FINDINGS OF THE UK INVESTIGATION OF THE 1992 ERZINCAN EARTHQUAKE

İNGİLİZ İNCELEMELERİNDEN 1992 ERZİNCAN DEPREMİNE AİT BULGULAR

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ABSTRACT

A mission to Erzincan in Eastern Turkey was mounted by the UK-based Earthquake Engineering Field Investigation Team in the aftermath of the earthquake of 13 March 1992. The team performed a number of detailed damage surveys in Erzincan and the surrounding villages, aimed at assessing the principal design faults causing collapse, the distribution of damage and the relative vulnerability of the various building types. Efforts were also made to correlate observed intensities with measured strong motion parameters. This paper concentrates on three aspects of this work. Firstly, the principal modes of failure of the various building types are outlined with brief reference to examples. This is followed by an account of surveys carried out at the three hospitals in Erzincan, all of which suffered serious damage during the earthquake. Lastly, distributions of damage both within the city and across the Erzincan Basin are presented. The lack of any obvious, consistent trends, makes it difficult to establish a clear "basin effect" from the distributions.

INTRODUCTION

The earthquake which struck Erzincan on 13 March 1992 was the first large event to affect the modern construction resulting from the recent Turkish economic and population boom. While many building types suffered high levels of damage, the earthquake followed a recently observed worldwide trend, in that most of the casualties were caused by the collapse of reinforced concrete (RC) buildings. However, the affected area also contains numerous villages consisting largely of traditional, low-cost forms of construction. There are thus several important aspects of structural performance which can be assessed from a careful review of the damage at Erzincan.

Shortly after the earthquake, a mission mounted by the UK-based Earthquake Engineering Field Investigation Team (EEFIT) visited Erzincan and surveyed building damage in the city and in the surrounding villages, both within the deep alluvial basin in which Erzincan is located, and in the mountains to the north. A full account of the team's

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findings has recently been published [1]; several aspects of the team's work are also described in a paper to this conference by Booth [2]. This paper concentrates on three main aspects of the work carried out by the EEFIT team. Firstly, the principal modes of failure of buildings in and around Erzincan are reviewed. Many of the points made here are amplified in the ensuing section, in which the three hospital buildings are used to illustrate many of the problems encountered in Erzincan. The final section of the paper deals with the distribution of damage both within the city and across the Erzincan Basin.

MODES OF FAILURE

Structural Types

A simplified plan of Erzincan is shown in Figure 1; it is a modern city, having been rebuilt following a devastating earthquake in 1939. The principal building types in the city are: mid-rise (up to six storeys) in situ RC; low-rise (one or two storeys) in situ RC; low rise brick masonry; single storey adobe masonry; and single storey prefabricated housing (either timber or concrete). There are very few steel structures. In the villages there is a large amount of traditional housing, including himis (timber frame with infill of adobe blocks), adobe masonry and rubble stone masonry. Roofs are frequently of the very heavy, flat, compacted earth type, though lightweight timber and corrugated steel roofs are also used. Additionally, there is an increasing amount of more modern brick or concrete block masonry and some reinforced concrete housing, particularly in the villages very close to Erzincan. While the worst damage occurred in mid-rise reinforced concrete structures, significant levels of damage were also found in the other structural types, with the exception of the prefabricated buildings; these low-rise, lightweight structures suffered little damage in the earthquake.

