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Architectural and Structural System Design of Precast Concrete Structures in Earthquake Zones

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Abstract
Precast concrete systems, which are the result of industrialization in the field of construction, are faced with the prejudice of insufficient earthquake resistance despite their many advantages and their use is limited in Turkey. These systems, which have proven earthquake resistance if they are designed properly, can be used safely in low-rise or multi-storey buildings with different functions in earthquake zones. The aim of this study is to determine the architectural design requirements of earthquake-resistant precast concrete structures and to reveal the structural system design approaches. In accordance with this aim, the earthquake effect on the structures was summarized and architectural design principles that would contribute to the earthquake resistance of precast concrete structures were determined firstly. Then, earthquake-resistant structural system design approaches of frame, panel, and cell construction were evaluated separately.

Keywords**:** Design, Earthquake, Earthquake Zone, Precast Concrete Structure, Turkey

1. Introduction

Technological developments and social events that took place during the historical process have also affected the construction industry and paved the way for the production and development of new materials and techniques. After the Second World War, aiming to produce higher quality, faster, and more economical buildings with less labor bring industrialization in building construction and, as a result, prefabrication (Tokgöz & Koçak, 2008). With this development, while precast concrete construction had a high application rate, especially in European countries, it was accepted with prejudice due to earthquake resistance in Turkey and was limited to a share of about 7% in the general construction industry (Ekinci et al., 2007). The adaptation of the first precast concrete construction practices in Turkey from Western Europe, where there is no earthquake risk, formed the basis of these prejudices (Ersoy & Tankut, 1988).

The extent of the damage to the precast concrete structures that were not built with sufficient earthquake resistance was revealed by the 1998 Adana-Ceyhan and then the 1999 Marmara earthquakes. As a result of the researches carried out in Adapazarı after the 1999 Marmara earthquake, it was observed that about 80% of the precast concrete structures were partially or completely damaged (Yılmaz, 2004). These damages occurred again in the 2011 Van earthquake, but as a result of the investigations, it was seen that the structures with the correct design and in accordance with the new earthquake regulations survived the earthquake without damage (Özden et al., 2012).

Recent studies suggest that precast concrete structures can be used safely in high-risk earthquake zones if they are designed consciously (Ersoy & Tankut, 1988). Designing precast concrete structures to be earthquake-resistant is important, in terms of preventing possible destruction and benefitting from the advantages of prefabricated systems resulting in the increased use of safe structures.

The aim of this study is to reveal the general approaches and principles in the architectural and structural design of earthquake-resistant precast concrete structures to be built in earthquake zones.

2. Materials and Methods

It is aimed to improve the opinions that precast concrete structures are insufficient in terms of earthquake resistance, to reveal the methods that can be used safely in earthquake zones, and thus to increase the application rate, which is low in Turkey along with this study. In accordance with these, data were collected within the framework of scientific methods, the obtained data were analyzed, interpreted, and reported.

Previous scientific studies regarding earthquake resistance of precast concrete structures, experiences gained as a result of earthquakes, 2018 Turkey Building Earthquake Regulation, resources and internet resources created by the Precast/Prestressed Concrete Institute (PCI) and Turkish Precast Concrete Association (TPB) are the study materials.

The data obtained through these materials were arranged from general to specific, and the study was shaped around this method. Accordingly, first of all, the earthquake factor and the effect of the earthquake on the structures were researched. Then, the general design approaches of precast concrete structures in earthquake zones were discussed and this subject was evaluated under two headings: architectural and structural system design. The study has been advanced with the clauses and connection details in the Turkey building earthquake regulations and supported with precast concrete building examples that survived the earthquake without damage in Turkey.

3. Effect of Earthquake on Structures

An earthquake is the ground motion that occurs as a result of the sudden release of energy on the fault plane. Various types of waves that release from the earthquake focus with this motion are called seismic waves. Lands under the effect of earthquakes indicate different behaviors depending on their characteristics.

The resistance of the building mass to earthquake movements on the ground causes dynamic earthquake loads to occur in the structures (Toprak, 2002). These loads that affect the building are shaped depending on the variables resulted from the structure, ground and earthquake. These variables can basically be summarized as earthquake energy, the distance between the epicenter and the building, the characteristics of the ground layers where seismic waves propagate, the ground quality on which the building is located, and the structural system of the building (Düzgün, 2002). Of these variables, which can affect the building and cause damage, only those of structural origin is under the control of the designer.

Establishing the structure-ground interaction soundly/properly will reduce the destructive effect of the earthquake on the structures. Resonance, which is one of the most important loads that occur as a result of earthquakes, is a situation that occurs when the ground and structure period are the same and increases the vibration amplitude of the structure. The vibration period that occurs on the ground during an earthquake change according to the type of land and becomes shorter as the land stiffness increases. The design of structures should be carried out in accordance with these features, which can be determined in advance. Low-rise buildings should be preferred on loose lands, as the building periods increase as the floor height increases. Otherwise, special precautions must be taken.

Although an earthquake is one of the biggest loads that can affect the structure during its life cycle, it rarely occurs during the service life of the structure compared to other loads like wind and snow loads. This situation requires consideration of the economic factor in the building design. In this direction, the most suitable design of the building as earthquake-resistant is to provide the optimum point between economy and safety.

