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Cost Benefit Analysis Of The Structures Designed For Alternative Seismic Hazard Levels

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ABSTRACT

In this study, multiple performance objectives under the various earthquake hazard levels are investigated. In case of well defined earthquake hazard, as an alternative of classical earthquake resistant design principles, it is possible to design structures at different performances depending on structure's initial cost and economic life. In this study, costs of the structure with different performance levels are discussed.

Current study is carried out on the reinforced concrete structures that are designed and analyzed for various seismic hazard levels. The aim is to determine, if the risk is released, whether the economic losses can be acceptable or not. In the study, cost of reinforced concrete ductile frames and dual systems that are designed for various seismic performances, are also compared for the economical aspects.

To that end, in the first step 3, 5 and 8 storey frames and dual systems of several structures at Life Safety and Immediate Occupancy performance levels was designed for the earthquake hazards of 2% and 10% probability of exceedance in 50 years. The study reveals that if both direct and indirect effects of earthquake such as retrofitting costs, cost of temporary moving, temporary accommodation costs, cost of demolition and reconstructing the building, cost of damage to household goods and business disruption, social disturbance, are be taken into consideration, initial design performance level can be accepted as Immediate Occupancy performance level rather than Life Safety performance which is proposed current earthquake codes. The cost due to injuries and cost due to loss of lives are not included.

INTRODUCTION

The current built environment is considered to be getting more vulnerable compared with last years. As seen in Figure 1, the economic cost from earthquakes has an increasing tendency during the period of 1974 to 2003. It is noteworthy that richer countries tend to rank frequently in a listing of the most expensive 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, the richer countries place as those with highest losses [1]. As noted, in Figure 1, the most expensive disaster was the Kobe earthquake in 1995 with US$159 billion. The next highest loss, adjusted again to 2003 US dollar values, was the earthquake of 1980 in southern Italy that totaled about US$44 billion. The next most expensive earthquake was in the area of Los Angeles in 1994 (US$32.34 billion). Turkey has faced with a US$20.566 billion damage cost in17th August 1999 Marmara earthquake.

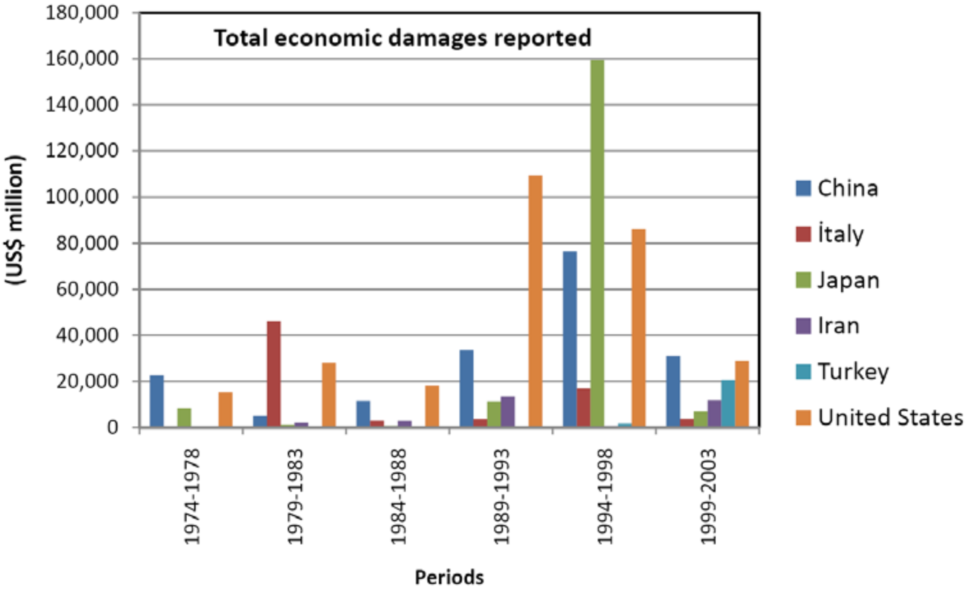

Figure 1 Total economic damage costs reported during the period of 1974-2003 [1]

It is well known that earthquake damage is caused by a number of factors such as strength of ground shaking, duration, type of the subsurface conditions and quality of the building. Although, the first three items cannot be prevented or controlled, the quality of the building can be managed to mitigate the earthquake vulnerabilities.

