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SELECTION OF PARAMETERS OF SEISMOISOLATION FOUNDATIONS

A.A. DOLGAYA, T.A. SANDOVICH, A.M. UZDIN

Kamchatka Center on Earthquake Engineering and Natural Disaster Reduction,
SPB Branch
Bulvar Novatorov 94-58, Saint-Petersburg, 198215, Russia

ABSTRACT

Specifying of the parameters of damping devices of displacement is one of the most important problems in the design of seismoisolation systems. Many different recommendations have been proposed on this problem, but they are mostly contradictories.

The paper shows that the reason of the discrepancy between results of different authors is the difference in specifying of the seismic impacts.

When calculating the seismoisolation system, the design impacts are to meet a diversity of criteria which have been proposed by the authors of the present paper for example: the limitation of residual displacement on the design seismogram, the range of correlation of maximums of amplitudes, speed accelerations e.t.c.

Observing the whole complex of criteria the authors come to a conclusion that optimal parameters of seismoisolation depend not on the spectrum frequency composition of the earthquake, but on its intensity.

The paper presents the optimal parameters of the power absorbing devices in the seismoisolating foundations with the dry friction dampers.

KEYWORDS

Seismoisolating foundation, dry friction dampers, tuning, optimization.

INTRODUCTION

At present the seismoisolation is regarded as one of the most effective means of increasing the seismic stability of the structures. One of the engineering concepts assuring the seismoisolation of the structure is the seismoisolating foundation (SF) on elastic and kinematic supports. Among structures with such seismoisolation are the buildings with flexible ground floor which were severely damaged during the earthquakes in Skople, Bucharest, Mexico City. The reasons of destruction of the seismoisolated building have been studied in literature (Albert I.U. et al., 1988; Savinov O.A. et al., 1989). These are justified by significant mutual displacements of the lower and the upper foundation plates that result in destruction of the support elements. To reduce these displacements SF must have damping devices among which the dry friction dampers (DFD) are the simplest ones. The selection of the DFD parameters has been considered in (Albert I.U. et al., 1988; Renault J. et al., 1979; Uzdin A.M. et al., 1993) but the unified recommendations to determine the friction forces which depend on the amplitude and spectral composition of impact and the period T of the main tone of the seismoisolated system oscillations have not been developed yet. Up to now the engineering concept of SF without additional damping devices which do not ensure the seismic stability of the structure are in use. The data enabling to specify the friction forces in DFD of SF of the type being considered in the first approximation are given below.

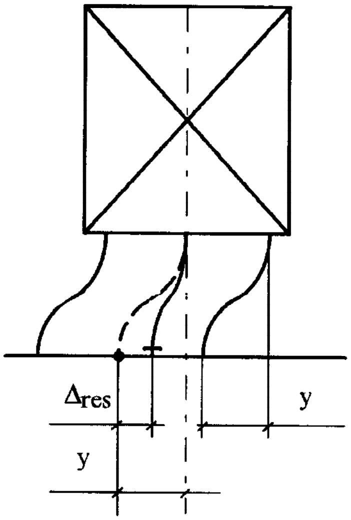

Fig.1. Design diagram of structure on seismoisolating foundation with dry friction damper

FORMLATION OF THE PROBLEM

To select the SF parameters in accordance with the investigations at hand (Albert I.U. et al., 1988; Uzdin A.M. et al., 1993; Renault J. et al., 1979) it is sufficiently to consider the simplest system with one degree of freedom (Fig.1) which can be described by equations: if the DFD is closed

$$m\ddot{y} + b_1\dot{y} + r_1 y + c_d(y - y_{res}) = -m\ddot{y}_o; \tag{1.a}$$

if the DFD is opened

$$m\ddot{y} + b_2\dot{y} + r_2 y + F_{fr}\,\mathrm{sign}\,\dot{y} = -m\ddot{y}_o, \tag{1.b}$$

where m - mass of the structure

y - displacement of center of gravity of the structure relative to the base which is roughly equal to the mutual displacement of the SF foundation plates;
b_1 and b_2 - coefficients of damping at the closed and opened DFD;
r_2 and $r_2=r_1+c_d$ - stiffness of the system under the closed and opened DFD;
c_d - stiffness of the damper;

y_o - displacement of the base
F_{fr} - friction force; to characterize the force F_{fr} the coefficient of friction $K_{fr}=F_{fr}/mg$ will be introduced, where g - acceleration of force of gravity
y_{res} - residual displacement in DFD.

