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SEISMIC PROTECTION OF BUILDINGS IN PERU USING ENERGY DISSIPATION AND BASE ISOLATION

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Abstract

Peruvian buildings are currently including different devices for seismic protection, in order to greatly reduce structural damage, to protect their contents under severe earthquakes, and assuring their operation soon after such earthquakes. The systems being implemented are energy dissipation and base isolation devices. This paper develops a brief history of the recent important earthquakes in Peru and a description of the typical buildings that need to be protected by devices like those already mentioned. The motivation for this recent interest in structural vibration control is explained, such as hospital buildings, office buildings, library buildings, schools, housing buildings. Some of the first structures using seismic dissipation and base isolation devices in Peru are presented. The analyses results show significant reduction in story drifts and important reductions in seismic forces, which ensures more safety and more comfort for the users.

Keywords: Seismic protection; base isolation; energy dissipation; Peru; earthquakes

1. Introduction

Before 2010 in Peru, the use of seismic protective systems in structures was not a current issue, due to the lack of information and the high costs involved. However, the 2010 Maule, Chile earthquake (M8.8), put attention that Peru is prone to suffer similar seismic events because the important earthquakes in both countries are caused by the subduction of the Nazca plate under the South American plate. In addition, the good performance of several Chilean buildings with seismic protection devices, become a topic of great interest between the Peruvian engineers and contractors. These reasons have motivated the Peruvian engineering community to start a review and study of the seismic protection systems used in other countries, in order to be included in new buildings, as well as use them for seismic retrofit of existing buildings.

Structures with seismic protection are being developed in Peru quite more often since then. The main objectives are to reduce structural damage, to protect the buildings' contents under severe earthquakes, and to ensure the capability to continue operation soon after such earthquake. The construction companies are playing an important role in the dissemination of the benefits of seismic protection devices among the population. The Peruvian Seismic Code has been recently updated in January 2016 [1] (Sencico, Norma E.030 Diseño Sismorresistente in Spanish); it has included the possibility of use of seismic protection systems in buildings, in which the design can be done using the ASCE standard [2], as far as it is possible.

2. Major earthquakes in Peru

In Peru, there have been major earthquakes with thousands of deaths and large economic losses. These disasters have motivated the scientific community to investigate the origin and the effects of earthquakes and it is a common aspect considered in Peruvian engineering projects. An example of this concern is the constant review and change of the seismic code over the recent years.

The older important earthquakes that produced significant losses and tsunamis afterwards are given in Table 1, with historic magnitudes taken from the literature [3]. The major earthquake disaster in Peru of 1970 occurred in the region of Ancash, about 400 km north of Lima. Due to the high vulnerability of the adobe and unreinforced masonry constructions, there were more than 70,000 deaths and several cities destroyed. The majority of these victims were the result of a mud flood that buried the town of Yungay in the Andes highlands. In recent years, the destruction caused by medium earthquakes of 2001 and 2007 have been reported [4] [5], and the Peruvian community is concerned on the possibility of suffering a major earthquake in the coming future.

Table 1 – List of important earthquakes in Peru

Date	**Magnitude**	**Affected region**
Oct. 20 1687	8.2	Lima
Oct. 28 1746	8.4	Lima
Aug. 13, 1868	8.6	Tacna (south Peru), Arica
May 24, 1940	8.2	Lima
May 31, 1970	7.8	Ancash
Oct. 3, 1974	7.5	Lima
June 23, 2001	8.4	Arequipa-Tacna (south Peru)
Aug. 15, 2007	8.0	Ica

On the other hand, the earthquake of February 27, 2010 in Chile (Mw = 8.8), hit several buildings with seismic protection devices in capital city of Santiago. The good performance observed in such buildings ([6], [7]) raised the interest in the construction industry to include such kind of devices in Peruvian buildings.

