A New Approach for Assessment and Retrofit Designs of R/C School Buildings in Turkey

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ABSTRACT

This study investigates whether the new performance based approach yields benefits in the earthquake assessment and retrofit design of existing reinforced concrete school buildings in Turkey.

In the methodology set out for one of the components of Istanbul Seismic Risk Mitigation and Emergency Preparedness Project, some modifications to the Turkish Earthquake Code 2007 are proposed for assessment of school buildings. The reason for these changes is simply to remove some areas of unnecessary conservatism that are likely to have a significant effect on the assessment and retrofit of the particular buildings to be considered. The objective is to minimize the costs of retrofit of these buildings and at the same time achieve and demonstrate an acceptable resistance to the effects of earthquake. The impact of the new approach will be to allow more buildings to be assessed and retrofitted for the same cost. Thus, a comparison will be made between the results using the adopted approach to assess and retrofit school buildings for seismic performance improvement of school buildings and an approach recently recommended and used by Prota Engineering Ltd. under the scope of the Project.

The proposed methodology calculates the expected ground motions using a recent ground-motion predictive model derived by Akkar and Bommer (2007). The proposed methodology also adopts a deterministic approach for assessing the likely seismic hazard levels that are based on a realistic scenario event for maximum credible earthquake. The structural analyses, in general, were based on the equivalent lateral static load method except for the structures with dominant vertical irregularities. In such cases the mode superposition method has been applied per code provisions.

The subject school buildings were assessed both by considering the Life Safety and Immediate Occupancy performance levels dictated by the scenario earthquake.

The results would indicate that the new approach minimizes the cost of retrofitting and achieve an acceptable performance level to the earthquake effects.

Keywords: Earthquake Performance Assessment, Retrofitting Designs

1 INTRODUCTION

Prota Engineering and Consultancy Ltd (Prota), supported by specialist sub-consultant Beca International Consultants (Beca) carried out the seismic assessment of 241 school buildings within the Municipality of Istanbul undertaken for the Istanbul Project Coordination Unit (IPCU) as part of the Istanbul Seismic Risk Mitigation and Emergency Preparedness Projects.

The assessment methodology developed by the Authors (in close cooperation with the IPCU) was based on the requirements and methods presented in the Chapter 7 of the 2007 edition of the *Turkish Earthquake Code* (TEC2007)[1] and *Guidelines for Seismic Retrofitting of School and Hospital Facilities in Istanbul*[2] issued in draft by the IPCU in May 2008. In the methodology set out below, various modifications and alternative approaches to the TEC2007 are proposed for assessment of school buildings.

The reason for these modifications is to provide relaxation to some areas of unnecessary conservatism that is likely to have a significant effect on the assessment and retrofit of the particular buildings to be considered. The objective is to lower the costs of retrofitting these buildings and at the same time upgrade them to an acceptable resistance to the effects of earthquake. The impact of the new approach will be to allow more buildings to be assessed and retrofitted for the same cost without increasing their seismic risk.

In addition to the detailed methodology submitted for approval early in the project, a series of nonlinear push-over analyses have been undertaken to confirm the demands on foundations, and to minimize the strengthening required to meet the performance criteria. Prota's strengthening methodology sought to minimize disruption and redecorating costs by providing additional external members wherever possible. The success of this has been confirmed by the construction cost estimates.

Within the content of this project, 242 individual building blocks in 121 campuses had been assessed, with a total floor area of 401,557 m^2. This paper presents modifications made on TEC2007, in terms of assessment and retrofit design and beneficial consequences through the applied methodologies.

1.1 Standards, Codes And Utilized Software

First Earthquake Code in Turkey has been published following the Major Erzincan Earthquake in 1940. The Code is named as Provisional Building Guidelines in Earthquake Zones. This code was subjected to revisions in 1942 and 1947. The Code dated as 1953 in the name of Regulations on Buildings to be Built in Earthquake Zones accepted as first significant publication. A revision was published to this in 1961. The first complementary Earthquake Code, Regulations on Buildings to be Built in Disaster Regions was published in 1968. The Code re-published in 1975 with the same name has been admitted as the first code prepared in consideration of similar applications in developed countries. This Code has been almost re-written in 1998. Distribution of project buildings in terms of effective codes during their construction is given in Table 1.

