SEISMIC DRIFT RESPONSE OF PRECAST CONCRETE BUILDING STRUCTURES LOCATED IN EARTHQUAKE-PRONE REGIONS IN TURKEY CONSIDERING NONLINEAR ANALYSIS PROCEDURES

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ABSTRACT :

Industrial structures are commonly built as precast concrete structures both in Turkey and the World. Two major earthquakes, namely Marmara Earthquake (August 17th, 1999) and Duzce Earthquake (November 12th, 1999), occurred subsequently in Turkey. In the aftermath of these earthquakes, excessive levels of damage were observed at precast concrete structures especially in the city of Izmit and its vicinity. The modes of damage were mainly destruction at column-girder connections or column failures. The observations emphasize that there is a need for investigation of seismic behaviour of precast concrete structures located at this highly earthquake-prone region. In this study, seismic drift response of precast concrete building structures representative of the current design practice in Turkey are examined. The buildings are designed considering the current seismic code in Turkey which refer to performance based design. They are subjected to ground motions from the recent earthquakes in Turkey. Seismic drift response and the expected level of damage for these buildings are examined in the light of results of nonlinear analyses. The results of these analyses show that when the structure is exposed to some effective ground motions, the safety limits provided in the seismic code are exceeded.

KEYWORDS: Precast concrete, earthquake-prone region, nonlinear analysis, performance based design

1. INTRODUCTION

Two major earthquakes, namely Marmara Earthquake (August 17th, 1999) and Duzce Earthquake (November 12th, 1999), occurred subsequently in Turkey. In the aftermath of these earthquakes, excessive levels of damage were observed at precast concrete structures located at this highly industrialized part of the country. The observed damage was mainly in the form of destruction at column-girder connections or column failures which emphasize that there is a need for investigation of seismic behaviour of precast concrete structures. In this study, seismic drift response of precast concrete building structures representative of the current construction practice for industrial buildings in Turkey are investigated. The buildings are designed considering the current seismic code in Turkey which refer to performance based design.

The application of performance based design is becoming more popular at earthquake-prone regions. In recent decades 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 and Ozturk 2003). Ozturk (2003) considered the effect of ground velocity, base shear strength of the structure and initial period of the structure on its seismic behavior. In this study, a perspective regarding investigation of seismic behavior of precast concrete structures will be introduced.

The seismic behavior of two prefabricated industrial buildings (Building 1 and Buiding 2) subjected to different ground motions will be investigated. 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 (Ceyhan 1998, Marmara 1999, Duzce 1999). Upon application of nonlinear analysis procedures, their seismic behavior is evaluated regarding the principles of performance-based design.

As an outcome of this study, nonlinear time-histories and maximum lateral drift values for the investigated precast concrete buildings are obtained.Upon evaluation of analysis results, it is observed that for Ceyhan (Ceyhan 1998) and Izmit (Marmara 1999) ground motion records, the structures give relatively safe values while upon the application of Bolu (Duzce 1999) ground motion records, unsafe lateral drift values are obtained.

2. INFORMATION ABOUT THE INVESTIGATED BUILDINGS

In this study, two industrial structures 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 (Figures 1&2). 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. The columns are 7 m in height. In X direction there are six spans with a span length of 6.65 m each and in Y direction there are seven spans with a span length of 8 m each. Total weight of the structure is around 3300 kN.

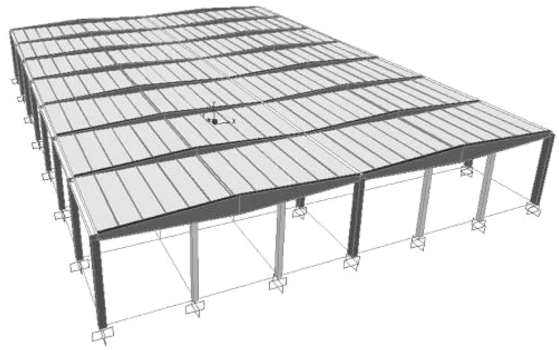

Figure 1 Structural System of Building 1

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 and in Y direction there are eight spans with a span length of 7.5 m each. The weight of the structure is around 4400 kN.

