A COMPARATIVE SEISMIC PERFORMANCE ASSESSMENT AND REHABILITATION OF EXISTING SCHOOL BUILDINGS

A. Yakut[1], Y. Tonguç[2] and P. Gülkan[1]

[1] *Dept. of Civil Engineering , Middle East Technical University, Ankara, Turkey*
[2] *Promer Consultancy Engineering Ltd. Co., Ankara, Turkey*
Email: ayakut@metu.edu.tr, yukselt@promer-eng.com.tr,a03516@metu.edu.tr

ABSTRACT :

Past destructive earthquakes in Turkey have revealed that seismic performance of existing school buildings is inadequate as evidenced by significant damage experienced by these buildings. As a result of the unexpectedly poor performance a comprehensive study has been initiated to assess and rehabilitate existing school buildings in many parts of the country. A special emphasis was given to the buildings located in İstanbul due to the perceived high probability of a severe earthquake there. Within this framework, a large number of school buildings in İstanbul have been selected for detailed assessment to determine whether there is a need for their rehabilitation to improve their performance. The study under the World Bank program ISMEP has been directed by a unit under the Governorship of İstanbul. Each school building was thoroughly surveyed to obtain its as-built structural layout, member sizes, geometrical features and material properties. The assessment was based on the recently promulgated Turkish rehabilitation code that suggests linear as well as nonlinear procedures for the assessment and rehabilitation purposes. In addition to code specified seismic forces, site specific seismic hazard analyses were carried out considering an M7.2 earthquake occurring in the Marmara sea segment of North Anatolian Fault. This study presents the results of seismic assessment carried out for approximately 50 reinforced concrete school buildings. Details of the building statistics containing their material quality, structural and architectural features are provided. All of the schools were investigated using linear analysis procedure whereas three selected schools were also assessed using nonlinear procedures based on pushover analysis. Due to lack of adequate calibration and validation of the procedures the code recommendations were found to be too conservative in the linear and nonlinear analyses.

KEYWORDS: Seismic assessment, School Buildings, Rehabilitation, RC buildings

1. INTRODUCTION

Recent strong earthquakes that occurred within the last decade in Turkey have led to significant damage of many school buildings that were observed to be seismically deficient. During the May 1, 2003 earthquake a number of seriously damaged buildings led to loss of lives of many students. Especially the tragic collapse of the Çeltiksuyu primary school dormitory in Bingöl in 2003 that killed 84 children had striking evidence of how vulnerable these buildings were (Turer et. al., 2003). These undesired consequences have prompted government officials to take actions in reducing seismic vulnerability of existing school buildings throughout the country. Within the comprehensive evaluation program, İstanbul gains a special emphasis due to its high probability of being struck by a major earthquake in the near future. The governorship of İstanbul has established a unit to implement the World Bank Program called ISMEP that is responsible for the seismic rehabilitation of important buildings in İstanbul. This study presents the methodology and results of evaluations carried out within ISMEP for a sample of sixty eight school buildings located in İstanbul. The objective of the project was to first assess the seismic performance of existing school buildings according to the requirements of the Turkish earthquake code (TEC, 2007) and recommend appropriate retrofit designs for the ones that were found to have inadequate capacity.

For all school buildings detailed site investigations were conducted to obtain their as-built properties and prepare all architectural and static plan drawings. So survey teams that were deployed to each site made necessary measurements, took adequate concrete samples and carried out destructive as well as nondestructive tests to obtain member sizes, member detailing and the mechanical properties of the materials. Geographical distributions of the buildings studied are shown in Figure 1. It is clearly seen that all buildings are located in the European side of İstanbul. The closest distance of these buildings to the Marmara segment of North Anatolian Fault (NAF) that was considered as the major seismic source ranges from 15-30 km.

