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LESSO NS LEARNED FROM THE 2008 SICHUAN EARTHQUAKE AND APPLICATION TO THE RETROFIT PROGRAM IN ISTANBUL, TURKEY

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ABSTRACT

Worldwide, a large percentage of older residential and commercial buildings in areas of high seismicity are constructed of unreinforced masonry or non-ductile concrete frames. Past earthquakes have demonstrated that these types of structures are vulnerable to major damage and collapse. The latest somber reminder was the 2008 Sichuan earthquake in China that collapsed thousands of such buildings. To mitigate the vulnerability of schools and hospitals to earthquakes in Turkey, the government of Istanbul, under the auspices of the World Bank has developed the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project. The project's primary objective has been to provide life safety performance for as many buildings as possible under the available funding by using effective earthquake retrofits. As part of the project, a comprehensive structural engineering retrofit implementation guideline has been developed. The implementation phase relies on the cooperation of local engineers and international experts to identify suspect buildings using construction documents, analysis and evaluation tools, and site visits. Extensive, multi-layer design reviews and construction inspections are conducted. To date, several hundred buildings have been retrofitted

Overview of the Sichuan Earthquake

Background

The magnitude 8.0 earthquake struck Sichuan, China on May 12, 2008. The earthquake epicenter was located 1500 kilometers southwest of Beijing. The authors (Miyamoto et al. 2008) were one of the first engineers to visit the site shortly after the earthquake to document the damage and identify the reasons behind the devastating collapses. Fatalities have exceeded 70,000 and millions were injured or left homeless; the damage is estimated at US $150 Billion.

Schools and hospitals were especially hit hard by the earthquake; many collapsed while fully occupied. Nearly all of the collapsed buildings had one or more of the following design or construction issues: unreinforced masonry, low ductility, little redundancy, questionable load paths, and undesirable seismic configuration such as soft stories. Robust and economical retrofit options are available to mitigate such deficiencies. Since schools and hospitals are critical

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buildings, the proposed retrofits focus on these buildings. Basic retrofit options can be designed to provide life safety only; however, higher retrofit goals such as immediate occupancy are also possible at a larger cost.

Damage to Schools and Hospitals

The three-story Juyuan Middle School is in Juyuan, a town with a population greater than 50,000 and approximately 20 kilometers from the fault rupture. The school, constructed in 1986, housed 1,000 students; more than 700 died when the building collapsed. Building construction consisted of non-ductile, cast-in-place reinforced concrete (CIP-RC) beams supported by un-reinforced masonry (URM) walls with precast concrete floor planks. Figure 1 shows the collapsed floor precast planks. Note that the inadequately connected and under-reinforced planks pulled away from the walls and were left hanging and attached to the opposite walls. Figure 2 shows the collapse of non-ductile bond (perimeter) beams.

The five-story Hanwang hospital was constructed in 1999. Building construction consisted of non-ductile CIP-RC framing and URM walls. The ground floor was designed as a parking garage; hence, the URM bearing walls were terminated at the first floor, creating a bottom story with a significant reduction in lateral stiffness. This soft-story (ground floor) collapsed during the earthquake (Figure 3) and the upper floors dropped down one floor.

Figure 1. Collapsed ceiling/floor planks

Figure 2. Collapsed concrete beam

Figure 3. Soft story collapse

Seismic Retrofit Options

Effective retrofit options are available to mitigate the type of deficiencies observed in this earthquake. Typical options are listed in Table 1 and schematically shown in Figure 4. Since schools and hospitals can be classified as critical buildings and high-density population areas, the presented options emphasize these buildings. While the basic ideas discussed here do not address substandard construction, retrofitting might have prevented the sudden and total collapse of many buildings and the subsequent loss of life. The retrofit options are intended to provide the basic life safety goal, which is to prevent collapse. Higher retrofit goals such as minimizing structural damage or immediate occupancy are also possible, albeit at a larger monetary cost.