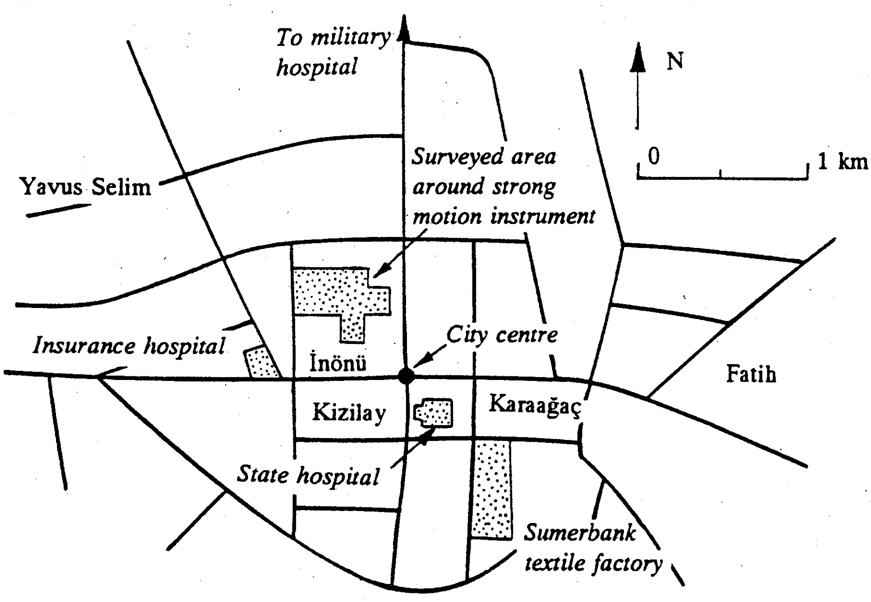

Figure 1 Plan of Erzincan Showing Districts and Buildings Referred to in this Paper

Reinforced Concrete Structures

The majority of mid-rise RC structures were located on the two main streets in Erzincan, running north-south and east-west. The proportion of these which collapsed or were damaged beyond repair may be as high as 40% [3]. Most of the collapses were of the bottom-up type, with failure first occurring at the ground floor level, and sometimes spreading to the upper storeys as the structure fell. In most instances, however, bottom-up collapses were restricted to the bottom one or two storeys, with complete failure at all levels relatively rare (Figure 2). Soft storeys at ground floor level were probably the most common cause of bottom-up collapse. These were extremely widespread among the major buildings on the two main streets of the city, where nearly all ground floors were used as shops. Several collapses were initiated by a series of short columns at semi-basement level, where windows frequently spanned the full width between columns. Weak column-strong beam design was also observed in numerous structures.

Torsional failures occurred in several instances. Large torsional loads can be developed when the centres of mass and stiffness are a significant distance apart due to, for instance, a large number of openings on a street-facing facade, or eccentric positioning of staircases. There were also several cases where lack of uniformity of openings from floor to floor or from side to side of a building led to uneven load distributions, and hence failure (see e.g. the State Hospital, later in this paper).

There was a small number of mid-storey collapses, in which one storey was lost while floors both above and below remained relatively undamaged (Figure 3). Only one case of top-down collapse was observed; this type of failure usually involves structures of more than six storeys, and so would not be expected to occur widely in Erzincan.

On the construction side, insufficient provision of confining reinforcement was noted in several instances, as was poor quality concrete (segregated or honeycombed, made using rounded aggregates). It has been suggested that the average compressive strength in damaged RC structures was only around 10 N/mm^2 [3], less than half the value required by the Uniform Building Code [4] for buildings in areas of high seismicity.

Low-rise RC construction was sometimes used for housing in Erzincan and the more accessible villages. These buildings mostly performed well, with damage limited to cracking of infill panels. However, a number of complete collapses were observed, usually due to a soft ground floor used for parking or storage.

All of the deficiencies in design and construction discussed in this section are well understood; many of the resulting failures may therefore be regarded as avoidable.

Brick or Concrete Block Masonry Buildings

While masonry structures in and around Erzincan suffered widespread damage, there were relatively few total collapses. Most failures were caused by the development of diagonal shear cracks, often initiated at door or window openings, or at re-entrant corners. This mode of failure was most clearly seen at the newly built cooperative housing estate in Üzümlü, 20km east of Erzincan [1]. Instances of masonry walls falling out-of-plane were also quite common. Most masonry structures were reasonably well built, and incorporated reinforced concrete ring beams, usually positioned at the tops of window openings. These proved very effective in arresting the growth of shear cracks, and in one or two instances they were strong enough to prevent roof collapse when an entire wall was lost. The most common design faults in masonry structures were the provision of excessive areas of window openings in load bearing walls and the irregularity of plan configurations, with re-entrant corners widely used.