While the buildings are designed to be resistant to earthquakes, earthquake loads that may affect the structure should be foreseen, the effects of the earthquake on the structure should be known, the structural system elements should be produced resistant to these effects, and the architectural and structural system should be designed to increase the strength of the building, and details should be produced in this direction

(Düzgün, 2002). The plastic behavior of structures should be formed consciously so that structures do not collapse and no loss of life is experienced (Figure 1).

Figure 1: Example of damage caused by an earthquake (Parsa, 1999)

4. Architectural and Structural System Design of Precast Concrete Buildings in Earthquake Zones

Precast concrete buildings are types of structures in which most of the structural components are produced in factories and assembled on construction sites. Serial production with the help of machines brings the standardization of the elements. In order for the elements that make up the building to be compatible with each other and with the whole system, a basic module has been determined in which dimensional coordination can take place. Architectural and structural system design is shaped depending on this module (Figure 2). Slab and facade panels produced in certain sizes in factories cause modulation to occur mostly within the framework of these dimensions.

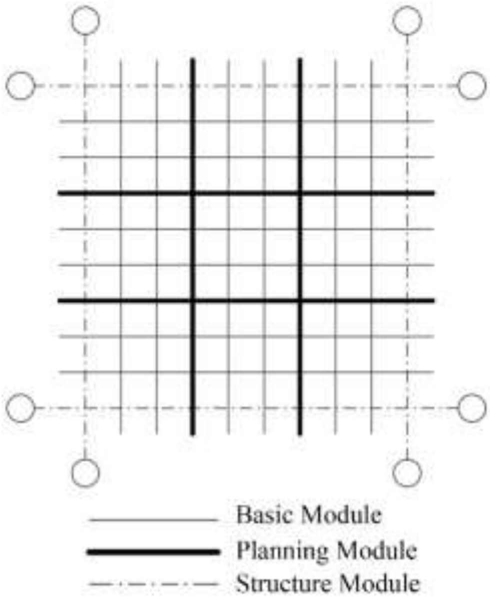


Figure 2: Module types (Gökhan & Baytin, 1979)

Precast concrete structures can be constructed by linear elements such as columns and beams, planar elements such as wall and floor panels, or modular units, which are three-dimensional spatial elements. In this direction, they are basically classified in three different ways: the frame system using linear elements, the panel system using planar elements, and the cell system using three-dimensional units (Figure 3). Buildings with a precast concrete structural system can be constructed with precast elements completely, or they can be used together with cast-in-place elements. Foundations are mostly cast-in-place elements, as they are difficult to carry due to their shape and weight.

a b c

Figure 3: Precast concrete systems (a) Frame system, (b) Panel system, (c) Cell system (URL-1) (URL-2)

In these systems, which are formed by fixing precast concrete elements, an important design element is the structural connections. These connections, which can vary according to the type of elements joined together and the force transmission mechanisms, can be constructed as dry connections using bolts, welding, and similar applications, or as wet connections using concrete. The extreme strain of the connections under the effect of earthquakes reveals that the connections are very effective in earthquake resistance of structures.

Another method that can be used in connections is post-tensioning. Prefabricated elements with channels arranged in them are mounted in place and then tensioned by passing post-tensioning tendons through them. The tendons stretched to the calculated forces are locked, the grout is filled into the pipe and the process is completed (Figure 4) (URL-3). This connection, which can transmit moment, can also be used in earthquake zones.

Figure 4: Post-tensioning steps (URL-3)

In the design of precast concrete buildings in earthquake zones, it is necessary to consider the dynamic loads that will occur due to earthquakes. Accordingly, it is necessary to create the building geometry and architectural design in a way that will increase the earthquake resistance, to choose the structure system to be used in the building consciously, to produce the element dimensions in sufficient sections, and to minimize the detail failure.

In precast concrete structures, architecture and structural system design develop together, as it should be. The production, design, and behavioral characteristics of precast concrete structures, which differ from those of cast-in-situ structures, cause the development of building-specific architectural and structural system design criteria in earthquake-resistant designs.

4.1. Earthquake Resistant Architectural Design of Precast Concrete Structures

Architectural design is a process that tries to meet external factors affecting the building and includes many variables. Although it is desired to respond to all inputs in line with the needs and demands, life safety and seismic performance factors must be considered in earthquake zones. The main criterion to be considered in the architectural design of earthquake-resistant structures is to be avoided the factors that cause irregularity in the horizontal and vertical planes of the building. In this direction, designs with a simpler form, symmetrical plan, and continuous structural elements should be preferred. Since seismic waves can affect the structure from any direction in the horizontal plane, the structure must be resistant to earthquake effects that may come from all directions (Balyemez & Berköz, 2005).

Precast concrete structures are mostly structures with simple forms and regular designs, due to the use of standardized element sizes and designing the modular construction technique. The structural systems, in which the elements are brought together with horizontal and vertical joints, show continuity. For these reasons, they are mostly earthquake-resistant structures in terms of architectural design.

