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RESEARCH ACTIVITIES IN CHILE ON BASE ISOLATION AND PASSIVE ENERGY DISSIPATION

María Ofelia Moroni, Mauricio Sarrazin, Rubén Boroschek
Dept. of Civil Engineering, University of Chile, Casilla 228/3 Santiago, Chile
mmoroni@ing.uchile.cl, sarrazin@ing.uchile.cl, rborosch@ing.uchile.cl

ABSTRACT

The latest research activities in progress at the University of Chile on base isolation and passive energy dissipation are presented. These include analysis of seismic records obtained at seismic isolated structures and shaking table test results from scale model structures: a shear wall building with base isolation and a steel frame building with copper based alloy dissipative bracing. The scale models were subjected to different seismic inputs, including horizontal as well as vertical components. Analytical models are developed to reproduce experimental results.

1. INTRODUCTION

To date in Chile three base isolated buildings have been built and one is under construction. Two of them are hospitals, one is for educational purposes and the oldest one is for residential use. The latest structure has been instrumented since 1992 with a local array of accelerometers that have recorded approximately 40 moderate earthquakes. From these records a clear reduction in the horizontal accelerations has been observed with some amplification in the vertical acceleration. In order to investigate the effect of more severe earthquakes, a scale-model of the instrumented building has been tested on a shaking table. The same facility has been used to study the effect of adding SMA copper-based bracing to a bare steel frame building.

With respect to bridges in Chile, many of them have been built with neoprene or natural rubber pads between piers and the superstructure. Three of them have been instrumented with local accelerometer networks. Although only moderate earthquakes have hit those structures in the last two years, seismic records obtained have permitted calibration of theoretical models and advancement in the knowledge of their seismic behavior. Other effects such as wind and temperature are also being studied for a bridge equipped with viscous dissipation devices and friction bearings.

2. SHAKING TABLE TESTS

2.1 Comunidad Andalucía Building

2.1.1 Description of the model

A 1:10 scale acrylic model of the Comunidad Andalucía building was constructed and tested on a small shaking table. Two support types were studied: HDRB and sliding bearing. The same model was also tested for fixed conditions at the foundation. Dimensions of the model are 1 x 0.6 m in plan and 1 m high. The elastic modulus of the acrylic is 3353.8 MPa and the specific weight is 1.17 ton/m^3; both values were obtained experimentally. The wall thickness is 0.5 cm and the slab thickness is 1 cm. Figure 1 shows a view of the model and the shaking table.

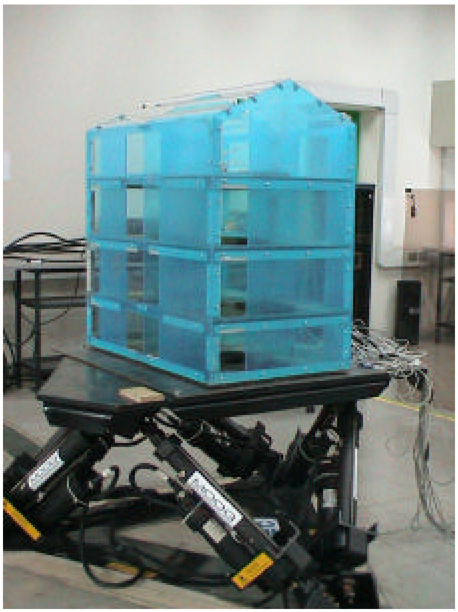

Figure 1 General view of the acrylic building model

Recorded magnitudes were horizontal and vertical input acceleration, horizontal and vertical accelerations in the first and fourth floors and longitudinal displacement in the first and fourth floors.

Initially, pull-back tests were performed and fundamental periods and equivalent damping were obtained from acceleration signals using both the method proposed by Ibrahim et al (1977) and the logarithm decrement method. Fundamental periods of 0.086 and 0.069 sec in the longitudinal and transverse direction were obtained for the fixed base conditions and the equivalent damping ratios are 3.8 and 3.9%, respectively. The model weighs 50.5 kgf and an additional 65.7 kgf have been distributed in the four slabs.

