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Investigation on the Possibility of Matching Vulnerability Assessment with Field Observations for Real Structures

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ABSTRACT

Assessment of exiting structures is a challenging issue that is of increasing importance in the last decades. There are, however, a number of uncertainties, which may result in unrealistic estimations of the expected demand. It is widely accepted, for example, that the uncertainties in defining the seismic loads may be one of the main reasons of non-accurate estimations of the structural response. The misprediction of the overall response may however be significantly affected also by the use of different techniques and approaches in calculation of the expected demand on the structure.

This paper is focused on two real case study structures that were built in the highly influenced areas from the 1999 earthquake of Kocaeli. The characteristics of the structures, as well as the field measurements allowed the authors to work on the structures in detail and calibrate their model and findings of the analyses and assessment. The assessment approach given in the latest version of the Turkish Earthquake Code (TEC) of 2007 has been adopted to approximate the structural demand as well as the observed structural damage distribution.

Results of the structural analyses based on TEC and those of the structural identification have been combined to assess the building performances, paying special attention to the possibility of matching the assessment results with the observed field data. There exist inconsistencies between the reality and the estimations, the possible reasons of which will also be discussed at the end of the paper.

INTRODUCTION

Just after the recent TEC was issued in 1997 the Marmara Earthquake that struck the Kocaeli, Sakarya and Bolu provinces on Tuesday, August 17, 1999, at 3:02 a.m. local time, Then after a new study for the new Turkish Earthquake Design Code (TEC, 2007) were initiated and has been enforced on the date 06.03.2007. The importance of the code was the being the first earthquake code in the world that includes the requirements applicable to existing buildings for evaluation and retrofitted before or after an earthquake. The assessment method given in TEC is based on the flexural deformation limit states and shear strength of the bearing members, which makes the approach performance based.

In the relevant chapter of the current TEC, the equivalent linearization methods, nonlinear static (pushover) procedures, and nonlinear time history analysis are provided for the structural assessment. Since the first two methods are based on linear elastic theory, it is easily applicable by current civil engineering community. It is worth mentioning that these methods are admittedly not verified by observed earthquake damages and there is no consensus about the validity of the procedures proposed in the TEC among structural engineering community and researchers. The method that is accepted with consensus as the best approximation for assessment of structures is the nonlinear time-history analysis. The sophistication, Uncertainties, and issues of ground motion selection of which have been subject to concerns and extensive research [2].

During the last two decades, performance based design and assessment methods have become rather more popular than the era they were firstly proposed. In the near future, it is likely that when new generation seismic codes are released, performance based approach will be the most common tool for the design of new structures. Currently, however, performance based design tools suffer from a major drawback that the representation of the seismic behavior is restricted with a single mode response. Therefore such methods can be reliably applied only to the two-dimensional response of low-rise, regular buildings.

The research project entitled as “Improvement of the Performance Based Design and Assessment Methods by Comparisons with the Structural Performances Observed After Earthquakes in Turkey” that is being funded by “The Scientific and Technological Research Council of Turkey (TÜBİTAK)” under the Grant No: 108M303 has the principal objective of verifying and calibrating the displacement based assessment procedures given in TEC as well as EC8 and FEMA 356 procedures. One of the prime objectives of the project is to contribute to the evaluation of the Turkish Earthquake Design Code, which is published on March 6th, 2007 and comparison with the other assessment codes such as FEMA 386, Eurocode 8, etc.

It was reported following the 1999 earthquakes that approximately 214,000 residential units and 30,500 business units were damaged in various degrees from light to substantial damage. Most of the damaged buildings were repaired and strengthened to conform to the 1998 Turkish Seismic Design Code. After the past eight years following the 1999 earthquakes, the researchers of the project have investigated a few hundred of the buildings that are still remaining untouched, just as the morning of August 17, 1999, due to several reasons. Among them, to crosscheck the results of the analysis methods, fifteen cast-in-place reinforced concrete buildings were selected for the detailed assessment studies. Eight of the selected buildings are located in downtown Adapazarı, while the rest are in Gölcük where earthquake epicenter is located. Fortunately, among the selected eight buildings six were bare frame reinforced concrete shear-bending moment resistant structures with several degrees of damages leading thus to a valuable opportunity of detailed investigation of the damages experienced.