However, the architectural design factors that affect the earthquake behavior of a precast concrete building are not limited to this. Upon generally evaluated, precast concrete structures, similar to other structures, should also meet the following characteristics;

- The fact that the forces on the structures in earthquakes are directly proportional to the weight of the structure, causes the earthquake load of light structures to be less. Therefore, the lightness of the buildings is advantageous in terms of earthquake resistance (Paksoy, 1993).

- The center of gravity and rigidity should be at the same point whenever possible. Factors that prevent this, such as irregular structural element placement and unbalanced element weights, should be avoided.

- In split-plan structures such as L, T, +, X and H, even if the center of rigidity and gravity coincide at the same point, the ratio of the length of the protrusion of the structure to the length of the building should be less than 20% in both directions of the structure plan. Otherwise, the structure should be separated by dilatation (Figure 5) (TBDY, 2018).

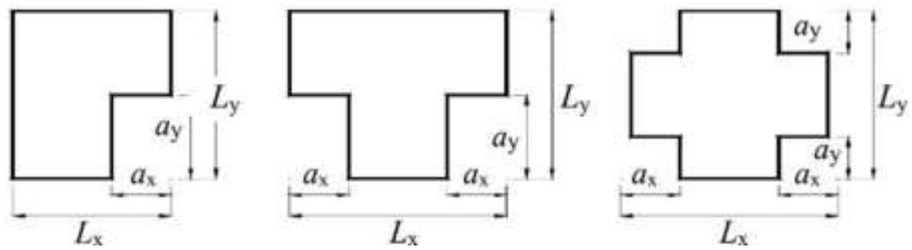


Figure 5: Arrangement of protrusions on the plan (Ax < 0.2 Lx and Ay < 0.2 Ly should be.) (TBDY, 2018)

- The structure should also be regular in the vertical plane, and sudden weight and rigidity changes should be avoided. Different floor heights should not be applied in the same building.

- Slab openings should be prevented from causing torsion. The sum of the openings should be less than one-third of the gross floor area (TBDY, 2018).

In precast concrete structures, unlike cast-in-situ structures, precast slabs used must be arranged in a way that contributes to the earthquake resistance of the structures. In this direction, slab openings should be determined at the project stage and the production of special elements should be carried out in production facilities without losing their strength. The arrangement of slab layouts to meet earthquake loads in two directions and avoiding the use of flooring with different stiffnesses in the same structure are also effective in the seismic performance of buildings.

Another factor to be considered in precast structures is to include the connections in the design in such a way that they are not affected by corrosion and do not lose their bearing capacity.

4.2. Earthquake Resistant Structural System Design of Precast Concrete Structures

Structures in earthquake zones must resist the forces coming from the earthquake and the bearing system must be designed accordingly. However, for a building to be earthquake resistant, it is not enough to resist the loads reached by calculations. The elements and connections of the structure must be of sufficient strength, as well as rigid and ductile behavior sufficiently. The fact that the structure is sufficiently stable in its equilibrium position, that it dissipates sufficient energy, and that moment transmitting harmony among the elements is within the desired limits is also effective in the earthquake-resistant design of the structure (Demirkaya, 2009).

Precast concrete structural elements are of high strength as they are produced with high material quality, and workmanship, and are subject to controls in production facilities. In terms of earthquake safety, the most important factor for precast concrete structures to perform as well as cast-in-situ concrete structures are the joints they have, unlike monolithic structures. The fact that the joints of the precast concrete structure are not as rigid as the cast-in-place structure causes insufficient energy dissipation at these points. In addition, it is more difficult to provide at the joints of precast concrete structures, the ductility provided by the reinforcements connected up to the bond length at the joints of the cast-in-situ structures (Bayülke, 1987).

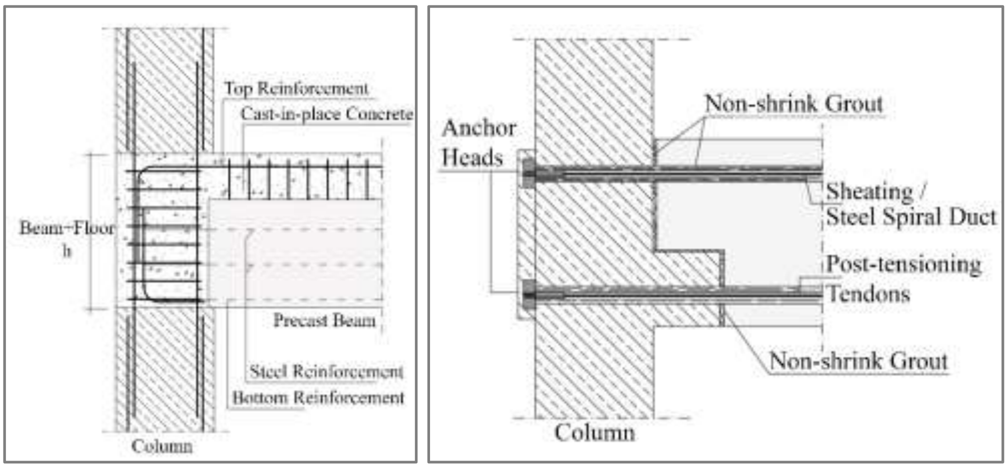
Another effective factor in the design of earthquake-resistant precast concrete buildings is that the slab can fulfill the diaphragm function. Slabs consisting of precast elements must be rigidly connected to the vertical bearers to transfer the horizontal loads resulting from earthquakes. One of these methods is to apply structural coating concrete on the floor panels to which the connections are jointed.