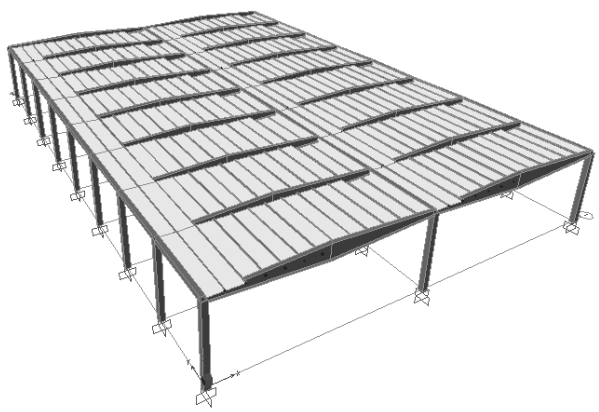

Figure 2 Structural System of Building 2

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 1&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 1 Structural Periods of Building 1

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

Table 2 Structural Periods of Building 2

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 and spectrum constant, *K* is evaluated using Equation 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. Upon application of Equation 1, *K* value is evaluated as 0.98 m/sec^2.

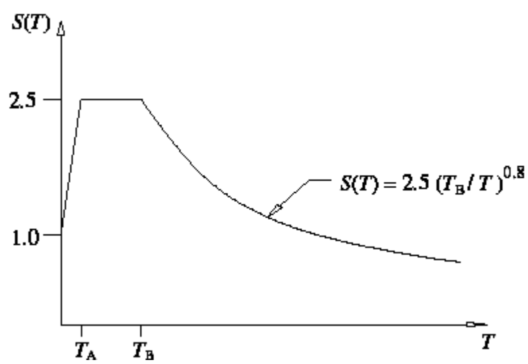

Figure 3 Spectrum Function

$$K = \frac{A_O \cdot I \cdot g}{R} \tag{1}$$

Spectrum constant, *S(T)* is calculated to be 1.6 for Building 1 and 1.62 for Building 2 using Equation 2 .

$$S(T) = 2.5(\frac{T_B}{T})^{0.8} \tag{2}$$

4. NONLINEAR ANALYSIS OF THE STRUCTURES

Using the building, soil and seismic region properties of the industrial buildings explained above nonlinear analyses are conducted both in X and Y directions for the ground motion records provided in Table 3. These are Ceyhan EW and Ceyhan NS records which were recorded during 1999 Adana Ceyhan earthquake, Izmit EW and Izmit NS records which were recorded during 1999 Marmara earthquake and, Bolu EW and Bolu NS records which were recorded during 1999 Duzce earthquake. For the given earthquake data maximum ground acceleration values (PGA) are given in Table 3.

Table 3 Ground motion records and maximum ground acceleration (PGA) values

Ground Motion Record	Maximum Ground Acceleration (PGA)
Ceyhan EW (Ceyhan1998)	0.23 g
Ceyhan NS (Ceyhan1998)	0.28 g
Izmit EW (Marmara 1999)	0.23 g
Izmit NS (Marmara 1999)	0.17 g
Bolu EW (Duzce 1999)	0.82 g
Bolu NS (Duzce 1999)	0.75 g

Maximum displacement response values are observed at upper nodes of the columns located at corners of the structures. Nonlinear displacement time-histories for the corresponding nodes are provided in Figures 4 – 15. The maximum displacement response values are tabulated in Tables 4 & 5.

4.1 NONLINEAR DISPLACEMENT TIME-HISTORIES FOR BUILDING 1

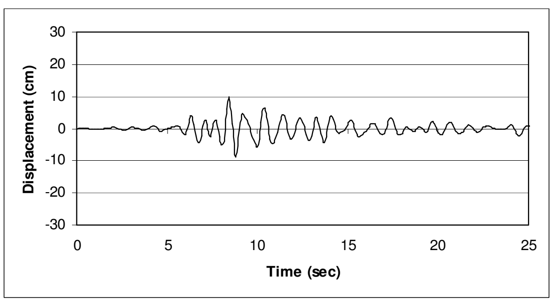

Figure 4 Story Drift in X direction (Ceyhan-EW)

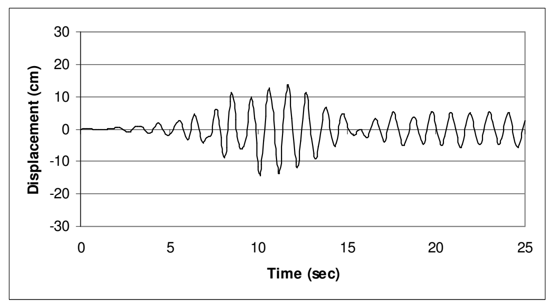

Figure 5 Story Drift in Y direction (Ceyhan-EW)

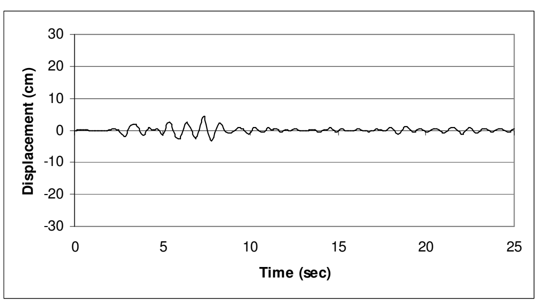

Figure 6 Story Drift in X direction (Izmit-NS)

