Performance Evaluation of the Adapazari City Hall Building Retrofitted Prior to the August 17, 1999 East Marmara Earthquake (M_w 7.4)

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Summary

The Adapazari City Hall was at a closest distance of 11 km to rupture of the July 22, 1967 Akyazi earthquake (M_w 7.0). The building with five-story R/C frame system was heavily damaged and retrofitted through conventional methods in an eight-month period after the earthquake (The retrofit project and application were carried out by the authors). After 32 years later, the retrofitted building suffered a strong earthquake (M_w 7.4) on August 17, 1999. The closest distance to the rupture of Adapazari was only 3.1 km (PGA 0.4g). Following the main shock, it also suffered a moderate aftershock (M_w 5.7) with PGA 0.35g and a strong main shock (M_w 7.2). These earthquakes caused collapse and heavy damages at many buildings in Adapazari. The Adapazari City Hall during these earthquakes experienced no structural damage and it was utilized as the city crisis centre. The lateral rigidity of the building after 1967 earthquake was provided by new shear walls instead of existing non-ductile structural elements. Retrofitted columns, new rigid beams, new structural masonry walls, repaired slabs and beams contributed the enhanced remarkable performance as well. Seismicity and geology of Adapazari and the seismic response of the building are discussed.

Keywords : Adapazari City Hall; damage; earthquake; performance evaluation; reinforced concrete (R/C); retrofitting

1. Introduction

The July 22, 1967 Akyazi (Mudurnu Valley) earthquake occurred as a result of the historical westward progression of large earthquakes along the North Anatolian Fault (NAF) since 1939 Erzincan earthquake. This earthquake is reported to be M_s=7.1 [1],[2] and M_w= 7.0 [3] with an approximate focal depth of 10 km [2].

The Adapazari City Hall was heavily damaged during the July 22, 1967 Akyazi earthquake. Adapazari was in a 36-km epicentral distance and 11-km the closest distance to the rupture. The building was retrofitted using conventional methods by Yapi Merkezi Inc. within an eight-month period after earthquake [4].

The Adapazari City Hall experienced the August 17, 1999 East Marmara (Kocaeli) earthquake 32 years later after retrofitting. This earthquake (M_w 7.4, M_s 7.8) is the largest and most damaging earthquake in Turkey within last 60 years along NAF. A 140-km rupture composed of four distinct segments extending from Hersek Peninsula to Eften Lake occurred during this earthquake. Adapazari, whose provincial capital is Sakarya, was among the hard-hit sites during the earthquake. Many buildings either collapsed or suffered to substantial damage. In Adapazari the assigned seismic intensity on the MSK scale is X [5]. The Adapazari City Hall was one of a few buildings in central area of Adapazari that sustained little or no structural damage [6], [7] and this building was used as the crisis management centre to direct earthquake relief efforts.

This paper evaluates the geology of Adapazari, the seismic characteristics of 1967 and 1999 earthquakes, the structural details of building, the retrofitting works after 1967 earthquake, the performance during the August 17, 1999 earthquake and post-earthquake reconnaissance.

2. Geology and seismotectonics of Adapazari

2.1 Geology of Adapazari

Adapazari is located at the edge of a sedimentary basin. The basin, which is a former lake bed, is underlain by thick sediments of clay. Quaternary alluvium, primarily consisting of silt and fine sand, deposited by Sakarya River and its tributary overlay the lake sediments. Thickness of alluvium is highly variable, increasing from a few meters on the south through north, reaching 200 m under the densely urbanized central section. The groundwater level is consistently high throughout the city, ranging between 0.2- and 3.0-m depths, even in the driest season [8] [9]. The most closest strong motion station to the rupture is the station of Sakarya Bayindirlik ve Iskan Müdürlügü (SKR). Its location is on a gentle hillside decomposed Eocene limestone [10].

