CONCRETE BUILDINGS SUBJECTED EARTHQUAKES IN TURKEY

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Introduction

Over the past two decades Turkey has been hit by several moderate to large earthquakes that resulted in significant loss of life and property. These are: 1992 Erzincan, 1995 Dinar, 1998 Adana-Ceyhan, 1999 Kocaeli, 1999 Duzce, 2002 Afyon-Sultandagi, and 2003 Bingol earthquakes. 1999 Kocaeli and Duzce earthquakes are the largest natural disasters of 20th century in Turkey after 1939 Erzincan earthquake. For the Kocaeli earthquake, the official death toll was more than 15 000, with approximately 44,000 people injured and thousands left homeless. A total of 330,000 residences were damaged; the shares of light, moderate, and severely damaged or collapsed units are 118 000, 112 000, and 100 000, respectively [1, 2].

A summary of major earthquakes over last two decades is given in Table 1. Remarkable number of casualties and heavily damaged or collapsed buildings in Turkey has highlighted inadequate seismic performance of reinforced concrete building stock in Turkey and in countries with similar construction practice. Devastating life and property losses were mainly caused by heavily damaged or collapsed multistory reinforced concrete buildings, typically three to seven stories in height.

Table 1. Destructive earthquakes in Turkey over past two decades [1]

Date (dd/mm/yy)	**Magnitude**	**Location**	**# of deaths**	**# of injured**	**# of heavily damaged buildings**	**Latitude (N)**	**Longitude (E)**	**Depth (km)**
13.03.1992	$M_s = 6.8$	Erzincan	653	3 850	6 702	39.68	39.56	27
01.10.1995	$M_s = 5.9$	Dinar	94	240	4 909	38.18	30.02	24
27.06.1998	$M_s = 5.9$	Adana-Ceyhan	146	940	4 000	36.85	35.55	23
17.08.1999	$M_s = 7.4$	Kocaeli	15 000	32 000	50 000 or 100 000 residences	40.70	29.91	20
12.11.1999	$M_w = 7.2$	Duzce	845	4 948	15 389	40.79	31.21	11
03.02.2002	$M_w = 6.5$	Afyon-Sultandagi	42	325	4 401	38.46	31.30	6
01.05.2003	$M_w = 6.4$	Bingol	176	521	1 351	38.94	40.51	6

In literature, there are many studies related to the aforementioned earthquakes in Turkey, especially about 1999 earthquakes [2-9]. Observed structural damages and their sources, performance of structures, structural deficiencies etc. were covered in these studies. Many structural deficiencies and mistakes such as non-ductile details, soft and weak stories, short columns, strong beams-weak columns, large and heavy overhangs, and poor concrete quality were observed. Studies concluded that there are thousands of buildings vulnerable to severe damage in moderate or larger earthquakes.

General observations and conclusions of the studies are briefly summarized as: (1) there is a consensus about that mid-rise reinforced concrete buildings with low technology engineered residential construction have been responsible for considerable life and property losses during seismic events, (2) structural damages were mostly due to repetition of well known mistakes of the past in the design and construction of reinforced concrete buildings, (3) damaged buildings generally had irregular structural framing, poor detailing, and no shear walls, (4) Turkey has a modern seismic code that is compatible with the codes in other seismic countries of the world and periodically updated to reflect progress of knowledge in the field of earthquake resistant design. However, major weaknesses are in the enforcement of seismic codes and regulations and lack of an effective design and construction supervision system, (5) altering the member sizes from what is foreseen in the design drawings, poor detailing which do not comply with the design drawings, inferior material quality and improper mix-design, changes in structural system by adding/removing components, reducing quantity of steel from what is required and shown in the design, and poor construction practice were listed among common problems.

Inel et al. [10] evaluated concrete strength of existing buildings through an experimental study. They carried out an extensive field and laboratory study on existing public buildings using core sampling method. The field and laboratory study of 167 public buildings showed that 33 buildings have concrete strength of less than 8 MPa while 56 buildings have concrete strength of between 8 and 10 MPa. They concluded that almost one-half of the investigated buildings seemed to be critical in terms of concrete strength based on collapsed buildings in the past earthquakes having concrete strength of 8 to 10 MPa.