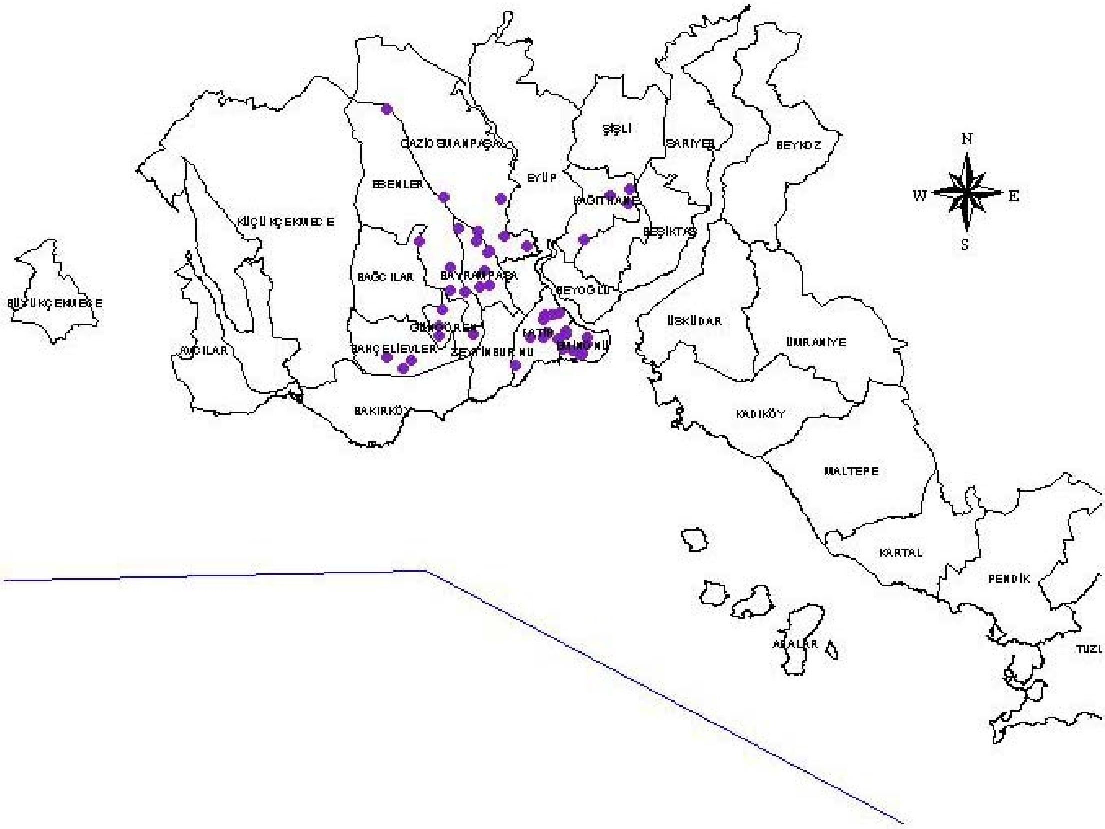

Figure 1 Distribution of buildings and the Marmara segment of NAF

2. STATISTICS OF EVALUATED BUILDINGS

Sixty eight reinforced concrete school buildings were investigated in this study. Figure 2 presents building statistics with respect to the number of stories. Majority of buildings had 3-5 stories dominated by 4 stories. Fifty eight buildings were located in the second highest seismic zone of Turkey, the remaining ten being in the highest zone according to the current seismic zone map. As indicated earlier, at least three core samples per floor were taken to determine the building specific concrete compressive strength to be used in the assessment. Distribution of concrete compressive strength shown in Figure 3 reveals that the concrete compressive strength was generally between 8-16 MPa with an average value of approximately 11 MPa. It is worth noting that the current code requires a minimum of 20 MPa for the design of buildings. From visual inspection, it has been observed that generally plain bars having characteristic yield strength of nearly 200MPa were used.

