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SEISMIC PERFORMANCES and TYPICAL DAMAGES OF BEAM-COLUMN JOINTS IN THE RC BUILDINGS

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ABSTRACT:

The major reason for the damage in reinforced concrete buildings is non ductile designs. It has been observed that on reinforced concrete buildings, damage has arisen from utilization of concrete having not sufficient resistance, soft storey, weak reinforcement of column-beam joints, designs resulting in short columns. The columns are not tied with beams continually in one line. As a matter of fact, in a lot of cooperative buildings, as a result of fixing two consecutive beams to different tips of the column, the additional torsion in these columns has caused severe damage in the columns. In Turkey, last and heavily destructive earthquake is occurred in Bingol, on May 01, 2003. The earthquake had a moment magnitude of 6.4. In this earthquake, many buildings were heavily damaged and some have totally collapsed. In the highlight of such findings, essentials given by Turkish Earthquake Regulation (2007) with respect to design shall be discussed particularly for buildings constructed after the date such regulation is put into effect, and seismic features of the earthquake shall be commentated according to the data in connection with the strong ground motion obtained. The encouragement to use appropriate material and the use of ready mixed concrete will ensure that the damage will be minimized in probable future earthquakes. In addition to those, the extensive use of shear walls even in low-rise buildings may be an alternative approach to prevent earthquake damage. By means of illustrations and photographs demonstrating damages and collapses obtained during the investigation in connection with the structural system elements, assessments shall be made. Finally, suitable and effective reinforcement means shall be discussed with respect to reinforced concrete buildings damaged at a level of fortifiability.

KEYWORDS: Seismic performance, earthquake damages, reinforced concrete

1. INTRODUCTION

The main reason for the damage in reinforced concrete buildings is that those buildings are not designed to show a ductile behaviour to earthquakes. During the R/C structural system choosing and design of the beam-column joints, the column axes, dimensions of column and beam concrete sections, rigid direction of columns and distribution of the rigid directions of columns, shear walls and its directions on the plan are important points of the structural design. Generally, a structural design based on accounting for the orthogonal earthquake effects. In some special cases biaxial earthquake analysis is not satisfactory; therefore, well-designed structures should be capable of resisting motions equally from three directions of earthquake effects.

On the other hand, it has been observed that the damages in reinforced concrete buildings have happened because of design and construction reasons such as use of insufficiently resistant concrete, the weak reinforcement of soft stories and column beam joints, designs causing short columns, not caring for shear reinforcement and use of strong beam-weak column. It is obvious that the damages in unreinforced buildings happen because it is not complied to the construction rules appropriately. In this article, the observations and findings of the writer on the damaged reinforced concrete and unreinforced buildings have been offered, in the light of these findings, the conditions of the Turkish Earthquake Codes (2007) directed towards design have been discussed especially for buildings

constructed after the codes have become effective, the seismic properties of the earthquake have been analysed based on the obtained data of strong ground motion. Also, evaluations have been made through photographs obtained during field studies, and showing collapses and damages of structural units.

2. SEISMIC PARAMETERS OF THE EARTHQUAKES IN LAST 20 YEARS

In Turkey, in last 20 years six very important earthquakes (with a magnitude of larger than Ms=6) are happened. These are 03.13.1992 Erzincan, 10.01.1995 Dinar, 06.27.1998 Adana, 08.17.1999 Kocaeli (Izmit), 11.12.1999 Duzce, 05.01.2003 Bingol earthquakes, respectively. Erzincan, Kocaeli, Duzce, Bingol are situated at one of Turkey's seismically most active regions. Erzincan, Kocaeli and Duzce are at a place where North Anatolian Fault Zones intersect. Bingol is at a place where North Anatolian Fault (NAF) and East Anatolian Fault (EAF) Zones intersect. In the same region, there also takes place many small and large fault zones. Adana and Dinar are also, located in seismically active regions of Southern Anatolian Fault Lines (SAF) and West Anatolian Fault Lines (WAF), respectively. The records of earthquakes with great effect are given in the following table.

Table 2.1 The records of earthquakes with great effects

Event	Date	Station	M	a_{max} (T) (mG)	a_{max} (L) (mG)	a_{max} (V) (mG)
Erzincan	03.13.1992	Erzincan	M = 6.9	505.5	486.1	243.0
Dinar	01.10.1995	Dinar	M_L = 6.0	336.1	287.1	153.6
Adana	27.06.1998	Ceyhan	M_L = 5.9	278.8	227.6	88.1
Kocaeli	08.17.1999	Yarimca	M_w = 7.2	322.2	230.2	241.1
Duzce	11.12.1999	Bolu	M_w = 7.2	713.8	806.8	198.7
Bingol	05.01.2003	Bingol	M_L = 6.4	545.5	276.8	472.3

