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BUILDING DAMAGE PATTERNS IN BINGOL-TURKEY AFTER THE MAY 1ST, 2003 EARTHQUAKE

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SUMMARY

A major earthquake of magnitude 6.4 (M_w) hit the city of Bingol on May 1, 2003, causing significant damage to buildings and killing 168 people. Bingol, which is located in the eastern part of Turkey is a moderately small city with an overall population of 250,000 people. According to 2000 building census statistics, there are 17,000 buildings in Bingol including the provincial area. A study was undertaken to investigate the spatial distribution of damage observed throughout the city along with the local soil conditions and proximity of the buildings to the epicenter. In this framework, the affected area was surveyed after the quake in order to investigate the reasons for the patterns of damage observed. Nearly 96 buildings were surveyed in the central area of the city. Among these 96 buildings, 21 of them were school buildings and 18 were other public buildings. Majority of the studied buildings were R/C structures with masonry in-fill walls, and the remaining buildings were masonry type of construction. The number of stories, type of the structural system, ratio of structural element areas to the overall floor area, soil conditions, presence of soft and weak stories, and proximity of the buildings to the epicenter were selected to be the major study parameters. For each building the GPS coordinates were also recorded. Each building was assigned a damage state based on the damage suffered by its structural as well as non-structural components. This paper concentrates on the common damage patterns observed and their relationship to selected parameters such as apparent material quality, number of floors, year of construction, etc. It is observed that although buildings may have been heavily damaged, total collapse was prevented if shear walls existed. Similar to many destructive earthquakes occurred in developing countries, the majority of heavy damage cases resulted from poor concrete quality and workmanship, improper detailing, substandard structural design, and lack of technical control and inspection of the construction.

INTRODUCTION

The earthquake with a moment magnitude of 6.4 occurred with an epicenter located at 10 km north of Bingol at 03:27 AM (local time) on 1 May 2003. The epicenter of the earthquake was at 38.94N- 40.51E.

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The depth of the quake was estimated to be at 6 km. A previous devastating earthquake of magnitude 6.8 struck the area in 1971. After the earthquake, a team of researchers from Middle East Technical University (METU) was dispatched to Bingol in order to document the damage patterns along with the information on the building characteristics. In this context, the performance of buildings within the provincial area of Bingol was investigated through post-earthquake damage assessment conducted shortly after the earthquake. Inspection studies have been conducted between May 5th and May 9th, 2003. The majority of the building stock investigated was reinforced concrete residential buildings, only a small number of masonry buildings were included. The team inspected a total of 96 buildings in Bingol, of which 57 were residential buildings, 21 were schools, and 18 comprised other government or official buildings. This paper presents the observations made by the team on residential buildings only. Typical damage patterns observed, the structural characteristics of the buildings, visual quality assessment results, and the observed building performances are given with respect to the location. The significances of certain structural and nonstructural attributes on the observed damage are highlighted.

OBSERVATIONS

Damage Assessment Methodology

The Bingol provincial area mostly contains reinforced concrete buildings of up to 6 stories in height. The majority of these buildings were built within the last decade. Only visual damage assessments were made because of limitations on available time for inspection.

Post-earthquake damage assessment involves a great deal of challenge because it requires necessary expertise from the assessor to convert physical damage visible in terms of cracks, deformations, and failures to the loss in the capacity of the components and, in turn, of the whole building. This introduces judgment into the evaluation process and renders it somewhat subjective. Thus the final decision regarding the state of damage or condition of the building is not certain and depends on the person conducting the survey. The uncertainty can be minimized if certain general criteria are set and followed in the assessment. Therefore, the damage assessment criteria used in our survey after the Bingol earthquake is explained to evaluate better the distribution and extent of the damage presented in this report.

