The History of Development in Turkish Seismic Design Codes

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A major part of Turkey is located on active seismic zones. Earthquakes that occurred in recent years in populated towns have left many people dead and caused substantial damage to buildings. This has made the issues of designing an earthquake-resisting building and determining the safety level of buildings against earthquakes topical. Taking precautions towards determining the safety level of the building has a vital importance on reducing the possible damages of future earthquakes. This paper describes the development of seismic design codes in Turkey. Destructive earthquakes have usually resulted in revisions to the codes. This study includes a detailed comparative study among seismic design codes from 1940 to 2007. As a result this paper is expected to form a guide for universal engineers and architects.

Index Terms—Code Standards, Construction, Earthquakes

I. INTRODUCTION

Earthquake is one of the major problems for Turkey because of its location on the Alp-Himalayas Fault, which is one of the most active earthquake areas on the world. Being very close (about 5-30 km) to the surface, the earthquakes that occur especially on the North Anatolian fault are very dangerous. Table 1 lists seismic events in the evolution of seismic codes in Turkey [1]. Destructive earthquakes have usually resulted in revisions to the codes. As it was seen from the table 1, catastrophic consequences were observed after recent severe earthquakes in Turkey leading thousands of casualties. Main reason of the extent of the damage and losses are generally believed to be the construction malpractice and lack of adequate inspection of enforcement of the application of seismic design code [2].

The aim of this paper is to examine the role of Turkish Seismic Codes on structural design. Although the preliminary aim of Turkish earthquake regulations is to provide knowledge for designers to control structural and constructional system of buildings that can resist disasters in the pre-disaster period, these regulations couldn’t be successful to prevent collapses or life losses.

II. INVESTIGATION OF SEISMIC DESIGN CODES OF TURKEY

A. 1940 Seismic Design Code

The first seismic design codes for buildings was published in 1940 in Turkey after the great Erzincan Earthquake that occurred in 1939. Because of the earthquake 32,962 people were killed and 116,720 buildings collapsed or were damaged. Thus, the government of that time felt the need for a legal enactment. On 17th January 1940, Law No.3773 “Law Related to Aids for Erzincan Earthquake Area” was decreed [3]. This law was the first disaster law of the republic but it was basically about post-event response. It only contained economic support for the earthquake victims. For example, free land was donated to people whose houses collapsed or became unfit for use, and construction material was also provided for those people.

Due to the masonry structures were common in that period regulation was described generally on architectural issues.

<table>
<thead>
<tr>
<th>Year</th>
<th>Place of Occurrence</th>
<th>Magnitude</th>
<th>Loss of Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>1939</td>
<td>Erzincan</td>
<td>7.9</td>
<td>32962</td>
</tr>
<tr>
<td>1940</td>
<td>First seismic code published</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1944</td>
<td>Bolu-Gerede</td>
<td>7.2</td>
<td>3959</td>
</tr>
<tr>
<td>1944-1949</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1953</td>
<td>Yenice, Gönen</td>
<td>7.4</td>
<td>265</td>
</tr>
<tr>
<td>1953</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957</td>
<td>Fethiye</td>
<td>7.1</td>
<td>67</td>
</tr>
<tr>
<td>1962</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td>Varto</td>
<td>6.9</td>
<td>2394</td>
</tr>
<tr>
<td>1968</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td>Gediz</td>
<td>7.2</td>
<td>1086</td>
</tr>
<tr>
<td>1975</td>
<td>Lice</td>
<td>6.9</td>
<td>2385</td>
</tr>
<tr>
<td>1975</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>Çaldıran, Muradiye</td>
<td>7.2</td>
<td>3840</td>
</tr>
<tr>
<td>1992</td>
<td>Erzincan</td>
<td>6.8</td>
<td>653</td>
</tr>
<tr>
<td>1995</td>
<td>Dinar</td>
<td>6.3</td>
<td>94</td>
</tr>
<tr>
<td>1997</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>Ceyhan, Adana</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>Kocaeli</td>
<td>7.4</td>
<td>17408</td>
</tr>
<tr>
<td>1999</td>
<td>Düzce, Kaynaşlı</td>
<td>7.2</td>
<td>845</td>
</tr>
<tr>
<td>1999</td>
<td>İzmit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>Sultandağı, Çay</td>
<td>6.3</td>
<td>42</td>
</tr>
<tr>
<td>2003</td>
<td>Bingöl</td>
<td>6.1</td>
<td>184</td>
</tr>
<tr>
<td>2005</td>
<td>Seferihisar-İzmir</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>Hakkâri</td>
<td>5.4</td>
<td>3</td>
</tr>
<tr>
<td>2007</td>
<td>Seismic code revised</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Başyurt - Elâziğ</td>
<td>6.0</td>
<td>42</td>
</tr>
<tr>
<td>2011</td>
<td>Van</td>
<td>7.2</td>
<td>604</td>
</tr>
</tbody>
</table>
B. 1944 Seismic Design Code