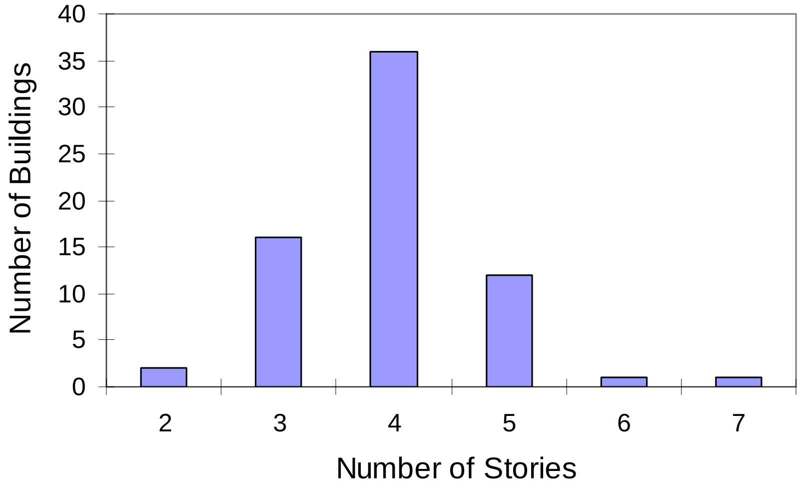

Figure 2 Distribution of number of stories

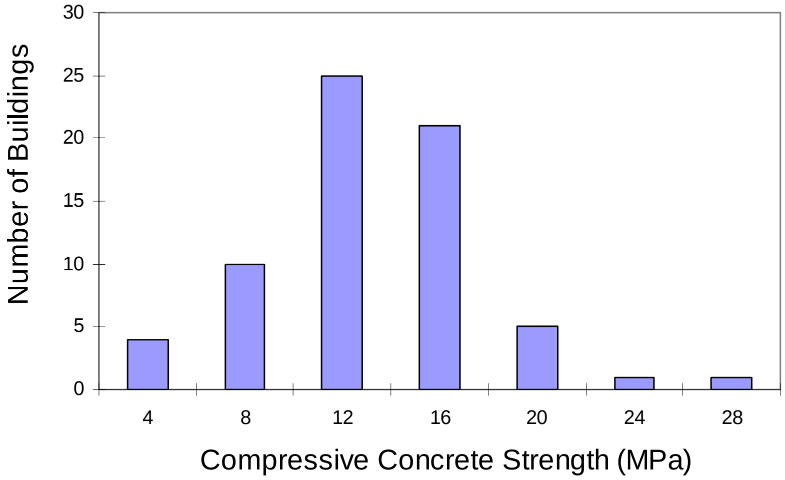

Figure 3 Distribution of concrete compressive strength

The structural system of all buildings studied was made of reinforced concrete with varying percentage of the column and shear wall area. Since the density of shear walls in a given principal direction is believed to have a prominent role in the seismic performance of the buildings (Gulkan and Sozen, 1999; Yakut, 2004), the histogram showing shear wall densities were obtained as presented in Figure 4. The shear wall densities obtained here represent the minimum value of the shear wall area divided by the total floor area above the ground floor level corresponding to the two principal directions of the building. It is not surprising to observe that most of the buildings have no shear walls.

The response spectrum given in the Turkish seismic code (TEC, 2007) corresponding to seismic zone 2 is shown in Figure 5 along with the predominant periods of the buildings evaluated. As evidenced in this figure, most of the buildings fall into the constant velocity region of the spectrum.

