Committee Report : JCI- TC073A

Technical Committee on Utilization of Prestressing Techniques

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Abstract

The Committee summarized issues on prestressed concrete construction since the conclusion of JCI's "Technical Committee on the Applicability of Prestressed Concrete" organized in 1989, searching the literature in Japan and overseas particularly regarding next-generation prestressed concrete construction and innovative uses for prestressing techniques. The Committee also focused on items that should be clarified for the current design and construction about which information is not fully available. These include the performance requirements for grout for prestressed concrete and post-tensioned connections, effect of statically indeterminate stress on seismic performance, and evaluation of residual crack width after earthquakes. The Committee collected as much data regarding these items as possible. An overwhelmingly larger number of structures have been constructed with prestressed concrete in the civil engineering field than in the architectural engineering field. The committee members from the civil engineering field, in which prestressing techniques are mostly utilized to bear vertical or gravity loads, and those from the architectural engineering field, in which it is to be utilized for improving seismic performance, worked in cooperation, discussed the effective use of this technology, and summarized the results in a report.

Keywords: bond, durability, grout, precast, prestress, seismic resistance, unbond

1. Introduction

Prestressed concrete construction, which has been used to improve the performance of reinforced concrete construction under vertical or gravity loads, has recently been attracting attention for its effectiveness in enhancing the seismic performance, showing small residual deformation. Attempts have also been made to utilize the different levels of bond properties of plain bars, strands, and deformed bars for the improvement of its structural performance. Design methods whereby the control of bonding leads to an improvement in the structural performance have thus been explored. Studies have also been conducted on environment-friendly structures constructed using unbonded tendons and precast segmental members so as to allow the reuse of members.

The Committee dealt with prestressed concrete construction since the completion of the Technical Committee on the Applicability of Prestressed Concrete organized in JCI in 1989. A survey of the literature in Japan and overseas was conducted regarding the above-mentioned next-generation prestressed concrete construction and innovative applications of prestressing techniques. The Committee also focused on items that should be clarified for the current practice of design and construction but are not fully understood, such as the performance requirements for grout for prestressed concrete (PC grout) and post-tensioned connections, the effect of statically indeterminate stress on seismic performance, and the method of evaluating residual crack width.

Table 1: Members of the Committee

Chairman	Minehiro NISHIYAMA	Kyoto University
Vice-chairman	Tadashi NAKATSUKA	Osaka Institute of Technology
	Susumu INOUE	Osaka Institute of Technology
Secretary	Akio KASUGA	Sumitomo Mitsui Construction Co., Ltd.
	Kazuhiro KITAYAMA	Tokyo Metropolitan University
Member	Makoto HIBINO	Kyushu Institute of Technology
	Ichizo KISHIMOTO	Osaka University
	Yuzuru HAMADA	JR West Japan Consultants Company
	Masahiro SUGATA	Takenaka Corporation
	Kazunori OSAKO	P.S. Mitsubishi Construction Co., Ltd.
	Haruhiko OKAMOTO	Aichi Shukutoku University
	Shinji KISHIDA	Shibaura Institute of Technology
	Shigeru MIZOGUCHI	Neturen Co., Ltd.
	Kuniyoshi SUGIMOTO	Obayashi Corporation
	Shin-ichi TAKEZAKI	Taisei Corporation
	Naoki NAGAMOTO	Sumitomo Mitsui Construction Co., Ltd.
	Tadahiko TSUTSUMI	Fuji P.S. Corporation
	Shuji YANAI	Kajima Corporation
	Yuji TAJIMA	Tokyo Metropolitan University
	Masanori TANI	Kobe University
	Makoto MARUTA	Kajima Corporation
	Satoru FUKAI	Nikken Sekkei Ltd.
	Tsutomu KOMURO	Taisei Corporation
	Yasuhiko MASUDA	Obayashi Corporation
	Hiroyuki UEDA	Takenaka Corporation
	Tsuyoshi FUKUI	P.S. Mitsubishi Construction Co., Ltd.
	Masayuki AWANO	Nikken Sekkei Ltd.
	Jiandong ZHANG	Nanjing University of Technology
	Atsuhiko SUGITA	Oriental Shiraishi Corporation