Precast concrete buildings are structures made of linear, planar, and three-dimensional elements and their combinations. The difference between the connection types and force transmission mechanisms between the elements causes the earthquake effects and damage types to occur at these points to be different. For this reason, in the design of earthquake-resistant precast concrete buildings, design approaches shaped according to frame, panel, and cell system structures are needed.

4.2.1. Precast Concrete Frame Structures

Precast concrete frame structures, mostly preferred in single-storey industrial buildings, are the structures consisting of the column, beam, and floor panels produced as prefabricated and their various connections. Earthquake-resistant precast concrete frame structures can be designed in different ways according to the connection details.

The first design method is to construct the column-beam connections to transmit the moment. In these systems, earthquake energy dissipation takes place at the column-beam connections, similar to the hinging that occurred at the ends of beams in cast-in-place structures. Another important issue for the connection points is to provide ductility under the effect of earthquake loads. Accordingly, the connection of elements should be equivalent to cast-in-place (Paksoy, 1993). According to the Earthquake Regulation, these connections can be constructed as wet column-beam connections (Figure 6a), fully post-tensioned connections (Figure 6b), emulative-welded connections (top wet-bottom welded column-beam connection-MAB3) (Figure 6c), and sleeve-pin connections (Figure 6d) (TBDY, 2018).



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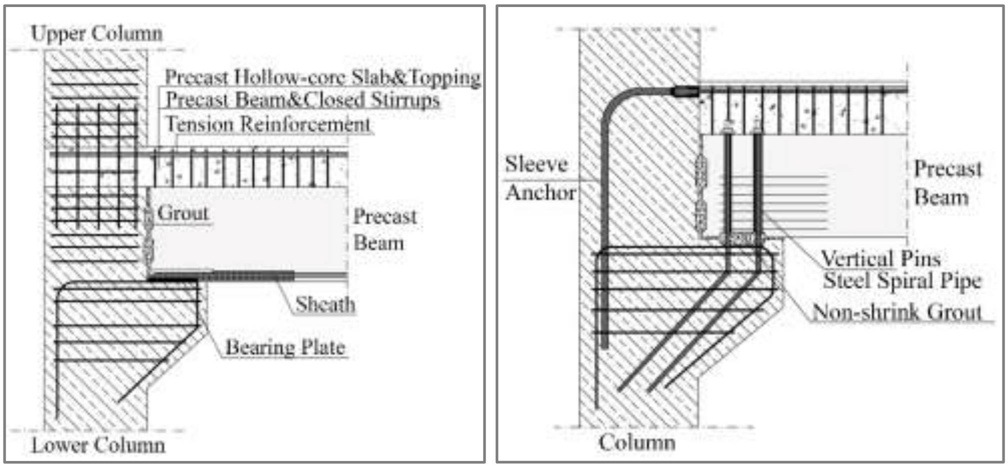

c d

Figure 6: Moment resisting connection sections (a) Wet column-beam connection, (b) Fully post-tensioned connection, (c) Emulative-welded connection and (d) Sleeve-pin connection (TBDY, 2018)

One of the structures constructed by this method is the Aktek Palmiye building built in Van in 2005 (Figure 7a). The building is a seven-storey residential structure constructed with post-tensioned connection details that can transmit moment. The columns of the building, having approximately 380 m² of ground area, were produced in one piece and mounted on the foundations at the construction site (Figure 7b). Thinned prestressed beams were placed on the hidden corber in the columns and the moment transmission was provided by partial post-tensioning (Figure 7c). The structure was subjected to the 7.2 magnitude earthquake that occurred in 2011, and there was no structural damage to the slots and joints where the post-tension cables were located. The earthquake survived with minimal cracks in the non-bearing walls (Özden et al., 2012).

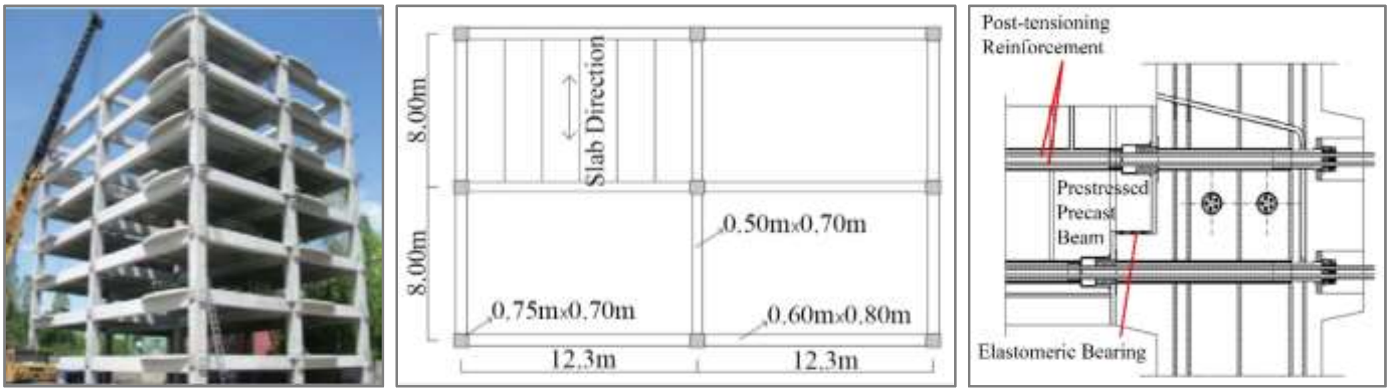

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Figure 7: Aktek Palmiye residence (a), Plan (b) and Column-beam connection detail (c) (Özden et al., 2012) (Bayar, 2018)

