STRUCTURAL PRECAST CONCRETE IN TURKEY: DEVELOPMENT AND EARTHQUAKE PERFORMANCE IN LAST DECADES

Hilal Meydanli Atalay

Department of Civil Engineering,
Kocaeli University,
Kocaeli, Turkey,
hilal.meydanli@kocaeli.edu.tr

Şevket Ozden

Civil Eng. M.Sc., Ph.D.,
Istanbul, Turkey

sevketozden@yahoo.com

Erkan Akpınar

Department of Civil Engineering,
Kocaeli University,
Kocaeli, Turkey,
erkan.akpinar@kocaeli.edu.tr

Hakan Erdoğan

Department of Civil Engineering,
Kocaeli University,
Kocaeli, Turkey,
hakan.erdogan@kocaeli.edu.tr

***Abstract*—In recent decades, the precast concrete structures become increasingly popular in Turkey. Besides its cost efficient and time-saving nature, sufficient earthquake resistance should be provided at the design stage for proper and safe utilization of those structures. For this purpose, prime importance should be given to joint locations such as beam-column connections where considerable amount of energy dissipation is required to ensure earthquake resistance. In this paper, the development of the structural precast concrete in Turkey over the last decades is discussed with special emphasis on the research and developments in the area of beam-to-column connections. In addition, the performance of the existing precast concrete structures in recent earthquakes is also reported in order to highlight the significance of know-how transfer to avoid the repetitive errors both at design and construction stages.**

Keywords: Precast concrete structure, Beam-column connection, Seismic performance.

1. INTRODUCTION

Structural precast concrete technology provides various advantages compared to the conventional cast in- place construction method. These well-known advantages may be listed as the minimized construction duration, higher compatibility with the architectural details, lower labor and material cost due to mass production process in a factory or a manufacturing site, reduced risks caused by the local climatic conditions by spending less time in construction site, easier and reliable quality-control process at prefabrication stage compared to in-situ construction [1]. In this technology, the structural elements of load-bearing system such as columns, beams and slabs were first produced and stocked up in a factory plant. Afterwards, the prefabricated structural elements were transported to construction site and assembled. The most critical requirement of this construction method is the specially automated system of industrial plant, since the design and production stages have to be well-organized together in an efficient manner.

Precast concrete structures were classified into two main groups according to their load bearing systems named as frame and panel systems respectively. Frame systems generally consist of beams, columns and floor elements whereas panel systems composed of wall and floor panels. The systems constructed using both frame and panel systems were called as composite systems [2].

The structural performance of precast concrete systems generally depends on the connection types between the precast concrete members [3]. Pin connected precast concrete systems were mostly preferred for industrial one-story structures with large girder span lengths. The well-known drawback of such systems is the non-moment resisting behavior that leads to unrepairable damages under lateral loading such as earthquake. On the other hand, moment resisting frame connection types may be divided into two groups namely dry and wet connections [4].

In the early years of application, precast concrete structures were generally used in low seismicity regions. By time, these type of structures spread through the seismically active regions depending on the growing interest. Accordingly, the rigidity, strength, ductility and energy dissipation capacities of the structures become more critical in the design of such structures. For this purpose, the studies in the literature generally focused on obtaining a behavior similar to monolithic frame systems without sacrificing strength, ductility and energy dissipation capacities at the connection regions [5].

In this study a detailed review about the development and improvement of precast concrete systems in Turkey was presented and the performance of these systems under recent earthquakes is discussed.

2. PRECAST CONCRETE STRUCTURES IN TURKEY

Manufacture of State Fez building is known as the first structure that was built by precast technology in Turkey. The structure was built in 1868 and having 8.000 m^2 closed area. The load-bearing system of this building was constructed with shed roof sitting on thin walled cast iron cylindrical columns. Bulgarian Orthodox Church between Balat and Fener districts in Istanbul was reported as the first full prefabricated structure of the Ottoman period. Those buildings were built by steel precast structural systems due to poor soil conditions. The structural members were connected with bolts, nuts, rivets and welding.

In 1955, first prefabricated concrete structural elements, (centrifugal concrete poles used for street lightning purposes) were manufactured in order to balance the overproduction of the cement plants in Turkey. This may be accepted as the pioneering investment in concrete prefabrication industry in Turkey. Later on, first precast concrete structural constructions were built as one-story school buildings in the first half of 1960's. These buildings were constructed by using semi-precast systems. First, the surrounding walls were constructed. Afterwards, 7.20m wide span was covered by truss roof system that consists of iron rods and concrete top chord. The prefabricated roof panels were placed on the roof truss. A total of 234 school buildings were constructed in same manner in three months time and opened to public service (Fig. 1).