Records from the March 3, 1985, Llolleo-Chile earthquake scaled both in time (scale factor = 2,236) and magnitude (scale factor = 2) were used. Unfortunately due to limitations of the shaking table, the input acceleration to the scale model differed sustantially from the real ones; figure 2 shows the response spectra for Llolleo N10E for the original, the scaled record and the effectively registered one on the shaking table for a 5% damping. This problem arose from the necessity of scaling the records in time thus shifting the frequency content to a high frequency region where the shaking table has a limited response.

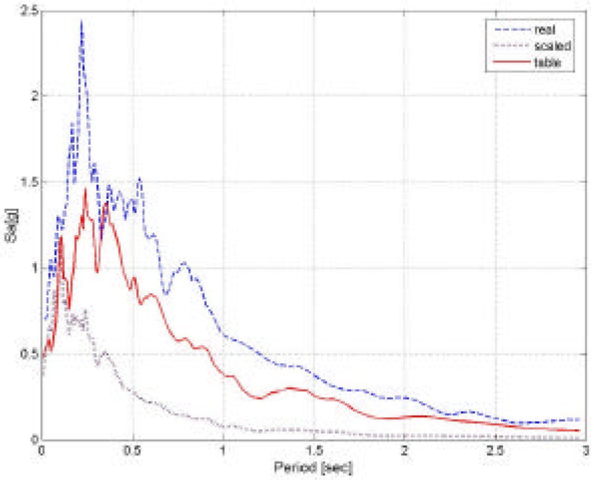

Figure 2 Response Spectra for Llolleo N10E

2.1.2 HDRB

In this case four bearings were located at the middle of each side of the base of the building model. A rubber shear modulus of 0.85 MPa and equivalent damping of 7.6% were obtained for samples of 3 x 3 x 0.28 cm strained at 50%. Based on these values the bearings were designed with a total rubber thickness of 10 cm, 3.9 cm diameter and total height 12.84 cm, Brull (2005).

Three pull-back tests were performed with different added weights; fundamental periods and equivalent damping are shown in Table 1. It was found that values are quite similar for both direction, thereby corroborating the SDOF behavior of these structures. The period and the damping increased with increasing weight. Because of the slenderness of the rubber bearings an important bending effect on its lateral stiffness was found, with a value half the one that occurs when only shear deformation is present.

Table 1 Period and equivalent damping for scale model building with HDRB

Added weight (kgf)	Period (sec)		Equivalent damping (%)	
	Longitudinal	Transverse	Longitudinal	Transverse
40	0.449	0.447	7.54	7.92
64	0.503	0.491	8.30	8.87
100	0.573	0.551	9.8	9.48

The model with an added weight of 100 kgf was tested on the shaking table. Five records were applied in the longitudinal direction and two were applied in both horizontal directions. Due to limitations of the shaking table as previously mentioned, the effect of the isolation is rather low, although some reductions in peak accelerations are noticed. Shear deformation at the bearings were up to 28.5%. A predominant frequency of 1.7 Hz was determined from the records at the 4th floor using Fourier analysis.

2.1.3 Sliding bearing

Eight friction bearings and two rubber bearings were used to provide restoring forces, figure 3. The friction bearings consist of a Teflon sheet 4.5 cm diameter and 0.5 cm thick that can slide on a square polished stainless steel plate that has dimensions of 10 by 10 cm and 2 mm thick. The friction coefficient varied between 0.11 to 0.16 for lubricated and non lubricated conditions, respectively. The rubber bearings are 3.9 cm diameter and 12.6 cm tall; at both extremes 0.5 cm thickness square plates were added to join it through bolted connections to the shaking table and to the base of the structure, Muñoz (2005).