Another design method used in earthquake-resistant precast structures is that the column and beam connections are constructed where the moment effects of horizontal loads are minimal. Connections are constructed in the middle of the columns, where the moment is almost zero (Figure 8). Thus, it is sufficient for column-column connections to transmit only the shearing forces. Beam-beam connections, on the other hand, must be able to resist twists caused by earthquake forces. One of the solutions to this issue is the arrangement of beam-beam connections through a long area (Bayülke, 1987).

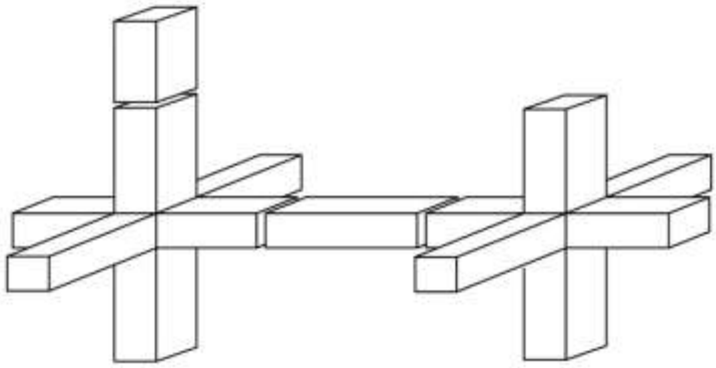

Figure 8: Connection where the moment is minimum (Bayülke, 1987).

The use of hinged systems in seismic zones which were adapted to Turkey from countries without earthquake risk in the past is possible if they are applied within the rules in single-storey structures (Figure 10a) (Ersoy & Tankut, 1988) .The connections of the hinged structures are not as ductile as the monolithic structural system. For this reason, the earthquake forces affecting the structural system built with hinged connections are much higher than the monolithic structures. In addition, there is no auxiliary system that can prevent collapse by bearing these loads when damage occurs to the elements. The construction of beams with hinged connections that cannot transmit moment to the columns causes the collapse to occur in the hinges occurred at the base of the column. Since the hinging occurring at the columns is a dangerous situation, it must be prevented. Accordingly, constructing the columns stronger than the beams is among the methods that can be applied (Geydirici, 2001). According to the Earthquake Regulation, hinged connections can be constructed slotted (Figure 9a), welded (Figure 9b), and pinned (Figure 9c) (TBDY, 2018).

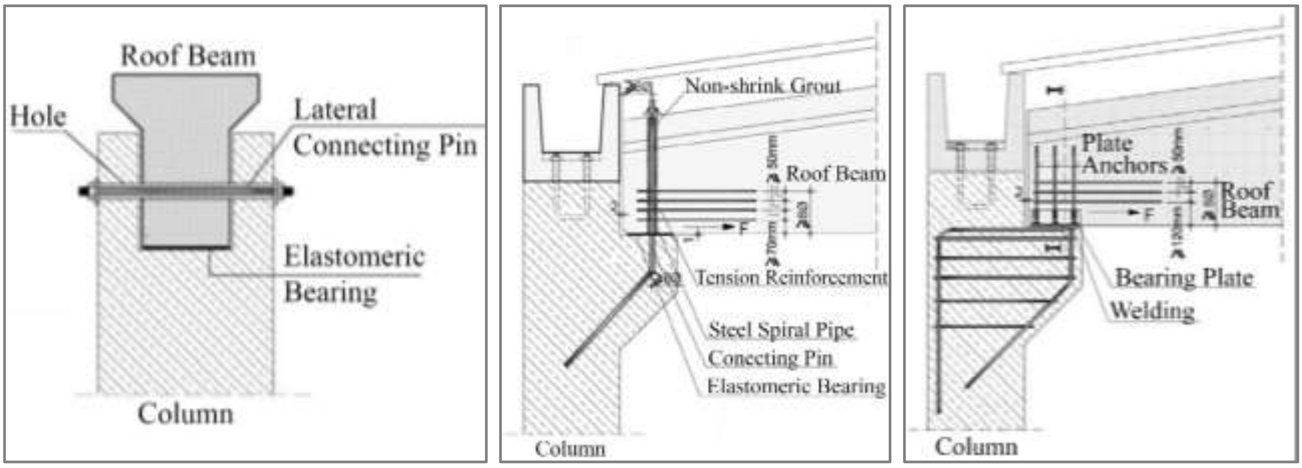

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Figure 9: Hinged connection sections (a) Slotted connection, (b) Welded connection, (c) Pinned connection (TBDY, 2018)

The use of hinged connections in multi-storey structures in seismic zones is possible if they are applied together with reinforced concrete shear walls (Figure 10b) (TBDY, 2018). Thus, in these systems, where the columns bear only vertical loads, horizontal loads are met by shear walls or cell units. The horizontal displacement that occurs in the cast-in-place cells and shear walls, which meets all the horizontal forces, shows its effect, especially on the upper floors. Under this effect, the column beam connections should slide, but the beams and slabs should not fall off the supports (Paksoy, 1993). Accordingly, the length of the support zone should be more than the maximum displacement the system can make during the earthquake.