Three damage states, namely light/none, moderate and heavy/collapse were employed when assigning damage for both structural and nonstructural components. In assigning a damage state to the structural system of the building, usually the most severely damaged floor, in most cases the ground floor, was studied, its structural components were examined for any visible cracks, deformations or palling/crushing of concrete and the decision was made for the building’s damage state. Damage state definitions employed are given in Table 1 for each component. It should be noted that a single component itself does not dictate the damage level of the whole building, thus the overall condition of many components is taken into account when assigning the damage states.

In the post-earthquake damage assessment when assigning damage state to the building under consideration, the reparability status and the life-safety performance criteria have been taken into account together. Therefore, a cost-effectively repairable building is deemed to have served satisfactorily in meeting the life-safety performance criteria.

Table 1. Damage state definitions employed

Damage State	Column	Beam	Shear Wall	Infill Wall
Light/none	Visible flexural hairline cracks	Visible flexural and inclined hairline cracks	Visible flexural hairline cracks	Surface cracks along the boundaries
Moderate	Clear flexural and shear cracks	Wide flexural and inclined cracks, spalling of concrete	Visible inclined hairline shear cracks and clear flexural cracks	Diagonal cross cracks, separation from the frame
Heavy/collapse	Wide cracks, spalling and crushing of concrete, buckling of reinforcement, excessive deformation	Large cracks, plastic hinge formation, crushing of concrete	Complete diagonal cracks, spalling of concrete, exposure of reinforcement	Through cross cracks, rupture of bricks, formation of empty spaces or out-of-plane dislocation.

Damage Statistics

Among a large reinforced concrete building stock existed in Bingol area, a total of 57 residential buildings are randomly selected from major districts of the city. A group of adjacent buildings are investigated to capture a snapshot of the damage distribution in each one of the selected vicinities. Each building was assigned a damage degree based on the criteria mentioned earlier, and a quality classification of the materials was made by visual inspection whenever possible. Three levels of material quality were employed; poor, average and good. Nineteen buildings were judged heavily damaged/collapsed, 14 were assigned moderate damage and the remaining 24 were identified as either undamaged or lightly damaged. An overall summary that contains observed damage, structural system, number of floors, and apparent material quality of the surveyed residential R/C buildings is presented in Table 2. The geographic distribution of building locations and pertinent damage index values are shown in Figure 1.

Table 2. Damage Survey Summary

Building ID	Location	Const. Year	No. of Floors	Type	Apparent Quality	Damage
BNG-10-4-4	Inonu	1998	4	RCF	average	moderate
BNG-10-4-5	Inonu	1997	4	RCF	poor	severe/collapse
BNG-10-4-6	Inonu	1976	4	RCF	average	moderate
BNG-10-4-7	Inonu	1988	4	RCF	average	light
BNG-10-4-8	Inonu	NA	4	RCSW	poor	severe/collapse
BNG-10-4-9	Inonu	2002	4	RCSW	good	light
BNG-10-3-10	Inonu	NA	3	RCF	poor	moderate
BNG-10-5-11	Inonu	1988	5	RCF	average	light
BNG-6-3-1	Yenimahalle	1991	3	RCF	poor	severe/collapse
BNG-6-4-2	Yenimahalle	2001	4	RCF	poor	severe/collapse
BNG-6-4-3	Yenimahalle	2003	4	RCF	poor	severe/collapse
BNG-6-3-4	Yenimahalle	2003	3	RCF	average	light
BNG-6-4-5	Yenimahalle	1996	4	RCF	good	light
BNG-6-4-6	Yenimahalle	1996	4	RCSW	poor	severe/collapse
BNG-6-4-7	Yenimahalle	1996	4	RCSW	poor	severe/collapse
BNG-6-2-8	Yenimahalle	1992	2	RCF	poor	severe/collapse
BNG-6-4-9	Yenimahalle	NA	4	RCF	poor	severe/collapse
BNG-6-3-10	Yenimahalle	1995	3	RCF	average	light
BNG-6-3-11	Yenimahalle	NA	3	RCF	poor	light
BNG-6-3-12	Yenimahalle	NA	3	RCF	average	light
BNG-5-5-1	Bahçelievler	Pre 1990	5	RCF	poor	light
BNG-11-4-1	Yesilyurt	1998	4	RCSW	poor	severe/collapse
BNG-11-4-2	Yesilyurt	1989	4	RCF	poor	severe/collapse
BNG-11-2-3	Yesilyurt		2	RCF	poor	moderate
BNG-11-4-4	Yesilyurt	2000	4	RCF	poor	moderate
BNG-11-4-5	Yesilyurt	1997	4	RCF	average	moderate
BNG-3-4-1	Karsiyaka	1998	4	RCF	poor	light
BNG-3-4-2	Karsiyaka	1996	4	RCF	poor	light
BNG-3-4-3	Karsiyaka	NA	4	RCF	poor	light
BNG-3-4-4	Karsiyaka	NA	4	RCF	Poor	light

