

Committee Report : JCI- TC093A

Technical Committee on Performance-based Design and Utilization of Precast Concrete Products

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Abstract

Precast concrete products (hereinafter “PCa Products”) are expected to greatly contribute to the advent of a recycling-oriented society through such means as higher qualitative stability, shorter time for construction works and promotion of the use of various recycled materials. In order to acquire technical data which contribute to the method for performance-based design of PCa Products as well as of structures derived from them based on the result of JCI-TC071A’s 2-year surveys and research in FY2007 and FY2008, the committee was divided into two working groups; Product Design WG and Structure Evaluation WG, and conducted survey/research activities to sort out and examine problems specific to PCa Products. This paper summarizes its major activities.

Keywords: Precast concrete, performance-based design, coupling, construction

1. Introduction

Precast concrete products (hereinafter referred to as “PCa Products”) are expected to greatly contribute to the advent of a recycling-oriented society due to their stable quality, shorter time for construction works, availability of a variety of recycled materials, etc. Particularly, when considering the prospective shrinkage of the construction work force due to the decline in birthrate and aging of the population that will be faced by Japan in the not-so-distant future, development of technology for proper performance-based design and use of PCa Products and the structures that go with them is a critical task for concrete engineers to make the Japanese social foundation more reliable.

With a view to examining problems specific to PCa Products, the JCI-TC071A “Technical Committee on Performance-based Design and Utilization of Precast Concrete Products” was inaugurated to undertake 2 years of survey/research activities in FY2007 and FY2008. The Committee established WGs with attention focused on matters such as PCa Product design methods, highly functional PC products, engineer development, and use of

poor-quality/recycled materials, and was able to identify the matters necessary in specifying PC product performance. On the other hand, it became clear that the following problems still remained unsolved:

- 1) PCa Products are quite diversified and a different performance is required for each product. Many PCa Products are not manufactured by a specific performance-based design method, thus leaving a technical problem of ensuring PCa Product quality.
- 2) With regard to PCa Product design, despite the importance of such a design not only for products but also for the structures derived from them, no systematic design technique has been developed.

In view of such a situation, for the purpose of developing technical data which contribute to a performance-based method of designing PCa Products as well as the structures derived from them, based on the achievements of the JCI-TC071A Committee, the JCI-TC093A “Technical Committee on Performance-based Design and Utilization of Precast Concrete Products” was set up. It was divided into two working groups to undertake 2 years of survey/research activities in FY2009 and FY2010.

While taking existing multiple categorizations into account, the Committee considered the starting point of examination as a reflection of the specification of PCa Products on their design and manufacture retrospectively from the upstream (derived structures) side, which is different from the conventional viewpoint. Repeated discussions were held on the work flow from design/manufacture of PCa Products to design/construction of resulting structures as well as elucidating the performance required of PCa Products, and whether or not it is possible to introduce “ease of replacement” into the conventional design, and the following were outlined as goals of this committee:

- Point 1: Concept of PCa Product design/manufacture and structure design/construction based on the required performance of the structure
- Point 2: Points to note for PCa Product design/manufacture (especially, the structural design method for a thin-walled structure, and how to handle as well as evaluate a concrete cover, and other durable design methods)
- Point 3: Points to note when a PCa Product-derived structure is designed and built
- Point 4: Points to note (as a future issue) when a PCa Product-derived structure is maintained/managed

Table 1: Committee Members

Chairman	Makoto HISADA	Tohoku University
Advisor	Katsuro KOKUBU	Tokyo Metropolitan University
Secretary-General	Yoshihisa NAKATA	Nihon University
Manager	Makoto KAWAKAMI	Akita University
	Masami ISHIKAWA	Tohoku Gakuin University
	Norikazu ONOZATO	Kogakuin University
	Kazuhisa SHIMIZU	Asahi Concrete Works Co., Ltd.
	Tetsuya MATSUYAMA	Nihon Kogyo Co., Ltd.
	Hajime ITO	Toyama Prefectural University
Committee Member	Noriyuki HOSHIDA	Milcon Co., Ltd.
	Satoru MATSUOKA	Landes Co., Ltd.
	Masafumi KITATSUJI	Miyagi University
	Masaaki IRIE	Nihon Kutai Koji KK
	Akira SHINMURA	Obayashi Corporation
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	Hiroshi NAKANE	Ohki Corporation
	Osamu KANEKO	Maeta Seihin Hanbai Ltd.
	Norihito YUASA	Chiba Yogyo Co., Ltd.
	Yuji TADOKORO	Koken Sangyo Co., Ltd.
	Soichiro NAKAYAMA	Ishikawajima Construction Materials Co., Ltd.
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	Akihisa KAMIHARAKO	Hirosaki University
	Masaru OKAMOTO	Railway Technical Research Institute
	Atsushi HATTORI	Taisei Corporation
	Keiichi KATORI	Toyo University
	Yuji SHITAYA	Civil Engineering Research Institute for Cold Region, Public Works Research Institute as an incorporated administrative agency
	Koji OSADA	Flowric Co., Ltd.
	Hiroshi KATAHIRA	Public Works Research Institute as an incorporated administrative agency
	Shunichi SHIMIZU	P.S. Mitsubishi Construction Co., Ltd.
	Hideaki SHISHIDO	Hokuetsu Co., Ltd.