This study presents damaged concrete buildings during 2003 Bingol earthquake. All presented data and pictures are obtained from May 1, 2003 Bingol Earthquake report by Ozcebe et al. [11].

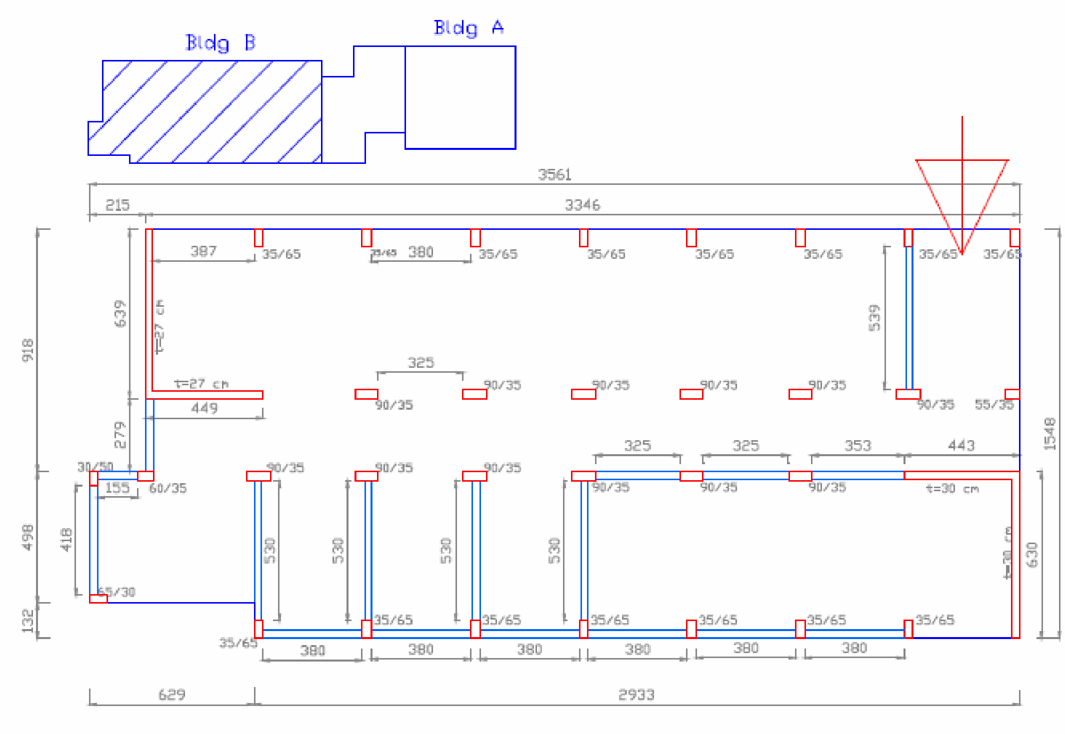


Figure 1. Plan view of Bingol High School

Table 2. Building description of Bingol High School

Building Type	School
Construction Year	NA
# of floors	4
Type	RCSW
Damage	Light

Figure2. Bingol High School after 2003 Bingol Earthquake (Heavy)