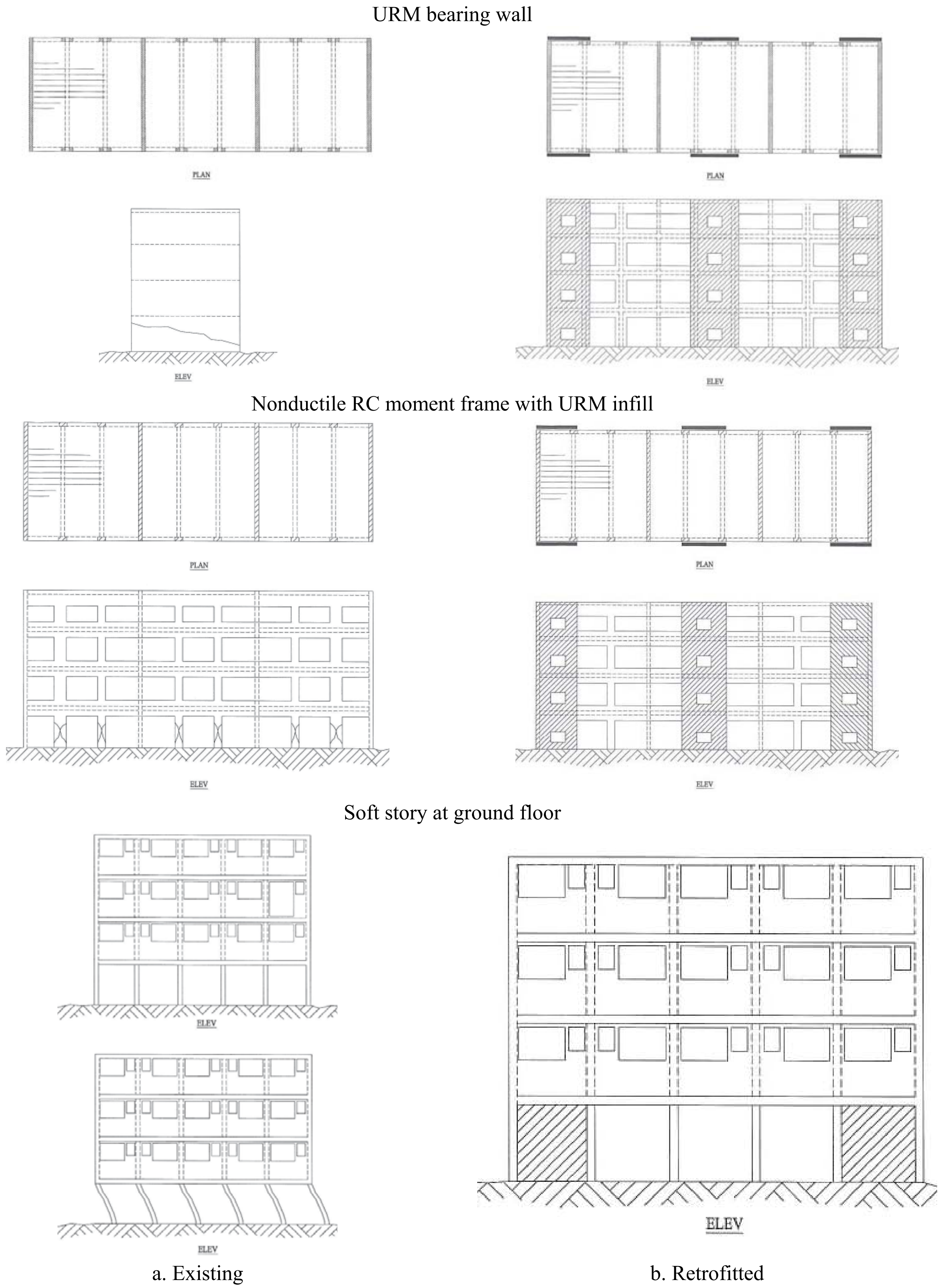

Figure 4. Proposed retrofit schematics

Table 1. Proposed building retrofit options

Building Type	Deficiencies	Retrofit design
All	Lack of diaphragm action (load path)	Check strength and ductility of the RC ring beams.
		Reinforce and confine them as required.
		Add ring beams at each floor if not present.
URM bearing wall	Lack of lateral capacity and ductility	Add full-height ductile, RC shear walls on the exterior of the building.
		Apply engineered cementations concrete (ECC) to the exterior of the walls.
		Place the structure atop of seismic isolators.
Non-ductile RC moment frame with URM infill	Lack of strength, stiffness, and ductility	Add full height ductile RC shear walls on the exterior of the building.
		Add shotcrete to the existing members.
		Place the structure atop of seismic isolators.
	lack of column confinement	Wrap columns using Fiber Reinforced Polymers (FRP).
	captive columns	Cut the connection between the partial height infill URM walls and concrete columns.
	Inadequate joint shear capacity	Add prestressing or confinement to joints.
Soft story at ground floor	Lack of lateral stiffness and capacity at a floor	Add single-story ductile RC shear walls on the exterior of the building.
		Add single story steel braces on the exterior of the.
		Add viscous or viscoelastic dampers to the ground floor.

Worldwide Lessons and Applications

The Sichuan Earthquake produced results that were expected and had been observed in many other earthquakes. Unfortunately, dangerous URM and non-ductile RC buildings, structural irregularity, poor seismic detailing, questionable material quality and construction practices are not limited to only China's infrastructure. These dangerous building types are found worldwide, including South America, the United States, Canada, Japan, throughout Asia, and Southern and Eastern Europe. It is imperative to upgrade these structures to protect lives in future and inevitable earthquakes.

The remainder of this paper will discuss the vulnerability of structures in Turkey, describes an ongoing World Bank project in Istanbul to mitigate earthquake risk, and presents valuable lessons applicable to other countries.