2. Concept of PCa Product design/manufacture and structure design/construction based on the required performance of the structure

In the context of performance specification in concrete structure design, construction/manufacture, and maintenance/management, the performance required for such a structure includes safety, workability, restorability, other attributes (including scenic beauty or landscape), or durability defined as resistance to time variation of such performance and, in

general, appropriate concrete materials used for the structure, their composition, bar arrangement, overlay, etc. are specified in accordance with the procedure to check this performance.

Contrary to this, it seems that a conventional PCa Product comes into being, at least, as a product if it satisfies such standards as are set out in specifications like Japanese Industrial Standard (hereafter referred to as JIS). Actually, however, conventional PCa Products have not so far undergone any examination of the matters that would have been examined to ensure that poured concrete satisfies the required performance. For example, it seems that, at present, composition, design and curing time (temperature, humidity, periodic control, etc.) are defined with a view mainly to lessening percent defects including color shading or reducing manufacturing costs rather than to ensuring durability.

However, this is applicable to small-scale products in particular, and some large-size PCa Products used as building components are examined for matters to meet the required performance. PCa is thus found in many large varieties. In existing reports and other documents from societies/associations, there are many categories including those focusing on the application such as architectural or civil engineering, product size, and whether or not they are specified by JIS.

3. Points to note for PCa Product design/ application

3.1 Overview

The points to note for PCa Product design/application were summarized. First of all, required performance and evaluation indices were extracted based on the criteria/standards applicable to PCa Products including JIS Standards and design/application manuals. Next, problems arising when shifting to the limit state-based design method were extracted so that the workability, durability and safety of PCa Products can be checked in line with the performance design, and a solution to such problems was proposed. Then, major PCa Products were taken up to verify their performance using both conventional and performance-based design methods, and the difference in results due to difference in design methods was compared.

We have further examined not only the quality assurance method by way of the manufacturing process and product inspection, but also points to note for the design/application of PCa Products which take into account the mitigation of environmental impacts such as recycled aggregate concrete and molten slag aggregate-based concrete.

3.2 PCa Product limit state-based design method

As for PCa Products, unlike the case of poured concrete covered by many guidelines and standards, concrete cover of embedded steel can be made small by contriving the precasting method such as through casting from a component's side or centrifugal moulding/compaction. However, due to small concrete cover of steel, a check of its durability including large cracks and steel corrosion due to neutralization and salt water may not be satisfied.

To apply the limit state-based design method to PCa Products, it is considered important to examine such problems and try not to lose the economy or technical rationality of using the combination of poured concrete and PCa Products to build a structure.

When proposing the PCa Product-targeted limit state-based design method, as shown in **Fig. 1**, we first examined whether or not there are any items which do not satisfy rated or limit values or inconsistent items if the limit state-based design method for ordinary concrete structure is applied to PCa Products. It was decided that, based on the result, a method applicable to PCa Products should be proposed.

We took up the flexural crack strength and flexural crack width listed as problems in the previous Committee Report, steel corrosion due to neutralization and salt water not covered by conventional design checking, and flex-bearing force largely affected by sectional specifications as items to be examined. Furthermore, a safety factor to include in the uncertainty of design values and equations which consider characteristic variation of materials used for the limit state-based design method was also examined.

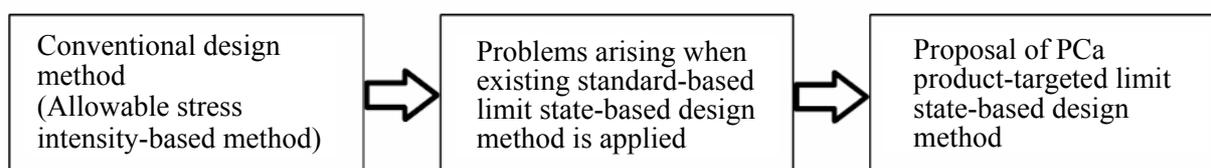


Fig. 1: Flow of PCa Product Design Examination

Particularly in the examination of flexural crack strength, the equations for standards cover only 200mm or more, and there is too large a difference in value between different criteria/standards as shown in **Fig. 2** to apply to thin-component PCa Products. Based on this, we examined a new calculation method where the result of an experiment conducted by the

JIS Council for a component thickness of about 100mm is to be obtained by destructive energy and the ratio of sectional height/aggregate size, and proposed the method.