In this article, two bare frame reinforced concrete structures are studied from the database of the research project of 108M303. The on-site measurements, damage states and distribution as well as the nonlinear analysis and assessment methods and their results are discussed in detail.

METHODOLOGY FOLLOWED

The structural assessment started with a visual inspection of the buildings. The available structural design documentations were collected for this purpose. The required input parameters, which were necessary for modeling of the structures, have been evaluated, and collected. The bore-hole data and related reports were extracted from the reports existing in the archives of the municipalities. The microtremor measurements at the test field and related evaluations were also collected. Concrete core samples have been gathered from some of the case study buildings and laboratory tests have been performed on the collected samples to obtain the material strengths. Concrete strength was determined by using rebound hammer testing for the rest of the buildings. The hammer is calibrated through laboratory tests on the core drilling samples.

Sophisticated finite element structural models were established to perform modal analysis, nonlinear static procedures and dynamic time history analysis. The rigidity center and mass center of the test buildings were computed by running the structural models. In order to record the ambient responses and forced vibration responses (i.e., harmonic responses) of the structures, 10 structurally important observation points were instrumented with three component accelerometers as shown in Figure 1. Locations of the sensors are the key points, which are assumed to reflect the structural characteristics. The equipment used for the measurement and data acquisition are DAC series accelerometers manufactured by Arel Electronics [3]. In case of the force vibration tests, eccentric vibration generator manufactured by Kinemetrics was mounted at the mass center of the top floor as shown in Figure 2.

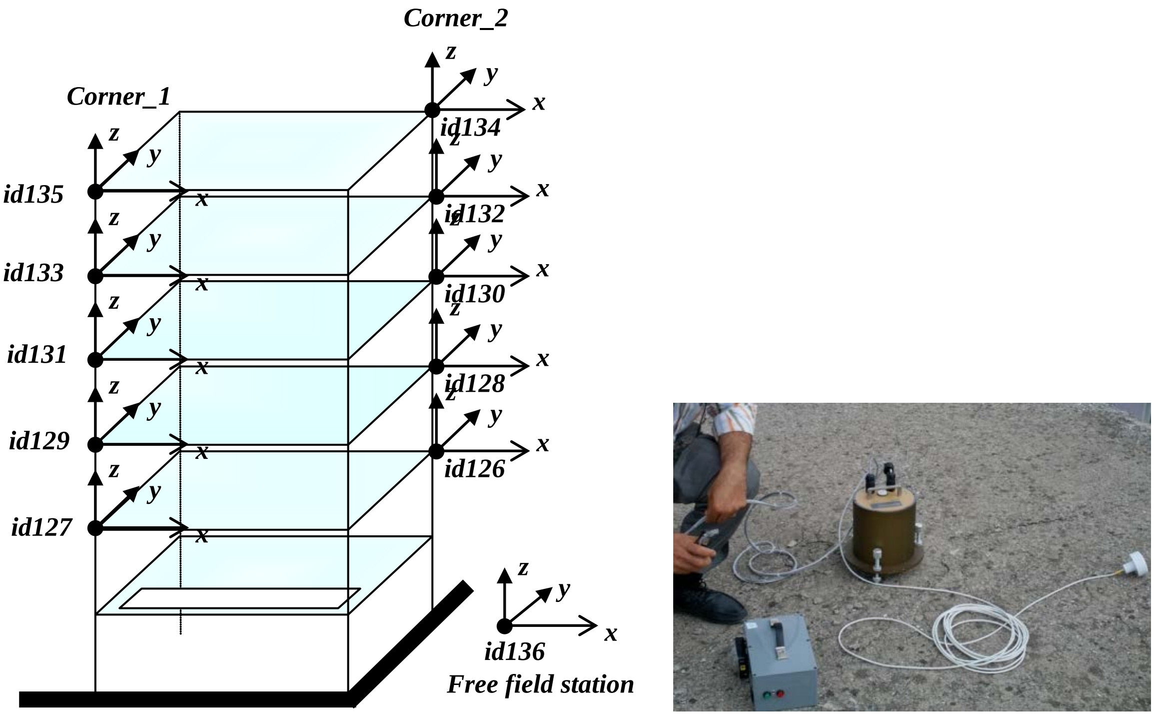

Figure 1 Building instrumentation

Figure 2 Vibration generator manufactured by Kinemetrics mounted at the top of the building

The data recorded from the ambient responses and harmonic responses of the structures were used to calibrate the accuracy of the mathematical models. Nonlinear static procedures and dynamic time history analysis were applied to the test structures to approximate the structural demand as well as the observed structural damage distribution for the structures.