Many of the lessons learned from Sichuan also are applicable to Istanbul. For example, for both sites, past events serve as a notice of future large earthquakes. Furthermore, in both locations, structures have been constructed that have seismic deficiencies such as unreinforced masonry, nonductile concrete, or soft stories. Additionally, many of structures in both sites have questionable construction quality and used low-strength material.

Seismic Vulnerability of Buildings in Istanbul, Turkey

Damage from the 1999 Earthquakes

The 1999 magnitude 7.6 Izmit (Kocaeli) and magnitude 7.2 Duzce earthquakes caused extensive damage to its local region. Fatalities exceeded 18,000 while casualties exceeded 50,000, with a direct financial loss of over US $6 billion. High ground accelerations were recorded. During these earthquakes and during the other strong Turkish earthquakes, many vulnerable structures have either collapsed or have been severely damaged A review of post-earthquake surveys in Turkey (Sezen et al. 2000) reveals that many of the types of structures that were damaged in the Sichuan earthquake also performed poorly during the 1999 earthquakes in Turkey. For example, as shown in Figure 5, soft story collapses occurred when the lateral stiffness of the bottom floor was lower than that of upper floors and URM buildings or infill walls collapsed (NISEE 2009), as shown in Figure 6.

Figure 5. Soft story collapse (Sezen 2000)

Figure 6. URM infill collapse (NISEE 2009)

Vulnerable Buildings in Istanbul

Figure 7 depicts a vulnerable building in Istanbul taken during a recent site visit and its condition-assessment survey. For this building, the walls terminate above the first floor to allow parking beneath. This introduces a soft-story mechanism and can lead to collapse in a future earthquake. This structural configuration is not much different from those observed in China (see Figure 1). Once such dangerous buildings are identified, it is important that steps be taken to address their vulnerabilities.

Many thousands of schools, hospitals, and government buildings in Istanbul use reinforced concrete moment frames. There are over a dozen subgroups within the same design group. The main differences between the various subgroups are the layout of the frames, geometry of the structure, and the presence of URM walls. The most common type (see Figure 8) is a three or four story, regularly configured building, with a basement, and an emergency staircase attached to the short sides of the structure.