	Yukio HIROI	PC Bridge Co., Ltd.
	Kazuhiro NISHIMURA	Sumitomo Mitsui Construction Co., Ltd.
	Masahiko ARIMITSU	PC Bridge Co., Ltd.
	Hidenori MANABE	Kokusai Structural Engineering Corporation
	Hidehiro UCHINO	Fuji P.S. Corporation

2. Current state of prestressing techniques

Prestressing techniques, which have been developed to improve the performance of reinforced concrete construction under gravity loads, are effective in preventing cracks, controlling crack width, and controlling deflection. In addition to these original purposes, prestressing techniques have recently been applied to various uses. One such example is structural systems with small residual deformation utilizing the restoring force characteristics derived from prestress.

The environments for prestressing techniques in the civil and architectural engineering fields can be expressed by the following keywords:

- Civil engineering: durability, use of precast units, PC grout, pregrouting, steel corrosion prevention
- Architectural engineering: seismic resistance, deign method, popularization, education, residual deformation, self-centering, unbonded tendon, long-term high-quality residence

3. Composition of the Committee

Two working groups (WGs) were organized in the Committee: Fundamental technology WG and Next-generation technology WG.

The Fundamental technology WG (Managers: Prof. Kazuhiro Kitayama and Prof. Makoto Hibino, Secretaries: Prof. Ichizo Kishimoto and Dr. Yuzuru Hamada) took up matters that are fundamental but have not been addressed, such as the performance requirements for PC grout and post-tensioned connections and the method of incorporating these into design, as well as the hysteretic restoring force characteristics of members and joints. The WG obtained data that are also useful for current design and construction.

The Next-generation technology WG (Managers: Prof. Minehiro Nishiyama and Dr. Akio Kasuga, Secretaries: Dr. Masahiro Sugata, Dr. Hidenori Manabe (up to March 2008), and Mr. Hidehiro Uchino (since April 2008)) collected innovative next-generation technologies using prestress. These data were derived from a wide range of sources including those under study to those already put into practical use, including the improvement of structural performance by bond control and disassembable structures utilizing unbonded tendons. Fundamental tecbnologies to serve as bases for the development of next-generation tecbnology were also clarified, with the interaction between fundamental and next-generation technologies being summarized. Moreover, this WG formulated a datahase of representative structures constructed using prestressing techniques.

4. Looking back on the report published in 1991

The Tecbnical Committee on the Applicahility of Prestressed Concrete (1990-1991) chaired by Prof. Hiroshi Muguruma summarized the state of the art of the prestressed concrete tecbnology of the time. The committee published an interim report titled "To promote broad use of prestressed concrete" in the August 1990 issue of the *Concrete Journal*, naming problems hindering the spread of prestressed concrete particularly in the architectural engineering field. The present report investigates how these problems posed 20 years ago turned out to be – whether they were solved or remain problems, or have become worse – based on the report by committee member Mr. Satoru Fukai at the workshop held by the Committee during the JCI Annual Convention 2008 at Kyushu.

To begin with, the current state of the design and construction of prestressed concrete structures is summarized from the aspect of comparison between architectural and civil engineering fields.

In the architectural engineering domain, clients are mostly in the private sector, normally not well acquainted with structural construction. Design is normally carried out by a design office in cooperation with a contractor specializing in prestressed concrete. A general contractor undertakes the job as a package, and prestressed concrete work is assigned to a subcontractor specializing in prestressed concrete construction. The cost for the structural framing normally accounts for one-third of the total construction cost, which is not so large as the other costs such as equipments, sanitary facilities and air-conditioning systems.

