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Applications of seismic isolation in the USSR

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ABSTRACT:The program of analytical and experimental investigations of a structural seismoisolation system is shortly described.Specific for this seismoisolation system is that it is not expensive,simple in construction and its elements are made of usual simple building materials: concrete,steel a.a.

1 INTRODUCTION

In the beginning of the 70-th a program of analitical and experimental investigations of structural seismoisolation was initiated in TsNIISK,Department of Structural Earthquake Resistance, a.a. institutes and the author of this paper took part in these investigations.

The mathematical models used in this program have taken in consideration the uncertainty of the predicted spectra and other motion parameters of the future earthquakes.

Experimental,model and full-scale, static and dynamic tests were fullfilled.Designs of different structures using seismoisolation were developed taking into account the investigation results.Some of the seismoisolation systems were implemented in construction of structures in North Baikal City,Sevastopol, Frunze and other cities of the USSR.

In this paper some results of the research program and description of the seismoisolation systems applicated at Petropavlovsk-Kamchatka are presented.

2 RESEARCH PROGRAM

Research program was fullfilled in the last years to develop not expensive and safe seismoisolation systems for buildings and other structures.

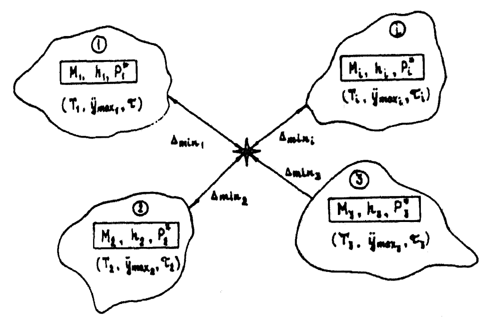


Figure 1. Parameter of expected earthquakes definition.

✢- construction site
1 - probably epicenter areas
M,h,Δ,P-seismological date (magnitude,depth of the foci, epicentral distance and probability of occurence)
$T, \ddot{y}_{max}, \tau$,-parameters which are calculated(predominant period,maximum acceleration and effective duration)

2.1 Analitical Research

The analitical part of the program included:

1. Development of mathematical models of earthquake motion for practical use,taking into account the uncertainty of seismological and geological data. The mathematical models are sets of non-stationary ramdom processes. The predominant periods,spectra configurations and

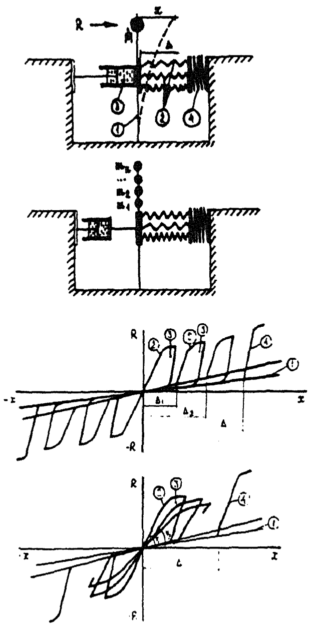
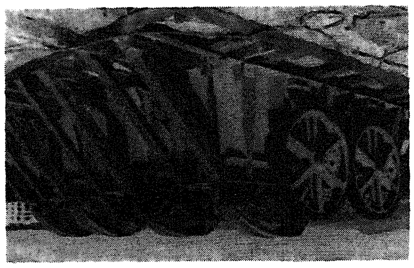


Figure 2. Mathematical models of SDOF (a) and MDOF (b) with system reserve disengaging elements.

1- flexible support elements
2- reserve disengaging elements
3- energy dissipation (histeretic or dry friction)
4- stops (displacement limiters)
Δ- clearance between the flexible elements and stops

a.



b.

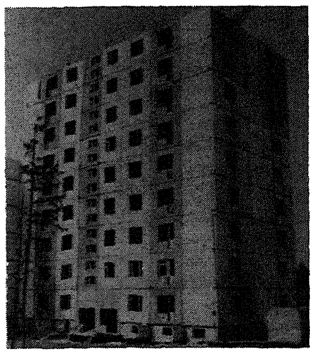


Figure 3.Full-scale dynamic tests.

a. A powerful exciter.Its inertia force can be 200 tons and more.
b. The tested seismoisolated building.

duration filled a definite range of values reflecting the above-mentioned uncertainty of predicted earthquake motion parameters. Any member of the standard set of accelerograms could be the next earthquake motion model and therefore a designer has to take into account all of them. Using this approach a set of artificial accelerograms was produced.

