Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1517

EVALUATION OF SEISMIC SAFETY OF EXISTING REINFORCED CONCRETE BUILDINGS IN WESTERN REGION OF TURKEY

Kasim A. Korkmaz[1], Ayhan Irfanoglu[2], Ali H. Kayhan[3], and Aykut Deniz[4]

ABSTRACT

Turkey is one of the most earthquake-prone countries. In 1999, two major earthquakes hit the northwestern region of Turkey and damaged or destroyed many buildings. The damaged building types are typical and can be encountered all over the country. Western region of Turkey is also known to be an active seismic zone with its complex tectonic setting. Accordingly, seismic safety of the buildings in this region also is of concern. In the current study, seismic safety of existing reinforced concrete buildings in western region of Turkey is investigated in detail through various approaches. Probabilistic seismic hazard estimates are used to establish the seismic hazard level in the region and compared with currently enforced seismic zonation maps. Nonlinear dynamic analyses are made to estimate the seismic vulnerability of various types of representative buildings. Results indicate that the majority of the existing reinforced concrete buildings in western region of Turkey are vulnerable to damage during expected future earthquakes.

Introduction

Heavy destruction caused by recent earthquakes in Turkey has increased interest in seismic hazard and risk assessment of urban areas in Turkey (Schneider and Schauer 2005). The studies about western Turkey concentrated on Izmir (Fig. 1). Following the RADIUS investigation in 1997, an earthquake master plan for Izmir was published by the Metropolitan Municipality of Izmir (MMI 2000). Various researchers have reported that the seismic risk exposure of Izmir is very high (Erdik et al. 2004; Emre et al. 2005; Ilhan et al. 2004).

Seismic Setting of Western Turkey

Western Turkey (Anatolia) is a very active seismic region. Earthquakes in the Aegean Graben System and the Aegean Trench (Akinci et al. 2000) dominate the seismicity of the region. Both historic and instrumental records indicate that large earthquakes occur frequently. Fig. 2 (Emre et al. 2005) shows the locations of the major earthquakes occurred in the region before 1900 and between 1900 and 2005. In modern times, in 1944 a magnitude M_S=6.8 earthquake occurred near Gulf of Edremit, 125 km north of Izmir. One of the most severe earthquakes in the region happened in 1953 and had a magnitude of M_S=7.2. In 1974, during an earthquake of magnitude

---

[1] Suleyman Demirel University, Civil Engineering Department, Isparta, Turkey
[2] School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907
[3] Pamukkale University, Civil Engineering Department, Denizli, Turkey
[4] Teknolojik Mühendislik Hizmetleri, Perge Blvd., 115 2/5, Antalya, Turkey

M_S=5.2 at an epicentral distance of approximately 10 km (NNE), 47 apartment buildings were damaged and 2 people died in Izmir. In 1992, an earthquake with magnitude of M_S=6.0 and 50 km SSW of Izmir caused damage to 100 buildings (RADIUS 1997). In 2003, an M_w=5.8 earthquake occurred 50 km southwest of Izmir but caused no damage. In 2005, a sequence of three earthquakes with M_S=5.5, 5.9, and 5.9 occurred in the same region as the 2003 event.
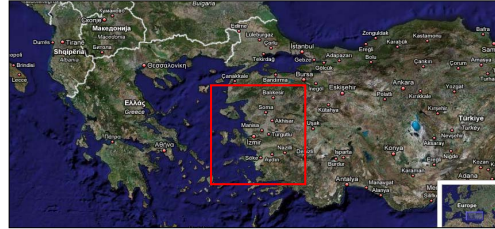

