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

Design of a base isolated confined masonry building

M. Sarrazin & M.O. Moroni
Universidad de Chile, Chile

ABSTRACT: The design and construction of a confined masonry building supported by seismic isolators as well as the results of verification tests of the isolators and the actual behavior of the building are described below. The four-storied building is 6 by 10 m in plan, weights 210 ton and it is resting on eight high damping rubber bearings. It corresponds to one unit of a group of low income housing buildings located in the city of Santiago. The project also considers the construction of a similar building, as a reference prototype, with these same characteristics but without isolation.

1 INTRODUCTION

Seismic isolation systems are very effective in protecting buildings and their contents from earthquake damage. The objective of this project is to develop a low cost isolation system that could be used in a massive practical application.

Two identical buildings are under construction, except for the fact that one of them rests on isolators. Both buildings will be equipped with accelerographs, aimed at comparing their response to a destructive earthquake.

The isolators considered are made of natural rubber and are reinforced with steel plates. The energy dissipation is obtained by means of high internal damping rubber.

2 OUTLINE OF BUILDINGS

The buildings are comprised of 4-stories, each containing four duplex apartments: two of them can be accessed through the ground floor, while the entrance for the remaining two apartments is located on the third floor. Each building shares a staircase with other nearby buildings.

Figure 1 shows the plan and elevations of the building. This clearly indicates that the first story is structured primarily with reinforced concrete walls, whereas the rest of the construction is confined masonry. All floors have a slab of reinforced concrete which is 10 cm thick. The roof has a wooden structure.

The isolated building is mounted on 8 rubber isolators, which rest on foot foundations, connected between them with reinforced concrete beams (see Figure 2). A small retaining wall surrounds the building and is separated from it by a 20 cm gap. Its function is to permit the isolation bearings to move during an earthquake. As an emergency device, fail-safe pedestals have been located on the footings to support the building in the highly improbable event of a failure in the isolator pads. An inspection camera has been provided adjacent to each isolator.

The lines for services are flexible in order to allow for displacements during quakes.

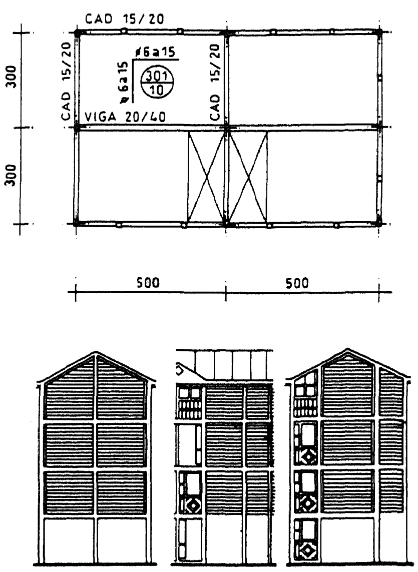

Figure 1. Plan view over 3[erd] floor and elevations

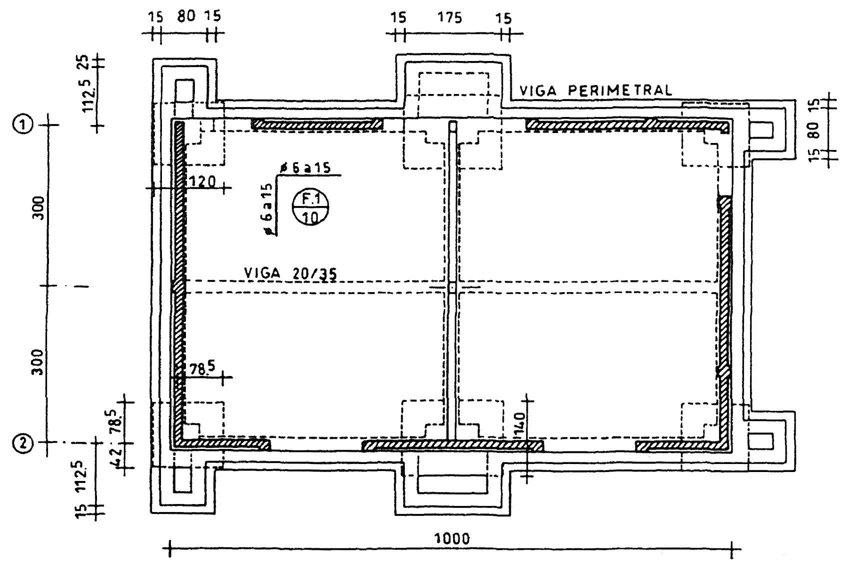

Figure 2. Foundation

Table 1. Seismic analysis results.