2.2 The July 22, 1967 Akyazi and August 17, 1999 East Marmara (Kocaeli) Earthquakes

The 1967 Akyazi, 1999 East Marmara and Düzce earthquakes are the results of the westward mitigation in the NAF since 1939. The August 17,1999 earthquake filled the gap between the 1963 and 1967 events (Fig. 1, Table 1). During the July 22, 1967 Akyazi earthquake (M_s 7.2, M_w 7.0), almost of the 80-km length surface rupture occurred crossing the EW direction. The maximum and average fault offsets were respectively 260 cm and 90 cm. The surface rupture occupies a 1-3 km-wide shear zone.

In the August 17, 1999 East Marmara (M_w 7.4) earthquake, the rupture initiated at Gölcük with a bi-lateral propagation into the Gulf of Izmit on the west and into Sapanca Lake on the east. This rupture triggered another main shock from Arifiye to the Eften Lake near Düzce [11] (Fig. 1). Thus, at least 140-km rupture occurred in 38-sec duration. The multiple strike-slip rupture process is

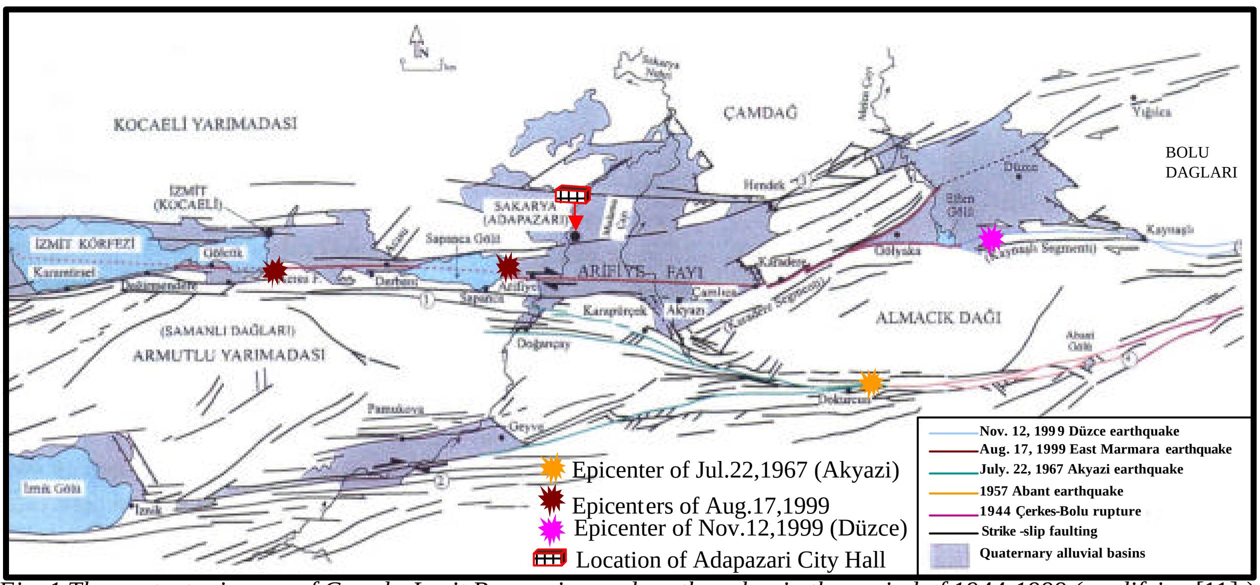


Fig. 1 The neotectonic map of Gerede-Izmit Bay region and earthquakes in the period of 1944-1999 (modifying [11] *)*

composed of four consecutive segments of the NAF: Gölcük, Sapanca, Sakarya and Karadere. The right-lateral surface offset reaches a 4.5 m, nearly maximum, on the Sakarya segment to which strong-motion station (SKR) (40.737°N, 30.384°E) is in a 3.1-km closest distance. The records of near field station SKR operated by ERD has a PGA value of 407 gal (EW), 259 gal (UD), an EPA value of 287 gal (EPA/PGA ratio 0.70) and a PGV value of 79.8 cm/sec. The earthquake devastated the provinces of Kocaeli, Sakarya, Bolu and Yalova. About 18 thousand people are estimated to have died, and around 45 thousand people were injured, of which perhaps two-fifths will permanently disabled. The mentioned provinces contributed over 7 % of the country's GDP (Gross domestic product at current prices of 1998) and about 14 % of industrial value added. Economic impact of the earthquake may be predicted to have amounted to $13 billion (Arioglu, Ersin, Arioglu, Ergin, 2002) [12].

