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The need for upgrading the seismic performance objectives

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Abstract. The economic consequences of large earthquakes require a revolutionary change in the seismic performance objective of residential and commercial buildings. The majority of total construction costs consist of non-structural and architectural costs. Therefore, the aim of this research is to upgrade current Life Safety performance objectives and to offset adverse effects on country's economy after an occurrence of large earthquakes. However, such a proposal cannot easily prove the feasibility of cost-benefit analysis in structural design. In this paper, six generic reinforced concrete frames and dual system structures designed based on Turkish Seismic Code were used in cost analysis. The study reveals that load bearing structural systems with Immediate Occupancy performance level in seismic zones can be achieved with negligible costs.

Keywords: seismic codes; performance based seismic design; building stock; cost-benefit

1. Introduction

In 1910, the earliest quantitative seismic design procedure was developed by an Italian government committee (Priestley *et al*. 2007), where for the first time, earthquake forces on structures as a percentage of their weight was applied. The method was used in the first formal code for seismic design in Japan, after the 1923 Great Kanto earthquake. In the USA, seismic design became mandatory only after the 1933 Long Beach earthquake. This traditional seismic structural design was based primarily on forces (Priestley 2000). It is accepted that structural damages due to earthquakes are essentially controlled by strength of the design structure. Existing codes for the seismic design of new buildings are prescriptive in nature and are intended principally to achieve specific performance, these are, avoidance of collapse and protection of life safety (Whittaker and Soong 2003). The philosophy behind these prescriptive provisions is to prevent structural and non-structural elements of buildings from any damage in low intensity earthquakes; to limit the damage in structural and non-structural elements to repairable levels in medium-intensity earthquakes, and to prevent the overall or partial building collapse in high-intensity earthquake areas in order to avoid loss of life (TSC-07; CEN, 2004). The shortcomings of prescriptive procedures include fuzzy definitions of performance and hazard and the fact that the procedures do not include an actual evaluation of the performance capability of a design to achieve

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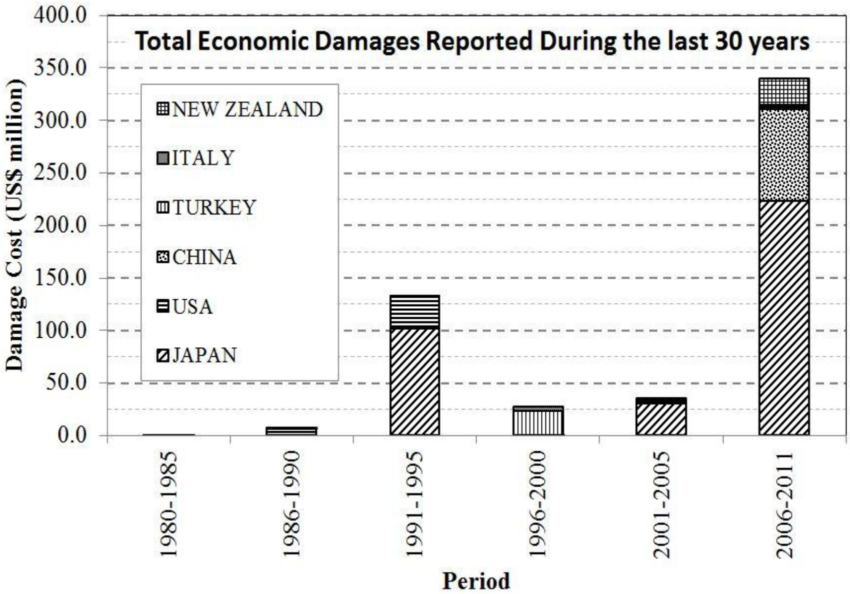

Fig. 1 Total economic damage costs reported during the period of 1980-2011 (EM-DAT 2013)

any of these performance objectives (Whittaker and Soong 2003). In prescriptive provisions, qualitative performance objectives cannot be quantified and seismic protection is based on judgments by design professionals.

Performance-based seismic design originally evolved as a concept whereby the desired performance level for a given structure (including the nonstructural components housed within), along with a specified level of shaking, is defined at the initiation of the design process. The decision-maker is asked to select one or more of these performance levels, and a ground motion event or hazard level for which this performance is to be achieved and a designer is expected to develop a design capable of meeting these expectations (Bachman *et al*. 2003; Gilmore *et al*. 2010).