Table 2. Damage Survey Summary - cont'd

Building ID	Location	Const. Year	No. of Floors	Type	Apparent Quality	Damage
BNG-1-5-1	Saray	NA	5	Tunnel Form	Poor	light
BNG-10-I-4-1	Inonu	NA	4	RCF	average	light
BNG-10-I-4-2	Inonu	NA	4	RCF	poor	severe/collapse
BNG-10-I-4-3	Inonu	NA	4	RCF	poor	severe/collapse
BNG-10-I-4-4	Inonu	1984	4	RCF	poor	severe/collapse
BNG-10-I-4-5	Inonu	1998	4	RCF	average	moderate
BNG-10-I-4-6	Inonu	1995	4	RCF	poor	moderate
BNG-10-I-4-7	Inonu	2000	4	RCSW	average	light
BNG-10-I-8	Inonu	Pre 1971	4	RCF	average	severe/collapse
BNG-10-I-9	Inonu	NA	4	RCF	poor	moderate
BNG-10-I-10	Inonu	1985	4	RCF	poor	moderate
BNG-10-I-11	Inonu	1980	3	RCF	poor	moderate
BNG-10-I-12	Inonu	1982	4	RCF	poor	moderate
BNG-10-I-13	Inonu	1973	4	RCF	poor	light
BNG-I-3-1	Yenimahalle	NA	3	RCF	NA	light
BNG-I-3-3	Yenimahalle	NA	3	RCF	NA	light
BNG-I-3-5	Yenimahalle	NA	3	RCF	NA	light
BNG-I-4-7	Yenimahalle	NA	4	RCF	poor	light
BNG-I-2-11	Yesilyurt	NA	2	RCF	NA	light
BNG-I-4-12	Bahçelievler	NA	4	RCF	average	light
BNG-I-5-13	Saray	1999	5	RCSW	poor	moderate
BNG-I-5-14	Saray	NA	5	RCF	NA	severe/collapse
BNG-I-4-15	Saray	NA	4	RCF	poor	moderate
BNG-I-4-16	Saray	NA	4	RCF	poor	severe/collapse
BNG-I-4-17	Saray	NA	4	RCF	NA	severe/collapse
BNG-I-5-18	Saray	NA	5	RCF	NA	light
BNG-I-4-19	Saray	1998	4	RCF	NA	severe/collapse