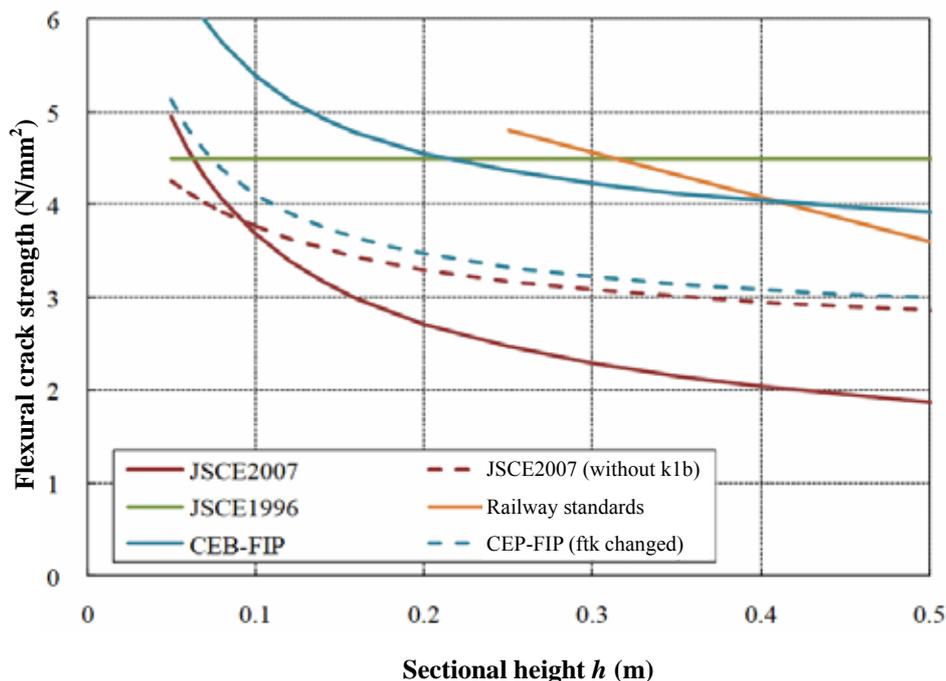


Fig. 2: Comparison of Flexural Crack Strength under Various Standards

3.3 Application of performance checking-type design to products and problems

PCa Products widely range from relatively large retaining walls, box culverts, architectural products, bridge girders, etc., to small thin-walled U-shaped street gutters and plain-concrete plates. Most of these precast products are even now designed based on the allowable stress strength-based design method.

On the other hand, there is a tendency to shift to the performance checking-type design method which provides rational design in which, taking account of the natural/social conditions of the structure and the structure's capability to be constructed, economy, adaptability to the environment, etc., the target performance (including safety, workability and restorability) required for individual structures is defined and checked by testing and analysis. However, the performance checking-type design method is still unpopular in precast product designing.

We therefore compared the results from the method with those from the conventional design method (allowable stress intensity-based design method) by showing the specific required performance and performance checking cases for individual PCa Products. The comparison revealed problems and issues regarding the possible application of the performance checking-type design method to PCa Products.

In general, although PCa Products are thin-walled and cover only a small part of embedded steel, their quality is stable and their strength can be checked as products. Based on these characteristics, the effectiveness of the performance checking method suitable for such PCa Products was demonstrated.

The Committee compared, for examination, the conventional design method with the performance checking-type design method for the following nine products:

- (1) L-shaped retaining wall
- (2) Box culvert
- (3) Shielding works-purpose segment
- (4) Pile
- (5) Centrifugal Reinforced Concrete Pipe
- (6) Prestressed concrete girder
- (7) Architectural Building
- (8) Street gutter
- (9) Plain concrete products

Since architectural Buildings are required to have a performance equivalent to that of poured concrete and their performance as products can hardly be specified, a required performance specific to PCa Products (manufacture, delivery, assembly, concrete pouring) was introduced.

3.4 Technology to ensure PCa Product quality

PCa Products are manufactured at a factory specializing in product manufacture such as JIS standard PCa Products, or those including building components, track slabs, and bridge components manufactured at a temporary factory located near the construction site considering product delivery, and ensuring quality to satisfy required performance as a product is an important issue in both cases.

As for building components, the quality of final structures is ensured by quality assurance technology complying with the Architectural Institute of Japan's Standard Specification (JASS5) and Specifications for PCa (JASS10), as well as with related guidelines for construction.

With respect to manufacture at a factory specializing in PCa Products for general civil engineering, since the work environment is different from that of structures built on site, manufacturing facilities and diverse test equipment facilitate the standardization of

manufacturing processes and process control, and further, products can be tested directly and judged for acceptability before they are built on the site, it seems feasible to judge the superiority of PCa Products for quality assurance.

