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PERFORMANCE OF R/C AND MASONRY STRUCTURES DURING THE 2003 BINGOL EARTHQUAKE IN TURKEY

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SUMMARY

On May 01, 2003, at Bingol, Turkey, an earthquake with a moment magnitude of 6.4 as occurred. In the earthquake, many buildings were heavily damaged and some have totally collapsed. 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 stories, weak reinforcement of column-beam joints, designs resulting in short columns, and such means as not taking care of shear reinforcement, strong beam-weak column utilization and such similar design and instruction means have been observed. In this report, findings and observations of the writers as to the reinforced concrete and masonry buildings are submitted. On the other hand, in the highlight of such findings, essentials given by Turkish Earthquake Regulation (1998) with respect to design are discussed particularly for buildings constructed after the date such regulation is put into effect, and seismic features of the earthquake are commentated according to the data in connection with the strong ground motion obtained. By means of illustrations and photographs demonstrating damages and collapses obtained during the investigation in connection with the structural system elements, assessments are made.

INTRODUCTION

Bingol city center and its near surroundings were shaken on May 1 2003, by an earthquake with a magnitude of Mw=6.4. The biggest damage happened in the center of Bingol, a lot of buildings were seriously damaged and some of them totally collapsed. Bingol and its surroundings are located in one of the most seismically active regions of Turkey, at the intersection of Northern Anatolian Fault (NAF) Lines and Eastern Anatolian Fault (EAF) Lines. There a lot of fault zones in this regions. This region has been seismically very active both in the past and in the past several decades. The earthquake, which happened on the NAF line in 1784, has caused a surface fracture of 100 km. long. A big earthquake happened in 1789 on the EAF line passing through the east of Bingol. Besides these earthquakes, there were also destructive earthquakes in the region at the end of the 19th century. In the recent past, between the Bingol-Goynuk valley, a destructive earthquake with a magnitude of 6.8 happened on May 12, 1971. 875 people lost their lives in this earthquake and thousands of buildings were seriously damaged. 1992 and 2003

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Pulumur, 2002 Kigi earthquakes are other recent earthquakes, which have happened in the region recently.

Some interesting findings have been obtained as a result of the examinations made at the city center and its surroundings. For example, more than half of the demolished buildings are public buildings. Another interesting point is that some of these buildings have been constructed after the Turkish Earthquake Codes 1998 [1], which is a contemporary code, has become effective. The greatest number of mass casualties happened at Celtiksuyu Regional Boarding Primary School, which is again a public building.

The main reason for the damage in reinforced concrete buildings is that those buildings are not designed to show a ductile behavior to earthquakes. 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 writers on the damaged reinforced concrete and unreinforced buildings have been offered, in the light of these findings, the conditions of the Turkish Earthquake Codes (1998) directed towards design have been discussed especially for buildings constructed after the codes have become effective, the seismic properties of the earthquake have been analyzed 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.

SEISMIC PARAMETERS OF THE EARTHQUAKE

Bingol and environments are situated at one of Turkey's seismically most active regions, at a place where North Anatolian and East Anatolian Fault Zones intersect. In the same region, there also takes place many small and large fault zones. The magnitude of the earthquake which took place 10 km. north of Bingol has been determined as Md=6.1 (DAD); Ms=6.4 (KOERI, USGS). The epicenter of the earthquake has been determined as 38.94N–40.51E (DAD-Ankara); and its depth as 6 km. After the main shock, a total of rearguard earthquakes with magnitudes between Md=2.8 and Md=4.3 have been recorded. According to the record taken from the Directorate of Public Works and Settlement, the peak values of the ground accelerations are 0.545g, 0.277g and 0.472g in NS, EW and Vertical directions respectively. The duration of strong ground motion is measured as 17 seconds.