Performance-based seismic design serves better the interests and objectives of owners, by allowing more rational decision-making, with explicit verification of performance levels related to property loss and operation of a facility under frequent or occasional earthquakes. “Performance-based earthquake engineering” in particular tries to maximize the utility from the use of a facility by minimizing its expected total cost, including the short-term cost of work and expected value of life loss in future earthquakes (in terms of casualties, cost of repair or replacement, loss of use, etc.) (Fardis 2008; Ayala *et al*. 2012).

The need for changes in the existing seismic design methodology implemented in codes has been widely recognized (Fajfar 2000). The development in performance based engineering concepts offered ~~the~~ great opportunities to quantify, monitor and control the performance in a manner that responds to the diverse needs and objectives of owners and society.

Following the widely accepted earthquake resistance design requirements, building structures in Turkey are designed and constructed to withstand seismic action associated with a 10% probability of exceedance in 50 years, without local or global collapse, thus retaining its structural integrity and a residual load bearing capacity after seismic events (CEN 2004).

But, it becomes clear that nonstructural components' damage can cause major economic loss as well as life safety threats. With the current building environment the damage to nonstructural components is more frequent comparing to the damage done to structural components within the last 30 years. As seen in Fig. 1, the economic cost of earthquakes had an increasing tendency during the period of 1980 to 2011. It is noteworthy that more affluent countries tend to rank frequently in listings of the most costly disasters. Japan, Italy, and the United States, for example, head the list for earthquakes, because of higher insured values of property linked to higher labor costs for reconstruction, rich countries place as those with the highest losses (EM-DAT, 2013). As noted, in Fig. 1, the most expensive disaster was the Tōhoku earthquake in 2011 with US$223 billion. Turkey faced with a US$20,566 billion damage cost on August 17th, 1999 Marmara earthquake (Kutanis *et al*. 2011). Therefore, the importance of nonstructural component issues in seismic design and performance evaluation started to be recognized by researchers as well as practicing engineers due to the recent earthquakes (Whittaker and Soong 2003). Turkey is situated in one of the most seismically active regions of the world with a large part of the country at significant major catastrophe risk (Bommer *et al*. 2002). Therefore, the economic evaluation of Turkey's building stock needs to be investigated.

The objective of this paper is to evaluate in economic terms the structures designed according to Life Safety and Immediately Occupancy performance levels through the same seismic hazard level. In the first performance level, no collapse and damage limitation is considered as generally accepted in seismic design codes. In the second case, performances of the structures are accepted as to be returned to a fully operational state within an acceptably short timeframe after the earthquake occurrence. Comparisons were made of analyzing ~~the~~ six optimally designed reinforced concrete moment resisting and dual frame buildings according to the Turkish Seismic Code. Nonlinear static pushover analysis procedure has been effectively used in this regard. It is aimed to conclude with convincing financial results to encourage people and the public officials to design dwellings according to the Immediate Occupancy performance level.

2. Building Inventory in Turkey

The majority of Turkey's urban population lives in multi-story apartment blocks constructed of reinforced concrete with masonry infill walls. The basic form of construction is the reinforced concrete frame, cast in-place; the vertical structure consists of columns 0.30m by 0.50m in thickness, the ground floors have a height of 4m, the regular story height is 2.80m, the structures are generally residential building with shops at the ground floor. Floor and roof slabs are generally 0.12m reinforced concrete two way slabs supported by reinforced concrete beams. The reinforced concrete frame is filled with walls of clay brick, hollow tile or other masonry blocks which have 0.10 and 0.20m thickness of interior and exterior walls, respectively (Gülkan *et al*. 2003).

Since 1965 four building censuses has been conducted at centers of provinces, districts; sub-districts and villages of Turkey, to determine the number of buildings, use of building, construction year, number of stories, number of residential buildings and building materials. To determinate the stock and building quality in Turkey, the last census was carried out in 2000, but the building inventory data is updated each year by the Turkish Statistical Institute (TUIK 2001). The information obtained from the census conducted in 2000, classification according to structural system, 48% of building was constructed as reinforced concrete frame structure and 51% of