The equation (1.a) will be realized if:

$$c_d(y - y_{res}) \leq F_{fr}, \tag{2}$$

If the condition (2) is violated there occurs a sliding in DFD and the systems will be described by equations (1.b). The return to the equation (1.a) will take place if $\dot{y}=0$.

The investigations carried out before (Albert I.U. et al., 1988; Savinov O.A. et al., 1989) initiated from normalizing the design impact (accelerations) by the MSK-scale. In doing so there appeared a dependence of optimal friction on force of impact which can be determined by maximum accelerations $K_s g = \ddot{y}_o^{(max)}$ of the base. To eliminate this dependence under the numerical simulation we will introduce a new variable.

$$\eta = y / K_s g, \tag{3}$$

If $b_i = \gamma_i k_i m$ where γ_i - coefficient of non-elastic resistance $k_i=\sqrt{r_i / m}$, $k_d=\sqrt{c_d / m}$ we shall obtain the following resoluting equations after the replacement of (3):

$$\begin{aligned} &\ddot{\eta} + \gamma_1 k_1 \dot{\eta} + k_1^2 \eta + k_d^2(\eta - \eta_{res}) = -\ddot{\bar{y}}_o, \quad &&\text{if} \quad \eta < \frac{f}{k_i^2}; \\ &\ddot{\eta} + \gamma_2 k_2 \dot{\eta} + k_2^2 \eta + f \operatorname{sign} \dot{\eta} = -\ddot{\bar{y}}_o, \quad &&\text{if} \quad \dot{\eta} \neq 0, \end{aligned} \tag{4}$$

where $f = \frac{k_{fr}}{k_s}$ - relative coefficient of friction;
$\ddot{\bar{y}}_o$ - normalized accelerogram of the earthquake.

Representation (4) enables to ignore the question of normalizing the design accelerograms and the optimal coefficient of friction $K_{fr}^{(opt)}$ appears to be in proportion to the value K_s:

$$K_{fr}^{(opt)} = f_{opt} \cdot K_s, \tag{5}$$

where f_{opt} - value of relative coefficient of friction obtained after optimization of the equation's solution (4).

Note, that the method of replacing the variables in accordance with (3) is in full measure applicable for the multimass systems.

CALCULATING ANALYSIS RESULTS

A number of solutions of the equations (4) was realized on a computer with the use of procedure (Sakharova V.V. and Uzdin A.M., 1987; Uzdin A.M. et al., 1993; Uzdin A.M., 1986), analytic representation of solution being used on each linear interval of integration interval (interval between the points of tabulating the impact).

The results of calculations as dependences of maximum relative accelerations of the system

$$\beta = \frac{W_{max}}{K_s g} = \frac{(\ddot{Y} + \ddot{Y}_o)_{max}}{K_s g}$$

and maximum relative mutual displacements of foundation plates $\eta_{max} = y_{max} / K_s g$ for three typical earthquakes are shown in Fig. 2.