Figure 7. A vulnerable structure

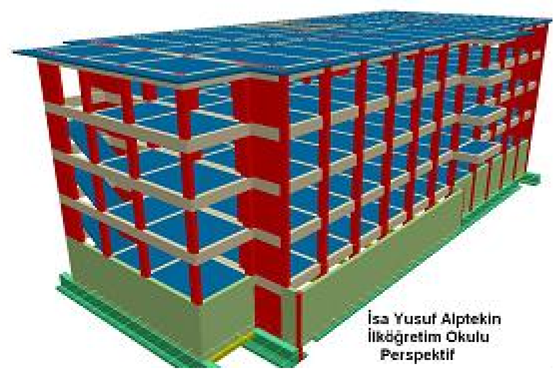

Figure 8. Typical building schematics

The World Bank Project for Istanbul

Overview

The historic city of Istanbul is Turkey's largest city with more than 20% of the country's population. Istanbul also generates a large portion of Turkey's GDP. Since the 1999 earthquakes, the city has grown substantially. Istanbul is also is located in an active earthquake region. Its seismicity is comparable to those of California and Japan and there is a high probability of a major earthquake occurring in Istanbul in the next 20 to 40 years. Without extensive building strengthening throughout the city, such an earthquake will result in high casualties and a tremendous economic loss. These factors served as the background for the World Bank project.

ISMEP (Project) Scope and Organization

To address the earthquake vulnerability of public buildings in Istanbul and to prepare for the next major earthquake, the World Bank and the Turkish government initiated the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). The ISMEP project, initiated in 2006, scheduled for completion in 2014, and has a total World Bank loan of an estimated US $600 million.

The first engineering assessment and preparation mission was conducted in October of 2002 (Yanev 2002). The World Bank financed and supervised project (WB 2007) is implemented through the Istanbul Project Coordination Unit (IPCU), (ISMEP 2009), and is responsible for implementing the project. IPCU lists five primary goals for the project. This paper is primarily focused on task 3 - evaluation and retrofit work for public buildings.

- Strengthening institutional and technical capacity of emergency management
- Increasing emergency preparedness and response awareness
- Retrofitting/Reconstruction of priority public buildings
- Vulnerability inventory and project design for cultural and historical heritage assets
- Taking supportive measures for the efficient implementation of development law and building codes.

Retrofitting (Strengthening) and Reconstruction (New Design) Of Public Buildings

Task Organization

To ensure the successful implementation of the project, a collaborate effort between domestic and international consulting engineering companies was required and established. This arrangement took advantage of the strength of both groups. The local engineers are familiar with the in-situ designs and construction practices and can readily identify vulnerable structures. The international consultants, mostly from other well-known earthquake-prone countries, are well versed in the science and art of seismic rehabilitation and can more readily identify deficiencies in proposed retrofits, given their expertise and extensive background in the earthquake engineering rehabilitation practice. The international consultants also typically have extensive earthquake retrofit experience around the world and are familiar with the latest and most cost-effective retrofit techniques. Academics from Turkey were also involved in the review of the completed designs, as well as assisting in the development of criteria and guidelines for the work.

Rehabilitation Guidelines

The objectives of this project are to identify, evaluate, and to retrofit/reconstruct as many vulnerable structures as possible with the available funding. To ensure that the project would strengthen and/or rebuild cost-effectively as many structures as possible, the project participants developed guidelines for selection and rehabilitation of vulnerable structures. The Guidelines (IPCU 2007) are based on the provisions of the Turkish code (TEC 2007) and ASCE 41 (ASCE 2006) and other publications. While the Turkish code is written for new construction, the Guidelines are intended for retrofit. To ensure that the project would encompass as many structures as possible, certain levels of damage are deemed acceptable in the provisions. The key provisions of the Guidelines are as follows:

- Condition assessment: Data is gathered in sufficient detail to identify structural and non-structural components that participate in resisting lateral loads, and potential seismic deficiencies in load-resisting components. As-built condition evaluations should utilize construction documents and testing, among other resources.
- Seismic deficiencies: Common structural deficiencies (for example, irregular configuration, non-ductile reinforcement detailing, and URM infill walls) are identified.
- Seismic hazard: The seismic demands are defined in terms of design response spectra or suites of acceleration time histories. The hazard due to earthquake shaking is defined on either a probabilistic or a deterministic basis.
- Analytical procedures: Acceptable procedures, ranging from simplified static to non-linear dynamic analyses, is allowed based on structural configuration and retrofit..
- Structural performance levels: Various performance levels are defined and the level of damage for each level is described. The appropriate performance level for a given earthquake intensity is identified. More detail is provided below.
- Retrofit: Both conventional and innovative techniques are described.