After the post earthquake assessments, the performances of structures during the earthquake are measured according to structural damage state such as Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP). In case of LS damage level, retrofit and strengthening decisions for the structures can be taken for the intervention. The current state of seismic design practice, for economical reasons, the structures are designed and constructed to withstand the design 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 the seismic events [2]. The performance requirements for the dwellings to be satisfied are the avoidance of collapse of the structural system and limited damage requirements.

In this study, an economical analysis is performed to compare the two design practices for conventional dwelling houses in Turkey. In the first case, no collapse and damage limitation is considered as generally accepted in seismic design codes (ultimate limit state). In this case, cost of the repair and retrofit costs are included in the analysis. In the second case, performances of the structures are accepted as to be returned to a fully operational state within an acceptable short timeframe after the earthquake occurrence (serviceability limit states). Since costs of the non-structural components are increased more than earthquake resistance structural components, the cost of the no collapse and damage limitation case computed as higher than serviceability limit states.

The main scope of the present study is to perform the cost-benefit analysis of the buildings designed different seismic design level, so that increase in cost can be neglected by comparisons with increase in safety. The study reveals that for new buildings, costs for a IO performance level in the earthquakes with magnitude of 10% probability of exceedance in 50 years earthquake is about 3 to 10% of the load bearing system construction costs which is the 40% of the total construction costs. The upgrading of existing buildings was calculated as 350TL/m^2 which is quite expensive.

METHODS

To extend the proposed solution to increase seismic safety, 6 benchmark reinforced concrete buildings were optimally designed for two seismic hazard levels, according to Turkish Earthquake Code (TEC) 2007 provision [3]. In the first case, it is desired the buildings to withstand 10% probability of exceedance in 50 years which is applied since 1920s [4]; on the other hand, in the second case, 2% probability of exceedance in 50 years is considered. In the first case, the building performances are calculated as LS level with a probability of exceedance of 10% in 50-year periods. In the second case, the performances are LS level with a probability of exceedance of 2% in 50-year periods and IO level at 10% in 50-year periods.

The cost estimation procedures were carried out by the unit price documents published annually by Turkish Ministry of Public Works and Settlement. In the first case of the design, in addition to initial cost 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 benefit analysis. Foundation design and construction costs are also excluded.

NUMERICAL ANALYSIS

The buildings which were selected for the purpose of the present analysis were the typical moment resisting frame and dual buildings of 3, 5 and 8 stories. The buildings designed for high seismic zone with the rock soil profile. All the buildings have the same material properties (C20, S420) and loading conditions. The common floor plans of the frame and dual system buildings designed are given in the Figure 2 and 3, respectively, below. In dual system buildings %1 shear walls are supplied in both directions. The optimal column dimension determined so that the reinforcement ratios in column provided greater than minimum code reinforcement requirements. In this way, big column sizes with minimum code reinforcement requirements are prevented in design.

