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THE ROLE OF MODERN TECHNOLOGIES TO SAFEGUARD HOSPITALS DURING EARTHQUAKES

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ABSTRACT

During the September 19, 1985 Earthquake the performance of public and private hospitals was poor. Unfortunately, the problem is chronic, as during the October 9, 1995 Manzanillo Earthquake, a similar behavior was observed in Manzanillo. Modern technologies such as passive energy dissipation and base isolation offer multiple advantages towards the goal of constructing safe hospitals from an earthquake engineering, performance-based viewpoint. Many public hospitals in Mexico City have been retrofitted after the 1985 earthquake. However, only two of them were retrofitted with passive energy dissipators. Although Mexico was one of the pioneering countries that used modern technologies to improve the seismic safety of hospitals, the country is in a disappointing dormant status. Certainly, in order to improve the seismic safety of hospitals and their contents, Mexico needs more applications of structural control systems in hospitals. Therefore, we have to work in finding the right way to introduce these technologies to hospital owners and managers from both the public and private sectors.

Introduction

During the September 19, 1985 Earthquake (M_s=8.1), the performance of public and private hospitals was poor, given that their design and construction was before the publication of modern seismic design guidelines. That was the case of the Hospital Complex known as “Centro Médico Nacional” (National Medical Center) in Mexico City, the most important of his class in the country, where there were important damage and partial collapses in several buildings (Figure 1a), and two very well-known collapses: Hospital General (General Hospital, Figure 1b), and Juárez Hospital (Figure 1c), the most important public maternity hospitals at the times.

According to official information (OPS 1985), 1,107 people were killed for partial and total collapses of hospitals in Mexico City during the September 19, 1985 earthquake, where 561 were in Juárez Hospital, 295 in General Hospital and 10 in the National Medical Center. During the collapses of Juárez and General hospitals, 100 doctors, 37 nurses, 385 new-born-babies, 85

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patients, 242 workers and 3 visitors were killed.

a) Medical Center Century XXI b) General Hospital c) Juárez Hospital

Figure 1. Observed damage and collapses in hospitals during the September 19, 1985 Michoacán Earthquake (OPS 1985 and Gabok-17 2009)

Unfortunately for Mexico, the problem is chronic nationwide, as there are still many public and private hospitals that were not design according to modern seismic codes. Therefore, these old and unretroffited infrastructure is vulnerable to strong earthquake events.

For example, during the October 9, 1995 Manzanillo Earthquake (M_w=8.0), a similar behavior was observed in old public hospitals in the port of Manzanillo (Tena-Colunga *et al.* 1997), among them: Hospital Civil (Civil Hospital) and Hospital de la Secretaría de Salud (Health Ministry Hospital, Fig 2).

Figure 2. Observed damage in the Health Ministry Hospital at Manzanillo during the October 9, 1995 Manzanillo Earthquake

Even the most modern hospital at the times, the General Zone Hospital number 10 (HGZ-10) for the Mexican Social Security Institute (IMSS), designed according to the 1976 code, experienced important structural and nonstructural damage due to construction-detailing errors and soil settlements (Tena-Colunga *et al.* 1997). This hospital (Fig 3a) was designed as a reinforced concrete, special moment-resisting frame building (RC-SMRFs). However, its seismic behavior was modified because of construction-detailing errors, such as placing very rigid and strong stone-masonry walls at the basement (Fig 3b) and RC-cladding walls (Fig 3c) within the perimeter, which favored a short column effect, as the wall-frame interaction was not considered during the design process. Damage due to a 10 cm soil settlement and structural pounding was also very evident (Figure 4).

a) b) c)

Figure 3. Observed damage in HGZ-10 IMSS hospital at Manzanillo during the October 9, 1995 Manzanillo Earthquake

a) b) c)

Figure 4. Observed damage in HGZ-10 IMSS hospital at Manzanillo during the October 9, 1995 Manzanillo Earthquake due to soil settlements and structural pounding

Hospitals were disrupted again in Colima city during the M_w=7.8, January 21, 2003 Tecomán Earthquake (Reyes *et al.* 2006).