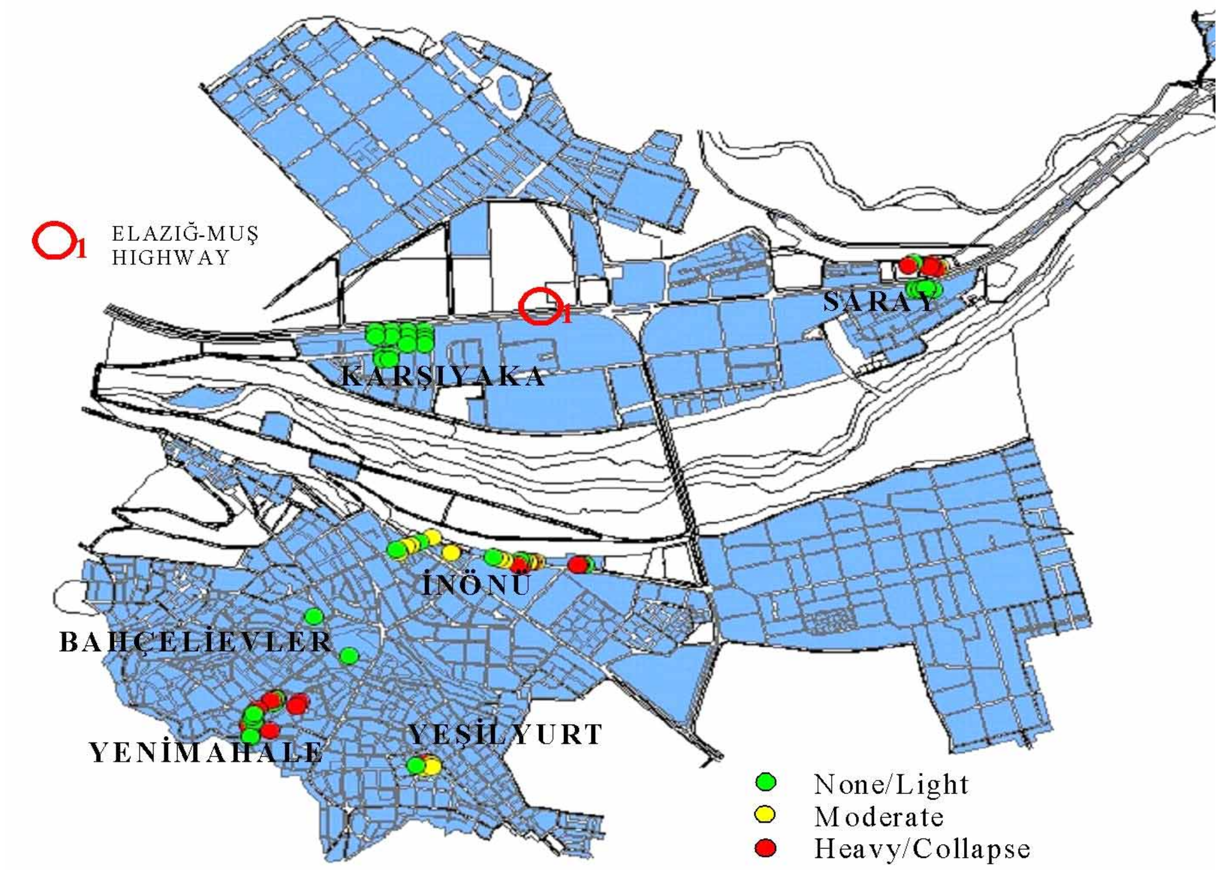

Figure 1 Observed damage distribution plot on Bingol map

The majority of buildings surveyed comprised of four story reinforced concrete frame buildings as shown in Figure 2. The damage distribution among each building group shows that heavy damage percentage is the highest for 4 story buildings (Figure 3). The relationship between the damage level and material quality is also illustrated in Figure 4. Although a rough trend between damage and material quality is evident, the lack of quality assessment for the buildings that had collapsed or had no damage prevents us from making a general conclusion. Year of construction versus damage level assessment showed no direct relationship.