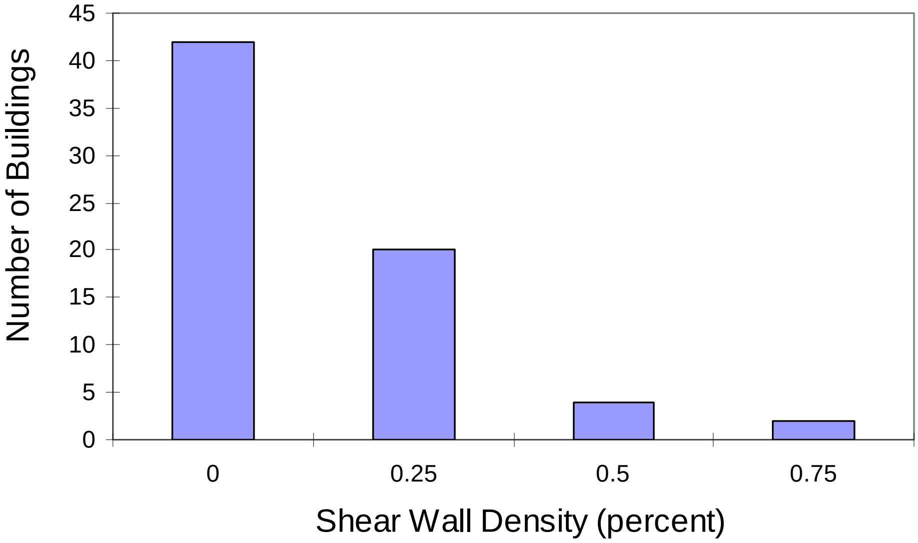

Figure 4 Shear wall density of the buildings

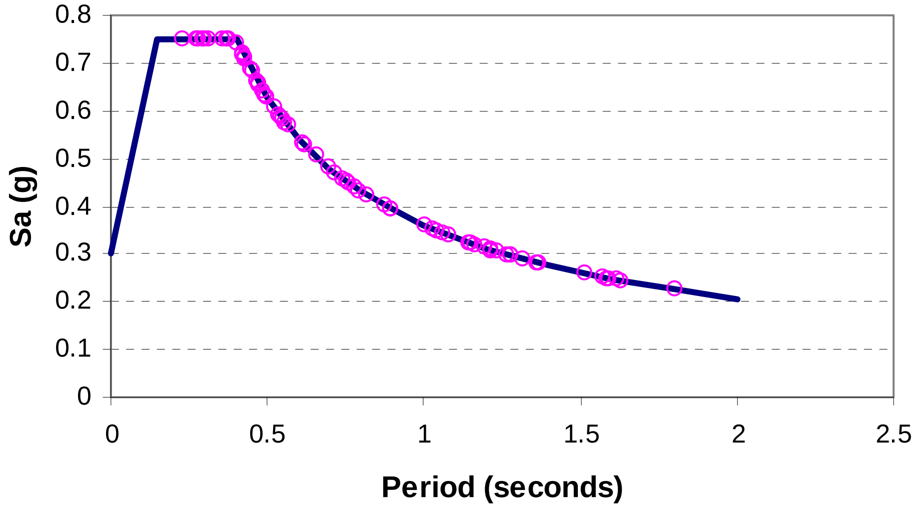

Figure 5 Response spectrum and periods of the buildings

3. ASSESSMENT OF BUILDINGS

3.1. Preliminary Assessment

For a first round of screening of the buildings, a preliminary assessment procedure developed by Yakut (2004) was applied to identify the buildings that are highly vulnerable. For this reason, shear wall and column areas in the ground floor were used along with the corresponding concrete strength to approximately obtain the basic capacity index (BCPI) using Equation 1. Here, V_{yw} and V_{code} are the approximate yield base shear capacity and the code base shear demand, respectively. Evaluation of damage data obtained from past earthquakes indicated that a limiting value of 1.2 is reasonable cutoff to classify highly vulnerable buildings. Figure 6 presents BCPI calculated for each buildings and the cutoff value. The buildings located below the cutoff value are classified as highly vulnerable.

$$BCPI = \frac{V_{yw}}{V_{code}} \qquad (1)$$

The results of this evaluation show that forty seven buildings have inadequate capacity and are considered highly vulnerable (Figure 6). Included in the forty seven building set with high vulnerability are generally the ones without shear walls (forty buildings).

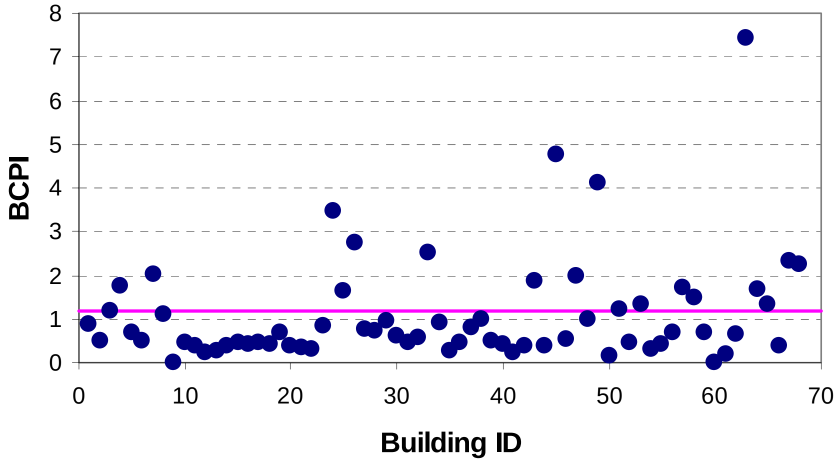

Figure 6 Shear wall density of the buildings

3.2. Detailed Assessment

In order to determine whether any of these buildings need retrofit, detailed assessment of these buildings were carried out based on the linear analysis procedure outlined in the Turkish seismic code (TEC, 2007). The procedure required by the code is based on linear static or dynamic analysis of structural models under the spectra either specified in the code or obtained from site specific analysis. A scenario earthquake of M_w7.2 on the Marmara segment of NAF was considered to obtain the site specific response spectrum at each site. The spectrum (either code spectrum or site specific spectrum) that had the maximum intensity at the fundamental period of the building was used in the analysis.