This section introduces specific cases by the following categories of independent quality control technology specific to PCa Products which may reduce the safety factor to be used in the limit state-based design method due to a prospective shift to the performance checking-type design method in the future, taking the impact of material quality fluctuation into consideration for civil engineering-purpose PCa Products:

- 1) Management, inspection, and testing
- 2) Manufacturing process technology
- 3) Measures against product defects, cases
- 4) Cases of durability

For 4) in particular, a questionnaire survey of how PCa Products deteriorate and are repaired or replaced in environmentally harsh regions was conducted to grasp the actual situation. Hokkaido, as the selected district, has severe freezing/melting conditions in winter, and muriated antifreezing agent is dispersed to ensure smooth traffic. Concrete structures including PCa Products in Hokkaido District can therefore be considered to be affected by not only frost-damage deterioration, but also by complex deterioration where salt infiltrating concrete accelerates frost-damage deterioration, and to be used under more harsh environmental conditions than elsewhere in Japan. Based on the above, a questionnaire survey of matters listed in (1) to (3) below was conducted for road/river administrators as respondents with a view to developing a source material to set the service life and replacement/repair time of PCa Products.

- (1) Product information (class, composition, manufacturing method), environmental conditions
- (2) State of product deterioration
- (3) Measures for products (replacement, repair, etc.)

Survey results will be given in a Committee Report slated for this year.

3.5 Product design taking account of a reduction in environmental burden

A reduction in environmental burden is required for all industries. Specific measures include (1) utilization of recycled materials (reduce wastes), (2) CO₂ reduction, and (3) ensuring environmental safety. Construction-related industries consume a large quantity of

materials, and have enormous positive and negative impacts on the environment.

The Committee has examined the use of the limit state-based design method as the method of designing a PCa Product. If recycled materials are used, their quality fluctuates tremendously, and the handling of the safety factor becomes a problem. There are no previous cases where the structure of any PCa Products comprising such recycled materials which have not been used in ready-mixed concrete was calculated using the limit state-based design method, and this report cannot present any proper life adjustment for materials. For recycled materials not used in ready-mixed concrete, therefore, it is considered necessary to accumulate data before applying the limit state-based design method to PCa Products. PCa Products containing recycled materials are used for products with poor required performance. For example, refuse molten slag and recycled coarse aggregate M are for those with a standard design strength of 36N/mm^2 or less, and many product kinds are replaceable. This indicates the possibility of performance checking with a conventional allowable stress intensity-based design method or deemed-to-satisfy provisions. Basically, performance checking is carried out to judge whether the required performance of a finished product itself is complied with, regardless of whether or not recycled materials are used.

This section examined (1) molten slag which is more abundantly used as an aggregate than any other recycled material, and (2) recycled coarse aggregate M which is highly expected to be used more in the future, as well as (3) blast-furnace cement/slag and (4) fly ash, from a standpoint of their effects on reducing CO₂ emissions and effective use of industrial waste, although less used in PCa Products. In addition, (5) the burden on the environment (LCA) was estimated for those materials.

3.6 High-performance PCa Products

This section introduces PCa Products using (1) ultra-high strength fiber-reinforced concrete and (2) hydrous solidified blast-furnace slag as new materials and their present applicability, and examples of their application to actual structures as well as related study results.

Ultra-high strength fiber-reinforced concrete is a composite material of ultra-high strength mortar combined with steel fiber, and has high tensile strength and toughness. Hydrous solidified blast-furnace slag is a material which uses fine blast-furnace slag powder in part of the binding material and fine blast-furnace slag aggregate for the total quantity of fine aggregate, and boasts significant resistance to sulfuric acid, frost damage, alkali-silica

reaction, hydrosulfate, carbonation, chloride ion permeability, etc.

4. Points to note when a PCa Product-derived structure is designed and built

4.1 Survey of codes

PCa Products made available as components were organized under the title of “Points to note when a PCa product-derived structure is designed and built” with the assumption that they shall satisfy a required performance. As its first step, the work started with the survey of various codes concerning the design of the PCa components-based structure part. In this work, codes concerning the design of a PCa components-based structure which were revised in the past decade were first identified for the civil engineering and building engineering. Regarding the civil engineering field, the standards listed in **Table 2** refer to PCa mainly intended for bridges. Details will be provided in the committee report slated for this year.

