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STATE OF THE ART : RESEARCH AND APPLICATION OF PRECAST / PRESTRESSED CONCRETE SYSTEMS IN INDONESIA

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ABSTRACT :

Recently more extensive use of precast/prestressed concrete components, which are fabricated off-site and then connected on-site, has been taking place in Indonesia. This technology becomes more popular in Indonesia since it shows significant benefits compared to the conventional poured on site concrete technology. Among others, the benefits are in accelerating the construction time, enhancing the quality of concrete works, improving its durability and in general generating competitive structural cost.

In view of the fact that Indonesia is located in a region with high-seismic risks, implementing the Precast/Prestressed Concrete System in this country requires special connection detailing in order to guarantee its full continuity and monolithic action. Various research works, therefore have been focused in developing the most suitable joint-systems, which meet the criteria of safety, economy and workability to meet the capability of local workers.

The most recent development of research works of these equivalent monolithic systems and their applications in some building projects are discussed in this paper.

KEYWORDS: precast/prestressed concrete, equivalent monolithic, cost efficiency, high-seismic risks

1. INTRODUCTION

The capabilities of both state and private sectors to supply good quality low-cost housing units in Indonesia have always been a vital issue. As a country with 220 million inhabitants, the needs of providing low-cost residential units are enormous. Around mid-1980s the Indonesian government started to seriously promote the construction of low-cost multi-storey residential buildings, especially in the big cities. However, not until 2004, i.e. when the State Ministry for People's Housing Affairs launched a national movement to construct *one million* low-cost residential units, precast concrete has been known widely as an appealing alternative building construction material. Since then precast concrete has been used intensively. In 2007 the new Indonesian government endorsed its ambitious program to build *thousand towers* to meet the increasing demand of high quality low-cost housing in several major cities. The Indonesian Association of Precast and Prestressed Engineers (IAPPI – *www.iappi-indonesia.org*) has been invited to play an active role to ensure that this program can certainly become a reality.

Meanwhile non-residential building construction projects in Indonesia are also growing rapidly. Cast-in place concrete has so far been predominantly used since its basic materials are readily available anywhere around the country. In a developing country, such as Indonesia, construction works using cast-in place concrete seem to also have an advantage since they are labour intensive. However, this may not always be appropriate in meeting the rising competitiveness of global construction market. Again the precast concrete systems may be able to offer attractive alternative solutions for architects and structural engineers to meet these more demanding building criteria, especially in terms of total cost efficiency, construction speed, high quality of works, reduced weight of the upper structure, and more environmental friendly projects.

Recently there are various types of precast/prestressed concrete elements, which are able to be found in many construction projects in Indonesia, ranging from concrete piles, slabs (hollow-core, waffle-slab or precast/prestressed planks), double-T, rectangular beams and U-shaped beams, columns, wall panels, staircase units, to architectural façades. Since Indonesia is located in an earthquake prone region, some structural designers are still reluctant to use them, especially due to their lack of confidence in the seismic behaviour of connections between these individual precast concrete components. This paper describes the state of the art of research and applications of precast/presetressed concrete systems in Indonesia.

2. SEVERAL RECENT RESEARCH WORKS

Since 1995 a number of research works have been carried out by state and private bodies to study the seismic behaviour of various precast concrete systems, which were later patented locally in Indonesia. At this moment, IAPPI already accepted 27 precast-concrete systems that can be used by the Indonesian construction industry. Most of the experiments were conducted at a state-owned laboratory in Bandung. The laboratory has the capability to accommodate quasi static tests with full scale models. It is equipped with one metre thick strong floor and 1.5 metre thick reaction wall. Precast/prestressed concrete specimens with a minimum age of 28 days were normally tested using a displacement based controlled system until they were totally fail. Hysteretic curves obtained from the test results were analysed based on ACI T1.1R-01 (2001). The acceptance criteria of the test specimen should comply with the requirements of strength, energy dissipation ratio and stiffness. Conventional push-over analyses were then conducted to reconfirm the test results. Recommendations regarding the displacement ductility factors and the response modification factors (=R) were given as a reference for carrying out seismic analyses in the future. Below can be seen some research works which were conducted by private companies involving the author:

