Precast/Prestressed Concrete Systems at Seismic Prone Area in Indonesia

S. Wijanto

*PT. Gistama Intisemesta, Jakarta, Indonesia*

**ABSTRACT:** Precast/prestressed concrete construction methods are nowadays becoming more popular in Indonesia in conjunction with the rapid construction development. A large part of the Indonesian region is in a seismic prone area, therefore all building structures should be designed to accommodate gravity and also seismic loading. The design and implementation of the precast/prestressed system requires special attention, where no local official design guidelines exist yet.

This paper provides an overview of the development in the use of precast concrete systems in Indonesia and the application details of the connection system between the precast elements as well as between precast elements with the cast-in-place concrete structures. The connection system must be easily applicable and must not reduce the required detailing which is of primary importance in seismic prone areas.

1 **INTRODUCTION**

Construction in Indonesia started to develop in the 1960 decade. The constructions mostly use the reinforced concrete system, because the materials for concrete work are easily available in almost the whole Indonesian region at relatively low prices as compared with other materials. Although construction work using concrete material requires more workers, the lower labour cost in a developing country serves as an advantage for construction. Concrete also has other advantages such as fireproofing, durability and low maintenance. Construction continued to develop in line with the economic development and population growth. This rapid growth in population, particularly in big cities such as Jakarta and others, has resulted in limited available land and created the need for the construction of multi-storied buildings. In mid-1980 the Government started to encourage the construction of apartment housing of four to eight floors in anticipation of increased housing requirements. The construction of low cost apartment housing continues to be intensified. In 2004 the Indonesian Government through the Directorate General of Housing and Residential Areas proclaimed a “National One Million Houses Movement” to anticipate for the population boom, which will be sold or leased to the low-income sector.

These phenomena resulted in designers and contractors seeking alternative construction methods in order to meet the demand of the competitive construction market. One popular alternative for constructing multi-storied buildings is the use of the precast concrete systems. The precast concrete system itself has been used in Indonesia for more than 40 years. Initially the use of precast concrete elements for the construction of buildings was only limited to precast-slabs or beams in small sizes to facilitate transportation during the erection stage, etc. The use of precast concrete in large members for structural elements of a multi-storied building was carried out for the first time in Jakarta and the construction itself was completed in 1977. Then the development of the precast concrete system in Indonesia experienced a drawback due to the quite significant difference in initial construction cost of the cast-in-place system and precast concrete systems. However, in 1995 several precast concrete suppliers, in conjunction with some universities and government laboratories, conducted several research investigations of precast concrete systems suitable for the seismic conditions in Indonesia. This development resulted in a variety of precast concrete systems which were later patented locally in Indonesia. Recently the Directorate General of Housing and
Residential Areas has adopted the precast concrete system as the standard for constructing low cost apartment blocks in Indonesia.

Several obstacles still found in the use of the precast/prestressed concrete system in Indonesia are, among other things: the system is still relatively new and its popularity has not yet reached all regions in Indonesia, there is an absence of an official precast concrete regulation, low crane capacity often used in construction works, width of road for transporting the precast elements and also permission from the traffic police for road use particularly during busy hours. Although several constraints as mentioned previously exist, the development of construction to meet the government’s project requirement, which is of a mass and typical character, and the private projects which have developed lately, the use of precast concrete for construction has started to reach a quite significant market sector. Several precast/prestressed concrete systems and project examples are discussed in the following paragraphs.

2 REINFORCED CONCRETE MATERIALS

For a long time concrete has been used for construction in Indonesia and has developed quite significantly like in other countries. The local regulations of Structural Concrete Design Guidelines for Buildings SNI 03-2847-2002 used currently have been adopted from ACI-318 1999. Various concrete grades are used in building construction, and based on code requirements the minimum concrete grade for structural elements is 20 MPa, while the maximum grade normally used in building constructions is 45 MPa. Concrete of higher grade than 45 MPa is still possible if the work is carried out under strict supervision and the location of the concrete batching plant is within the project’s area such as the precast concrete factory plant.

