RETROFIT STRATEGIES AND GUIDELINES FOR PUBLIC SCHOOLS AND HOSPITALS IN ISTANBUL, TURKEY

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Abstract

A task committee comprised of local structural engineers and earthquake engineering experts from abroad was formed to assess the seismic performance of public schools in under auspices of this group; a guideline has been developed better assess the existing conditions and develop retrofit options for school and hospital buildings in Istanbul. The project is financed by World Bank (WB). The Istanbul Project Coordination Unit was responsible for implementing the project and has developed a retrofit Guideline is based on provisions of the ASCE 41 and Turkish earthquake code and is purposed to address the seismic design requirements for hospital and school facilities in Istanbul and recommends effective retrofit measures. Many such buildings were constructed prior to adoption of seismic codes and use non-ductile concrete moment frames and unreinforced masonry walls to resist earthquake loading. Recent earthquakes have shown that this type of construction is particularly sensitive to earthquake damage and even complete collapse due to the inadequate design and construction practices. The engineer is charged with condition assessment, followed by analysis and determination of deficiencies. Both conventional and state-of-the-art retrofit measures have been implemented. It is hoped that the implementation of this project will drastically reduce the level of damage and loss of life in the public buildings during the next earthquake.

Introduction

The government of Turkey and the International Bank for Reconstruction and Development (IBRD) has entered into a loan agreement implementing the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). The goal is to improve the city of Istanbul's preparedness for a future earthquake. Seismic retrofit of school and hospital buildings vulnerable to earthquake damage is of great political and social importance in Turkey. The last two major earthquakes in the region have shown the vulnerability of these buildings in particular and of the built environment in general.

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As part of this effort Guidelines for seismic retrofit of schools and hospital facilities in Istanbul, (hereafter referred to as the Guidelines) has been developed. The aim of the proposed is to implement a procedure that leads to safeguarding Istanbul school and hospital buildings against a future earthquake in the area. The project scope is intended to protect as many buildings as possible, use cost-effective methodologies, produce on-schedule and high-quality construction, and ensure that the buildings meet their performance objectives. Fully implemented, the Guidelines describe retrofit methods that would significantly improve the seismic performance of school and hospital buildings in Istanbul. To remain cost-effective, a certain level of building damage is considered acceptable for school buildings, but Immediate Occupancy and Life Safety performance is highly likely. In this Guideline, supplements to Turkish Earthquake Code (herein referred to as TEC2007) are proposed for use specifically under the scope of ISMEP. These supplements are intended to increase confidence that collapse is prevented and damage is limited. The overall objectives are to minimize the retrofit cost, achieve acceptable earthquake performance, and to allow more buildings to be evaluated.

Motivation for the project

The 1999 magnitude 7.6 Izmit (Kocaeli) and magnitude 7.2 Duzce earthquakes caused extensive damage. Fatalities exceeded 18,000 while casualties exceeded 50,000, with a direct financial loss of over US $6 billion. High ground accelerations were recorded. Many vulnerable structures collapsed or were severely damaged during these earthquakes (and all other recent and strong Turkish earthquakes). Post-earthquake surveys (Elwood et al, 1999(indicate 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 1, soft story collapses occurred when the stiffness of the bottom floor was lower than that of upper floors and URM buildings or infill walls collapsed (NISEE 2011) , as shown in Figure 2.

Figure 1. Soft story collapse in the 1999 earthquakes

Figure 2. URM infill collapse

Figure 3 depicts a vulnerable building in Istanbul taken during a recent site visit and condition-assessment survey. For this building, the walls terminate above the first floor to allow for parking. This introduces a soft-story mechanism at this level and can lead to collapse in a future earthquake. Once such dangerous buildings are identified, it is important that steps be taken to address the vulnerabilities.

Many thousands of school, hospital, and government buildings in Istanbul use reinforced concrete moment frames. There are over a dozen sub-groups within the same design group. The main differences between the various subgroups are the layout of the frames, geometry of the structures, and presence of URM walls. The most common type (see Figure 4) 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 3. A vulnerable structure

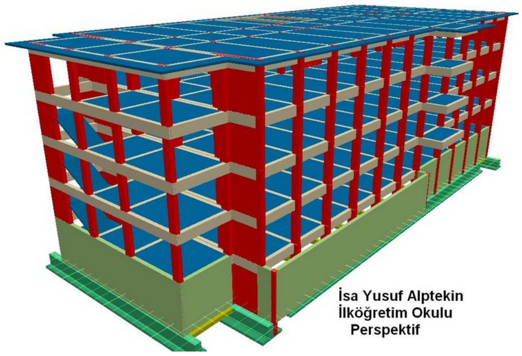

Figure 4. Schematics of a typical building

The historic city of Istanbul is Turkey's largest city. More than 20% or the country's population lives in Istanbul and the metropolitan area generates a large portion of Turkey's GDP. The city has grown substantially since the 1999 earthquakes. It is located in an active earthquake region. Its seismicity is comparable to California and Japan. Similarly to these areas, there is a high probability of a major earthquake occurring in the next 20 to 40 years. Without extensive building strengthening throughout the city, such an earthquake will result in high casualties and tremendous economic losses. These factors served as the background for the World Bank project described here.