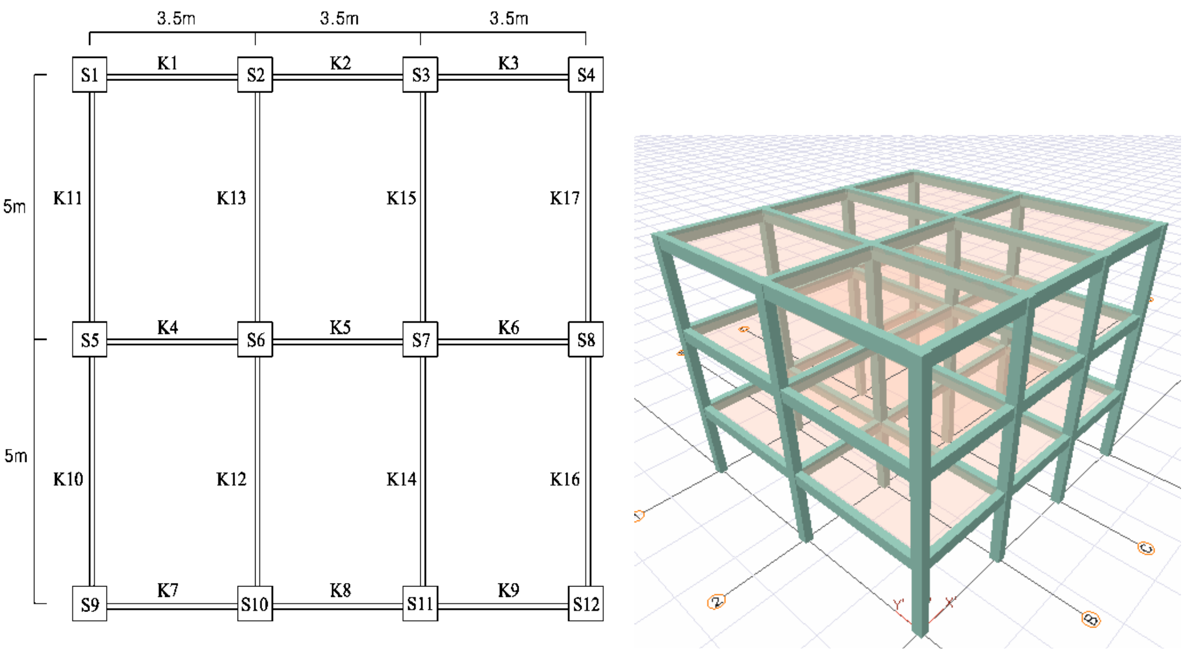

Figure 2 Floor plan and 3 dimensional elevation of frame benchmark building [3]

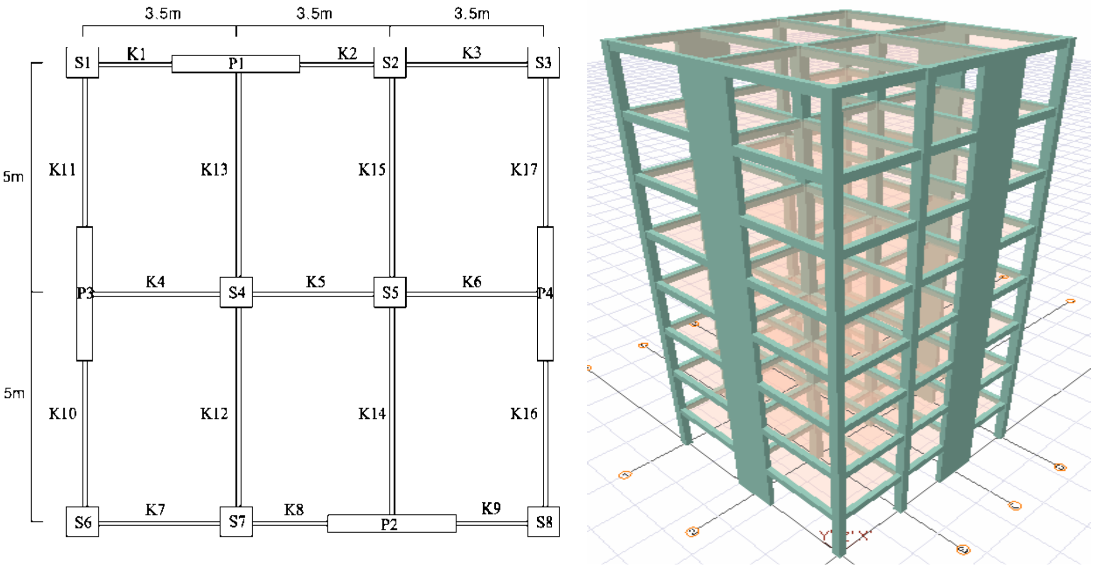

Figure 3 Floor plan and 3 dimensional elevation of dual system benchmark building [3]

In calculation of the weight of the structure, exterior and partition walls and 30% of live loads are also included. The fundamental vibration periods are given in Figure 4 by comparison with periods calculated from empirical formulas given in the earthquake codes.