	Isolated building	Rigid foundation.
Mass (T/m/s²)	17.55	13.38
T_x (sec)	2.0	0.125
T_y (sec)	1.998	0.109
Base shear x (T)	5.043	11.44
Base shear y (T)	5.052	11.64
Base disp. (m)	0.06	0.0

3 STRUCTURAL DESIGN OF THE ISOLATED BUILDING

3.1 Vertical loads

In addition to the corresponding dead loads, the following live loads have been considered, according to the NCh1537 Chilean code: 200 kg/cm² on floors and 30 kg/cm² on roof.

3.2 Seismic loads

Seismic loads according to Chilean code NCh433.Of72 have been considered. Table 1 contains the results of the dynamic seismic modal analysis of both buildings, using the corresponding design spectra. It can be seen that the effect of the isolation system is to elongate the natural period of the building and to reduce the base shear force. However the horizontal displacement of the base for the isolated building becomes significant.

4 DESIGN OF THE ISOLATORS

The isolator's characteristics are determined by means of three fundamental variables: the vertical load, the required lateral stiffness, and the total lateral displacement. The first is a function of the amount and location of the isolators. In this case the maximum vertical force is 35 ton.

In order to produce a shift in the fundamental period of the building from 0.1 sec (for rigid foundation) to nearly 2 sec (for the isolated case) the required stiffness for each bearing should be 21.6 ton/m.

To determine the minimum required horizontal displacement, Appendix 1 of the SEAOC Code was used. Step-by-step integration for historical quake records was performed by means of the DRAIN-TABS program. The isolators were modeled as springs with bi-linear characteristics, as it is shown in Figure 3. A damping factor of 5% was used. Table 2 contains the maximum displacements produced at the base level for the following acceleration records of the chilean March 3, 1985 earthquake: LLolleo N10E, Melipilla NS, Viña del Mar S20W and San Fernando EW. They were obtained using different values for the stiffness characteristics of the isolators.

Based on the above results, the design displacement was taken as 23 cm. Special note should be made that the maximum displacement occurs for the Llolleo record, however, the buildings under construction are in Santiago, where the seismic risk is much smaller.

Figure 4 shows the installation of one of the isolators. It is bolted firmly both to the building and to the foundation. It has 34, 6.7 mm rubber layers and 33, 2 mm steel sheets. Its overall dimension are 32.6 cm height and 31.5 cm in diameter.

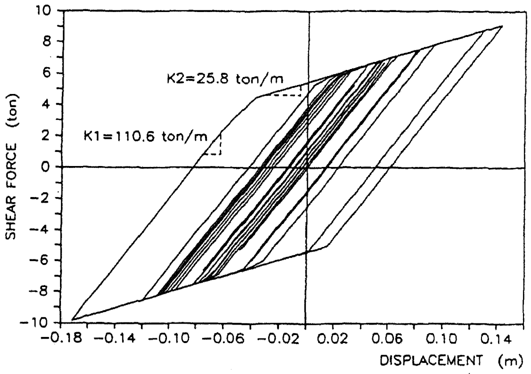

Figure 3. Stiffness characteristic of isolators

Figure 4. Installation condition of one isolator.

5 ECONOMIC EVALUATION

The economic evaluation projected elevated costs for the incorporation of the isolators which bordered on 25% of the total cost of the construction. The additional expense was not only a result of the cost of the isolators themselves and their anchorages, but also reflected the cost of additional civil works (an additional slab, deeper foundations, etc). Moreover, the reduced seismic forces affecting the isolated building were not taken into consideration for this project. The primary reason for this was the need to compare buildings with equivalent physical characteristics. It is also worth mentioning that the total cost of the building is extremely low (US$8,000/apartment with only 4 apartments per building). The relative low cost of the initial construction itself causes the utilization of isolators to increase expenditures significantly.

6 PRODUCTION AND TESTING OF THE ISOLATORS

The isolators were produced in a rubber factory in Santiago. Quality control was extreme. Each isolator was subjected to vertical and horizontal testing, static and dynamic, in a special device designed for that purpose. Figure 5 shows the testing machine used. Two additional isolators will be tested at the University of California, Berkeley, in order to verify the results.

