ISSN 2229-5518

From The Architectural Point of View: Statistical Evaluation of the Existing and Strengthening Hospital Buildings

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Abstract—Although over the past ten years many buildings in Turkey have been seismically strengthened, resulting architectural impacts have not been evaluated. In most cases, strengthening process of a building decided by civil engineer rather than architectural evaluation. In the present study 130 different hospital buildings in Turkey, which were subjected to seismic performance analysis in the last ten years, were studied. General building properties, seismic performance values and the preferred strengthening methods concerning these hospitals were interpreted in statistical terms. According to performance based analysis, a limited number of these hospital buildings were observed to be worth strengthening. It is obtained that infill shear wall and concrete jacketing are mostly preferred in the strengthening processes. In a limited number of 130 buildings that were decided to be strengthened. In these strengthened buildings, the architectural projects of the pre- and post-strengthening stages were evaluated. According to this evaluation, the ground floor plan of the buildings had changed for using strengthening members. Significant functional losses emerge with the strengthened. The main reason of this is observed to be the locations of the shear walls preferred and the reinforced concrete jackets. The results show that; in order to minimize the potential spatial problems that would emerge after the strengthening, spatial relationships of the hospital buildings shall be analyzed according to alternative strengthening projects and the method that would have the least effect on these spatial relationships shall be preferred.

Index Terms— Building, Erathquake, Strengthening, Statistical Evaluation, Architecture

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1 Introduction

In Turkey, like many other countries, most buildings are constructed from reinforced concrete (RC). In the research published after earthquakes over the past 20 years, the buildings damaged by the earthquakes had many common defects, and a large number of the existing RC buildings did not have sufficient strength, stiffness or ductility because of these defects [1], [2]. Some of the structural defects in question arise from deficiencies that occur during construction, and some arise from an insufficient structural system. The earthquakes that have happened in Turkey in the last century have caused significant damage and destruction, particularly in public buildings.

Comprehensive seismic performance analyses were made for the current public buildings in order to minimize the losses that might occur in the next massive or moderate grade earthquakes.

These seismic performance analyses are made in accordance with the conditions of Turkish Earthquake Code (TEC-2007,2007) [3], and seismic performance knowledge is gained depending on the levels of performance. The analyses show the potential levels of damage for the buildings, and performance level of each building is gained based on these data.

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This performance level helps in deciding whether to use the building in its current condition or to strengthen or destruct it. When a building is decided to be strengthened, some changes might be necessary for the architectural functions of the building regarding space (such as adding-removing walls, adding partitions, changing the places of doors and windows, setting up new locations, etc.). These changes might affect the space syntax. Thus; spatial analysis of the building must necessarily be made when adding seismic strengthening components into a building that has insufficient seismic performance.

In Turkey, comprehensive seismic performance analyses have been made for hospital buildings, which make up a significant risky part of the public buildings of the country. Whereas a majority of the buildings that have gone through these performance analyses are decided to be destructed, some of them are decided to remain in force following strengthening. Seismic strengthening of hospital buildings brings about some changes in the utilization of the spaces, depending on the kind of the preferred strengthening.

In the strengthening process, frequently, at least in Turkey experience, the approach to seismic upgrades has been driven by structural engineering and economic concerns, rather than by architectural considerations. In some cases the architectural outcomes are less than desirable [4].

The paper concludes firstly; statistical evaluation of the 130 different hospital buildings in Turkey, which were subjected to seismic performance analysis. General stock properties, seismic performance values and the preferred strengthening methods concerning these hospitals were interpreted in statistical terms. A limited number of these hospital buildings were observed to be worth strengthening. In these buildings that were decided to be strengthened, the architectural projects of the pre- and post-strengthening stages were assessed and reported the changes post-strengthening process.

2 Turkish Earhquake Code (TEC) Development and Seismic Zone Map in Turkey

Destructive earthquakes occur in Turkey along an active seismic belt in very short time intervals. More than 150,000 people died and 900,000 buildings were damaged to various extents in the earthquakes that occurred in Erzincan (1939), Tosya (1943), Gerede (1944), Varto (1966), Adapazarı (1967), Erzincan (1992), Dinar (1995), İzmit (1999), Düzce (1999), Afyon (2002) and Bingöl (2003). Turkish earthquake code has changed dramatically after big earthquakes.