Therefore, it is clear that hospitals in Mexico have been very vulnerable to strong earthquakes so far. Their seismic performances have been below the expectations of the Mexican society. Then, there is a need to build new safer hospitals and to retrofit some other important hospitals to achieve the goal of having functional and safe hospitals that can help attend the emergencies during and after a strong earthquake event, as it is discussed in following sections.

The Role of Modern Technologies

Modern technologies such as passive energy dissipation and base isolation offer multiple advantages towards the goal of constructing safe hospitals from an earthquake engineering, performance-based viewpoint. Among them, are the following:

- No damage in conventional structural elements (beams, columns, walls, braces, etc.) can be achieved, as nonlinear or damped response can be exclusively concentrated in dissipators, dampers and/or isolators.
- Reduced drifts can be obtained in the superstructure.
- No damage in nonstructural elements can also be achieved with proper detailing.
- Reduced peak floor accelerations (including vertical ones) can be achieved by selecting and designing properly a suitable base-isolation system and/or by increasing damping for some energy dissipators (i.e., viscous dampers). Therefore, building contents can be safeguard too.

Mexican Experience

Passive energy dissipation can be used in any soil profile type, but offers many advantages for medium-rise and tall structures built in soft soils sites, such as those found in Mexico City lakebed zone (i.e., Martínez-Romero 1993, Tena-Colunga *et al.* 1996, Tena-Colunga and Vergara 1997, Tena-Colunga 2007).

Base isolation offers many advantages for relatively firm, firm and rock sites. There are many structures built in such soil conditions in the zones of highest seismic risk of Mexico; many of them are hospitals or medical centers. However, there are not base-isolated hospitals available in Mexico yet (Tena-Colunga 2007).

Many public hospitals in Mexico City were retrofitted after the 1985 Michoacán earthquake. However, only two of them were retrofitted with passive energy dissipators:

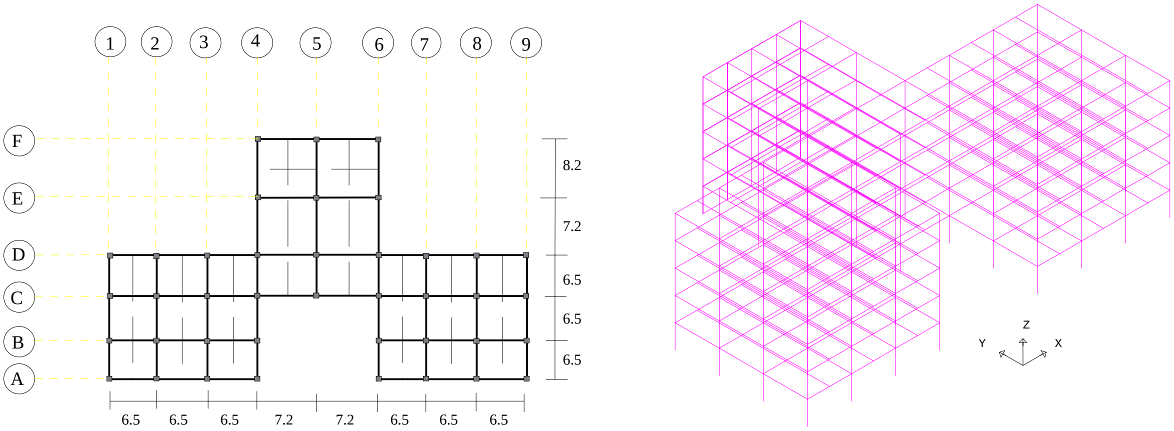
- IMSS Cardiology Hospital in the National Medical Center Century XXI in 1990 (Martínez-Romero 1993), using ADAS devices (Figure 5) and,

Figure 5. Retrofit of IMSS Cardiology Hospital with ADAS devices

- ISSSTE 20 de Noviembre (November 20th) Hospital Complex (five buildings) in Mexico City during 1992-1994 (Sánchez and Urrutia 1994), with a buttress system that includes a slotted-bolted-connection (SBC) at the base (Figure 6).

