ALEXISISMON SEISMIC ISOLATION LEVELS
FOR TRANSLATIONAL AND ROTATIONAL SEISMIC INPUT

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SUMMARY

This paper studies the effect of the torsional component of seismic input upon the response of a six-story building isolated with "Alexisismon", a base isolation system developed by the author. To demonstrate the efficiency of this isolation, two "seismic isolation levels" are selected --each level being represented by a given maximal horizontal displacement of the base of the building in relation to its foundation-- and the seismic intensities up to which the building is protected --including different (a) translational and (b) simultaneously translational and torsional seismic inputs-- are assessed for each level of isolation.

INTRODUCTION

Over the last decade, the seismic isolation of structures has been given an increase of attention and many papers have been published about various isolation schemes and their efficiency. Yet, almost no attention has been paid to date to the effect of the torsional component of seismic input (rotation about vertical axis) upon the seismic response of an isolated structure although, depending on the site conditions and the dimensions of the structure as well as its dynamic characteristics, the contribution of this component of seismic input to the horizontal displacements of the base of the isolated structure in relation to the foundation can be substantial.

The author has written several papers about the application to buildings, bridges and nuclear power plants [Refs. 1 to 4] of the Alexisismon ("A"), a seismic isolation system developed by him over the past 15 years, patented in the U.S. and in other seismic countries and first implemented in 1972 in a high rise building. In this paper, the effect of the torsional component is investigated for the case of a six-story building horizontally isolated with the "A" system.

It is well known that a high degree of isolation against very severe earthquakes can only be achieved through a great flexibility of the isolation system, i.e., through large horizontal displacements of the base of the isolated structure in relation to its foundation and therefore, the maximum horizontal displacement experienced by the structure is a main design parameter. For our building two levels of maximal horizontal relative displacement are chosen to evaluate two levels of seismic isolation. To each level correspond a maximum base shear and definite seismic intensities up to which the structure is protected including different types (frequency content) of translational as well as simultaneously translational and torsional seismic inputs. This constitutes a new approach to the expression of seismic isolation efficiency.

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ISOLATION SYSTEM

The "A" system has been described extensively in many previous papers [Refs. 1 to 4] and therefore no description is given here except for Fig. 1 which shows the general scheme of the system (disc, A.D.; springs and sliding bearings, A.S.; and the connecting steel bars, A.C.) and a main detail of its support.

(a) (b)

Fig. 1: "A" system: (a) general scheme; (b) detail of its support

Although this system is similar in scope to other isolation systems, i.e., decoupling of structure and ground and reduction of accelerations transmitted to the structure, it differs radically in its approach.

Linearity

The main mechanical parameter of the seismic response of an horizontally isolated structure is the force (shear)-deformation (relative horizontal displacement) function of its isolation system.

On basis of this function, the isolation systems can be classified into two main categories: 1) the bilinear systems, whose design substantially excludes the transmitting to the superstructure of horizontal forces (shear) greater than a certain level (Fig. 2). This property is inherent in these isolation systems and is achieved by the sliding or the yielding, etc.., of their components during the seismic oscillation. The function of these systems is displacement-dependent and they rely on permanent displacements given the absence of substantial centering forces; 2) the linear systems, which do not possess the above property. In the range of displacements 2a (Fig. 3) for which they are designed, the force-displacement function is substantially linear. There is no force level beyond which the forces cannot be transmitted to the superstructure. On the contrary, the forces induced in it increase continuously until the performance limit of the system is reached. These systems are force-dependent and include strong centering forces.

The "A" system belongs to the latter category. It does not in itself limit the transferring of forces greater than a certain level but the whole structural system --the superstructure plus the isolation system-- possesses the key property of having very large oscillation fundamental period, which greatly reduces the sensitivity of the structure even to very strong real earthquakes.

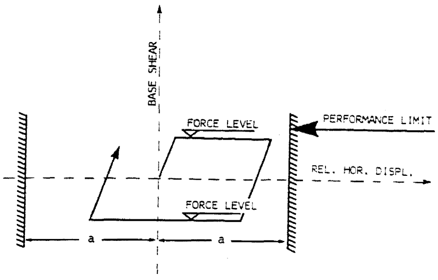

Fig. 2: Bilinear Systems

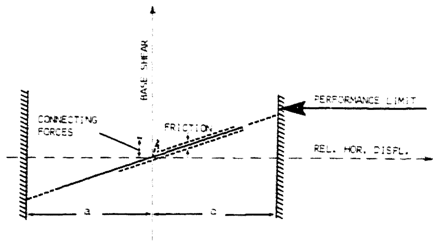

Fig. 3: Linear Systems

Separation of Functions

A basic idea of the "A" system is that the role of transmitting vertical loads and that of following the structure horizontal relative displacements and inducing horizontal restoring centering forces cannot be safely undertaken by the same element or elements and that only the separation of these basic functions can lead to great efficiency and reliability. That is why, for severe earthquake design, these two functions are uncoupled and can be performed safely by adequate independent components (Fig. 4):