The parameters of the accelerograms take account of epicenter locations and foci nature in the region as well as soil-geological conditions of the building site (Figure 1.).

When determining quantitative characteristics of the earthquake being forecast, a complex approach is used which includes all available local seismological information. Frequency range of possible seismic ground motions, possible peak accelerations for every dominant period of ground motions with considerations for return periods of every type of the earthquake are determined.

To take into account the geological conditions of a given building site it is necessary to do recomputations of regional artificial accelerograms from a ledge rock base to a day surface or else to interior point of the medium. Soil conditions simulation follows the thin-layer media method.

Six instrumental accelerograms of strong earthquakes with different predominant periods are also used. They are accepted as representative models for possible earthquakes.

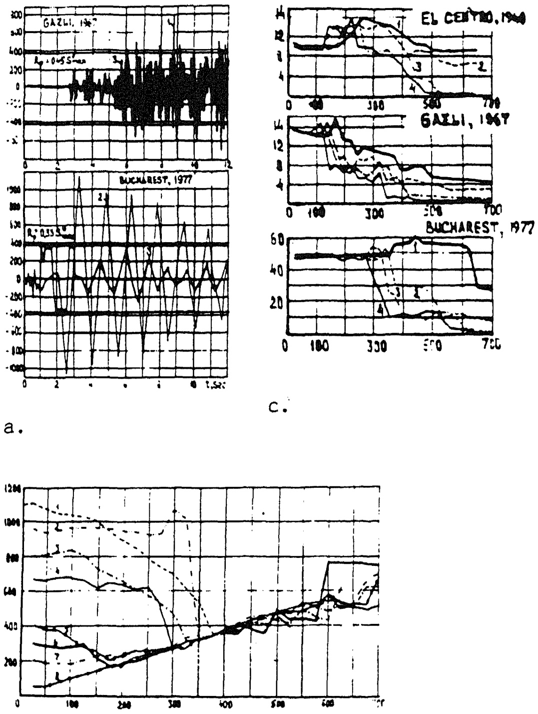
2. Development of mathematical models of seismoisolated structures as non-linear,inelastic non-stationary systemes(Figure 2.).

The general differential equation of seismic motion is

$$[M]\ddot{X} + [C]\dot{X} + R(X) = -[M]\ddot{X}_0 \qquad (1)$$

$[M],[C]$- mass and viscous damping matrixes,
$\ddot{X},\dot{X}$- acceleration and velocity vectors of the system,
$\ddot{X}_0$- ground motion acceleration vector
$R(X)$- vector of restoring forces.

The R-X loading curve is described by the Eisenberg exponential expression :



a. c. b.

Figure 4.Earthquake response base-isolated structures .

a.Response acceleration (1-non-isolated system,T=0.2sec,Gazli; 2- non-isolated system, T_{lim}=1.5 sec,Bucharest; 3- seismoisolated system, T=0.2 sec, T_{lim}=1.5 sec, Gazli-above,Bucharest-down)
b.Acceleration response versus-strength of the reserve fuse elements (calculated using 8 accelerograms)
c.Response displacements versus fuse elements strength (calculated using accelerograms El Centro 1940,N-S,above,Gazli,1967, W-E,Bucharest,1977,N-S,down) 1,2,3,4-systems with different initial periods.

$$R_x = R_{px}[1-e^{\Sigma K_i \frac{X}{\overline{X_{pi}}}}] \qquad (2)$$

R_{px}, K_i, X_i, X_{pi}- are the values which depend on the types of reserve elements.

The unloading dependency is modelled as a straight line.

3. Development of optimal design approaches for seismoisolation system using the earthquake motion models which take into account the uncertainty of seismological and geological data.

The procedure of optimization contained the minimax problem solving.

The first step is the definition of the maximum seismic load parameter combination for each element of the set of design earthquakes.

The second step is the definition of the probable minimum seismic load of all maxima and the correspondent set of structural parameters.