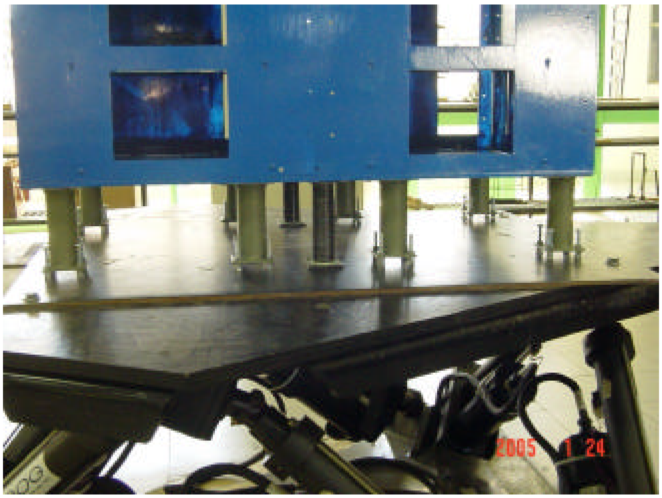

Figure 3 Friction and rubber bearings

During the test, an additional weight of 48.75 kgf was applied to each floor in order to obtain a fundamental period of 1.12 sec, which would represent a 2.5 sec period in the prototype building. Although similar records to those applied to the previous model were selected, peak accelerations at the shaking table were much larger than before. Figure 4 shows the peak acceleration recorded at the fourth floor in the isolated and conventional buildings as a function of the input peak acceleration measured at the shaking table. Peak accelerations in the model with sliding bearings are about 20% less than the input peak acceleration, and peak accelerations in the conventional model are 40 to 90% larger than the peak acceleration in the same model. Figure 5 shows the Arias intensity calculated at the fourth floor in the model with sliding bearings and in the fixed base model as function of the Arias intensity of the input acceleration; this function represents the energy that is transferred to the structure. In most cases, the energy transferred to the isolated model is less than the one transferred to the conventional model.

Maximum shear deformation in the rubber bearings varies between 1.2 and 1.9 cm and the permanent displacement varies between 0.01 to 0.4 cm for the different records, thus indicating that the rubber bearing restoring forces were effective.