For school buildings, two performance objectives namely immediate occupancy and life safety are required to be satisfied. For immediate occupancy the spectrum shown in figure 5 that corresponds to a probability of exceedence of 10 percent in 50 years is used whereas for life safety the spectrum of figure 5 is multiplied by 1.5 to imply the probability of exceedence of 2 percent in 50 years. For RC buildings, columns, shear walls and beams are considered as primary structural elements that are classified as ductile or brittle based on their expected failure mode. The code requires all members to be ductile and allows a certain number of members to not satisfy the acceptance limits given in the code for each performance level. The acceptance limits are specified in terms of demand capacity ratios that depend on the member type and parameters related to confinement and ductility. The acceptance criteria for ductile members represent the bending moment demand divided by the bending moment capacity. Each member is first checked to determine its expected damage state based on the specified damage limits. The ranges of the damage state limits for each member are given in Table 1. For beams these limits depend on the confinement, shear force level and reinforcement percentage. The level of axial load, confinement and the shear force are used to determine the damage limit values for columns. For shear walls, only two damage limit values that are based on the presence of confinement at wall end region are given. Once all members are checked against these limits, the decisions regarding acceptability of the building is made based on a global evaluation. In the case of immediate occupancy, no column or wall is allowed to exceed the minimum damage limit but at most 10 percent of the beams are permitted to exceed these limits in each floor. For life safety performance objective, however, in each floor 20 percent of the columns/walls and 30 percent of the beams are permitted to exceed the significant damage limits.

Table 1. Demand Capacity Ratio ranges for all damage states

Member	Minimum Damage Limit		Safety Limit (Significant Damage Limit)		Collapse Limit (Severe Damage Limit)	
	Minimum value	Maximum value	Minimum value	Maximum value	Minimum value	Maximum value
Beam	1.5	3.0	2.5	7.0	4.0	10.0
Column	1.0	3.0	1.0	6.0	1.0	8.0
Shear Wall	2.0	3.0	4.0	6.0	6.0	8.0

The linear assessment results indicated that 64 school buildings did not satisfy the requirements of the code. The ones that were found to satisfy the code had basic capacity index value greater than 2 and the shear wall density greater than or equal to 0.6 percent. Out of 64 buildings that were found to be inadequate, 18 were decided to be demolished mainly due to their inadequate capacity. Most of these buildings did not have any shear walls and had low concrete compressive strength. It is also important to emphasize that retrofit schemes for some of these buildings led to unfeasible costs which directly affected the decision. These outcomes indicate that the linear assessment procedure outlined in the code is over conservative as compared to the preliminary assessment.

3.3. Assessment using nonlinear procedure

In order to make comparisons, the nonlinear assessment procedure described in the code was applied to three selected buildings that were found inadequate according to the linear assessment procedure. In the nonlinear assessment procedure, pushover analyses of selected buildings have been carried out first. Then performance point on the pushover curve was calculated under the code spectrum. Figure 7 shows the pushover curves and performance points for the weak direction of the buildings analyzed. Since nonlinear assessment of the code is based on comparison of damage state limits that are expressed in terms of the strain values, maximum strains in steel and concrete are obtained in each member corresponding to the performance point.