4. Cost-benefit analysis of the seismoisolated structures.

The seismoisolation application leads to:

- less expensive structure with the same reliability as that of non-isolated structure
- more safe structure with the same cost as that of non-isolated structures
- some combinations of the first and second

2.2 Experimental research

Experimental part of the program included:

1. Shaking table model and fragment
2. Full-scale building dynamic loading of the structure by means of an exciter corresponded to the design load of 9 MM-intensity and more (Figure 3.).

Static and dynamic tests of the elements of seismoisolation systems (flexible supports,dampers,dry friction elements a.a.).

2.3 Results

Investigations included the parametric response analysis using the results of experimental studies. The design and theoretical investigations were carried out in two stadies: identification of a design model and prediction of the system behaviour during strong earthquakes. For this purpose above mentioned accelerograms of seismic motions were used as input effects in the prediction of the structural seismic behavior. The design set included instrumental accelerograms of several strong earthquakes, their spectra are sufficiently various: predominant frequencies are 0.1 to 2.5 sec.,namely: El-Centro,NS 1940,Gazli,EW,1976, San Fernando 16 SW,1971,Bucharest,NS, 1977,Mexico,EW,1985,Gukasjan,EW,1988,

Table 1. Response displacements base-isolated DRES and non-isolated buildings.

Number of disengaging reserve steps element (lines)		Fundamental Periods, sec.			Reserve element system	Relation max, flexible / max DRES	
		initial T_o	final, T_f possible	realized		Gazli	Bucharest
General Number	Switched-off number						
1	1	0,1	1,25	1,25	8,3	1,1	4,9
6	4	0,1	1,25	0,9	5,6	1,5	7,3
23	10	0,1	1,25	0,6	3,6	2,3	11,5

Table 2. Cost and material expense comparison for 9-story large panel Kamchatka buildings, non-isolated and with different isolation systems (in percents).

	DRES-isolation buildings	Rocking Suppots buildings	Sliding belts buildings	Non-isolated buildings
TOTAL COST	88	96	97,5	100%
STEEL TOTAL WEIGHT	87,8	79	81,2	100%
CEMENT TOTAL WEIGHT	78	82,5	82,5	100%

a.a., and design sets of artificial accelerograms.

To select rationally parameters of seismoisolation systems with disengaging braces, the following parameter were varied:

- the value of the threshold level of the disengaging braces failure
- the size of the clearance between a stop(displacement limiter) and disengaging elemenents
- the ductility of disengaging elements

The studies showed that:

1. In structures with seismoisolation system such as disengaging elements,the resonance does not develop, irrespective of the kind of amplitude -frequency spectrum of seismic motion.

2. Seismic loads on a structure reduce 2 to 4 times in comparision with loads on rigid non-isolated structures. For example, the calculated respons acceleration is shown for two earthquakes: a. Gazli,1967 and b.Bucharest, 1977 (Figure 3 a). The dependency of the acceleration response and the strength of reserve elements for 8 different accelerograms are plotted too (Figure 3 b). The initial fundamental period of the building under consideration is 0.2 sec., the limit state period, after reserve elements disengaging, is 1.5 sec.

3. Seismic displacements of structures with the system of disengaging braces are considerably (2-6 times) less than those of flexible structures (Figure 3 c,Table 1).

Therefore the main bearing elements can remain in almost elastic deformation stage even during strong earthquakes. It is advisable to use disengaging elements with sufficiently large yield capacity.

As a result of the research program different structural systems of seismoisolation are designed and used recently in constructions in Siberia, Far East,Crimea,Caucasus,Middle Asia and other earthquake dangerous areas of the USSR. Speciffic for these systems is that they not only provided seismic reliability of isolated buil-

Table 3. Seismoisolated structures in USSR.

