

## 9 DAMAGE TO BUILDINGS

### 9.1 Natural Period of Structures in Turkey

The natural periods of structures first were measured by Aykut and his work was later followed by Bayülke (1978). Their data together with new additional ones are plotted as a function of number of stories in Figure 9.1. This experimental data were fit to a linear function by considering the number of stories up to 8. The following relations approximately hold between the natural period  $T$  of the building and the number  $N$  of stories:

$$T = 0.05N \quad (9.1)$$

The United State Seismic Code (USCC) recommends the use of the following formula to obtain the natural period of the buildings:

$$T = 0.09N \sqrt{\frac{D}{H_f}} \quad (9.2)$$

where  $D$ : the side length of the building in the direction of shaking;  $H_f$ : building height. This formula seems to be capable of estimating the natural period of buildings. Nevertheless the simple formula (9.1) can also be used to the natural buildings up to 8 floor. The natural periods buildings with 4,5,7,8 stories are obtained from Eq. (9.1) are 0.20s, 0.25s, 0.30s, 0.35s and 0.40s. The natural period of minarets are also between 0.35-0.40s.

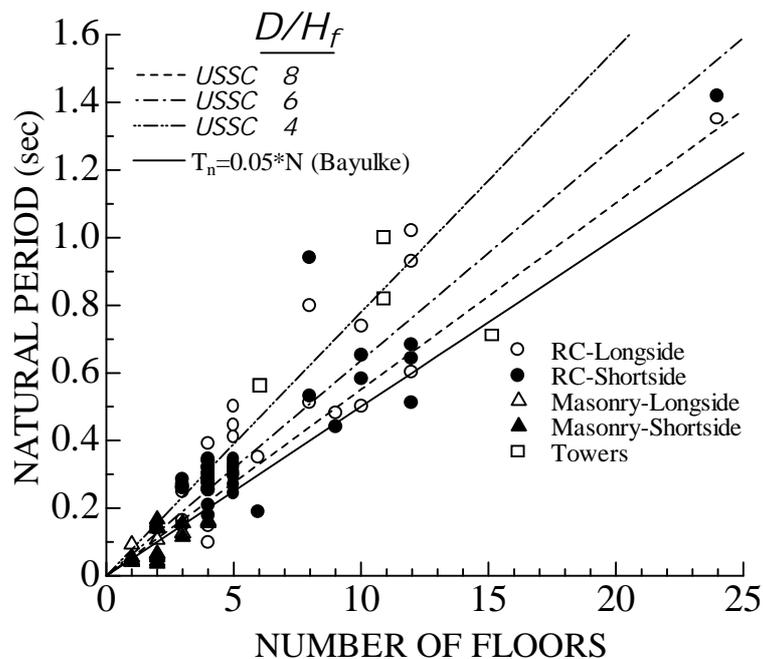


Figure 9.1 Natural periods of structures in Turkey

## 9.2 Reinforced Concrete Structures

The totally collapsed or heavily damaged apartment buildings had 5-8 stories as shown in Figure 9.2. The natural periods of these buildings mostly coincide with the dominant periods of the horizontal earthquake motion. These structures were designed as moment-resistant frame structures with in-fill walls made of hollow bricks. The diameter of reinforcing bars and stir-ups were mostly 8-16 mm and 4 mm respectively. Bars were generally of smooth type. However the use of deformed bars were observed in buildings under construction or new buildings.

The ground floors of collapsed buildings were mostly used as either shops or garages. As a result, this type of usage constitutes a soft (weak)-floor situation. Furthermore, many buildings had heavy balconies of cantilever type.

The causes of damage were almost the same as those seen in previous earthquakes and listed below;

**Poor workmanship:** There are two kinds of poor workmanship. One of them is that the connections of columns and beams were very weak since the connections of steel bars were not properly done and detritus materials at such locations were not cleaned.

The second one is that the granulometry of the sand and gravels of concrete was very poor and the range was wide. In addition, big gravels blocked the concrete during casting at locations where steel connections were dense and this resulted in very porous and weak connections. Such connections were quite common in collapsed or heavily damaged buildings. During shaking, it seems that concrete at the connections first failed and this subsequently caused the buckling of steel bars at such locations and rupturing in-fill hollow brick walls in a brittle sense. As a result, the collapse of buildings ended up in a pancake mode.