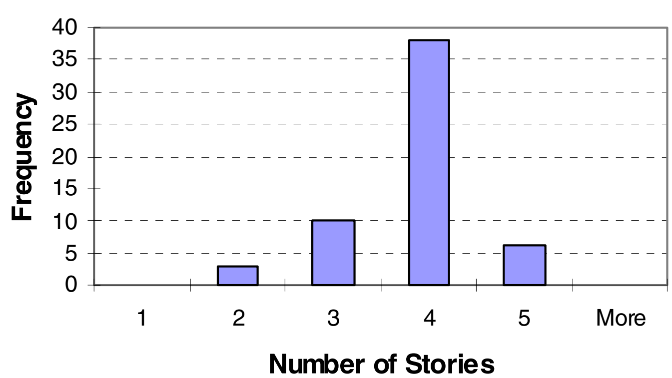

Figure 2 Distribution of buildings according to height

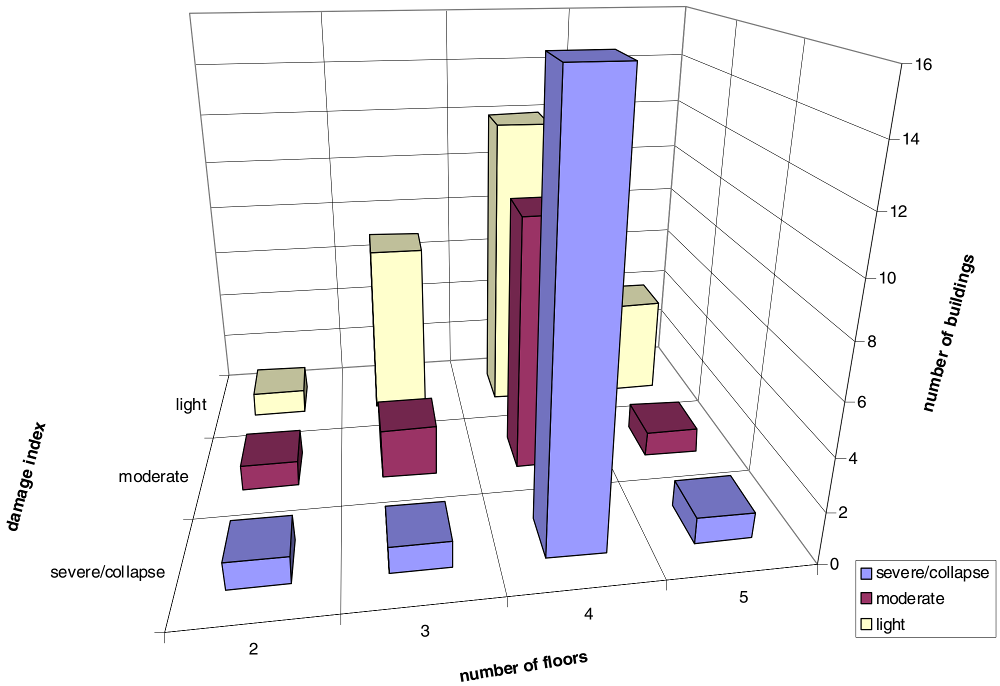

Figure 3 Observed damage versus number of floors matrix

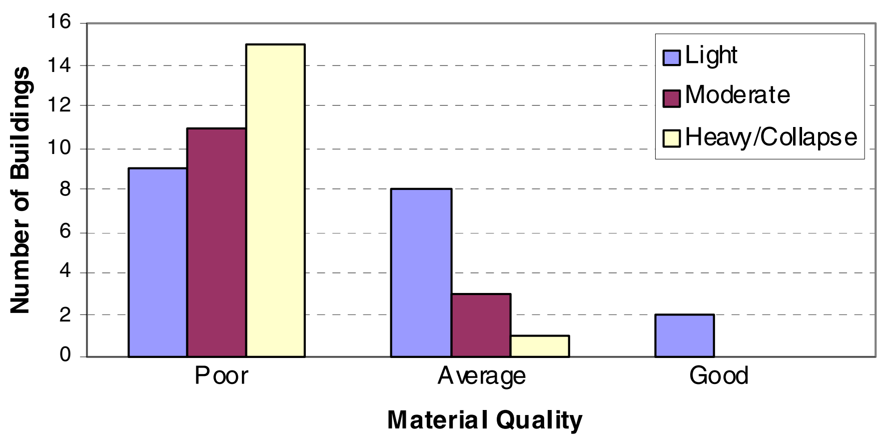

Figure 4 Observed damage versus material quality

Typical Damage Patterns

Common damage patterns are observed in majority of the investigated buildings in Bingol: shear cracks in columns, complete hinging at column ends, buckling of reinforcement, spalling and crushing of concrete in reinforced concrete members, dislocation of columns, joint failures, total collapse of the ground floor, excessive damage to large shear walls (if existed), diagonal cracking and separation of infill walls from encasing frames, were the typical damage patterns observed. Unlike other major historic earthquakes, damage due to pounding, pancake collapses and damage due to existence of over-hangs were not very frequently seen in Bingol earthquake.

A spectacular example of the diagonal tension crack at the upper end of the column due to a combination of inferior material quality and inadequate transverse reinforcement is shown in Figure 5. These columns belong to a three-story residential building. In this building, despite extremely poor performance of the columns, the masonry walls, which were made of unreinforced solid brick blocks, are believed to have prevented the total collapse.

Figure 5 Column hinging and shear

Figure 6 shows loss of story in reinforced concrete frame buildings due to insufficient column confinement. As it is known, insufficient structural resistance combined with the poor construction quality and detailing causes catastrophic failure of the structures. Shear failure, plastic hinging, and joint failure often times coexist at the same time causing member dislocations and floor collapses.

Figure 6 Column connection shear/dislocation in weak axes

Among the concrete buildings that were surveyed throughout the city only a few had limited and in some cases primitive shear walls contributing to their lateral load resistance. The presence of these shear walls very likely prevented the collapse of the buildings despite their inferior material quality. The walls picked up a significant part of the seismic force experiencing substantial damage. In Figure 7 heavy damages in shear walls are given. Once again substandard construction and material quality were the major factors that led to heavy damage.

Figure 7 Heavy damage to shear walls