3. Buildings in Peru and seismic protection devices

Nowadays, in the major cities of Peru, the predominant building materials are masonry and reinforced concrete. Masonry buildings are mainly self-constructed with little technical direction. There are some mixed steel buildings but in less number. In the case of residential buildings, which get to be 3 to 20 stories high, the most used structural systems are those with reinforced concrete shear walls and frames. Since about year 2001, a new construction system called Shear Walls Buildings with Limited Ductility, has become popular for housings up to 7-8 stories. For commercial and office buildings, the most used structural system is the dual system (combination of frames with shear walls). The current tallest building in Peru is located in Lima, the capital city, and has 40 stories.

Regarding hospital buildings, the Peruvian Ministry of Health and the 2016 Peruvian Seismic Code have disposed that all new hospital buildings in seismic zones 4 and 3 (coastal regions with the higher seismic hazard) must use seismic base isolators. For other essential buildings (ports, airports, communication centers, firemen and police buildings, schools, public buildings for important document records and files), the use is not compulsory but several institutions are interested in the possibility of their use. Also, for important buildings (those that gather a large number of people) and even for common buildings (office, housing or similar), the use of such devices are being considered.

Currently the country has a limited number of buildings already built with seismic protection. However, several buildings with these systems are under development. The types of seismic protection in use are the energy dissipation and base isolation devices. The most commonly used types of energy dissipation in Peru are the viscous fluid dampers and hysteretic dampers. Only a few existing buildings have been studied for reinforcement, with inclusion of energy dissipation devices.

4. Base isolation systems

The seismic isolation systems are well known for their ability to reduce the seismic demand by 80% to 90%. For that reason, a good engineering design should tend to reduce the seismic demand to the minimum specified by the Peruvian seismic code.

Currently, in Peru the installed base isolation systems are only based on elastomeric isolators, with and without lead core. Still no frictional pendulum isolators (fps) are in use. The current design practice has shown that a combination of elastomeric isolators and friction sliders turned out in higher percentages of damping and minor displacements.

The first office building with isolators built in Peru, was the building of private company GyM headquarters office (Fig. 1) designed by the structural firm "Prisma" in 2013. Regarding such building, a cost comparison was done of the isolated building with respect to a conventional design (with RC frames and walls). The result of the study conducted by Prisma and GyM, gave that the isolation system was only 3% more expensive compared to the conventional system.

Fig. 1 “GyM” office building– Lima, Peru

In 2014, the real estate “Labok” built the first apartment building with seismic isolators called “Atlantik Ocean Tower” in which the structural design was by Prisma. This 15-story plus 4 basements building, has 40 elastomeric isolators and friction sliders (Fig.2). Subsequently, Prisma developed in 2015 the first building for economic housing apartments, using a system of seismic protection. This building called “Paseo Colonial” has started construction in May 2016; it has 15 floors plus 2 basements and 72 elastomeric isolators (Fig. 3).