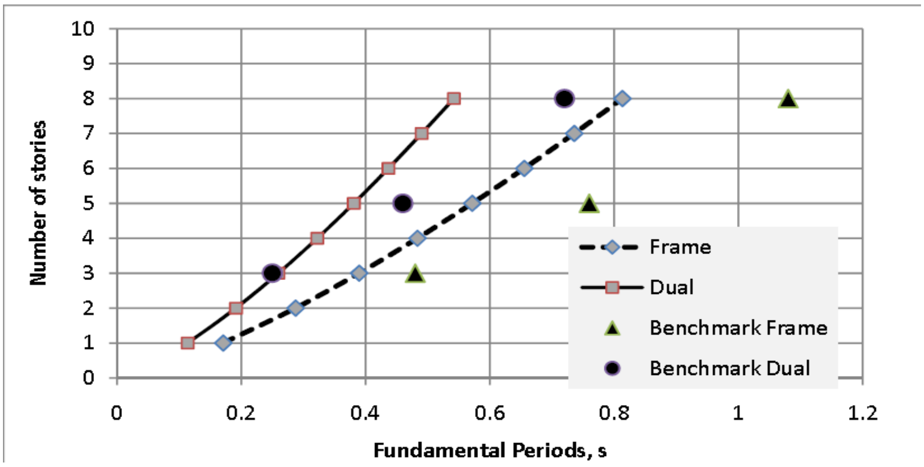

Figure 4 Fundamental vibration periods of designed buildings compared with periods calculated from empirical formulas [2].

RESULTS

It is investigated that as the cost of load bearing (structural) elements (columns, shear walls, beams, etc…) remain nearly constant, that of the architectural (non-load bearing walls, elevators, equipments, ceilings, chimneys, parapets,…etc), mechanical and electrical components increases by comparison.

The cost of the structures are computed according to Turkish Ministry of Public Works and Settlement's Construction Unit Costs, published annually, given in Table 1, below. These costs include only the load bearing system construction expenditures such as columns, beams, slabs, formworks…etc. In other words, these are the 40% of the total construction costs (Table 2). As seen in Table 2, costs to non-structural components are larger than for structural ones.

Table 1 Cost Comparisons Between Seismic Hazard Levels.

Structural System	10% probability of exceedance in 50 years		2% probability of exceedance in 50 years		Unit Cost Difference (TL/m^2)
	Total Cost (TL)	Unit Cost TL/m^2	Total Cost (TL)	Unit Cost TL/m^2	
3 story frame	24,886.1	79.00	24,960	79.24	0.23
3 story dual system	28,407.4	90.18	29,351.1	93.18	3.00
5 story frame	41,607.6	79.25	43,189.5	82.27	3.01
5 story dual system	47,936.8	91.31	51,635.1	98.35	7.04
8 story frame	69,815.9	83.11	115,598.4	137.62	54.50
8 story dual system	82,774.2	98.54	93,471.4	111.28	12.73

Table 2 Construction Subsystem Cost Ratios Calculated from Turkish Ministry of Public Works and Settlement's Construction Unit Costs

DWELLING CONSTRUCTION SUBSYTEMS	**(%)**
Load-bearing systems (structural framing, shear walls, slabs, formworks)	40
Pipes, ducts, electric wirings	10
Finishing, paintings, glasses, tiles	10
Doors, windows, interior plastering	15
Floor tiles/coverings	6
Exterior plastering	6
Heating systems (equipments, furnaces, pipes)	8
Roof, peripheral arrangements	5
Total	**100**
% 25 Contractor's income	Excluded.
% 18 Value Added Tax	
Project office costs, land costs	

According to Turkish Statistical Institute (TUIK), reinforced concrete structures stock increases annually an average of 39,063,108 m^2 in Turkey. In 2010, the gross domestic product (GDP) in Turkey was calculated as 950,098,000,000TL (US$633,398,000,000).

It is notable to mention that in the analysis, the structures designed for the seismic hazard level of 2% probability of exceedance in 50 years have performed IO performance level in the earthquake with magnitude of 10% probability of exceedance in 50 years.