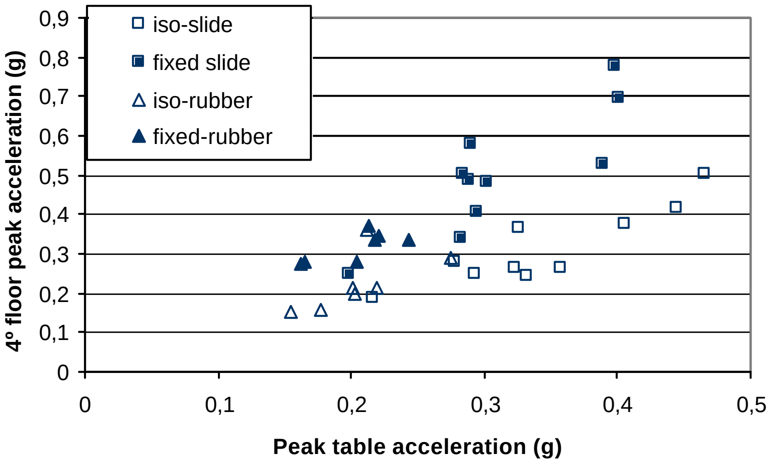

Figure 4 Peak acceleration comparison

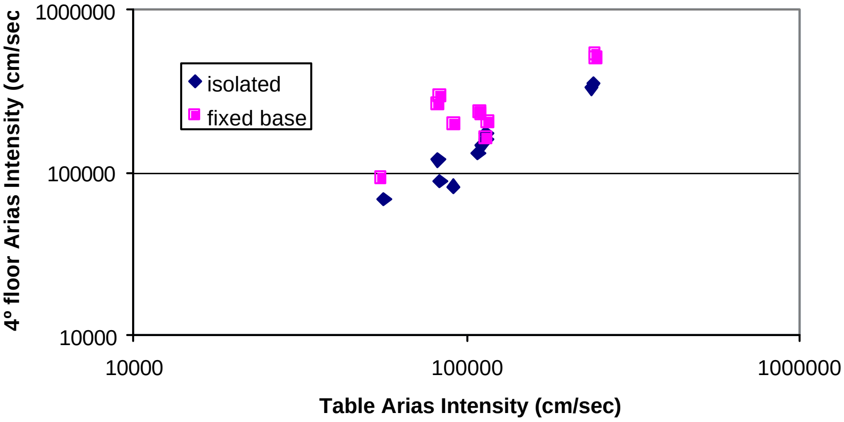

Figure 5 Arias Intensity comparison

2.2 Effect of SMA Braces in a Steel Frame Building

Shape Memory Alloys are metallic alloys that can undergo large strains, while recovering their initial configuration after unloading or by heating, without any permanent deformation. They dissipate energy in the loading-unloading process. This behavior makes them suitable to be used as seismic dissipation devices. Damper devices based on SMA CuAlBe wire were installed in the longitudinal direction of a scale model of a three-story moment resistant steel frame building. Shaking table tests were performed on the bare frame structure and on a braced one.

2.2.1 Characteristics of SMA Braces

CuAlBe shape memory alloy wires (ϕ = 0.5 mm) were selected as energy dissipation devices. Previously, sinusoidal displacements were applied to wires in order to investigate their actual behavior and their dependence on the thermal treatment applied to them; tests were performed at 1 Hz. Four wires were heated to 717ºC during different periods of time, followed by a water quenching and aging at 88ºC for 20 h and at 96ºC for 4 h. For comparison, an untreated wire was also tested. Figure 6 shows one cycle of the superelastic stress-strain relationship of a 127.2 mm long wire heated at 717ºC for 225 sec; the wire had a pre-strain of 7.1%. Table 2 shows some results from the tests as secant stiffness, energy loss per cycle, internal friction, pre-strain, and maximum strain attained. Heating softens the wires and the energy loss increases. Based on these results the wires installed in the structure were heated at 717ºC for 225 sec, followed by water quenching and aging as explained earlier.

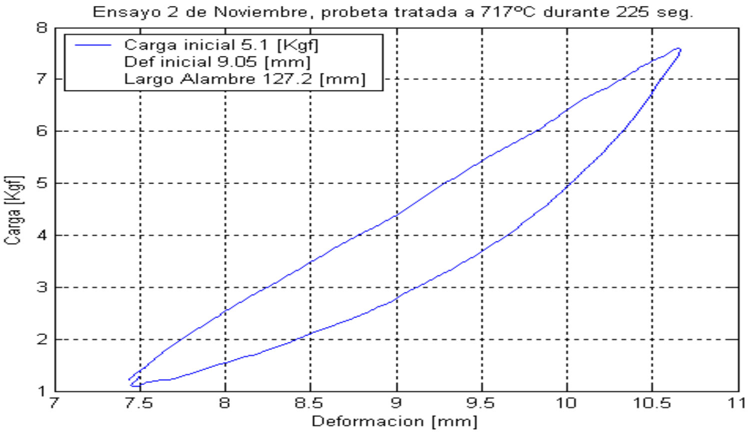

Figure 6 Stress-strain relationship of CuAlBe wire

Table 2 Characteristics of CuAlBe wires

Time of heating at 717ºC [sec]	Secant stiffness [kgf/m]	Energy loss [kgf mm]	Internal friction [%]	Pre-strain [%]	Maximum strain [%]
0	3541.8	2.99	2.13	2.9	3.82
90	2488.6	3.87	5.20	4.9	6.08
135	2536.1	3.71	4.90	5.2	6.50
180	2795.2	3.69	5.30	7.0	8.36
225	2148.0	4.10	4.45	7.1	8.40

2.2.2 Description of the Model

The dimensions of the model are 120 cm high, 70 cm long and 50 cm wide; the columns (3 x 0.4 cm) are bolted to the beams which are welded to the floor slab. In the short direction four steel wires (ϕ0.5 mm) were installed at each floor to avoid torsion; each floor weighs 18 kgf given a total weight of 54 kgf, (see figure 7), Cerda (2005).

