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EARTHQUAKE EXPERIENCE OF TURKISH PRECAST INDUSTRY

S. Ozden[1], G. Barka[2], H. Atakoy[3], B. Hancioglu[4], U. Ozkan[5]

[1] Turkish Precast Concrete Association, TPCA Technical Advisor
Associate Professor, OKAN University, Tuzla Campus, Akfirat-Tuzla Istanbul
sevketozden@yahoo.com

[2] Turkish Precast Concrete Association, TPCA Technical Committee Chairman
Turkiye Prefabrik Birligi, Farabi Sk., 39/10, Ankara, Turkey
gbarka@barkamuh.com

[3] Turkish Precast Concrete Association, TPCA Technical Committee Member
Turkiye Prefabrik Birligi, Farabi Sk., 39/10, Ankara, Turkey
h.atakoy@afaprefabrik.com.tr

[4] Turkish Precast Concrete Association, TPCA Technical Committee Member
Turkiye Prefabrik Birligi, Farabi Sk., 39/10, Ankara, Turkey
bhancioglu@alacali.com.tr

[5] Turkish Precast Concrete Association, TPCA Technical Committee Member
Turkiye Prefabrik Birligi, Farabi Sk., 39/10, Ankara, Turkey
umit.ozkan@adimltd.com.tr

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Abstract. *The high seismic activity of the three fault zones in Turkey developed damaging earthquakes in the last five decades that affected the precast-concrete building structures in the region. Among others, the 1998 Adana, 1999 Kocaeli, 2003 Bingol and 2011 Van earthquakes are considerably important regarding the seismic performance of the precast structures. Earthquake performance of frame structures in the form of industrial-halls, shopping malls, multi-storey residential buildings and gymnasiums along with the wall structures mainly in the form of residential housing, under these seismic actions, revealed valuable information on the effectiveness of the prevailing technology and the design practice. The quality control system, inherently developed within the member companies of the Turkish Precast Concrete Association, TPCA, resulted better performance of the precast structures. The structural system of the multi-storey residential buildings in Bingol, Kocaeli and Van, regardless of the structural system, were in the state of immediate occupancy, while the cast-in-place buildings in the vicinity experienced damage ranging from life safety up to total collapse. Beside the residential buildings, bigger span structures like shopping malls gymnasiums and the industrial structures of TPCA members after the Adana and the devastating Kocaeli earthquakes responded between immediate occupancy and life safety.*

1 INTRODUCTION

Turkey is located in a seismically active region and frequently experiences large earthquakes. The high seismicity of the region is mainly caused by the North and East Anatolian fault zones. The North Anatolian Fault Zone (NAF) is a strike-slip fault in Northern Anatolia which runs between the Eurasian and the Anatolian Plates having an approximate length of 1500 km [1]. On the other hand the East Anatolian Fault (EAF) is another 550 km length strike-slip fault zone in South-Eastern Turkey, forming the boundary between the Anatolian Plate and the northbound moving Arabian Plate (*Fig. 1*).

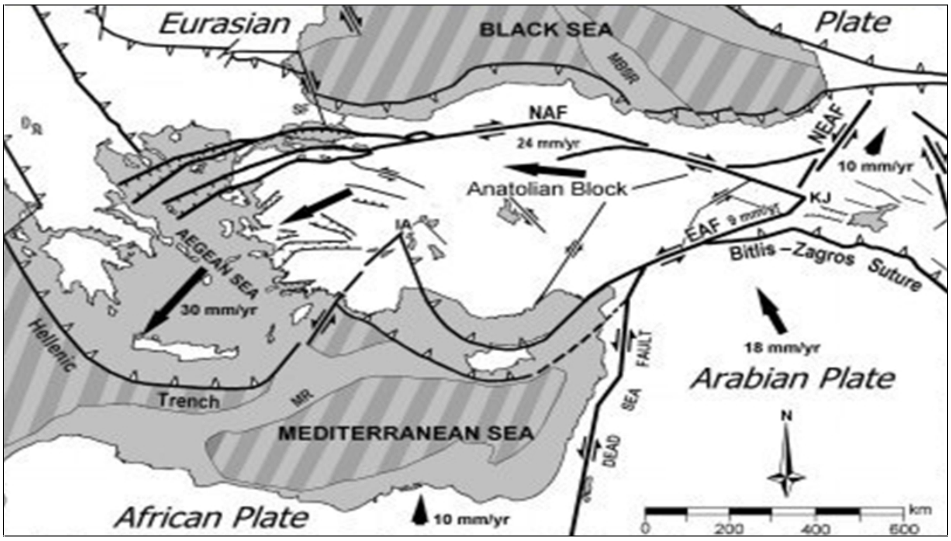

Figure 1 – The Anatolian Fault Zone [2]