In the 1939 Erzincan earthquake (M 7.9), almost the entire city was destroyed, and 30,000 people died. After this earthquake, the first seismic code and seismic zone map were prepared in 1940. This Code was prepared in parallel with the Italian earthquake code of that time. The earthquake Code was updated many times between 1949 and 1968. Significant changes occurred in 1968 and 1975 [5]. New approaches to earthquake load calculation were created and ductile structure design was discussed. In addition, sub-limits for column cross sections and column longitudinal reinforcement's ratios, for example, were changed.

The earthquake Code and earthquake zone map were revised in 1997 [6]. The definitions of the mode superposition method and linear and nonlinear dynamic analysis (time history analysis) were also included as alternatives to measurement according to equivalent earthquake load. Some arrangements were made in the significant parameters to calculate the earthquake load, such as the ground acceleration coefficient, building importance factor, spectrum characteristic periods, and response modification factors, in parallel with the UBC (Uniform Building Code) of that time.

The recently published version of the Turkish Earthquake Code (TEC-2007) and seismic performance evaluation and seismic retrofitting sections that are parallel to those in FEMA 356 [7] and FEMA 440 [8] were included in the Code.

3 Building Performance Assessment Criteria and Strengthening According to TEC-2007

Seismic performance can be defined as 'the building safety state that is determined based on the level and distribution of the potential damages of a building under a certain seismic effect." In order to determine the seismic performance of current buildings, it is necessary to have sufficient knowledge about the state of the building's carrier system. So; the statistical and architectural projects of the buildings shall be procured at first place, and if those are not available, the building survey of the carrier system has to be performed. Following these; a sufficient amount of concrete core and reinforcement bar samples shall be obtained from the building's carrier system in order to find out the properties of the building regarding the materials used and the ground.

A ground study shall be performed through pressure and tension tests. The steps of obtaining information about the building structural system and foundation are in Fig.1, respectively. In Fig.1a and Fig 1b. some site survey conducted for obtaining soil and foundation type. Fig.1c and Fig.1d shows taking concrete core samples from the structural system. Fig.1e and Fig 1f also shows steel tension test.

In the light of the results gained from the tests and studies, the structural model of the building is analysed according to the "linear" or "non-linear" analysis methods mentioned in TEC-2007 and the performance level of the building is determined based on the results obtained. The performance level of a building can be determined to be "Immediate Occupancy (IO) performance level," "Life Safety (LS) performance level," Collepse-Prevention (CP) performance level" or "Collapse State (C) performance level." In IO performance level, the building can remain in use in its current state. In the other performance levels, it is necessary to strength or destruct the building.

When a building is determined to be at LS or CP performance level, it is determined to be strengthened. Thanks to the developing systems and technologies, several methods can be utilized in strengthened buildings given in Fig.1 and Fig.2. Reinforced concrete structures are mainly strengthened through jacketing the columns (Fig.1a), beams or shear walls with concrete or steel plates; wrapping the columns (Fig.1b), beams or partitions with fibre polymer; adding reinforced shear wall partitions (Fig. 2a) to the carrier system or through retrofitted the base of the carrier system (Fig.2b).

It is significant in strengthening studies that; each building to be strentgthened is analysed based on its specific properties and the best strengthening method is determined for the building.

In Japan, Turkey and Mexico City [9], [10]; one of the most common methods used was providing additional shear walls to the existing structural system. The advantage and disadvantage of adding new shear walls to structural system should be discussed. Another better alternative used in these countries is RC jacketing the columns. With this method the increased lateral resistence is uniformly distubuted the whole structure.

Fig. 1a

Fig. 1b

ISSN 2229-5518

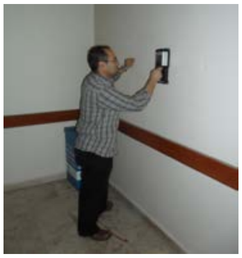

Fig. 1c

Fig. 1d

Fig. 1e

Fig. 1f

Fig 1. Obtaining information about the building structural system and foundation

Usually the strengthening method is aimed the increase the lateral strength of the structure. However when increasing strength generally ductility tends to decline. In this point; judgement of sufficient strength/sufficient ductility and suffiecient stiffness should be done from engineering perspective.