Table 1: Distribution of Buildings According to their Effective Earthquake Codes

Year of Construction	Before	1940	1953	1968	1975	After
Ratio of Buildings to Total	1%	5%	19%	22%	50%	3%

Latest Earthquake Code in Turkey has been published in March 2007, *Specification for Buildings to be Built in Seismic Regions* (TEC2007) by the Ministry of Public Works and Settlement, Government of the Republic of Turkey. Its use in ISMEP is really one of the first test cases for the implementation of assessment and retrofit standards that are regulated by this 2007 revision. Our methodology did propose to waive in some parts of this code namely in *Chapter7, Assessment and Retrofit of Existing Buildings.*

Assessment analyses have been carried out using the software Probina Orion V15[3], the in-house development of Prota and SAP200 V10[4].

2 DESCRIPTION OF THE METHODOLOGY

2.1 Seismology and Ground Motion

The design spectra given in the TEC2007 are based on the peak ground acceleration (PGA) estimations computed from the median +1σ values of the Joyner and Boore (1981) predictive model. Today, it is widely accepted that this relationship will lead to conservative predictions of shaking due to the lack of magnitude saturation in the functional form, and the limitations of the database of strong motion records that was as a basis for their derivation over 25 years ago. In other words, the latest research would indicate that the maximum earthquake which might occur under the Marmara Sea along a specific part of NAF is very unlikely to produce shaking of the intensity represented in TEC2007. In fact, the extensive research into the seismicity of Marmara region by Ambraseys and his co-workers (Ambraseys and Jackson, 2000[(5)]; Ambraseys, 2002[(6)]; Ambraseys 2006[(7)]) showed that the greatest damage in İstanbul was caused by the earthquakes of 1509, 1754 and 1766 with magnitudes, M_s, ranging between 6.8 and 7.2. The corresponding fault rupture lengths are anticipated to be between 70 and 80 km. These events are smaller than the largest earthquakes experienced by the region (i.e., 1719 - M_s 7.4, 1912 - M_s 7.3, and 1999 - M_s 7.4).

For this project it is proposed to derive the expected ground motions using the more recent attenuation relationship of Akkar and Bommer (2007)[(8)]. This predictive model utilizes a greater database of strong motion records that is now available, including records from the recent earthquakes in Turkey (e.g. 1999 Kocaeli and Duzce earthquakes), and addresses many of the recognized concerns of the earlier Joyner and Boore estimates. Two scenario earthquakes are developed for this project:

- An earthquake with moment magnitude, Mw=6.5 occurring on the North Anatolian Fault (NAF) for use in the assessment of immediate occupancy requirements, and
- An earthquake with moment magnitude, Mw=7.5 occurring on the NAF for use in the assessment of life safety requirements.

For both scenarios, the earthquakes are assumed to originate at the shortest distance from each building to the NAF. The effect of the particular soil classification at each site is also taken into account as described below. Figure 1 gives the site-to-source distances of the school buildings considered in this project.

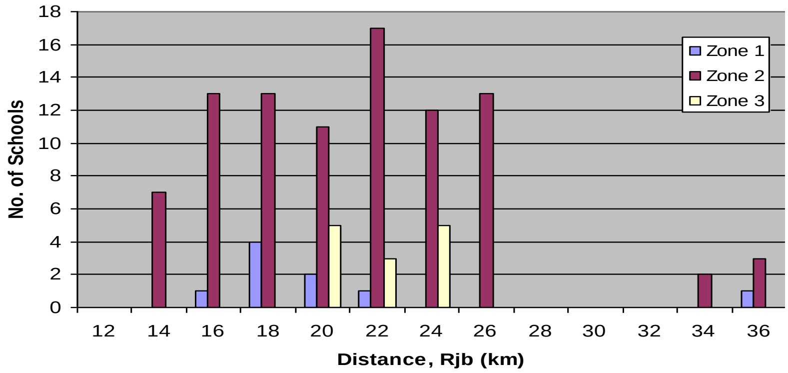


Figure 1. Distribution of school buildings as a function of distance and earthquake zones in TEC 2007 Performance Assessment Methodology