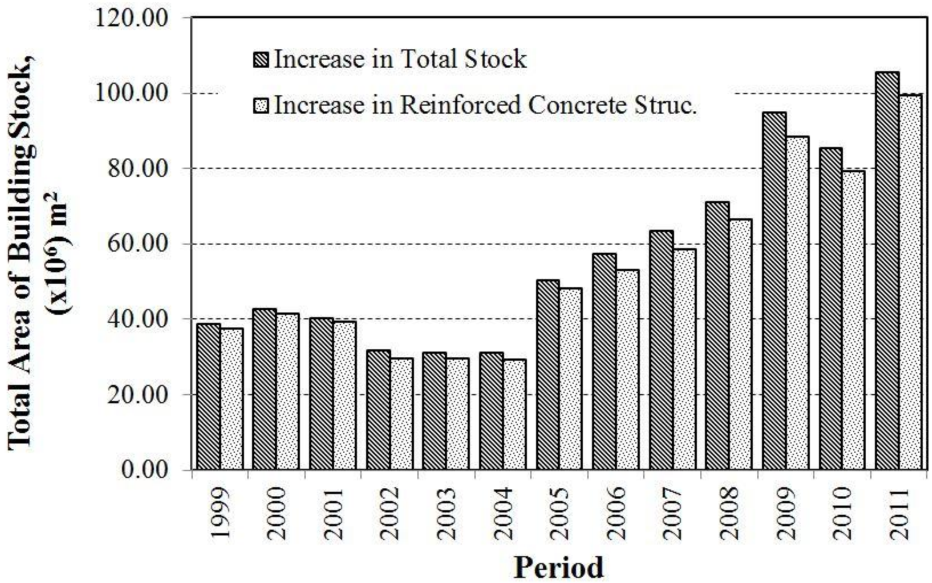

Fig. 2 Building stock developments in Turkey during the last decade (TUIK 2012)

Table 1 Earthquake zones and elements under risk in Turkey (Available from URL: http://www.deprem.gov.tr).

Earthquake zone	Population (%)	Surface area (%)	Major industry centers (%)	Dams (%)
Zone I (PGA ≥ 0.40g)	45	42	51	46
Zone II (0.40g > PGA ≥ 0.30)	26	24	25	23
Zone III (0.30g > PGA ≥ 0.20)	14	18	11	14
Zone IV (0.20g > PGA ≥ 0.10)	13	12	11	11
Zone V (0.10g > PGA)	2	4	2	6

(g: gravitational acceleration, g=9.81 m/s2)

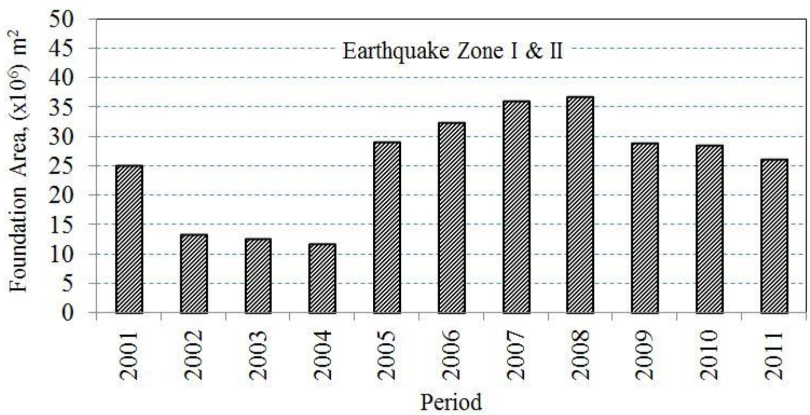

Fig. 3 The rate of building stock in seismic risk zones during the last decade in Turkey (TUİK 2012)

buildings were constructed as masonry. The ratio of buildings constructed with tunnel model system was 0.1%. According to 4th building census from the year 2000, 7,838,675 buildings were counted. Ratio of increase had been 79% compared with previous census in 1984. The average number of stories was determined as 2.1. Average construction area of buildings has been calculated as 132 m^2 (TUIK 2001).

The recent increase trend in building stock during the period of 2001-2011 in terms of building total area is illustrated in Fig. 2. Despite economic crisis in the whole world, the construction industry produced an average of 54,848,306m^2 building stock each year in Turkey.

It is notable to mention that Turkey is located on a highly active Eurasian Geological Plate which has caused numerous big scale earthquakes throughout the history (Lettis *et al*. 2000; Bozkurt 2001). The earliest earthquake records dates back to 411 B.C. There have been nearly 100 earthquakes with magnitudes of 7.0 or greater in Turkey in the last 2000 years. Also, 14 earthquakes with casualties more than 10,000 have occurred since 342 A.D. As a result Turkey ranks high among the countries that have suffered from significant losses of life and property dues to earthquakes (NGDC 2013). Table 1 shows that 71% of the country is under high earthquake risk (Zone I and Zone II) and about 66% of the population lives in either highest or high risk zones (Available from URL: http://www.deprem.gov.tr).

In this study, building stock located on high earthquake risk zones, where during the last 30 years period large earthquakes occurred, are only considered. At high seismic risk zones, an average of 31,303,415 m^2 building stock has been built during the last 10 year periods (Fig. 3).