ISMEP (Project) scope and organization

To address the earthquake vulnerability of public buildings in Istanbul and to prevent the devastation that could occur in the next major earthquake, the World Bank and the government of Turkey initiated the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). The first engineering assessment and preparation mission was conducted in October of 2002. The World Bank financed and supervised project (WB, 2007) is implemented through the Istanbul Special Provincial Administration (ISPA). The Istanbul Project Coordination Unit (IPCU), established under the ISPA (Kazzam, 2007), is responsible for implementing the project. The ISMEP project started on 1 February, 2006, and is expected to be completed by the end of 2014. The total World Bank loan amount is estimated at US $600 million (Kazzam, 2007). The primary goals of the project, as listed by IPCU (Kazzam, 2007), are summarized here. This paper is primarily focused on task 3 - the process for the 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 and Reconstruction of Public Buildings

Task organization

In order 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 extended background in 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.

<u>Rehabilitation Guidelines</u>

The objectives of this project are to identify, evaluate, and 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) with input from ASCE 41 (2006) and other relevant publications from around the world. While the Turkish code is written for new construction, the Guidelines are intended for retrofit work. In order to ensure that the project would encompass as many structures as possible, the Guidelines are less stringent than the current Turkish code. Certain levels of damage are deemed acceptable in the provisions. The key provisions of the Guidelines are as follows:

- Condition assessment. Data are gathered in sufficient detail to identify structural and nonstructural 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, such as 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 deterministic basis.
- Analytical procedures. Acceptable procedures, ranging from simplified static to nonlinear 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. Innovative, but generally accepted methodologies are encouraged.

The Guidelines strenuously attempt to address and correct the weaknesses of recent and current general Turkish earthquake engineering and construction practices while incorporating state-of-the art practices from around the world, and 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 systemic issues, such as engineering education and licensing. Many of the buildings that have already been strengthened were constructed relatively recently.

<u>Key differences between the guidelines and TEC2007</u>

The Guidelines has been developed to assist structural engineers in seismic retrofit of vulnerable school and hospital buildings in Istanbul, Turkey. TEC2007 primarily addresses new construction. Similar to other building codes worldwide, TEC2007 is prescriptive and is intended to provide life safety. By contrast, the Guidelines heavily rely on performance-based engineering. The Guidelines include eight (8) major modifications to TEC2007. These items are elucidated below.

- In the Guidelines, the latest database of geotechnical knowledge is used to prepare seismic hazard.
- TEC2007 requires that the computation of seismic mass include 60% of the live load acting on the structure. In the Guidelines, the inertial mass from live load is reduced to 30%.
- The Guidelines only addresses concrete structures. Hence only concrete infill walls are considered with their corresponding r factor from Table 7.4 of TEC2207.
- The Guidelines provides a comprehensive detailing package for seismic retrofit in its appendix. The Guidelines also requires that the new interior walls be placed with an offset with respect to the existing building frames to avoid brittle and premature failures.
- Compared to TEC2007, the Guidelines allows a 10% higher limit for the percentage of primary beams and columns in a damage zone and meeting the performance target.
- The Guidelines defines an rs factor of 3.0 for foundations. TEC2007 does not specify a factor
- The Guidelines retains the drift requirements of TEC2007 and in addition, requires that the existing concrete columns be checked for deformation compatibility.
- The Guidelines provides a detailed discussion on the rs values of TEC2007, but instead uses m factors for demand to capacity ratio computations

<u>Specified performance levels</u>

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 limits as shown in Figure 5. 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. Such performance levels are expected from the rehabilitated (strengthened) public buildings in Istanbul.

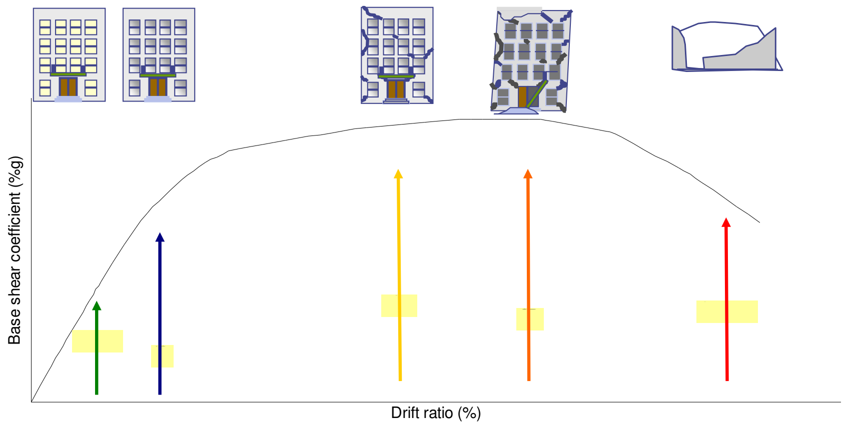

Figure 5. Performance Levels

Retrofitted buildings would satisfy the LS performance level if both of the following conditions were met.