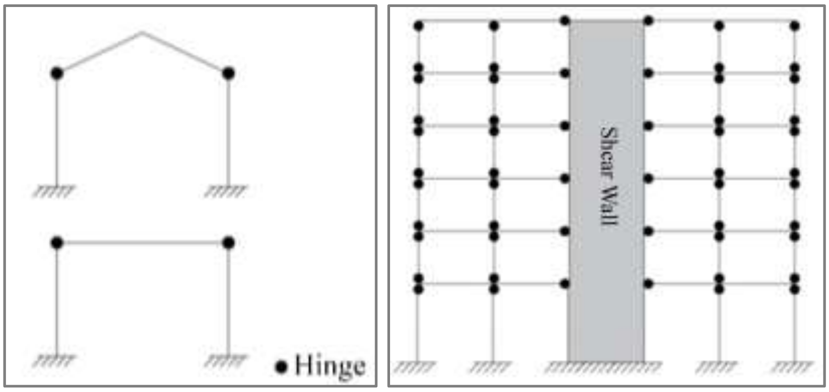

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Figure 10: Hinged connection systems (a) Single-storey, (b) Multi-storey structures (Ersoy & Tankut, 1988)

The two-storey sports hall structure, built in the earthquake zone and exposed to the 7.2 magnitude Van earthquake, is a structure where two-pin details, one of the hinged connection types, are used in the column beam connections. The structure, built on raft foundations, is designed with the cast-in-place concrete shear wall up to +7 elevation and contains only precast concrete columns between +7 and +10 elevation (Figure 11). The large amount of shear wall area used and the constructed rigid diaphragms in the intermediate storey were effective in surviving the earthquake without damage (Özden et al., 2012).

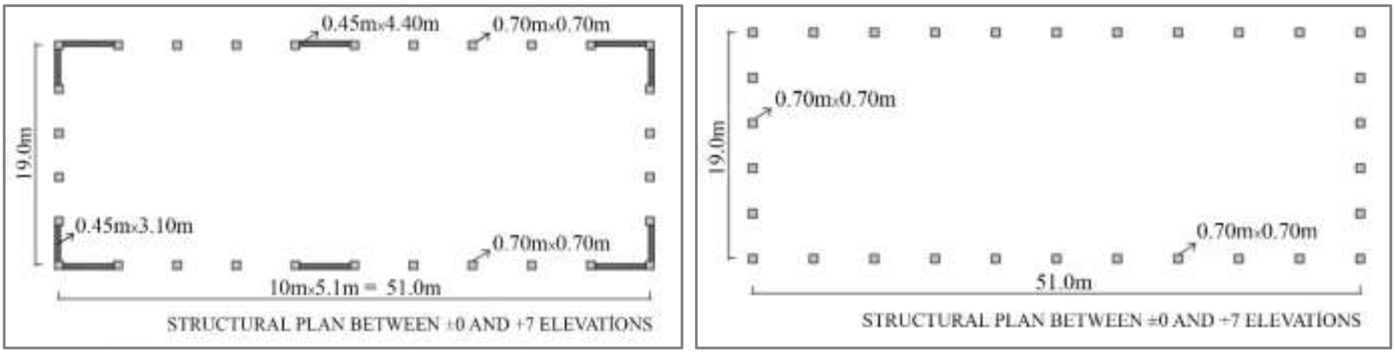

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Figure 11: An example of an undamaged hinged building (Ground floor(a) and first floor(b) structural system plan) (Özden et al., 2012).

4.2.2. Precast Concrete Panel Structures

Precast concrete panel structures are structures constructed by combining vertical load-bearing wall panels and horizontal slab panels. Ductility and energy dissipation capacity, which are the requirements of earthquake-resistant structure design, should also be provided for precast concrete panel structures. However, the fact that the connection points in precast panel structures are not as rigid as the cast-in-place structures makes it difficult to provide these conditions (Tümer, 2006).

A point to be considered in precast concrete panel structures is to prevent the sudden collapse of the structure in case any of the load-bearing wall panels lose their bearing power by disjointing due to the effect of an earthquake. Accordingly, one of the measures to be taken is to ensure that the rest of the structure behaves like a simple or cantilever beam by arranging the beams that serve as horizontal and vertical connections (Başkan, 2009).

Due to the fact that precast concrete panel structure connections show different behaviors according to their bearing power and energy dissipation capacity, there are different design options to provide earthquake safety for the structures (Figure 12) (Paksoy, 1993).