Figure 2 Bottom-up Collapse of RC Building in Karaağaç District, with Partial Survival of Upper Storeys

Figure 3 Mid-Storey Collapse of RC Building in Karaağaç District, other Floors Severely Damaged

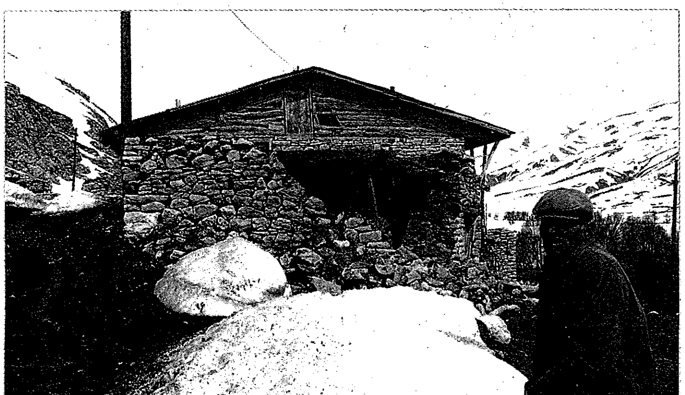

Figure 4 Partial Collapse of a Stone Masonry Building in the Mountain Village of Mecediyeh

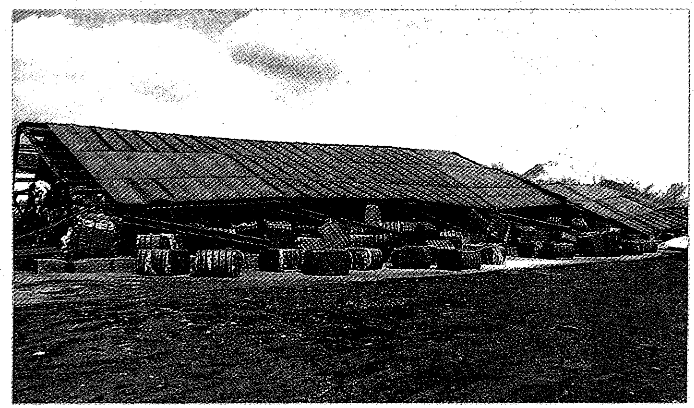

Figure 5 Westwards Failure of Steel Storage Shed at the Sumerbank Textile Factory

Traditional Forms of Construction

Structures with stone or adobe block walls generally fared very badly in the earthquake, particularly in cases where the roof was of the heavy, compacted earth type (Figure 4). In addition to shear failures of the walls, many roof collapses were caused by a loss of bearing as the supporting walls moved. In buildings where roof joists protruded well beyond the walls or were supported by timber props just inside the walls, cases of roof collapse were considerably fewer. Himis houses suffered moderate levels of damage, with spalling of plaster and loss of infill adobe blocks, but cases of collapse were comparatively few, due to the ability of the timber frame to sustain very large displacements without failure.

Directionality of Damage

Attempts were made to assess the principal direction of collapse of many of the buildings surveyed, from which two main conclusions were drawn. Firstly, structures whose long axis was oriented in the east-west direction appeared to suffer more severe damage than those whose long axis ran north-south. A good example of this is the behaviour of two lightweight storage structures at the Sumerbank Textile Factory, whose location is shown in Figure 1. These consisted of unbraced steel frames, open at the sides and with steel sheet cladding on the roof; the two structures were identical but for their orientation. The frame with its long axis running east-west collapsed completely, falling to the west (Figure 5), while the other structure, positioned at right angles to it, survived with no visible damage. This finding suggests that the east-west ground motion during the earthquake was stronger than the north-south motion. This is in agreement with the strong motions recorded in the centre of Erzincan, and suggests a strike-slip fault mechanism.

Secondly, it was found that the majority of structures collapsing on an east-west axis fell to the west, while those failing along a north-south axis mostly fell southwards. This characteristic was noted for individual members as well as for structures, with west and south facing walls of buildings suffering out-of-plane failures at a far greater frequency than east or north facing ones.

THE HOSPITALS

Hospitals are among the most crucial buildings in a major emergency. It is obviously important that they should survive strong earthquakes and other natural disasters without severe disruption. The EEFIT team visited all three hospital sites and collected information on their structural and operational performance during and immediately after the earthquake. In addition to their obvious strategic importance, these structures serve to illustrate a number of the general points made in the preceding section.

The State Hospital

The state hospital consists of six major buildings occupying a site very close to the city centre (see Figure 1). Of these, the two storey obstetrics building constructed in 1980, the three storey chest hospital built in 1990 and two smaller single-storey buildings suffered only minor damage. The most serious damage occurred in the nursing school, a five storey building with basement constructed prior to the introduction of the 1977 earthquake code, illustrated in Figure 6. The western half of this building collapsed completely, killing 22 of the approximately 50 occupants. Referring to Figure 6 a number of structural features which may have contributed to the collapse can be identified.