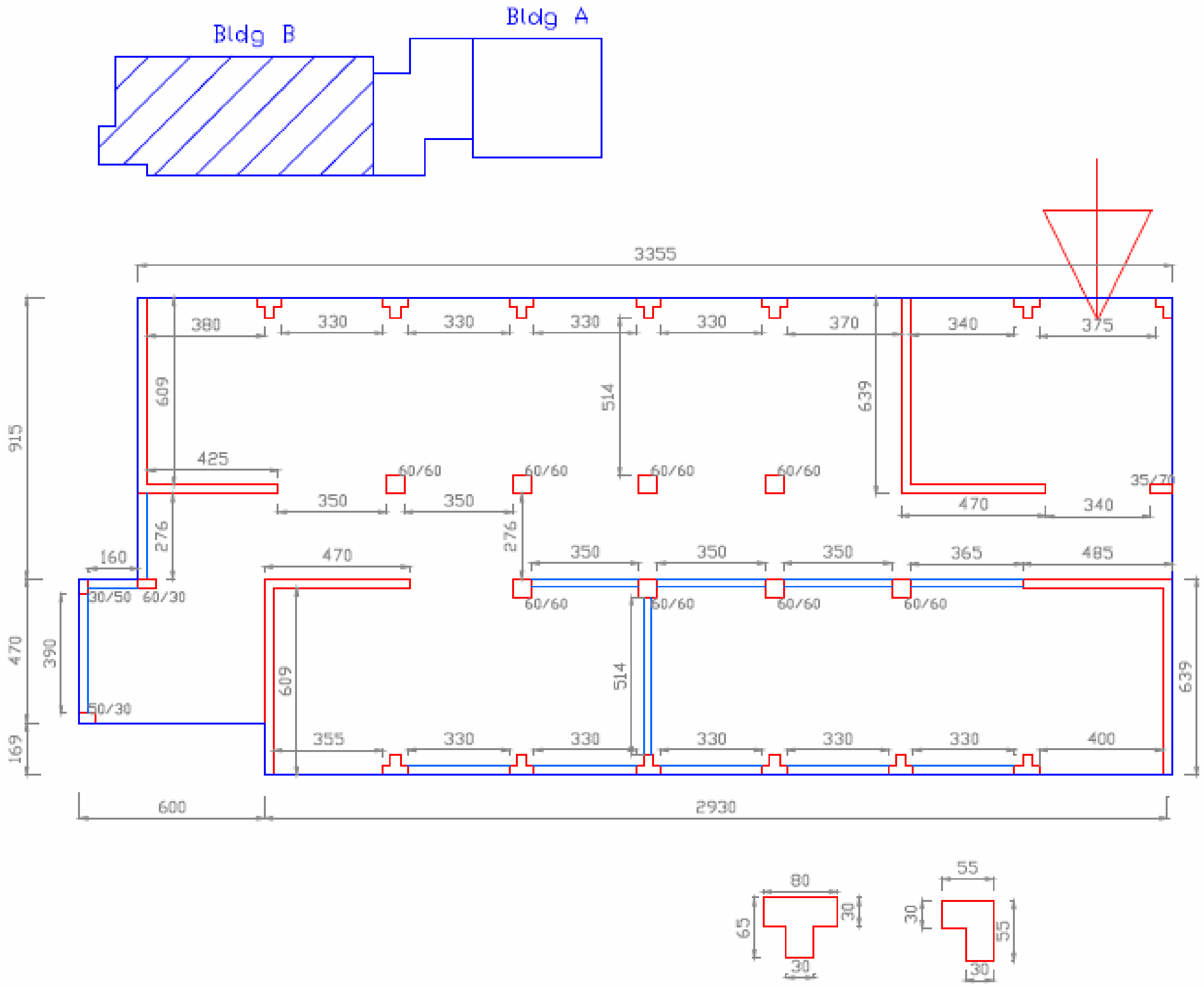


Figure 3. Plan view of Rekabet Kurumu High School

Table 3. Building description of Rekabet Kurumu High School

Building Type	School
Construction Year	NA
# of floors	3
Type	RCSW
Damage	Light

Figure 4. Rekabet Kurumu High School after 2003 Bingol Earthquake (Light)