The Mw =6.5 and Mw = 7.5 spectra are respectively based on median and median +1σ of shaking. The later spectra represent an increase of approximately 35% on the median estimates for the same earthquake. The Mw =7.5 spectra derived above may be considered to be maximum credible levels of shaking in accordance with internationally accepted procedures.

The verification of Life Safety performance requirements is carried out using demand spectra derived conservatively as follows;

- The 5% damped earthquake spectrum having an exceedence probability of 2 % in 50 years (2%/50) is calculated in accordance with TEC2007 using the appropriate earthquake zone and soil class.
- The 5% damped site specific median+1σ spectrum is calculated for the Mw = 7.5 scenario earthquake using the spectral ordinates estimated by Akkar and Bommer (2007).
- The average of the site specific spectrum and the 2%/50 spectrum described in the first bullet is be calculated and used for the analyses.

This averaging technique described above provides comfort that the demand spectra adopted for this project do not differ markedly from TEC2007.

2.1.1 Performance Analysis Method

For the seismic performance analysis of existing and retrofitted buildings, "Linear Elastic Performance Assessment Method", which is presented in Chapter 7.5 of TEC2007, has been used. "*Equivalent Earthquake Load Method*" may apply to the buildings those torsional irregularity coefficient (η_b) is less than1.4. As stated in the code, otherwise, "*Modal Superposition Method*" has been used. R_a has been set equal to 1 (unity) for the calculation of total base shear and the right hand side of the equation has been multiplied by λ coefficient. λ coefficient will be taken 1.0 for one or two storey buildings and 0.85 for others. The general outline of the methodology will not be outlined here since it can be referred from the TEC2007 in details, rather mainly the modifications and relaxation made will be focused.

2.1.2 General Modelling Considerations and Parameters

TEC2007 requires that the calculation of seismic mass to include 60% of the live load acting on the structure. In the proposed approach, the inertial mass is comprised of dead load, snow load and 30% of live load. This more realistic approach takes into account that is unlikely that most of the live load would be present during a seismic event. Flexural rigidities (EI_c) of cracked section for the structural members under the bending effect have been used.

Additional accidental eccentricities have not been applied, building importance factor have been ignored and infinitely rigid end zones were defined at the beam/column connections in the analyses as recommended by TEC2007. Knowledge level coefficient will be taken as "1.0" due to the fact that detailed information on geometry and material properties have been collected from the school buildings.

2.1.3 Performance Levels

Due to the nature of the way the method described in TEC2007, Linear Elastic Performance Assessment Method generally yields more conservative results than non-linear analysis approaches. According to TEC2007,

a) A building meets the life safety (LS) performance level, when no more than 30% of primary beams and 20% of the columns are in the "Severe Damage Zone" for any direction of earthquake loading.

b) A building meets the immediate occupancy (IO) performance level, if no more than 10% of primary beams and no columns are in the "Moderate Damage Zone" for any direction of earthquake loading.

Based on the results obtained by several case studies carried out to compare linear and non-linear approaches these limits are increased to 40% for primary beams and 30% for the columns for LS and to 20% of primary beams for IO performance level.

For all performance levels, if at least 75% of the total base shear force is carried by shear walls (whether existing or retrofitting walls), the performance checking of the beams were ignored along that earthquake direction.

2.2 Retrofit Design Methodology

By adding the new shear walls to the existing building, a new structural system has been revealed. These new members have been designed to achieve sufficient capacity for the actions of new (total) structural system.