4 Statistical Properties of the Hospital Buildings Studied

Particularly after the Marmara earthquake that took place in 1999, comprehensive studies and analyses have been made in Turkey for the last ten years as the public buildings [11], [12], [13], [14], [15]. Particularly the hospital buildings have been greatly affected by the destructions. 130 buildings which were subjected to seismic performance analysis were studied within the scope of this research.

4.1 Grouping the Hospital Buildings According to their Seismic Performance

The performance analysis results of these 130 buildings revealed out that; 57% of the buildings needed to be destructed. This shows; a significant amount of the hospitals studied failed to meet the expected performance level. The performance analysis also showed that; 93% of the buildings required either strengthening or destruction, which means, almost all of the buildings are risky for usage.

RC-Column Jacketing

FRP Wrapping

Fig 1. Type of Strengthening Method Used in RC Buildings

Adding Reinforced Concrete Shear Wall

Retroffitting Foundation

Fig 2. Type of Strengthening Method Used in RC Buildings

In Table 1, the buildings are grouped according to the seismic zone (Seismic Ground Acc.Assumed as 0.4g; Seismic Ground Acc.Assumed as 0.3g; Seismic Ground Acc. Assumed as 0.2g; Seismic Ground Acc.Assumed as 0.1g; Seismic Ground Acc.Assumed as 0.0g). It can be observed that; 53% of the buildings are located in the 1st-degree seismic zone.

TABLE 1
STATISTICAL DISTRIBUTION OF HOSPITAL BUILDING TO SEISMIC REGIONS

	IO	LS	CP	C
		Decision		
Seismic Region (Seismic Zone Degree)	Non-Operation	Strengthening		Failure
1.	2	21		50
2.	0	5		15
3.	2	13		4
4.	4	5		5
5.	1	3		0

In Table 2, the buildings are grouped according to the type of the ground. %81 of the buildings are located in Z2 and Z3 grounds. Z2 grounds are observed to be more efficient in ensuring the expected level of performance (Z1; Strong Soil-Very dense; Z2; Dense; Z3; Medium Dense; Z4; Loose - Soft Soil).

TABLE 2
STATISTICAL DISTRIBUTION OF HOSPITAL BUILDING TO SEISMIC REGIONS

	IO	LS	CP	C
		Decision		
Seismic Region (Degree Seismic Zone)	Non-Operation	Strengthening		Failure
Z_1	0	**6**		13
Z_2	7	**18**		17
Z_3	2	**20**		41
Z_4	0	**3**		3

Table 3 presents the kinds of reinforced concrete steel bars used in buildings. Most of the buildings have S220 steel class. The results obtained show that; the steel class also has an effect on ensuring the expected level of performance and that; S420 is more efficient in ensuring the expected level of seismic performance. When the buildings were studied in terms of the average concrete comprehensive strength (concrete class), they were observed to be rather below the 14MPa (C14).

TABLE 3
STATISTICAL DISTRIBUTION OF HOSPITAL BUILDING TO STEEL TYPES

	IO	LS	CP	C
	Decision			
Steel Type	Non-Operation	Strengthening		Failure
S220 (Plane bar)	2	**29**		52
S420 (Ribbed bar)	3	**18**		14
S220-S420 (Mix)	4	**0**		8

Turkish earthquake regulations went through a comprehensive revision in 1998. The buildings studied within the framework of this research were also grouped according to their construction dates. Most of the buildings were observed to be constructed before 1998 (Table 4). It was found out that; construction decisions of the buildings that were built before and after 1998 did not show significant differences. This is related to the fact that; the terms of the regulations are not actually put into practice.

TABLE 4
STATISTICAL DISTRIBUTION OF HOSPITAL BUILDING TO CONSTRUCTION YEAR

	IO	LS	CP	C
	Decision			
Construction Year	Non-Operation	Strengthening		Failure
Before 1998	7	**27**		41
After 1998	2	**10**		25

4.2 Grouping the Hospital Buildings According to Their Strengthening Type

Preliminary strengthening projects were prepared for 47 buildings which had insufficient seismic performance, yet, which had strengthened potential theoretically. Whereas the "Shear Wall Adding + Jacketing" strengthening method was preferred in 21 of these 47 buildings, "Shear Wall Adding" was used in 10 of them. It is observed that; the reinforced concrete shear wall adding was mostly preferred in the strengthening process of the buildings (Fig. 3). In all of the buildings, it was necessary to strength the infrastructure (the base).