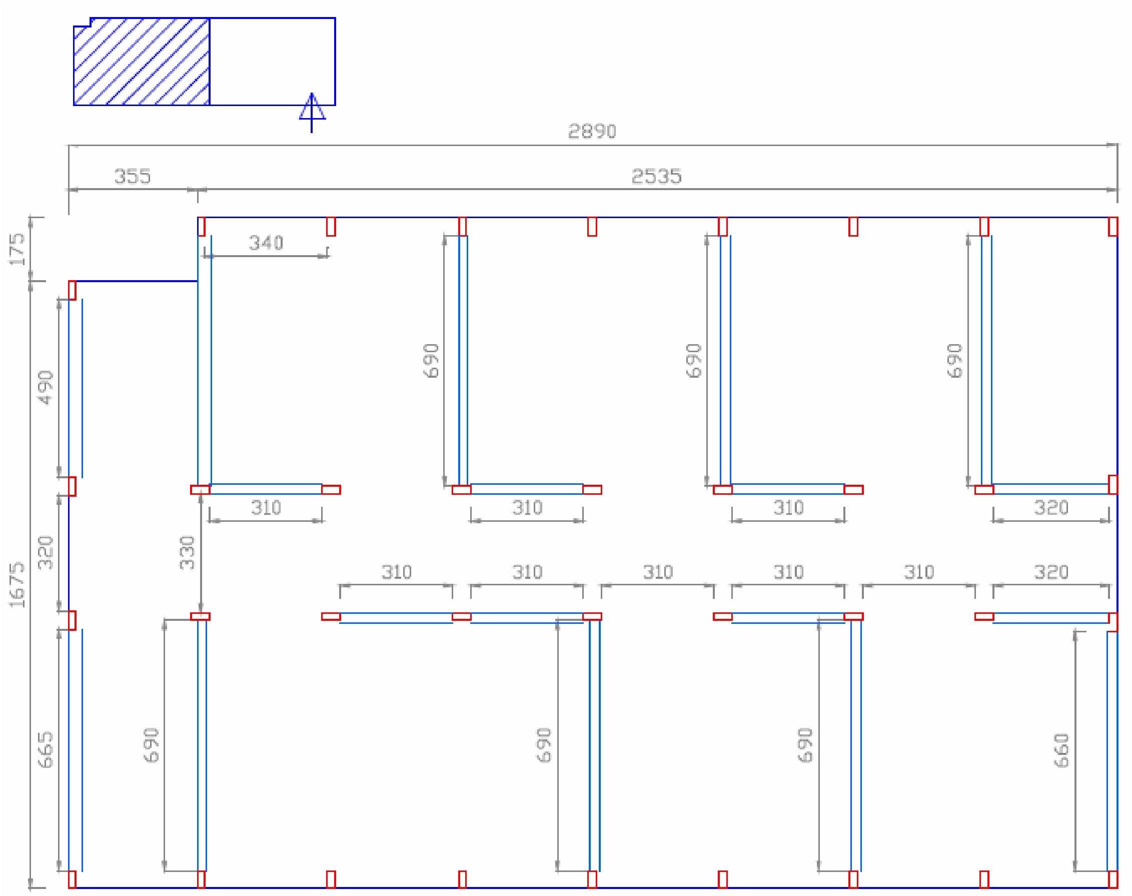


Figure 5. Plan view of Anodolu Ogretmen High School

Table 4. Building description of Anodolu Ogretmen High School

Building Type	School
Construction Year	1974
# of floors	3
Type	RCSW
Damage	Moderate

Figure 6. Anadolu Ogretmen High School after 2003 Bingol Earthquake (Moderate)

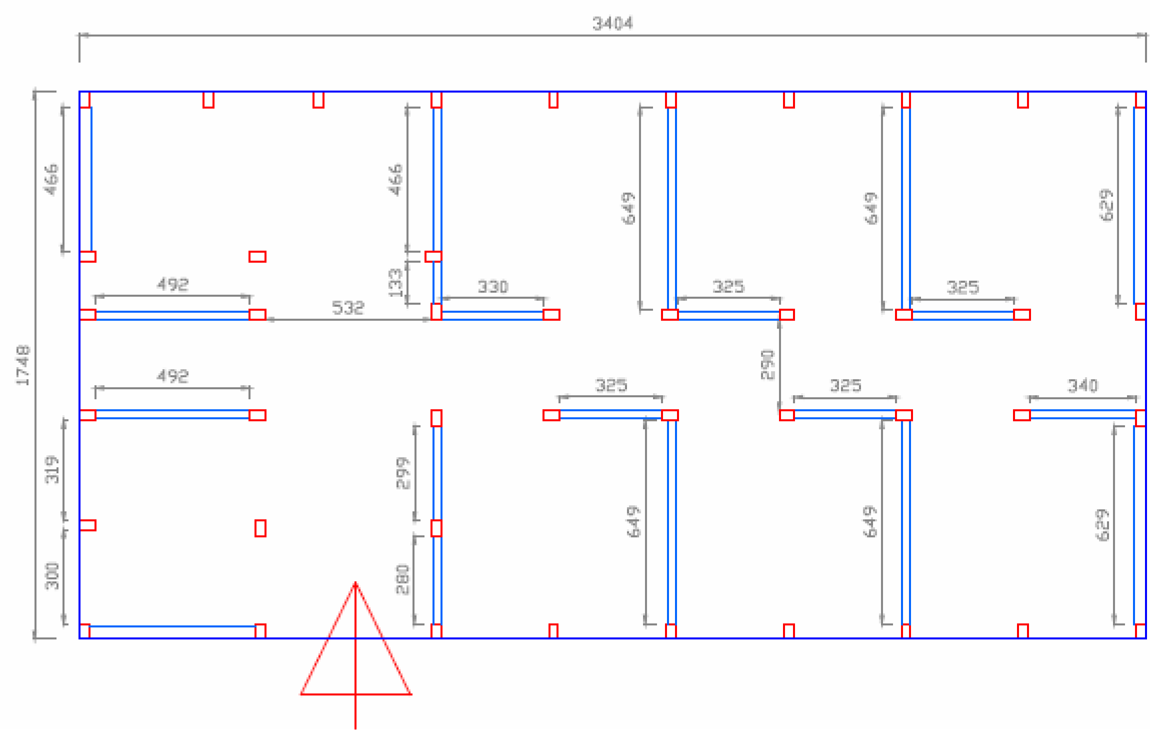
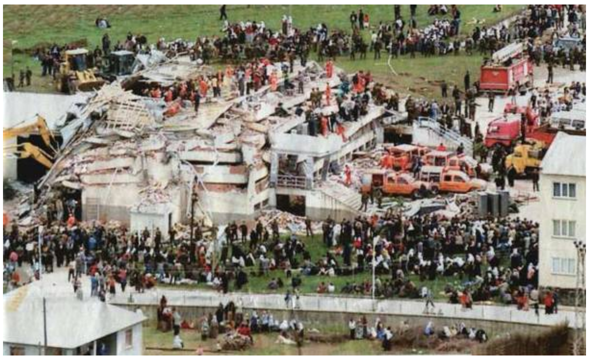


