INVESTIGATION OF SEISMIC BEHAVIOR OF REINFORCED CONCRETE SHEARWALL BUILDING FRAMES SUBJECTED TO GROUND MOTIONS FROM THE 1999 TURKISH EARTHQUAKES

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ABSTRACT :

In this study, the seismic behavior of reinforced concrete shearwall frames subjected to ground motions from the 1999 Turkish Earthquakes are investigated. The shearwall frames constitute a shearwall building proposed for Turkey with two different frames in the EW and the NS directions, respectively. These frames are analyzed for selected effective ground motions recorded during both Marmara Earthquake (August 17th, 1999) and Duzce Earthquake (November 12th, 1999). The analyses are conducted using both static and dynamic analyses procedures. The static analysis procedure provides an instrument to define the base shear shear strength coefficient, C_y of the shearwall frames while the dynamic analysis procedure helps to define the corresponding seismic response of the building. The nonlinear displacement response histories of the proposed shearwall frames subjected to the ground motions recorded during the 1999 Turkish earthquakes are evaluated. The base shear strength coefficient, C_y values of the shearwall frames, which are 32% in the EW direction and 34% in the NS direction, are comparatively high. The calculated relatively low displacement response values emphasize that the application of shearwall frames provides a positive impact in the seismic performance of the building structures located in seismically active regions in Turkey.

KEYWORDS: Shearwall frame, Displacement response, Base shear strength coefficient, Seismic performance

1. INTRODUCTION

This study focuses on the analysis and investigation of the seismic behavior of a representative five-story shearwall building modeled as a MDOF (multi-degree-of-freedom) system. Two reinforced concrete shearwall frames, one of which is in the EW direction while the other frame is in the NS direction, are representing the structural system of this building. The building is proportioned considering the base shear strength coefficient, C_y and the initial period, T. The variation in the nonlinear displacement response of the frames is investigated considering these two parameters.

The frames are subjected to ten strong ground motions which were recorded in Turkey during Marmara Earthquake (August 17th, 1999) and Duzce Earthquake (November 12th, 1999). Accordingly; a total of 20 response-history analyses are conducted. These acceleration records and their peak ground acceleration values are tabulated in Table 1.

Table 1. Ground Motion Data

Name of the Earthquake	Name of Ground Motion	Peak Ground Acceleration (PGA)
Marmara Earthquake	Duzce-EW	0.38g
Marmara Earthquake	Duzce-NS	0.32g
Marmara Earthquake	Izmit-EW	0.17g
Marmara Earthquake	Izmit-NS	0.23g
Marmara Earthquake	YPT-EW	0.23g
Marmara Earthquake	YPT-NS	0.33g
Duzce Earthquake	Duzce-EW	0.52g
Duzce Earthquake	Duzce-NS	0.42g
Duzce Earthquake	Bolu-EW	0.75g
Duzce Earthquake	Bolu-NS	0.82g

The main emphasis is to increase the base shear strength of a typical frame building in order to reduce the displacement demand. Hence, nonlinear dynamic analyses are applied on the proposed shearwall building. The analyses are conducted using both the static and the dynamic versions of the LARZ program (Saiidi 1979a and 1979b; Lopez 1988). The static version is used to define the base shear strength coefficient, C_y of the model building for a triangular (linear) story force distribution. The dynamic version of the program helps to define the dynamic response of the building structures and their response histories during an earthquake. The results of the analyses reflect that adequate safety is attained in terms of the nonlinear displacement response of the frames and performance-based design approach.

2.SHEARWALL BUILDING AND PROPERTIES OF FRAMES ANALYZED

The building plan of the proposed shearwall building is given in Figure 1. Typical story height is three meters for the building while its unit weight is taken as 800 kg/m^2 (approx. 8kN/m^2). As previously mentioned, it consists of two structurally different frames which are characterized with 1% ratio of longitudinal reinforcement in the columns, ρ_{column} and 1% ratio of longitudinal reinforcement in the beams, ρ_{beam}. The frames are proportioned considering the effect of variation of base shear strength coefficient, C_y, and initial period, T.