Two types of reinforcing bars grade, 240 MPa and 400 MPa, are commonly used. Recently grade 500 MPa began production locally. The production system of local reinforcing bars is generally by the quench and tempered system. Strand with a strength of 1860 MPa is used for prestressed concrete components.

3 SEISMIC DESIGNS FOR PRECAST CONCRETE IN BUILDINGS

In broad outline the structural calculation of a multi storey building design with the precast concrete system does not vary much from the design of an ordinary building which is cast-in-place. There are several additional loading considerations in designing the precast concrete components themselves, such as: the manufacturing process in the factory, transportation method, condition during transportation, stacking on site and during initial installation whereby the composite character with the cast-in-place concrete is not effective yet.

In the year 2002, Indonesia released a new seismic code (SNI 03-1726-2002), which has adapted the UBC-97 and is generally still focused on Force Based Design Concepts. Most seismic analysis uses the Modal Equivalent Static method. The design base shear force for the equivalent static method is obtained from multiplication of the appropriate spectra of seismic coefficient (= C) based on seismic zone area from 1 to 6 with 500 years return period and soil conditions, response modification factors (R = 1.6 to 8.5), Importance factor of the structures (= I) and the total seismic structure weight (= W_t) :

\[ V = \frac{C \times I}{R} W_t \]  

(1)

Distribution of the lateral seismic forces is carried out as follows:
\[ F_i = \frac{W_i z_i}{\sum_{i=1}^{n} W_i z_i} V \]  

(2)

Where \( W_i \) is the floor weight of storey \( i \), \( z_i \) is the height of storey \( i \) measured from the base of the structure, while \( n \) is the number of storeys.

There is a limitation on fundamental period of the building, which shall not exceed a value as follows:

\[ T_1 < \zeta n \]  

(3)

<table>
<thead>
<tr>
<th>Seismic Zone</th>
<th>( \zeta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.20</td>
</tr>
<tr>
<td>2</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.18</td>
</tr>
<tr>
<td>4</td>
<td>0.17</td>
</tr>
<tr>
<td>5</td>
<td>0.16</td>
</tr>
<tr>
<td>6</td>
<td>0.15</td>
</tr>
</tbody>
</table>

A modal dynamic analysis shall be used to determine base shear force and factored up to correspond to the equivalent static base shear multiplied by 0.8. This is to modify the shape of lateral force vector.

Mostly building analyses are carried out using a 3-D model with the assistance of the ETABS program. Modeling of the structural system in the computer analysis must be as close to the reality of a building construction on site as possible. In seismically active areas the structural designer needs to clearly determine the flow of loads on the construction structural elements in vertical and horizontal direction. There are 3 generally used basic structural systems for designing multi-storied buildings, i.e.: open moment resisting frame, structural shear wall and a combination of moment resisting frame and structural shear wall (wall-frame). Experience from several earthquakes which have occurred, moment resisting frame structures will suffer significant damage, which is among other things caused by the vast lateral movement as well as the rotation at the joints of its structural elements. The vast lateral movement will cause damage to structural and non-structural elements such as partition walls, perimeter walls, ceiling, mechanical, electrical, and other facilities. To reduce the vast lateral movement in multi-storied buildings when experiencing a seismic load, a structural combination is used of a moment resisting frame and shear wall. This combination will be very advantageous in limiting the extent of the building’s lateral movement. The existence of a shear wall in a configuration will stiffen the structure’s lateral stiffness. Although the shear wall will experience cracking during a repetitious seismic load, because of its high stiffness, the reduction of stiffness as a result of the concrete wall’s cracking will not greatly affect the overall stiffness of the structure. From various earthquake disasters, structures with a combination of shear wall and moment resisting frame have proven their resistance without experiencing significant damage. In Indonesia, open frame systems are generally used for low rise buildings, while the wall-frame systems are used for medium to high-rise buildings.