Meanwhile, the residential houses of Ereğli Iron Steel Factory were constructed by a well known precast concrete panel system called Larsen-Nielsen System that was developed in Denmark in 1948. The structural components of this system were wall and slab panels. The primary objective of Larsen-Nielsen System is to minimize in-situ construction process. The wall and floor panels were first assembled by bolt connections and then those connection regions were filled with mortar to ensure continuity which is a good example of wet type of connections. Total of 446 apartment were constructed by using mentioned method in one year time. It is possible to register the year 1961 as the birth of precast concrete were using in public buildings and residence (Fig. 1).

Fig. 1 School buildings and the residency of Ereğli Iron Steel Factory [6].

The utilization of precast concrete systems in construction of industrial buildings has been started in the second half of 1960s. The industrialization thrust in those years triggered the heavy and urgent demand for rapidly constructed industrial structures for storing and sheltering the machinery safely. The rapid construction of those buildings has prime importance due to loan cost of the machinery.

In 1968, The Ministry of Industry decided to establish small industrial sites at different districts to promote industrial development. In the late 1970s, Tekel tobacco warehouse was built by fully prefabricated system from foundation to roof. A total of 32 dormitories were built with prefabrication between the years of 1984 and 1989. These buildings were constructed with either panel system consisting of hollow core slabs and wall panels or frame system consisting of prefabricated column, beam and double tee flooring unit. The popularity of precast concrete systems in construction of residential buildings increased significantly in 1980s. Bingöl earthquake houses and Kocaeli immigrant houses were the significant examples of residential buildings constructed by precast concrete systems in 1980s (Fig. 2). In 1990s, technological improvements in conventional methods such as widespread production and use of ready mixed concrete with increasing number of ready mix concrete plants and achievement of tunnel formwork concrete construction suddenly paused the growing interest in prefabrication especially for residential buildings [7].

Turkish Precast Concrete Association was founded in 1984 with the collaboration and supports of manufacturer companies. Beyond its representative role in order to promote the use of precast concrete,

Fig. 2 Bingöl earthquake houses [6].

Turkish Precast Concrete Association also put emphasis on the research and development activities, technical publications and regulations, etc. TS 9967 (1992) regulation including analysis principles and manufacturing and assembly rules of reinforced concrete prefabricated structural elements and structural systems was published by Turkish Standards Institute with the contributions of Turkish Precast Concrete Association [8].

The restrictive and router rules in design of precast structures were explained in Turkish Earthquake Code that activated in 1998 (TEC, 1998). The guidelines about precast concrete structures were then modified in Turkish Earthquake Code 2007 (TEC, 2007) according to performed research and development by different institutes.

3. RESEARCHES ON PRECAST CONCRETE SYSTEMS IN TURKEY

Precast concrete systems are most preferred construction method for industrial buildings, 85 percentages, in Turkey. It is vise versa in the case of residential structures, only 4 percentages [9]. Typical industrial structures are single-story and consist of simple portal frames of which connections fixed at the bottom side and hinged at the top side. Such precast framing systems which have hinged beam-to-column connections could be used in multi-story structures in case of that seismic load would be carried by cast in place reinforced concrete walls. Moreover, precast concrete structures with moment resisting connections are applicable for earthquake prone regions. It should be proven that such connections could provide equivalent strength and ductility as monolithic connections under reversed cyclic loading [10]. Basically, there are two methods to build moment resisting connections for precast concrete systems namely dry connection and wet connection. Outcomes of the experimental studies in Turkey on moment resisting connections for precast concrete beam-to-column joints are summarized in this section.

3.1 Dry Connections

In application of typical dry connections, steel rods and plates are embedded at both ends of precast beams during casting in order to connect those beams to columns by bolts or welding in construction site. Most of the time welding was preferred compared to bolted connections. Another type of dry connections was implementation of post tensioned steel for assembling purposes [4].

3.1.1 Welded connection

The first comprehensive research program that focused on the moment-resisting connection of precast structures in Turkey was performed in the Structural Mechanics Laboratory of METU. Precast beam-column connections, designed in multi-storey buildings located in seismic area, were modified to resist for earthquake loading [3]. Later on, the dry beam-column connections located away from column face were tested by Ersoy and Tankut. The connection between the column bracket and the precast beam consisted of steel plates, those were welded to plates embedded in the members on both top and bottom faces. According to test results, a modification was proposed to obtain a behavior similar to monolithic connections. In this modification, double steel plates were used on both top and bottom faces for moment transfer and additional double plates were used on both sides to provide shear transfer. The test results indicated remarkable increases in terms of strength, rigidity and energy dissipation capacity of the specimens [11].