In Table 3, in case where the performance level is increased from LS to IO level in the earthquake with magnitude of 10% probability of exceedance in 50 years, the resultant costs are tabulated for 6 benchmark structures.

Table 3 Effects of Unit Cost Differences and Comparison With The Gross Domestic Product in Percentage

Structural System	Unit Cost Difference (TL/m^2)	Total Costs (TL)	Percentage in GDP
A	B	C=B·39063108	D=C·100/950098·10^6
3 story frame	0.23	9,164,329	% 0.001
3 story dual system	3.00	117,028,111	% 0.012
5 story frame	3.01	117,702,725	% 0.012
5 story dual system	7.04	275,175,414	% 0.029
8 story frame	54.50	2,129,055,645	% 0.224
8 story dual system	12.73	497,459,380	% 0.052

DISCUSSION

As seen in Figure 1 during the 30 years period (1974 to 2003), earthquake damage cost for the Turkey was about 22,590,000,000.-US$. It means that Turkey spent 0.0079% of its GDP to the earthquake damages annually. As an example, if performance level were accepted as IO level in an earthquake with magnitude of 10% probability of exceedance in 50 years rather than LS level, the resultant cost would be % 0.0295 of GDP for 5 story dual systems which is less than the annual earthquake damage cost of Turkey.

Another comparison was tabulated in Table 4, where the budgets of some institutions in 2010 were given and compared with its percentage in GDP of Turkey.

Table 4 Selected Turkish Institutions 2010 Budgets

Institutions	Annual Budgets In 2010 (TL)	Percentage in The Gross Domestic Product (GDP)
Ministry of Defence	15,118,234,000	1.59123
Ministry of Public Works and Settlement	774,446,000	0.08151
Presidency of Republic of Turkey	72,500,000	0.00763
Sakarya University	117,578,000	0.01238
Middle East Technical University	234,779,000	0.02471
Pamukkale University	126,945,000	0.01336

For economic reasons, buildings are usually designed to get LS performance level in case of the earthquake with magnitude of 10% probability of exceedance in 50 years. In this seismic hazard level, if the structural capacity losses are not exceeded %50, the repair and retrofit applications can be considered. The repair and retrofit costs of buildings are mostly depends on the structural capacity lost during the earthquake. As structural capacity decreases, the cost of strengthening increases. Cost of repair includes load bearing system strengthening, architectural works, finishing, heating, ventilation, and air-conditioning (HVAC) costs. Repair costs can be estimated an average of 100TL/m^2 [5]. Additional costs are relocation (20TL/m^2), cost of damage to household goods (30TL/m^2) and business interruption losses are accepted as twice the structural damage costs (200TL/m^2) [6]. To sum up, the total repair and retrofit costs can be estimated as 350TL/m^2 (230US$/$m^2$).

REFERENCES

[1] EM-DAT: The OFDA/CRED International Disaster Database. (http://www.em-dat.net), UCL - Brussels, Belgium. (In: Human Casualties In Natural Disasters: “Progress in Modeling and Mitigation”, ed. R. Spence, E.So, C. Scawthornp Springer: Dordrecht, Heidelberg, London, New York, 2011: pp.13-24),

[2] EC8 Part 1 (2004) Design of structures for earthquake resistance -Part 1: General rules, Seismic action and rules for buildings, CEN European Committee for Standardization, prEN 1998–1: December 2004

[3] Abut, Y. (2010) “Farklı Performans Düzeyleri İçin Tasarlanan Çerçeveli ve Perdeli-Çerçeveli Betonarme Yapıların Ekonomik Açıdan Karşılaştırılması (in Turkish)”, *Master Thesis*, SAU FBE, Sakarya.

[4] Frangopol, D. M., Structural optimization using reliability concepts. *Journal of Structural Engineering, ASCE*, 1985, 111, 2288-2301.

[5] Erdurmuş, S. B., (2005) “Benefit-Cost Analysis for Retrofitting of Selected Residential Buildings in Istanbul”, *Master Thesis*, *ODTÜ FBE*, Ankara.

[6] Dowrick D, (2009) “Earthquake Resistant Design And Risk Reduction”, John Wiley and Sons Ltd., 2nd Edition, Tauranga, New Zeland.