Appropriate connection details have been provided to achieve sufficient integrity between the new members and the existing building. The main design objective of the anchor system is to transfer the inertial forces from the existing structure to the added shear walls such that the estimated lateral load capacity of the added wall can be achieved. Connection design was performed by the analysis results that are using the spectrum determined for the Life Safety performance evaluation in Section 2.1 of this report, since it is greater than the Immediate Occupancy Spectrum.

In many situations, separated building blocks were connected by removing the construction joints to prevent the pounding of the parts during the earthquake excitations. Appropriate connection details have been provided to achieve sufficient integrity between the connected blocks.

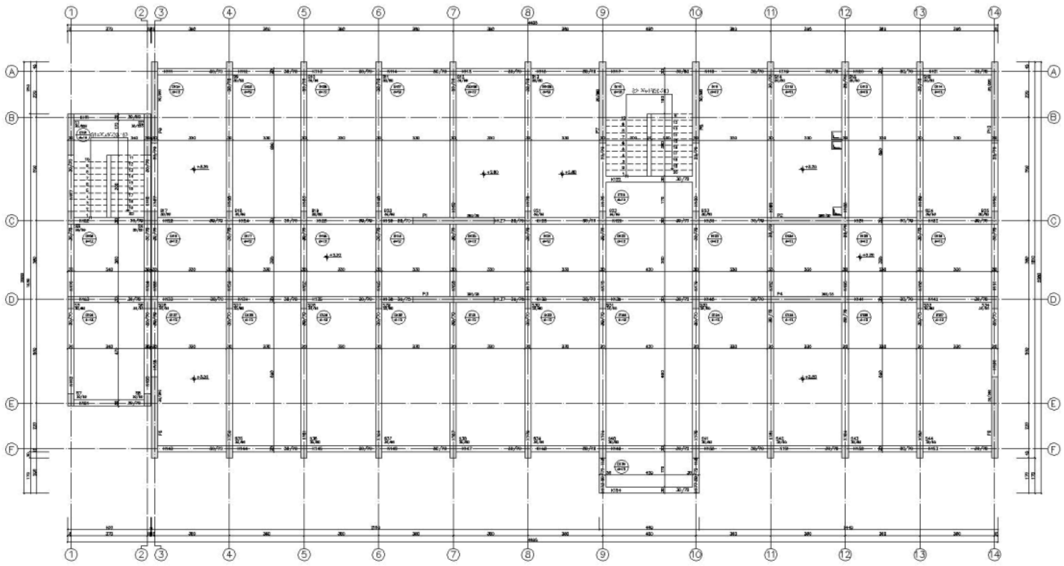
3 ILLUSTRATIVE EXAMPLE ON IMPLEMENTATION

The building selected for being an illustrative example was a typical design (Type 10403YA) issued by the Ministry of Public Works and Settlement, designed according to 1975 code and constructed in 1993. Within the content of the work, there were 34 buildings of this typical school group.

3.1 General

The particular school building under consideration had two blocks separated by an expansion joint constructed using in-situ concrete (Figure 2). The four storey 40 x 19 m main building is a reinforced concrete frame structure. The stair tower is attached to the left edge of main building (Figure 3).

Figure 2: Front Exterior and Aerial Views of Example Building



+3.20 KOTU KALIP PLANI
+3.20 LEVEL FORMWORK PLAN

Figure 3. Typical Structural Plan of Example Building

In the main building, four shearwalls are placed within the interior frames along the longitudinal direction and four shearwalls at the edges and two at each side of the internal stairs are placed along the transverse direction. For enhancing the lateral stiffness of the stair tower, two short shearwalls were provided to each side of the stairs which are effective only along the transverse direction. Typical storey height of the four storey building blocks are 3.1 m. 120 mm thick two-way slab panels are forming the floor rigid diaphragms in all floor levels. This school was located on Z3 class soil (as defined in TEC2007) and two-way grillage type foundation consist of 1 m deep beams located along the frame lines were constructed.