On the other hand, the clients of civil structures are govemment offices or public institutions, who are well aware of prestressed concrete. These are designed by consultants, while general contractors undertake the construction. The cost for the structural framing accounts for a substantial part of the tutal construction cost.

In the 1990 report, the following nine items were named as obstacles to the spread of prestressed concrete in the architectural engineering field:

(1) Structural design engineers

(2) Codes and standards

(3) Design process
(4) Anchoring methods
(5) Peculiarity of buildings
(6) Evaluation of prestressed concrete buildings
(7) Use of precast members
(8) Unbonded system
(9) Construction

The current state of the above items is investigated in the following sections:

(1) Structural design engineers

The 1990 interim report pointed out the small number of structural design engineers who know the design method for prestressed concrete. Only a limited number of universities offered courses in prestressed concrete, and this situation still remains unimproved. Also, a structural design engineer does not necessarily have to select prestressed concrete construction for a building having long spans but can choose an alternative structural form, such as construction using steel. Another reason that general structural designers do not learn prestressed concrete is because prestressed concrete members are virtually designed by contractors specializing in prestressed concrete. However, the Licensed Architect Act was revised to require that the name of the structural design engineer be expressly provided in the design of a building of over a certain size. It is therefore anticipated that the situation will improve, including the improvement in the status of structural design engineers.

The 1990 report proposed the publication of instruction manuals and introductions and the holding of training sessions as measures to solve the problems. Instructive and introductory books have been published, though not many, and training classes have been provided since then.

(2) Codes and standards

There are three codes for prestressed concrete buildings in Japan: Guidelines for Design and Construction of Prestressed Concrete by the Building Center of Japan, Standard for Structural Design and Construction of Prestressed Concrete Structures (PC Standard) by the Architectural Institute of Japan (AIJ), and Recommendations for Design and Construction of Partially Prestressed Concrete (Class III of Prestressed Concrete) Structures (PRC Recommendations) by AIJ. The differences of their requirements and usages are confusing.

Unification of the PC Standard and PRC Recommendations, as well as separation of the design and construction requirements have therefore been proposed in AIJ but have yet to be realized. Nevertheless, new design recommendations applicable to both prestressed and reinforced concretes are being formulated in AIJ, unifying PC standard and PRC Recommendations. Also, there is another argument that design and construction requirements should not be separated, as these are inseparable in prestressed concrete, such as the calculation of statically indeterminate stress depending on the order of introducing prestress and construction.

(3) Design process

In contrast to reinforced concrete subject to structural design by the calculation of permissible stress, prestressed concrete is designed differently by the ultimate strength design based on stress by elastic analysis, being unfamiliar to general structural design engineers. Prestressed concrete construction requires the investigation into the stress during construction and calculation of statically indeterminate stress, which are complicated. Moreover, these processes are not included in integrated structural calculation computer programs, hampering easy access. This is a factor impeding the popularization of prestressed concrete construction.

When a new structural design based on Capacity Spectrum Method was introduced in 2000, it was expected that the difference between prestressed concrete and reinforced concrete would be reduced to the assumption of damping, leading to unification of their basic design procedures. However, recommendations for the design method for prestressed concrete have yet to be provided. No structural calculation computer program for performing the whole design process of prestressed concrete has been developed. A simple method of calculating the damping of an entire building from the damping of constituent members has not been established either.

(4) Anchoring methods

The anchoring methods for the design of prestressed concrete structures pose a problem that design engineers are not sure which anchoring method should be selected before the type and number of prestressing steel are decided. To cope with this problem, provisional design using multi-cables 12.7 mm in diameter is recommended, as these can normally be dealt with by any anchoring method. As countermeasures, the report proposed reorganization and coordination of anchoring methods and unification of the type of steel to be used. However, these can conversely limit the choices of structural engineers. It is urgently necessary to develop an appropriate manual to cope with this problem.