Year	Location	Magnitude
1930	Hakkari	7.2 *(M_s)*
1939	Erzincan	7.8 *(M_s)*
1942	Erbaa	7.0
1943	Ladik	7.4
1944	Gerede	7.5
1953	Yenice	7.2 *(M_s)*
1957	Abant	7.1
1964	Manyas	7.0 *(M_s)*
1966	Varto	6.7
1967	Mudurnu	7.2
1971	Bingol	6.9
1976	Muradiye	7.5 *(M_s)*
1983	Erzurum	6.9 *(M_s)*
1992	Erzincan	6.8
1995	Dinar	6.1 *(M_s)*
1998	Adana-Ceyhan	6.2 *(M_s)*
1999	İzmit	7.6
1999	Duzce	7.2
2003	Bingol	6.4 *(M_w)*
2011	Van	7.2 *(M_w)*

Table 1 – Some Earthquakes of the Anatolian Fault Zone

Since the disastrous 1939 Erzincan earthquake (*Table 1*) on the East bound of Turkey, there have been several earthquakes on NAF and EAF zones hitting the residential and commercial areas, causing casualties and economic losses. Approximately 95 percent of the Turkish land, as well as residential and industrial facilities, are under the direct thread of earthquakes. The residential housing in the form of brick and adobe structures form the main percentage of the building stock in small residential centers, while cast-in-place reinforced concrete frame type of structures and precast concrete frame or wall systems are more common in the big residential cities and in the industrialized regions.

Precast concrete in Turkey has a wide range of application ranging from highway bridges to city furniture, and to single- and multi-storey building structures. The precast concrete building structures, as compared to the cast in place counterparts, are mostly preferred for the shopping centers, gymnasiums, multi-storey housing, and for single or multi-storey industrial facilities. The building structures for the industrial facilities among the others cover the highest percentage within the precast concrete production in Turkey.

2 PERFORMANCE OF PRECAST INDUSTRIAL FACILITIES

Precast construction was introduced in Turkey in the 1960s. During the 1990s, approximately 90% of the warehouse and light industrial facilities were constructed using precast members [3]. The most common structural system for these facilities is based on a structural configuration that was developed in Western Europe to carry gravity loads only [4]. However Turkish engineers modified the unique connection details for each producer company so that the precast buildings have the capacity to resist seismic lateral loads. The connection and other details of such structures vary appreciably from producer to producer [5].

Figure 2 – Industrial Building under Construction in Adana in 1998 [6]

Adana (on EAF), Kocaeli and Sakarya (on NAF) are the industrial heartlands of Turkey and hit by two devastating earthquakes in the year 1998 and 1999 respectively. The precast construction in Adana was mainly in the form of single storey industrial buildings, while multi-storey industrial buildings also exist in the Kocaeli region. The structural system of single storey industrial buildings consists of cantilever columns, fixed at the base and pin connected to the roof beams at the top. It is reported that the workmanship and the material quality of the precast concrete elements in Adana were significantly over those of the cast in place residential buildings (Fig.2). It is also reported that the Schmidt hammer measurements of the concrete elements yielded a mean value for the compressive strength of f_c= 60 N/mm^2 while the yield strength of the reinforcement steel is assumed to be f_y = 420 N/mm^2 [6]. The local damage of such buildings were confined to the connections where roof beams were pin connected to the columns. The structures conforming to the Turkish Earthquake Code experienced minimal damage confined to the partition walls and some connections, while the ones not conforming to the code experienced local failures. The column dimensions played an important role on the damage distribution in such buildings.