2.1 Precast Concrete Wall Panel with Precast/Prestressed Half Slab

In mid of 2003, a cyclic quasi static test was conducted to study the seismic performance of precast concrete wall panel with precast/prestressed half slab plus topping. Two storey full scale model was tested to represent up to four storey low-cost housings. The joint system of NMB-splice sleeve was used for connecting vertical elements while a dry joint system was used for connecting horizontal components of the precast wall panel. These dry joint connections were then covered with grouting material for fire resistant. The specimen model and its hysteretic response are shown in Figure 1.

2.2 Beam Column Joint (exterior & interior)

In 2006, the seismic behaviour of three beam column joint specimens from an eight storey building model were examined using a cyclic quasi static tests. The first specimen is a cast-in-place interior joint, second is a precast/prestressed interior joint and the third one is a precast/prestressed exterior joint. The common mild steel arrangement for cast-in-place (see also Figure 11) was used in the precast/prestressed-beam column joint area. A metal corrugated joint system with high strength grout was also used to connect the bottom column part and the upper precast columns. The second interior beam column (second) specimen and its hysteretic response are shown in Figure 2.

2.3 Cast on Site Concrete Wall with Hollow Core Slab Plus Topping

At the end of 2007, PRECON SW-20 was tested and it represented an alternative for 20 storey low cost housing in Indonesia. It consisted of cast-in-place concrete shear-walls with single layer rebar in the middle part and two layers at the boundary element areas. Special steel formwork was used to accelerate the construction speed and to have better surface result on both faces of the wall. Hollow core slab (HCS-125) with 60 mm topping was used and an additional fail-safe connection was applied between the HCS-125 and the concrete shear wall. The PRECON SW-20 specimen and hysteretic response are shown in Figure 3.

Recommendation factor for displacement ductility and response modification factors (=R) for all specimen are presented in Table 2.1.

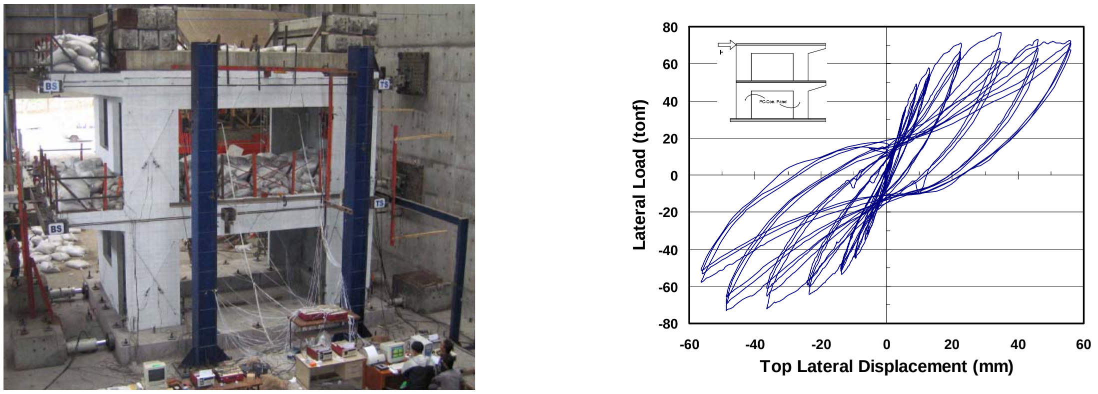


Figure 1 PC-wall panel with precast/prestressed half slab full-scale model and hysteresis diagram