After the Erzincan Earthquake (M= 7.9) in 1939, between the years of 1939-1944, other major earthquakes occurred in Turkey. The most significant one was Bolu-Gerede earthquake (M=7.2) in 1944. On 18th July 1944, Law No.4623 called “Measures to Be Put into Effect Prior and Subsequent to Ground Tremors” was enacted, which started earthquake mitigation works. This law made obligatory to take preventive measures before an earthquake disaster [3]. The 1944 code was similar to the Italian seismic code of that time [4, 5], and the base shear, \( V \), was calculated as the product of a lateral force coefficient, \( C \), and the weight of the building, \( W \), namely:

\[
V = C \cdot W
\]  

(1)

The value of \( C \) was set equal to 0.10 regardless of the location of the designed structure in Turkey. The base shear force was distributed over the height of the building using a uniform load pattern.

The heights and the number of storeys that a building could have was first specified in the 1944 code considering no exception of the seismic level of the construction zone [6]. 1944 seismic code also require raft or pile foundations for construction on the filled grounds.

C. 1949 Seismic Design Code

An earthquake zonation map for Turkey was promulgated in 1945. The map listed all provinces in Turkey. Three seismic zones were identified in the map: first degree (hazardous); second degree (less hazardous); and no hazard. The lateral-force coefficients were between 0.02 and 0.04 in the first-degree zone, and 0.01 and 0.03 in the second degree zone. The specific value assigned to was a function of soil and construction type. The weight of the building was calculated as:

\[
W = \sum w_i = \sum (g_i + np_i) \]  

(2)

where \( w_i \) the weight of the \( i \)th floor, is the dead load of the \( i \)th floor, \( n \) is a live load coefficient (equal to 0.33 for houses, 0.5 for commercial buildings, and 1.0 for high-occupancy buildings), and \( p_i \) is the live load of the \( i \)th floor.

Allowable stresses were increased by 50% for component checking using earthquake load combinations [7].

D. 1953 Seismic Design Code

The 1953 code introduced load combinations for earthquake effects. Required strength, \( U \), for earthquake design were calculated using

\[
U = G + P + E + 0.5J
\]  

(3)

where \( J \) is the wind-load effect and \( G, P \) and \( E \) are the dead, live, and earthquake load effects, respectively.

In 1953 some certain ratios of width to height of the building were brought. The 1953 code specified the thickness of load bearing vertical members both in the ground and 1st floor levels according to the type of the building. Besides, the maximum spans in between the structural members were restricted in both directions. This code standardized the quality and the dosage of the concrete. 1953 code also require raft or pile foundations for construction on the filled grounds. Specifications for minimum dimensions of the connecting members as well as the reinforcing elements were first seen in 1953 code [8].

E. 1968 Seismic Design Code

Upon new needs and new experiences from the earthquakes, floods and landslides between the years of 1960-1967, Law No.7269 was amended by Law No.1051 in 1968 [3].

The 1968 seismic code was substantially different from earlier codes. 1968 codes that first specified the dimensions of the rest of the structural members such as shear walls, beams, floors and foundations. The shear walls are restricted with 20 cm and 1/25 of the floor height as the minimum width. The minimum thickness of the floor slabs used to be 10 cm which should also satisfy the 1/12 of the span for cantilevers. And also the structural irregularity was first specified in the 1968 codes with the description of columns and shear walls and their configurations [9].

The code did not specify minimum spacing for beam stirrups and column ties, but required that “…sufficient transverse reinforcement shall be provided…” and “…where beams frame into columns, the spacing of stirrups and column ties shall be half the spacing at the mid-regions of these members, within a distance not less than the effective depth of the deepest member framing into the joint. Column ties shall be continued within the story beams. ...”