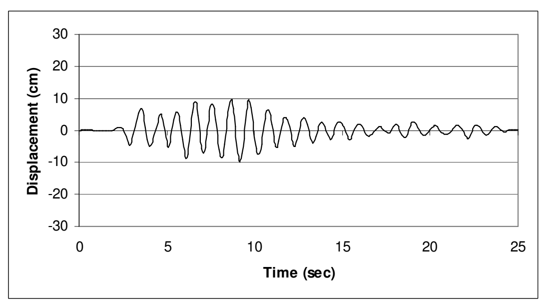

Figure 7 Story Drift in Y direction (Izmit-NS)

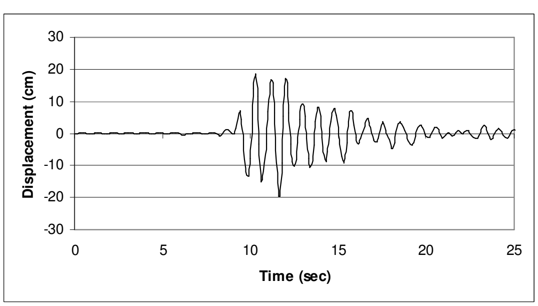

Figure 8 Story Drift in X direction (Bolu-NS)

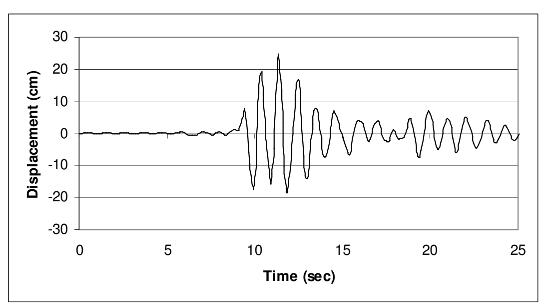

Figure 9 Story Drift in Y direction (Bolu-NS)

Table 4 Performance level of Building 1 subjected to different earthquake ground motions

Ground motion data	Structural height, H (m)	Δ_{imax} (m)	Δ_{imax}/H (%)	Performance level
CEYHAN E-W (X direction)	7.00	0.10	1.4	Instant Use
CEYHAN E-W (Y direction)	7.00	0.14	2.0	Collapse Risk
IZMIT N-S (X direction)	7.00	0.04	0.6	Safe
IZMIT N-S (Y direction)	7.00	0.10	1.4	Instant Use
BOLU N-S (X direction)	7.00	0.20	2.9	Collapse Risk
BOLU N-S (Y direction)	7.00	0.25	3.6	Collapse

4.2 NONLINEAR DISPLACEMENT TIME-HISTORIES FOR BUILDING 2

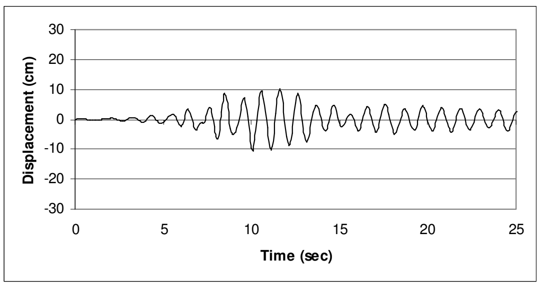

Figure 10 Story Drift in X direction (Ceyhan-EW)

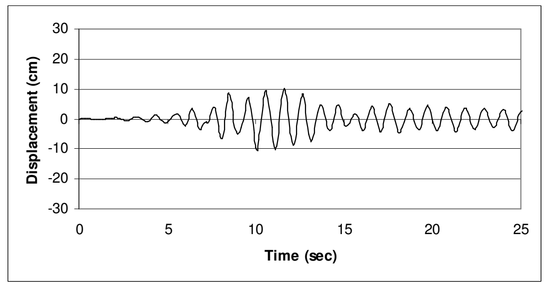

Figure 11 Story Drift in Y direction (Ceyhan-EW)

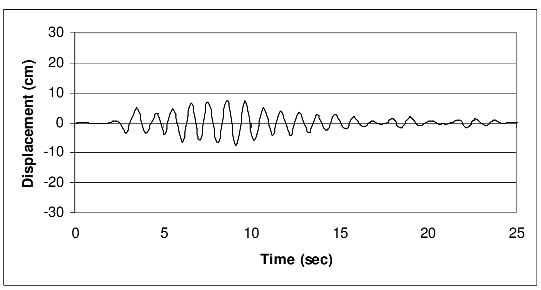

Figure 12 Story Drift in X direction (Izmit-NS)

