Seismic Performance Assessment of Industrial Structures in Turkey Using The Fragility Curves

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ABSTRACT:
Precast concrete building structures are the main type of construction for industrial buildings in Turkey. Recently, some major earthquakes, which are namely the Marmara Earthquake (August 17th, 1999) and the Duzce Earthquake (November 12th, 1999), occurred in Turkey. It was observed that industrial buildings showed poor performance with excessive levels of damage, especially after the two subsequent 1999 earthquakes named above. The observed damage was mainly destruction at column-girder connections or column failures. Accordingly, investigation and evaluation of seismic behaviour of precast concrete structures located at highly earthquake-prone regions in Turkey is crucial. In this study, precast concrete industrial building structures representative of the current design practice in Turkey are examined. They are subjected to ground motions recorded during several major earthquake events in Turkey, and their seismic responses and anticipated levels of damage are evaluated using the results of dynamic analyses. The fragility curves are developed in both X and Y directions, in order to evaluate the performance of investigated industrial buildings subjected to selected earthquake excitations. The peak ground accelerations (PGA) are used for the development of fragility curves and to evaluate the probability of failure for the investigated precast concrete structures.

Keywords: Seismic performance assessment, industrial structures, fragility curves

1. INTRODUCTION

Excessive levels of damage were observed at precast concrete structures in the highly industrialized part of Turkey, after two recent major destructive earthquakes which are namely the Marmara Earthquake (August 17^{th}, 1999) and the Duzce Earthquake (November 12^{th}, 1999). There is need for investigation of seismic behaviour of precast concrete structures, since the observed damage was mainly in the form of destruction at column-girder connections or column failures.

Performance based design has been very popular in earthquake engineering. In recent decades extensive scientific research has been conducted regarding the investigation of behavior of reinforced concrete building structures located at regions of high seismicity (Shibata and Sozen 1976, Shimazaki and Sozen 1984, Lepage 1997, Ozturk 2003, Ozturk 2006). Ozturk (2003) considered the effect of ground velocity, base shear strength of the structure and initial period of the structure on its seismic behavior.

Moreover, there has been research (Ozturk and Demiralan 2007, Ozturk et al. 2008, Demiralan 2009, Ozturk 2009, Sadak 2009, Ozturk and Sadak 2010, Yildiz 2011) aiming at determination of seismic behavior of precast concrete building structures. In this study, the fragility curve, representative of seismic behaviour and performance of precast concrete structures in Turkey, will be provided. The peak ground accelerations (PGA) are used for the development of corresponding fragility curves.

The fragility curves have been developed for estimation of probability of failure under earthquake excitations (Hwang and Jaw 1990, Singhal and Kiremidjian 1996, Shinozuka et al. 2000, Cornell et al. 2002). It is a performance-based seismic analysis technique which helps to estimate the level of damage in structures considering statistical analysis methods. The fragility curves and its applications are being used to solve various earthquake engineering problems (Akkar et al. 2005, Ramamoorthy et al. 2006, Zareian and Krawinkler 2007, Kwan and Elnashai 2007).

In this study, the fragility curves are developed in order to assess the seismic behavior of two precast concrete industrial buildings (Building 1 and Buiding 2) subjected to different earthquake excitations. Building 1 is located at a region of high seismicity (seismic zone 1) while Building 2 is located in seismic zone 2. Both of the investigated buildings are constructed considering the current earthquake design practice. In design of these buildings and evaluation of their seismic behavior, principles provided in TS 498 (1987), TS 9967 (1992), TS 500 (2000) and Regulation for Buildings to be Constructed at Earthquake-Prone Regions (2007) are applied. These buildings are subjected to different ground motions which were obtained during recent earthquakes in Turkey (i.e. Ceyhan 1998, Marmara 1999, Duzce 1999).

As an outcome of this study, the development of fragility curves considering the principles of performance-based design provides information about the seismic behavior of both of the investigated precast concrete buildings representative of similar industrial buildings in Turkey.

2. INFORMATION ABOUT THE INVESTIGATED BUILDINGS

In this study, two industrial structures (Figures 2.1&2.2), one of which is designed to be built at seismic zone 1 while the other one is designed to be built in seismic zone 2, are investigated in order to develop their corresponding fragility curves. In the design of the structures current seismic codes in Turkey (TS 498 1987, TS 9967 1992, TS 500 2000) and Regulation for Buildings to be Constructed at Earthquake-Prone Regions (2007) are used.