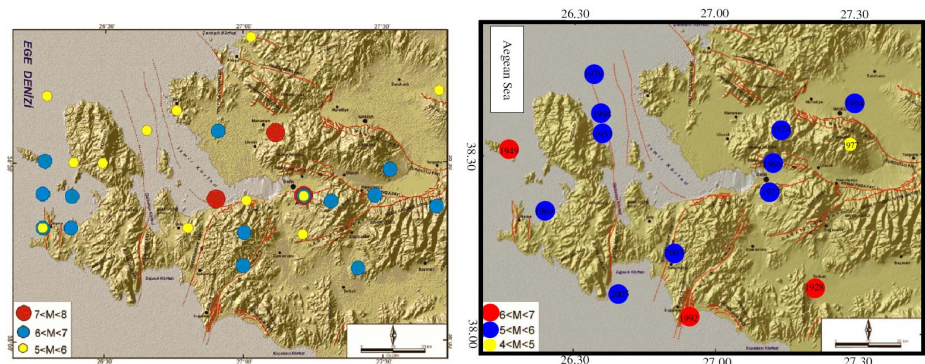Figure 1. Western Turkey (Google Earth 2008). Izmir is at the center of the red box.

Figure 2. Significant earthquakes in western Anatolia, before 1900 (left) and during 1900-2005. (modified from Emre et al. 2005)

We studied the seismic environment around Izmir, the largest city in western Anatolia and the third largest city in Turkey, in Korkmaz et al. (2009a). We used a comprehensive earthquake database covering earthquakes in 1900-2005 within 250 km of Izmir (27.15˚ E long and 38.40˚ N lat) to develop a probabilistic seismic hazard model for the region. The database events were distributed over 10 main and 4 background seismic source zones according to the location of their epicenters. We carried out regression analyses to obtain the seismicity parameters for each seismic source zone. We considered peak ground acceleration (PGA) as the earthquake intensity parameter and used the attenuation relationships of Gulkan and Kalkan (2002) and Boore et al. (1997) for rock sites to estimate the PGA for events generated by each seismic source zone. We used a logic tree approach to account for the consequences of the uncertainties in the seismicity parameters of the seismic source zones. The outcome is quantitative measure of likelihood, in terms of probability of exceedance, for any given PGA level, or the PGA levels for a given probability of exceedance, i.e. spatially distributed consistent hazard level. One such distribution is given in Fig. 3, namely, the seismic hazard map in terms of PGA on rock sites and corresponding to a return period of 475 (equivalent of 10% exceedance probability in 50 years).

The site response is different for rock, soil and soft soil sites under the same earthquake excitation. One may use amplification factors to approximate the differences. One should note that the differences depend, in actuality, on the frequency of the ground motion. Often, however, frequency-independent factors are used. For example, for soil sites an amplification factor of

1.2~1.3 and for soft soil sites an amplification factor of ~1.5, both compared to rock sites, could be used (see, Gulkan and Kalkan 2002; Boore et al. 1997). For example, the 0.34g PGA estimate with a return period of 475 years for rock sites metropolitan Izmir (see Fig. 3) becomes 0.44g for soil sites and 0.51g for soft soil sites. It should be noted that these values are approximately equal to the design acceleration values given in the current seismic hazard zone map (MPWS 1996) used in the Turkish seismic design code (MPWS 2007). Hence, we consider the current code-based seismic hazard levels for the metropolitan city of Izmir, and the region, to be accurate in an overall sense.
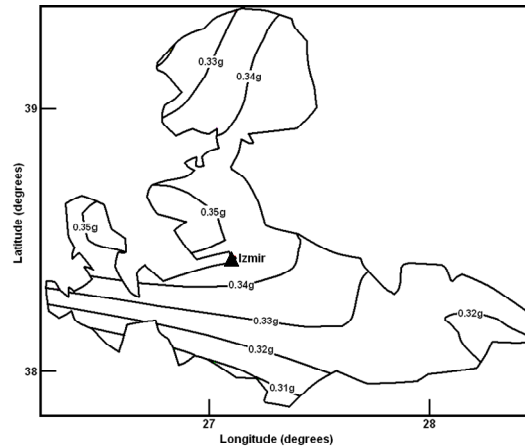

Figure 3. Map for seismic hazard (return period of 475 years) in terms of PGA (g) on rock site.