Fig. 2 “Atlantik Ocean Tower” building in Lima, Peru

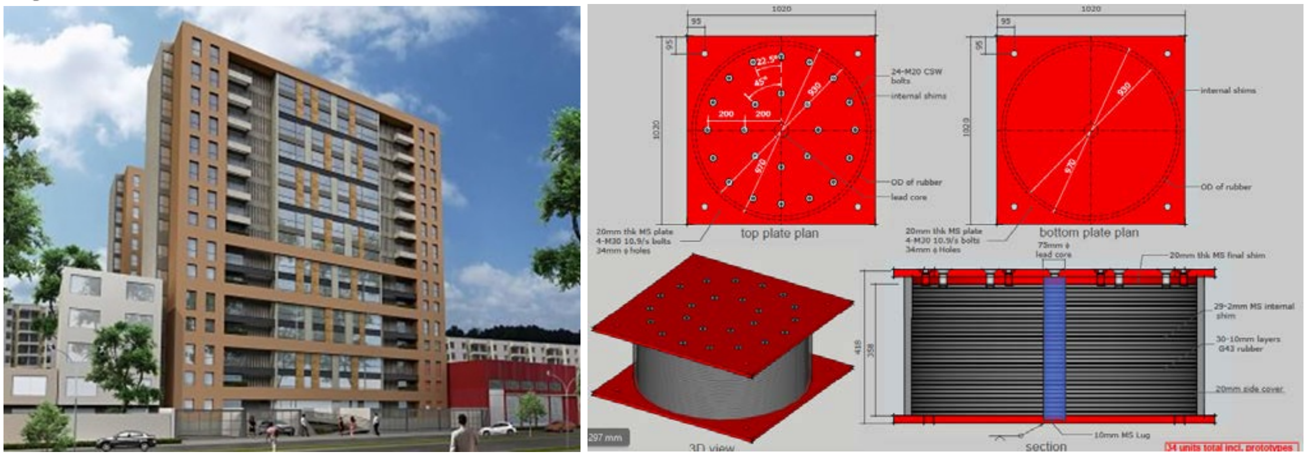

Fig. 3 "Paseo Colonial" building in Lima, Peru.

Some Peruvian universities have also chosen to incorporate base isolation systems in their new buildings. This is the case of the following universities: *Pontificia Universidad Católica del Perú, Universidad Privada de Tacna, Universidad Nacional de Ingeniería, Universidad de Ciencias Aplicadas* and *Universidad de Ingeniería y Tecnología del Perú.*

Since 2014, an addendum to the Peruvian seismic code, has been enforcing that major hospitals must have seismic base isolation, if they are in seismic zones 3 and 2 of the 2003 Peruvian seismic code [6]. The new Seismic Code that was recently published in January 2016 keeps this requirement. Therefore, currently there are more than 10 hospitals in design or construction with an elastomeric system of isolation, as the one shown in Fig.4. Also, some private clinics took the initiative to incorporate isolation systems in new buildings. This is the case of the Medical Specialties Clinic in San Borja, Lima, or The Hamilton Naki Clinic in Huancayo. However, since the publication of the Code in January 2016, the new buildings in private clinics are required to have base isolation, if they are located in the new seismic zones 4 and 3, and they belong to the second and third tier in the classification of health establishments from the health ministry of Peru.

Fig. 4 "Daniel Alcides Carrión Hospital" in Cerro de Pasco, Peru

In Fig. 5, the global result of the design achieved for the Chilean company Sirve in alliance with the Peruvian company Prisma for the Rioja Hospital of Peru is shown. The original vibration period of 0.75 s was moved to 2.9 s (almost 3.9 times). The pseudo acceleration for design, using the damping reached, was on the lower limit of the pseudo acceleration specified by the Peruvian seismic code.