Building 1 has a length of 40 m in X direction and 56 m in Y direction. Its columns are 7 m in height. In X direction there are six spans with a span length of 6.65 m each, while in Y direction there are seven spans with a span length of 8 m each. Total weight of the structure is around 5300 kN.

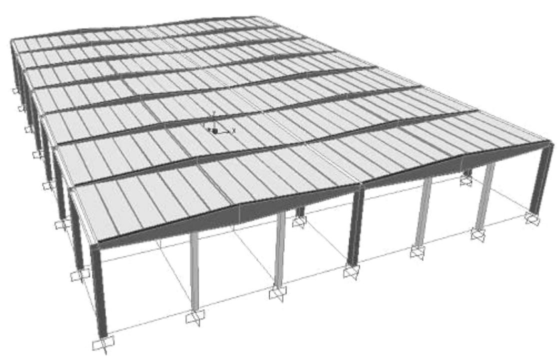


Figure 2.1 Structural System of Building 1 (Demiralan 2009)

Building 2 has a length of 40 m in X direction and 60 m in Y direction. Its columns are 7.5 m in height. In the X direction there are two spans with a span length of 20 m each, while in Y direction there are eight spans with a span length of 7.5 m each. The weight of the structure is around 7250 kN.

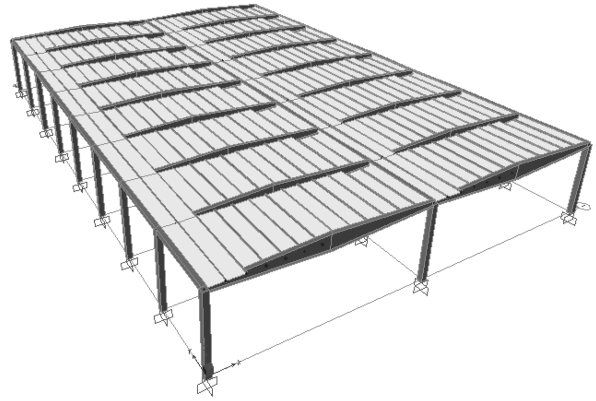


Figure 2.2 Structural System of Building 2 (Demiralan 2009)

3. MODAL AND RESPONSE SPECTRUM ANALYSIS OF THE STRUCTURES

For the analyses of the structures, SAP2000 Program (2000) is used. First four structural periods obtained as a result of modal analyses are provided in Tables 3.1&3.2. An additional response spectrum analysis is applied for the structures. In the analyses, a damping ratio of 5 % is considered. The periods of first two modes of Building 1 are 1.05 sec in the short direction (Mode 1) while 0.88 sec in the long direction (Mode 2). For Building 2 the periods of first two modes are 1.03 sec both in short and long directions (Modes 1 & 2).

Table 3.1 Structural Periods of Building 1 (Demiralan 2009)

Mode	Period (sec)	Mode	Period (sec)
1	1.05	2	0.88
3	0.77	4	0.53

Table 3.2 Structural Periods of Building 2 (Demiralan 2009)

Mode	Period (sec)	Mode	Period (sec)
1	1.03	2	1.03
3	0.91	4	0.34

The soil type on which Building 1 is constructed is defined as Z3 with T_A= 0.15 sec and T_B= 0.6 sec, respectively. The corresponding spectrum function is given in Figure 3.1 and spectrum constant, K is evaluated using Eq.3.1. In the analysis, effective ground acceleration constant, A_O value is 0.4g, building importance constant, I value is 1.0 and building ductility constant, R value is taken as 3. K value is evaluated as 1.31 m/sec^2, accordingly.

Building 2 is also constructed on Z3 soil type. The effective ground acceleration constant, A_O value is 0.3g, building importance constant, I value is 1.0 and building ductility constant, R value is 3. When Eq.3.1 is applied, K value is evaluated as 0.98 m/sec^2.