3.2 Material Properties

The original structural designs of this particular building were available. As in all other school buildings, reinforcing steel details for the structure above ground level were confirmed by Ferroscan to be as shown on the original construction drawings.

In order to determine the concrete quality, cores have been taken from the concrete members in all floors. Concrete compression strengths ranging from 11 to 24 MPa with an average of 18 MPa and σ of 2 MPa were obtained. The representative concrete compression strength for the building was determined using mean minus 1σ of these results yielded 16 MPa. The representative steel strength was determined by carrying out a test on a steel bar sample taken from the building, yielding 220 MPa. All the reinforcement used in the building is undeformed plain bars.

3.3 Design Spectrum

The site-specific design spectrum for the 2475-years scenario event and the corresponding design spectrum proposed by TEC (2007) have been averaged to define the seismic input level for the seismic performance assessment of the school buildings in this project.

For this particular example building the final spectrum obtained by averaging is more conservative than the deterministic spectrum obtained by Akkar and Bommer (Figure 4). Figure 5 gives the spectra used for the example building for Life Safety and Immediate Occupancy performance levels.

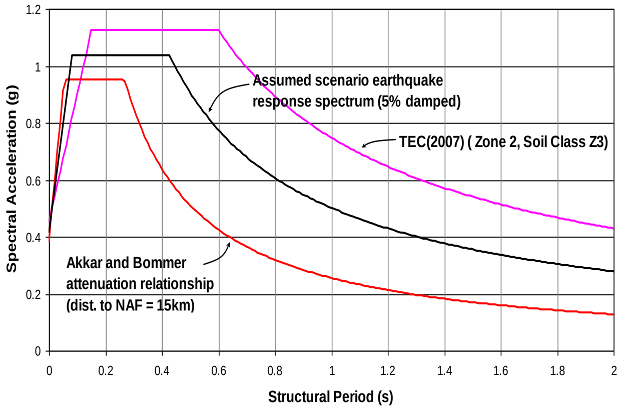


Figure 4. Scenario Earthquake Acceleration Spectrum

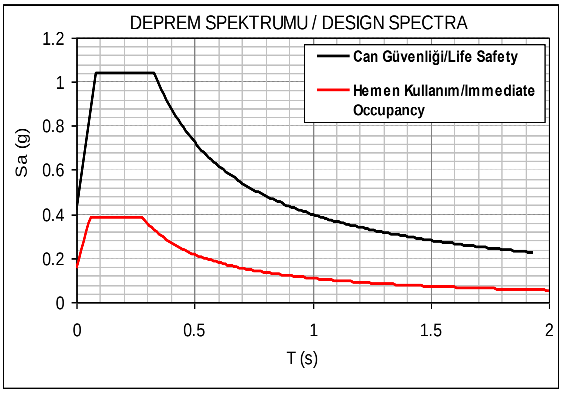


Figure 5. Scenario Earthquake Acceleration Spectrum

3.4 Performance Assessment and Retrofit Design

The linear elastic analysis methods defined in Section 7.5 of the Turkish Earthquake Code (TEC2007) with the above mentioned modifications have been used to verify the adequacy of the retrofit of this building. In addition, several analyses using the non-linear static (single-mode) pushover method defined in Section 7.6 of the TEC2007 have been carried out without considering the relaxations proposed in the above outlined approach to verify the results of the linear-elastic assessment method. These non-linear analyses were carried out to selected representative buildings for fine-tuning the modified parameters.