The Guidelines strenuously attempt to address and correct the weaknesses of the Turkish earthquake engineering and construction practices while incorporating state-of-the art practices from around the world, particularly from countries that have conducted extensive and systematic strengthening of structures in earthquake regions over many years. This also includes considerations related to other systematic issues, such as engineering education and licensing. Many of the buildings that have already been strengthened were constructed relatively recently.

A key feature of the provisions is the use of performance based engineering (PBE). In PBE, three structural performance levels are considered: Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP). These performance levels relate to damage states for elements of lateral force resisting systems and have specific drift limitations as shown in Figure 9. The IO limit state implies that only limited structural damage has occurred. The basic vertical- and lateral force resisting systems of the building retain nearly all their pre-earthquake strength and stiffness. The LS damage state implies that significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. The CP performance level implies that the post-earthquake damage state of the building is on the verge of partial or total collapse. However, all significant components of the gravity-load-resisting system continue to carry their load. Although the retrofit objectives are project specific, typically it is expected that the retrofitted buildings will attain IO, LS, and CP, for the service, design, and extreme earthquakes, respectively.

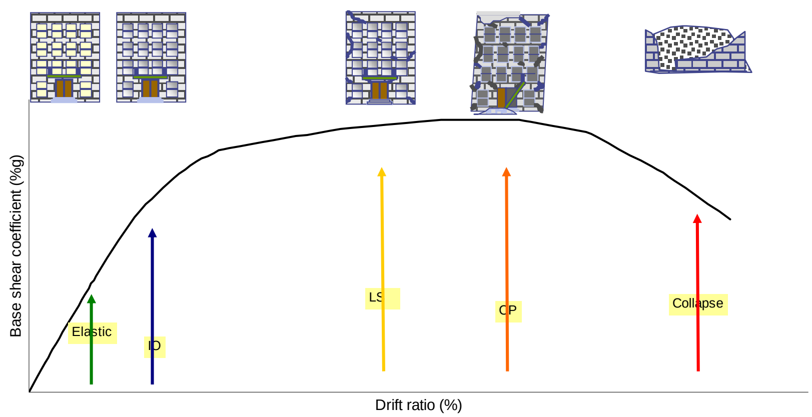

Figure 9. Performance Levels (FEMA 2000).

Implementation

To implement the project successfully and to transfer as much technological information as possible, the international consultants work closely with the local engineers. To ensure that the retrofits are properly designed and constructed, international consultants review both the design and construction phases. The consultants often participate directly in the engineering design and decisions. Their findings are submitted to IPCU as individual project reports. In the design phase, structural plans and calculations are reviewed to ensure that the retrofit is effective, it does not introduce structural irregularities, a clear load path is defined, and the response of the existing structural members is accounted for. During the construction phase, the consultants visit the site to survey the retrofit work first hand. During their site visit, they determine if the construction is following what has been prescribed in the plans, and whether the retrofit as proposed and implemented is robust.

In addition to the reviews at the design level, two additional design reviews are conducted. A World Bank earthquake-engineering consultant reviews the general quality and direction of the project work while an earthquake engineering consultant to the IPCU, reviews many specific projects. The IPCU spends much of its time assuring the quality of both the designs and construction.

It is projected that by the end of calendar year 2009, over 700 structures will have been strengthened or reconstructed. As listed in Table 2 (ISMEP 2009), the bulk of the effort has been concentrated on schools and hospitals.

Table 2. Projected list of completed projects at the end of 2009

	Schools	Healthcare	Administration	Social services
Retrofitted/Reconstructed	662	34	12	18

Retrofit Case Study

The addition of shear walls (Figure 10 and Figure 11) is the most widespread retrofitting method for the Istanbul strengthening work. This technique is attractive because of its effectiveness, relative simplicity of construction, and cost effectiveness. The key reason for effectiveness is that the additional shear walls are designed to resist a large portion of the lateral seismic loads, which significantly reduces the demand on the existing frame members.