One year after Adana earthquake, Posada and Wood [5] reported similar results for the industrial buildings. Authors investigated the industrial buildings in Sakarya, Kocaeli, and Gebze. It is reported that the damage level of the industrial buildings are mainly influenced by the drift demand and the drift capacity of the buildings. The damage of precast structures in Sakarya was more pronounced due to the drift demand invoked by the soft soil conditions, as compared to the no damage in Gebze where the soil is basically stiff clay to rock. It is also reported that the buildings with larger column sizes, in other words the buildings conforming the Turkish Earthquake Code (TEC) performed well [5] (Fig.3). The site investigations and elaborations on the structural design calculations revealed that most of the damaged buildings were not conforming to the drift limits of TEC. Besides, the design was made only in the frame direction, and the earthquake loading is not made in the transverse direction. The damage of precast concrete industrial buildings confirming to the TEC drift limits on both orthogonal directions, even in the vicinity of the epicenter, were in the range of immediate occupancy to life safety [7].

Figure 3 – Typical Single- and Multi-Storey Warehouses after Kocaeli Earthquake [5]

In some of the single-storey industrial buildings in Adana earthquake, the damage was confined to the out-of-plane toppling or leaning of the triangular roof beams. TPCA Technical Committee developed a design methodology and enforced the use of double bars to fix the triangular roof beams to the corbel of the columns (Fig.4). The forces Fi resulting from the earthquake excitation is resisted by the moment around a beam corner due to gravity and due to the force couple created by the double bars as shown in Fig.4. [8].

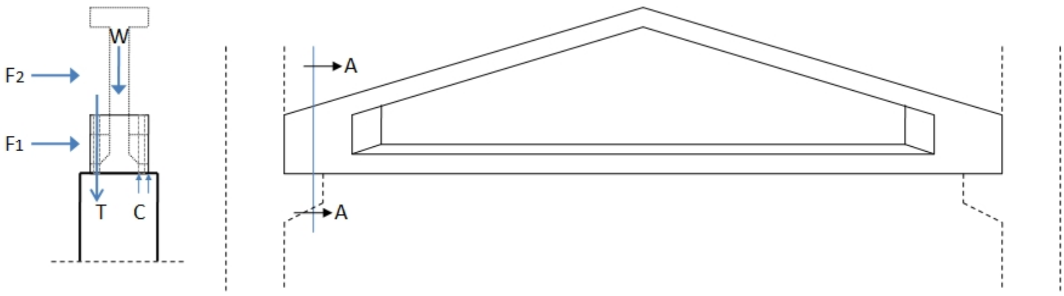

Figure 4 – Forces on the Roof Beams and the Resisting Mechanism

3 PERFORMANCE OF MULTI-STOREY RESIDENTIAL HOUSING

The first multi-storey post-earthquake housing in precast concrete was constructed at Genc-Bingol in 1986 after the damaging earthquake of Bingol in 1971 (Table 1). The housing complex contains 36 blocks with 5 floors including basement; basement having monolithic peripheral walls. The joint system of the precast frame was cast-in-place. Seismic lateral loads were resisted by the precast moment resisting frame system and the cast-in-place reinforced concrete shear walls spanning from the foundation up to the roof level. The plan dimension of the blocks was 8.20x32.90 meters with a story height of 2.70 meters.

Figure 5 – Precast Multi-Storey Building during Construction and After 2003 Bingol Earthquake [9]

Post Earthquake investigation (Bingol-2003) on the Genc-Bingol housing complex revealed that the buildings were in the performance state of immediate occupancy, although the surrounding cast-in-place reinforced concrete structures underwent damages ranging from life safety to collapse.

In 1999, a devastating earthquake hit the city of Kocaeli leaving thousands of casualties and a considerable economic loss both due to the damage in infrastructure and due to the industrial production losses (Table 1). The spread of damage was more pronounced in the sediment basins such as Adapazarı, and in the regions close to the East bound of the Kocaeli Gulf such as Golcuk and Kavaklı. The displacement demand due to the soft sub-layers caused many buildings to collapse, left many beyond the life safety performance limit. The precast wall type of 5 storey residential construction at Golcuk, which was constructed in 1991 experienced no damage (immediate occupancy performance level) while all the surrounding buildings were collapsed. The walls and the slabs of the building complex with 2 blocks were of hollow core slabs. The wall to slab and wall to wall connections were cast-in-place with special reinforcement detail (Fig.7).