Firstly, while there was a transverse shear wall just to the west of the entrance hall, there were no longitudinal shear walls; the main longitudinal walls are unlikely to have acted as shear walls due to the large number of door and window openings. Secondly, the uneven layout of window openings would have caused an uneven distribution of horizontal load throughout the structure. A further source of stiffness eccentricity was the single stairwell located on the south side of the building. There were also numerous locations where short columns may have developed between windows. Lastly, the long axis of the building ran east-west, with the collapse occurring on the western side.

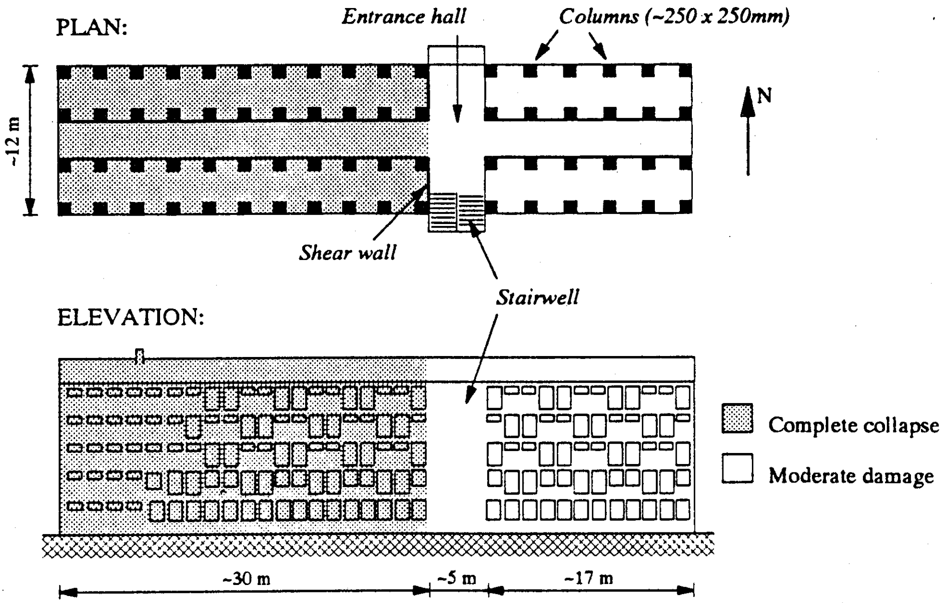

Figure 6 The Nursing School; Typical Floor Plan and Elevation Showing Distribution of Window Openings (not to scale)

The sixth building on the site, a three-storey operations clinic, suffered severe damage to columns and diagonal cracking of infill masonry at the ground floor level. In this building most of the windows were concentrated at one end of a facade, and the layout was exactly reversed between the north and south facades, giving rise to significant torsional effects. Again, the long axis of the building was oriented east-west.

Although several of the buildings remained intact, the state hospital was not able to respond well to the earthquake [5]. The collapse of the nursing school dominated the efforts of hospital staff in the first few hours. Power and water supplies were lost. Many operations were carried out in the open air or in tents. The unexpectedly high number of people requiring treatment for burns also caused problems.

The Insurance Hospital

This hospital, located to the west of the city centre (see Figure 1), consisted of two rectangular buildings, each measuring approximately 40m east-west by 20m north-south, one having five storeys and the other four. A common stairwell joined each building at a corner. The earthquake caused collapse of the five storey building and moderate structural damage to the four storey structure. The site was cleared before the EEFIT team reached Erzincan. Inspection of the surviving building showed that the infill panels were relatively strong (made of solid brick), and suggested the possibility of a short column effect at semi-basement level. An unofficial estimate put the number of fatalities in this collapse at 21.

The Military Hospital

This large six-storey structure, located to the north of the city, is shown in plan in Figure 7. While most of the building had a very regular, uniform configuration, the vulnerability of the end sections was increased by the large number of re-entrant corners. The earthquake caused complete collapse of the section at the western end, a mid-storey collapse in the remainder of the western half, and severe structural damage to the rest of the building. Inspection of photographs of the structure prior to the earthquake suggested that a soft storey was the most likely cause of the collapse, though it is possible that there was also some pounding from the low-level extensions to the north of the main structure. A military spokesman told EEFIT that there were no fatalities in the hospital, which had around 80 occupants at the time of the earthquake.