Table 2: List of Standards for PCaPC (Relating to Bridges)

No.	Name	Publisher	Published in	Applicable part	Remarks
1	Standard Specifications for Concrete Structures [Design]	Japan Society of Civil Engineers	2007	Chapter 15	
2	Specifications for Road Bridges III –Concrete Bridge	Japan Road Association	March, 2002	Chapter 17	Under revision
3	Japan Highway Public Corporation Design Procedure Collection II - Bridge Construction	East Nippon Highway Company Limited Central Nippon Highway Company Limited West Nippon Highway Company Limited	July, 2009	-15, -21	
4	Guidelines for Prestressed Concrete Road Design/Construction by Precast Cement Concrete Blocks Construction Method (Draft)	Japan Prestressed Concrete Contractors Association Public Works Research Institute	December, 1995		Base for design method
5	Design Standards For Railway Structures and Commentary - Concrete Structures	Supervised by Railway Bureau, Ministry of Land, Infrastructure, Transport and Tourism Edited by Railway Technical Research Institute	April, 2004	14.18	
6	External Cable Structure/Precast Segment Process Design/Construction Code	Edited by Japan Prestressed Concrete Engineering Association (Gihodo Shuppan Co., Ltd.)	June, 2005	III	
7	Bridge Engineering Handbook	Editorial Board of Bridge Engineering Handbook (Gihodo Shuppan Co, Ltd.)	April, 2004	4.8, 4.9	
8	PC Floor Board Design/Application Manual (Draft)	Japan Prestressed Concrete Contractors Association	May, 1999		
9	PC-Composed Bridge Design/Construction Guidance [Revised edition]	Japan Prestressed Concrete Contractors Association	May, 2007		
10	JIS Girder-Based PC Road Bridge Design/Manufacturing Manual (JIS 5373-2004)	Japan Prestressed Concrete Contractors Association	June, 2004		
11	JIS Light-Load PC Slab Bridge Design/Manufacturing Manual (JIS 5373-2004)	Japan Prestressed Concrete Contractors Association	June, 2004		
12	JIS Road Bridge Girder Segment Design/Manufacturing Manual (JIS 5373-2004)	Japan Prestressed Concrete Contractors Association	September, 2004		
13	JIS Synthetic Floor Board Precast Board Design/Manufacturing Manual (JIS 5373-2004)	Japan Prestressed Concrete Contractors Association	September, 2004		
14	JIS Road Bridge Precast Floor Board Design/Manufacturing Manual (JIS 5373-2004)	Japan Prestressed Concrete Contractors Association	July, 2004		
15	Anti-salt Damage Precast PC Bridge Girder Design/Construction Data	Japan Prestressed Concrete Contractors Association	March, 2005		

On the other hand, in the building engineering, PCa Product reinforced concrete-structured buildings were roughly divided into Wall Precast Reinforced Concrete (W-PC) Structures, Wall Rahmen Precast Reinforced Concrete (WR-PC) Structures and Rahmen Precast Concrete (R-PC) Structures. Among these, the W-PC Structure has a long history, and has been widely employed since the Architectural Institute of Japan’s “Wall

Precast Reinforced Concrete Structure Design Code and Commentary” was published in 1965. Meanwhile, the WR-PC Structure and R-PC Structure are relatively new, and since the “Cast-in-Place Concrete-Equivalent Type Precast Reinforced Concrete Structure Design Guidelines (draft) and Commentary (2002)” and the “Wall Rahmen Reinforced Concrete Structure Design/Construction Guidelines” were published by the Architectural Institute of Japan in 2002 and The Building Center of Japan in 2003, respectively, they have been widely employed. Before these guidelines were set, PCa-employed reinforced concrete buildings had to be accredited by the Minister of Land, Infrastructure, Transport and Tourism except when PCa was only partly used. However, the establishment of these guidelines eliminated the need for accreditation of such PCa reinforced concrete buildings 60m tall or shorter. **Fig. 3** shows the results for PCa reinforced concrete buildings contained in the Building Letter with building heights as the vertical axis and years as the horizontal axis from 2000 to 2009 (including some prestressed concrete-structure buildings). Although the Building Letter contains buildings that were evaluated for performance with the purpose of acquiring accreditation by the competent minister, it contains no 60m or shorter buildings since 2003 except for quake-absorbing structures.

