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OPERATING EXPERIENCE IN DESIGNING AND CONSTRUCTION OF THE SYSTEM OF SPECIAL SEISMIC PROTECTION OF BUILDINGS AND CONSTRUCTIONS IN THE FORMER RUSSIA

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ABSTRACT

A research and development program for building seismic isolation has been started in Russia in the early 70th in the Earthquake Engineering Research Center (EERC) in Moscow.

The analytical part of this program was based on mathematical modelling of seismic motions in view of the fundamental uncertainty of seismological data concerning the parameters of future earthquakes. likewise, an optimization procedure was elaborated so as to make the cost of a maximum safety structure minimal (to achieve minimum vulnerability). Experimental studies were carried out in EERC with the use of shaking tables (model studies) and powerful exciters (full-scale tests).

To meet the architects demands different types of low-cost seismic isolation were designed. Among such constructions are buildings on flexible supports or rocking (kinematic) supports plus dampers, adaptive fuse elements, buildings on sliding belts (steel-teflon pairs) etc.

As a result of these studies, different design codes and recommendations were elaborated. Seismic isolation systems had been used in more than 200 buildings, more than in any other country. Seismic isolation systems developed in Russia are characterized by their low cost. Conventional building materials (steel, concrete and masonry) are used and the construction technology is simple.

Laminated rubber-steel isolation system was applied to isolate buildings from ground vibration induced by subway trains in Moscow (Russia) and Minsk (Belorussia). Several buildings with seismic isolation were affected by the October 5, 1994 destructive earthquake at Kuril Islands, city of South-Kurilsk, Far East. Damages of buildings with seismic isolation were sufficiently less if compared with damages of not-isolated buildings. Seismic isolation with kinematic (rocking) supports was applied in these buildings.

Seismic isolation with pneumatic supports for responsible objects and nuclear facilities were developed in 1975-1980 in the Research Center of Capital Construction in St.Petersburg.

KEYWORDS

Seismoisolation, rocking supports, sliding belt, rubber cushions, pneumatic cushions

INTRODUCTION

In the beginning of the 70th a program of analytical and experimental studies of structural seismic isolation was started in EECC, TsNIISK, Moscow, Russia [Eisenberg, 1976,1977].

The very first seismic isolated buildings were erected near Baykal lake in 1974 and in Sevastopol city in 1975. Some analytical results and modern seismic isolation ideas had been published even earlier [Eisenberg, 1965, Fintel et al., 1969, Ikonomou, 1972]. Several reasons led to the development of modern seismic isolation. A better understanding of seismic ground motions nature was among them. One of the reasons was a contradiction between the architects and engineers. The things is that the architects often prefer open ground stories. But recent severe earthquake have demonstrated a very poor seismic behaviour of buildings with flexible ground stories.

Their low safety was proved at severe earthquakes in Mexico-city, 1957, Scople, 1963, Caracas, 1966, San-Fernando (California), 1971, Erzincan, 1992, Northridge, 1994, Kobe, 1995. A lot of buildings with soft ground stories collapsed and many people lost their lives [Bertero et al., 19]. Observations and analysis led to the conclusion that there are two main reasons which caused the collapses of lower stories while upper stories left almost intact.

First: The predominant periods of the earthquake acceleration not necessary belong to the range 0,2-0,3 sec or so. The predominant periods of ground motion during the above-mentioned earthquakes were in the interval from 0,6 to 1,5 sec and in Mexico-city was even about 2,5 sec. As a result, quite large seismic forces not-predicted by design codes have been evolving in the flexible ground story buildings causing collapses or heavy damages.

Second: even if the predominant periods of accelerations are relatively short and the response accelerations are not too high sometimes quite large response displacements occurred. These displacements exceed the bearing capacity of the columns. Besides, the P-!!!effect became important, it means occurrence of additional bending moments due to both vertical static and seismic loads on the horizontal displacements which sometimes reached values of dozen centimeters.

All these effects led to the collapses of soft ground stories while the upper stories stay in good condition.