Figure 6. Retrofit of November 20th Hospital Complex with slotted-bolted-connections (SBC)

Surprisingly as it may seem, Mexico does not have base-isolated hospitals yet, although the advantages of using base isolation has been illustrated for the specific case study of HGZ-10 IMSS hospital at Manzanillo (Fig. 3), which plan and 3D isometric model is shown in Figure 7 (Villegas-Jiménez 1999, Villegas-Jiménez and Tena-Colunga 2000).



a) Plan (dimension in meters)

b) 3D Isometric model

Figure 7. HGZ-10 IMSS building

The final design for the isolation system project for HGZ building consisted of a total of 40 circular lead-rubber bearings 61.5 cm in diameter and 37.5 cm in height, with a lead core diameter of 13.8 cm. The total maximum isolator displacement (considering bidirectional effects) was Δ_M=20.5 cm and the yield displacement was Δ_y=2.27 cm. The design base-isolated period for HGZ-10 was T_I=1.8s, whereas its fixed-end period was T_e=0.43s. Then, the dynamic uncoupling was reasonable as T_I/T_e=4.19. In order to make a comparison as fair as possible, a "new" fixed-based HGZ-10 building was designed according to the 1990 seismic code for the state of Guerrero (RCGS-90, described in Tena-Colunga 1999).

To verify peak dynamic responses for the isolation system, nonlinear dynamic analyses were performed using the 3D-Basis program considering bidirectional input for the ground motions. Typical acceleration time histories for Mexican earthquakes recorded on rock sites during recent strong earthquakes events were used. Five of the acceleration records (AZIH, CALE, PARS, UNIO and VILE) were obtained during the September 19, 1985 earthquake (M_s=8.1), three (AZIH, PAPN and VILE) for the September 21, 1985 aftershock (M_s=7.6), and four (CPDR, MSAS, SMR2 and VIGA) for the April 25, 1989 earthquake (M_s = 6.9). The records for the September 21, 1985 and April 25, 1989 earthquakes were scaled to an earthquake magnitude M_s=8.1 using a method described elsewhere (Tena-Colunga *et al.* 2007), which is based on the seismological model ω^2. Some results obtained in the study described in detail in Villegas-Jimenez (1999) are summarized in Table 1 for the base-isolated project and in Table 2 for the fixed-based project.

Table 1. Peak dynamic displacements and base shear for the LRB base isolation project of HGZ-10 hospital