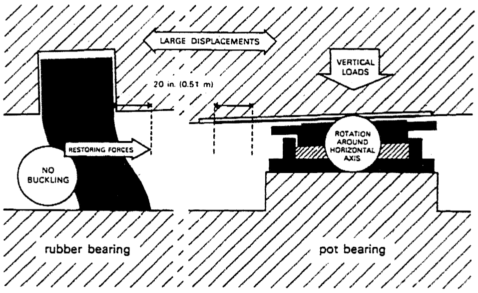

Fig. 4: Uncoupled Functions

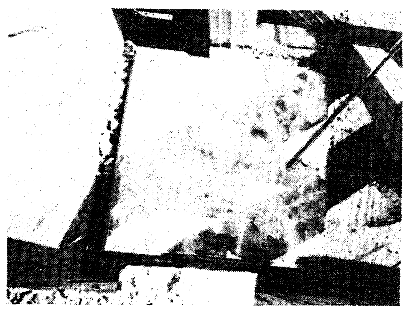

Fig. 5: Installation of Sliding Bearing

The sliding pot bearings (Fig. 4) support all the weight of the structure and allow displacements of the structure relative to the ground on the order of 20 to 40 in. Fig. 5 shows the installation of a sliding pot bearing in the six-story building.

The springs (rubber bearings in Fig. 4) do not support any vertical load. Therefore, no problem of buckling is to be feared. Their function is to follow the movements of the superstructure providing restoring forces. They exert only horizontal forces and only when the structure is displaced in relation to the ground. Thus, they ensure a controlled oscillation of the superstructure.

ISOLATION DESIGN

The isolated structure is a conventional six-story building (under construction in 1973).

The main mechanical characteristics of this "A" design are:

<u>Fundamental Period of the Isolated Structure: 5 seconds</u>

According to our experience on a large number of actual accelerograms, such a big fundamental period provides a satisfactory isolation for the whole range of periods between 0.1 and 3 seconds. This is also true for bad soil conditions and remote epicenters of very severe earthquakes as well as for the artificial earthquakes A1 and D1 (Ref. 5).

Besides, for fundamental periods greater than 4 seconds the dependence of the seismic forces induced in the structure on the damping coefficient is almost negligible.

Eventually, the greater the fundamental period, the smaller the necessary stiffness of a linear isolation system and the more efficient the system becomes. In such a case, both the cost of the isolation system and, in view of the great reduction of the seismic forces induced, the cost of the structural system of the superstructure become minimum.

<u>Maximal Relative Displacements Between Base of Superstructure and Ground</u>

Two levels: 1.- 0.50 m (about 20 in.)
2.- 1.00 m (about 40 in.)

Two levels of maximal relative displacement have been selected for this study to evaluate two "levels of seismic isolation". The above six-story building has been designed for level 1.

<u>Friction (R) of the Sliding Elements: 3.5 % of the Weight of the Superstructure</u>

This is a value which meets satisfactorily the following requirements: a) it is small enough to guarantee the most practical reduction of the horizontal seismic forces and b) it is large enough to limit the horizontal relative displacements. Owing to the adaptability of "A", this value may be increased or decreased in-situ if new data prove that earthquakes with longer or shorter periods have to be expected.

<u>Damping of the Rubber Springs: 5 % of the Critical Viscous Damping</u>

As mentioned before, the viscous damping does not influence substantially the force or the displacement seismic response. A value of 5 % of the critical damping was selected, given such a value can easily be guaranteed in practice. Given the high Alexisismon period, a lower value could easily be accepted as well as, of course, a higher one.

<u>Connecting Forces: 2 % of the Weight of the Isolated Superstructure</u>

Equation of Motion

The seismic response for both translational and torsional input of such a conventional low rise building with fundamental period greater than 4 sec. is substantially constant for all its height. That is why a 1 DOF model was selected to evaluate the "seismic isolation levels" in this study.

The equation of motion of this single DOF model for the translational oscillation is:

$$m\ddot{u} + c\dot{u} + ku + R\frac{\dot{u}}{|\dot{u}|} + F(u) = m \cdot \ddot{u}_g$$

A similar equation of motion is used for the torsional oscillation.

SEISMIC INPUT

The seismic intensities up to which the building is protected for the above mentioned two levels of relative displacement (0.50 m and 1.00 m) for translational as well as for synchronously translational and torsional input were calculated for the frequency contents of the following accelerograms:

1.- Real Accelerograms:

a)	Pacoima Dam, SI6E, 1971	(peak acceleration: 1.24 g)
b)	Lake Hughes	(- - 0.50 g)
c)	Temblor	(- - 0.36 g)
d)	El Centro, SOOE, 1940	(- - 0.34 g)

2.- Artificial Accelerograms:

a)	A 1	(peak acceleration: 0.384 g)	(Ref. 5)
b)	D 1	(- - 0.500 g)	(-)

The following torsional seismic input $\ddot{\varphi}_g(t)$ (acceleration) is assumed:

$$\ddot{\varphi}_g(t) = \left[\ddot{u}_g(t - \frac{L/2}{C_s}) - \ddot{u}_g(t)\right] / L/2$$

where

$\ddot{u}_g$ = seismic acceleration component perpendicular to the direction in which the seismic wave propagates.