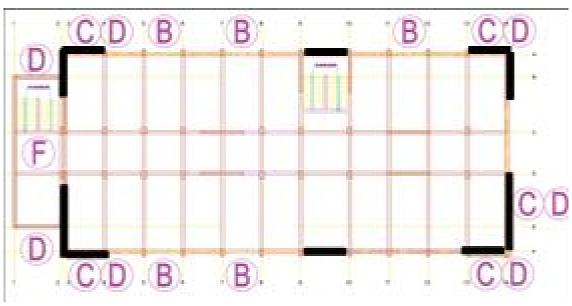

Figure 10. Retrofit with new concrete walls

Figure 11. Construction of exterior concrete walls for school retrofit

The IPCU independent consultants reviewed a number of proposed retrofits with new shear walls. To ensure proper design and construction, they have recommended that the final designs comply with the following:

- The walls must be designed and detailed to have adequate ductility.
- Connections between new and existing structural members should be properly designed.
- The existing members should be analyzed to ensure they could resist the imposed loads.
- Diaphragms, collectors, and diaphragm anchorage to the new walls should be evaluated.
- Connections between existing and new concrete components shall be checked.

Summary and Conclusions

- Nearly all the collapsed were constructed with very little seismic resistance, ductility or redundancy. URM bearing walls, non-ductile concrete moment frames, questionable load paths, lack of diaphragm, poor detailing, and non-desirable structural configurations all contributed to the observed damage.

- It is vital to identify these seismic hazards and to develop retrofit programs for hazardous structures. Cost-effective retrofit options are available for vulnerable structures.
- Istanbul provides an excellent example of cooperation between world and Turkish government agencies, local engineers, and world experts in mitigating earthquake hazards for essential buildings and for vulnerable structures.
- Given the high earthquake hazard present in many regions of the world and the large number of suspect buildings present in these areas, it is important to keep the lessons of recent devastating earthquakes in mind, use the Istanbul project as an example, and address these vulnerable structures.

References

American Society of Civil Engineers (ASCE), 2006. *ASCE/SEI 41: Seismic Retrofit of Existing Buildings*, Reston, VA, US,

Federal Emergency Management Agency (FEMA) 2000, *FEMA 356: Prestandard and Commentary for Seismic Rehabilitation of Buildings*, Washington DC.

Istanbul Project Coordination Unit (IPCU), 2007. *Guidelines for Seismic Retrofit of Schools and Hospital Facilities in Istanbul*,, Istanbul, Turkey.

Kazıım Göökhan ELGİİNN, Director ICPU, 2009, Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP)

Miyamoto, K., Gilani, A. and Wada, A,, 2008. Reconnaissance report of the 2008 Sichuan Earthquake, damage survey of buildings and retrofit options, *Proceedings of the 14th World conference on Earthquake Engineering*, Beijing, China.

National Information Service for Earthquake Engineering (NISEE) 2009. *The Earthquake Engineering Online Archive*, Pacific Earthquake Engineering Resource center, University of California, Berkeley, Berkeley CA.

Sezen, H., Elwood, K. Whittaker, A. Mosalam, K. Wallace, J. and Stanton, J. 1999. Structural Engineering Reconnaissance of the August 17, 1999 Earthquake: Kocaeli (Izmit), Turkey. *PEER Report No. 2000/09*. Pacific Earthquake Engineering Resource center, University of California, Berkeley CA.

Turkish Earthquake Code (TEC), 2007, *Specifications for Structures to be built in Earthquake Areas, and Appendix*, The Ministry of Public Works and Settlement, Turkey.

World Bank (WB), 2007. Marmara Earthquake Reconstruction Project, Ankara, Turkey.

Yanev, 2002. *Observations on Earthquake Risk and Engineering Practices in Istanbul, Turkey*, Report to the World Bank, Orinda, CA