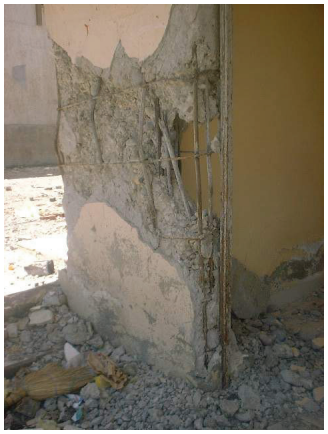
3. BEHAVIOUR OF REINFORCED CONCRETE BUILDINGS

The biggest parts of the buildings in the cities are reinforced concrete buildings that have not undergone a serious engineering treatment. There are a lot of various reasons for the damage in reinforced concrete buildings because of the earthquake. But the main reason is the use of material of poor quality. River sand and pebbles are used in the production of concrete and it is used manually. The ready mixed concrete plants which have been recently installed, have not been operated sufficiently and local river sand and pebbles are used in the production of ready mixed concrete. Structural and non structural damage and mistakes of design and production in the reinforced concrete buildings are examined below.

Vertical acceleration being so close to the horizontal acceleration indicates that the acceleration has been recorded from exactly the epicentre of the earthquake. On the other hand, in the area where such figures are measured, it can be said that a horizontal load approximately half of their weights has affected. This has particularly caused the damage to result heavily in the region. Local ground conditions have been substantially influential on heavy damage and high loss of casualties.

3.1 Concrete and steel

Generally, local materials have been used in almost all reinforced concrete buildings until the last destructive earthquake in Turkey, and concrete has been produced through primitive methods. The ready mixed concrete plants have been idle since people have not given up their habits. Also, even though these installations had been used, since the production would have been with the local material, the same results could have been reached. The biggest problem in the production of concrete is the use of casual aggregate and not an appropriate granulametric mixture. The materials observed in the reinforced concrete buildings both in rural areas and in the centre of the city by the writers are not within the acceptable limits. The minimum concrete strength should be C20 (20 MPa) according to the Turkish Earthquake Code 2007 in Erzincan or Bingol and its vicinity which is considered a 1st degree earthquake region in the earthquake zones map of Turkey. However the average concrete strength is way below the limit value of the code in the damaged buildings. As described above, the aggregate maximum grain diameters are high values such as 13-15 cm, and this leads to the weak resistance of concrete. The getting together of such big pebbles has created flaws in structural members and damage happened in these parts. The partial defects formed because of poor concrete, mixture defects and very big aggregate, have led to the formation large cracks in structural members and to the collapse of concrete under the shear and compression forces.



(a)

(b)

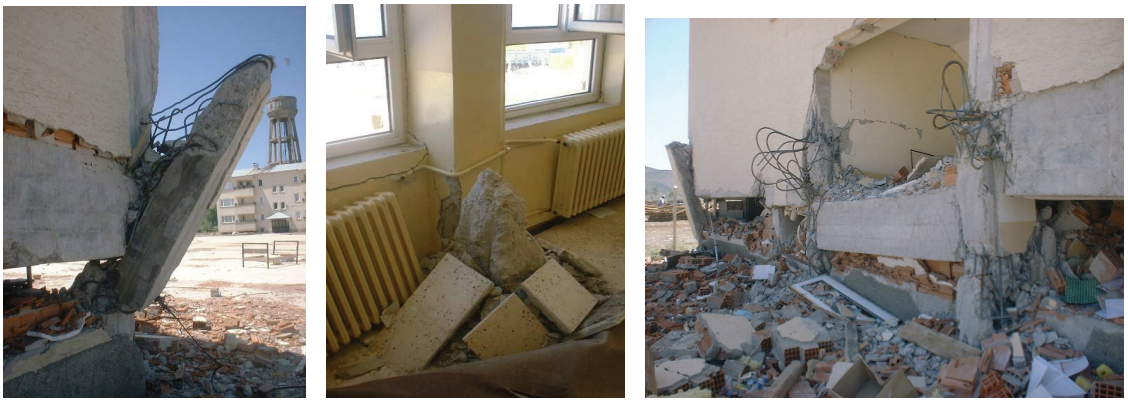
(c)

Figure 1 Some examples of earthquake damage
(a) Poor quality concrete
(b) Diagonal tension failure
(c) Short column

In Turkey mild steel is used as reinforcement steel. In the buildings where mild steel is used, since adherence is negative and concrete resistance is weak, the reinforcements were immediately separated from the concrete and have caused the structural system to collapse through deformation. This is the case in almost all of the seriously damaged or collapsed buildings.

It has been noted damage in the columns mostly because of strong beam-weak column situation, and damage at column-beam intersections because of improper reinforcements and poor concrete. The Turkish Earthquake Code which has become effective in 2007 stipulates enforcements for the application of especially strong columns-lesser strong beams condition. In the reinforced concrete buildings which have been constructed according to the Turkish Earthquake Code of 1975, the structural member dimensions and column dimensions in general are inadequate; it was based on the construction of stronger beams than the columns.