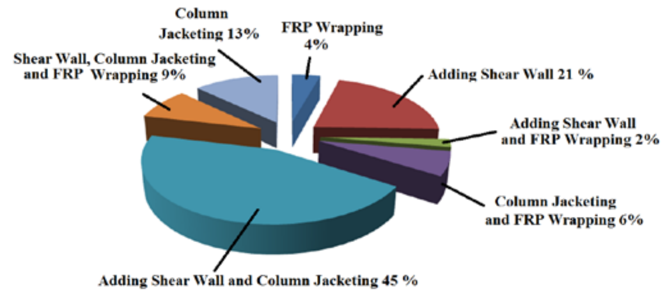

Fig 3. Distribution of strengthening types in examined Hospital Buildings

The most significant criterion in deciding whether to apply the prepared strengthening project or not is that; the cost shall not exceed 40% of the construction cost. As the strengthening costs exceeded 40% of the reconstruction costs in 80% of these 47 buildings, they were deemed to be inappropriate for strengthening. The final reinforced concrete strengthening projects and the relevant architectural projects were prepared for the remaining buildings.

5 EVALUATIONS OF THE STRENGTHENING BUILDINGS

Within the scope of the study, 47 of the 130 buildings that had been subjected to seismic performance analysis in Turkey in the last ten years were found to be worth strengthening. As the strengthening costs estimated in the preliminary strengthening projects exceeded 40% of the re-construction costs in the majority of these buildings, they were deemed to be inappropriate for strengthened. The carrier system final strengthened projects and the post-strengthening stage architectural projects were prepared for the remaining buildings. All of the strengthened buildings the ratio of strengthening got lower on the upper floors, the strengthening process created more significant changes on the architectural projects of the ground and underground floors. In the strengthening of these buildings, reinforced concrete shear wall addition and reinforced concrete jacketing method used.

During the study these main areas worthy of consideration emerged,

1. How the upgrade has affected users' experience of the building,
2. Whether there has been a loss of fundamental structural integrity.
3. How the strengthening has affected other architectural qualities such as interior space, lighting and acoustics. In this evaluation a suitable method should be chosen. it has been difficult to assess these parameters.
4. How affect the seismic upgrading of the building users' experience of, for example, scale and proportion, textural effects, daylight and hearing?
5. From an architectural perspective, does the structural strengthened solution cause new additional aesthetic problems?

6 CONLUSION AND FINAL REMARKS

The findings of this research can be expressed as the following items:

1. Structural strengthening is an issue that is on the agenda in highly seismic countries such as Turkey. The particular structural objective is that the building acquires the expected level of seismic performance of the strengthening. On the other hand; determination of the strengthening methods that would minimally affect the architectural structure of the building is also a significant research subject.
2. As most of the current hospital buildings in Turkey are insufficient in terms of seismic performance, these buildings need immediate strengthening or destruction.
3. As the strengthening costs exceed the reconstruction costs for the hospital buildings theoretically, not all the buildings can be strengthened.
4. Partitions and jacketing are mostly preferred in the strengthening processes.
5. In strengthened hospital buildings studied in this research, significant functional losses emerge with the strengthened. The main reason of this is observed to be the locations of the partition walls preferred and the reinforced concrete jackets.
6. It is very significant for the re-use of the strengthened building to perform with an suitable analyses before the production of the strengthening project advised for the complex buildings such as the hospitals.
7. In order to minimize the potential spatial problems that would emerge after the strengthening, spatial relationships of the hospital buildings shall be analysed according to alternative strengthening projects and the method that would have the least effect on these spatial relationships, shall be preferred.
8. The decision to repair and/or strengthen existing RC buildings depends not only on the field inspection of the structures but also in a cost/benefit analysis of the different alternatives of strengthening. In all steps archicetural evaluation of the buildings should be done.

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