NUMERICAL ANALYSES

The first case study structure (Dayal) is located in Serdivan district in Sakarya of the Marmara region, where the recent Turkish earthquakes of 1999 hit the most. The case study structure is a 6-storey RC bare frame apartment building that was under construction during the 17 August 1999 Kocaeli earthquake. Minor damages on some columns are inspected. Plan of the structure can be seen in Figure 3. Infill walls were partially constructed in some bays in the ground floor. The regular storey height is 2.80m except at the sub-floor formed inside the ground floor.

As part of this research work, concrete and steel samples were taken from the structures and tested in the laboratory. The material properties have been used as the values that the concrete has 20MPa compressive strength and steel has 420MPa yield strength. In the field measurements, stirrup spacing has been measured as 10cm in the confinement zones.

The second structure (A. Levent) is located in Gölcük in Kocaeli of the Marmara region, where the epicenter of the 17 August 1999 Kocaeli earthquake is located. The case study structure is a 7-storey RC bare frame apartment building that was also under construction during the earthquake. In this structure, the floor system is designed as the embedded-beam floors (the beams were embedded as shallow beams and joists have been created in between the beams) to reduce the overall depth of a traditional cast in place reinforced concrete beam and slab systems (Figure 4). The depth, width and spacing of the joists are 32cm, 10cm and 40 cm, respectively. The slab topping thickness is 7 cm and wide flat beams are usually 80x32cm in dimension. Plan of the structure can be seen in Figure 4. The bricks were carried to the floors and stocked, but infill walls were not constructed yet. The regular storey height is measured as 2.80m. Moderate damages on some columns are inspected. To determine material strengths, concrete and steel samples were taken from the structures and tested in the laboratory. The material properties have been used as the values that the concrete has 20MPa compressive strength and steel has 420MPa yield strength. In the field measurements, stirrup spacing has been measured as 20cm both in the confinement zones and mid-spans.