Skepticism is still encountered with regard to designing precast concrete floors which are to function as a horizontal diaphragm. Some publications explain the necessity for topping to allow
the horizontal diaphragm to distribute the lateral seismic load to the vertical diaphragm, with a minimum thickness of 60 - 65 mm with single reinforcement (CAE-1999). This concrete layer, in addition to joining every precast concrete component as a rigid slab, is also capable of reducing deflection, controlling vibration and increasing the slab capacity in receiving gravity load (CAE-1999). Several latitudes can be tolerated towards hollow-core-slab without topping if it can be proven that the structural frame still behaves elastically under lateral seismic load. However, this is currently not carried out in designs. Taking the above mentioned into consideration, it is considered necessary to apply concrete topping on top of precast half–slabs or hollow-core-slabs and also that they meet the requirements of the local regulations of reinforced concrete design (SNI 03-2847-2002, chapter 23.7.)

4  JOINT SYSTEM BETWEEN PRECAST CONCRETE COMPONENTS

Joints become the main subject of attention when designing precast concrete systems, especially for constructions in seismic prone areas. The joints, which function to transfer loads, must also be capable of joining each precast concrete component into a continuous monolith. Several criteria which must also be fulfilled with regard to the design and in the choice of joint type between the precast concrete components, comprise among others (PCI-2004) : strength, ductility, volume change accommodation, durability, fire resistance and easy to be constructed without disregarding quality. The strength of a precast concrete joint must at least equal that of a cast-in-place concrete joint. If the precast concrete components use bonded prestressed strand (usually the pre-tension system) then these will produce dimensions that are relatively more slender, therefore requiring a more detailed consideration of deflection and effects from vibrations on these elements.

There are two types of joints known in local Indonesian precast concrete systems, which are the dry and wet connection. The dry connection makes use of an ancillary steel plate as connector between the precast concrete components and the connection between the respective steel plates is made with a bolt or by welding. The welding system on site requires expertise of the welder as well as strict supervision to guarantee good quality welding results. The wet connection is used to emulate cast-in-place detailing. Splices used to emulate cast-in-place detailing will normally be in the form of lapped bars, mechanical splices and welded splices. Splices should be in accordance with the latest Indonesian concrete regulations (SNI 03-2847-2002 chapter 14 and also chapter 23). Concrete pouring on the joint parts is carried out on the spot using concrete quality which need not be of equal concrete grade to the precast concrete components. It is natural to select the inflection points as points to break monolithic systems apart and to reconnect as an emulative precast system. Various locations of possible framed connections are shown in figure 1.

![Figure 1 : Samples of alternative precast frame elements](image-url)
It is recommended to provide additional reinforcing bars, which will be field-bent, with regard to joints between precast concrete half slabs as well as joints with beams. The reinforcement is called “fail safe connection” (Wijanto, S & Yee, A.A. 2002), and can add shear capacity in the joint areas as well as overcome the problem of bearing requirement of the precast concrete components themselves. Connections made by welding reinforcing bars must be carried out with extreme care and the design engineer must be fully cognizant of the fact that the steel grade produced in Indonesia is allowed to be welded without reducing its quality. Emulating cast-in-place detailing which is familiar and used in precast concrete systems can be viewed in figure 2 to 8.

5 APPLICATION OF PRECAST/PRESTRESSED CONCRETE SYSTEMS IN BUILDINGS

The use of precast concrete in large members for structural elements of multi-storey buildings was carried out for the first time in Jakarta in 1974 and completed in August 1977 (see figure 9). The building was designed by Alfred A. Yee and Associates, and built by a foreign contractor in conjunction with a local contractor. The main office tower is a 15-storey building with a 5-storey parking structure. The advantage of using the precast/prestressed concrete system at that time had an impact only on acceleration of the construction period, anticipation of construction difficulties at the perimeter columns and maintaining the same beam height by using precast/prestressed concrete beams. The building is currently still in good condition although it has experienced several quakes at MMI-scale range between IV-V.