- Not greater than 40 % of the primary beams should be in the "Severe Damage Zone" for any direction of earthquake loading. If at least 75% of the total base shear force for any direction of loading can be carried by shear walls, the performance of the beams can be ignored.
- The ratio of the sum shear force carried by the columns and shear walls in the "Severe Damage Zone" to the total shear force at any storey for any direction of loading should be less than or equal to 0.4 for the top storey, and 0.2 elsewhere.

Retrofitted buildings would satisfy the IO performance level if both of the following conditions were met.

- Not greater than 20 % of the primary beams should be in the "Severe Damage Zone" for any direction of earthquake loading. If at least 75% of the total base shear force for any direction of loading can be carried by shear walls, the performance of the beams can be ignored.
- All the columns and shear walls should be in "minimal damage zone" for any direction of earthquake loading.

<u>Retrofit schemes for vulnerable concrete buildings</u>

Key deficiencies and retrofit procedure for reinforced concrete structures and their main components are summarized in Table 1.

Table 1. Seismic deficiencies and retrofits for RC buildings

Seismic deficiency	Retrofit options
Inadequate lateral strength	Add new RC walls
	Add new braced frames
	Shotcrete members
	Reduce seismic mass
	Seismic isolation
	Supplementary damping
Inadequate lateral stiffness	Add new RC walls
	Add new braced frames
	Increase size of beams and columns
	Supplementary friction damping
Soft or weak story	Add strength or stiffness to story
Torsional irregularity	Add balancing walls, braced frames, or moment frames
Inadequate collector	Add steel or concrete beams

Weak beam-column joints	Jacket or prestress joints
weak column- strong beam	Jacket columns, reduce beam strength
Inadequate shear strength	Fiber composite wrap
Lack Confinement or short splices	Fiber composite wrap Concrete/steel jacket
Inadequate shear capacity of floor diaphragms	R/C topping slab overlay
	RP overlays

<u>Implementation</u>

To successfully implement the project and to transfer as much technology 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. They also often participate directly in the engineering designs. 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. In 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 enough.

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 further many specific projects. The IPCU spends much of its time assuring the quality of both the designs and the construction. This redundant system for quality assurance is a primary factor in the success of this complex and large project.

It is projected that by the end of calendar year 2009, over 700 structures will have been strengthened or reconstructed (completely rebuilt). As listed in Table 2 (Kazzam, 2007), the bulk of the effort has been concentrated on schools and hospitals. These type of high-occupancy and essential facilities have been vulnerable in the past and their poor performance has had tragic consequences. As such, they rightfully belong to the top echelon of the retrofit program. It is also noteworthy that roughly seven school buildings, for example, can be strengthened for every single building that is rebuilt completely.

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

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

<u>Retrofit case study</u>

The addition of shear walls (schematics shown in Figure 6 and construction photograph for a school building is shown in Figure 7) 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. This technique has been widely used to retrofit a significant number of public schools and hospitals in Istanbul, as well as in California, Japan, New Zealand, etc.

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

- 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.

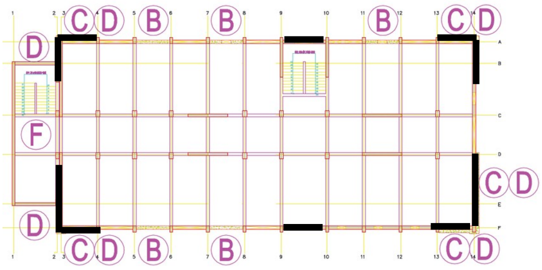

Figure 6. Example of retrofit with new concrete walls

Figure 7. Construction of exterior concrete walls for a school retrofit

Application of the Istanbul Project to Romania and Europe

Europe, especially Italy and South Eastern Europe, including Romania is not immune to powerful and destructive earthquakes. As shown in Figure 1 (ESMC 2010), besides Italy and Turkey, large events have occurred in Greece, Macedonia, Bulgaria, Romania, and elsewhere. The EU (ESMC 2010) classifies both Romania and Bulgaria (see Figure 2) as being very vulnerable to earthquakes and the resulting damage. Unfortunately, even far wealthier countries, such as Italy, have done little to nothing to alleviate the problem, as compared to countries such as California, Japan and New Zealand. That was spectacularly demonstrated in the recent L'Aquila, Italy earthquake.