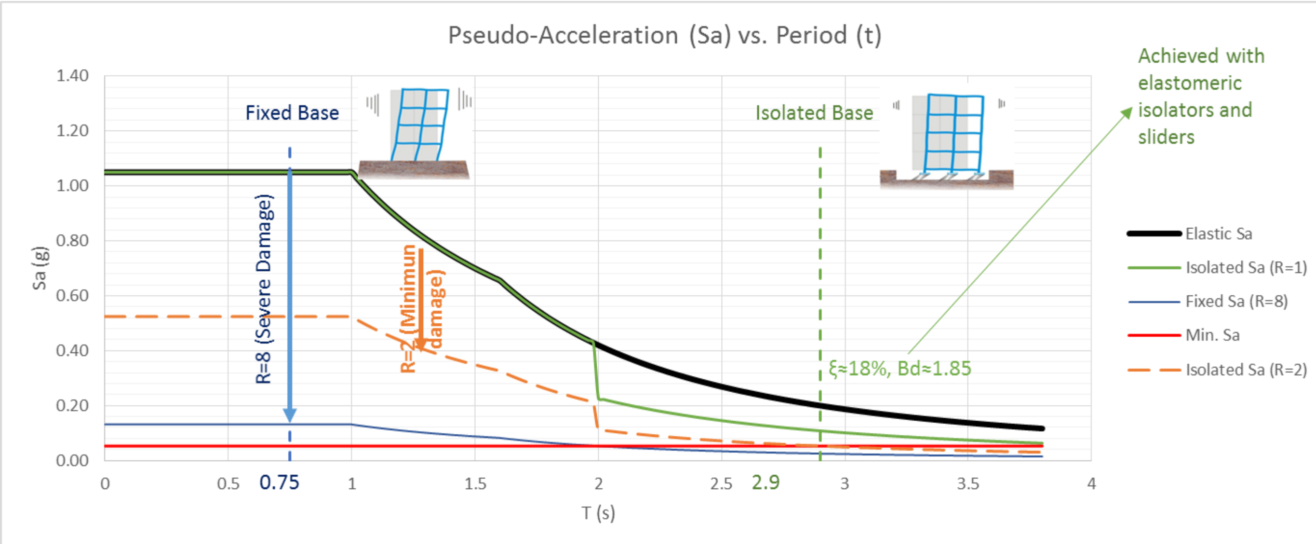

Fig. 5 Reduced demand using seismic isolation for Rioja Hospital in Peru

The displacement spectra for isolated buildings, obtained using the 2016 Peruvian Seismic Code, on the three seismic zones of higher hazard (zones 4, 3 and 2), and the four types of soils defined in the Code, are shown in Fig. 6. A correctly designed building in seismic zone 4 (the most hazardous), without torsional effects and having an effective damping of 20%, should have a seismic joint less than 400 mm between the isolated and non-isolated parts. If the same building is located in seismic zone 3, the seismic joint could be less than 300 mm, and for seismic zone 2, it could be less than 250 mm.

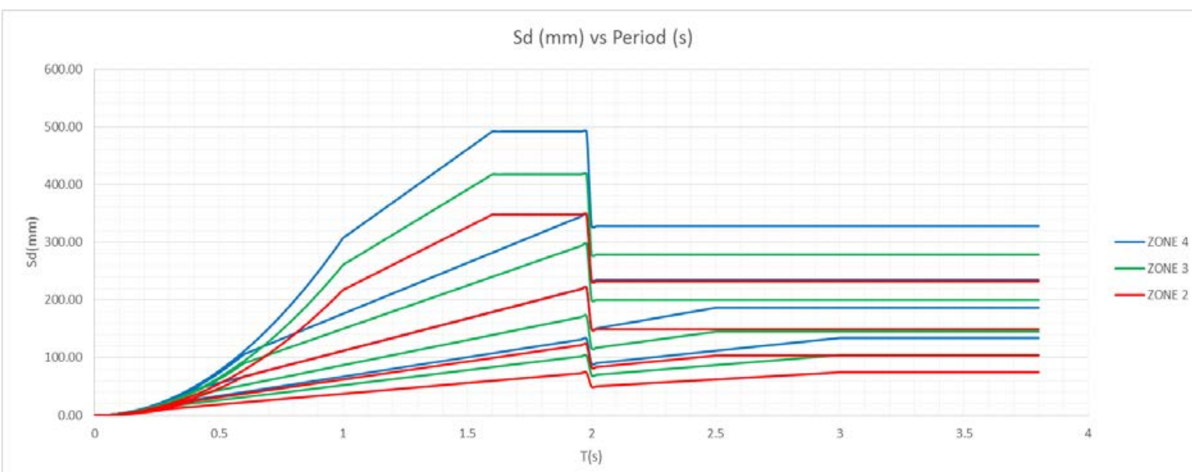

Fig. 6 Displacement spectra according to the Peruvian seismic code (2016)

In table 2 a summary of a representative sample of isolated buildings that are being designed or constructed in Peru so far is presented. Around 30 buildings have isolation systems. All the structures chosen belong to Lima city and are located in firm soil, in which the seismic code specifies the peak ground acceleration (PGA) of 0.45 g. Also, the main parameters of performance achieved in the design of each building in the main structural directions (X, Y) are shown in table 3.