Figure 6 – Precast Multi-Storey Wall System Building during Construction and After 1999 Kocaeli EQ. [10]

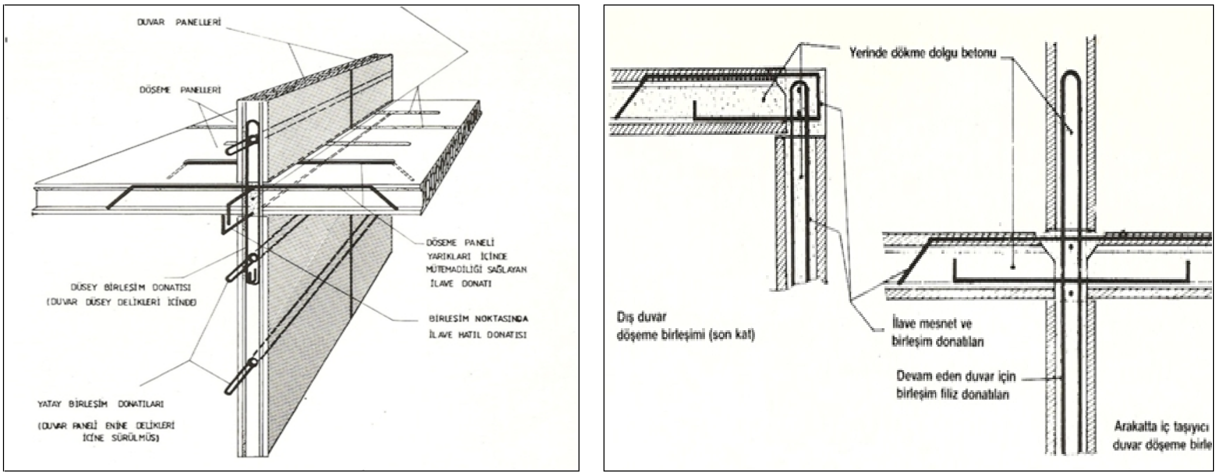

Figure 7 – Slab-to-wall and Wall-to-Wall Connections in Multi-Storey Wall System Building. [10]

Figure 8 – Frame Building with Post Tensioned Connections, and the Performance after 2011 Van EQ. [11]

Starting with the 1990s precast concrete moment resisting frames with post tensioned connections took place in the Turkish Precast Concrete market. Multi-storey industrial and residential buildings with such connections were constructed in Turkey. The recent earthquake in 2011, in the city of Van (Table 1) revealed valuable information on the performance of such connections. The residential multi-storey moment resisting frame building with post tensioned connections in Van had 7 storeys with an approximate foot-print area of 380 m2. Plan geometry was rectangular: two bay by two bay. The bays were Lx=12.30m, Ly=8.00m. Floor system was with hollow core slabs which were supported by the 12.30m spans. The beams spanning in the short direction were 50/70cm, while the ones spanning on the long direction were 60/80cm. The columns of the frame were 75x70cm. The columns of the building were constructed in single pieces with a height of seven storeys (approximately 22m) and transported to the construction site. A cast-in-place socket type of foundations were used and designed as fixed support. Beams with tapered end were seated on square corbels of the columns and post tensioning was used for the connection continuity.

Post-earthquake damage investigation on that specific building revealed no structural damage on neither pre-cast, pre-tensioned members, nor the post-tensioned connections, and post-tensioning ducts. The column to foundation connections were carefully investigated and no flexural or shear cracking was observed. The frame performance during the Van Earthquake of October 2011 was immediate occupancy. However, some the dry partition walls experienced minimal damage.

4 PERFORMANCE OF LARGE SPAN SHOPPING MALLS

The shopping malls, with the economic development of Turkey, became a market field for the precast concrete structures. The spans were relatively long, and the service loads were high in such structures. The shopping center given in Fig.9 was in the epicenter of Kocaeli earthquake (Table 1). The building had a central part with two storeys, while the surrounding

Figure 9 – Performance of a Shopping Mall after 1999 Kocaeli Earthquake [12]

frames were three storey height. The frame connections were cast-in-place. The structural system was in the immediate occupancy performance level. However, the false ceilings and the material racks toppled and service of the mall suspended for a while.

5 CONCLUSIONS

The post earthquake field investigations revealed that the performance level of the precast concrete structures in Turkey is clearly influenced by the building conformity to the Turkish Earthquake Code. None of the buildings designed and constructed by the TPCA members underwent a damage beyond the minimal level.

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