Figure 4. Typical RC building in Turkey. From Izmir, western Turkey.

Seismic Vulnerability Assessment of Typical Buildings in Western Turkey

There are no heterogeneities in the design and construction of low to mid-rise buildings in western Turkey. In Fig. 4, two reinforced concrete (RC) buildings under construction in Izmir are shown. This kind of construction, i.e. RC structure with hollow clay tile infill walls is ubiquitous in Turkey, and dominates the building inventory. Accordingly, we have decided to study the seismic risk in RC buildings in western Turkey. Majority of the existing buildings in western Turkey were designed according to 1975 Turkish seismic design code (MRR 1975). To represent the building inventory, five typical reinforced concrete buildings were designed per the 1975 code, modeled and assessed for seismic vulnerability. The sample structures represent typical existing RC hospital, school, public and residential buildings in western Turkey.

Review of Representative Buildings
The following five buildings are chosen to represent the typical building types that dominate the building inventory in western Turkey: a 5-story public building, a 6-story hospital building, a 4-story school building, a 6-story residential building, and a 10-story residential building. They were designed per the 1975 Turkish seismic design code. The 1975 Turkish seismic design code included detailed requirements for ductile design and construction of RC structures, and provided explicit definitions for modern ductile design concepts such as confinement zones and minimum longitudinal transverse reinforcement requirements.

As a representative public building, a 5-story reinforced concrete moment-frame building which is a typical model applied all over Turkey including Marmara region, was selected. Plan and elevation views of the example public building are given in Fig. 5. All but four columns of the structure are oriented to have their strong bending axes in the transverse (i.e. shorter) direction of the plan. The ground story is 3.4m high; the rest of the stories are 3.1m high each. 26 columns are grouped in seven classes regarding dimension and reinforcement. Column dimensions are either 80x30cm or 100x35cm. Perimeter beams are 60x35cm in cross-section; interior beams are 60x30cm. Layout, size, and reinforcing details for the beams and columns are repeated at each story. The longitudinal reinforcement ratio in the columns varies between 1% and 1.4%.
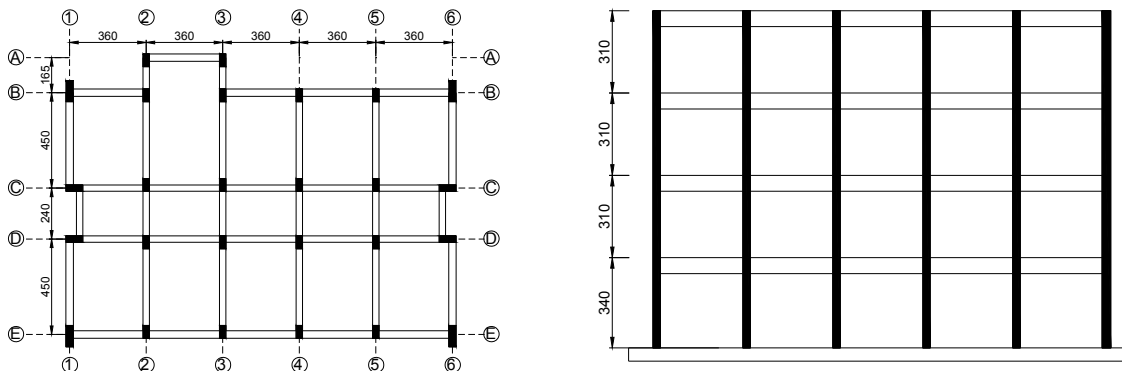

Figure 5. Public building: plan (left) and elevation (right) views

For a typical hospital building, a 6-story reinforced concrete moment-frame building was selected. Fig. 6 shows the plan and elevation views of the hospital building model. Interior columns are 70x25cm and perimeter columns are 40x30cm in cross-section. Longitudinal reinforcement ratio is 1.3% in the interior columns and 1% in the external columns. The story height is 3.2m throughout the building.