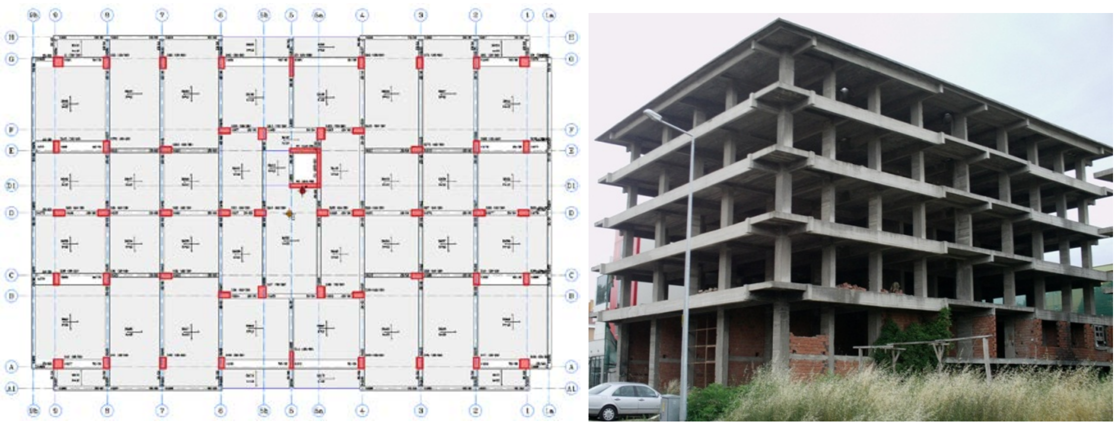

Figure 3 Dayal building floor plan and 3D view

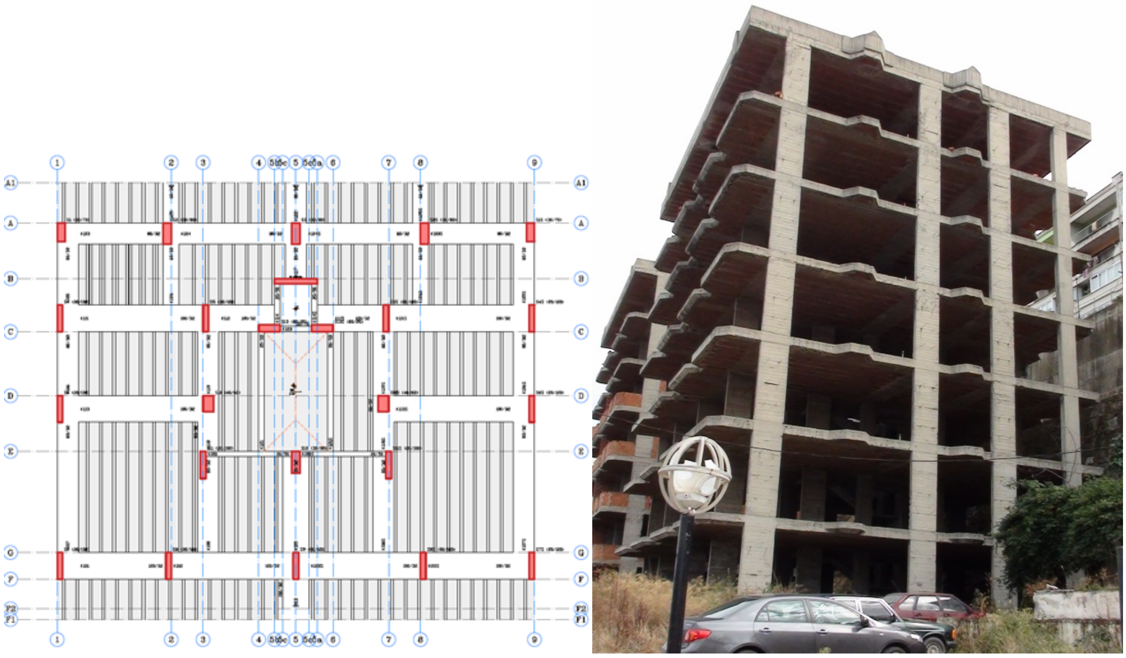

Figure 4 A. Levent building floor plan and 3D view

RESULTS AND DISCUSSION

Data were sampled at 200Hz in all field measurement studies . Six sets of ambient vibration measurements were carried out to identify the dynamic characteristics of the structure along with the free-field measurements in the courtyard in order to quantify and minimize the effects of changing environmental conditions. In case of ambient vibration measurement, each set was recorded for duration of 5 minutes. In the forced vibration tests, recording time in data acquisition was changing 2 to 6 minutes depending upon structural responses and test conditions. Some basic preprocessing tasks such as base-line correction (linear and polynomial, if needed), decimation for eliminating high frequency spikes in the record, band filtering between frequencies of 0.1 Hz and the Nyquist frequency of 100 Hz were performed.

In Tables 1 and 2, under forced and ambient vibrations, modal frequencies and corresponding modal damping ratios for identified first 8 modes in x direction are given. In Table 3, the first two modal frequencies calculated from the finite element model are listed.