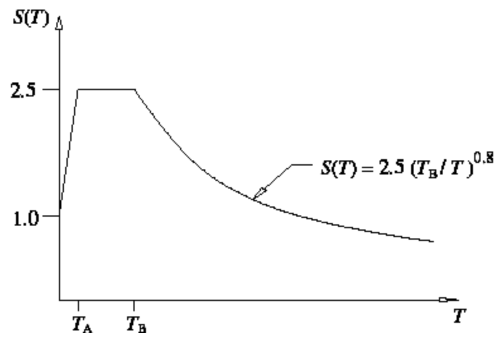


Figure 3.1 Spectrum Function

$$K = \frac{A_O \cdot I \cdot g}{R} \tag{3.1}$$

Spectrum constant, S(T) is calculated to be 1.6 for Building 1 and 1.62 for Building 2 (Eq.3.2).

$$S(T) = 2.5(\frac{T_B}{T})^{0.8} \tag{3.2}$$

4. DEVELOPMENT OF THE FRAGILITY CURVES

Using the building, soil and seismic region properties of the industrial buildings explained above analyses are conducted, and the fragility curves in both X and Y directions of the investigated buildings are developed for the ground motion records provided in Table 4.1. The maximum ground acceleration values (PGA) of these 20 ground motions are ranging in between 0.12g for Izmir EW record which was recorded during 1977 Izmir earthquake, and 0.82g for Bolu EW record which was recorded during 1999 Duzce earthquake.

Table 4.1 Ground motion records and maximum ground acceleration (PGA) values (Sadak 2009)

Ground Motion Record	Maximum Ground Acceleration (PGA)	Ground Motion Record	Maximum Ground Acceleration (PGA)
Ceyhan EW (Ceyhan1998)	0.23 g	Duzce EW (Duzce 1999)	0.41g
Ceyhan NS (Ceyhan1998)	0.28 g	Duzce NS (Duzce 1999)	0.52g
Bingol EW (Bingol 2003)	0.28g	Erzincan EW(Erzincan 1992)	0.48g
Bingol NS (Bingol 2003)	0.55g	Erzincan NS (Erzincan 1992)	0.41g
Bolu EW (Duzce 1999)	0.82 g	Izmir EW (Izmir 1977)	0.12g
Bolu NS (Duzce 1999)	0.75 g	Izmir NS (Izmir 1977)	0.39g
Denizli EW (Denizli 1976)	0.29g	Izmit EW (Marmara 1999)	0.23 g
Denizli NS (Denizli 1976)	0.35g	Izmit NS (Marmara 1999)	0.17 g
Dinar EW (Dinar 1995)	0.33g	Sakarya EW (Marmara 1999)	0.35g
Dinar NS (Dinar 1995)	0.28g	Sakarya NS (Marmara 1999)	0.21g

Equation 3.3 is used for the evaluation of probability of failure and the development of corresponding fragility curves (Cornell et al. 2002).

$$P_f = \varphi\left(\frac{-\ln\left(\dfrac{SA_c}{SA_R}\right)}{\sqrt{\beta_C^2+\beta_R^2}}\right) \tag{3.3}$$

where, P_f , probability of failure,

SA_C , median value of drift capacity,

SA_R , median value of drift demand,

β_c , standard deviation of the natural logarithm of capacity,

β_R , standard deviation of the natural logarithm of demand

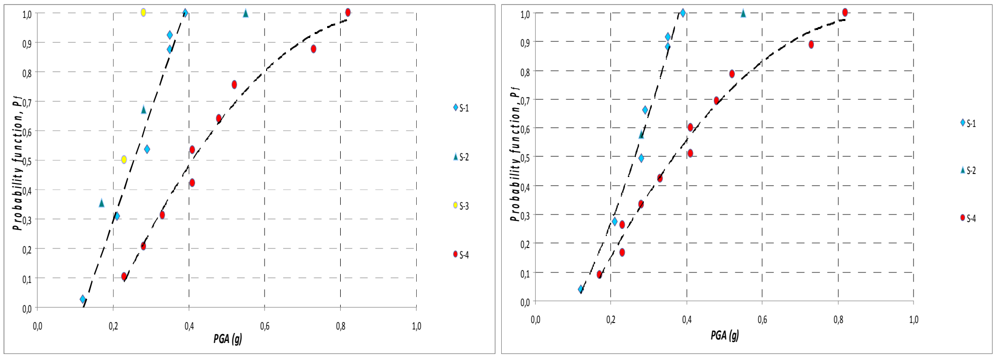
The fragility curves providing information about probability of failure for both Building 1 and Building 2 are shown in Figures 4.1 & 4.2. The performance levels of the investigated structures, their performance ranges and the corresponding evaluation codes are tabulated in Table 4.2 (Yildiz 2011).