For a school building, a 4-story reinforced concrete building, a common type widely applied in Turkey, was selected. Fig. 7 shows the plan and elevation views of the structure. The dual-system structure has six shear walls placed along the transverse (shorter) direction of the floor plan. Thickness of the shear walls is 30cm. The shear walls are 210cm, 600cm, and 720cm in length. There is no irregularity in plan. The ground story is 4.2m high and the rest of the stories are 3.4m high. Interior columns are 60x50cm and the perimeter columns are 50x40cm in cross-section. Beams are 40x80cm in cross-section in the first story; for the rest of the structure, beam cross-sections are 30x80cm. Beams supporting the stairs are 100x40cm. Longitudinal reinforcement ratio is 1.5-2% for the first story and 1% in the upper stories.

To represent residential buildings, a 6-story and a 10-story building are chosen. In Fig. 8, plan and section views are given for the 6-story building, named Residential-1. Plan and elevation views for the 10-story building, named Residential-2, are given in Fig. 9. In both buildings the story height is 2.7m. Columns have a cross-section of 25x 55, 60, 65, 70, 80, 85, 90 or 100cm. The longitudinal reinforcement ratio varies between 1% and 1.2%.
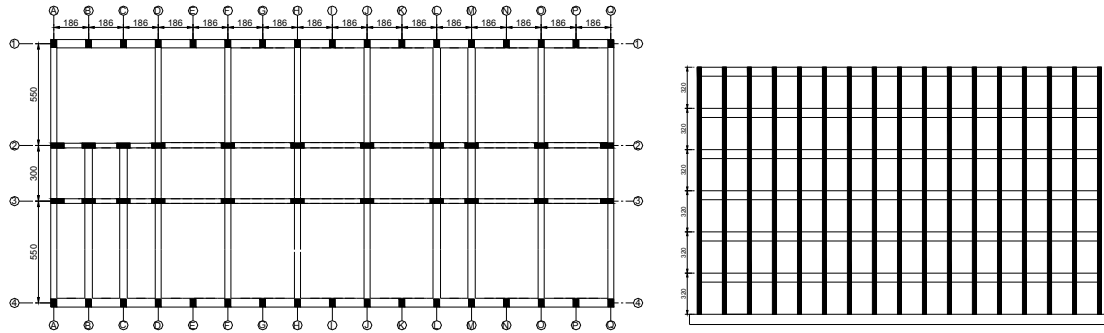

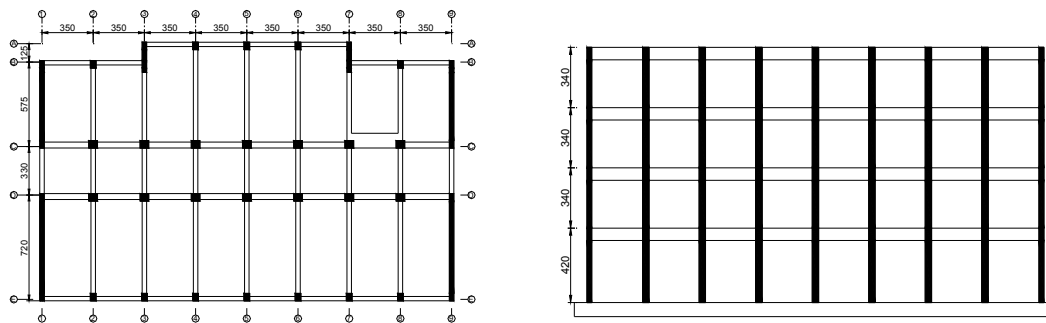Figure 6. Hospital building: plan (left) and elevation (right) views

