Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Seismic rehabilitation of a shear wall building by means of base isolation

G.C. Delfosse
Centre National de la Recherche Scientifique, LMA, Marseille, France

P.G. Delfosse
Société ERA, Venelles, France

ABSTRACT: A feasibility study is performed for the seismic renovation of a typical ten story shear wall office building. It is found that the rehabilitation by means of rubber bearings base isolation is much safer and at least 64% cheaper than the conventional reinforcement of the superstructure.

1 INTRODUCTION

A feasibility study is performed for the seismic rehabilitation of a typical ten story shear wall office building by means of a conventional reinforcement versus a rubber bearings base isolation technique.

The building is supposed to be located in french seismic zone II. It was designed accordingly to the french PS 1969 earthquake regulations and our purpose is to rehabilitate the building accordingly to the new AFPS 1990 Recommendations which are going to replace the PS 1969 in the next future. This project will allow the building to resist a 0.25 g maximum horizontal peak ground acceleration earthquake, which is about 1.5 higher than that of the original design.

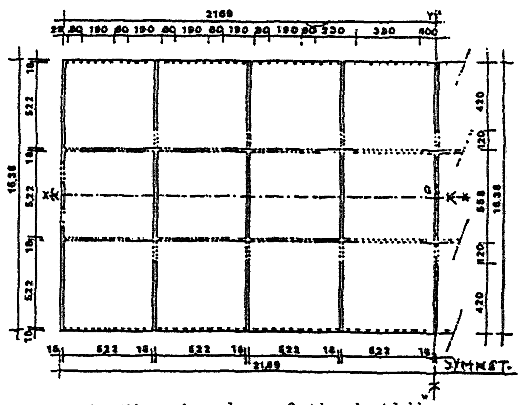

Figure 1. View in plan of the building

2 CHARACTERISTICS OF THE BUILDING

It is a 10 floor building measuring 43.38 m x 16.38 m in plan with three additional garage levels (fig.1 and 2). The resisting elements are made of 18 cm thick reinforced concrete shear walls which are symmetrical about the XX and YY axes passing through the center of mass. Floor slabs are 12 cm thick with a live load of 250 Kg/m^2 from which only 20% are taken into account in seismic design.

Masses are supposed lumped at floor levels with a value of 711.64 tons for current floors and 613.4 tons for the 10th floor. The total seismic mass is 7018 tons.

The first natural periods in both horizontal directions are:

$$T_{FX} = 0.21 \text{ s}; \qquad T_{FY} = 0.43 \text{ s}$$

and the corresponding spectral accelerations (with an inelastic reduction factor of about 3 included):

$$(AS)_{FX} = 0.1 \text{ g}; \qquad (AS)_{FY} = 0.086 \text{ g}$$

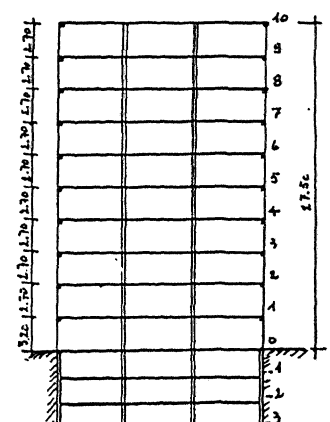

Figure 2. Vertical cross section of the building

Considering the first mode only, the base shears write in both directions:
V_{FX} = 688.5 KdaN; V_{FY} = 592.1 KdaN

2 REHABILITATION BY MEANS OF CONVENTIONAL REINFORCEMENT

We are now concerned with the rehabilitation of the building by means of a conventional reinforcement of the superstructure. We apply the new PS 1990 Recommendations with the following parameters:
- site S1 (compact sands and gravels);
- max.horizontal ground acceleration: 0.25g;
- topographical amplification coefficient: 1;
- inelastic reduction factor: 3;
- damping: 5% of critical.

Only the first mode is considered as in the initial design and we suppose that the vertical acceleration has no influence on the rehabilitation.

Natural periods are unchanged; spectral accelerations write now, using the normalized PS 1990 design spectrum :

$R(T)_X = 6.25\ m/s^2$; $R(T)_Y = 5.968\ m/s^2$

Base shears including the inelastic reduction factor are:

V'_{FX} =1462.1 KdaN; V'_{FY} = 1396.0 KdaN

Table 1 gives the story distribution of base shears.