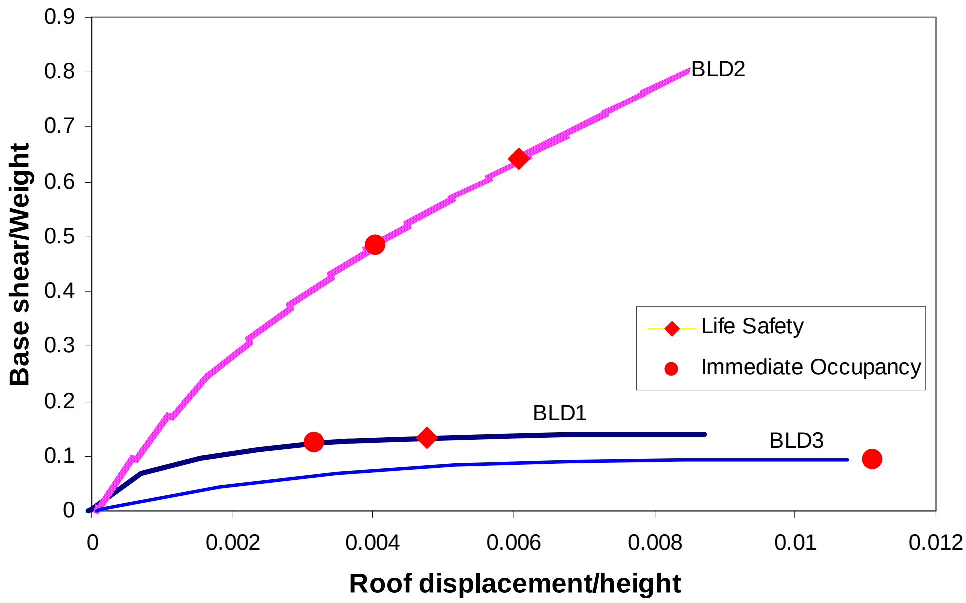

Figure 7 Pushover curves and performance points

The building identified as BLD2 has much larger capacity than others mainly due to its small total plan area (1531 m^2) and high concrete strength (15.4 MPa). BLD3 has no shear walls and relatively low concrete strength (10.8 MPa) leading to very low seismic capacity as illustrated in Figure 7. Although BLD1 has shear walls (with a density of 0.31 percent) its low concrete strength (7.5 MPa) resulted in low capacity. As can be seen from Figure 7 the target displacements corresponding to the two required performance objectives reveal that BLD1 and BLD3 do not satisfy the performance requirements. BLD2 satisfies life safety requirements but fails immediate occupancy performance. It is worth noting that all of these buildings were classified as highly vulnerable in the preliminary assessment phase. Although, both nonlinear and linear procedures suggest that these buildings be retrofitted, the number of members not satisfying any given performance objective are much larger in the linear procedure. This is due to that the damage limit states expressed in terms of steel and concrete strains in the nonlinear procedure are very high.

4. REHABILITATION OF BUILDINGS

The final decisions that came out of the assessments led to classification of four buildings as safe, forty six buildings as needing rehabilitation and the remaining eighteen buildings to be demolished. The most feasible and practical rehabilitation scheme was found to be insertion of reinforced concrete walls and jacketing of the columns. This type of rehabilitation is the most common technique used for RC buildings in Turkey. The aim is to strengthen the overall structure relying on the capacity of newly added walls and increase axial load capacity of columns by RC jacketing. Regardless of the existing material properties, concrete compressive strength and reinforcing steel yield strength for the added components and parts were specified to be 25MPa and 420MPa, respectively. A typical rehabilitation scheme designed for BLD3 is shown in Figure 8. As can be seen, added walls are generally placed between the columns to fill the whole span. This way an efficient connection between the added walls and the existing framing is ensured. All rehabilitation designs were checked by assessing the performance of rehabilitated buildings according to the linear analysis procedure of the Turkish code to verify their adequacy. A comparison of shear wall densities in the rehabilitated versus existing buildings displayed in Figure 9 reveals that added shear wall density varies from 0.1 to 0.6 percent. The typical density of shear walls per total floor area in rehabilitated buildings was around 0.4 percent.

