-12 Hz in vertical direction and 5-10 Hz in horizontal direction. Amplitude of the vertical component acceleration was 2/3 of the horizontal acceleration amplitude.

In the existing approaches for evaluation of efficiency of seismic protective foundations the main initial precondition is the assumption of the lack of influence of initial loading condition of each of the supports on the system dynamics. Such assumption permits to simplify substantially the foundation design model if combining the supports into groups or replacing them with one element in the structural model, force characteristic of which is determined by simple adding the characteristics of separate devices. This assumption for a number of design cases appears to be incorrect. The paper presents the results of investigation of the stiffening effect of the ground base, base slabs and support structure on the results of evaluation of seismic isolated foundations efficiency.

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INTRODUCTION

Application of the 3-D seismic isolation of a building introduces a series of special features into the structural layout of the building. Consideration is being given to the main of them: presence (in addition to the building base slab which transmit load from the seismic isolators to the building) of the additional base slab, on which the seismic isolation system is located. Deformability due to the this plate dimensions would have a profound effect on the seismic isolators response in accordance to their layout and stiffness degree of the foundation soil. Seismic isolation system realization as an element of the building foundation involves determination of the possible limitations.

SET OF LIMITATIONS, ASSOCIATED WITH OPERATION CONDITIONS OF THE SEISMIC ISOLATION SYSTEM

Procedure of choosing the rational layout of the seismic isolators under a building which is based on strengths investigation and base slabs deformability has a series of limitations.

The main limitations can be formulated as follows:

- limitations on the maximum stresses $\sigma(x,t)$, acting in the base slabs sections under the static and dynamic loads

$$\max \sigma^i(x,t) < [\sigma], \qquad (1)$$

where $i=1$ - for the building base slab;
$i=2$ - for the base slab of the structure as a whole
$[\sigma]$ - allowable stresses for the reinforced concrete of the corresponding grade under the elastic conditions:

- limitations on the maximum conceivable inclinations of the embedded pieces in the seismic isolation bearings at the base slabs deformations under all loading conditions:

$$\max_{i} |H_i - H_i^0| < \sigma, \ i\ (1,N), \qquad (2)$$

where H_i^0 - eccentric distance of embedded pieces of the ith support, which are located on the base slabs;
H_i - distance between the points which are located on the embedded pieces circuits of the ith support;
N - number of supports in the seismic isolation system;
σ - permissible value of nonhorizontality of the embedded elements surfaces;

- limitation on the overall dimensions of the seismic isolation bearings under the condition of sufficient load-carrying capacity:

$$\min r > \max (\min r_{imaint}, \min r_{erect}), \ i\ (1,l) \qquad (3)$$
under the condition $N x Q > G$,

where r - minimum distance between the seismic isolation bearings (or supports) and lateral walls of the base slab;
r_{imaint} - minimum distance between the supports, needed for servicing and repairing the i-type supports, prescribed due the specifications;
r_{erect} - minimum distance between the supports, specified in accordance with the technological requirements on the system installation;
l - number of the support types used in the system;
Q - load-carrying capacity of one device;
G - maximum total weight of the protected object;
N - total number of the seismic isolation bearings;

- limitation on the value of the spread in forces in the supports ΔP relatively the average P level:

$$\Delta P \rightarrow \min, \text{ where } \Delta P = P_i - P, \ i\ (1,N) \qquad (4)$$
P_i - force in the ith support.

Introducing the last limitation is related to the fact that when a building is under construction technological (erection) supports are used, which are replaced by seismic isolators after the construction ending. Removal of the erection supports is possible only in case when the building weight load would be removed from them. In the seismic isolation system in question the release of the erection supports is produced by filling all of the pneumoshock-absorbers and does not involve any additional devices.

DESIGN CONDITIONS

For the seismic isolation system loads on the building and its base slab there had been taken the forces, arising in the supports (seismic isolators or erection supports) under various conditions of system operation on the object construction and operation steps.

Calculation of the loads acting on the building base slab in the layout positions of the seismic isolation system supports was carried out under the following conditions:

1. Vertical loads act on the embedded pieces compression, horizontal ones - on their shear, in this condition the design loads application area has circular form which is symmetrical relatively the embedded piece centre.
2. Loads to the base slab are applied in accordance with the seismic isolation bearings layout.
3. The following design loading modes were considered: construction mode, pneumoshock-absorbers filling mode, operation mode.
4. For the construction mode there was specified the value of the centre of mass displacement of the object under construction at various total mass values. Under this condition there was assumed, that on the steps which precede building construction completion, possible centre of mass displacement will be less, than on the initial steps.

5. For the pneumoshock-absorbers filling mode there was assumed that the pressure variations in all the devices are simultaneous, in this condition until the forces in the support does not exceed the erection forces, stiffness of the element which simulates a support, corresponds the strut stiffness.
6. Under operation conditions there was assumed, that 0,9 of the total building mass is perceived by devices with monotonous force characteristic, and 0,1 of the total mass - by devices which form a step characteristic. Calculations were carried out for the case of the total building mass.

METHOD OF ANALYSIS

To design a building seismic isolation system under the static loads action there was used a finite-element model of the building and the lower base slab with the corresponding boundary conditions. As a basic finite element there had been taken a triangular element of a thin plate. This element has 18 degrees of freedom.