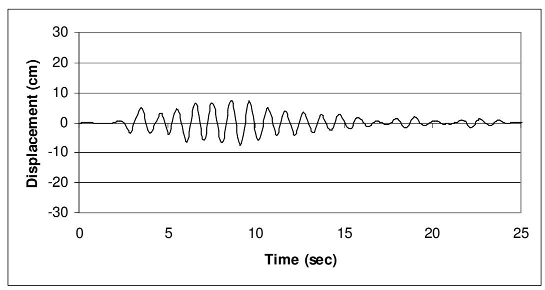

Figure 13 Story Drift in Y direction (Izmit-NS)

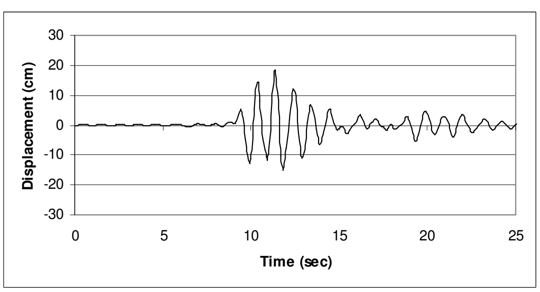

Figure 14 Story Drift in X direction (Bolu-NS)

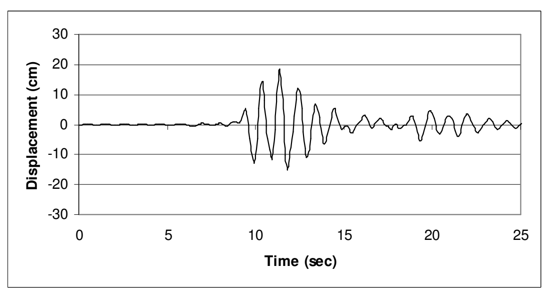

Figure 15 Story Drift in Y direction (Bolu-NS)

Table 5 Performance level of Building 2 subjected to different earthquake ground motions

Ground motion data	Structural height, H (m)	Δ_{imax} (m)	Δ_{imax}/H (%)	Performance level
CEYHAN E-W (X direction)	7.50	0.11	1.5	Instant Use
CEYHAN E-W (Y direction)	7.50	0.11	1.5	Instant Use
IZMIT N-S (X direction)	7.50	0.08	1.1	Instant Use
IZMIT N-S (Y direction)	7.50	0.08	1.1	Instant Use
BOLU N-S (X direction)	7.50	0.19	2.5	Collapse Risk
BOLU N-S (Y direction)	7.50	0.19	2.5	Collapse Risk

In order to evaluate the expected behavior of a structure during an earthquake, destruction control parameters given in Table 6 are used. As it is observed in the nonlinear displacement response time histories of Building 1 and Building 2 (Figures 4 – 15 and Tables 4 & 5), Bolu-NS ground motion record (November 19th, 1999) causes story drifts exceeding 2% both in X and Y directions of the buildings. This seismic behavior of the buildings corresponds to their collapse risk and/or collapse. Meanwhile, the buildings respond reasonably well to Izmit-NS and Ceyhan-EW ground motion records where maximum story drift is equal to or less than 2%. Building 1 which is located in seismic zone 1 (Table 4) is exposed to relatively more demanding seismic drift response compared to Building 2 which is located in seismic zone 2 (Table 5).

Table 6 Destruction Control Parameters

Relative interstory drift Ratio	**Performance Level**		
	Instant Use	Collapse Risk	Collapse
$(\delta_i)_{max}/h_i$ (%)	0.8 %	2 %	3 %

$(\delta_i)_{max}$: Maximum calculated relative interstory drift of vertical elements in the related story

h_i : Story height

5. RESULTS

Application of principles of performance based parameters gains importance in design of buildings in earthquake prone regions. In this study, seismic behavior of two prefabricated industrial buildings, one of which is designed for seismic zone 1 while the other is designed for seismic zone 2, is discussed. Both of these buildings are designed according to the current design codes and are subjected to different ground motions.

Ground motion records obtained during recent earthquakes in Turkey (Ceyhan 1998, Marmara 1999, Duzce 1999) are used in order to investigate the nonlinear behavior of the structure. In the light of the current design criteria, regarding the maximum drift response values Ceyhan (Ceyhan 1998) and Izmit (Marmara 1999) ground motion records cause relatively safe displacement response while Bolu (Duzce 1999) ground motion records cause displacement response values exceeding life safety limits. In addition, it has to be noted that Building 1 which is located in seismic zone 1 (Table 4) is exposed to relatively more demanding seismic drift response compared to Building 2 which is located in seismic zone 2 (Table 5).

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