In 1968 codes the determination of the building height were given under the responsibility of the local governments but the critical height was described as 44 meters and above which must satisfy the necessary dynamic calculations regarding the possible earthquake magnitudes and soil conditions.

In 1968 seismic code introduced modern concepts relating to spectral shape and dynamic responses. The design base shear, \( V \), of Equation 1 was calculated using the weight estimate of Equation 2 and a lateral force coefficient, \( C \), that was defined as

\[
C = C_0 \alpha \gamma \]  

(4)
where \( C_o \) was a seismic zone coefficient and equal to 0.06, 0.04, and 0.02 for Zones 1, 2, and 3, respectively; \( \alpha \) was a soil coefficient equal to 0.80 for rock, 1.00 for sand, gravel, and hard clay, and 1.20 for "...loose soil containing water and poorer soils..."; \( \beta \) was an importance factor equal to 1.50 for critical, high-occupancy, or historically important buildings, and 1.00 otherwise; and \( \gamma \) was a dynamic coefficient. The dynamic coefficient, \( \gamma \), introduced spectral shape into the Turkish seismic code for the first time, and was calculated as for period \( T \) greater than 0.5 sec and 1.00 for \( T \) less than or equal to 0.5 sec; the minimum value of was 0.3. The fundamental period could be calculated as

\[
T = 0.09 \frac{H}{\sqrt{D}} \quad (5)
\]

where \( H \) was the height of the building above the foundation in meters, and \( D \) was the width of the building in the direction under consideration.

The base shear was distributed over the height of the building using the following equation

\[
F_i = V \frac{w_i h_i}{\sum w_i h_i} \quad (6)
\]

TABLE 2.

<table>
<thead>
<tr>
<th>Structure type</th>
<th>Filler wall type(^1)</th>
<th>( K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>All building framing systems except as hereafter classified</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Buildings with box systems with shear walls</td>
<td></td>
<td>1.33</td>
</tr>
<tr>
<td>Buildings with frame systems where the frame resists the total lateral force</td>
<td>a</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>1.00</td>
</tr>
<tr>
<td>a. Ductile moment-resisting frame</td>
<td></td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>1.50</td>
</tr>
<tr>
<td>b. Non ductile moment-resisting frame</td>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>1.20</td>
</tr>
<tr>
<td>Shear wall systems with ductile frames capable of resisting at least 25% of the total lateral force</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Filler wall types: a= reinforced concrete or reinforced masonry walls; b=unreinforced masonry block partition walls; c= light partition walls or prefabricated concrete partition walls

The spectral coefficient was calculated as

\[
S = \frac{1}{0.8 + T - T_0} \quad (8)
\]

where \( T \) and \( T_0 \) are the fundamental periods of the building and soil column, respectively.

Soil types were classified on the basis of blow counts or shear wave velocity, and values for were set for each type. Shear wave velocities for soil types I through IV were set at greater than 700 m/sec for I, 400 to 700 m/sec for II, 200 to 400 m/sec for III, and less than 200 m/sec for IV. The fundamental period was taken as the smaller of the value calculated using Equation 5 and

\[
0.07N \leq T \leq 0.10N \quad (9)
\]

where \( N \) is the number of stories in the building above the foundation and "... the value of the coefficient ... shall be determined by interpolation between the values of 0.07 and 0.10 according to the degree of general structural flexibility." [11].

Geometry and detailing requirements for reinforced concrete components were also modified in the 1975 code. The 1975 code provided information on minimum details for columns. The minimum rectangular column dimension was limited to 250 mm or 0.05 times the story height; the
maximum column width-to-depth ratio was 3.0. The minimum and maximum longitudinal rebar ratios were 0.01 and 0.035, respectively.

**G. 1997 Seismic Design Code**

The 1997 code could be seen as a revolution in the seismic design code of structures. In 1997, 1975 disaster regulation called “Specifications for Structures to be Built in Disaster Areas” was revised in the same name.