Table 1 Strong motion records in Sakarya Bayindirlik ve Iskan Müd. (SKR) of significant earthquakes in the period of 1967-1999

Earthquake	Time (GMT)	Epicenter		h (km)	R_e (km)	R_{cl} (km)	M_s	M_w	M_o x10^{26}	PGA (gal)		
		Lat.	Lon.						dyn.cm	N-S	E-W	U-D
Jul. 22, 1967	16:56:58	40.7	30.8	10	36	11	7.2	7.0	2.7	400*		
Aug.17,1999	00:01:37	40.75	29.86	17	34.9	3.1	7.8	7.4	29	-**	407.0	259.0
Nov.11, 1999	14:41:25	40.74	30.27	22	17.5		5.5	5.7	0.03	206.5	345.3	133.3
Nov.12,1999	16:57:21	40.74	31.21	10	69.5	48	7.5	7.2	6.7	17.3	24.7	11.5

Definitions on earthquake : h=the focal depth, R_e=the epicentral distance, R_{cl}=the closest distance to the rupture, M_w= the moment magnitude, M_s=the surface magnitude, M_o=the seismic moment, PGA=peak ground horizontal (N-S, E-W) and vertical (U-D) acceleration

* Predicted value due to not existing strong motion network in Turkey until 1976.

** Only lateral accelerogram was recorded due to a malfunction.

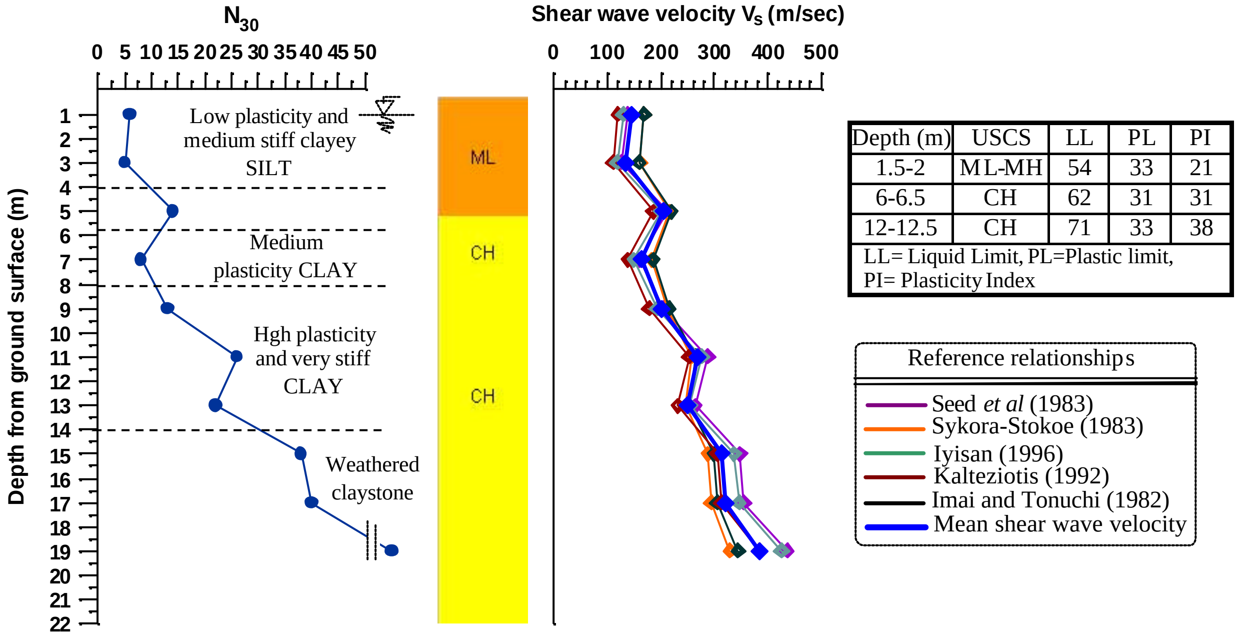
3. Technical Characteristics of the Adapazari City Hall