Besides heavy damages, there were some buildings which experienced moderate damage indicating that load-resisting elements performed well with respect to life-safety. An example of such building is given in Figure 8. This building does not have any shear wall and the resistance to lateral loads was mainly provided by the columns and hollow clay tile infill walls. The increased strength demand in the first floor was supplied by the contribution of infill walls as evidenced by heavy infill wall damage concentration in that floor.

When solid clay tiles are used for partitioning as infill walls, the building performance is improved and damage level is reduced even though no shear walls existed. Solid clay tiles have larger compression area and can resist larger compressive forces compared to hollow clay tiles. Solid clay infill walls are not easily damaged, stiffer, and behave similar to shear walls. Buildings that were constructed prior to 1980 commonly used solid clay tiles for portioning walls.

Figure 8 Infill wall damage

Most of the buildings in Bingol city, as well as in other cities in Turkey, have several undesired architectural features that are worth mentioning here. The presence of a mezzanine floor, commercial use of the ground floor causing soft story formation, the penthouse and strong beam - weak column connections are some of those features that can be seen from Figure 8. Generally the infill walls are composed of conventional hollow clay tile used in practice for partition walls. The nonstructural components (i.e. hollow clay tile infill) of buildings with no shear walls commonly suffered severe damage (like in Figure 8) whereas reinforced concrete components had experienced moderate damage. It is noteworthy that the ratio of holes in the tile directly affects the load carrying capacity of the wall and the level of the damage in a building.

Summary and Reasons of Damage

The Bingol earthquake of May 1st, 2003 resulted in substantial damage to residential buildings that were generally 3-5 story reinforced concrete frames with infill wall type construction. The most widespread damage pattern was the collapse or heavy damage confined to the ground floor occupied by the commercial stores. The cases of pounding damage, pancake collapse, and damage due to over-hangs were quite rare and might be attributed to the short duration of the earthquake. Examples of significant damage attributed to short/captive columns were also observed.