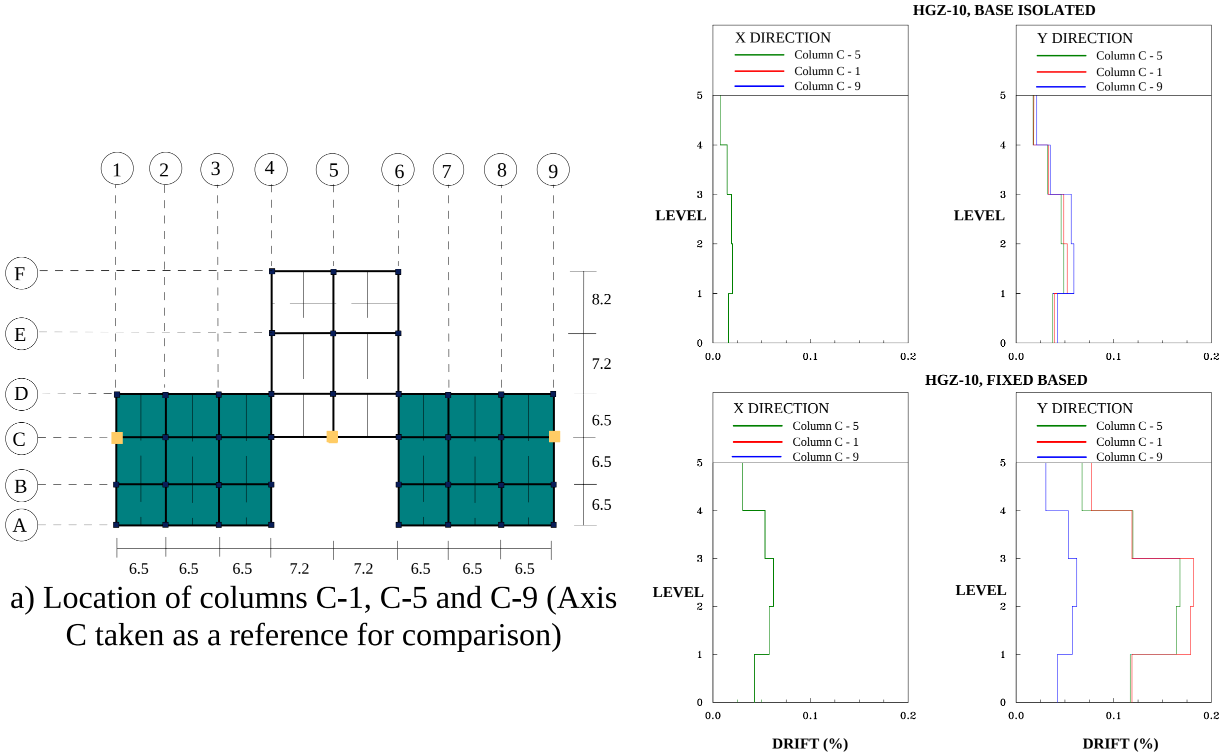
Event	**Station**	**Maximum relative roof displacements with respect to the isolation level (mm)**		**Peak normalized displacements for the LRB isolation system**	**Normalized base shear**	
		Δ_{xmax}	Δ_{ymax}	Δ_{imax}/Δ_M	V_x/W	V_y/W
	AZIH	3.2	5.8	0.283	0.108	0.096
09/19/85	CALE	3.0	4.6	0.219	0.099	0.078
	PARS	1.9	4.2	0.097	0.062	0.073
	UNIO	2.6	6.3	0.273	0.084	0.109
	VILE	3.4	4.4	0.268	0.111	0.077
04/25/89	SMRZ	3.2	4.9	0.434	0.101	0.085
09/21/85 (Artif)	AZIH	3.9	4.4	0.607	0.130	0.071
	PAPN	1.9	5.2	0.161	0.056	0.083
	VILE	1.8	5.5	0.156	0.058	0.097
04/25/89 (Artif)	CPDR	2.9	6.4	0.605	0.098	0.104
	MSAS	2.4	4.4	0.224	0.081	0.079
	VIGA	3.5	4.0	0.405	0.115	0.064

As it can be observed in Table 1, peak dynamic responses for the isolation system project for HGZ-10 building were stable when subjected to the considered acceleration records, associated to the design spectrum for RCGS-90 code (i.e., Tena-Colunga 1999, Villegas-Jiménez 1999). Maximum relative roof displacements with respect to the isolation level were negligible for practical purposes, as the structure essentially moves as a rigid body over the isolation system. The peak base shear transmitted to the superstructure is considerably smaller than the one the building should have experienced if designed as a fixed-based structure in a conventional design (Table 2). Because the base-isolated building essentially behaves as a rigid body, the floor acceleration time histories are very similar to the base ground motions used as an input. Torsional coupling because of the plan irregularity are considerably diminished in the superstructure for the base-isolated project with respect to the fixed-based project (Figure 8). Therefore, the results obtained in this study lead one to believe that HGZ-10 hospital at

Manzanillo could have been retrofitted effectively with lead-rubber bearings. However, such retrofit strategy was not selected. This building is still unretrofitted and abandoned nowadays.

Table 2. Peak dynamic displacements and base shear for the fixed-based project for HGZ-10 hospital

Event	**Station**	**Maximum relative roof displacements with respect to the base (mm)**		**Normalized base shear**	
		Δ_{xmax}	Δ_{ymax}	V_x/W	V_y/W
	AZIH	3.8	23.0	0.188	0.320
09/19/85	CALE	8.3	12.8	0.204	0.185
	PARS	3.0	6.2	0.110	0.088
	UNIO	8.3	22.0	0.239	0.330
	VILE	6.5	19.0	0.157	0.273
04/25/89	SMRZ	8.9	9.8	0.236	0.165
09/21/85 (Artif)	AZIH	11.1	25.3	0.312	0.343
	PAPN	5.2	18.5	0.259	0.253
	VILE	2.2	6.1	0.057	0.093
04/25/89 (Artif)	CPDR	5.5	21.5	0.231	0.312
	MSAS	4.7	14.5	0.213	0.235
	VIGA	16.5	24.3	0.457	0.368



a) Location of columns C-1, C-5 and C-9 (Axis C taken as a reference for comparison)

a) Peak dynamic drifts

Figure 8. Comparison of the torsional response in the superstructure for the base-isolated and fixed-based projects for HGZ-10 IMSS building