3.1 Soil Conditions

On the August 17, 1999 event the foundation displacements in the forms of settlement, tilting and lateral movement were broadly observed in the Tigcilar, Cumhuriyet, Orta and Kurtulus districts of Adapazari [8] [9]. But collapse and heavy damage (20-40 % of total number of buildings in district) occurred in the Istiklal and Karaosman, Semerciler, Pabuççular, Yenicami and Yenidogan districts [8] in which no or limited foundation displacements due to bearing capacity failure and liquefaction phenomena was reported. The Adapazari City Hall also locates in Semerciler district and the soil profile (from data provided by Köksal referring DRM-MERM research project [13], [14]) down to 20 m depth in its vicinity is given in Fig 2. Thick CLAY layers with medium to high plasticity prevented soil displacements and liquefaction phenomena. About 14 m depth the sequence grades into weathered claystone. At 10 m depth the average shear wave velocity corresponding to N_{30} count 26 is predicted as V_s 270±20 m/sec from mentioned relationships (Fig. 2). The described soil profile of the Adapazari City Hall site signifies the class B2 according to site soil classification system in [15]. This site class stands for stiff cohesive soils with medium depth (< 60 m) for V_s>150 m/sec and NEHRP D class as well. The soil condition B2 of the Adapazari City Hall ~7.5 km away from SKR station in which the PGA value was recorded as 407 gal (EW) implies not amplified PGA values with respect to the site-dependent acceleration relationships. This fact was confirmed in [8] as well.

3.2 Structural System

The Adapazari City Hall was constructed in the period 1959-1964. The building was a five-story R/C frame system to be assumed without basement due to the water table only 1 to 2 m in depth. The horizontal plan is 14.2 m by 40.0 m and consists of 3 frames in the longitudinal (x) direction and 13 frames in the transverse (y) direction [4]. For the rigidity to lateral forces of the building 2 shear walls with 23 by 550 cm and 35 columns were provided throughout the height. Two shear walls not placed symmetrically on the Grids 5 and 6 of the y direction created a significant eccentricity as indicated in Table 2.Columns sizes varied from 230 to 400 mm in width and from



Depth (m)	USCS	LL	PL	PI
1.5-2	ML-MH	54	33	21
6-6.5	CH	62	31	31
12-12.5	CH	71	33	38
LL= Liquid Limit, PL=Plastic limit, PI= Plasticity Index				

Fig. 2 Soil profile and predicted shear wave velocities from N_{30} count in the vicinity of Adapazari City Hall

300 to 700 mm in depth. The floor framing system was a 370-mm-deep joist system infilled with lightweight bricks and the widths of the beams were 400 by 1140 mm. Concrete (cube) compressive strength was 16 MPa. Two types of infill walls not designed to resist lateral or gravity loads existed, one the 100 by 150-mm-thickness lightweight brick infill walls also used in elevator shaft, second one the hardboards filled sawdust.

3.3 Structural Performance During the 1967 Akyazi Earthquake

During July 22, 1967 Akyazi earthquake and subsequent July 30, 1967 aftershock, the Adapazari City Hall suffered heavy damage. No concept of ductile detailing knowledge were available in the early 1960s (Fig. 3, 4). A typical damage section in the longitudinal direction is seen in Fig. 3. Excessive deformations concentrated in columns of the lower stories occurred in the form of unloading, spalling, crushing, compression failure and reinforcement buckling. In the lightweight brick infill walls of the stair and elevator shaft heavy shear cracks were observed. Beams of joist slab floors sustained damage as well.