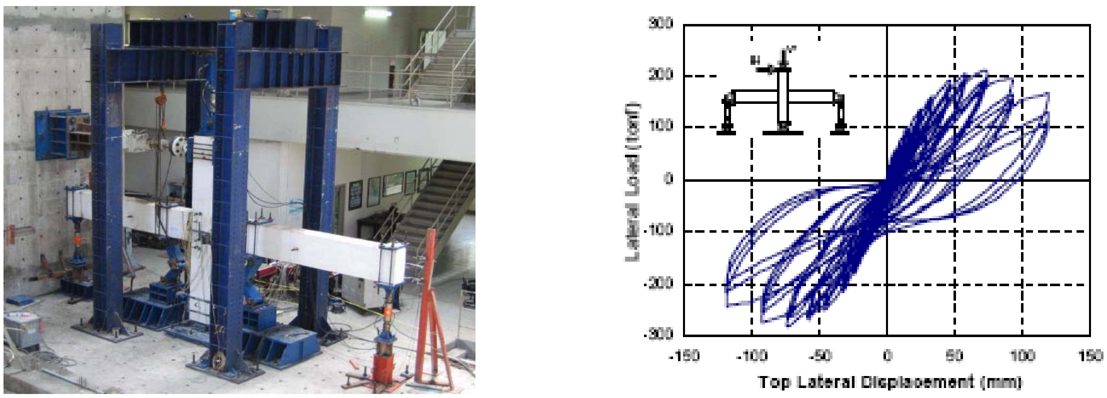


Figure 2 Interior PC-beam column joint full-scale model and hysteresis diagram

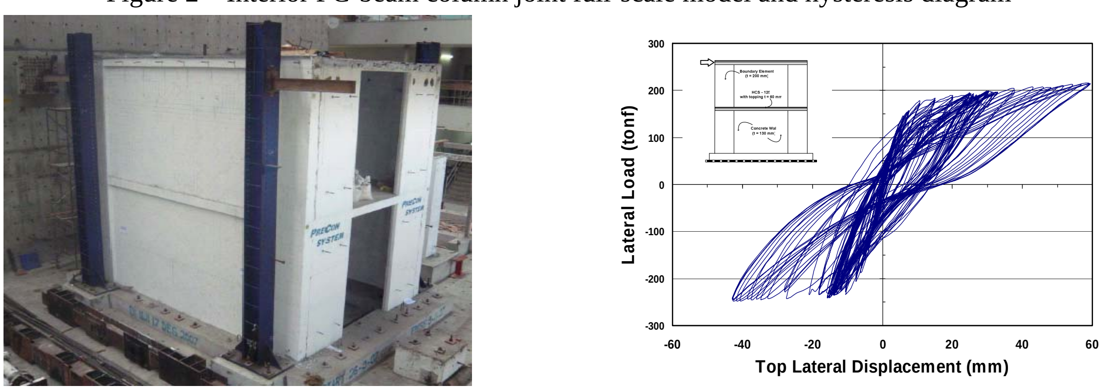


Figure 3 Concrete wall panel with hollow-core slab full-scale model and hysteresis diagram

Table 2.1 Recommendation factor for seismic design analysis

No.	Precast/Prestressed Systems	Value
1	PC-Wall Panel with Precast/Prestressed Half Slab:	
	- Ductility factor	4.90
	- R value	6.20
2	Emulating cast-in-place beam column joint:	
	- Ductility factor	2.96
	- R value	4.80
3	PRECON SW-20:	
	- Ductility factor	4.00
	- R value	6.40

3. APPLICATION OF PRECAST/PRESTRESSED CONCRETE IN INDONESIA

3.1. Major Precast Concrete Projects in Indonesia

The application of precast/prestressed concrete in Indonesia was reported below in three sections. Each section describes different types of precast/prestressed concrete application. Since connections between the precast/prestressed concrete components are very vital in order to ensure the structural robustness and recommended connection systems are also discussed in this chapter.

3.1.1 Low-Cost Residential Buildings: The Rusunawa/Rusunami Project.

To meet the increasing demand of low-cost residential units, the Indonesian government since 2007 has endorsed the implementation of the *thousand tower* program. As part of this program, a five storey precast concrete twin block with 2,100 sqm ground floor area was built at South Kelayan, Banjarmasin, South Kalimantan as low-cost leased flats as shown in Figure 4. Another six storey twin block similar to that is currently under construction. The building is located at Marunda, Jakarta as shown in Figure 5. Both projects were designed as precast concrete open frames with cast-in-place core-wall at emergency staircases. This precast system emphasizes the use of 65 mm precast concrete half slab with 60 mm topping for the floor slabs, precast concrete column, beam and staircase. After the completion of these low-rise/low-cost residential buildings, a series of twenty floor low-cost apartments are planned to be built in several major cities.