The reinforced concrete buildings in the cities are 4 -10 storeys high and reinforced concrete shear wall has not been used. Since reinforced concrete cores designed around the elevator shaft and/or the stair wells are not placed appropriately in the plan, and their frame system connections are not appropriately made, they could not resist the earthquake loads.



(a) (b) (c)

Figure 2 Examples of column-beam joint damages of an earthquake effect in vertical direction
(a) Lack of proper anchorage and joint steel
(b) Punching 1st floor slabs by ground floor columns
(c) Weak column- strong beam and eccentric beam connection

3.2 Reinforcement situation

Almost all the longitudinal and lateral reinforcements used in reinforced columns and beams are mild reinforced concrete steel. It has been observed that longitudinal reinforcements of different diameters in the same cross-section at the columns have been used and that lesser reinforcements than what is required for these types of reinforcements have been used. To give an example, instead of using 6Ø16 reinforcement according to the project, 4Ø16 + 2Ø14 reinforcements have been used in the cross-sections. The most important deficiency observed has been that shear reinforcements have been placed with intervals of 40 cm mostly, and sometimes up to 50 cm. and the shear reinforcement at the column-beam intersection points have not been used. This situation is not within the limits of both the old and the new code.

When the projects of reinforced concrete buildings have been examined, it has been noted that calculations for lateral loads have not been made and structural system has been designed only according to vertical loads. Therefore, yielding has resulted in the reinforcements at the intersection points. Another frequently seen damage type has been that the bending moments were not met by the longitudinal reinforcements and as a result of binder spacing being large, the buckling has emerged at the column longitudinal reinforcement. The cross sections of column longitudinal reinforcements are inadequate and the workmanship is very poor.

Although the condition of bar spacer has been met, because of the aggregate with big grains forming the concrete material and large bar spacer, the efficient distance in the moment lever arm has been diminished, this has especially decreased the load carrying capacity of columns.

3.3 Structural system design

Frame system is used in the buildings as structural system. The shear wall and reinforced concrete cores designed to resist the earthquake loads have almost not been used. There is not continuity in one direction in some of the frame systems. Secondary beams are used frequently. Because of the use of strip windows at ground levels of the reinforced concrete buildings, there have been damages because of short column behaviour.

(a) (b)

Figure 3
(a) Lack of confinement steel in columns, inadequate reinforcement arrangement
(b) Eccentric continuous beam connection, diagonal torsion (tension) failure of a column

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The short columns in reinforced concrete buildings as it is known from the past earthquake experiences, are exposed to shear forces as a result of dynamic effects. This effect causes diagonal tension cracks in the columns and the demolishing of the frame system. The best way is to give up the design of structural system which will be exposed to such type of behaviour although some precautions may be taken during design and construction stages. The codes stipulate additional obligations for short columns anyway and do not recommend their uses.

3.4 Negative effects of architectural planning to structural system

A structure system mistake from the facade design in the architectural design in Turkey in general, and not only in Bingol, or Erzincan or Kocaeli is that the columns are not tied with beams continually in one line. As a matter of fact, in a lot of cooperative buildings, as a result of fixing two consecutive beams to different tips of the column, the additional torsion in these columns has caused severe damage in the columns.
On the other hand, since the beams connecting the columns in the reinforced concrete slabs, in facade axes have not been desired to be seen, the beams have not been constructed along the frame. Therefore this situation causes the continuity not being provided in the frame system.

Another planning mistake made because of architectural requirements is the use of soft story in reinforced concrete buildings because of commercial purposes. These types of buildings have been constructed extensively in Turkey. As it is widely known, in case the ground stories of the buildings are higher than other stories and interior walls are not used between the columns, that story is called a soft story. Although codes allow the soft stories, they stipulate certain conditions from the aspects of lateral displacements and design. A lot of buildings with moderate and severe damage have been noted in Turkey because of soft storey.

4. CONCLUSIONS

The six destructive earthquakes in last twenty years have shown us once again that the inadequacy of seismic design and application along with poor material and workmanship, are the main reasons for the damages in the reinforced concrete buildings. Structural system problems such as soft storey, short column, and beam discontinuities are other important factors. If the Turkish Earthquake Code (2007) is applied as it should, the damage reasons resulting from the inadequacy of design will be minimized. However, the most important problem in Turkey is that the workmanship and the materials are of poor quality. The encouragement to use appropriate material and the use of ready mixed concrete will ensure that the damage will be minimized in probable future earthquakes. In addition to these, the extensive use of shear walls even in low-rise buildings may be an alternative approach to prevent earthquake damage. Finally, an analysis of a structural system under earthquake loads should be considered in three-directional, instead of biaxial earthquake effect.

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