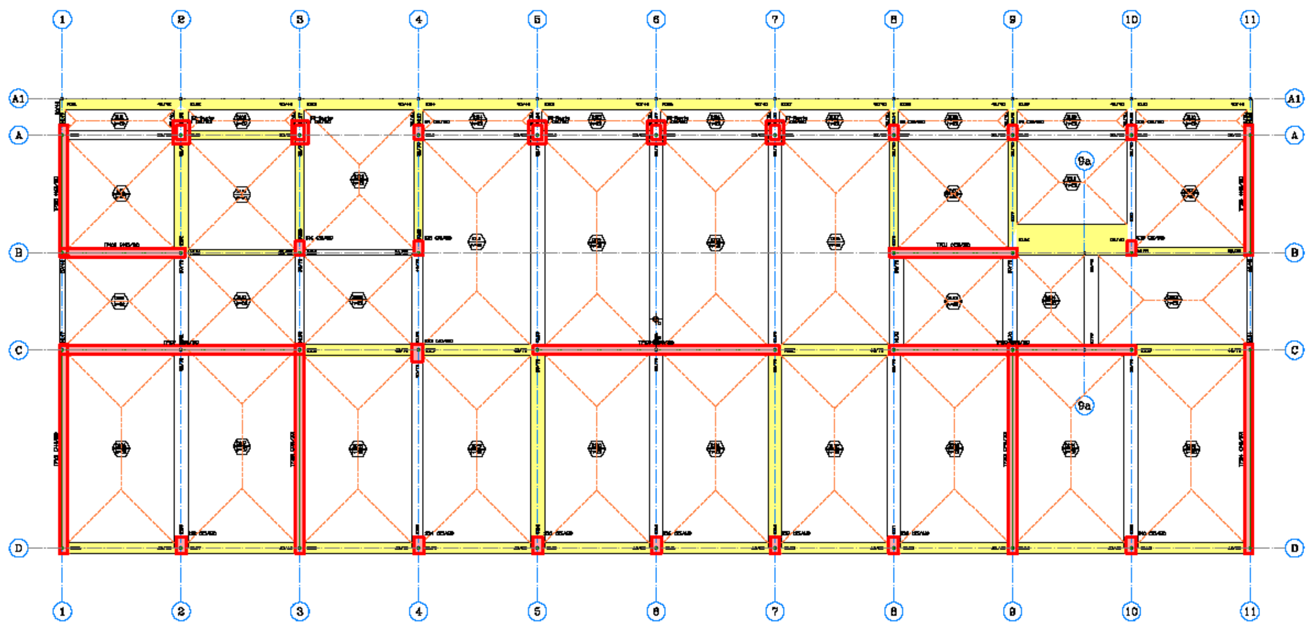

Figure 8 Floor plan of rehabilitated BLD3

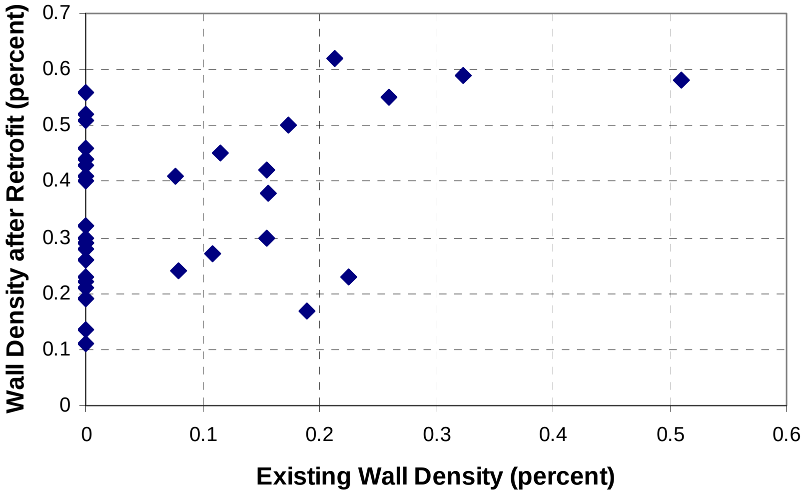

Figure 9 Shear wall densities in rehabilitated versus existing buildings

5. SUMMARY

A subset of existing school buildings located in İstanbul was assessed according to the requirements of Turkish seismic code to determine their expected seismic performance. The buildings were also assessed by a preliminary procedure using their basic structural features. In order to make a comparative evaluation three buildings were subjected to the nonlinear assessment procedure as well. It has been found that the assessment based on the linear procedure results in more conservative evaluation with respect to the preliminary assessment procedure. Based on the requirements of the code forty six buildings were rehabilitated by adding RC concrete walls and jacketing the columns to increase their axial load capacity. The buildings studied here comprise only a part of some 500 buildings that are included in the ISMEP project. The next step that is underway will be to implement the rehabilitation designs developed here.

ACKNOWLEDGMENTS

Structural Engineers, Bora Eyce and Senay Uzun of PROMER Ltd. Co. carried out modeling and structural analyses of the buildings, their contribution is greatly acknowledged. The authors would like to extend their appreciation to graduate student Ilker Kalem for his help with the post processing of data.

REFERENCES

Gülkan, P. and Sozen, M. A. (1999). Procedure for Determining Seismic Vulnerability of Building Structures. *ACI Structural Journal*, Vol. 96, No. 3, pp.336-342.

Turkish Ministry of Public Works and Settlement, TEC. (2007). Specifications for Buildings Constructed in Disaster Areas, Ankara, Turkey.

Turer, A., Akyuz, U., Yakut, A. And Yalim, B. (2003). School Building Damage Assessment after Bingöl Earthquake, *International Conference in Earthquake Engineering to Mark 40 Years from Catastrophic 1963,* Skopje, CD-ROM.

Yakut, A. (2004). Preliminary seismic performance assessment procedure for existing RC buildings, *Engineering Structures*, Vol. 26, No. 10, pp. 1447–1462.