It has span lengths of four meters. The base shear strength coefficient of the building is 0.32 and 0.34 in the EW and NS directions, respectively. The properties of frames in both directions are the same except for the number of spans. There are six spans in the EW direction and four spans in the NS direction. The properties of the shearwall building are given in Table 2.

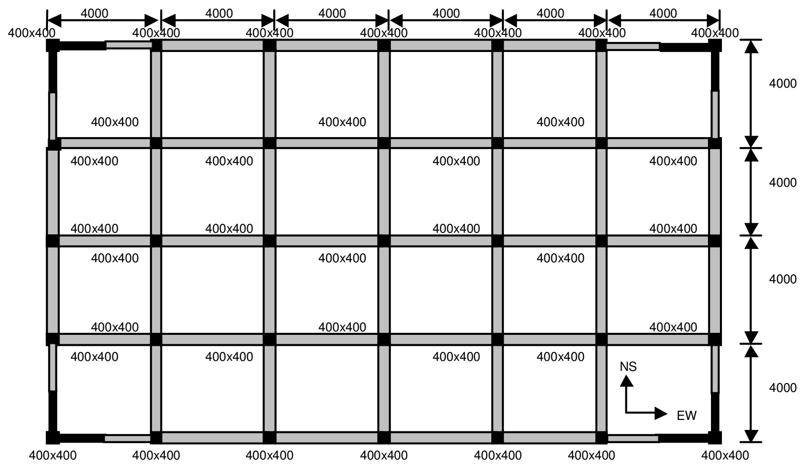

Figure 1 Floor plan of Shearwall Building (in mm) (Ozturk 2003)
Shearwall Dimensions: 200mm thickness and 2200 mm length
Beam Dimensions: 300x450 mm both in EW and NS directions

Table 2 Building Information for SHEARWALL-EW and SHEARWALL-NS Frames of Shearwall Building (Ozturk 2003)

Name of the Frame	**SHEARWALL-EW**	**SHEARWALL-NS**
Number of Bays	6	4
Span Lengths, m	4	4
Column Information		
Column Capacity, in kN.m		
Side	170	170
Inner	170	170
Column Size, m	0.4x0.4	0.4x0.4
ρ_{column}, %	1%	1%
Beam Information		
Beam Capacity, in kN.m		
$Moment^{+}$	140	140
$Moment^{-}$	70	70
Beam Size, m	0.30x0.45	0.30x0.45
ρ_{beam}, %	1%	1%
Shearwall Information		
Shearwall Capacity, in kN.m		
$Moment^{+}$	1800	1800
$Moment^{-}$	1000	1000
Shearwall Size, m	0.2x2.2 L-shaped	0.2x2.2 L-shaped
Shearwall Area, m^2	0.8	0.8
$\rho_{shearwall}$, %	0.25%	0.25%
From Static Analysis		
Base Shear Strength Coefficient, in %W	32	34
Total Weight, in kN	15070	15070
Base Shear Strength, in kN	4800	5100
T, Period of the Building, in sec	0.42	0.44
f_y , in MPa	220	220
f'_c, in MPa	16	16

*Unit weight of the Shearwall Building is 800 kg/m^2

Its columns have dimensions of 400 mm by 400 mm while its beams have a width of 250mm and a depth of 450mm. The shearwalls placed at the corners of the building have a thickness of 200mm. They are L-shaped with a length of 4400mm in both directions of the building. Their longitudinal reinforcement ratio, $\rho_{shearwall}$ is 0.25%. The moment-curvature relations of the structural elements of the shearwall building are calculated referring to the common construction practice in Turkey (Ozturk 2003).

The building has a period of 0.42 sec and 0.44 sec in the EW and NS directions, respectively. It has a weight of 15070 kN. The concrete strength, f'_c is 16MPa and the yield strength of the longitudinal steel, f_y is 220 MPa.