It specifies the irregular type of buildings that have seismic design faults both in plan and in vertical direction. This code also mentions about earthquake resistant building design principles and brings the concepts of rigidity, stability and strength. Response-spectrum and linear and nonlinear dynamic analysis procedures were introduced in the 1997 edition of the seismic code. The lateral force coefficient $C$ of the 1975 code was replaced by

$$C = \frac{A(T)}{R_s(T)} = \frac{A IS(T)}{R_s(T)} \tag{10}$$

where $A$ is the spectral acceleration coefficient; $T$ is the fundamental period; and $R_s$ is the effective ground acceleration coefficient. The importance factor $I$ vary between 1 and 1.5, and is equal to 1.0 for ordinary structures. The spectrum coefficient $(S)$ which defines the design acceleration spectrum is given by three equations in the short-period, constant acceleration, and constant velocity.

In the 1997 edition of the earthquake code, reinforced concrete buildings are classified as systems of either high or nominal ductility, based on the detailing of the components.

Detailing requirements are more stringent for systems with high ductility. The detailing requirements for columns being designed for high or nominal ductility levels are very similar [12].

**H. 2007 Seismic Design Code**

The most hazardous earthquakes of the 20th century in Turkey occurred in 1999. First one was ‘Kocaeli - Gölcük’ earthquake (M= 7.8) in 17th August 1999 and the second one was ‘Düzce’ earthquake (M=7.5) in 12th November 1999. 47 Although the centers of these earthquakes were Kocaeli-Gölcük and Düzce, earthquake area was so large that Adapazari, Yalova, İstanbul (Avcılar, Küçükçekmece and Tuzla), Bolu, Bursa and Mudanya were also affected. These areas had high population density and also the significant industrial center of Turkey was there. Hence, the effects of these two earthquakes were not limited in a region; these two earthquakes affected the whole Turkey.

A great number of existing buildings were not strong enough to resist a new earthquake and some of them were also damaged. Hence, there was a need for rehabilitation of existing buildings. In order to prevent exploitation of this subject, a regulation about seismic assessment and rehabilitation of existing building was needed. For this reason, 1998 disaster regulation was revised in 2007 and a new chapter called “Seismic Assessment and Rehabilitation of Existing Buildings” added. This new regulation was called “Specifications for Buildings to be Built in Earthquake Areas” and it came into effect on 6th March 2007 [13].

The current seismic design code in Turkey recommends two procedures to be used for seismic performance assessment of existing reinforced concrete buildings. These procedures are based on linear and nonlinear analyses of the structure to be assessed. In the linear assessment, equivalent static lateral load analysis or dynamic analysis can be used. The nonlinear assessment is carried out based on either nonlinear static (pushover) or nonlinear dynamic analyses.

Linear elastic procedure is an assessment in which the building is analyzed elastically under vertical (gravity and live loads) and earthquake loads separately. Linear elastic procedure can be applied to the buildings which:

- are at most 25 m in height from ground level,
- have at most 8 stories,
- have torsional irregularity constant smaller than 1.4.

Nonlinear assessment is the other procedure to estimate the performance level of an existing structure. In this procedure, a deformation capacity of each member is calculated, nonlinear analysis is performed and plastic deformations are analyzed. Each member is assessed according to its deformation compared with limits and finally global performance of a structure is obtained. This procedure is closer to the real situation, because this analysis considers redistribution of forces after the yielding of members. Both assessment procedures provide the performance levels of each member of a building. However, main aim of these assessments is to estimate the performance of the whole building.

**III. CONCLUSION**

Turkey has always been vulnerable to various kinds of disasters, and earthquakes are the most hazardous kind of these disasters. Each major disaster has been an experience for Turkey’s disaster management. Hence, after these major disasters, new laws and new regulations enacted or old ones were revised. Turkey’s current disaster regulation, “Specification for Buildings to be Built in Earthquake Areas”, was enacted in 2007 after the experiences 1999 Marmara earthquakes.

It must be known that laws and regulations are systems of rules developed by government or society to control social or business relationships. Before laws and regulations, there should be ethical values. Then, mission of laws and
regulations can be accomplished. Past experiences have been showed that the revisions of earthquake codes did not provide the enhanced of building performances.

REFERENCES


Dr. Asena SOYLUK is currently scholar in the department of architecture at Gazi University. Her areas of interest include earthquake-resistant design, seismic design codes, construction materials and dynamics of buildings.

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