Table 1 Modal Frequencies and Damping Ratios for Forced Vibration Analysis for x Direction (Dayal)

	mode 1	mode 2	mode 3	mode 4	mode 5	mode 6	mode 7	mode 8
Modal Freq. (Hz.)	1,429	1,662	1,916	2,013	4,348	5,397	7,536	14,000
Modal damp. ratio	2,445	5,234	11,958	33,145	3,199	4,891	8,343	2,699

Table 2 Modal Frequencies and Damping Ratios for Ambient Vibration Analysis for x Direction (Dayal)

	mode 1	mode 2	mode 3	mode 4	mode 5	mode 6	mode 7	mode 8
Modal freq.(Hz.)	1,441	1,707	2,284	2,794	5,064	7,95	12,23	13,912
Modal damp. ratio	4,329	2,144	29,98	4,082	0,683	5,00	5,579	2,148

Table 3 Modal Frequencies Calculated from the Numerical Analysis for x Direction (Dayal)

	mode 1	mode 2
Modal freq.(Hz.)	2.5108	8.23873

In Tables 4, from ambient vibration analysis, modal frequencies and corresponding modal damping ratios for identified first 8 modes in x direction are given. In Table 5, the first two modal frequencies computed from finite element model are listed.

Table 4 Modal Frequencies and Damping Ratios Inferred from Ambient Vibration Analysis for x Direction (A.Levent)

	mode 1	mode 2	mode 3	mode 4	mode 5	mode 6	mode 7	mode 8
Modal Freq. (Hz.)	0.67	2.55	4.53	6.79	8.05	8.85	11.45	11.7
Modal damp. ratio	1.78	0.56	0.77	0.43	0.71	1.26	0.97	0.65

Table 5 Modal Frequencies Calculated from Numerical Analysis for x Direction (A.Levent)

	mode 1	mode 2
Modal freq.(Hz.)	1.41488	4.494579

Probina Orion software [4] has been used for the analyses presented in this study. Probina is commercial software that can conduct nonlinear static procedures, which are suggested in TEC 2007. The structure has been analyzed by adopting the Incremental Response Spectrum Analysis (IRSA) [5].

In case of the characteristic structural dynamic properties, there are clear differences between the results inferred from measured ambient and forced vibration analysis and computer model modal frequencies as well. First differences among the measured field data studies are due to different characteristics of the ambient input forces and harmonic inputs with different dominant frequencies and amplitudes. Secondly, differences between the numerical model and the field is mostly attributed to the earthquake damaged structural members in the building but In addition to these differences partially to the possible inconsistencies between the numerical model and the test structure in the field.

The Dayal building exhibits torsion behavior in the first mode shape represent representing significantly serious torsion. The 3rd, 6th and 9th modes were similar in the x direction. The A. Levent building shows translational behavior in the first and second modes. The first, fourth and seventh modes were in the x directions.

The displacement Demands are calculated by using the equivalent displacement rule given in the TEC’07 and found as 0.086m (for top displacement). The calculation of the displacement demand by using the TEC’07 methodology has been graphically shown in Figure 5.