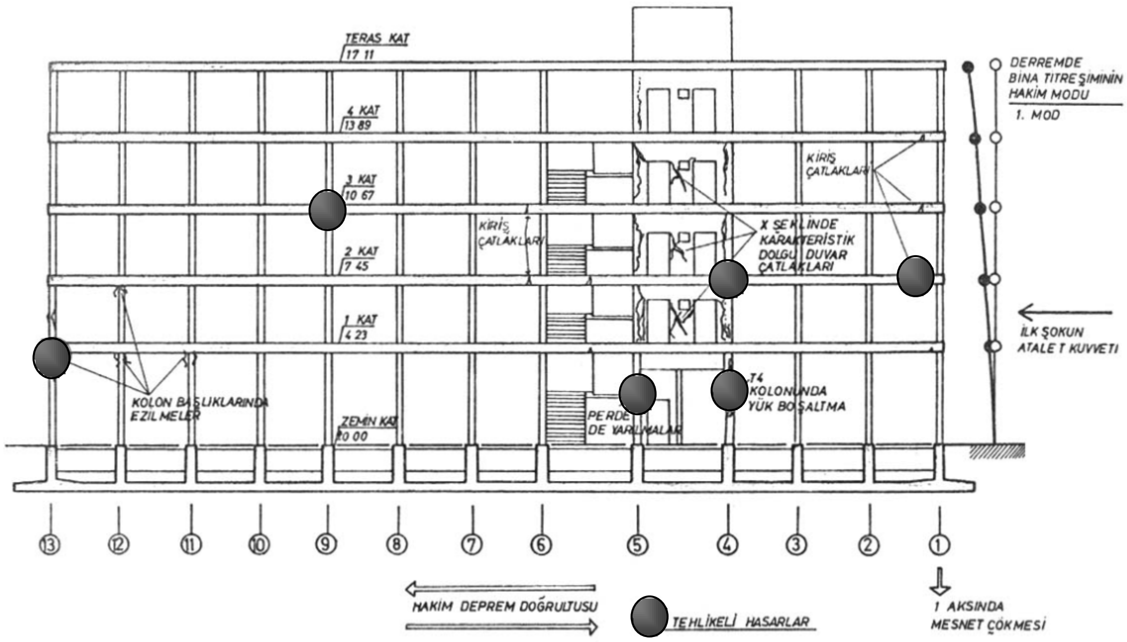


Fig 3. Damage pattern of the Adapazari City Hall Building after the 1967 Akyazi earthquake [4]

Translation definitions in Fig. 3 : Kat (*floor*), kolon (*column*), perde (*shear wall*), kiris (*beam*), merdiven (*stair*), asansör bos. (*elevator shaft*), kesit (*section*), dolgu duvar çatlaklari (*in-fill wall heavy shear cracks*), tehlikeli hasarlar (*dangerous damages - implying plastic hinge failures in structural frame*-),yarilma (*split*), ezilme (*chrushing*), kolonunda yük bosaltma (*unloaded column*), ilk sokun atalet kuvveti (*seismic forces in the main shock*), bina titresimi hakim modu (*fundamental mode of building*), hakim deprem dogrultusu (*main direction of seismic motion*), mesnet çökmesi (*foundation settlement*)

3.4 Characteristics of Repair and Strenghtening After 1967 Earthquake

The authors of this paper undertook the retrofitting responsibility of the Adapazari City Hall contrary to some opinions that the *building should be demolished.* All retrofitting works including repair and strengthening were completed using conventional methods within 8 months. To increase seismic performance new transverse perimeter shear walls were constructed on the Grids 1 and 13 throughout the height of the building (Fig. 5). Transverse interior shear walls were added on the Grids 8, 9 and 10 and short longitudinal shear walls were placed to the four corners as well. 18 columns were included into the new added shear walls, other 17 columns were retrofitted by jacketing minimum 10 cm after removing cover. To improve the lateral rigidity of building the new rigid deep beams were constructed in the sizes of 30 by 90 to 51 by 90 cm in the ground and roof floors. At the other floors new beams of 52 by 40 cm were added to the system. The structural masonry walls of solid brick to ground floor were added to enhance seismic energy damping ratio. The foundation system was strengthened by enlargement. The roof covering was lightened by removing heavy gravel load with isolation aim.