2.1 Shearwall Model

Shear force vs shear displacement relationship assumed for the "Shear Spring" of a wall in the Shearwall Building is given in Figure 2 (Ozturk 2003). The shear strength, V values of each L-shaped shearwall located at the corners of the building are provided in Equations 2.1 and 2.2 given below:

$$V_{cr} = 1063 \text{ kN} \quad (2.1)$$

$$V_{critical} = 1232 \text{ kN} \quad (2.2)$$

where:
V_{cr} : the cracking strength of shearwall model
$V_{critical}$: the strength of shearwall model

The shear strength values given above correspond to $v_{cr} = 4\sqrt{f'_c}$ for cracking (Lopez 1988) and $v_{critical} = \alpha_c\sqrt{f'_c} + \rho_n f_y$ for the expected limiting shear strength of the "shear spring" (ACI-318 2002).

In the equation of $v_{critical}$:

$\alpha_c = 3.0$ for $h_w / l_w < 1.5$
$\rho_n = 0.0025$ (vertical web reinforcement of the shear wall)
$f_y = 220$ MPa (yield strength of steel)

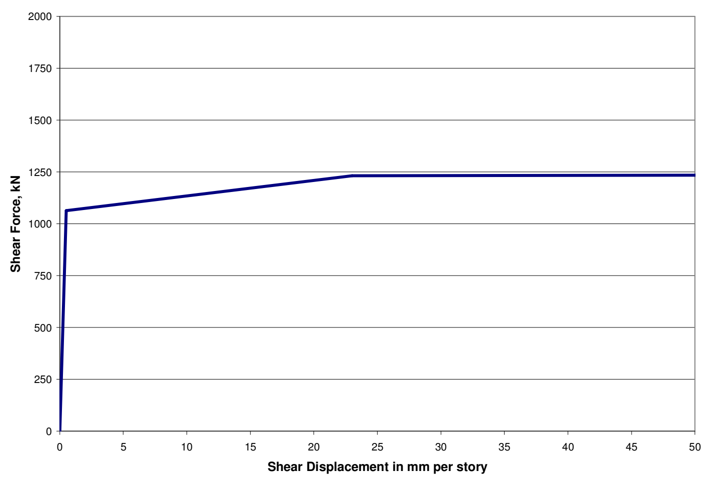

Figure 2 Shear force vs shear displacement relationship for the "Shear Spring" of a shearwall in the proposed building (Ozturk 2003)

2.2 Evaluation of the Base Shear Strength Coefficient, C_y by the Application of Static Analysis

The base shear strength coefficient, C_y of the five-story shearwall building frames are evaluated using the static version of the program LARZ (Saiidi 1979a and 1979b; Lopez 1988). The C_y values of each frame are given in Table 2. For the shearwall building C_y is 0.32 in the EW direction while it is equal to 0.34 in the NS direction. The C_y values provide very valuable information among with the initial period of the building frames in assessing the nonlinear behavior of building structures since these two parameters are correlated with the maximum nonlinear displacement response (Ozturk 2003).

2.3 Nonlinear Displacement Histories of Shearwall Building

Nonlinear displacement response histories of the frames of shearwall building are obtained for the initial 20 sec. of strong motion records by using the dynamic version of the program LARZ (Saiidi 1979a and 1979b; Lopez 1988). They are presented for four analyses cases regarding both EW and NS directions in Figures 3 – 6 of which Figures 3 - 4 correspond to EW direction while Figures 5 – 6 correspond to NS direction (Ozturk 2003).

In Table 3; in addition to the spectral response analysis results for linear displacement response with 2% critical damping, maximum roof drift response values obtained by the dynamic version of LARZ are given for the shearwall building.

The observed nonlinear displacement responses of the reinforced concrete shearwall building frames are found to behave similar to the nonlinear behavior of SDOF systems; it is assumed that the roof displacement in the multi-story frame may be obtained by multiplying the SDOF displacement response by a factor of $\frac{3}{2}$ which is approximately correct for shearwall frames (Ozturk 2003).

Physically identical SDOF and MDOF systems ("shear beams") with the same initial period, T and the same base shear strength coefficient, C_y can be correlated closely by Equation 2.3 which provides an upper bound.

$$\Delta_{MDOF} = \frac{3}{2}\Delta_{SDOF} \tag{2.3}$$

where:
Δ_{MDOF} : Nonlinear displacement response of a MDOF system
Δ_{SDOF} : Nonlinear displacement response of a SDOF system

The results of the nonlinear dynamic analyses which are shown in Figures 3-6 and tabulated in Table 3 reveal that under the same strong motion applied on a structure, the increase in the base shear strength coefficient, C_y significantly helps to reduce the maximum nonlinear displacement response.