Figure 4 South Kelayan low-cost residential building

Figure 5 Marunda low-cost residential building

3.1.2 Several Major Industrial Buildings

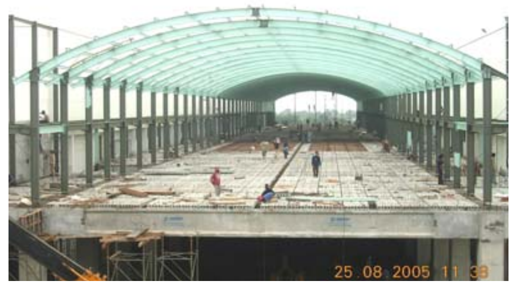
Since 2005, several major industrial buildings were designed and constructed using precast/prestressed concrete system instead of conventional steel structures. The first one is the new plant of PT Astra Honda Motor located at a 20 hectare-site inside the Industrial Complex MM-2100 at Cibitung. The total floor area of this new plant is 110,000 m^2 (equivalent to 11 hectares). The project consists of four main production buildings and some other supporting facilities, such as: two storey office building, large dining room to accommodate 1800 workers, mosque, power house, warehouse, water treatment plant, etc. Figures 6 show the bird-eye view of the plant and the construction site, respectively.

Using the equivalent monolithic concept, precast concrete beams with hollow core slabs (200 – 250 mm slab thickness) and 70 mm topping were used to form elevated ground floors for all buildings. Precast concrete columns of 16 m high were installed for the main factory buildings. Each column consists of two parts with corrugated metal duct connections at its bottom part. High strength non-shrink grout was then used to fill these corrugated metal ducts. Steel truss was used for the roof structure with a span of 40 – 50 m. For the two storey office buildings precast concrete beams were used with hollow core slabs and 55 mm topping. The columns consist of two storey height precast concrete units with block opening at the second floor and corrugated metal duct connections in the column lower parts. A large dining room connecting the four factory buildings with 20 m span and 5 m cantilever on both sides were constructed using precast concrete I-beams and joint with postensioned prestressing. A total cost saving of around 7-10% was achieved by using precast concrete instead of steel structures. Right after its 55 weeks speedy construction was completed in 2006, this project received a special commendation from the Institute of Structural Engineers, United Kingdom for the category of excellent industrial and process structures.

a. Aerial View

b. Precast columns

c. PC columns, beams and HCS with 70 mm topping at Main Factory Building



d. PC I-beam and HCS with 60 mm topping at Dining Room

Figure 6 New Plant Astra Honda Motor factory at Cibitung

The second industrial project was the Extension Pakoakuina factory building which constitutes a one storey building and constructed with precast concrete columns and precast concrete gutter beams connecting the upper part columns. Again corrugated metal duct connections have been used at the bottom part of the columns using high strength non-shrink grout. The light weight roof structure with a span of 24 m uses single steel beams. The previous building was constructed using steel structure system and it was more costly compared to the precast concrete system.

The Toyota-Astra Motor (TAM) warehouse with a total building coverage of around 40,000 m^2 is the third major industrial project built with precast concrete components. The T-columns which were specially designed by the architect representing the initial of Toyota were constructed for the whole inside ware-house and made of precast concrete with excellent exposed concrete surface. Precast concrete gutter was connected between these precast T-columns. Elevated slab was constructed with cast-in-place beams and 200 mm hollow core slabs plus 70 mm topping on top of it. Precast prestressed beams with hollow core slabs plus topping were also used for the mezzanine floor and its office building.