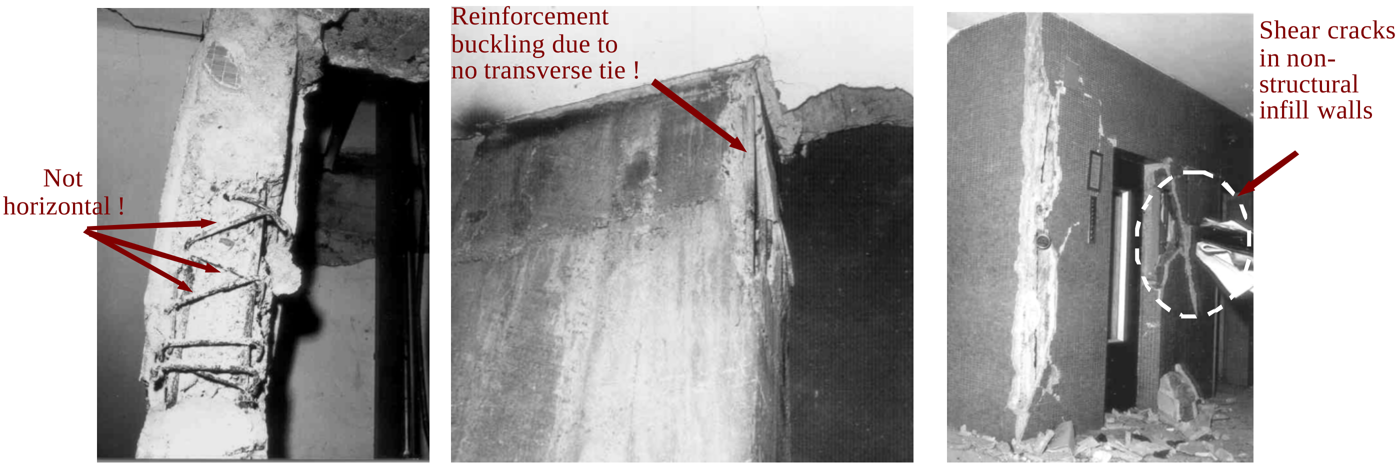


Fig.4 Typical examples to structural and non-structural heavy damage in the building after July 22, 1967 earthquake [4]