The high initial construction costs when using the precast/prestressed concrete system compared with the conventional system has been the reason for its rather slow development. With the occurrence of the economic crisis in Indonesia in 1997, when steel prices were soaring because its material still had to be imported, precast concrete became the main alternative system. Several precast concrete element types used at the construction site are as follows:

1. horizontal components: precast half-slab/solid plank, hollow-core slab with and without topping, precast concrete beams, double-T, waffle-crete, etc.
2. vertical components: precast concrete walls, precast concrete columns and multi level precast concrete columns

In addition to a quick construction period, the use of the precast concrete system for high-rise buildings has other advantages such as a neat construction site, better guaranteed material quality, and lighter weight of the building when using the precast/prestressed system as compared with the cast-in-place system. With the reduced weight of the building, the design base shear of the building will also be reduced.

Several projects using the precast/prestressed concrete systems in which the author was involved as a structural designer of buildings, are as follows:

- The biggest mosque in Indonesia, “Al-Akbar” was constructed in Surabaya with a visitor capacity of 30,000 members (see figure 10-a and 10-b). The initial design, whereby a cantilever at a height of around 13 meters from the ground surface utilized cast-in-place concrete, was altered to the precast concrete system which accelerated the construction period, reduced the application of formwork and provided a smooth curved parapet finish. The above application of the precast concrete system resulted in a significant increase in structural costs but it was capable of significantly accelerating the construction period with good results.

- Multipurpose building: A two-storey mosque and three-storey locker room, with motorcycle parking area in North Jakarta, were completed by the end of 2001. The original design was a conventional concrete structure. Due to limited construction time, the contractor proposed 65 mm precast prestressed half slab with 65 mm topping and precast joist beam to replace the existing concept (see figure 11). On this project, apart from gaining profit from the viewpoint of time saving, the contractor appeared to have also gained a cost saving of around 5% from the viewpoint of using concrete material and the formwork as well.
- Shopping centre at Balikpapan (see figure 12) was initially designed and offered for tender in the form of a cast-in-place concrete design. The contractor who won the tender proposed to change to the equivalent monolithic concept in order to accelerate construction period and obviously to be more profitable for the contractor. Precast concrete elements comprised precast concrete solid planks with 55 mm topping, secondary precast beams and main precast concrete beams.

- In mid 2003, a consortium of contractors, suppliers and the author introduced the Precast Concrete Panel system for low-rise buildings and also made it possible for middle rise buildings as can be seen in figure 13. This system emphasized the use of the totally precast concrete system such as precast concrete wall panels with a thickness of 130 mm, 65 mm precast half slab with 65 mm topping for the floor slab, precast column, beam and staircase. The joint system between the precast concrete elements meets the requirements for earthquake and fire resistant construction. The precast concrete panel will already be in good and smooth condition which therefore will not require additional plastering. In addition the shaped space module will be free of beams and more efficient. The laboratory test result of a full-scale two-storey building, conducted in a government laboratory, was very satisfactory. At the end of 2003 the system was applied for the construction of a penitentiary on the Batam Island region and proved very suitable for replacing the previous, existing construction standard system. The partition walls between the cells, which were initially designed with infill brick walls, were replaced by 150 mm precast concrete panels which are naturally stronger and not easily penetrated.

- Two newly completed factory projects at the end of 2005, first the New Factory Plant PT Astra Honda Motor (see figure 10) and Extension Pakoakuina Factory (see figure 14), have used the equivalent monolithic concepts. For the first project, Astra Honda Motor, precast beams and hollow core slabs (200 mm – 250 mm slab thickness) with 70 mm topping were used at the ground floor of the factory building, while the perimeter and inner columns of sufficient height at 16 m were divided into two parts with corrugated metal duct connections at the bottom part of the column. A steel truss structure was used for the roof structure with a span of 40 – 50 m. For the two storey office building precast concrete beams were used along with hollow core slabs with 55 mm topping as well as two storey height precast concrete columns with block opening at the second floor and corrugated metal duct connections on the columns’ lower part. High strength non-shrink grout was used to fill the corrugated metal ducts. Secondly, the Extension Pakoakuina factory building consists of a one storey building and is constructed with precast concrete columns and precast concrete gutter beams connecting the tops of the columns. Corrugated metal duct connections have been used at the bottom part of the columns using high strength non-shrink grout. The light roof structure with a span of 24 m uses single steel beams.