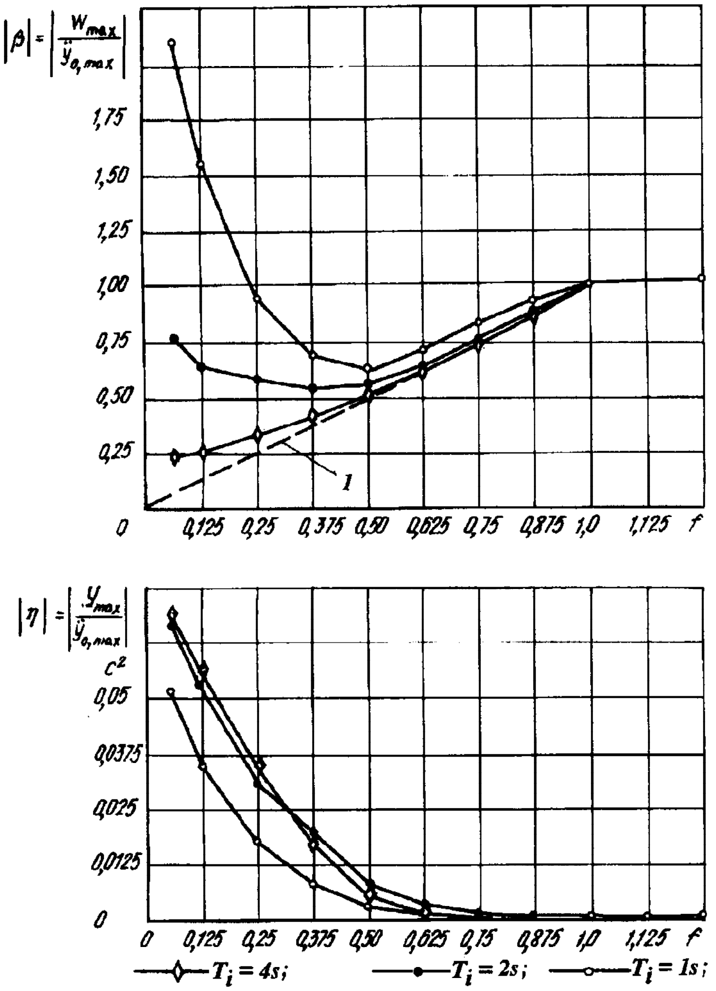

Fig.2. Dependences of β and η on f for El-Centro Earthquake;
1 - accelerations of the structure with seismobelt.

The figures show that the conclusion [1] about the availability of optimal adjustment of SF by friction, which minimizes the acceleration of the structure, and about the independence of this adjustment on the period T_i of seismoisolation is true in a limited range $0.8 < T_i < 2$ s, and $T_i < 1.5$ s for severe impacts. The dependence of optimal friction parameter f_{opt} upon the value T_i for different impacts is presented in Fig. 3.

According to the results obtained there is such critical value T_i, that if $T_{kr}>T_i$ the minimization of accelerations inside the interval of changing the value f is impossible.

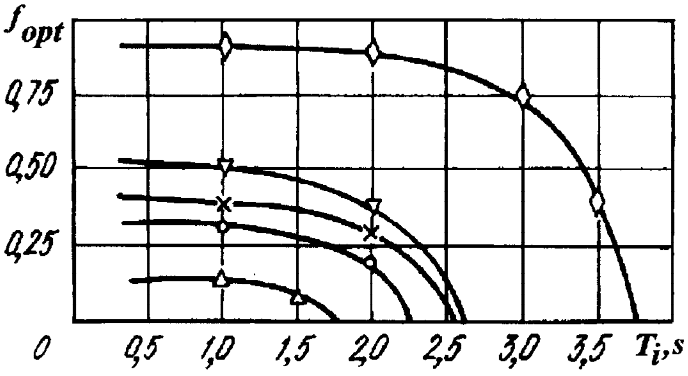

Fig.3. Dependence of f_{opt} on prevailing pemod of impact T_i.

Depending on complying the condition $T_i>T_{kr}$ the approach to specify the value f may be different. If $T_i<T_{kr}$ and $f=f_{opt}$ the decrease of friction forces in comparison with the optimal ones causes both the increase of mutual displacements of the plates and the growth of accelerations of the structure. If SF doesn't meet the requirements of seismic stability on the condition of limiting the mutual displacements when $f=f_{opt}$ it is necessary to increase the friction forces, but if $f \geq f_{opt}$ the dependence is rather smooth and it is necessary to increase significantly the value f to limit the displacements. Effect of seismoisolation which is determined by value β will be far lower. In accordance with the abovementioned when $T_i<T_{kr}$ the seismoisolation is expedient if for $f=f_{opt}$ the seismic stability of the system is assured.

If $T_i>T_{kr}$ the effect of seismoisolation is growing when the coefficient of friction is decreasing. Hence the value f should be accepted as low as possible proceeding from the condition of limiting the mutual displacements of foundation plates by the allowable value.

As the plots show the optimal value of the parameter f introduced depends on the spectral composition of the impact. In Fig. 4 presents the relationship between f_{opt} and prevailing period of impact if T_i=2s.

It has been suggested the prof. O.A.Savinov articles (1988, 1989) the universal adjustment of SF by friction which assures the acceptable accelerations and displacement of system within the broad class of impacts, as noted in the articles this adjustment being not optimal for each particular impact. The dependences $f_{opt}(T_s)$ received allow to consider the universal adjustment to be rather close to optimal by the coefficient of friction K_{fr}. It is connected with existence of correlation connection between maximum accelerations and prevailing periods of impact. In Fig. 4 there are given the values of optimal coefficient of friction K_{fr}^{opt}, calculated by the formula (5) in supposition Abakarov A.D. (1988), that $K_s=0.25/(T_{eq}/T_o)$ where T_o=1s. As the Fig.4 shows K_{fr}^{opt} does not practically depend on T_s; for the seismicity of 9 on MSK-scale $K_{fr}^{opt} \cong 0.14 \div 0.16$.