Korkmaz and Tankut investigated the behavior of moment resisting precast concrete beam-to-beam connections under reversed cyclic loading. The connections consist of a middle precast beam that is placed on a cantilever beam connected to the column. Within the connection region, the continuity of the bottom reinforcement was provided by welding them to the steel plate at the junction of middle and cantilever beams. On the other hand, continuity of top reinforcement was satisfied by lap-splicing and in-situ concrete casting. However, the performance of those specimens was questionable. Therefore, the insufficient anchorage due to lap-splicing on top was eliminated by welding the reinforcing bars. The test results indicated that the quality of workmanship in welding the bars has prime importance to avoid premature failure in the vicinity of welded region [12].

3.1.2 Bolted connection

Ertas et al. [13] developed a special bolted connection detail to minimize the duration of assembling in site. The connection detail consisted of rectangular steel boxes allowing dimensional advantages during construction. This detail was proposed especially for short span and low level of shear forces formed by vertical loads. In addition, steel plates were placed at the top and bottom of the beam section to delay crushing of the concrete adjacent to the column surface. Steel bars were welded around the steel boxes and rods passing through the box section to eliminate any possible sliding of the steel boxes with respect to concrete beam. Bolts were pre-tensioned during assembly of connection and specimens were tested under reversed cyclic loading. The test results revealed that the performance of bolted connection is better than monolithic connection in terms of strength, ductility and energy dissipation capacity.

3.1.3 Post-tensioned connection

Post-tensioned connection detail was first developed and tested by Pınarbaşı in Turkey. The effect of post tensioning steel ratio on behavior of precast connections was investigated. The test results indicated significant increase in strength, ductility, rigidity and energy dissipation capacity by application of post-tensioning[14]. Another post-tensioned connection detail was tested by Kaya and Arslan. The effect of diameter of post-tension strands was investigated in their experimental study [15].

Ozden and Ertas also proposed a special hybrid connection to improve the moment resistance of precast beam-column connections. The main objective of the study was to investigate the effect of mild steel reinforcement ratio on behavior of post-tensioned precast concrete connections. The performance of hybrid connections improved significantly by increase of mild steel reinforcement ratio such that the capacity of companion monolithic subassembly was almost reached in terms of strength, stiffness and energy dissipation [16].

3.2 Cast in Place Connections

The most common moment resisting connection detail using in precast concrete structures is cast in place connection in other words wet connection. The well-known type of wet connection is composite connection of which reinforcement continuity provided by welding or bolts. In general, tension due to positive moment is transferred through the welding or bolts while tension due to the negative moment is transferred through reinforcing steel bars longitudinally placed in cast in place concrete. It is revealed that adequate performance parameters such as strength, ductility and energy dissipation capacity can be provided with the composite connections. One of the well-known study was conducted by Ersoy and Tankut. The flexural reinforcement at the bottom of the connection was supplied by welding of steel plates embedded into joining portions of the beam and the corbel on the column. Besides the positive findings obtained from the tests, it was revealed that the observed damage accumulates in the connection region even though the connection is designed to be stronger than the joining members [17].

The composite connection is the most preferred cast in place connection type used in Turkey as basically described above. The composite connections was also examined in the study done by Ertas et al.. It was concluded that the viability of the connection in seismic areas were provided in terms of strength and energy dissipation capacity while ductility of connection was less than that of the monolithic one. It was thought that the low ductility level of the composite connection was caused by the adverse and overturning effect of the welding process on material characteristics [13].

In addition to composite connection, there are several types of cast in place connections. It is known that the connection region could be arranged in different locations in beam-to-column joint even outside of the joint zone. Two different cast in place connection techniques were summarized and tested in the research which was carried on by Ertas et al.. There is not any cast in place topic concrete along the upper side of beams in those wet connection types namely cast in place in column and cast in place in beam. Only concrete casting process is limited in either joint zone in column for "cast in place in column connections" or joining end of the beam for "cast in place in beam connections". The precast concrete beams protruding U shaped reinforcing bars which serves as both positive and negative flexural reinforcement at the connection region considering the anchorage issue are used in the either techniques. There is a gap of which height is precisely equal to beam depth at mid-height of precast concrete column so that precast concrete beam can be easily seated and aligned in the assembling process in the cast in place in column connections. On the other hand in the cast in place in beam connections, there is no gap inside the column and U shaped reinforcing bars protruding from the column like joining beams are placed at the mid-height of the precast columns. Single leg ties are placed into joining zone and steel fiber reinforced concrete is used for filling the empty space in connection region. It is recommended that both precast concrete connections are suitable for high seismic areas in terms of strength properties and energy dissipation [13].