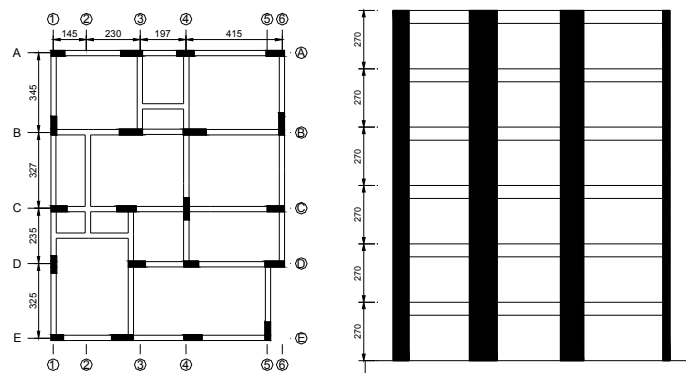Figure 7. School building: plan (left) and elevation (right) views

Figure 8. 6-story residential building (residential-1): plan (left) and elevation (right) views

For reinforcement, S220 (f_y=220 MPa) steel was used. Concrete design strength f_c' was taken as 12 MPa (approximately 2/3 of the code required level) based on field data obtained from existing buildings. According to 1975 and 1997 Turkish seismic design codes, the volumetric ratio of transverse reinforcement in column confinement regions should be taken to be 1% and in column middle regions, the volumetric ratio of transverse reinforcement should be reduced to half of that

for the column confinement regions. However, in the applications especially before 1997, field observations indicate that, typically, the column confinement region details were ignored during construction and the column middle region transverse reinforcement details were used through the height of the columns. To obtain realistic capacity estimates, in all of the representative buildings considered in this study, the transverse reinforcement steel in the columns was taken to be 8mm-dia hoops with 20cm spacing, i.e. typical column middle region reinforcing detail per the code, throughout the height of the columns.
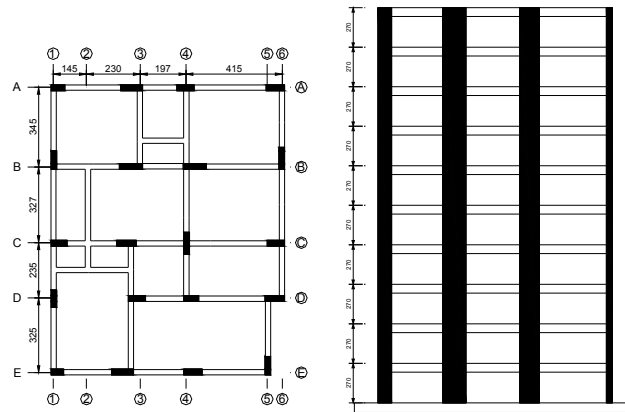

Figure 9. 10-story residential building (residential-2): plan (left) and elevation (right) views

Earthquake Performance Estimation

Expected performance of existing typical reinforced concrete buildings in Izmir during possible strong earthquakes in the future are estimated using several approaches. In Korkmaz et al. (2009b), we describe all of the approaches and detailed results. For sake of brevity, only two approaches will be described in here. First one is a simple vulnerability ranking method, called the Hassan index approach (Hassan and Sozen 1997). It is used to compare the considered buildings with those reinforced concrete structures affected by the 1999 earthquakes in Turkey (Donmez and Pujol 2005). Based on this simple comparison, general performance estimates could be given for majority of buildings in western Turkey. Second approach is the nonlinear dynamic analysis. Two different site soil classes, known as Soil Z2 which is similar to class B soil of FEMA356 (FEMA 2000) and Soil Z3 which is similar to class C soil of FEMA356 are considered in the nonlinear analyses. For the dynamic analyses artificial ground motion data ("design-basis earthquakes") compatible with the design response spectra of the current (2007) Turkish seismic design code (MPWS 2007) are generated and used.