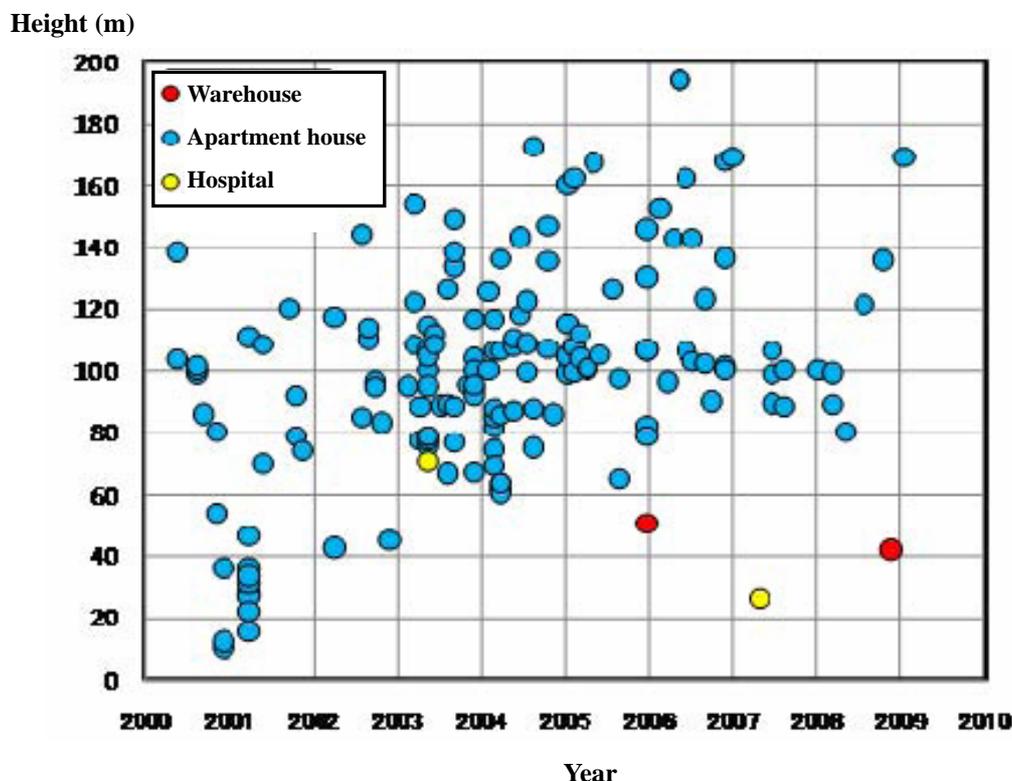


Fig. 3: Relationship between Heights of the PCa Buildings Evaluated for Performance and Years (from the Building Letter)

4.2 Specific examples of structures using PCa components

The final committee report introduces, as specific examples of structures using PCa components, mainly the structures built during these 5 or 6 years as shown below.

- 1) Kaiser slab for elevated railroad¹⁾
- 2) JR West Osaka Higashi Line Kyuhoji elevated bridge²⁾
- 3) Elevated rail bridge construction works in the Project for Continuous Overhead Crossing near Keikyu Kamata Station³⁾
- 4) Railway construction work between Musashi-kosugi and Hiyoshi under the Tokyu Toyoko Line Track Quadruplication Project⁴⁾
- 5) Rinko Railway Kinjofuto Line (Shiodome-Sorami) Elevated Railway Line Construction Work⁵⁾
- 6) Specific Business-Entrusted Construction Work (again) in 2nd District, 4-chome, Higashi-ikebukuro⁶⁾

In addition to the above, construction methods using PCa components in the possession of construction companies are also introduced.

4.3 Analytical examination of stress transmission at joints

When a structure is designed/constructed using PCa components, it is most important, to ensure the structure's required performance, to know how to appraise the continuity at a joint between PCa components. WG2 therefore decided to list up typical coupling types now in use and, at the same time, exemplify the evaluation of joint performance by numerical analysis. The test results covered by this examination are from the experiments on precast RC columns by Aida et al⁷⁾. Here we give an analytical example of No.1 and No.2 test pieces in their literature (**Fig. 4**). No.1 test pieces were prepared with their footing and column section by integrated concrete placement. In the case of No.2 test pieces, their column section is a precast part, and there is a joint of 450mm between the footing and the column section. In addition, No.2 test pieces use screw-deformed bars in their column's main reinforcement. At the joint, the main reinforcement is bonded as shown in **Fig. 5**, using mortar-filled couplings. This examination attempts nonlinear limited element analysis, with No.1 and No.2 test pieces as reference data. **Fig. 6** shows a contour map of each principal strain analytically obtained for the maximum load at $5\delta_y$ displacement. Analytical results for No.2 test pieces correspond to those with the maximum bond strength at the coupling section as 0.7 times. The figure indicates that the area where tensile strain developed in No.2 test pieces is wider, although

only slightly, than in the case of No.1 test pieces. This suggests the possibilities that stress redistribution states are slightly different between the two even if there is no difference in capability to withstand load and toughness between integrally placed and precast concrete as in this example. The above is expectedly due to great involvement of the joint bond characteristics in the in-plane direction. Integrated analogical inference from analytical results may well indicate that, if adequate bond strength at joints cannot be maintained due to too dense a bar arrangement, it is desirable to appropriately grasp the dynamic aspect through prior analysis as in the example of this examination before designing the joint section.