- The Cimahi City Council building consists of 3 interconnecting buildings (see figure 15). Totally precast concrete systems used in this project comprise precast/prestressed concrete tie-beams, precast/prestressed concrete beams, 65 mm solid precast/prestressed planks with 65 mm topping and single layer reinforcement, precast concrete columns with “NMB” mechanical splices at the bottom part, precast concrete staircase and also precast concrete parapets. The building is square, sufficiently symmetrical and the design was based on seismic zone 4 (SNI 03-1726-2002). To anticipate for seismic lateral load the wall-frame system was used. The location of the fire staircase on the two edges of the building plan was used to place the cast-in-place concrete shear wall. The building was completed in accordance with the schedule and fully operational by the end of 2005.

A review of the various projects that applied the precast/prestressed concrete system in Indonesia, has shown that other benefits can be gained such as concrete and steel material savings, cost savings, using less labour force, thereby resulting in a higher quality building as compared with the cast-in-place concrete structure system. Finally, social benefits and the preservation of the earth’s natural resources and ecosystem can be effected by proper implementation of the precast concrete technology (Wijanto, S & Yee, A.A. 2002).
6 CONCLUSIONS

The precast/prestressed concrete systems in Indonesia will continue to develop and still constitutes an attractive alternative construction method compared to the cast-in-place system. In addition to a quick construction period, the use of the precast concrete system for high-rise buildings has other advantages such as a neat construction site, better guaranteed material quality, reduced weight of the building when using the precast/prestressed system as compared with the pour on site system. With the reduced weight of the building, the design of the shear load of the building’s base will also be reduced.

The latest Indonesian seismic regulations SNI 03-1726-2002 and also the regulations on reinforced concrete design SNI 03-2847-2002, both of which have adapted the UBC-97 and ACI-318 1999 regulations, will easily facilitate the local engineer to follow the basic concepts of precast concrete design from USA such as PCI Hand Book (PCI-2004).

From the author’s experience in various Indonesian projects, the equivalent monolithic systems at precast/prestressed concrete constitute the best alternative precast concrete concept and easily carried out by local workers. This system also has been proven and extensively used in some countries with a high seismic risk.

REFERENCES:

ACI Committee 318. 2005, Building Code Requirements for Structural Concrete and Commentary, *American Concrete Institute*, Farmington Hills, MI, 430 p
CAE. 1999, Guidelines for The Use of Structural Precast Concrete in Buildings, *Report of a Study Group of the NZCS and NZSEE*, Centre for Advanced Engineering, University of Canterbury, New Zealand, 144 p
Figure 2: Typical connection of precast/prestressed concrete slabs and precast concrete beam

Figure 3: Connection of precast/prestressed concrete beam and cast-in-place column (CAE 1999)

Figure 4: Connection at pc-beams and pc-columns with a cast-in-place closure

Figure 5: pc-column to pc-column connection through conduits installed in an pc-beam

Figure 6: Typical types of mechanical splice or corrugated metal duct using high strength non-shrink grout

Figure 7: Floor slab-to-wall detail where diagonal dowels cross the wall joint into the opposite floor (ACI 550.1R-01. 2001)

Figure 8: End detail of a monolithic connection between precast concrete floor element and a pc-wall (ACI 550.1R-01. 2001)
Figure 9 : Hong Kong & Shanghai Bank

Figure 10-a : “Al-Akbar” mosque

Figure 10-b : PC-cantilever beams at “Al-Akbar” mosque

Figure 11 : Multipurpose building

Figure 12 : “Rapak” Mall at Balikpapan

Figure 13 : Prison at Batam Island