Vertical acceleration being so close to the horizontal acceleration indicates that the acceleration has been recorded from exactly the epicenter 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. Upon understanding from three acceleration components of the earthquake recorded at Bingol, the North-South component having a long period s-wave nature, points out that the break on the fault line is on the north-west direction, diverging from Bingol. Local ground conditions have been substantially influential on heavy damage and high loss of casualties.

GROUND CONDITIONS AND SITUATION OF NEW CONSTRUCTION

The city has been moved to region thought to be safer in terms of ground conditions after the earthquakes in the past. The center of the city which was previously on the banks of a river or in the valley, is now in the slopes of a valley. This has caused lesser number of damages in the city center. However, construction is again developing towards the valley along with the effect of urbanization.

BEHAVIOUR OF REINFORCED CONCRETE BUILDINGS

The biggest part of the buildings in the city is 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 locally 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.

Concrete and Steel

As explained above, local materials have been used in almost all reinforced concrete buildings until the last destructive earthquake in Bingol, 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 granulometric mixture. The materials observed in the reinforced concrete buildings both in rural areas and in the center of the city by the writers are not within the acceptable limits. The minimum concrete strength should be C20 (20MPa) according to the Turkish Earthquake Code 1998 in 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.

Fig. 1 Damage in a shear wall

Fig.2 Short column

Fig. 3 Diagonal tension failure

In the region 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.

The Dimensions of Structural System Members

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 1998 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, Ozgen [2].

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

Fig. 4 Poor quality concrete

Fig. 5 Strong beam-weak column connection, Diagonal tension failure of a column

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 8Ø16 reinforcement according to the project, 5Ø16+3Ø14 reinforcements have been used in the cross-sections.

The most important deficiency observed has been that shear reinforcements have been placed with intervals of 35-40 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 according to only 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 spacings 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.

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 behavior. 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 behavior 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, Torunbalci [3].

(a) (b) (c)

Fig. 6 Lack of confinement steel in columns, inadequate reinforcement arrangement

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, is that the columns are not tied with beams continually in one line, Torunbalci [3]. 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 storey in reinforced concrete buildings because of commercial purposes. These types of buildings have been constructed extensively in Bingol. 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 storey is called a soft storey. 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 Bingol because of soft storey.

Workmanship

The concrete and reinforcement workmanship is very inadequate in the region. There has not been enough care in the grading, preparation, placement, compaction and curing of concrete according to the project. Similarly, reinforcement workmanship is also very poor. Damage in structural system members has emerged in places of working joints. Especially there have been left inadequate splice length in column reinforcement, the reinforcements have been casually bent and placed. The stirrup hooks have not been bent 135˚ to grip the longitudinal reinforcement. Because the stirrup intervals are large and proper care has not been taken for the connection points of stirrup tips, these reinforcements have not reacted as expected, as a result of this, the longitudinal reinforcements have broken the spacer concrete and were twisted.

(a)

(b)

Fig. 7 Damages during the demolitions after the earthquake

The Damages During The Demolitions After The Earthquake

An interesting and legally very complex situation is that, a building without damage or with minimal damage after the earthquake, is damaged during the demolition of a building which has severe damage. It has been noted several buildings in Bingol, which have been damaged because of this.

This situation requires a very sensitive inspection such as the technical inspection during the construction of a building. The damages during the demolitions such as this, is a clear proof of inadequacy of the technical equipment infrastructure and technical staff in the local governments.

EXAMPLE OF SEVERE DAMAGED REINFORCED CONCRETE BUILDING

Celtiksuyu Regional Boarding Primary School Buildings are especially important, Celtiksuyu Student Dormitory Building had the most casualties with 84 deaths in Bingol Earthquake. Celtiksuyu Primary School Facilities consists of 3 separate blocks as the Primary School, Student Dormitory and Teachers' Apartments and they are relatively new buildings constructed with reinforced concrete skeleton system. The positions of the blocks are shown on the situation plan.