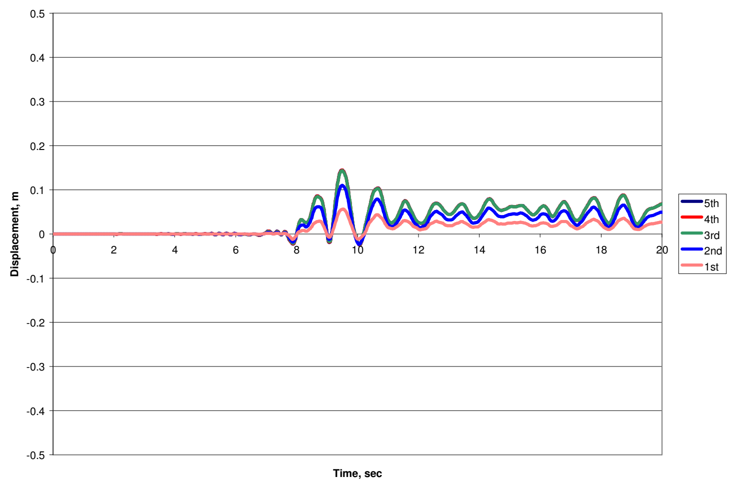

Figure 3 Displacement-time history in EW direction for Aug 17th 1999 – Duzce-EW record

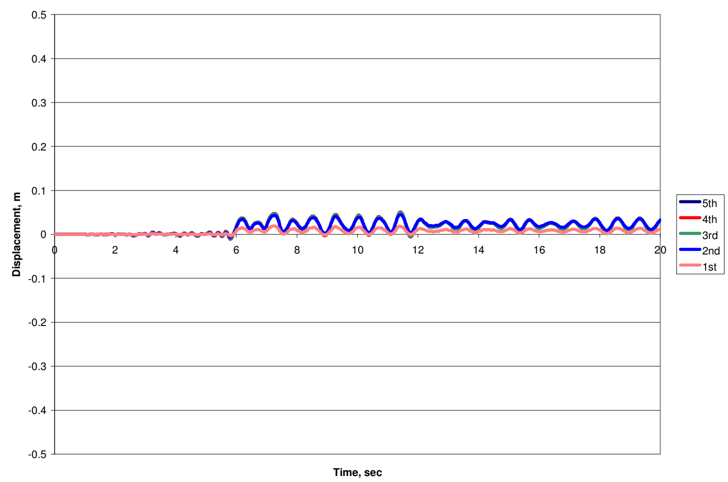

Figure 4 Displacement-time history in EW direction for Aug 17th 1999 – Izmit-NS record

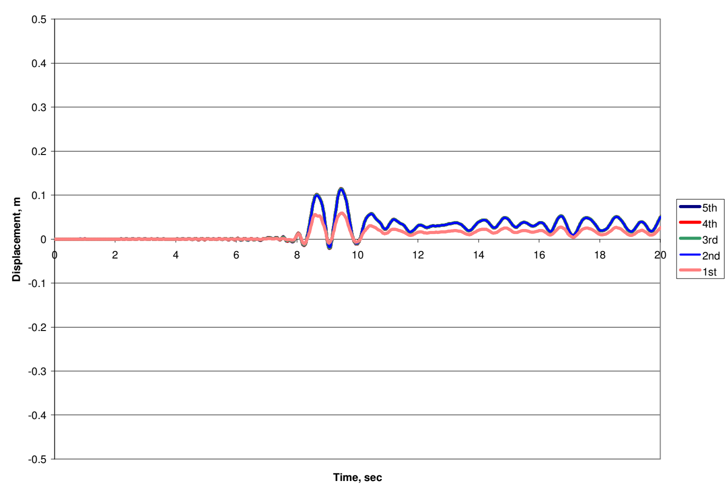

Figure 5 Displacement-time history in NS direction for Aug 17th 1999 – Duzce-EW record