	Type of seismoisolation		The most active organization or author	Year of const-	Number of constructed buildings
1	Pendulum suspension and steel springs (Ashabad-City)		F.D.Zelenkov	1959	1
2	Flexible ground story columns plus sequens series of energy dissipation switching-off elements plus rigid inelastic displacement limiters(North-Baikal city, a.a.)		TsNIISK J.M.Eisenberg, M.M.Deglina, V.I.Smirnov, A.M.Melentiev a.a.	1972-1990	91
3	Pile-in-tube system with switching-off inelastic elements		J.M.Eisenberg, A.R.Rakhimov	1989	2
4	Low-friction supports (pairs "teflon-steel) between the foundations and walls plus rigid displacement limiters		TsNIISK, Polytechnic Institute (Frunze) S.V.Poljakov, L.S.Kilimnik, L.A.Soldatova	1984-1990	25
5	Kinematic (rocking) reinforce concrete supports	rocking reinforce concrete columns with spheric ends plus switching-off element plus dry friction elements	Sevastopolstroy, TsNIISK V.V.Nazin, J.M.Eisenberg	1972-1974	3
		rocking supports - "upside-down mushroom" type	Kazpromstroy-NIIProject,(Alma-Ata)Y.D.Cherepinsky	1979-1989	55
		reinforce concrete columns (rocking) with plane ends plus displacement limiters plus friction	TsNIISK A.M.Kurzanov, N.N.Skladnev	1987-1990	4
6	Rubber-steel laminated supports		TsNIISK	1985	1
7	Pnevmatic supports for special non-building structures		V.Beljaev ,a.a.		
	T O T A L				182

dings but they also are simple in construction and not expensive.

4. Some results of the cost-benefit analysis for a 9-story large panel buildings with different base-isolation systems constructed in Petropavlovsk-at-Kamchatka are given on the Figure 4.

The calculations have been made for a given set of predicted seismic motion parameters.For other combination of parameters, the results could be different.

2.4 Principal demands to the Seismoisolation Systems

As result of the research program, the following main principles were assumed as a basis of seismoisolation structural design 1-6:

1. Considerable damping.
2. Considerable flexibility of limit system and rigidity of an initial system.
3. Conservation of members bearing vertical loads in the elastic stage, completely or partially, under large horizontal displacements.
4. Application of rigid stops-limiters of very large displacements.
5. Cost of ordinary seismoisolated apartment buildings should be not higher and the reliability should be not lower than that of non-isolated buildings.
6. Reliability of some especially significant seismoisolated structures (nuclear reactors etc.) should be higher than the reliability of non-isolated structures under reasonable rise in price.
7. Parameters mentioned in points 1-6 should be specified with regard to prediction of seismic motion parameters.

3 APPLICATION OF DIFFERENT STRUCTURAL TYPES OF SEISMOISOLATION (Table 2.)

About one hundred buildings with open

relatively flexible qround stories are erected in towns North Baikal, Sevastopol, Frunze, Petropavlovsk-Kamchtsky, Tbilisi. Vertical loads are perceiving by usual reiforced concrete columns. Between columns there are rigid elements perceiving only horizontal earthquake loads. These elements are plane R/C panels or spatial elements. Energy absorption and variation of rigidity and natural frequences appear as a result of damages of panels themselves, rigid stops, metalic plates or bolts between elements. Natural periods of such systems in limit state are usually not exceeding 1.5 sec.

The variety of such systems are "pile-in-tube" systems with clearance between pile and tube up to 10 cm and with inelastic dampers in the upper part of the pile. Several such buildings are built in town Tynda, BAM.

The adaptation to spectra is reached by consecutively elements disengaging, that results in smooth rigidity decrease and energy dissipation preserving main elements bearing vertical loads in the elastic stage.

The flexibility in seismoisolated system under consideration is provided by using of elastic or rocking (hinged) supports in the ground floor. The isolated buildings fundamental periods are usually 1.0 to 3.0 sec. Damping is provided either inelastic deformation of non-structural elements (hysteresis damping), or/and dry friction.

This type and other seismoisolated buildings have been constructed in earthquake dangerous areas of the former USSR (see Table 2.).

4 CONCLUSIONS

1. About 200 seismoisolated structures are constructed last decades in the former USSR.

2. Specific for seismoisolation application in the USSR is that the isolation system elements are produced of steel, concrete and other usual duilding materials. Thus, the systems are comparatively simple and not expensive.

3. Decision of parameters of seismoisolation to be used in a definite structure is depending on two groups of parameters:
   - demands of architects which need or do not need open spaces in the ground stories of the building, or one and the same type of structural system is preferable for all stories including ground story
   - predicted spectral and other parameters of future earthquake for the site (predominant high-frequencies, or low-frequencies, or both, narrow band or broad-band spectra etc).

4. Further investigations are necessary for better understanding of the demands stated above in point 3 and also to analyse the safety and optimal design problems, to observe and analyse the behaviour of seismoisolation systems during strong earthquake.

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