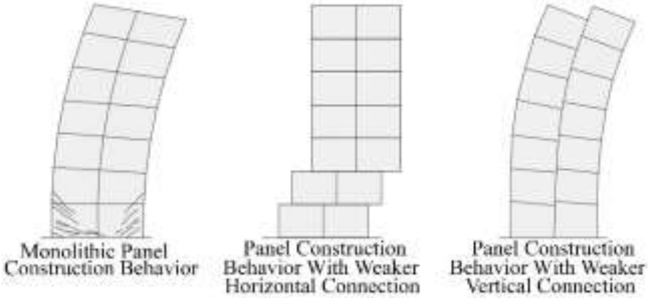

Figure 12: Precast concrete panel construction behavior (Paksoy, 1993)

Providing that precast concrete panel structures show similar behavior to ductile cast-in-place shear wall structures is one of the design approaches that can be preferred in seismic regions. In the method of this design, the connections must carry shearing force and the bases of the wall panels must provide sufficient ductility. Accordingly, being widened or recessed the panel ends yields positive results. In order to provide the monolithic behavior of the structure, it may be preferred to construct the only slabs or some stroyes completely cast-in-place. Another way is to connect all wall panels to the foundation with post-tensioned steel (Bayülke,1986).

In some systems, in order to provide a monolithic structure, it is aimed to construct cast-in-place columns by arranging supplementary reinforcements, and stirrups between the panels. Columns jointed with beams at floor levels provide the construction of the system. This system, constructed with panels whose ends serve as formwork, behaves like cast-in-place shear-wall structures under the effect of earthquakes (Paksoy, 1993).

The Bulgarian migrant lodgings, constructed in a similar way to the monolithic structures in Kocaeli Gölcük in 1990, are the structures constructed with the precast concrete panel system and survived the 1999 Marmara earthquake without damage although many structures were damaged around them (Figure 13). Hollow core slot slabs were used in the 5-storey structure built as a residence and workplace (Nergis, 2003). In order to provide the continuity of the slab panels, the splice is arranged by creating slots. The joints between the wall panels were constructed by passing horizontal joint reinforcements to the inner of the transverse holes in these panels and also by adding beam reinforcements to the joints (Figure 14).

Figure 13: The Bulgarian migrant lodgings, Turkey (Yüksel, 2016)

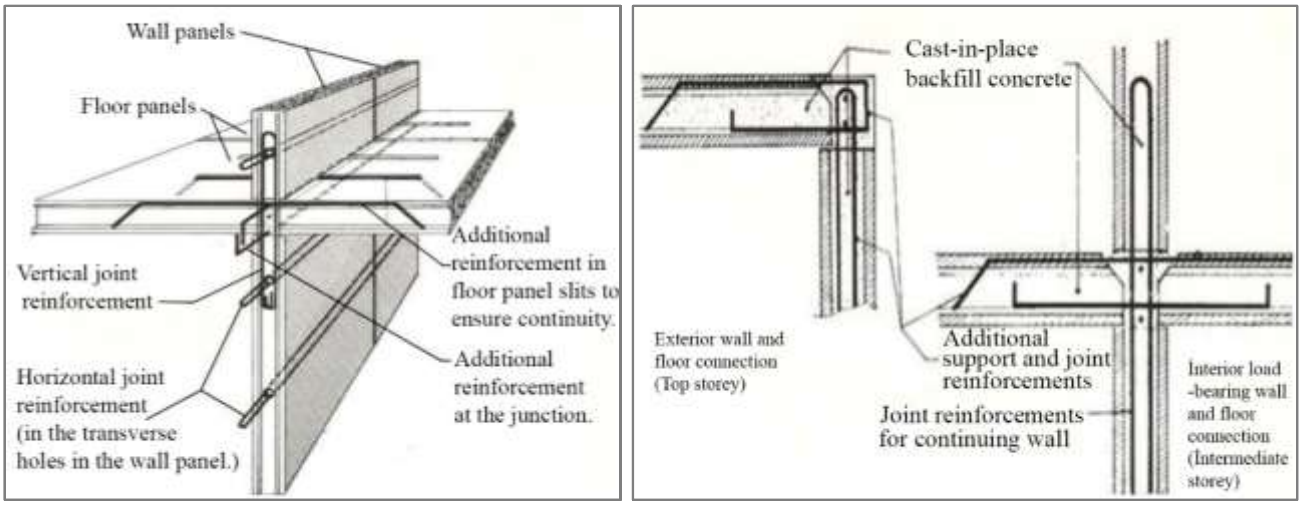

Figure 14: The Bulgarian migrant lodgings panel connection details (Yüksel, 2016)

One of the appropriate ways to design structures earthquake resistant is to design the structure in a way that it can dissipate earthquake energy. In such structures, it is aimed to ensure the economy without risking rigidity. Accordingly, energy dissipation can be realized by providing the hinging of the vertical joints of precast concrete panel structures (Figure 15). However, precast concrete structure connections are not as rigid as cast-in-place structures. Therefore, when the connections cannot dissipate much energy, it may be needed to occur hinging to the panel elements (Tümer, 2006). Accordingly, the slotted panels can be preferred because they will reduce their rigidity, create internal deformations and result in less strain on the joints. Another solution is the use of lintels that extend to the height of the structure. These elements, which mostly do not take vertical loads and act as tie-rod elements between wall panels, dissipate significant energy due to the hinging of their ends.