International Experience

Nowadays, base isolation is being used extensively worldwide to improve the seismic safety of hospitals in countries like Japan, the United States, Canada, Italy, Turkey, Taiwan and India. Viscous dampers and energy dissipators are also being used for this purpose. Just to give a few examples for base isolation projects are, among others: The USC Hospital at Los Angeles, USA with natural and lead rubber bearings in 1991 (Fig. 9), the Gervasutta Hospital at Udine, Italy with high damping rubber bearings (Fig. 10), the Kocaeli University Hospital at Turkey with friction pendulums (Fig. 11), the Tzu-Chi Hospital at Taipei with lead-rubber bearings and viscous dampers (Fig. 12) or the Bhju District Hospital in India with lead-rubber bearings (Fig. 13). Among the examples for passive energy dissipators in other countries are: Sharp Memorial Hospital in San Diego, USA with Pall friction devices (Soli *et al.* 2004) and St. Vincent Hospital in Ottawa, Canada (Fig. 14).

Figure 9. USC Hospital (RSL-2009)

Figure 10. Gervasutta Hospital (Dolce and Martelli 2005)

Figure 11. Kocaeli University Hospital (Erdik and Mungan 2005)

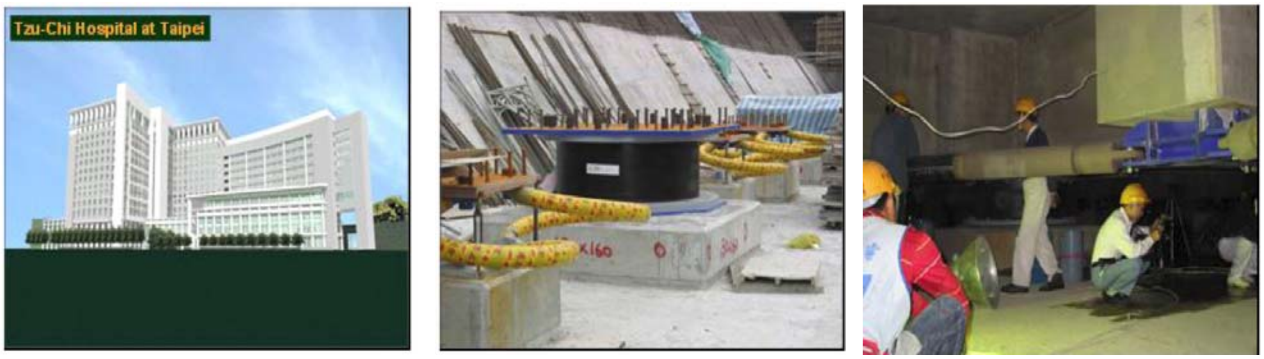


Figure 12. Tzu-Chi Hospital (Chang and Uang 2005)

Therefore, the use of modern technologies to safeguard hospitals during earthquakes is starting to become a reality in seismic countries worldwide. However, the development in some countries is slow or dormant, like in Mexico, unfortunately.

Figure 13. Bhju District Hospital (RSL 2009)

Figure 14. St. Vincent Hospital (Malhotra *et al.* 2004)

Concluding Remarks

Although Mexico was one of the pioneering countries that used modern technologies to improve the seismic safety of hospitals, the country is now in a disappointing dormant status. Nowadays base isolation is being used extensively worldwide to improve the seismic safety of hospitals. Viscous dampers and energy dissipators are also being used for this purpose. Certainly, in order to improve the seismic safety of hospitals and their contents, Mexico needs more applications of structural control systems in hospitals. Therefore, Mexican engineers and architects have to work together in finding the right way to introduce these technologies to hospital owners and managers from both the public and private sectors.

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