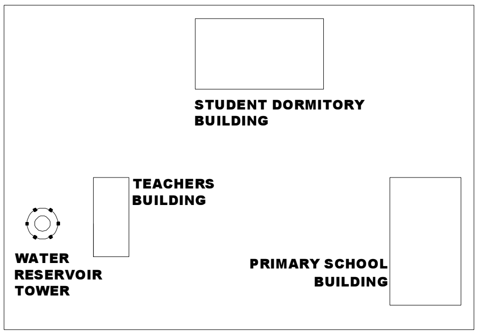

Fig. 8 Situation plan of the buildings

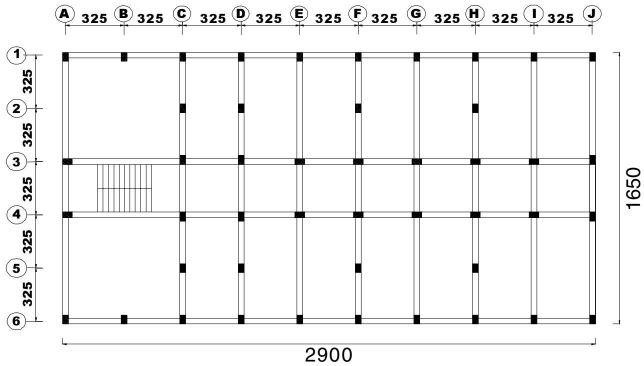

Fig. 9 Plan of the primary school building

The Primary School Building is a three-storey building with a ground storey and 2 regular stories constructed as reinforced concrete skeleton. Its dimensions in the plan are 16.50 x 29.50 m and the height of its stories are 3.50 m. The axis system of the columns is regular and the intervals of column axes are around 3.25 m and 6.50 m. Beam dimensions are 30/60 cm, column dimensions are 30/50 cm. The building is sitting on singular foundations. The ground of the buildings is alluvium-vegetable soil and the underground water level is at ground level.

(a) **(b)**

Fig. 10 Collapse of the ground floor of Celtiksuyu Primary School

Primary School Building collapsed through the complete fracturing of its columns, scattering of the concrete of its columns, heavy damage at its joints and the scraping of its reinforcements from the concrete. Although 1st and 2nd floors have not collapsed, these floors have been heavily damaged. The high vertical acceleration of the earthquake has caused the fracturing and the scattering of the columns at the ground level. The columns, which have not collapsed but fractured from their joints, have been pushed horizontally and have punched the upper floor slabs, which have fallen on them. 1st floor slabs, which have fallen on the fractured ground floor columns have been punched by the ground floor columns also by the effect of excessive horizontal displacements. Upon the examinations, it has been noted that the pebbles in the concrete mix were 12-15 cm, and the stirrup distances were at the 40 cm level at some locations. The poor quality of the building concrete has also negatively affected the adherence. Because of the use of mild and smooth surfaced steel, the reinforcements have been scrapped from the concrete and have deformed tremendously.

The Student Dormitory Building is the one with the loss of lives and has collapsed completely during the earthquake. Since the project of this building was not available along with the effect of the recovery efforts, no detailed information was obtained on the structure of the building. Similar findings have been noted for the materials in the concrete mix during the examinations. The concrete is of poor quality, and the aggregate in the concrete mix comprises very large pebbles. It is believed that besides the points described earlier for the building structure, the negative effects of the underground water level and the existing ground conditions have caused this building to collapse completely.

Fig. 11 Lack of proper anchorage and joint steel

(a) **(b)**

Fig. 12 Punching 1st floor slabs by ground floor columns

The Teachers' Apartments Building is a four-storey building with a basement, ground storey and 2 regular stories having a reinforced concrete skeleton building structure. The intervals of its column axes are around 3.25 m-4.00m, and reinforced concrete slab-beam system has been used. The external walls of the basement have been constructed as rigid walls. There are some unimportant cracks in the walls of the ground floor of the building, the gable wall of the roof has collapsed and besides that there have been no damages. It has been thought that the important effect on this is that the building has a rigid basement, the column axes intervals are smaller than the other buildings, and the reinforced concrete frames are built with brick walls at each storey.