As provided in Table 4.2; the linear elastic (S-1) performance range corresponds to the performance level of "initial level" and a part of "instant use" while the damage control (S-2) performance range corresponds to parts of "instant use" and "life safety". The limited safety (S-3) performance range covers parts of "life safety" and "structural stability" performance levels. Finally, the collapse prevention (S-4) performance range covers a part of "structural stability" and the performance level of "collapse".

Table 4.2 Performance Levels of the Structures (Yildiz 2011)

<table>
<tr><th>Performance</th><th>Performance Range</th><th>Code</th></tr>
<tr><td>Initial Level</td><td rowspan="2">Linear Elastic</td><td rowspan="2">S-1</td></tr>
<tr><td rowspan="2">Instant Use</td></tr>
<tr><td rowspan="2">Damage Control</td><td rowspan="2">S-2</td></tr>
<tr><td rowspan="2">Life Safety</td></tr>
<tr><td rowspan="2">Limited Safety</td><td rowspan="2">S-3</td></tr>
<tr><td rowspan="2">Structural Stability</td></tr>
<tr><td rowspan="2">Collapse Prevention</td><td rowspan="2">S-4</td></tr>
<tr><td>Collapse</td></tr>
</table>

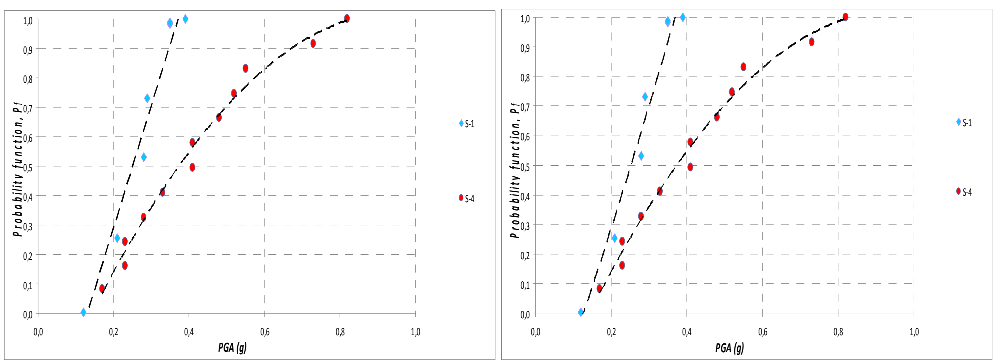
In Figure 4.1, the fragility curves for Building 1 are shown in both X and Y directions. The linear elastic (S-1) and the collapse prevention (S-4) performance ranges are observed to be the dominant modes of performance. Accordingly; the corresponding lines are drawn for these two modes of performance. It has to be noted that the development of the linear elastic range (S-1) occurs in between PGA values of 0.15g-0.4g while the development of the collapse prevention range (S-4) occurs in between PGA values of 0.2g – 0.8g.



(a) X direction (b) Y direction

Figure 4.1 Development of fragility curves for Building 1 in both X and Y directions

In Figure 4.2, the fragility curves for Building 2 are shown in both X and Y directions. The linear elastic (S-1) and the collapse prevention (S-4) performance ranges are examined to be the dominant modes of performance. The corresponding lines are drawn for these two modes of performance in Figure 4.2. Developments of both the linear elastic range (S-1) and the collapse prevention range (S-4) show the corresponding trends which were previously observed for Building 1 (Figure 4.1).



(a) X direction (b) Y direction

Figure 4.2 Development of fragility curves for Building 2 in both X and Y directions

5. CONCLUSIONS

In this study, seismic behaviors of two precast concrete industrial buildings, one of which is designed for seismic zone 1 while the other one is designed for seismic zone 2, are evaluated and discussed using the fragility curves. Both of these buildings are designed according to the current design codes in Turkey and are subjected to 20 different earthquake excitations, in order to investigate their seismic behaviors. The fragility curves are developed in both X and Y directions using the peak ground acceleration (PGA) values of earthquake ground motions. The maximum ground acceleration values (PGA) of these 20 ground motions are ranging in between 0.12g (for Izmir EW record which was recorded during 1977 Izmir earthquake) and 0.82g (for Bolu EW record which was recorded during 1999 Duzce earthquake).

The fragility curves provide an efficient tool in evaluation of the seismic behavior for precast concrete industrial building structures and assessment of their seismic performance. The development of fragility curves, considering the PGA values of different earthquake ground motions, for the investigated precast concrete industrial buildings built in Turkey provides a tool for assessment of probability of failure in similar prefabricated structures subjected to prospective future earthquakes.

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