Figure 7 Steel frame scaled model

Four dampers were installed in each floor. The details of the dampers are shown in figure 8. Each diagonal consists of a steel C angle 15 x 15 x 1.5 mm, 45 cm long, and one CuAlBe wire (ϕ 0.5 mm) 40 cm long. The wires were pre-stressed with a tension force of 3 kgf.

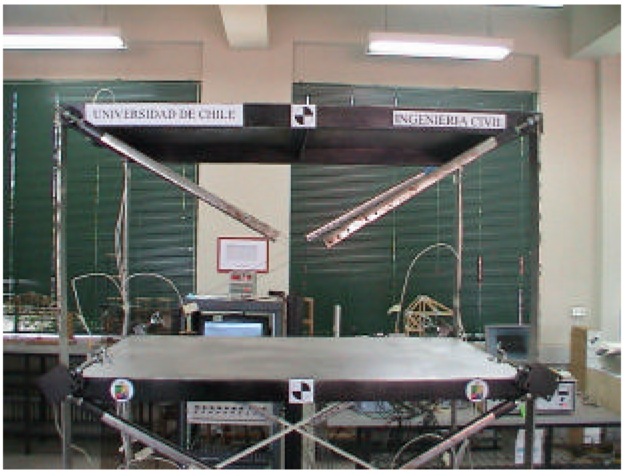

Figure 8 SMA Damper

2.2.3 Instrumentation and Experimental Results

Twelve accelerometers were installed in the bare structure that measure longitudinal and transverse accelerations. Additionally, in the damped structure eight load-cells and eight potentiometers were installed to measure forces and axial deformations in each damper located in the first and second floor as shown in figure 9.

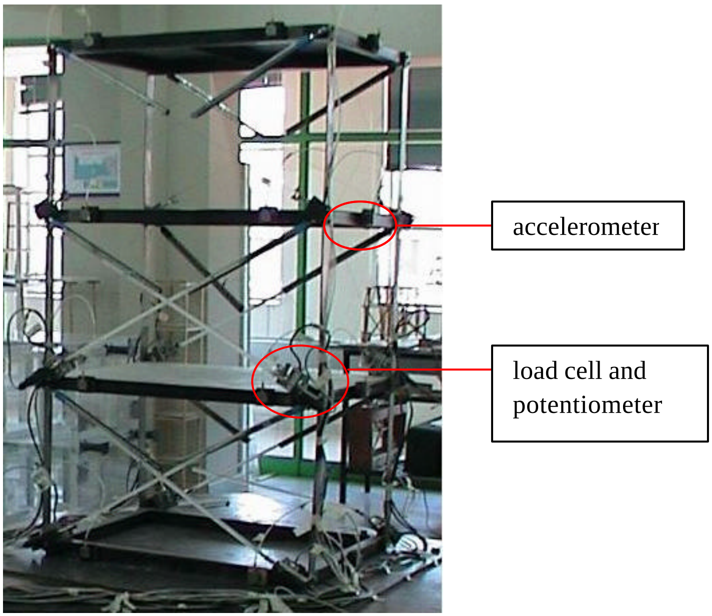

Figure 9 Instrumentation of the model

First, three pull-back tests were performed in the bare structure to obtain the three modal shapes in the longitudinal direction. Then shaking table tests were performed using 5 min white noise motion, scaled records from Sylmar, Kobe, Taft, El Centro and Llolleo earthquakes, followed by 25 min of white noise motion and ending with another three pull back tests. A similar sequence was followed in the damped model. All tests were performed at room temperature.

Table 3 shows the frequencies and equivalent damping obtained in the bare model after analyzing the signals from pull-back tests, previous and post shaking table tests, using the Ibrahim time domain method. Analytical results obtained from a SAP2000 model are also included. Differences are very small.