Recently, the Jakarta Green Field project of Phillip Morris has just been completed. The main production buildings and some other supporting facilities was located at a 41 hectare-site inside the Industrial Complex KIIC at Karawang. The total floor area of this first stage is 58,000 m^2. This new cigarette factory is the fourth major industrial building which was built with precast concrete components. It has Y-shaped precast columns which represent the symbol of the cigarette brand. Elevated slab was constructed with precast concrete beams and 200 mm hollow core slabs plus 70 mm topping on top of it. Precast hollow-core panels were also used for all perimeter walls which were meant to absorb the heat from outside during the day.

3.1.3 Miscellaneous Projects

In mid of 2003, a 5-storey shopping centre at Balikpapan was offered for tender. Initially it was designed with cast-in-place concrete structural system. The contractor who won the tender proposed to change the structural system into precast-concrete with equivalent monolithic concept in order to accelerate the construction speed and to enhance structural construction cost efficiency around 5-6%. The precast concrete elements used in this project comprised of 65 mm precast solid planks with 55 mm topping, secondary precast beams, and main precast beams.

At the end of 2003, the precast concrete system was also applied for the construction of a penitentiary in the Batam Island region. It was proved very suitable for replacing the previous existing construction standard. The partition walls between the cells, which were initially designed with infill brick walls, were replaced by 150 mm precast concrete wall panels which are naturally stronger and not easily forged. This system emphasized the use of the totally precast concrete system such as precast concrete wall panels with a thickness of 150 mm, 65 mm precast half slabs with 65 mm topping for the floor slabs, precast concrete columns, beams and staircases. The joint system between the precast concrete elements meets the requirements for earthquake and fire resistant constructions.

The Cimahi City Council building consists of 3 interconnecting buildings. A total precast concrete system which was used in this project comprised of precast/prestressed concrete tie-beams, precast/prestressed concrete U-beams, 80 mm solid precast/prestressed planks with 65 mm topping and single layer reinforcement, precast concrete columns with "NMB" mechanical splice sleeves connection types at the bottom part, precast concrete staircases and also precast concrete parapets. The building plan is square, sufficiently symmetrical and the design was based on seismic Zone 4 (SNI 03-1726-2002). To anticipate for seismic lateral load the dual structural system was applied which is a combination of precast concrete columns and cast-in-place shear walls. Location of the fire staircases 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 determined schedule and fully operational by the end of 2005.

a. Building view

b. Installation of PC-elements

Figure 7 Cimahi City Council

3.2. Recommended Connection Systems

Precast concrete components can only stand as an integrated monolithic construction system if they are connected by well designed and well assembled joints. These joints are not only required to be able to transfer all loadings, they must also satisfy certain vital criteria (PCI-2004, CAE-1999, FIB-2004), such as strength, ductility, volume change accommodation, durability, fire resistance, easy to be undertaken locally without disregarding quality. The strength of precast concrete joint in structures should at least equal the result of a cast-in-place concrete structure. If the precast concrete components use the bonded prestressed strand (usually the pre-tension system) then these will produce dimensions that are relatively more slender, therefore requiring a more detailed deliberation towards deflection and effects from vibrations on these elements.

Basically there are two types of joints known in precast concrete systems, i.e. dry and wet connections. 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 done by 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 has been used to emulate cast-in-place detailing. Splices to be used for emulating cast-in-place detailing will normally be in the form of lapped bars, mechanical splices and welded splices. It should be in accordance with the latest Indonesian concrete regulations (SNI 03-2847-2002). 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.