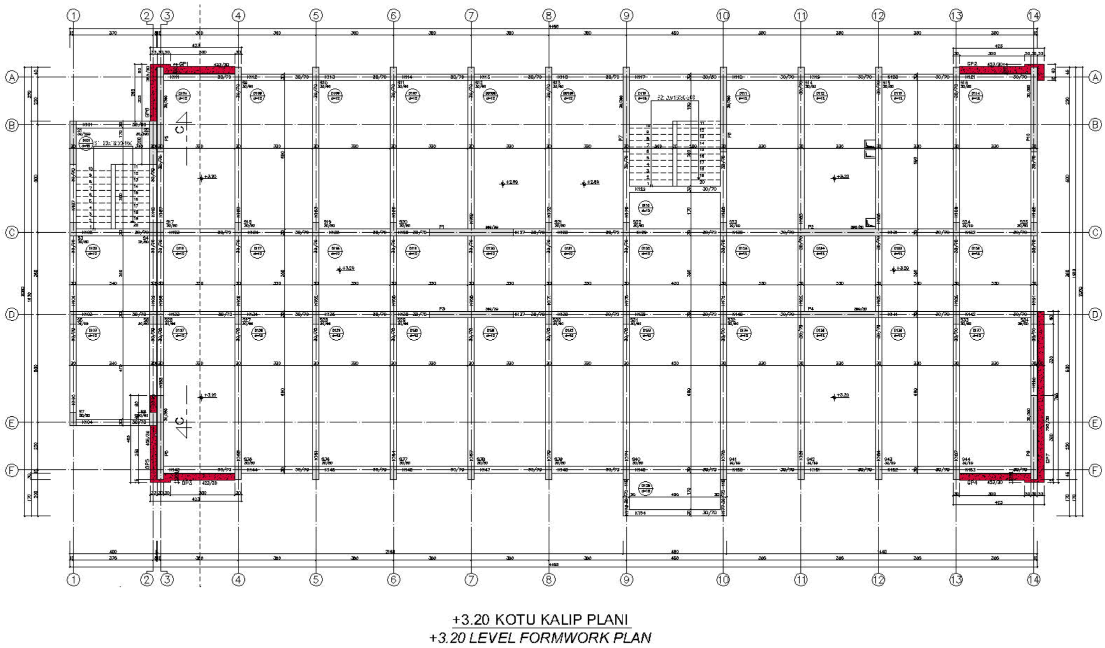


Figure 6. Typical Structural Plan of Retrofitted Building

After considering several retrofitting alternatives envisaged in the Preliminary Design Phase, it has been decided that four shear walls in the longitudinal direction and three shear walls in the transverse direction should be added to the building as the final retrofit decision (Figure 6). Mainly due to the fact that the lateral stiffness of the stair tower is considerably weak along longitudinal direction, the gap of the expansion joint between the two blocks of the building is insufficient to prevent the pounding of the parts during the earthquake scenario described above. For that reason, it has been decided to remove the expansion joint and connect the two blocks together to remove this deficiency.

A cost analysis has been completed for the final designs of all buildings. For the example building, the total cost of retrofitting process was 13% of the cost of new building.

4 CONCLUSIVE RESULTS

Based on the assessment analysis results of 121 campus and 242 buildings under the scope of the project, 5% of the schools (13 buildings) determined to have adequate strength to withstand to the scenario earthquake and 35% (87 buildings) were decided to be demolished. Demolish and re-built decision is taken for the buildings that retrofit cost is higher than 40 % of the new building cost as result of cost analyses. The remaining 60% of the schools (142 buildings) were decided to be strengthened and retrofit designs were prepared using the methodology outlined above.

Obtained results provide an overall indication on the earthquake performance status of the schools in Istanbul. Retrofit costs of schools have been decreased considerably by means of new retrofit techniques applied under the Project. It should also be noted that if corrosion problems which were observed in most of the schools haven't had been existed, the rate of retrofitting/new building costs would have dramatically been lowered.

Table 2. Distribution of Cost Rates of the Retrofitted Buildings

Cost Rates	11-15 %	16-20 %	21-25 %	26-30%	31-35 %
Ratio of Building to Total	39%	20%	14%	19%	8%
Number of Buildings	56	28	20	27	11

Table 2 shows the distribution of cost rates (retrofitting cost per new building cost) for the buildings which are to be retrofitted under the scope.

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