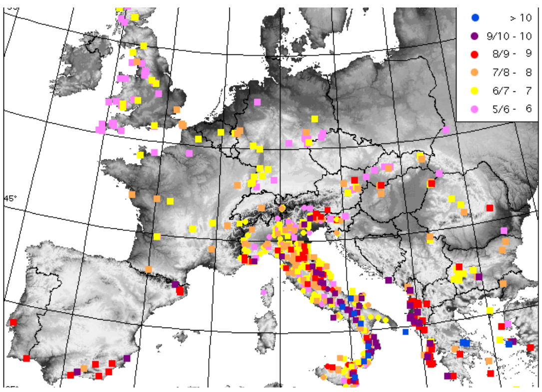

Figure 1. Historic earthquake intensities

Figure 2. Most seismically vulnerable new EU members

Romania is one of Europe's most seismically active regions mainly due to activity from within the Vrancea region. Romania has experienced past significant earthquakes. For example:

- It is believed that the 1802 earthquake of 1802 may have reached M=7.9 (?) and resulted in 3 fatalities and damage to the churches and houses in the region..
- The 1940 magnitude (M) 7.9 Vrancea, Earthquake resulted in over 1000 fatalities and 4000 injuries, mostly in Moldova.
- The 1977 Vrancea (Bucharest) Earthquake was magnitude 7.4 event. It resulted in over 1500 fatalities, 11000 injuries, and damage to over 35000 buildings. The total cost of this event was over $US2 billion. Many older buildings in Bucharest collapsed.
- The 1986 Magnitude 7.1 Vrancea, Earthquake, killed 2 people, injured 500. As a result, over 50000 buildings were damaged. This event was felt as far as Italy and Greece.
- The 1990 Magnitude 6.9 Vrancea, Earthquake also affected this area.

A repeat of one of these larger earthquakes today could result in catastrophic losses for buildings that are not engineered properly. Hence, it is important and time-critical to address the existing vulnerabilities and to undertake comprehensive programs to implement robust retrofits to protect life and infrastructure in Bulgaria's earthquake regions.

Conclusions

The Istanbul retrofit project developed under the auspices of the World Bank and ISMEP is intended to be used to mitigate earthquake hazard for schools and hospitals in Istanbul

- 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.
- It is expected that when the project is fully implemented, it will significantly reduce damage from seismic hazard for the Istanbul schools and hospitals.
- The seismic guideline is primarily based on TEC2007. However, recent research data and knowledge from ASCE 41 is also implemented. The Guidelines can be used as an effective tool in assessing existing conditions, identifying vulnerable components, and devising cost-effective retrofits. The Guidelines used performance based engineering and hence can lead to a more realistic assessment.
- Given the high earthquake hazard present in southeastern Europe and the large number of suspect buildings present in these areas, it is important to keep the lessons of recent devastating earthquakes in mind and use the Istanbul project as an example and address the vulnerable structures in this part of Europe.

References

IPCU (2007) Guidelines for seismic retrofit of schools and hospital facilities in Istanbul, Istanbul project coordination unit (IPCU), Istanbul, Turkey.

ASCE 41 (2006) Seismic retrofit of existing buildings, American society of Civil Engineers, VA, US.

TEC2007 (2007) Turkish Earthquake Code, Specifications for Structures to be Built in Earthquake Areas, and appendix, The Ministry of Public Works and Settlement.

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

NISEE (2011) National Information Service for Earthquake Engineering, The Earthquake Engineering Online Archive, PEER center, University of California, Berkeley.

World bank, Marmara Earthquake reconstruction project, Ankara, Turkey, 2007.

Kazıım Göökhan ELGİİNN (2007), Director ICPU, Istanbul Seismic Risk Mitigation and Emergency Preparedness Project

EMSC (2010) European-Mediterranean Seismological Centre, http://emidius.mi.ingv.it/EMID/presentation.html, last accessed on March 2010.

Author Biography

Kit Miyamoto: President and CEO of Miyamoto International. Dr. Miyamoto is a registered structural engineer in many states in the US and has been in charge of seismic design and retrofit of a significant number of buildings. Dr Miyamoto has spent the past 4 years working on development and implementation of the Istanbul retrofit project including site visits and project scope development and implementation.

Amir Gilani: Senior Associates at Miyamoto International. Dr. Gilani is a registered structural engineer in California and extensive experience in seismic analysis and retrofit of structures. Dr Gilani has been instrumental in development of the retrofit guidelines and review of implementation documents (including retrofit plans) in the past several years.