It is recommended to provide additional reinforcing bars, which will be field-bent, with regard to joints between pc-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 itself. Typical connections for precast/prestressed slabs, beams, columns and shear walls, which are adequate for seismic prone areas and imitate cast-in-place detailings can be viewed in Figures 8 to 13. (Wijanto, S. 2006 a-b)

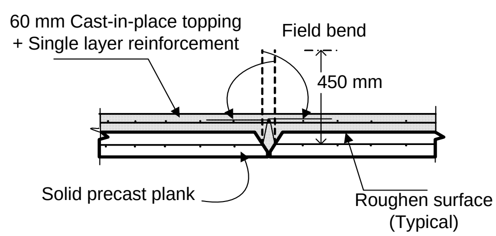


Figure 8 Typical connections between precast/prestressed concrete slabs

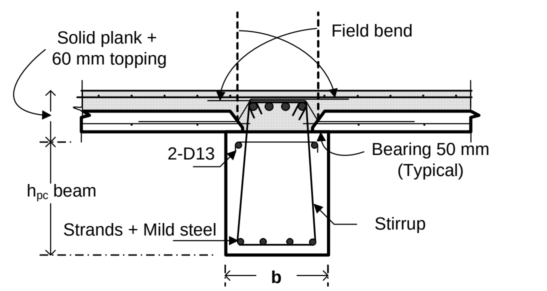


Figure 9 Typical connections of precast/prestressed concrete slabs and precast/prestressed concrete beam

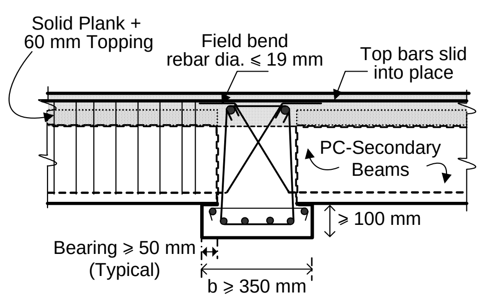


Figure 10 Typical connection of pc-secondary beams and main pc-girder

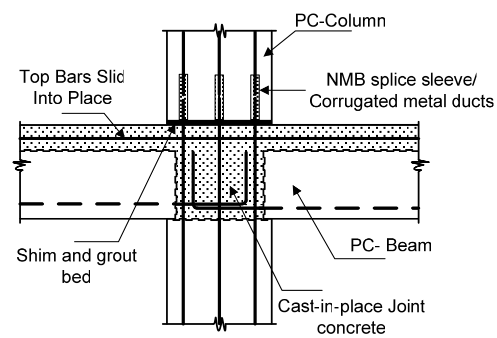


Figure 11 Connection at pc-beams and pc-columns with a cast-in-place closure (Park, 1995)

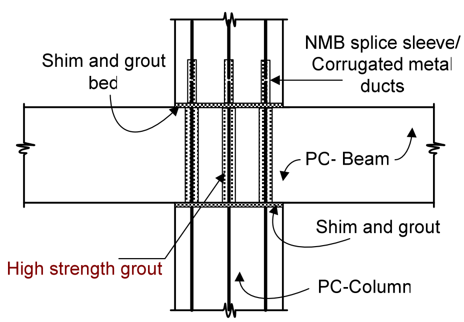


Figure 12 PC-column to pc-column connection through conduits installed in a beam

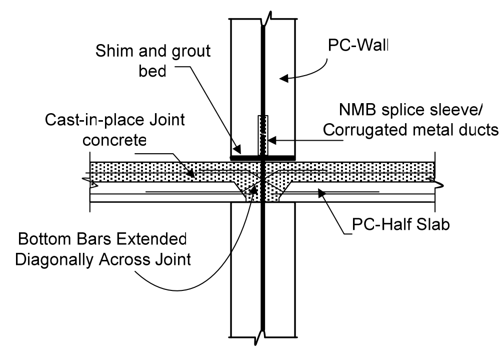


Figure 13 PC-slab to pc-wall detail where diagonal dowels cross the wall joint into the opposite floor

4. CLOSING REMARKS

The most recent development of research and application of precast/prestressed concrete in Indonesia have been described. The recommended connection systems were also discussed especially in the light of fulfilling the seismic design requirements. It was found that structural construction cost efficiency around 5-10% was generally obtained by replacing conventional structural systems with precast/prestressed concrete. It has also been proved that the construction speed was able to be increased significantly in-line with the achievement of better quality works and more eco-friendly construction projects. The use precast/prestressed concrete as structural components will definitely enhance in the future. It is therefore very important that every region agree upon common codes and standards for this type of structural system.

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