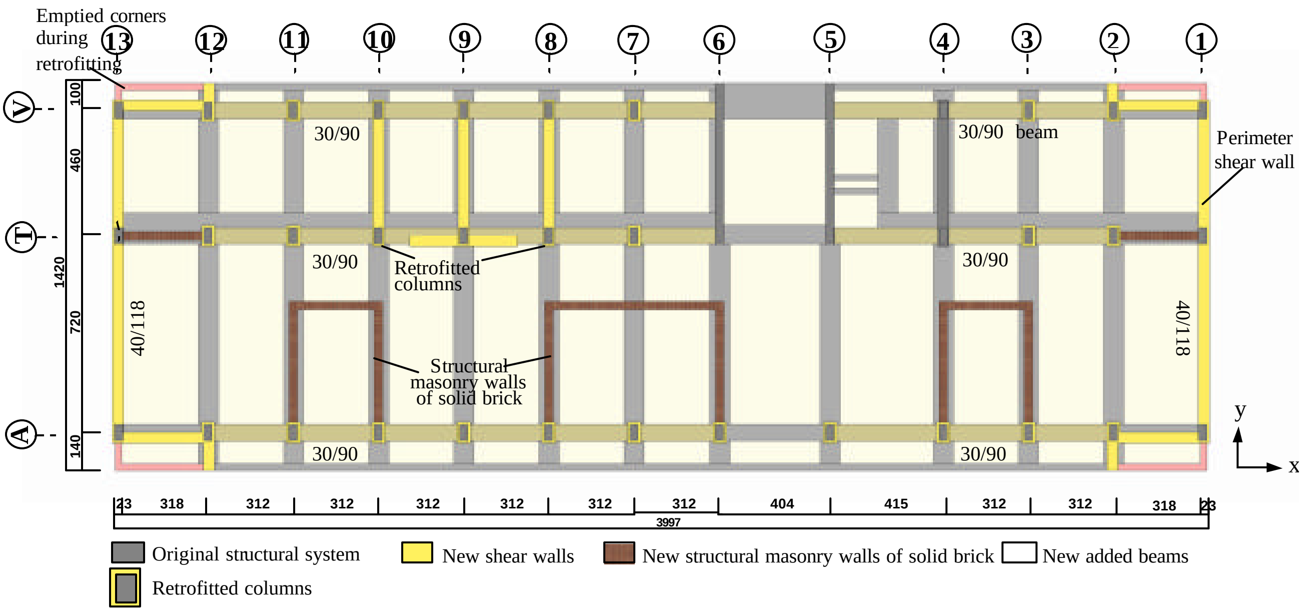


Fig.5 Main strengthening and repair works applied to Adapazari City Hall (the ground floor framing plan)

Table 2 Basic Design and Structural Characteristics of Adapazari City Hall before and after retrofitting

Basic Characteristics	***Original building***	***Retrofitted building***
Design input		
Average safety soil capacity (kN/m^2)	72	79.2
Fundamental period of soil (sec.)	~ 1	~ 1
Lateral force coefficient, C	0.04	0.07
Cube compressive strength (MPa)	16	16
Structural characteristics in the ground floor		
Total weight (kN)	43700	47320
Calc. fundamental period (x-direction) (sec.)	1.38	0.33 (0.35***)
Calc. fundamental period (y-direction) (sec.)	1.08	0.19
Eccentricity	e_x=17.7 %, e_y=14.2%	e_x=0 %, e_y= 1.1%
Total number of columns	35	17
Total column area in the 1st story (m^2)	6.24	6.5
Total shear wall area in the 1st story (m^2)	2.53	22.4
Total shear wall rigidity in x direction (kNm^2)*	$0.07x10^7$ (I_x=0.07 m^4)	$17.5x10^7$ (I_x=8.73 m^4)
Total shear wall rigidity in y direction (kNm^2)*	$6.55x10^7$ (I_y=6.55 m^4)	$278x10^7$ (I_y=138.96 m^4)
Structural masonry wall area in x direction (m^2)	0	5.73
Structural masonry wall area in y direction (m^2)	0	7.96
Predicted structural performance		
Energy absorption capacity	-	Good
Predicted damping ratio	0.02-0.03	= 0.08
Ductility	1.5-2.0	4
Wall Index** (I_w)	~ 0 (E-W), 0.23 (N-S)	0.33 (E-W), 0.65 (N-S)
Potential damage assessment	Heavy or collapse	No or minor

* Modulus of elasticity is assumed as 10 GPa (decreased due to observed deficiencies in concrete elements) for original and 20 GPa for retrofitted building

** According to the potential damage assessment method in [16]

***Determined according to [17]'s experimental method

The comparable structural and performance characteristics prior to and after retrofitting are compiled Table 2. As seen strictly, great differences before and after the retrofit exist on eccentricity, fundamental periods, lateral rigidities, experienced and henceforth anticipated responses. Briefly contrary to poor performance of original building, the rigidity and ductility requirements to resist a potential strong earthquake in the future were provided through the enhanced structural capacity in each direction.