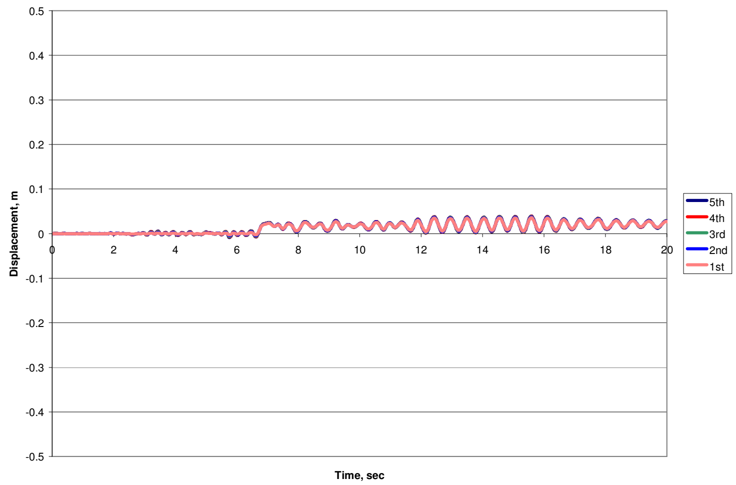

Figure 6 Displacement-time history in NS direction for Aug 17th 1999 – Izmit-NS record

Table 3 Maximum Nonlinear Displacement Response Values of the Building (Ozturk 2003)

Name of the Ground Motion Record	**SHEARWALL-EW**			**SHEARWALL-NS**		
	Spectral Response Analysis, in m (for 2% critical damping)	LARZ-Dynamic Analysis (Roof Drift, m)	LARZ-Dynamic Analysis (Mean Drift, %)	Spectral Response Analysis, in m (for 2% critical damping)	LARZ-Dynamic Analysis (Roof Drift, m)	LARZ-Dynamic Analysis (Mean Drift, %)
Duzce-EW (August 17th, 1999)	0.05	0.13	0.9	0.05	0.11	0.7
Duzce-NS (August 17th, 1999)	0.05	0.07	0.5	0.05	0.06	0.4
Izmit-EW (August 17th, 1999)	0.02	0.05	0.3	0.03	0.04	0.3
Izmit-NS (August 17th, 1999)	0.03	0.04	0.3	0.03	0.04	0.2
YPT-EW (August 17th, 1999)	0.05	0.10	0.7	0.06	0.11	0.7
YPT-NS (August 17th, 1999)	0.04	0.10	0.7	0.05	0.12	0.8
Duzce-EW (Nov. 12th, 1999)	0.05	0.21	1.4	0.05	0.18	1.2
Duzce-NS (Nov. 12th, 1999)	0.10	0.16	1.1	0.09	0.13	0.9
Bolu-EW (Nov. 12th, 1999)	0.07	0.21	1.4	0.07	0.23	1.5
Bolu-NS (Nov. 12th, 1999)	0.11	0.14	0.9	0.11	0.16	1.1

3. Results

In this study, the main emphasis is the application of shearwalls in order to increase the base shear strength of a typical frame building and to reduce the displacement demand for satisfying adequate safety in terms of the displacement-based design approach. Accordingly; a sample reinforced concrete five-story shearwall building which is proposed for Turkey is analyzed. Two shearwall frames with different base shear strength coefficient, C_y, and initial period, T constitute the building. They are exposed to the ground motions which were recorded during the 1999 Turkish Earthquakes.

Nonlinear dynamic analyses are conducted using the structural analysis program LARZ (Saiidi 1979a and 1979b; Lopez 1988). The results reveal the correlation in between MDOF (multi-degree of freedom) displacement response spectra and SDOF (single degree of freedom) displacement response spectra. It is observed that for a regular shearwall building, physically identical SDOF and MDOF systems with the same initial period, T and the same base shear strength coefficient, C_y, the roof displacement of the building and the SDOF displacement can be correlated closely by Equation 2.3 which provides an upper bound (Ozturk 2003).

It is noticed that under the same strong motion applied on a structure, the increase in the base shear strength coefficient, C_y significantly helps to reduce the maximum nonlinear displacement response and the shearwall structure behaves well in terms of the nonlinear displacement demand for the ground motions used in this study.

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