L = length of the building in the direction of propagation

C_s = velocity of propagation

It is assumed that the horizontal translational seismic components, (a) in the direction of the propagation and (b) perpendicular to it, are similar in frequency content and have equal peak accelerations.

The maximum relative horizontal displacement in the direction of propagation at the corner of the base of the building is given by additioning the maximum displacements calculated for (a) translational and (b) torsional input. This is, of course, an overestimation but it is acceptable for this study whose objective is only to estimate the order of the contribution of the torsional seismic component to the overall horizontal displacements of the base of the superstructure.

"SEISMIC ISOLATION LEVELS" AND CORRESPONDING EFFICIENCIES

Several analyses were carried out and the seismic intensities up to which the building is protected --in other words, the effectiveness of the isolation in reducing seismic loads to be resisted by the structure-- was assessed. It should be emphasized that the building, the equipment and the components of the isolation system (except for the breaking connecting elements) will behave elastically up to these intensities.

Seismic Isolation Level: ± 0.50 m / 11 %

When the first level of protection is provided, i.e., when the isolation is designed to allow maximal horizontal displacements of ± 0.50 m (about 20 inches), the building and equipment are protected against seismic input up to the following intensities calculated for three values of $\Delta t = \frac{L/2}{C_s}$ while the resulting base shear forces induced into the structure do not exceed 11 % of the weight of the structure (Table 1):

Seismic Component / Accelerograms	TRANSLATIONAL	TRANSLATIONAL + TORSIONAL	TRANSLATIONAL + TORSIONAL
Real Accelerograms / Δt	Δt = 0.000	Δt = 0.025	Δt = 0.050
Pacoima Dam	1.34 g	1.27 g	1.20 g
Lake Hughes	1.77 g	1.66 g	1.56 g
Temblor	4.30 g	3.90 g	3.60 g
El Centro	1.35 g	1.27 g	1.19 g
Artificial Accelerograms			
A 1	0.50 g	0.48 g	0.47 g
D 1	4.30 g	3.70 g	3.30 g

Table 1: Intensities of Seismic Protection for Max. Displ. = 0.50 m

Seismic Isolation Level: ± 1.00 m / 19 %

When the second level of isolation is provided, i.e., when the isolation allows maximal horizontal displacements of ± 1.00 m (almost 40 inches), the whole building and equipment are protected against seismic input up to the following intensities calculated for three values of $\Delta t = \frac{L/2}{C_s}$ while the resulting base shear forces do not exceed 19 % of the weight of the structure (Table 2):

Seismic Component / Accelerograms	TRANSLATIONAL	TRANSLATIONAL + TORSIONAL	TRANSLATIONAL + TORSIONAL
Real Accelerograms / Δt	Δt = 0.000	Δt = 0.025	Δt = 0.050
Pacoima Dam	2.38 g	2.27 g	2.17 g
Lake Hughes	3.36 g	3.17 g	3.00 g
Temblor	8.10 g	7.30 g	6.70 g
El Centro	2.46 g	2.32 g	2.21 g
Artificial Accelerograms			
A 1	0.75 g	0.73 g	0.71 g
D 1	8.90 g	7.90 g	7.00 g

Table 2: Intensities of Seismic Protection for Max. Displ. = 1.00 m

For a base of the building of 25 x 25 m surface and $C_s = 500\ m \cdot sec^{-1}$, that is, for $\Delta t = 12.5/500 = 0.025$, the efficiency of the isolation is found to be 5 to 7,5 % higher when ignoring the torsional component.

For $\Delta t = 0.050$, that is,for a 50 x 50 m base of the building, the difference is on the order of 10 to 15 %.

CONCLUSIONS

From the above results of our study, it is clear that a seismic isolation design should not overlook the torsional component of seismic input since this component implies larger horizontal displacements of the structure in relation to the foundation than calculated for translational component only. This is particularly true for long structures, e.g., nuclear power plants. For a 50 x 50 m structure, the isolation efficiency calculated for translational component only is cut by 10 to 15 % and for bigger structures, by still larger rates.

The expression of efficiency in terms of seismic isolation levels gives the designer a full picture of the system capacities and allows him to select a level of isolation corresponding to the need of his structure and thus to achieve optimum design.

Again it was shown that the "A" system allows to provide a structure with very high seismic safety. As described in previous papers, it also combines the advantages of being practical, reliable and low cost and as such, can be considered as a realistic design alternative for buildings, bridges and nuclear power plants to be built in very seismic areas.

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