Studies carried out show that when the vertical joints of the structures are constructed ductile and weak, these buildings can withstand earthquakes. The cracks formed at the beginning of the earthquake with the weak vertical joints provide energy dissipation by creating frictional forces between the overlapping panel rows (Bayülke, 1987).

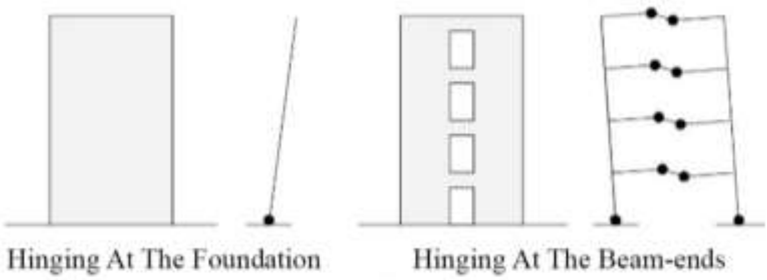

Figure 15: Hinging forms in the panel system structure (Paksoy, 1993)

4.2.3. Precast Concrete Cell Structures

Cell structures are structures formed by jointing the overlapped cell units produced by pouring the slab and wall panels separately or together in factories. These units include horizontal and vertical connections. The overlapped cells should be prevented from being slid and overturned by the effect of earthquakes. Although the frictional force among the elements contributes to the shear strength, it is not sufficient (Bayülke, 1986). Accordingly, the vertical joints of the structure are important in terms of preventing slides. These connections of cell units with the foundation and among themselves can be in bolted, mortared, welded, and similar forms (Figure 16).

Figure 16: Connection types of cell units (Wenke & Dolan, 2021)

Damage to a cell by the effect of lateral forces can cause the cells on it to collapse gradually. Therefore, the loads must be distributed properly, and the cells must also be jointed horizontally to adjacent cells. Thus, if a cell unit is damaged or detached, the structure shows cantilever behavior (Wenke & Dolan, 2021).

Welding the cells from the corners with a flat steel plate or providing their jointing with tension elements is among the applications that can be applied for earthquake resistance. Since the horizontal forces caused by the earthquake cause pressure and tensile force in the tension elements, they must be used in large numbers and have high strength (Bayülke, 1986). The fact that the cell units are formed by the planar panel elements causes the connection details to be similar to panel structures.

Conclusions

An earthquake is a disaster that threatens most parts of the world and causes great loss of life and property. Located in the Mediterranean-Himalayan seismic belt, 96% of the territory of Turkey and 99% of its population face earthquake risks at different levels (Türkoğlu, 2001). This situation also shapes the architectural design of the structures and the construction of the load-bearing system.

Studies carried out show that 95% of the damages in earthquakes resulted from three main reasons in recent years. These are failures related to structure geometry and system preference, detail failures, and construction failures. Precast concrete structures are advantageous systems where the probability of architectural failures due to standardization, detail failures with mass production, and construction failures due to factory production are less likely to occur for these reasons (Ersoy & Tankut, 1988). The factor that creates a disadvantage in precast concrete systems and plays a big role in earthquake resistance is the connections they have, unlike monolithic structures. A precast concrete structure, whose architectural design is made consciously, is earthquake resistant and can be used safely in seismic zones if the load-bearing system selection and details of connections are constructed properly. Thus, the lightness, economy, recycling, high quality, and performance advantages brought by precast concrete systems can be utilized.

Accordingly, the principles of design to be taken into consideration in earthquake-resistant precast concrete structures can be summarized as follows:

- The earthquake-resistant design of the structure should be shaped according to the characteristics of the zone where it is located, and the optimum point between safety and economy should be taken into account.

- It should be preferred that the precast concrete structures built in earthquake zones are regular, formed simply, and planned symmetrically. At the same time, it should be ensured that the center of gravity and rigidity is at the same point as much as possible.

• Precast concrete structures must have sufficient rigidity, ductility, and strength to show earthquake resistance. Connections must be able to dissipate sufficient energy.

• In order for precast floors to show diaphragmatic properties, they must be rigidly jointed and ensure that they show monolithic behavior.

• In precast concrete frame systems, hinged connections should be used in single-storey buildings, and when they are used in multi-storey buildings, they should be supported by cast-in-place shear walls or cells.

• In precast concrete frame structures in earthquake zones, moment transmitted connections should be preferred primarily. Post-tensioned connections are one of the methods applied in this direction and provided that the structure dissipates energy safely.

• The fact that the vertical joints in precast concrete panel structures are designed weaker than the horizontal joints is one of the most suitable solutions that can be preferred in seismic zones.

• It is necessary to join the cell units both horizontally and vertically. Precautions should be taken to ensure that the structures produced by the cell system do not slide and overturn due to the influence of earthquakes.

Conflicts of Interest

The authors declares that there is no conflict of interest regarding the publication of this paper.

Ethics Approval and Consent to Participate

Not applicable

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