4. Performance of the Adazapari City Hall during the Aug. 17, 1999 Earthquake

In the August 17,1999 East Marmara earthquake (M_w 7.4) at least 140 km fault was ruptured. The dextral slip reached a maximum of 5.10 ± 0.25 m near Arifiye. The Adapazari City Hall was in a ~7.5-km the closest distance from Arifiye segment and PGA value recorded by SKR station a few kilometres away was 407 gal (EW). The assigned seismic intensity (I) on the MSK scale in Adapazari was X [5] and this value coincides the relationship (1) between I and PGA [18] for the 17 August 1999 earthquake

$$I= 1.748 \ln PGA -1.078 \qquad (r=0.921) \qquad (1)$$

where r is correlation coefficient. The static offset was about 185 cm [10]. Structural damage was enormous at about central area in which the Adapazari City Hall also locates and the City Hall was one of a few buildings not suffered to structural damage [6], [7] (Fig. 6) and used as the crisis management headquarter to direct the earthquake relief efforts.

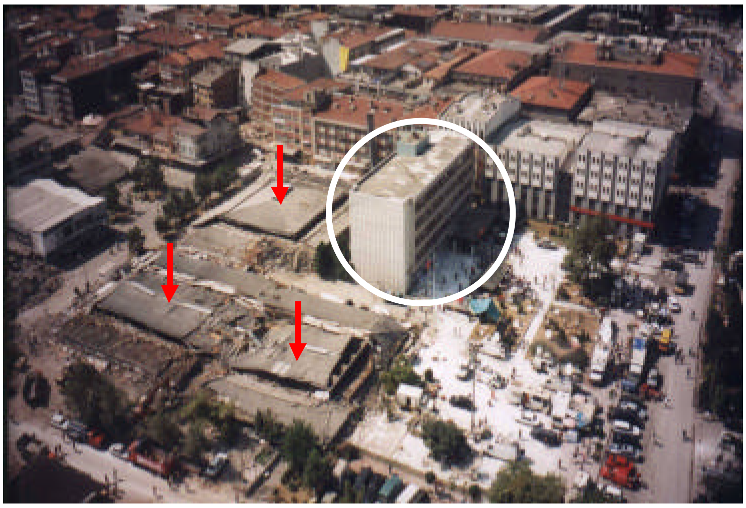


Fig. 6 An aerial view of the Adapazari City Hall and the pancake-type collapses in its vicinity (after the 17 August 1999 earthquake)

The significantly enhanced structural capacity and minimized torsional irregularities through removing eccentricity between mass ad rigidity centres resulted in the remarkable performance without structural damage of Adapazari City Hall in 1999 earthquakes. According to seismic vulnerability assessment method [16], which is calibrated on the 2-6-storey 54 R/C buildings suffered to damage at various levels during the 17 Aug. and 12 Nov. 1999 earthquakes, the minimum value 0.33 of the Wall Indices (I_w) in each direction (Table 2) is highly above the slight to no damage limit of 0.20 contrary to the almost zero value of original building prior to retrofitting.

Conclusion

The Adapazari City Hall during July 22, 1967 suffered heavy damage due to poor structural performance was retrofitted through strengthening and repairing with conventional methods by the authors of this paper. In the 1960's that the strengthening techniques with composites and other new methods have not yet developed, the basic strategy decided to retrofit a building with low ductility on deep alluvial basin had to be to construct rigid shear walls and structural masonry walls as energy absorbing main elements. On August 17, 1999, 32 years later, the Adapazari City Hall experienced a very strong earthquake (M_w 7.4) affecting all the Marmara region. The building at only 7.5 km (PGA 0.4g) the closest distance away from the rupture exhibited an excellent ductile performance. The City Hall sustained only minor damage during the main shock and the soon afterward during the aftershock (PGA 0.35g) contrary to the collapsed buildings in its vicinity. Long time years later this was a real experience to verify for the efficiency of applied retrofitting method.

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