Table 2 – Some representative buildings with seismic isolation in Peru

Project	Occupancy	Year Design	N° Stories	N° Devices
Clínica de especialidades médicas	Hospital	2015	6	32 "H4" Isolators + 7 flat sliders
Clínica Huancayo	Hospital	2014	4	73 "H4" Isolators + 19 flat sliders.
Complejo de Innovación Académica PUCP	Classrooms	2013	7	28 "H4" Isolators + 1 flat slider
Cortijo Business Center	Offices	2014	13	29 "H4" Isolators
Atlantik Building	Housing	2013	15	52 "H4" Isolators + 11 flat sliders
Madre Building	Housing	2014	17	48 LRB Isolators + 08 flat sliders
Colonial Building	Housing	2015	15	72 LRB Isolators

Table 3 – Performance Parameters of some representative buildings

PARAMETER	PUCP		ATLANTIK		CORTIJO		MADRE		COLONIAL		E. MEDICAS	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Fixed Period "T" (s)	1.3	1.09	1.7	1.81	2.18	1.95	1.66	1.86	1.78	1.94	1.22	1.27
Isolated Period "T" (s)	3.5	3.46	3.7	3.79	4.41	4.18	3.85	3.95	4.24	4.24	3.26	3.3
Period Shift	2.7	3.2	2.2	2.1	2.0	2.1	2.3	2.1	2.4	2.2	2.7	2.6
Maximum displacement "D_M" (cm)	22	21	18.4	17.9	21.6	22.3	20.1	19.6	23.2	22.5	28.6	28.5
Design displacement "D_D" (cm)	17	15.9	15.1	14.4	17.2	17.8	15.8	15.5	18.5	17.9	16.7	16.7
Maximum Drift (‰)	2	1.8	2.9	3.3	3.24	2.23	2.24	2.45	2.65	3.79	3.25	3.67
Drift reduction (%)	77.6	75	67.8	64.6	89.9	91.7	73.3	72.2	95.4	90.2	88	90.3
Maximum absolute acceleration (g)	0.14	0.16	0.2	0.2	0.176	0.186	0.15	0.16	0.25	0.28	0.255	0.267
Acceleration reduction (%)	82.1	78.9	75.6	71.7	86.6	81.6	86.5	84.3	88.3	80.3	84.2	78.7
Elastic base shear force Reduction (%)	93.9	95.7	80.1	80.9	90.6	92.1	86.2	83.9	91.7	92.2	90.4	91.4

From Table 3, it can be observed that the average reduction in floor accelerations of the structure is around 81%, while lateral shear force reduction is around 90%. As expected, the reduction in drift is around 82%.

Figure 7 shows the relationship between the fixed base period and the period with seismic isolation. Also, it can be observed the difference between the isolated period and the fixed period for the buildings in Table 2.