The rubber itself was subjected to durability test in an ozone ambient.

Figure 6 shows the shear modulus curve for the rubber. At 7.8% shear strain, the modulus of the rubber is around 19 kg/cm², with the dimensions of the bearing A = 31.5 cm, t_r = 22.78 cm, implies that the horizontal stiffness of the bearing is K_H = 650 kg/cm.
This result is consistent with the effective stiffness determined in the testing machine for the same shear strain.

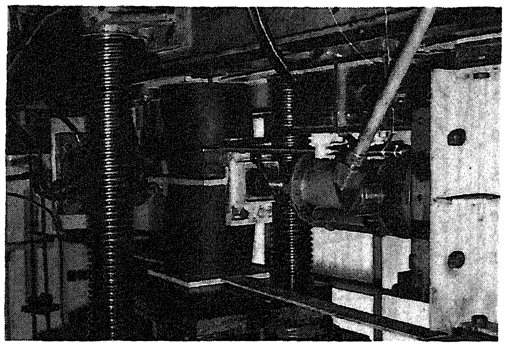

Figure 5. Testing machine

Table 2. Maximum displacements.

Component	Stiffness K_1 T/m	K_2 T/m	Displacement X cm	Y cm
Llolleo N10E	21.6	21.6	23.4	20.6
	25.8	25.8	21.3	21.2
	38.0	25.8	21.2	21.8
	110.	25.8	18.4	17.4
	216.	21.6	12.1	20.8
Melipilla NS	21.6	21.6	9.3	9.7
	25.8	25.8	8.0	8.5
	38.0	25.8	11.5	9.1
	110.	25.8	11.8	12.3
San Fernando EW	25.8	25.8	12.7	17.3
	38.0	25.8	13.6	10.0
	110.	25.8	7.8	13.8
Viña del Mar S20W	21.6	21.6	11.6	10.7
	25.8	25.8	13.1	11.3
	38.0	25.8	13.9	9.4
	110.	25.8	20.4	10.1

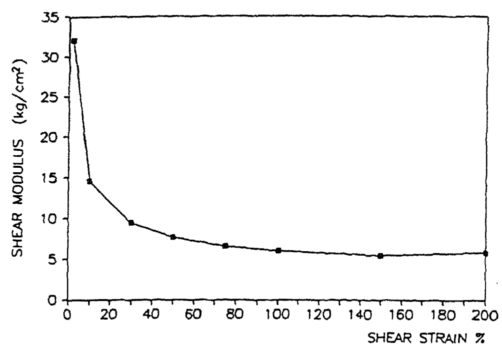

Figure 6. Shear modulus of the rubber

7 FOLLOW-UP SURVEY

The isolator's properties depend on the level of deformation. Therefore, two types of tests must be conducted in order to determine the period and damping of the whole system: microtremors observations and free vibration caused by large deformation pull-back tests.

After the completion of the buildings and in order to compare the design analysis with actual behavior and to confirm the isolation effect of the system, an earthquake observation array system will be installed in and under the buildings.

The isolators have been mounted with a device that allows their replacement. Therefore, new kinds of isolators can be mounted in the future, thus transforming the building into a true laboratory for the testing of isolation systems.

8 CONCLUSIONS

Results from theoretical studies show that the proposed system for building isolation is feasible and that the horizontal forces are substantially reduced. Additionally, it is worth mentioning that all the necessary elements can be produced with domestic technology.

Wide-spread use of isolators in residential constructions would produced a substantial reduction in their cost.

For the type of building that is been considered, the vertical load per isolator results quite small. To achieve a natural period of about 2 sec. rather soft isolators are needed. This may have as a consequence an instability problem in the isolators. A different solution could be to use multi-stage rubber bearings or hollow rubber bearings.

Once the building has been completed, instruments will be provided aimed at registering seismic events.

ACKNOWLEDGMENTS

The authors thank FONDECYT, Project 0897/88 and Project 882/92-T, for the financing of this work.

REFERENCES

Appendix to Chapter 1 of SEAOC Blue Book, General requirements for the design and contruction of seismic isolated structures, 1989.

Guendelman Israel, R. & Powell, G. 1977. DRAIN-TABS: a computer program for inelastic earthquake response of three dimensional building. EERC-08, University of California, Berkeley.

Instituto Nacional de Normalización, 1972. Cálculo antisísmico de edificios, Norma NCh433.0f72, INN, Santiago.