3. Review of seismic design and assessment methodologies in TSC-07

The current Turkish Seismic Code (TSC-07) uses “capacity design based seismic design” as the main instrument in conceptual design as well as detailed design. TSC-07 is organized in seven chapters. The first six chapters related to the seismic design of new structures which is based on the strength-based approach. The last chapter is devoted exclusively to seismic assessment and retrofitting of existing concrete buildings. Chapter Seven is based on the deformation-based seismic assessment procedures in which limiting strain values associated with different performance levels of reinforced concrete members are specified.

In the code, for the seismic design of new structures, the spectral acceleration coefficient A (T) is reduced by the response modification factors (R_a (T)) and applied to the building in each mode for a linear elastic analysis. The spectral acceleration coefficient is calculated as a function of the seismic zone coefficient, the building importance factor and the elastic spectrum coefficient evaluated for 5% damping ratio. The seismic zone coefficient (A_o) is taken as 0.40, 0.30, 0.20, and 0.10, for the first four seismic zones, respectively. The importance factor, I, is 1.0 for ordinary structures and varies between 1.0 and 1.5. The elastic spectrum coefficient S (T), which defines the design acceleration spectrum, is given by three equations in the short-period, constant-acceleration and constant-velocity ranges, respectively. These ranges are delineated by spectrum characteristic periods, T_A and T_B, which vary as a function of soil type. The maximum spectral amplification is 2.5. The response modification factors (R_a (T)) are determined by in terms of Structural System Behavior Factor, R, which is tabulated in the code, and the natural vibration period T. The value of R depends on the assumed ductility (high or normal) of the system and varies between 4 and 8 for the pour-in-cast reinforced concrete structures. (TSC-07; Sezen *et al*.

2000; Ilki and Celep 2012; Sullivan 2010). It is worth mentioning that the current codes of practice in Turkey and the United States are similar in terms of strength and detailed requirements.

In the TSC-07, nonlinear static procedures and nonlinear dynamic time history analyses are allowed for assessment purposes. In the Code, the deformation capacity of beam, column and shear wall is defined as the strain capacity of concrete and reinforcement at the critical sections. Strain capacity at the critical sections is obtained for total curvature demand by using moment curvature relation of the section. Total curvature demand is defined as the sum of plastic curvature demand and equivalent yield curvature. The sectional limit states for the ductile reinforced concrete load-bearing members that undergo the plastic deformation are defined in the Code as Minimum Damage Limit, Safety Limit and Collapse Limit.

At the Minimum Damage Limit, the yielding in which section is initiated. The concrete strain limit at the most outer concrete fibres is equal to 0.0035 or reinforcing steel bar to reach to 0.010. The limit state strain values in the Safety Limit are 0.0135 for the outer fibres of the core concrete and 0.04 for the reinforcing steel bar strain. In the Collapse Limit, wide flexural and/or shear cracks occur, buckling of longitudinal reinforcement may happen. Concrete strain at the outer fibres of the core concrete is less than or equal to 0.018 and the reinforcing steel bar strain is 0.06.

A short description of the flexural limit states used in the Turkish Earthquake Code of 2007 is given below: Immediate Occupancy is exceeded (moderate damage) if 10% of the beams or any of the columns in any section reaches the Minimum Damage Limit strains. Otherwise, the building is below Minimum Damage Limit (no or slight damage). Life Safety is exceeded (heavy damage) if more than 30% of the beams in the direction of loading or 20% of the columns reach the second limit state. Life Safety is also reached if two ends of the columns, which contribute in total to more than 30% of the base shear, reach the first limit state. The rest of the columns must remain below the second limit state in this case. Collapse Prevention is exceeded if more than 20% of the beams in the direction of loading reach the second limit state. Limit State 3 is also reached if two ends of ~~the~~ columns, which contribute in total to more than 30% of the base shear, reach the first limit state. The rest of the columns must remain below the third limit state in this case.

4. The building set used for comparative analyses

To extend the proposed solution to increase seismic safety, six generic reinforced concrete buildings were employed in the cost comparison analysis. The generic buildings which were selected for the purpose of the present analysis were the typical moment resisting frame and dual buildings of 3, 6, and 10 stories. It is assumed that they are located in a high seismic region with a soft soil site (Subsoil class Z4, and Zone I in Turkish Seismic Code, (TSC-07)). According to the TSC-07, the structural behaviour factor, R is 8 for moment resisting frame and, R is 7 dual buildings, and importance factor, I is selected as 1. All the buildings have the same material properties such as the concrete compressive strength is 20 MPa (design compressive strength is 13.33 MPa according to the Turkish codes), modulus of elasticity of concrete, Ec=28 000 MPa, concrete unit weight=25 kN/m^3 and limiting concrete compressive strain ε_u=0.003. The steel reinforcing bars yield strength is 420MPa (design strength is 365 MPa), strain at hardening = 0.008, and fracture strain = 0.10.