Hassan Index Based Vulnerability Ranking
Hassan and Sozen (1997) have proposed a measure called the priority index to rank reinforced concrete buildings with moment-frame and/or shearwall structural systems in seismic vulnerability. Since the 1992 Erzincan, Turkey earthquake, performance of several hundred buildings affected by strong earthquakes have been reviewed using the priority index (Ozcebe et al. 2004; Donmez and Pujol 2005; Gur et al. 2009). The priority index for a building is computed as the ratio of "effective" column and wall cross sectional areas to the total building floor area of the building:

$$\text{Priority Index} = \text{Column Index} + \text{Wall Index} \qquad (1)$$

$$\text{Column Index} = \frac{1}{2}\frac{A_{column}}{\sum A_{floor}} \qquad\qquad \text{Wall Index} = \frac{A_{RCwalls} + \frac{1}{10}A_{masonry\ walls}}{\sum A_{floor}} \qquad (2)$$

where A_{column} is the cross-sectional area of all columns at base level, $A_{RCwalls}$ is the cross-sectional area of reinforced concrete walls at base level, $A_{masonrywalls}$ is the cross-sectional area of masonry walls filling entire frame bays, and ΣA_{floor} is the summation of floor areas above the base of the structure (Hassan and Sozen 1997). The wall index is calculated considering the axes of the reinforced concrete walls and the infill walls for each principal plan direction. The lower of the two priority indices for a building is chosen to represent the building.
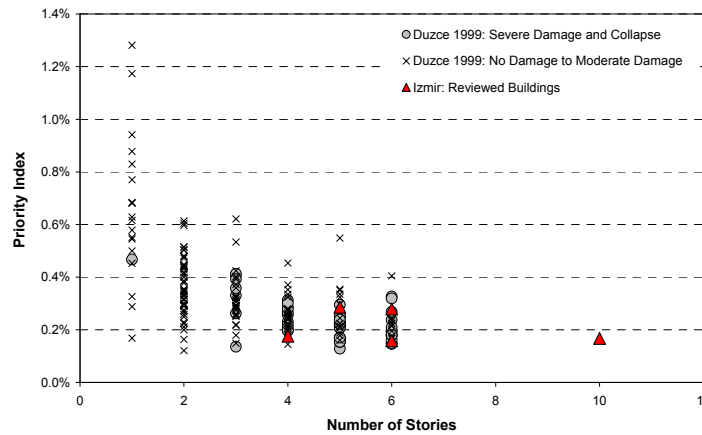

Figure 10. Comparison of the priority index (Hassan and Sozen 1997) values for the reviewed buildings in Izmir with those for the buildings investigated in Duzce after the 1999 earthquakes (modified from Donmez and Pujol 2005)

In Figure 10, priority index values for the buildings reviewed for this study are compared with those for the buildings in Duzce inspected after the 1999 earthquakes (Donmez and Pujol 2005). As the graph in Figure 10 indicates, the priority index values for the subject buildings are not higher than for those in Duzce. The comparison indicates that if these reviewed buildings were to experience ground motions similar to those in 1999 in Duzce, heavy damage and collapse could be expected. It should be noted that there is no scaling for earthquake ground motion parameters in the priority index and the damage states in Figure 10 could be carried over to western Turkey if similar ground motions would occur.

Nonlinear Behavior
Before carrying out nonlinear dynamic analyses, the nonlinear responses of the structures were studied through nonlinear static analyses, also known as pushover analyses. The buildings were loaded with live and dead loads for gravity loading, and then laterally loaded. For each building, the total weight of the building, total height, fundamental translational mode period, roof displacement, and lateral load capacity were recorded. Vertical and lateral loads were combined based on the rules of the 2007 Turkish design code (MPWS 2007), and capacity curves including the load combinations were obtained for each building. The equivalent static lateral load pattern