4. EARTHQUAKE DAMAGE IN PRECAST CONCRETE STRUCTURES

Severe and catastrophic earthquakes occurred frequently in Turkey as well as in the world in last decades. 92% of Turkish territory is located in a seismically active region which means that 95% of the total population and 98% of industrial facilities are placed in disaster prone and hazardous regions. Therefore excessive damage was observed in earthquakes occurred in Turkey and such events result in lots of fatalities and breakdown in industrial production [18]. The precast concrete structures exist in Turkey can be classified in three different categories which are panel systems, pin connected frame systems, moment resisting frame systems. The concrete precast structures exposed to Ceyhan Earthquake in 1998 for the first time in Turkey. 1999 Marmara Earthquakes and 2011 Van Earthquake caused to different level of damage on the precast structures as well.

Kocaeli immigrant houses and dormitory building have been built as concrete precast panel system which consists of slab panels and wall panels. There was not any significant damage in these buildings after Marmara Earthquakes in 1999. It was concluded that
the buildings were fully operational and occupied after the earthquakes (Fig. 3).

Fig. 3 Kocaeli immigrant houses.

Majority of the single-story precast industrial buildings are constructed with pin connections at beam-to-column joints. Severely damage was observed in these kinds of buildings in Marmara Earthquakes in 1999 [19, 20]. According to the field studies after the earthquakes, it was concluded that the main reason of the encountered excessive damage was inadequate and improper pin connection production in assembly phases of the prefabricated structural members. Encountered pin connection failures were caused by lack of transverse reinforcement around the pin holes, low strength and poor quality mortar usage for filling the holes and no washer, nut or welding detail consideration at the extruded ends of pins. It should be mentioned that overmuch lateral tip displacements of the columns in such structures due to improper cross-sectional design and lack of lateral rigidity also resulted in overloading and poor behavior at connections. Similar damage pattern was observed in only three pin-connected precast industrial structures which were under construction during the Van Earthquake in 2012. However, the level of damage was minimum in most of the precast industrial buildings. It is considered that the existence of external walls reduce the inter-storey drift, while the metallic roof cover results in a sort of diaphragm action (Fig. 4).

There were several examples of multi-story precast structures which have moment resisting connections subjected to recent earthquakes in Turkey. Dormitory building in Bolu could be given as an example of this kind of precast structures (Fig. 5).

Fig. 4 Undamaged Industrial building in the Van earthquake.

Fig. 5 Dormitory building in Bolu.

Moment resisting connections provided by welding steel plates which already placed at the contact points of the prefabricated beam and column at the bottom of the connection and additional longitudinal reinforcement passing through the connection region placed into cast in place topic concrete at the top of the connection in general. There was not any collapsed precast building which has moment resisting connections in Marmara Earthquakes in 1999. However, slight to moderate damages i.e. cracking in walls, plastification at end of structural members were observed such structures during the site surveys (Fig. 5).

Another way to build a moment resisting connection for precast systems is introducing the post-tensioning technique to the beam-to-column joints with special constructional details. During the site survey in Van Earthquake in 2012, such a multi-story concrete precast building with post-tensioned moment resisting connections examined closely. There were not any damage in precast structural members, the post tensioned connections and post tensioning ducts. In addition, flexural or shear cracks did not occur in column to foundation connections. On the other hand, shear cracks took place on some of the inner and outer walls due to incompatible displacement characteristics of the structural system and the walls (Fig. 6).

Fig. 6 Residential building in Van.

5. CONCLUSION

Prefabrication which is simply assembling of the precast concrete members in site and quick way to construct a concrete structure is a well known construction technology all over the world. The application area of the concrete precast systems got wider in Turkey last decades. Research issues and development are still in progress for the earthquake performance of precast systems. It is obvious that the performance of the connections dedicates the performance of the prefabricated structure since the structural members are produced individually in the factory under quality assurance. Several research projects were done in Turkey on performance and deficiencies of precast connection resulted in detailed and reliable connection design criteria.