Figure 7. Typical school plan without shear walls. All the walls shown in the drawing refer to those occupying a full span. Walls with openings are excluded. All the columns have dimensions of 0.3m x 0.5m. The arrow indicates the entrance to the building. Dimensions are in cm.

School Building



Dormitory Building

Figure 8. Celtiksuyu Boarding School after Bingol Earthquake

Table 5. Building description of Celtiksuyu Boarding School

Building Type	School
Construction Year	NA
# of floors	3
Type	RCF
Damage	Heavy/collapse

The most tragic collapse occurred at Çeltiksuyu Primary Boarding School. Since the earthquake occurred at 3:27 a.m. local time, the majority of the students were asleep in the dormitory in which 84 (out of 195) students and 1 teacher lost their lives.

Figure 9. Typical residential building after Bingol Earthquake (ID:BNG-6-4-3)

Table 6. Building description of a typical residential building (ID:BNG-6-4-3)

Building Type	Residential
Construction Year	2003
# of floors	4
Type	RCF
Damage	Heavy/collapse

Figure 10. Typical residential building after Bingol Earthquake (BNG-11-4-2)

Table 7. Building description of a typical residential building (ID: BNG-11-4-2)

Building Type	Residential
Construction Year	1989
# of floors	4
Type	RCF
Damage	Heavy/collapse

Figure 10. Typical residential building after Bingol Earthquake (BNG-10-5-2)

Table 8. Building description of a typical residential building (ID: BNG-11-4-2)

Building Type	Residential
Construction Year	1988
# of floors	5
Type	RCF
Damage	Light

Ground story collapse of 3-sroty building

Ground story collapse of 4-story building

Column and beam damage

Beam column joint in building under construction

Column end failure

Spalling and crushing concrete due to high axial loads

Figure 11. Damages observed in reinforced concrete buildings for 2003 Bingol earthquake

Brittle failure of column and buckling of bars

Seperation of column due to improper detailing

Column detailing in plastic hinge region

Column splice

Insufficient confined column

Shear failure of short column

Shear failure of shear walls (at ground and first floor)

Shear walls failure

Figure 12. Column and shear wall damages observed in reinforced concrete buildings