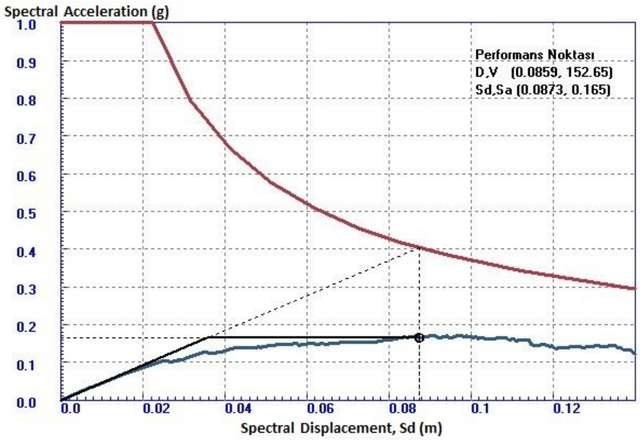

Figure 5 A. Levent building performance point

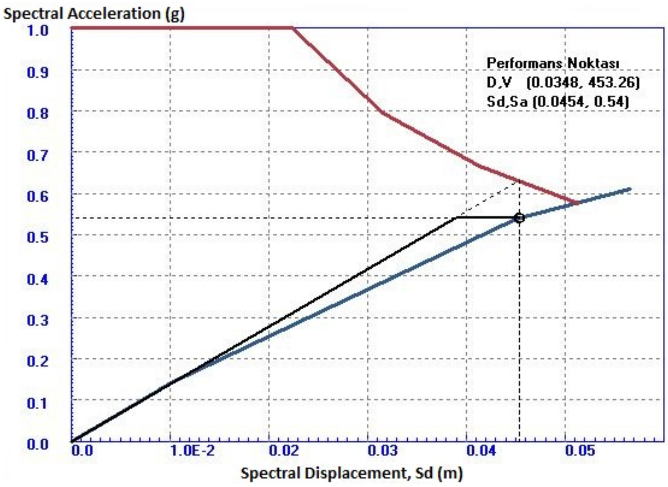

Figure 6 Dayal building performance point calculation according to TEC 2007

The displacement demand of Dayal building has been calculated by using the TEC'07 as 0.035m (for top displacement). The calculation of the displacement demand by using the TEC'07 methodology has been graphically shown in Figure 6.

As an overall result of the non-linear analyses and the assessment procedure applied, the demand level predicted by the TEC'07 does not cause significant damage in the structure. The overall damage of the both structures, according to the Global Limit States of TEC'07 are found as "Life Safety" performance level which corresponds to moderate damage. This is inline with the damage observed in A. Levent but it does not match with the damage level of Dayal Building.

CONCLUSIONS

This paper investigates the possibility of matching the predictions of the damage state of real structure with the observed field data collected after the strong earthquakes of 1999 in Kocaeli Turkey. Incremental Response Spectrum Analysis (IRSA) has been used in combination with the assessment procedure defined in the most recent Turkish Earthquake Code of 2007. The assessment procedure of TEC is essentially based on the application of equal displacement and equal energy rules depending on the fundamental period of the structure.

By detailed visual inspection, the Dayal structure was considered slightly damaged and in A. Levent building experienced moderate damage. The data collected from both the ambient and forced vibrations indicated that natural vibration periods of the structures are longer than the ones found in the finite elements numerical models. This is mostly attributed to the damage levels of the structures as well as the possible inconsistencies between the models and the reality. Another possible reason that can be discussed is intensive aftershocks which took place in the region for months. They might play an important role in either developing new damages or growing the progressive damages in the structural members. It needs to be verified through the analysis under sequential loading condition. Although the differences in modal characteristics inferred from the two field tests, for instance damping ratios, which increase in some loading frequencies may be indicative to assess the damages. But this is an issue, which will be re-evaluated in more detail in the future by the structural analysis for ambient and force vibration data obtained from the field. Efforts on this aspect have also been explained in other publications of the authors [6, 7 and 8].

The damage analysis by using the TEC limit states a moderate level of damage for the case study buildings and the methodology used for calculating the target displacement, on the other hand, points similar results too., However, observed damage state of Dayal building is not consistent with those estimated through the both methodologies.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Turkish Earthquake Code (2007). Specifications for the buildings to be constructed in earthquake hazardous areas. Ministry of Public Works and Settlement, Ankara, Turkey.

[2] Kutanis, M., (2006) Development of Finite Element Technologies for Nonlinear Static and or Dynamic Analysis of Structures. Report to TÜBİTAK-BAYG, SAÜ, İnşaat Mühendisliği Bölümü, Adapazari.

[3] Arel deprem İzleme Sistemleri, 2010, AREL-DAC serisi, http://www.areldeprem.com.tr

[4] Probina Orion (2011) PROTA YAZILIM Bilişim ve Mühendislik, Ankara.

[5] Aydınoğlu, M. N.,(2003)‘An incremental response spectrum analysis procedure based on inelastic spectral displacements for multi-mode seismic performance evaluation’, Bulletin of Earthquake Engineering, **(1)**.

[6] Beyen, K., Kutanis, M., Bal, İ. E. (2011) “Structural Identification of The Apartment Buildings Damaged During The 17 August 1999 Kocaeli Earthquake For Ambient and Forced Vibrations” 7. UDMK, İstanbul.

[7] Beyen, K., Kutanis, M., Bal, İ. E. (2011) The Uncertainties in The Structural Responses Inferred From The Nonlinear Static Analysis Methodology of The New Turkish Earthquake Code. 7. UDMK, İstanbul.

[8] Kutanis, M., Beyen, K., Bal, İ. E. (2011) Consistency of Code Assessment Procedures with Observed Earthquake Performance of Structures. 7. UDMK, İstanbul.