Reinforcement calculations show that it would be necessary to add 7.7 Kg and 30 Kg of structural steel on the average respectively to lintels and to wall panels. The quantity of required reinforcement increases from the top to the bottom of the building. Lintels would need, for instance:
- 4 more longidudinal bars 8 mm in diameter at level 9;
- 4 more longitudinal bars 16 mm in diameter and 26 stirrups 6 mm in diameter at level 1.

In the same manner,wall panels should be, for instance, reinforced with:
- 4 more vertical bars 8 mm in diameter at the 10th story;
- 4 more vertical bars 16 mm in diameter and 34 horizontal ties 6 mm in diameter at the first story.

The total reinforcement would amount to 3540 Kg and 15300 Kg of structural steel respectively for lintels and wall panels. It is to be emphasized that this kind of works has to be performed by highly qualified workmen scaffolding the whole building, removing a part of the outside and inside coatings and restoring them after placing the reinforcement.

Table 1. Story distribution of base shear in case of conventional reinforcement

Level or Story	XX dir. Force (KdaN)	XX dir. Shear (KdaN)	YY dir. Force (KdaN)	YY dir. Shear (KdaN)
10	231.5	231.5	221.2	221.2
9	242.3	473.8	231.3	452.5
8	215.8	689.6	206.1	658.6
7	189.4	879.0	180.8	839.4
6	163.1	1042.1	155.6	995.0
5	136.8	1178.9	130.6	1125.6
4	110.4	1289.3	105.4	1231.0
3	84.1	1373.4	80.4	1311.4
2	57.5	1430.9	54.9	1366.3
1	31.2	1462.1	29.7	1396.0

3 REHABILITATION BY MEANS OF BASE ISOLATION

Base isolation proceeds with quite a different philosophy in that sense that it is fundamentally conceived to reduce the horizontal seismic forces. A typical base isolation system is made of rubber bearings located at the base of the building, most often just below the first floor,under columns or shear walls. Rubber bearings consist of laminated layers of rubber and steel plates strongly bonded together during the vulcanizing process of rubber;they are designed with a vertical stiffness which is usually 300 to 1000 times higher than the horizontal stiffness. Such a system increases the first natural period in both horizontal directions to the range 1 to 2.5 seconds and decreases accordingly the response acceleration (except for buildings on soft soils for which natural periods should be increased to 3 s and more). Damping is usually comprised between 5% and 10% of critical, but can jump to as high as 20% with the addition of dampers. Base isolation technique meets presently a large interest among architects and engineers in France, U.S.A and Japan (Delfosse and al 1979, 1984, 1985, Thomas and al 1982).

In the present case, the isolation system comprises:
- 50 bearings of 500 mm in diameter, each of them with 6 ten millimeters thick layers of rubber;
- 100 dampers made of mild steel bars 50 mm in diameter and 120 mm long.

Damping is 15% of critical from which 10% comes from the dampers.
The stiffness caracteristics of the isolation system are:
- horizontal stiffnes: 246.3 MN/m;
- vertical stiffness : 72108.3 MN/m;

Table 2. Story distribution of base shear in case of base isolation

Level or Story	Force (KdaN)	Shear (KdaN)
10	42.2	42.2
9	48.4	90.6
8	48.4	139.0
7	48.4	187.4
6	48.4	235.8
5	48.4	284.2
4	48.4	332.6
3	48.4	381.0
2	48.4	429.4
1	48.4	477.8
0	48.4	526.2

- static vertical deflexion under the most loaded point (317 tons): 1.1 mm.

A building fitted with a well- designed base isolation behaves very like a one-degree-of-freedom system.With this hypothesis and a total seismic mass of 7730 tons including the mass of the floor just above the bearings, the dynamic characteristics of the building are now:

- first natural period in both horizontal directions:

$$T_X = T_Y = 1.11 \text{ s}$$

- first vertical natural period: 0.065 s;
- horizontal spectral response acceleration in both horizontal directions: 2.042 m/s^2;
- relative horizontal displacement: 0.064 m;
- base shear:

$$V''_{FX} = V''_{FY} = 526.2 \text{ KdaN}.$$

Table 2 gives the story distribution of the base shear for both horizontal directions.