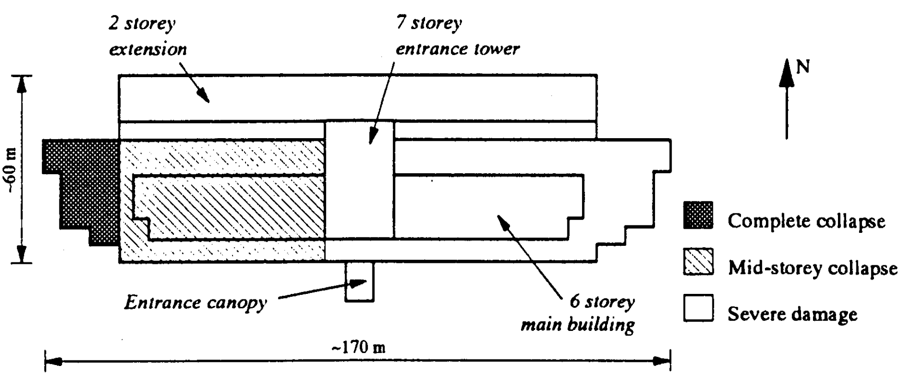

Figure 7 Plan View of Military Hospital (not to scale)

Common Features

A number of similarities are apparent from the surveys of these three sites. In each case a major collapse occurred at the western end of a long building whose major axis ran east-west (roughly parallel to the North Anatolian Fault). This agrees with observations of directionality given elsewhere in this paper, and with the measured strong motions, which were greatest in the east-west direction. All the collapsed buildings were five or six storey RC frames with a large number of window openings and no shear walls in the east-west direction. This again corresponds well with the measured strong motion characteristics; the strongest acceleration components occurred in the period range 0.2 to 0.3 seconds, close to the fundamental natural period of a typical mid-rise framed structure. Lastly, the poor performance of these three important structures is a cause for considerable concern. In addition to the numerous fatalities, the high damage levels seriously reduced the hospitals' ability to participate effectively in the recovery operation.

DAMAGE DISTRIBUTIONS

A number of damage surveys were carried out by the team in an attempt to assess the vulnerability of the various building types and the effect of the deep alluvial basin in which Erzincan is situated. These included:

- a detailed survey of low-rise RC frames, block masonry buildings, himis houses and prefabricated timber houses in the area around the strong motion instrument, just north-west of the city centre;
- a survey of an estate of newly built masonry houses in Üzümlü;
- surveys of low-rise RC frames and adobe masonry houses in the villages of Çukurkuyu and Yalnizbag, approximately 7km north-west of Erzincan;
- visits to ten other villages in the Erzincan Basin and the mountains to the north;
- a 3km north-south transect through the city, recording damage to chimneys and boundary walls (this survey is described in detail by Booth [2]).

Additional data was provided by the Ministry of Public Works and Resettlement, based on a house-by-house survey carried out very shortly after the earthquake. The main conclusions of these surveys are summarised below.

The City of Erzincan

The data published by the Ministry of Public Works and Resettlement indicated that, of the total building stock in Erzincan, approximately 8% were destroyed by the earthquake, 12% were moderately damaged and 15% suffered light damage. Subsequent unofficial reports suggest that these early figures may significantly underestimate the total damage levels. Instances of collapse and severe damage in Erzincan were concentrated in the central districts of İnönü, Kizilay and Karaağaç, in Yavus Selim on the north-west edge of the city, and in the district of Fatih to the east (see Figure 1). All of these districts have above-average densities of mid-rise buildings; areas consisting of predominantly low-rise construction suffered proportionately less damage.

A detailed damage survey was carried out in the area around the strong motion instrument in İnönü, just north-west of the city centre [5]. This covered 125 buildings, made up of roughly equal numbers of prefabricated timber frames, himis houses, brick masonry buildings and one to three storey RC frames. Table 1 summarises the damage distributions obtained from the survey. It can be seen that there were very few collapses in this area, but that large numbers of both himis houses and masonry buildings suffered moderate levels of damage. The RC frames covered by the survey were all of three storeys or less, and performed reasonably well. Comparisons with surveys carried out following other earthquakes showed that the overall damage level in this area was roughly as would be expected for an earthquake of this magnitude.