**Resonance:** Natural periods of structures mostly coincided with those of the earthquake ground motions and this resulted in the resonance of structures and their subsequent collapses. For buildings with 4 to 8 stories, the natural period ranges between 0.2s and 0.4s.

**Construction mistakes:** One of the most striking construction mistakes or negligence was the confinement of concrete at the beam-column connections (Figure 9.3) in spite of the Turkish design code for seismic regions. As stir-ups were very few at such locations without concrete adherence, the failure of concrete was very brittle and it could not absorb the work done by the earthquake forces. Furthermore, the diameter of steel bars were less than that required in the design code.

**Soft (Weak) floor:** Many buildings had shops at their ground floor. Since there are generally no shear-walls to take up the load during earthquakes, the total load is transferred on the columns. The super structure acts a top-heavy structure on the columns and in-fill walls, which are in poor contact with columns and beams, has no effect against the earthquake loading and they fail subsequently as seen in Figure 9.4. It was interesting to note that structures having solid bricks or angular rock blocks as in-fill walls and columns constructed after the construction walls performed much better and damage was none or very limited. (Figure 9.5)

**Collision of Adjacent Structures:** Buildings at the corners of streets were collapsed as a result of collision with the adjacent building (Figure 9.6)

**The use of untreated sea sand:** The use of uncleaned sand from sea caused the corrosion of steel bars which subsequently reduced the resistance of columns and beams against lateral load. This problem was observed in all collapsed and damaged buildings in Istanbul, Zmit, Gölçük and Yalova. This is a quite serious problem for buildings constructed in town and cities along the shores of Turkey.

**Liquefaction of ground:** The liquefaction of ground resulted in the reduction of bearing capacity of ground which resulted in either rigid-body like toppling or collapse of structures in a pan-cake mode as seen in Figure 9.7.



Figure 9.2 An aerial view of collapsed reinforced concrete buildings in Adapazar



Figure 9.3 Improper column-beam connections (Note that reinforcing bars have smaller diameter and are not hooked with each other and lack of stir-ups and also lack of adherence of concrete. The building is shown in Figure 9.14



Figure 9.4 Collapsed 5 story RC building in Avcılar (Istanbul)



Figure 9.5 Non-damaged reinforced concrete building with solid bricks in T c lar district of Adapazar where liquefaction was widespread



Figure 9.6 Collapse of 6 story RC building due to collision with a adjacent 8 story RC building in Avc lar ( stanbul)



Figure 9.7 Toppled and collapsed buildings in T c lar district of Adapazar

### 9.3 Masonry Structures

The masonry structures in Kocaeli and Adapazarı provinces may be divided into two categories:

- 1) Tuğla (Brick) masonry, and
- 2) Taş (Rock) masonry.

#### 9.3.1 Tuğla (Brick) Masonry Structures

The most severe damage was observed in houses made of delikli Tuğla (hollow bricks). Although the use of this type of brick as a load bearing element was forbidden after the experience in 1992 Erzincan earthquake, its use is presently widespread in Turkey. It should be noted that this material is very brittle. Once it starts to fail, it fails very quickly as stress-concentrations develop everywhere. The houses made with solid bricks and reinforced with concrete slabs for the continuity of structures and having stories less than four performed very well during the earthquake even in a liquefied district (Figure 9.8).



Figure 9.8 Non-damaged buildings made with solid bricks in Tıncalılar district of Adapazarı where liquefaction was widespread

### 9.3.2 Ta (Rock) Masonry Structures

This type of structure is quite rare in the earthquake-affected area. During the site investigation, three such buildings were identified. One of them was Sapanca railway station and the other ones were Yeni Cami (mosque, built in 1946) in Adapazar and a mosque in Gölcük. None of these buildings were damaged. Particularly Yeni Cami was founded on alluvial deposits and was experienced also 1967 Mudurnu Suyu earthquake. Many modern reinforced concrete buildings next to this mosque were totally collapsed (Figure 9.9).



Figure 9.9 Views of Yeni Cami and its close vicinity in Adapazar

#### 9.4 Ba dadi (Wood+Brick) Structures

This type of buildings is generally common when wood is locally available. The filling material of this type houses is adobe or solid brick and they are quite similar to truss structures. None of these structures was totally collapsed even some of them were quite old. The damage of these houses was taken place in the form of falling plasters or in-fill walls (Figure 9.10).



Figure 9.10 Views of Ba dadi houses in Adapazar city

### References

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