Damage was mainly concentrated in columns in the form of core crushing and buckling of longitudinal bars leading to local collapse and shear cracks confined generally to the column ends. Damage to beams was limited and insignificant.

The effect of material quality and structural configuration (including short/captive column, soft story etc.) was quite clear. All surveyed buildings with shear walls survived the earthquake without collapse but those that did not have adequate material quality and proper detailing suffered substantial damage. A general observation made by the survey teams revealed that buildings that had a combination of the typical construction mistakes inducing parameters mentioned previously experienced significant damage.

The contribution of the infill walls to the lateral load resistance of the building was once again proven to be effective since many buildings had survived with only damage to their filler walls. Especially buildings that had unreinforced solid clay tile infill were observed to perform better than the ones with hollow clay tile.

Our experience in Turkey with the destructive earthquakes of the last decade has taught us that there are some general reasons for the high damage rates experienced by the buildings. These reasons can be divided into three general categories: The peculiarities of the architectural configurations in Turkey, which follow the legal restrictions on land use for housing are known to affect the performance of buildings negatively. This enforces the designers to make an improper choice of structural configuration that in turn results in discontinuity in the lateral load resisting elements, weak and soft stories arising from sudden changes in the stiffness and strength, overhangs, captive or short columns, and irregularities in the plan and elevation. The second major cause of damage is believed to be improper-poor detailing and proportioning of the reinforced concrete components. This might be introduced at two different stages. In the design phase, the requirements of the code are not implemented and thus the reinforced concrete sections designed do not comply with the ductility and strength requirements dictated by the code. In the construction stage, poor workmanship and tendency to disregard the detailing shown in the design drawings (both intentionally to save from material-workmanship and due to sheer ignorance) is another reason that leads to improper detailing and proportioning. Insufficient transverse reinforcement at the critical sections of the members and at the connections is a common practice that is a major reason for the damage pertaining to poor detailing. Inadequate (90 degree) anchorage and splice length are other factors that lead to damage related with detailing. Poor material quality combined with improper structural configuration and detailing errors makes up a deadly blend of mistakes which commonly leads to heavy structural damage or total collapse.

Observations made in Bingol after the earthquake revealed that the factors mentioned above played significant role in the damage of many reinforced concrete buildings.

DISCUSSION OF RESULTS AND CONCLUSIONS

The Bingol experience revealed that common problems associated with poor performance of the buildings remain unchanged. The effect of soil on the observed damage appears to be insignificant because of the uniform soil properties throughout the city.

In Bingol, the performance of buildings with structural walls (with or without frames working in parallel) was observed to be quite satisfactory from the viewpoint of safety. Buildings with higher ratios of structural wall to floor area had less damage, because the stiffness of the lateral load resisting system reduced the drift demand and the damage to structural and nonstructural elements. The performance of shear walls was found to be satisfactory in meeting the life safety criteria despite inadequate detailing practices, inaccurate placement of reinforcement, and substandard materials.

These observations give us sufficient confidence to promote the use of structural systems which are less dependent on detailing in order to provide adequate safety against collapse. For this purpose we strongly recommend the compulsory use of shear walls especially in the construction of school buildings. These walls should be placed along both principal directions of the building plan and over the total height of the building, located as symmetrically in plan as possible.

It is relevant to note that Turkey has a modern seismic code and a modern reinforced concrete code of practice. However, there is a striking gap between the requirements of these codes and actual construction practice - both in the rural and the urban areas. The major cause of the differences between the code requirements and construction practice of reinforced concrete buildings is the lack of enforcement of the codes in effect. Special precautions should be taken for enforcement of the codes during construction. In Bingol, the poor implementation of code requirements resulted in a very high toll in terms of human lives and number of people left homeless.

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REFERENCES

1. 1 May 2003 Bingol Earthquake Engineering Report, Structural Engineering Research Unit, TUBITAK, 2004