Table 1 Damage Levels in Survey Around Strong Motion Instrument

Construction type	No. in survey	Number of buildings classified as having:		
		Light or no damage	Moderate damage	Severe damage or collapse
Timber frame	39	34	5	0
Himis	35	14	18	3
Brick masonry	28	10	17	1
RC frame	23	15	7	1

Surrounding Villages

The majority of villages visited by EEFIT were situated 4 to 10km west of Erzincan, with locations ranging from the middle of the basin to the foothills of the mountains to the north, very close to the North Anatolian Fault. In addition, members of the team visited three villages to the east of the city, two villages in the mountains to the north, and the town of Kemah, approximately 40km south-west of Erzincan. A detailed survey was performed in the villages of Çukurkuyu and Yalnizbag, situated just at the edge of the basin, 7km north-west of Erzincan. These villages suffered high levels of damage to their building stock, which consisted mostly of adobe masonry houses and low-rise RC frames. On average, the adobe houses fared the worse, with approximately one third of them severely damaged and one third moderately damaged; there were, however, very few cases of total collapse. While most of the RC structures suffered little or no damage, several collapsed completely.

The team also visited the town of Üzümlü, in the foothills of the mountains 20km east of Erzincan, and two nearby villages in the flat part of the basin. In Üzümlü most of the buildings suffered only light damage, the major exception being a new estate of masonry houses built along a north-south line running downhill from the town into the Erzincan Basin. In these houses the damage levels increased steadily from virtually nil at the northern end to complete collapse of the southernmost houses (nearest to the deep part of the basin). However, it is possible that other factors besides sediment depth influenced this damage distribution (e.g. age of construction).

The distribution of damage in the remaining villages is hard to interpret. On the west side of the basin damage levels were highest in the villages in the mountains to the north, close to the North Anatolian Fault. However, to the east, observed damage levels increased from the northern edge towards the centre of the basin. Other researchers have reported that damage levels on the south side of the basin were very low [6]. However, further to the south, outside the basin, damage levels increased again. In Kemah, 40km south-west of Erzincan, high levels of damage were observed in two major buildings, and numerous landslides and building collapses have been reported as far south-west as İliç, 80km from Erzincan [6]. It is possible that these effects were caused by some form of channelling along the Euphrates valley. Clearly, the damage distribution in the affected area is extremely complex. Effects appear to have been highly localised, so that it is not possible to infer a simple basin effect in the frequency range of interest.

CONCLUSIONS

The Erzincan earthquake caused high levels of damage in the city and in many surrounding villages, with reinforced concrete, brick masonry and traditional forms of construction all badly affected. While many mid-rise RC buildings suffered high levels of damage, low-rise RC construction appears to have performed well in the earthquake. Damage distributions within the city showed some correlation with building type and height, but there were no easily explainable trends in damage levels across the basin. The modes of failure and the structural deficiencies observed in Erzincan are well understood; many of the collapses can be attributed to non-compliance with code requirements rather than to gaps in understanding. The difficulty of adequately monitoring construction during a period of very rapid growth is obvious. Nevertheless, it is clearly unacceptable that even such crucial structures as hospitals should suffer very high levels of damage.

ACKNOWLEDGEMENTS

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İNGİLİZ İNCELEMELERİNDEN 1992 ERZİNCAN DEPREMİNE AİT BULGULAR

Martin S. WİLLİAMS

13 Mart 1992 depreminden hemen sonra, İngiliz esaslı Earthquake Engineering Field Investigation takımı tarafından, Türkiye'nin doğusunda yer alan Erzincan'da bir özel görev yapıldı. Bu takım Erzincan ve çevresinde ayrıntılı hasar çalışmaları yaptı. Amaç, göçmeye neden olan boyutlandırma hataları, hasarın dağılımı ve değişik bina tiplerinin göreli deprem duyarlılığı konularında değerlendirmeler yapmaktı. Gözlenen şiddetler ile ölçülen kuvvetli yer hareketinin parametreleri arasında ilişkiler kurmak üzere uğraşıldı. Bu yazıda çalışmaların üç yönü üzerinde yoğunlaşılmaktadır. Bunlardan birincisinde değişik bina tiplerinin göçme modları örneklere başvurularak özetlenmektedir. Bunu, deprem sırasında önemli hasar gören üç hastanedeki değerlendirme çalışmaları izlemektedir. Son olarak kentiçi ve havzadaki hasar dağılımı sunulmaktadır. Ancak bu dağılıma dayanarak açık bir "çanak etkisi" tanımlamak güçtür.