(5) Peculiarity of buildings

Generally speaking, only a small number of members among the structural members composing a building should be made as prestressed concrete members. Also, there are many details that are difficult to generalize in actual design, such as combination with reinforced concrete beams, level difference in a slab, the methods of opening holes through beams and calculating the load-bearing capacity, and the method of considering partial walls. Methods to cope with these situations have not been formulated into a manual.

Methods of designing holes through beams were included in the 1998 edition of the PC Standard, but other issues remain unimproved.

(6) Evaluation of prestressed concrete buildings

Prestressed concrete tends to be stereotypically connected with storehouses. It is seldom selected as a structural system based on proper evaluation of its performance and cost.

The use of precast prestressed concrete has recently been increasing for university buildings, etc. Its design and productivity have also been attracting attention since flat colunms were adopted at Saitama Prefectural University. However, it is necessary to intensify activities to raise awareness for the design versatility, structural performance, and durability performance of prestressed concrete.

(7) Use of precast members

While the use of precast prestressed concrete is increasing, the following problems of precast units are posed: It is rather difficult to decide all details at the design stage; and the construction cost is considerably unclear. The 1990 report already pointed out the necessity for organizing data that help actual design, including details and prices. Certain improvement has been made, but there is still much to be done.

(8) Unbonded system

The use of unbonded systems has been limited to beams and slabs other than earthquake-resisting elements, because the loss of the prestressing force due to steel rupture or anchorage failure can lead to the failure of members or even the entire structure.

However, the fact that the variance in the tensile force on unbonded prestressing steel is smaller than that on bonded steel and the improvement in the reliability of steel and anchors led to the revision of the notification on prestressed concrete construction in 2007. The use of unbonded prestressed members for such earthquake-resisting members as girders, colunms, and walls has become permitted provided that the system is designed by the structural calculation method introduced in 2000 based on Capacity Spectrum Method and that measures are taken to bear at least the long-term loads in the event of the failure of prestressing steel.

(9) Construction

The construction of prestressed concrete structural members is actually carried out by subcontractors specializing in prestressed concrete instead of general contractors. It is necessary for the widespread use of prestressed concrete to formulate a system whereby common general contractors can carry out the construction of prestressed concrete.

Twenty years now since the 1990 report, the circumstances surrounding prestressed concrete construction have not necessarily been improved, particularly in the architectural engineering domain.

5. Workshop at 2008 JCI Annual Convention in Kyushu

A workshop titled "Present and Future of Prestressed Concrete Technology" was held by the Committee during the 2008 JCI Annual Convention in Kyushu. It began at 9:30 Day 1 of the Convention with an address by Chairman Prof. Minehiro Nishiyama, quoting an article of *Scientific American*, "Concrete is made stronger by compression; steel, by tension. These opposing properties are combined to make a building material which is stronger than reinforced concrete and cheaper than steel alone. The combination is called prestressed concrete. Developed within the last few years, it is already recognized as one of the great advances in construction of the 20th century. Thousands of buildings and bridges have been built of it, and the manufacture of prestressed concrete in the U.S. is approaching a billion-dollar industry. It seems not too much to say that in construction we are passing from the age of steel to the age of prestressed concrete." He told the audience that the article was written 50 years ago and asked if the prediction turned out to be true. He went on to say, "Prestressed concrete is well-known in the civil engineering field, but its performance is underestimated in the architectural engineering field. How to popularize prestressed concrete in the architectural engineering domain is a subject of this workshop."

In Part 1, three people spoke to introduce the state of cutting-edge research and practice of prestressed concrete technology.