To increase the seismic safety of the buildings with open ground stories in EERC, TsNIISK there were developed several seismic isolation systems [Eisenberg, 1976; Cherepinsky, 1973]. To decrease the limiting horizontal displacements there are used dampers of different types: RC elements, mild steel elements, lead and/or rubber elements, etc. Under the condition when various earthquakes with different predominant periods are predicted adaptive self-adjusting structures with sacrifice reserve elements (fuse elements) are effective for a given site. Seismic isolation systems with sliding belts [Polyakov et al., 1984], pneumatic supports for nuclear reactor [Beliaev et al., 1993] were developed and applied in Russia.

Seismic isolation Design and Construction Codes for open story seismic isolated buildings, sliding belts buildings with dynamic damper systems were elaborated and edited in EERC, TsNIISK. The first time the seismic isolated buildings were affected by a destructive earthquake was at Kuril (Far East) earthquake in October,4,1994.

RESEARCH PROGRAM

A research program has been under fulfillment in Russia during the last 20 years. The aim of this program was to work out low-cost and safe seismic isolation system for buildings and other structures.

Analytical Research

The analytical part of the program included [Eisenberg, 1965,1976, 1977; Eisenberg et al. 1978, 1983; Polyakov et al. 1984] the following:

1. Development of mathematical models of seismic motion for practical use, taking into account the uncertainty of seismological and geological data. The mathematical models are sets of non-stationary random processes. Their predominant periods, spectra configurations and durations filled a definite range of values which reflect the above-mentioned uncertainty of predicted earthquake motion parameters. Any member of the standard set of accelerogramms could be used as a model of the next seismic motion and therefore the designer has to account all of them. On the basis of this approach a set of artificial accelerogramms was produced.

2. Development of mathematical models of seismic isolated structures as non-linear, inelastic, non-stationary systems.

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

4. Cost benefit analysis of seismic isolated structures.

As the parameters of the problem there were used:
P1. Various accelerogramms.
P2. Rigidity and natural periods of the buildings with flexible supports (without dampers and reserve elements).
P3. Initial rigidities of reserve elements.
P4. Ultimate horizontal force related to the limit of elastic deformation.
P5. Configurations of the on- and off-loading curves for reserve elements and/or dampers.
P6. Gaps between successively working reserve elements.
P7. Dry friction force in dampers depending on the damper type choice is used as alternative to P4.

Experimental Study

Experimental part of the program included:
1. Shaking table tests of models and fragments.
2. Full-scale building dynamic tests with the use of large exciters maximum dynamic loading of the structure with the exciter corresponded to the design load of MSK magnitude 9 and higher.
3. Static and dynamic tests of the elements of seismic isolation systems (flexible supports, dampers, dry friction elements, etc).

CONSTRUCTED SEISMIC ISOLATED BUILDINGS

Buildings with Flexible Base and Disengaging Damping Elements

Some one hundred buildings with open relatively flexible ground stories are erected in the cities of North Baykal, Sevastopol, Bishkek, Petropavlovsk-Kamchatsky, Tbilisi. Vertical loads are perceived by conventional reinforced concrete columns. Between the columns there are rigid elements perceiving only horizontal seismic loads. These elements are flat R/C panels or spatial elements. Energy absorption and variation of rigidity and natural frequencies appear as a result of damages of the panels in themselves, rigid restrainers, steel plates or bolts between the elements. Natural periods of such systems in limiting state usually do not exceed 1,5 sec.

Several "pile-in-tube" seismic isolated buildings with a clearance between pile and tube up to 10 cm and inelastic dampers in the upper part of the pile has been built in Tynda-city (Siberia).

Buildings with Rocking (Kinematic) Supports

Cylindrical R/C Columns with steel spherical ends with flat supports under small vertical loads are used in this type of buildings. In such buildings it is necessary to use displacement restrainers and for the case of intensive low-frequency seismic motion, inelastic or friction dampers are needed for energy absorption.

In such systems under the limit state (without dampers) natural vibration periods of structures can be 3 sec or more, depending on the geometry of supporting ends. Excessive horizontal displacements which can be prevented by using restrainers and dampers are critical. Buildings of such a type had been erected in the city of Sevastopol. In Alma-Ata city rocking supports in the form of overturned mushrooms are used.

Buildings with Sliding Belts

In such type of buildings which were to be built in Russia some time ago a combination of "teflon-stainless steel" was used as a sliding system. The friction coefficient in such a pair is about 0,1.