The common floor plans of the frame and dual system buildings designed are given in the Fig. 4, below. The optimal column dimension determined so that the reinforcement ratios in column

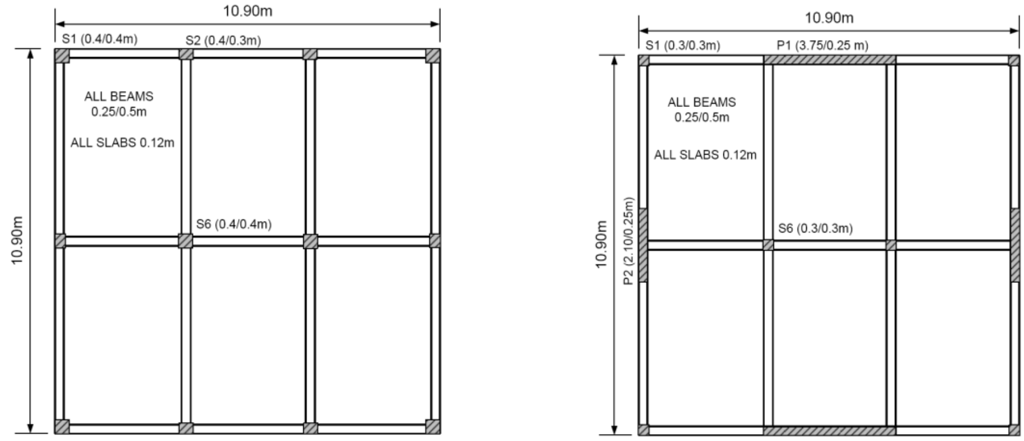

Fig. 4a First floor plans of generic 3 storey reinforced concrete frame and dual system buildings

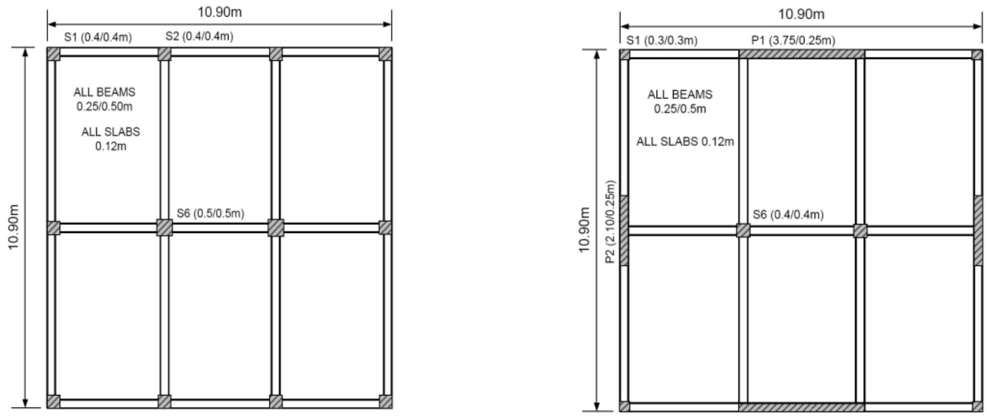

Fig. 4b First floor plans of generic 6 storey reinforced concrete frame and dual system buildings