defined as an inverted triangular load, corresponding to generic fundamental mode response, per the 2007 Turkish design code, was used. The load was increased monotonically and the structure was analyzed at each load level. P–delta effects were included in the analyses. The SAP2000NL structural analysis program (Wilson and Habibullah 1998) was used in the pushover analyses. Nonlinear bending and axial deformations were assumed to occur at certain plastic regions, whereas the other portions of the building were assumed to remain elastic. Plastic hinges were assumed to occur under pure bending moment in beams and combined bending moment and axial force in columns. Shear force and torsional moment capacities of beams and columns were also checked. Moment–plastic rotation relationships of column and beam sections were assumed as rigid-plastic. Cracked section stiffness values for columns and beams were taken as proposed in FEMA 356 (FEMA 2000). The force-displacement results for the weak direction of the buildings are given in Figure 11.
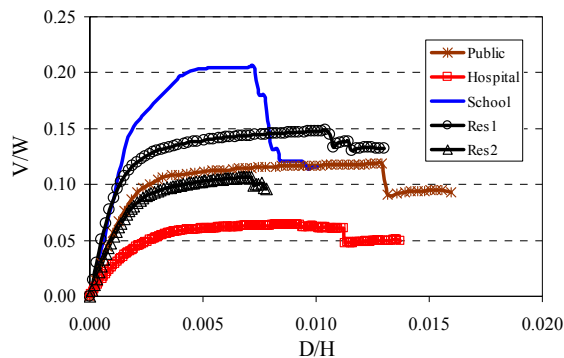

Figure 11. Force-displacement curves obtained through push-over nonlinear static analyses

Nonlinear Dynamic Analysis
Nonlinear dynamic analyses of the described representative buildings were made to incorporate the effects of variations in the dynamic characteristics of the structures in response estimation directly. The same structural models described for the pushover analyses were used in the dynamic analyses.

Unfortunately, very limited number of actual ground motion records exists from earthquakes in Izmir region. In this study, dynamic analyses of the buildings were carried out using artificially generated earthquake ground motions. The records were generated taking the design spectrum as the basis. For each building on each site soil condition, 30 different artificially generated ground motion data were used. To generate the input ground motions, RSCTH software (ESL 2004) was used. The generated ground motions have different strong motion durations, frequency contents and peak ground accelerations. Please see Korkmaz et al. (2009b) for details.

Review of the Results from the Analyses

The results from the simple, Hassan-index based vulnerability ranking approach when compared with data from 1999 Duzce earthquake indicates that; the priority index values for buildings in Izmir are not higher than for those in Duzce and Izmir has an important earthquake risk for a possible future earthquake.

According to the nonlinear dynamic analyses, displacement demands for soil Z3 is more critical

then soil Z2. For each building, mean values of the displacements for 30 different earthquake data increase when the site soil is changed from class Z2 to class Z3. In both soil types, the mean displacement demand for the hospital building is higher than those for the other buildings. For the public building, displacement demands are 0.8% (=14cm) and 1.0% (=17cm) for soil Z2 and soil Z3 respectively. For the hospital building, mean values of displacement demands are 1.3% (=26cm) and 2.0% (=39cm) for Soil Z2 and Soil Z3 respectively. For the school building, displacement demands are 1.4% (=20cm) and 2.2% (=32cm) for Soil Z2 and Soil Z3 respectively. For the 6-story residential building, displacement demands are around 0.8%~0.9% (=14cm) for each soil class. For the 10-story residential building, displacement demands are 0.6% (=17cm) and 0.7% (=19cm) for Soil Z2 and Soil Z3 respectively.

Conclusion

Using different assessment estimation approaches, the expected earthquake performance of typical reinforced concrete buildings in western Turkey has been carried out. The results indicate that many of the existing reinforced concrete buildings in the area face high risk of poor performance, including heavy damage or collapse, during possible strong earthquakes.

References

Akinci, A., Eyidogan, H., Gokturkler, G., Akyol, N. and Ankaya, O. (2000). Investigation of the seismic activity and seismic hazard of Izmir city and its vicinity. Proc. Eq. Risk Asses. West Anatolia Symp..