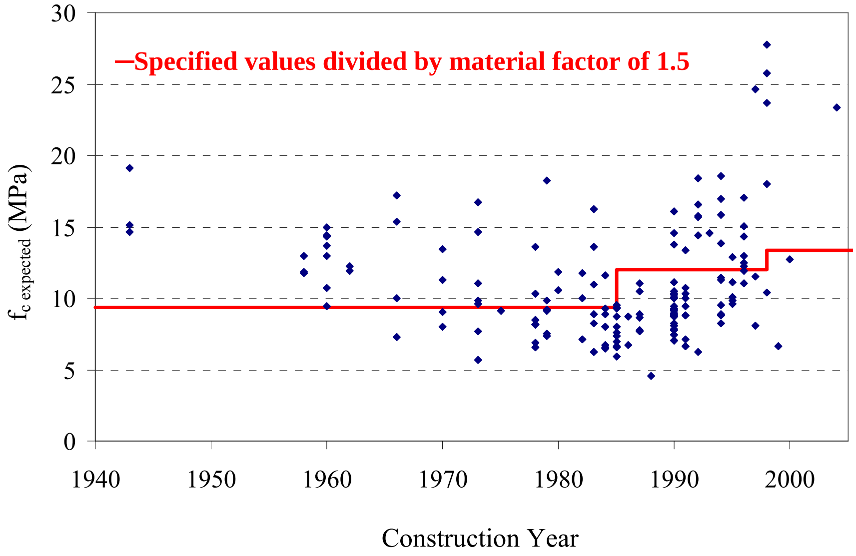


Figure. 13. Expected concrete strength values according to construction year of buildings (Inel et al. 2007).

Summary and Conclusions

2003 Bingol earthquake was unfortunately confirmed similar lessons learned from previous earthquakes. The observations in many documents reported the followings:

- Building plans are irregular.
- The quality of concrete used is poor.
- Defects in the detailing of both longitudinal and transverse reinforcement are very common.

It is relevant to note that Turkey has a modern seismic code that is compatible with the codes in other seismic countries of the world and periodically updated to reflect progress of knowledge in the field of earthquake resistant design. However, major weaknesses are in the enforcement of seismic codes and regulations and lack of an effective design and construction supervision system. Furthermore, engineers are, on the whole, well educated and competent.

The performance of buildings with structural walls was observed to be quite satisfactory for life safety aspect. Buildings with higher ratios of structural wall to floor area had less damage due to reduced drift limit demands with higher stiffness of the lateral load resisting system The performance of structural walls was found to be insensitive to inadequate detailing practices, inaccurate placement of reinforcement, and substandard materials.

References

1. General Directorate of Minister Affairs, Earthquake Research Department, www.deprem.gov.tr.
2. Sucuoglu H. The 1999 Kocaeli and Duzce-Turkey earthquakes, available at www.metu.edu.tr/home/wwweerc/guncel/koca-dzc.pdf.
3. Dogangun A. Performance of reinforced concrete buildings during the May 1 2003 Bingöl earthquake in Turkey, Engineering Structures, 2004; 26(6): 841-856.
4. Sezen H, Whittaker AS, Elwood KJ, Mosalam KM. Performance of reinforced concrete buildings during the August 17, 1999 Kocaeli, Turkey earthquake, and seismic design and construction practice in Turkey. Engineering Structures, 2003; 25(1):103-114.
5. Scawthorn C, Johnson GS. Preliminary report: Kocaeli (Izmit) earthquake of 17 August 1999. Engineering Structures, 2000; 22(7):727-745.
6. Adalier K, Aydingun O. Structural engineering aspects of the June 27, 1998 Adana–Ceyhan (Turkey) earthquake. Engineering Structures, 2001; 23(4):343-355.
7. Yakut A, Gulkan P, Bakır BS, Yılmaz MT. Re-examination of damage distribution in Adapazari: structural considerations. Engineering Structures, 2005; 27(7): 990-1001.
8. Ozcebe G, Ramirez J, Wasti TS, Yakut A. 1 May 2003 Bingol earthquake. Engineering Report, at http://www.seru.metu.edu.tr/archives/databases/Bingol_Database, 2004, Publication No:2004/1.
9. Inel M**,** S. M. Senel ve Un H. Experimental Evaluation Of Concrete Strength in Existing Buildings", Magazine of Concrete Research, 2008; 60(4): 279-289.
10. Inel, M**.**,H. B. Ozmen and H. Bilgin. Re-evaluation of building damage during recent earthquakes in Turkey, Engineering Structures, 2008*;* 30(2): 421-427*)*.
11. Ozcebe G., J. Ramirez, S.T. Wasti and A. Yakut. 1 MAY 2003 Bingol Earthquake Engineering Report, joint report of Tubitak and NSF.