Table 3 Frequencies and damping in bare model

Type of excitation	Previous to shaking table test		Post shaking table test		SAP2000 results
	Frequency [Hz]	Damping [%]	Frequency [Hz]	Damping [%]	
First mode	2.49	0.59	2.50	0.40	2.61
Second mode	7.25	0.35	7.20	0.54	7.31
Third mode	10.95	0.44	10.90	0.45	10.43

Table 4 shows the first fundamental frequency and equivalent damping in the damped structure after analyzing signals from the pull-back tests, previous and post the shaking table tests. In this case there is a range of frequencies indicating non-linear behavior of the wires. The logarithm decrement was used to determined damping.

Table 4 First mode frequency and damping in damped model

Previous to shaking table test		Post shaking table test	
Frequency [Hz]	Damping [%]	Frequency [Hz]	Damping [%]
3.35-3.71	5.63	3.45-3.73	4.44

Experimental data from shaking table tests show the effectiveness of the SMA dampers in vibration reduction. In figure 10 the longitudinal accelerations at the third, second and first floor of both building due to the scaled Kobe record are compared; the reduction in the damped model (right) with respect to the bare one (left) is as much as 58%.

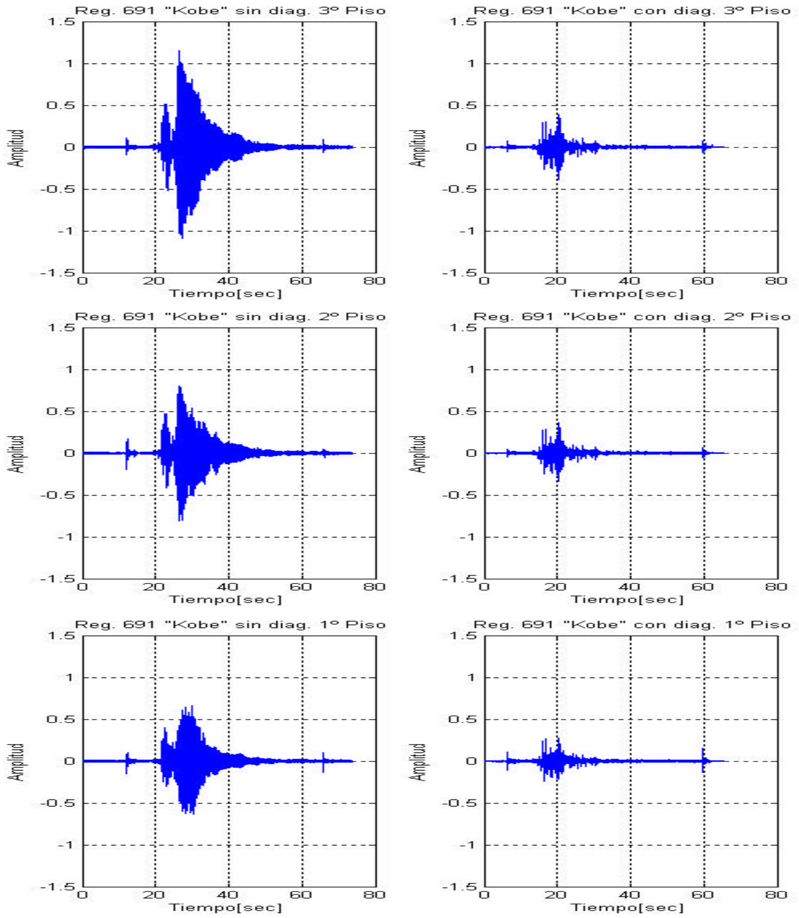

Figure 10 Longitudinal acceleration Kobe record

Figure 11 shows the stress-strain relationship for all dissipators located at the second and first floor during the scaled Sylmar record. Stiffness of the wires on the east side differed from those on the west side. Due to the procedure followed to pre-stress the wires, it is believed that the pre-strain differed from one side to the other which may explain the differences in stiffness. In fact, Dolce et al. (2000) tested Nitinol wires and bars for several different conditions and established, among others conclusions, that the secant stiffness varies depending on the pre-strain. Some wires in the first floor underwent displacement amplitudes up to 15 mm, corresponding to about 3.75% total strain in the wires. There could be some residual deformation that explains the loosening of the wires that was detected in all of them especially at the first floor.