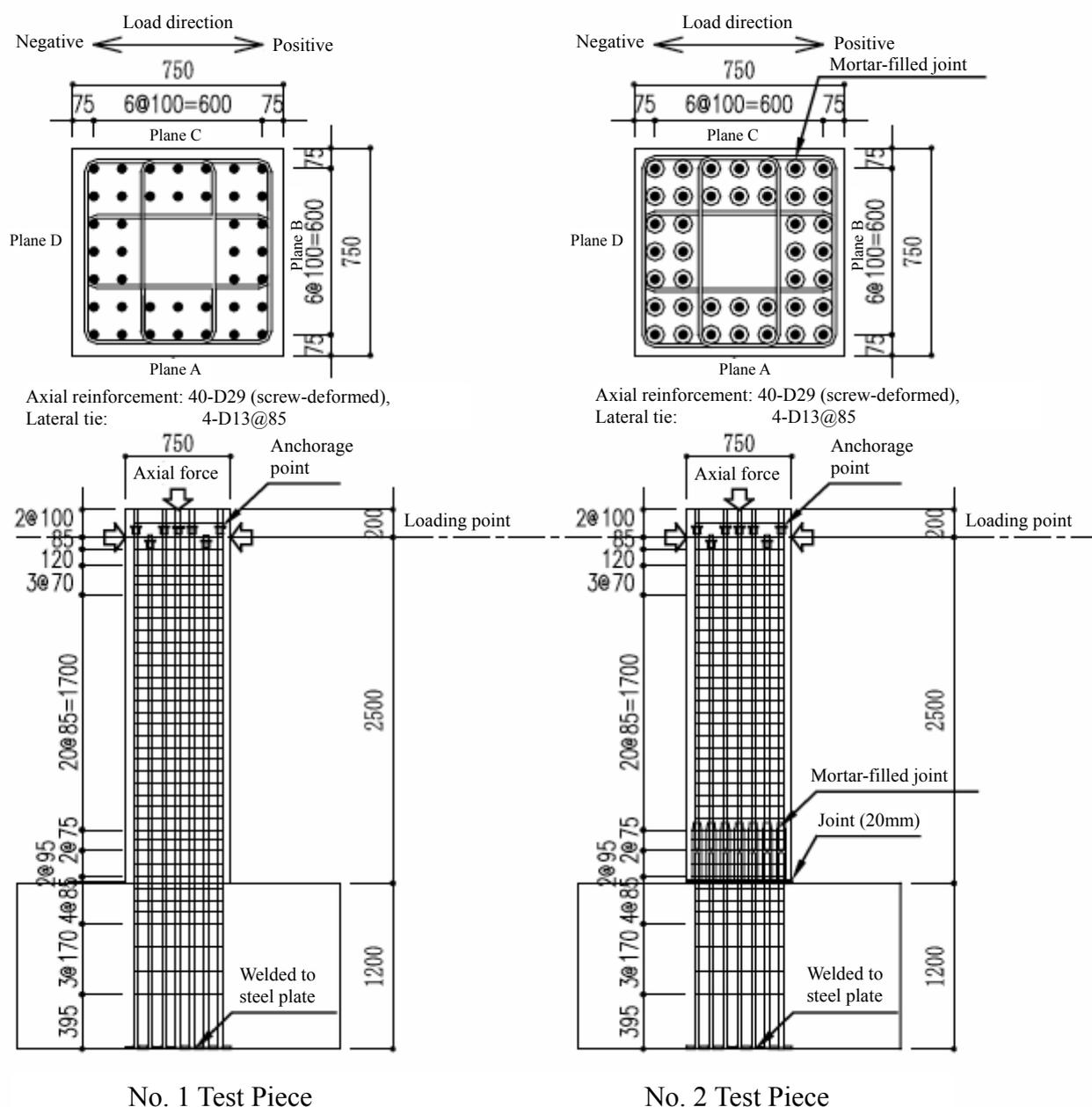


Fig. 4: Test Pieces of Precast RC Column for Experiments by Aida et al⁷⁾

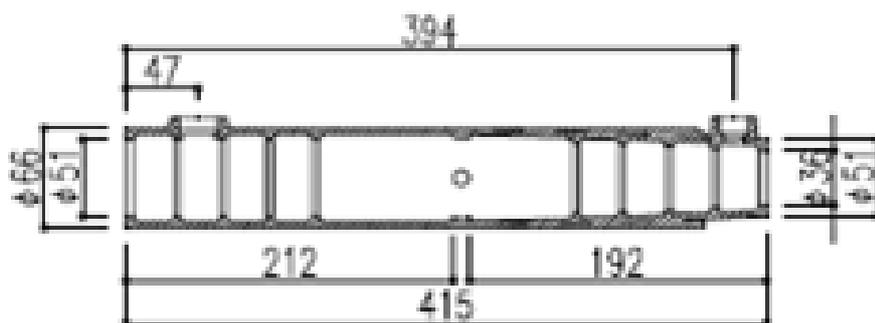


Fig. 5: Detail of Joint Section

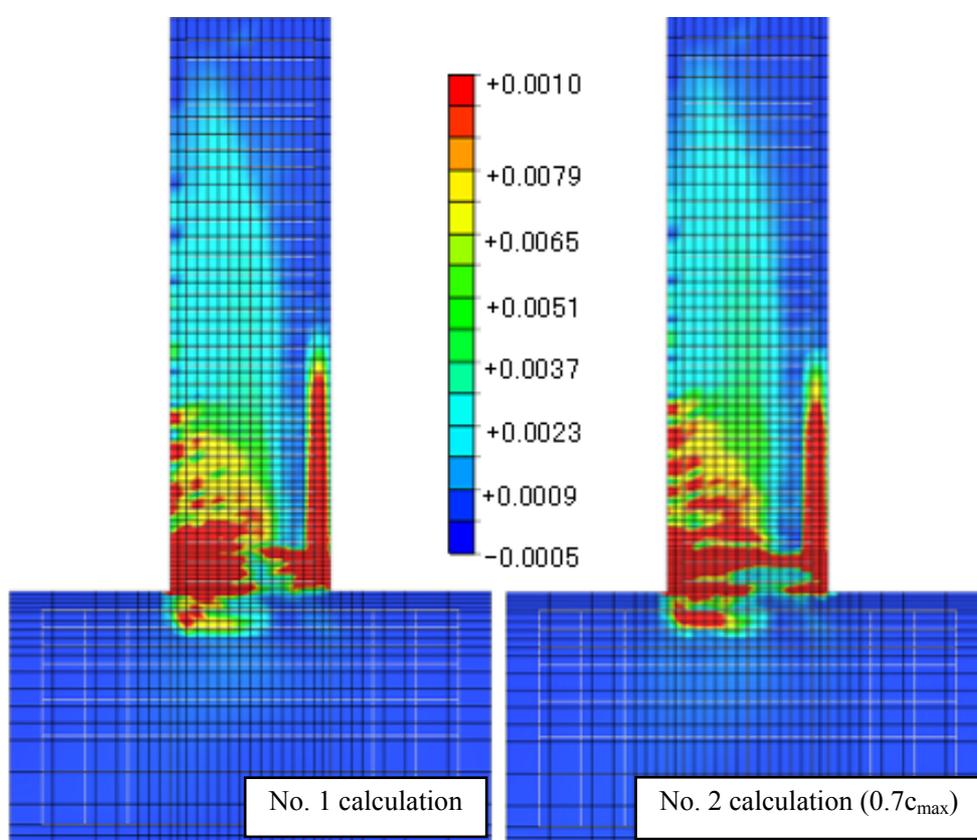


Fig. 6: Analytical Result

5. Summary

From our 2 years of research, we were able to identify the matters necessary to ensure PCa Product performance. The following points are future issues:

- (1) Further identification of problems toward diffusion.

To address the issue of being too particular about scenic beauty, namely, to make “rough”

PCa Products with satisfactory performance acceptable, it is necessary to promote the improvement of legal systems and gain the understanding of procurement departments.

(2) Clarification of the advantages of using PCa

In contrast with PCa Products whose work processes are mostly finished inside a factory, field placement needs exclusive jobs such as fresh concrete mixing and reinforcement work, and requires more people engaged in such jobs (in other words, personnel costs increase). This aspect leads to the merit of “labor saving.” In Japan, there are fewer large-scale PCa plants than overseas and this has made it difficult to employ workers for various jobs within plants.

In order that PCa may further prevail, it is considered necessary for the industry to make efforts to respond to customers’ demands by establishing technology which allows PCa to give full play to its advantage, and proposing a design method that can lower total costs.