It is noted that the water reservoir tower adjacent to these buildings and at the rear of the Teachers' apartments building, which has reinforced concrete structure, has not collapsed and has not had any damages.

BEHAVIOUR OF NON-ENGINEERED STRUCTURES

It has been observed that reinforced concrete skeleton construction in almost all the buildings in Bingol when the new settlement was moving to the slopes and hills from the valley after the earthquake of 1971. However, the brick and stone masonry buildings in both the city center and the rural areas have been examined during the limited time in the region and the damage observations in these buildings are presented below.

General Characteristics of Masonry Buildings

It is interesting that these masonry buildings constructed locally and non-engineered, have a certain static construction technique as a result of lessons from past earthquakes.

Stonework buildings

It has been noted that natural stone has been used for wall material and mud mortar has been used as binding material and that landfill flat roof are supported by these stonework walls in these two-storey local buildings with their lower storey being barns. The wall thickness is 50-55 cm in these two-storey stone masonry non-engineered buildings. Both of the sides of the wall are laid with big stones, and the middle part is filled with small stones. The corner joints of the walls of these buildings have been especially cared for. The stone at the corners are selected larger horizontally and special care has been taken that the joints at these points are horizontal. It has been noted that the window openings are 75 cm /140-150 cm and symmetrically arranged. The interfenestration is also very large. The logs which bearings the landfill flat roofs have a diameter of Ø15 cm and they are arranged with intervals of 50-60 cm and to cross over openings of 3.00–3.50 m. The floors are timber boarding sat on wooden beam.

(a) **(b)**

Fig. 13 Typical cracks in masonry buildings

Brickwork buildings

In brickwork buildings lime and cement mortar is used. In single-storey and double-storey masonry buildings, it has been noted that the walls are constructed with 1,0 brick, in certain two and three-floored buildings, ground floor walls are constructed with 1,5 brick or rough stone wall of 50 cm thick. It has been noted in these buildings that the maximum storey heights are 3.20 m and the largest span length is approximately 5.00 m, the floors are generally reinforced concrete and bearing walls are covered with tie beams. Sometimes, it has been observed that wooden floors have been used in two-storey buildings.

Damage Observations in Masonry Buildings

Characteristic damage types observed in this group of stonework buildings are, Separations in upper tips of corner joints of flat roof, Deterioration in the stone walls as a result of the clay mortar's loosing its binding properties through the seasonal effects, Because of the reasons above, the log beams which bearings the landfill flat roof break loose and the roof collapses, In case the windows and the door are close to corner joints, the cracks resulting in moderate damage and/or collapse in the wall, In case the wall length goes above 5.00 m, no wall stability and collapse as a result of moderate and severe damage in stonework wall.

In the damage examinations at the brickwork buildings, it has been determined that,
The damages are greater in buildings constructed with only lime mortar instead of lime and cement mortar, There are cracks at the corners of windows and doors along with tie beams, Since there are not enough spaces between the corners and the windows/doors, the diagonal shearing cracks reach the tie beams, and important damages emerge as a result of this depending on the thickness of the wall, and the resistance of mortar material.

CONCLUSIONS

Bingol earthquake has shown us once again that the inadequacy of seismic design project 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, beam discontinuities, are another important factor. If the Turkish Earthquake Code (1998) is applied, as it should be, the damage reasons resulting from the inadequacy of design will be minimized. However, the most important problem in Bingol 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 those, the extensive use of shear walls, even in a few-storey buildings, may be an alternative approach to prevent earthquake damage. There has been less damage than one would expect in non-engineered masonry buildings in rural areas. It can be concluded that masonry buildings have been constructed with more care after the lessons of the earthquakes of the past.

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