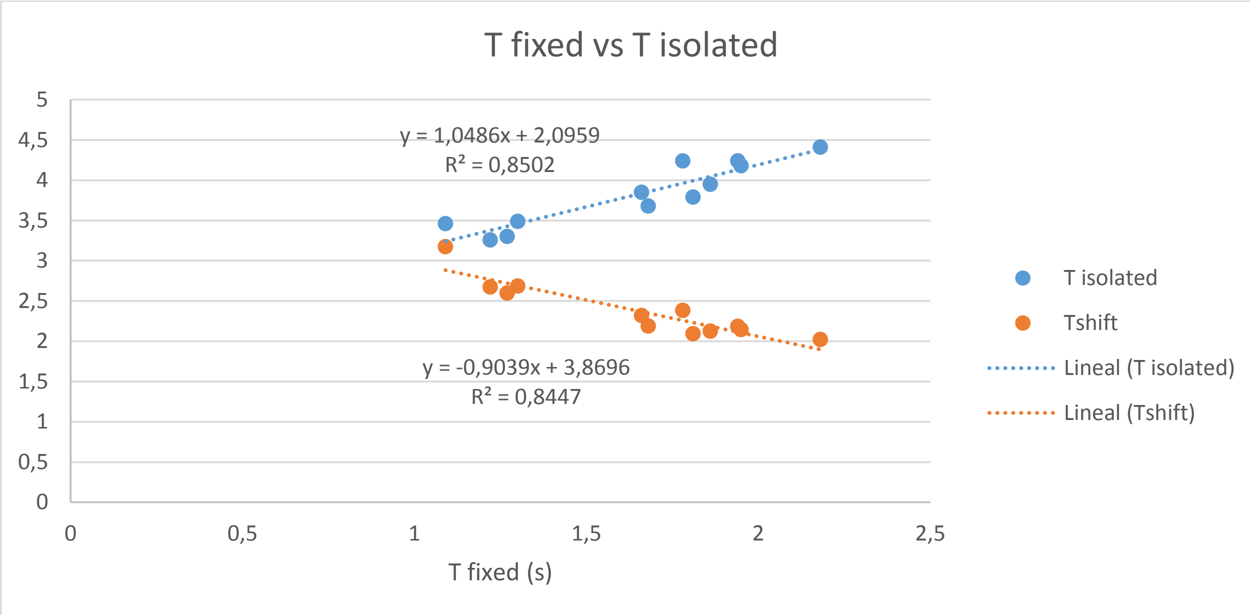

Fig. 7 Relationship between fixed and isolated period

5. Energy dissipation systems

In Peru, there are more than 10 building with some kind of dampers for reduction of seismic response. Of those, two are existing buildings that were reinforced by viscous dampers like the Control Tower building of the Jorge Chávez International Airport in Lima, Peru. The tower was designed by 1961; in 2007, it was seismically retrofitted by the structural firm GCAQ, with the inclusion of viscous dampers in chevron. Also, the 14-story building of the National Superintendence of Tax Administration of Peru (SUNAT) was built in 1981; the project to transform it to data center headquarters, required a seismic retrofit and reinforcement, which was done by the structural firm Prisma, with the inclusion of viscous dampers in diagonal members.

The devices used in Peru are currently viscoelastic dampers, hysteretic dampers (TADAS), and one building has a tuned mass damper (TMD).

Some of the most representative new buildings with energy dissipation systems in Perú are as follows. The “Barlovento Tower” is a new office building with 31 stories and 9 basements, designed with 156 hysteretic dampers TADAS, located between coupling beams that connect the structural walls of the elevators (Fig. 7). The construction of this building ended in 2015. Till now, this is the tallest building in Peru having an energy dissipation system. Also, the “Orquídeas Tower” is another office building, with 27 stories and 10 basements that finished its construction by the end of 2015. The design included 94 hysteretic dampers TADAS, in locations and distribution similar to the Barlovento tower (Fig. 8).