Additional elastic and rigid restrainers (displacement limiters) are applied as well. Several dozens masonry and large panel buildings with sliding belts has been built in Bishkek city, Kamchatka and other areas.

Buildings on Rubber Cushions

One 10-story building on rubber cushions was built in Minsk. The purpose of their application is isolation from excessive amplitudes during subway train movement.

Buildings with Foundation Plates on Sand Cushions

Such systems are designed for sites with high predicted earthquake intensity (9 MSK and higher) and bad soils. Studies had shown that the friction coefficient in such cushions is fluctuating from 0,5 up to 0,9. the foundation plate is protecting the building against excessive differential settlements, and sand layer is limiting very large horizontal accelerations.

Structures on Pneumatic Cushions [Beliaev et al., 1993]

In Russia for the new-generation mean-power NPP of enhanced safety (NPP VVER-640) we use effective multicomponent low-frequency system of seismic isolation designed for seismic input response with an acceleration up to W=0.5 g. This system is to be placed below the reactor building base slab.

This seismic isolation system is based upon the use of pneumatic dampers of original design. The pneumatic dampers in question are combined into seismic isolating devices, which are installed in the foundation of the structure between the lower and the upper base slabs. Arrangement of seismic isolation facilities in plan is subject to the construction features and stiffness characteristics of the structure, as well as to condition of facilities uniform loading.

In this case between the building base slabs there is formed an interlayer which is vertically and horizontally compliant and isolates the reactor building against seismic wave propagation.

Each seismic isolation facility consists of a rocking-type central rack and pneumatic dampers fixed thereto with the help of bracings. Dampers quantity specifies a carrying capacity of the whole facility from 300 to 1000 tons. The upper and bottom ends of the central rack of the seismic isolation device are almost spherical that provides free rotation of the facility relatively the vertical axis. Centers of the spherical ends radii are displaced relatively the axis of the rack that makes it possible to return the structure into the initial position after a horizontal action ends.

DESIGN RULES FOR SEISMIC ISOLATED BUILDINGS

Several Design and Construction Codes (Recommendations) were developed and edited in Russia.
- Recommendations for design of seismic isolated open ground story buildings with fuse reserve elements.
- Recommendations for design and construction of buildings with sliding belts.
- Recommendations for design of dynamic dampers on top of the structures.
- Recommendations for design of kinematic (rocking) supports isolation systems.

All recommendations consist of two parts. The first part includes recommendations on seismic load calculation including response spectra approach and time-history analysis. The second part gives several recommendations on the detailing the seismic isolation systems.

The revision of the Recommendations taking into account the lessons of recent earthquakes, particularly the Kuril, 1994, earthquake, is planned to be done in 1997-1997.

SEISMIC BEHAVIOUR OF SEISMIC ISOLATED BUILDINGS DURING KURIL EARTHQUAKE, 1994

Four seismic isolated buildings were recently constructed in the city of South Kurilsk, Kuril Islands, Russian Far East. The type of isolation is rocking (kinematic) supports [Cherepinsky, 1983].

The destructive earthquake hit Kuril Islands on October, 4, 1994. The isolated buildings together with surrounding not-isolated ones have been affected with high intensity earthquake motions and have been severely damaged. Unfortunately, the buildings were not instrumented. But the damages of isolated buildings were sufficiently less if comparing with not-isolated buildings. during the foreshock of magnitude 6 according to MSK-scale, the residents of not-isolated buildings felt strong motions and to leave their houses. The residents of seismic isolated buildings felt no seismic motion at all. Some experience of how to improve the design was obtained as a result of the analysis of these buildings behaviour.

CONCLUSIONS

1. More than 200 seismic isolated buildings have been constructed in Russia for the last years.
2. Specific for structural control and seismic isolation application in Russia is the fact that the isolation system elements are made of steel, concrete and other conventional building materials. Thus, the system are comparatively simple and not expensive.
3. Design Rules and Recommendations for seismic isolated buildings are developed and edited.
4. The seismic isolated buildings recently constructed in the city of South Kurilsk were affected by a destructive earthquake on October, 4, 1994. Their seismic behaviour was much better if comparing with behaviour of not-isolated buildings.

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