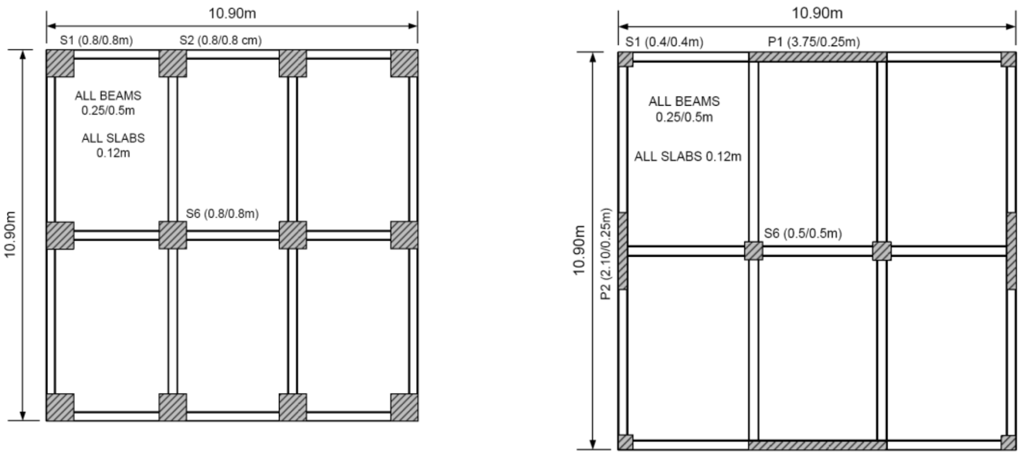

Fig. 4c First floor plans of generic 10 storey reinforced concrete frame and dual system buildings

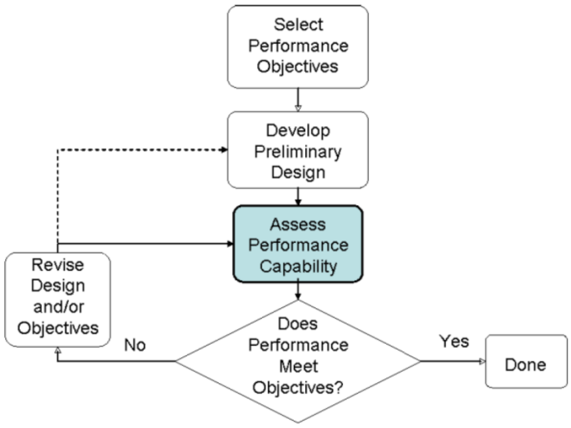

Fig. 5 Performance-based design flow diagram (ATC-58 2011)

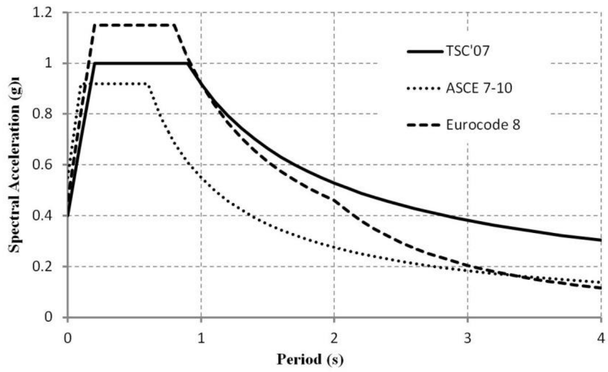

Fig. 6 Comparison of TSC-07, Eurocode 8 and ASCE 7-10 response spectra employed in earthquake resistant seismic design

Table 2 Target displacements associated with the generic reinforced concrete structures

	LS Performance level		IO Performance level	
	Top displacement (m)	Base Shear (kN)	Top displacement (m)	Base shear (kN)
3 story frame	0.160	847.58	0.111	1,136.78
3 story dual system	0.013	2,426.99	0.013	2,426.99
6 story frame	0.242	3,958.34	0.147	3,640.49
6 story dual system	0.012	4,102.54	0.079	4,558.02
10 story frame	0.131	1,963.08	0.097	2,472.41
10 story dual system	0.139	2,537.75	0.100	2,796.93

provided are greater than minimum code reinforcement requirements. In this way, big column sizes with minimum code reinforcement requirements are avoided in design. In weight calculation of the structure, exterior and partition walls and 30% of live loads are also included.

The performance based on a structural design process is an iterative procedure wherein a preliminary design is cycled through stages of analysis, assessment, and revision to achieve a design that satisfies various criteria best in some chosen sense (Irfanoglu 2000; ATC-58 2011), Fig. 5. The structural design initiated with the selection of design parameters. The material properties and structural plan configurations were assumed constant in this study; however, the member dimensions were to be varied during the design process. The intensity of the seismic loading experienced by the structure was computed using the pseudo-dynamic lateral-load calculation procedure, which is based on the response spectra described in the in TSC-07. As seen in Fig. 6, under the selected ground condition and seismic motion, the response spectra indicate ~~the~~ slight differences in the codes of practice in TSC-07, Eurocode 8 and ASCE 7-10 standards.

In the analysis stage, the preliminary and revised designs were analysed to obtain the values of ~~the~~ chosen performance parameters. At this stage, Probina Orion (2013), structural design software~~,~~ was utilized for three dimensional finite-element modelling and analyses of the generic buildings. In the analysis stage, the strength demand on each component of each structure was obtained and compared with available capacities by performing an elastic analysis.