Substantial increase of SF efficiency can be reached by passing from one DFD to their series [3]. In limit the multiseries damping is expressed in damping the energy by the wedge damper. The expediency of passing to the wedge dampers is proved by the formula (5).

Based on the obtained relative mutual displacements of the foundation plates η_{max} the friction force in the wedge damper can be specified as follows at $f=f_{opt}$ and dependence (5):

$$F_{fr} = m\alpha|Y| \qquad (6)$$

where $\alpha=300 \div 400 s^{-2}$ with $K_{fr}=\alpha| Y| /g$ and $f=\alpha(\eta)$.

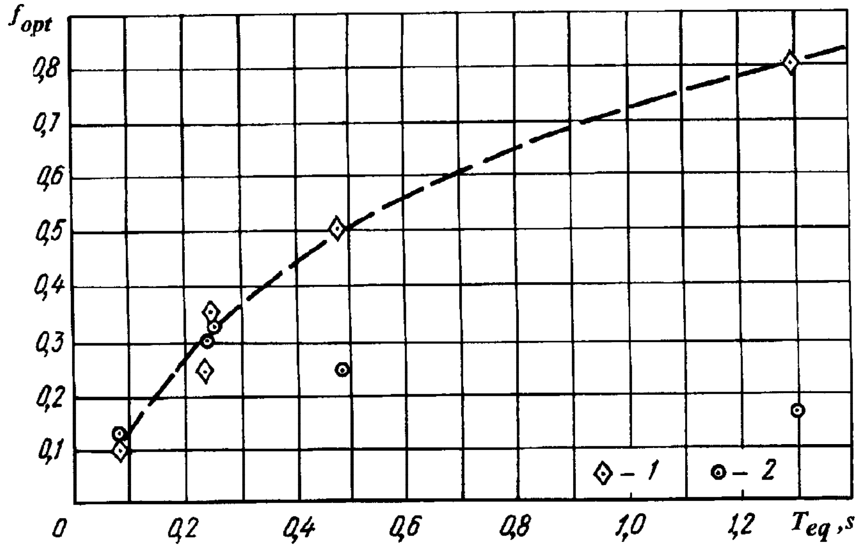

Fig.4. Dependence f_{opt} (T_{eq}) for different earthquakes
1 - normalization inaccordance with the high boundare of MSK-scale;
2 - normalization in accordance with the regression dependence $A(T_{eq})$.

SOIL-STRUCTURE INTERACTION INFLUENCE ON DAMPER TUNING

The recommendations on selecting the parameters of wedge damper and DFD are related to the case of the rock soil. In investigations (Albert I.U. et al., 1988; Uzdin A.M. et al., 1993) on effectiveness of seismic stability on non-rocky grounds at the first glance there are different opinions. On the one hand a low seismic stability of buildings on SF and soft soils is noted from the experience of the past earthquakes, on the other hand on the basis of theoretical researches it is shown that the base does not influence on the operation of seismoisolating structures due to their considerable flexibility. To analyze the influence of the base on the operation of SF the design researches of the "structure-SF-base" system, where the structures (4- and 5-storeyed buildings and NPS RR) were simulated by the system with 4 or 5 degrees of freedom and the base by the spring with a damper in accordance with the Russia construction code "Foundations under the machines with dynamic loads", have been fulfilled. All calculations were based on procedure given in the book of authors (Uzdin A.M. et al., 1993).

The dependences β and η_{max} on f for the Helena earthquake with the different modules of bases deformation determined for the NPS reactor room are given in Fig.5.

The calculations presented showed the following:

1. Both points of view about the efficiency of SF on non-rocky grounds represent the facts. This is derived from the fact that analysis of damage of the buildings on SF was carried out in comparison with conventional buildings located in neighborhood, the damaged buildings with SF having been designed without necessary damping of oscillations. As a result the conventional buildings were dis-

tinguished from the seismoisolated ones by considerable losses of energy at the expense of its emission into the base and hysteresis in the soil. If we consider the fact of increasing the prevailing period of impact on the soft soils, the growth of damagability of seismoisolated buildings in comparison with conventional ones is becoming clear.