Finally, we express our hearty gratitude to those who responded to our questionnaire survey, etc.

References

- 1) Kaiser Slab for Elevated Railroad , Nihon Kaiser , 2008.8.
- 2) Taijyu Yoneda et al., A Study on Erection Method of PREX SLAB and PREX PARAPET for Railway Elevated Bridge in the Neighboring Existing Railway , Maeda Corporation, Report of Technical Research Institute , Vol.47. 2006
- 3) Naomichi Hattori et al., Application of Railway Rigid-Frame Viaduct, Over and Along another Operating Line, with Half Precast Construction Method (HPCa), Japan Society of Civil Engineers, The Construction Technology Research Committee , 2009.11
- 4) Takaaki Yamamoto et al., Examination of Railway Rigid-Frame Viaduct, Over and Along another Operating Line, with Half Precast Construction Method, Japan Concrete Institute, Concrete Journal, Vol.43, No.7, 2005.7
- 5) Isao Takahashi et al. , Precast Rapid Construction Method of Railway Rigid Frame Viaduct for Rapid Urban Renewal, The Bridge & Urban PROJECT , 2003.7
- 6) Atsushi Hattori et al., Advanced Technology in the Design and Construction of Super High-rise Apartment Building , Japan Concrete Institute, Concrete Journal , Vol.49 , No.2 , 2011.2
- 7) Hironobu Aida et al, Reversed Cyclic Loading Test of the Precast Columns with Grout-filled Sleeves for Railway Viaducts, Japan Concrete Institute, Proceedings of the Japan Concrete Institute, Vol.27, No. 2, pp.613-618, 2005.7