In the assessment stage, displacement based procedures, based on inelastic deformations and uses nonlinear analysis procedures considering seismic demands and available capacities explicitly~~,~~ were employed. Most seismic assessment procedures in codes or guidelines consist of two main parts: a) definition of the target displacement, b) definition of the damage when the structure reaches the target displacement (Bal *et al* 2012). The target displacement is calculated by plotting the capacity curve over the demand curve in Spectral Displacement vs Spectral Acceleration format. The performance point is either calculated by using equivalent displacement or equivalent energy rules, as in the Eurocode 8 (CEN, 2004) and the Turkish Seismic Code (TSC, 2007). The calculated target displacement for the generic reinforced concrete buildings were given in Table 2. The performance level of the structures was determined by using the limit states that are defined in TSC-07 and explained in Section 3 in this article.

In the revision stage, the objective is to produce results that satisfy the Immediate Occupancy and Life Safety performance objectives. Convergence to this design takes place in an iterative manner and the rate of convergence depends on the nature of the problem.

After meeting the seismic performance objectives, the cost estimation of ~~the~~ generic buildings was achieved using the unit price documents published annually by the Turkish Ministry of Environment and Urbanization. In this study, in addition to initial prices of construction, repair and retrofit, architectural, temporary relocation, cost of damage to household goods business interruption costs are included. Since it is impossible to represent the real value of human life and injury, causalities and fatalities are not considered in the cost analysis. Slab and foundation design and construction costs are also excluded.

5. Analysis results and discussions

The estimated construction costs of the generic bare frame structures are tabulated in terms of unit prices in Table 3. These costs include only the load bearing system construction expenditures such as columns, beams, formworks, etc. If structural performances were upgraded from the Life Safety to Immediate Occupancy, in 3-story-dual structure, the construction unit cost was only increased about 4.24 %, on the other hand, in 10-story-dual structure ~~it was~~ increased about 27.4%.

Table 3 Cost comparisons of the generic bare frame structures between Immediate Occupancy (IO) and Life Safety (LS) Performance Objectives

Structural System	10% PE in 50 years (Design Earthquake) **IO** Performance		**LS** Performance		Unit Cost Difference ($/m^2)	Unit Cost Difference (%)
	Total Cost ($)	Unit Cost $/m^2	Total Cost ($)	Unit Cost $/m^2		
3 story frame	17,135.96	54.40	15,223.65	48.33	6.07	11.2
3 story dual system	22,050.72	70.00	21,115.11	67.03	2.97	4.24
6 story frame	41,813.14	66.37	32,939.50	52.28	14.09	21.23
6 story dual system	55,988.05	88.87	39,870.53	63.29	25.58	28.8
10 story frame	81,787.79	77.89	64,863.61	61.77	16.12	20.7
10 story dual system	103,197.59	98.28	74,894.87	71.33	26.95	27.4

Table 4 Construction Subsystem cost ratios calculated from Turkish ministry of environment and urbanization's construction unit costs

Components	Building construction subsytems	(%)
Structural	Load-bearing systems (structural framing, shear walls, slabs, formworks) (Bare frame structure)	35
Non Structural	Pipes, ducts, electric wirings	10
	Finishing, paintings	5
	Doors, windows, glasses, interior plastering	15
	Floor tiles/coverings	10
	Brick tiles/walls, Exterior plastering	8
	Heating systems (equipment, furnaces, pipes)	10
	Roof, peripheral arrangements	7
	Total	100
	Slab design and construction costs (concrete, rebar, formwork etc..) Foundation design and construction costs (concrete, rebar, formwork etc..) % 25 Contractor's income % 18 Value added tax Project office costs, land costs	Excluded.

Table 5 Effects on GDP in Percentage in case of increasing the building performance objectives from Immediate Occupancy to Immediate Occupancy under the 10% PE in 50 years earthquake hazard levels

Structural system	Unit cost difference ($/m^2)	Total cost ($)	Percentage in GDP
A	B	C=B*ABS	D=C*100/GDP
3 story frame	6.07	190,037,564	0.0246%
3 story dual system	2.97	92,977,104	0.0120%
6 story frame	14.09	440,913,067	0.0570%
6 story dual system	25.58	800,846,684	0.1036%
10 story frame	16.12	504,556,784	0.0653%
10 story dual system	26.95	843,782,845	0.1091%

Table 6 Selected Turkish Institutions 2012 Budgets (Available from URL: http://www.resmigazete.gov.tr/eskiler/ 2011/12/20111229M1-1.htm)

Institutions	Annual budgets	Percentage in
Presidency of republic of Turkey	77,055,556	0.0100%
Ministry of national education	21,760,766,217	2.8148%
Ministry of health	7,976,632,222	1.0318%
Ministry of defense	10,127,595,556	1.3100%
Ministry of environment and urbanization	516,563,333	0.0668%
Middle east technical university	154,454,444	0.0200%
Istanbul university	355,887,778	0.0460%
Sakarya university	87,583,333	0.0113%

The cost breakdown of the generic building's non-structural components according to the Ministry of Environment and Urbanization's unit price documents is estimated in terms of percentages, given in Table 4. According to the Turkish construction practice, 65% of the cost of buildings spent on nonstructural components and they constitute the biggest portion of the total investment risk.