Boore, D.M., Joyner, W.B. and Fumal, T.E. (1997). Equations for estimating horizontal response spectra and peak acceleration from Western North American earthquakes: A summary of recent work, Seismological Research Letters, Vol. 68, No. 1, pp. 128-153.

Donmez C and Pujol S (2005). Spatial distribution of damage caused by the 1999 earthquakes in Turkey. Earthquake Spectra 21 (1), 53–69

Emre, O., Ozalp, S., Dogan, A., Ozaksoy, V., Yildirim, C. and Goktas, F. (2005). *Active faults in the vicinity of Izmir and their earthquake potentials* [in Turkish], Report No: 10754, Geological Studies Department, General Directorate of Mineral Research and Exploration, Ankara, Turkey.

Erdik, M., Demircioglu, M., Sesetyan, K., Durukal, E. and Siyahi, B. (2004). Earthquake hazard in Marmara Region, Turkey, Soil Dynamics and Earthquake Engineering, 24, pp. 605-631.

ESL Software, 2004. RSCTH: software program for generating artificial earthquake data. http://civil.eng.buffalo.edu/engseislab/products.htm, Eng. Seism. Lab., SUNY Buffalo, New York.

Federal Emergency Management Agency [FEMA], (2000). *FEMA 356: Prestandard and commentary for the seismic rehabilitation of buildings*. NEHRP Guidelines, Washington D.C.

Google Earth, (2008). http://maps.google.com/maps?ll=38.442537,27.095737&z=10&hl=en&t=h.

Gulkan, P. and Kalkan, E. (2002). Attenuation modeling of recent earthquakes in Turkey, Journal of Seismology, v. 6, pp. 397-409.

Gur T, Pay AC, Ramirez JA, Sozen MA, Johnson AM, Irfanoglu A, and Bobet A (2009). Performance of school buildings in Turkey during the 1999 Duzce and 2003 Bingol earthquakes. Earthquake Spectra, 25:2, 239-256.

Hassan AF and Sozen MA (1997). Seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquakes. American Concrete Institute Structural J 94:1, 31-39.

Korkmaz KA, Deniz A, and Irfanoglu A (2009a). Probabilistic seismic hazard assessment for Izmir, Turkey. Pure and Applied Geophysics, *online available*.

Korkmaz, K.A., Irfanoglu A., and Kayhan A.H. (2009b). Seismic risk assessment of buildings in Izmir, Turkey, *Natural Hazards, online available*.

Metropolitan Municipality of Izmir [MMI] (2000). *Izmir Earthquake Master Plan*. http://www.izmir.bel.tr/izmirdeprem/izmirrapor.htm, MMI, Izmir, Turkey.

Ministry of Public Works and Settlement [MPWS] (1996). Seismic hazard map of Turkey, Ankara, Turkey.

Ministry of Public Works and Settlement [MPWS] (2007). *Specifications for structures to be built in disaster areas, the 2007 Earthquake Code*. In Turkish. Ankara, Turkey.

Ministry of Reconstruction and Resettlement [MRR] (1975). *Specifications for structures to be built in disaster areas, the 1975 Seismic Design Code*. English translation. Earth. Res. Ins., Ankara, Turkey.

Ozcebe G, Ramirez J, Wasti ST, and Yakut A (2004). *1 May 2003 Bingöl earthquake engineering report*. Rep. no. 2004/1, TÜBİTAK SERU Structural Engineering Research Unit, Ankara, Turkey.

RADIUS (1997). *Risk assessment tools for diagnosis of urban areas against seismic disaster Izmir earthquake master program*, Bogazici University Kandilli Observatory, Istanbul, Turkey.

Schneider, P. and Schauer, B. (2005). An earthquake risk assessment tool for Turkey, HAZTURK Strategies for earthquake loss estimation program for Turkey, Istanbul, Turkey.

Wilson E and Habibullah A (1998). *SAP2000NL integrated finite element analysis and design of structures basic analysis*. Reference Manual, Computers and Structures, Berkeley, CA.