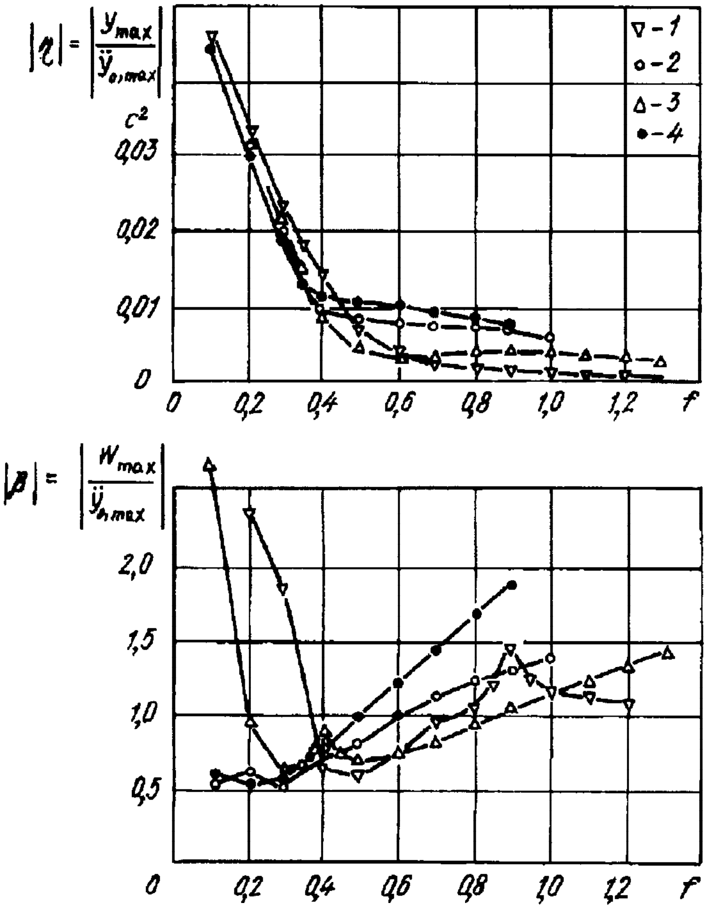

Fig.5. Dependences of maximum relative mutual displacements η of foundation plates and accelerations of seismoisolated structure on the value f at different moduls of the soil deformations.
1 - E_o=25MPa, 2 - - E_o=200MPa, 3 - E_o=500MPa.

2. Under the design seismicity $I \leq 8$ and $f=f_{opt}$ the low influence of the base on oscillations of seismoisolated systems is confirmed. If I=9 and $f \geq f_{opt}$ the influence of the base is becoming considerable for the seismoisolated system, because in this case DFD appears to be jammed during much of the earthquake and the structure behaves itself as a stiff one passing a considerable load to the base.

3. Optimal friction in SF DFD is increasing with decreasing the module of soil deformation E_0 and can be specified for the seismicity of 9 by the formula:

$$K_{fr}^{(opt)} = 0.14 + \frac{K_1}{\sqrt{E/E_o}}, \tag{7}$$

where E_o = 1 MPa;

K_1 - numerical coefficient depending on the relative mass of the structure $m_{rel} = m/\rho r^3$;
m - mass of the structure;
ρ - density of the soil;
$r = \sqrt{F/\pi}$;
F - area of the foot of foundation.

The higher the m_{rel}, the higher the K_1. For residential buildings $K_1=0.1\div0.3$, for the NPS reactor rooms $K_1=1.5\div1.7$.

The expediency of increasing the friction is justified by increasing the total losses of oscillation energy by the fuller engagement of the soil.

4. If the condition $K_{fr} \geq K_{fr}^{opt}$ is realized the buildings on SF with DFD is in better position than the similar ones on the rock soils as for the level of maximum accelerations of the structure and mutual displacement of the foundation plates. It is clearly seen in Fig.5. So, the conclusion about the low reliability of SF on the soft soils in general case is untrue and related to the improper designed foundations with $K_{fr} < K_{fr}^{opt}$. As shown in Fig. 5 there happens considerable rocking of the structure that has occurred in practice on fulfillment of the last condition.

The advanced considerations on selection of optimal parameters of power absorbing devices in the seismoisolation systems allow to design the most effective designs of seismoisolating foundations of the structures.

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