According to Turkish Statistical Institute, reinforced concrete structures stock in Earthquake Zone I and Zone II increases annually an average (ABS) of 31,303,414.60 m^2 in Turkey. The Gross Domestic Product (GDP) in Turkey was worth 773.09 billion US dollars in 2011 (Available from URL: http://www.tradingeconomics.com/turkey/gdp). In Table 5, the unit cost differences calculated in Table 3 is compared with the GDP in Percentage by considering the average increase in building stock annually.

As seen in Fig. 1 during the 30 years period (1983 to 2013), the earthquake damage cost for Turkey was about 24,509,800,000.-US$ (EM-DAT, 2013). This figure indicates that Turkey spends 816,993,333.33-US$ or 0.1057% of its GDP to the earthquake damages, annually.

Recent statistical data, compiled after the 17th, August 1999 Kocaeli and 07th, September 1999 Athens earthquakes, indicates that 15% of structures will be damaged during future earthquakes with 10% probability of excess in 50 years (ATC-13 1985; Erdik *et al*. 2003; JICA-IMM 2003; Eleftheriadou and Karabinis 2008). In this seismic hazard level, if the structural capacity losses are not exceeded 50%, repair and retrofit applications can be considered. Repair and retrofit costs of buildings are mostly depends on the structural capacity lost during an earthquake. This cost of repair includes load bearing system strengthening, architectural works, finishing, heating, ventilation, and air-conditioning (HVAC) costs. Repair and strengthening costs can be estimated at an average of 50 US$/m^2 (Erdurmus 2005). Additional costs such as temporary relocation, temporary accommodation is 10 US$/m^2, cost of damage to household goods, 20 US$/m^2 and business interruption losses are accepted as twice the structural damage costs, 100.-US$/m^2 (Dowrick 2009). To sum up, the total replacement cost can be estimated as 180US$/m^2. This figure coincides with 0.1093 % of Turkey's GDP in 2012.

Another comparison was given in Table 6, where the budgets of some institutions in 2012 were given and compared with its percentage in GDP of Turkey. Table 6 is given to load the meanings for the GDP percentages. Table 6 illustrates that if structures are designed with the Immediate Occupancy performance objectives, the additional 0.1% of GDP expenditures will not be very effective on the overall Turkish economic structure.

6. Conclusions

- It should be clear that for economic and technical reasons, the traditional building design codes have traditionally attempted to provide protection for structures against the effects of likely earthquakes with the basic objective of protecting against substantial loss of life. But, it is not possible to quantify the level of protection. This leads to very high repair costs and long downtimes while these repairs are being made. The total economic losses can be very high. Based on the researches in during the last three decades, currently, the performance-based design procedure offers great opportunities for the community such that design and construction of engineered systems whose performance levels and objectives can be quantified, performance can be predicted analytically and the cost of improved performance can be evaluated in a manner that rational trade-offs can be made based on life-cycle considerations rather than construction costs alone.
- The study reveals that non-structural components comprise the 65% of building costs in Turkey, and the importance of these components is the main factor to earthquake economic losses. Especially in high seismic zones, if ~~the~~ new buildings are designed and constructed for the Immediate Occupancy performance objectives, it will not create a negative impact on the overall country economic performance. The modification of the performance objective of the seismic building code from the Life Safety to Immediate Occupancy performance levels will only create a 0.1% of GDP which is 10 times greater than the budget of presidency of the Republic of Turkey.
- It also should be noted that in this study, while all structural members and connections ideally remain undamaged during seismic motion, fatal and nonfatal injuries which are based on the structural damage were not ~~be~~ critical. The rate of fatalities and injuries will probably decrease in the Immediate Occupancy performance objective.
- The overall cost comparison indicates that the cost of repair or replacement of non-structural components is a large part of the overall building cost, leading owners to seek methods to minimize damage done to them during earthquakes (Vaughan *et al*. 2002).

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