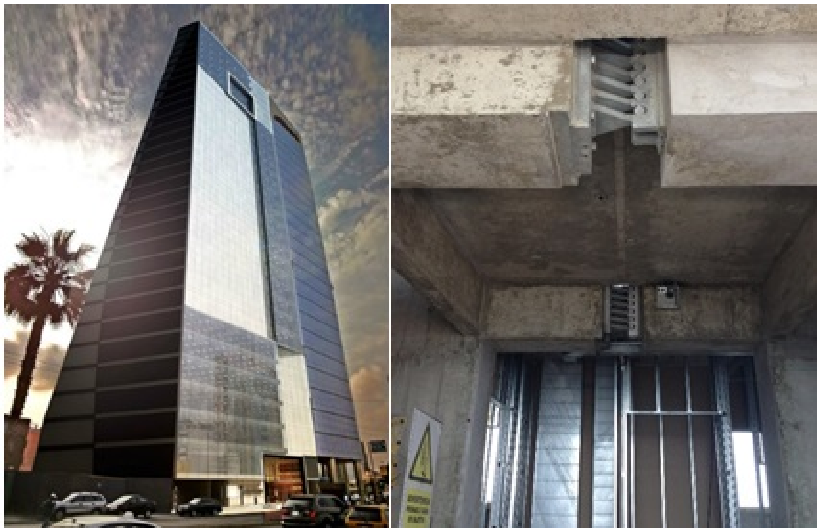

Fig. 7 “Barlovento Tower” building in Lima, Peru

Fig. 8 “Orquídeas Tower” building in Lima, Peru

Regarding seismic energy dissipation devices in Peru, the “Panorama Business Center” is an office building that has a singular role (Fig. 9). The project consists in two building towers of 20 stories each, and 8 common basement levels. This was the first project having viscous dampers, featuring 39 of such devices in each tower. The construction started in 2012, and finished in 2015. There were strict tolerances in the fabrication and construction of the steel structural elements holding the energy dissipation devices, which enforced the local factories to improve their control process in order to handle the small installation tolerances.

Fig. 9 “Panorama business center” tower buildings in Lima, Peru

6. Cost of the seismic protection systems in Peru

At the time of the 16WCEE, there are more than 25 buildings in Peru already built or under construction or under planning that include a seismic protection system. In Peru, the required investment in the building structure for a base isolation system represents around US $30 or $50 per square meter. In the case of dissipation devices, the cost represents around US $15 or $35 per square meter depending on the device. The cost of the devices is higher in Peru than other countries because there is no local production yet. Also, the Codes world around specify that each device to be installed must be previously tested in a laboratory. Although there are some structural labs in Peru, they still are not able to perform such tests. In the following years, it is probable that in Peru some factories and laboratories will be installed, in order to produce and test these devices.

Special attention must be given to the seismic protection systems in order to get an efficient and economic range for the building. The current experience indicates that the global costs of a building with any seismic protection device should not exceed by 10% the cost of a conventional building structure.

7. Conclusions

Peru is a seismic country, with many destructive earthquakes in the past similar to those that have hit Chile. A modern way to reduce structural damage as well as non-structural damage is to include seismic protection devices. After the 2010 Maule, Chile earthquake, good performance of buildings with base isolation and energy dissipation devices was observed. Therefore, the construction industry with structural engineers in Peru started the design and construction of buildings with such devices. Nowadays, in Peru several hospital and clinic buildings are under planning or construction with base isolation, following the 2016 Peruvian Seismic Code regulations. Also, important university and housing buildings are already built or under construction with base isolation. Taller office buildings are using energy dissipation devices in an increasing manner, which could be a trend in the coming future.

8. References

[1] SENCICO (2016): *Norma Técnica E.030 Diseño Sismorresistente* (*Peruvian Seismic Code),* Lima, Perú (in Spanish).

[2] ASCE/SEI (2010): *Minimum Design Loads for Building and Other Structures*, ASCE/SEI 7-10, Structural Engineering Institute of the American Society of Civil Engineers, Reston, Virginia, USA.

[3] Giesecke A, Silgado E (1981): Terremotos en el Perú. *Ediciones Rikchay Perú*, Lima, Perú (in Spanish).

[4] Muñoz A, Quiun D, Tinman M (2004): Repair and seismic retrofitting of hospital and school buildings in Peru, 13th World Conference on Earthquake Engineering, Vancouver, Canada.

[5] San Bartolome A, Quiun D (2008): Seismic Behaviour of Masonry Constructions In 2007 Pisco, Peru Earthquake, 14th World Conference on Earthquake Engineering, Beijing, China.

[6] Moroni M, Sarrazin M, Soto P (2012): Behavior of Instrumented Base-Isolated Structures during the 27 February 2010 Chile Earthquake. *Earthquake Spectra*, **28**, (S1), S407–S424.

[7] Boroschek R, Retamales R, Aguilar A (2013): Seismic Response of Isolated Structures Subjected to Mw 8.8 Chile Earthquake of February 27, 2010, *The International Symposium for CISMID 25th Anniversary Technological Advances and learned lessons from last great earthquakes and tsunamis in the world*, Paper No. M-2.