4 COMPARISON OF THE TWO METHODS

4.1 Technical comparison

Table 3 shows the base shears we found for the three cases. We see that base isolation technique provides shears which are from 11% to 24% smaller than those of the initial design and about 2.7 times smaller than those we obtained with the conventional reinforcement. We will emphasize the fact that we got this result without using a high performance isolation system, since we designed the building for a natural period of 1.11 s; it is indeed quite possible to design for a period of 2 s for instance still reducing the base shear of about 33%.

Table 3. Comparison of base shears

	XX dir.		YY dir.	
	Shear (KdaN)	Ratio	Shear (KdaN)	Ratio
Initial design :	688.5	1.31	592.1	1.13
Classical reinf.:	1462.1	2.78	1396.0	2.65
Base Isolation :	526.2	1.00	526.2	1.00

In addition, a comparison of the story shears between the base isolation method (table 2) and the initial design shows that the story shears are everywhere lower in the former case.

Three consequences arise from these results:

- rehabilitation through base isolation will confer the building a better protection against earthquakes due to the decreasing of shears;
- the superstructure will need no reinforcement;
- the foundation system will not need any reinforcement neither to resist the overturning moments which are ipso facto much smaller than those of the initial design.

4.2 Economical comparison

- Conventional reinforcement

We suppose that the foundation system does not need any reinforcement. Let us notice that this is only a hypothesis contrarily to the base isolation method for which it is a fact. In case the foundation system would need some reinforcement the cost would be strongly increased.

Works for conventional reinforcement are evaluated to 714,000 \$ plus an estimated 163,000 \$ for loss of income during the time of the works,the total amounting to 877,000 \$.

- Base isolation

Works for base isolation are estimated to 258,000 \$ without any loss of income, since the works can be achieved without interrupting the building activities.

We see that base isolation leads to savings of about 64% if loss of income is neglected and 71% if loss of income is considered.

5. CONCLUSION

A feasibility study is performed for the seismic rehabilitation of a typical ten story shear wall office building. The new project will allow the building to resist a maximum horizontal peak ground acceleration 1.5 times higher than that of the initial design.

The following general conclusions are to be drawn:

1. Reabilitation by means of base isolation provides base shears which are about 2.7 times smaller than those obtained by the conventional reinforcement. As a consequence base isolation provides a much better protection than the conventional reinforcement, not only to the building itself, but also to the occupants and to the equipment inside the building.

2. Rehabitation by means of base isolation needs no or little reinforcement of the superstructure and no reinforcement of the foundation system;

3. Rehabilitation by means of base isolation does not need any interruption of the activities relative to the building, since the works are made in the basement. As a consequence, there is no loss of income when the building is rehabilitated through base isolation, which is not the case with a conventional reinforcement.

4. Base isolation leads to savings of about 64%, if loss of income is neglected and 71% if loss of income is considered.

The conclusion is that base isolation is a powerfull and relatively cheap method for the seismic rehabilitation of buildings. It can be applied to any existing building like office, apartments or administrative buildings. It is particularly well suited to the renovation of historical buildings for earthquake as well as for vibration protection.

REFERENCES

Delfosse, G. 1979. Aseismic building isolation systems: better protection against earthquake damage. National congress on pressure vessels and piping technology. Proc.ASME 79-PVP-54. San Francisco.

Delfosse G. & P.Delfosse 1984. Earthquake protection of a building containing radioactive waste by means of base isolation system. Proc. 8th World Conference on earthquake engineering. San Francisco.

Thomas A.G.& C.J.Derham 1982. The design of laminated bearings.Proc. International Conference on Natural Rubber for earthquake protection of buildings and vibration isolation. Kuala Lumpur: Malaysia.

Bouc R.,Delfosse G.& B.Nayroles 1985. Calcul déterministe et stochastique de la réponse des structures sur appuis viscoelastiques in Génie Parasismique,V.Davidovici,Presses de l'Ecole Nationale des Ponts et Chaussées. Paris .