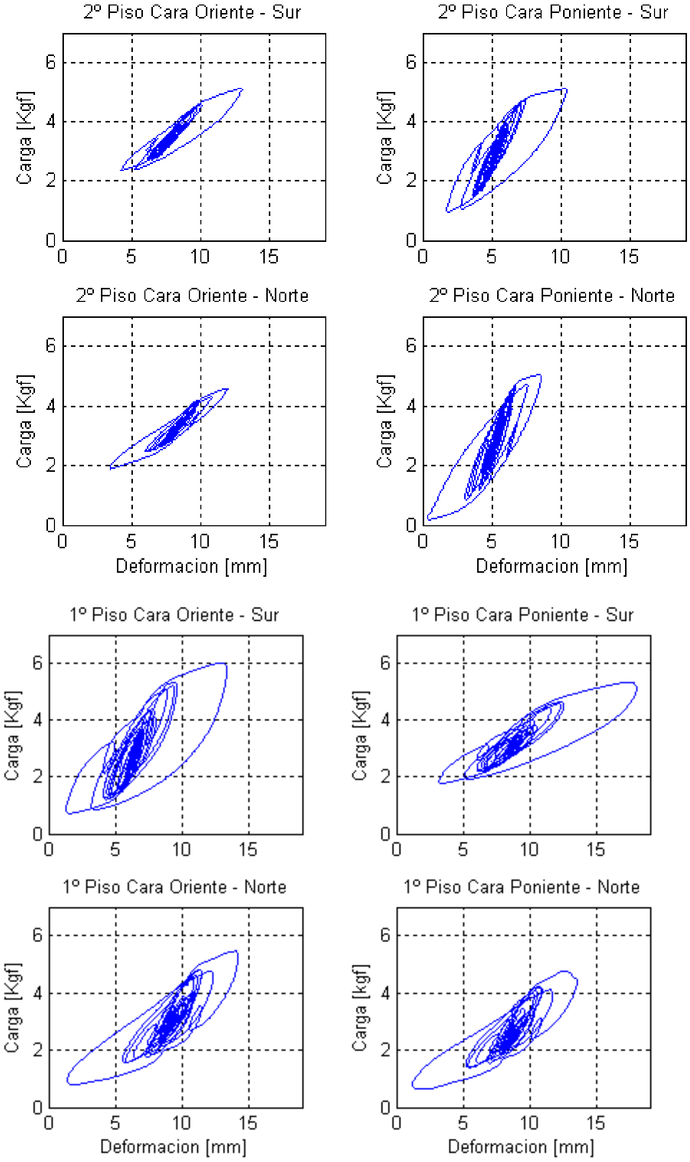

Figure 11 Stress-strain relationship, Sylmar record

3. ANALYSIS OF SEISMIC RECORDS

Since the last Conference in Yerevan only moderate earthquakes have hit the instrumented structures showing the same behavior reported previously. In summary, there is a clear beneficial effect of the isolation and energy dissipation devices in the longitudinal direction although the vertical accelerations are greatly increased, Sarrazin et al. (2005).

4. CONCLUSION

A 1:10 scaled acrylic model of the Comunidad Andalucía building was constructed and tested in a small shaking table for different earthquakes records. Two support types were studied: HDRB and sliding bearing. The same model was also tested for fixed conditions at the foundation. Results show that for this particular case the sliding bearings present the largest reduction in peak acceleration. However, this is not conclusive because of limitations in the capacity of the shaking table to reproduce the actual ground motion of the earthquakes, especially for high frequency signals.

Microstructure and mechanical properties of CuAlZn and CuAlBe alloys have been studied being some of the more promising dissipation devices. In fact, braces made of CuAlBe wires were attached to a steel frame scale model and tested on a shaking table. Significant reductions in acceleration (up to 58%) and displacement were observed. Damping measured from pull-back tests increased from 0.59% in the bare frame building to 5.95% in the building with dissipation devices. An analytical model representing the wire superelasticity is being developed and calibrated to match the experimental results.

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