As a boundary element in the shock-absorber model we use a single-degree-of-freedom element.

The building foundation was simulated with the use of single-degree-of-freedom elements of simple stiffness, which were located in each node of the finite-element model of the lower base slab. As the soil pressure was considered as applied in the model nodes, for each node there was determined the soil pressure application area as a part of the triangular elements area, which are contiguous to a node under consideration with this node centre of gravity.

Finite-element model of the seismic isolated building is performed based on the building construction representation as a spatial system of triangular plate elements and boundary elements in the isolator installation places. Total number of node connections is 244; total number of triangular elements is 474.

Elements thicknesses were specified in accordance with the thickness of walls and floors in a real structure. Since a building construction has two-plane symmetry, in the calculation there was used one quarter of the construction, with corresponding boundary conditions on the planes of symmetry which exclude rotation about the OX and OY axes for the planes 1 and 2 respectively and displacements in the OY and OX direction for the planes 1 and 2 respectively. In the calculation there were simulated both the lower and the upper base slabs, as well as the building lower part up to 10,5 m elevation. Mass of the structures and
components, which were above this level was accounted for as an external distributed load on the cylindrical and radial walls.

Precomputations have indicated, that minimization of ΔP value ensures the best conditions of load redistribution on the base slabs and load removal from all the erection supports takes place at lower pressure in the pneumoshock-absorbers.

As an example, in the Table 1 there are presented the results of solving the problem of seismic isolators layout for a building, located on the "soft" foundation soil.

Table 1

Radius of supports installation, m	Number of supports	P, t	max ΔP, t
22.7	27	853.75	0.05
20.3	35	851.0	2.5
15.4	4	843.2	-
12.0	4	840.0	-
8.9	12	870.3	-
5.5	6	890.2	-
0.0	1	883.0	-
For seismic isolation system as a whole	89	856.6	33.6

Base slabs thickness was:
1.5 m - for the building base slab;
3.0 m - for the structure base slab.

CALCULATIONS RESULTS

For the chosen layout of the seismic isolation bearings (Tab. 1) with the fixed structure base slab thickness (3m) investigations had been performed to evaluate the foundation stiffening effect on the force distribution of the supports. In the calculations the soil stress-strain modulus E altered within the range from 16 MPa ("soft" soil) up to 2500 Mpa ("hard" soil). Separately the case of undeformable foundation had been considered.

As a parameter for comparison of the alternate calculation modes we had chosen the deviation ΔP of the average force P_{av} from the force which corresponds to the pneumoshock-absorbers filling pressure (equal for all of them) P_{fill}, for each radii of support installation. For the corresponding radius of support installation (see Tab.1) the average force P_{av} was determined according to the formula:

$$P_{av} = \left(\sum_i P_i \right) / N_i \qquad (5)$$

where P_i - the forces in the ith supports;

N_i - number of supports on the corresponding radius of the installation.

Analysis of calculation results P_{av} has shown, that when the stiffness of the foundation soil increases the deviations of forces P_i from the average value have a reduction tendency.

Fig. 1 presents the calculations results ΔP for six types of soils. Analysis of the calculation results has shown that:

- for the chosen seismic isolation bearings layout the use of the structure base slab with 3m thickness is allowable for the soils with stress-strain modulus E within the limits 50 MPa - 200 MPa;
- supports, located on the "external" radii of the installation (R>15.4m), practically for any ground conditions turn out to be "underloaded" ($P_{av} < P_{fill}$);
- supports, located on the "internal" radii of the installation (R <15.4m), more commonly turn out to be "overloaded" ($P_{av} > P_{fill}$);
- for too "hard" soils (E >200MPa) it is required to change the filling pressure of the pneumoshock-absorbers, located on the "internal" radii of the placement, or to change the layout adding one support more;
- for too "soft" soils (E < 50MPa) it is required to increase the structure base slab thickness.

CONCLUSION

The results received testify that the absence of requirement on the geometry invariability of the base slab, (i.e. assumption of its deformability) does not cause special difficulties when the system is used as a vertical seismic isolation of pneumatic elements taking into account the limitations, related with the object operation under normal conditions.

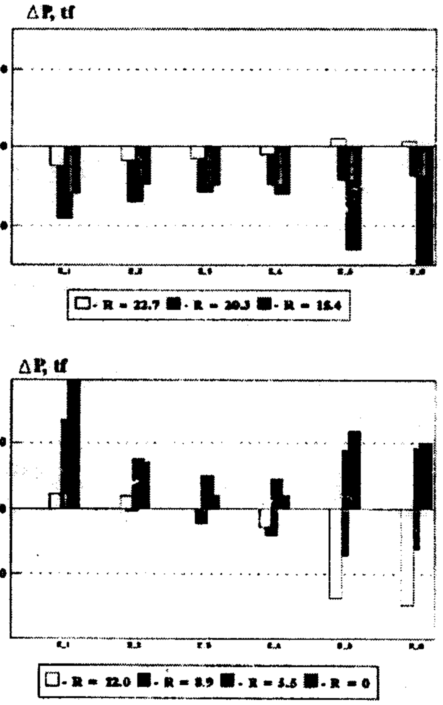

Figure 1. Dependence of ΔP deviation from the foundation soil stiffness