Precast concrete systems are generally used for construction of industrial type of structures especially in Turkey. Most of these structures are built as single story with 6-9 meter height and composed non-moment resisting connections which constructed with pin connections which transfer only shear and axial loads among the structural elements. On the other hand, few examples of concrete precast multi-story structures which have moment resisting connections are in service for residential purposes. It is observed that these buildings were achieved quit good performance in the past earthquakes in Turkey. Even though, earthquake resistant and easily applicable moment resisting connection details should be investigate to build fast and reliable residential multi-story buildings in earthquake prone areas in Turkey. In fact these kinds of studies on concrete precast systems are in progress almost all over the world, the comprehensive multi-partner research project of which actors should be government, universities and construction industry must be conducted for development of more reliable moment resisting connection details for earthquake resistant precast structures. It should be a lead to advance of both national and international knowledge about the precast systems but also result in widespread usage of the faster and safer construction method in earthquake prone regions.

REFERENCES

[1] Gül Polat and Atilla Damcı, "Factors affecting the use of precast concrete systems in the Turkish construction sector", *4th Construction Management Congress*, October 2005, Istanbul, Turkey.

[2] Y. Ayaydın, Prefabricated Structural Wall Structures, Yılmaz Offset Printing, 1987, Istanbul, Turkey.

[3] Ersoy, U., Tankut, T., Ozcebe, G., "Seismic Behavior of Precast Concrete Connections", TUBITAK Report No. INTAG-504, 1997, Ankara, Turkey.

[4] Hakan Ataköy, "Prefabricated structural system connection techniques", *Workshop of Prefabricated Structures and Earthquake*, Turkish Precast Concrete Association, 1998, Ankara, Turkey.

[5] Stanton, J. F., Havkins, N. M., Hicks, T. R., "PRESSS Project 1.3: Connections classifications and evaluations" PCI Journal, Vol. 36, No.5, 1991, pp. 62-71.

[6] Sinasi Acar, History of Concrete Prefabrication in Turkey, Turkish Precast Concrete Association, 2006, Ankara, Turkey.

[7] Turkish Precast Concrete Association, Ankara, Turkey.

[8] M. Tuncag, "TS 9967: The scope of the preparation of standard related to prefabricated buildings", Turkey Engineering News, Vol. 371, 1995, pp. 58-59.

[9] H. Ataköy, "17 August Marmara Earthquake and the precast concrete structures built by TPCA Members" Concrete Prefabrication, Vol.52-53, 2000, pp.5-14.

[10] Turkish Earthquake Code (TEC). Regulations on structures constructed in disaster regions. Ministry of Public Works and Settlement, Ankara; 2007.
[11] Ersoy, U. and Tankut, T., "Precast concrete members with welded plate connections under reversed cyclic loading", PCI Journal, Vol.38, No.4, 2003, pp. 94-100.
[12] Korkmaz, H. H. and Tankut, T., "Performance of a precast concrete beam-to-beam connection subject to reversed cyclic loading", Engineering Structures, Vol.27, No.9, 2005, pp. 1392–1407.
[13] Ertaş, O., Özden, Ş., Özturan, T., "Ductile connections in precast concrete moment resisting frames", PCI Journal, Vol.51, No.3, 2006, pp.2-12.
[14] S. Pınarbaşı, "Development and seismic performance of a precast concrete beam-column connection by post-tensioning", M.S. Thesis, METU, 2000.
[15] Kaya, M. and Arslan, A.S. "The effect of the diameter of prestressed strands providing the post-tensioned beam-to-column connections, Materials & Design, Vol.30, No.7, 2009, pp. 2604-2617.
[16] Ozden, S. and Ertas, O. "Behavior of unbonded, post-tensioned, precast concrete connections with different percentages of mild steel reinforcement", PCI Journal, Vol.52, No.2, 2007, pp.32-44.
[17] Ersoy, U. and Tankut, T., "Seismic behavior of a precast beam-column concrete connection used in Turkey", Concrete Prefabrication, Vol.22, 1992, pp. 5-15.
[18] Adalier K. and Aydingun O., "Structural engineering aspects of the June, 1998 Adana–Ceyhan (Turkey) earthquake", Engineering Structures, Vol. 23, 2001, pp. 343–55.
[19] Ozden, S. and Meydanlı, H., "Seismic response of pre-cast industrial buildings during 1999 Kocaeli Earthquake", Skopje Earthquake 40 Years of European Earthquake Engineering, August 2003, Skopje, Macedonia.
[20] Posada, M. and Wood, S.L., "Seismic performance of precast industrial buildings in Turkey",http://www.nd.edu/~linbeck/wood1.pdf.