Prof. Hitoshi Shiohara of the University of Tokyo reported a joint study with the Building Contractors Society (BCS), "Development of reinforced concrete office buildings aiming for the fusion of structural safety and production reasonableness"[1]. This study intends to break through the vulnerability of the system of technology clinging to the myth that offices should be made by steel construction and explores added performance/values to enhance the market competitiveness of reinforced concrete construction. These include lightweight floors; long spans; improved productivity, reparability, demolition performance; and damage control during an earthquake. Unbonded prestressed concrete post-tensioned framing with vibration control dampers was thus adopted for application to office buildings, with trial design of a typical model building and structural experiments being conducted. Problems were extracted and tackled through these development processes.

Dr. Masahiro Sugata, committee member, introduced "buildings by prestressed concrete block reuse system" proposed by Prof. Tadashi Nakatsuka, vice chairman. This is a construction system utilizing the unbonded prestressed concrete technique to achieve the reuse of members, whereby unreinforced precast blocks are assembled by prestress. They can be demolished and reused by releasing the prestress. Block joints using unwoven cloth were also developed and experimentally proven to achieve the required releasability as well as structural performance. The inclusion of detachable external dampers compensates for the weakness in unbonded prestressed concrete members with low hysteretic energy absorption. This building system has been proven technically feasible by verification tests for the structural members and ease of construction.

Dr. Akio Kasuga, committee member, reported on "hybrid structures for bridges," introducing a classification of hybrid bridges involving prestressing techniques and construction examples in Japan and overseas. Hybrid bridges are characterized by their lightweight and light impression of design. He showed the characteristics and examples of corrugated web bridges, composite truss bridges, space truss bridges, etc., as well as their changes over time. One of the problems in designing hybrid bridges is the differences between the design standards for concrete and steel. While these differences are planned to be resolved in the next revision of the Standard Specifications for Road Bridges, the selection of safety factors may remain a problem. Benefits brought about by a hybrid bridge include laborsaving, low costs, and weight reductions.

In the second part, a panel discussion was held with the following eight panelists: Mr. Hiroyuki Ueda, Mr. Kazunori Ohsako, Prof. Ichizo Kishimoto, and Mr. Satoru Fukai, committee members representing the architectural engineering field, and Dr. Akio Kasuga, Mr. Tadahiko Tsutsumi, Dr. Yuzuru Hamada, and Mr. Shuji Yanai, committee members representing the civil engineering field. They presented topics about the environment, cost issue, and education for prestressed concrete in architectural engineering departments in universities, as well as the durability of prestressed concrete and the review of grout control techniques initiated by a bridge collapse accident. The audience then joined the discussion, expressing their comments, such as "Prestressed concrete is not expensive in view of its durability," "Universities should educate students on prestressed concrete, if only a little," and "Use of prestressed concrete just once at a job site will make you a big fan."

6. Fundamental technology WG's report

The Fundamental technology WG, which works on Chapter **3** of the report, took up issues that are fundamental but have not been fully scrutinized. The planned table of contents for Chapter **3** is as follows:

3.1 Materials
- 3.1.1 Properties of prestressing steel
  - (1) Static tensile properties
  - (2) Relaxation properties
  - (3) Tensile properties at high temperatures
  - (4) Tensile properties at low temperatures
  - (5) Fatigue properties
  - (6) Corrosion resistance and hydrogen embrittlement (delayed fracture)
- 3.1.2 Sheaths
- 3.1.3 Concrete

3.2 Grout for prestressed concrete (PC grout)
- 3.2.1 Role and qualities of PC grout
  - (1) "Manuals for PC grouting" by the Japan Prestressed Concrete Contractors Association
  - (2) "Japanese Architectural Standard Specification for Reinforced Concrete Work (JASS5)" by AIJ
  - (3) "Standard Specifications for Design and Construction of Concrete Structures" by JSCE
- 3.2.2 Issues facing PC grout and current measures
  - (1) Issues derived from external factors, such as weather and construction season
  - (2) Issues related to materials
  - (3) Issues related to construction
  - (4) Issues related to sheath arrangement
  - (5) Issues related to construction machines
  - (6) Issues related to quality control/inspection
  - (7) Education/training of supervising engineers and workers
  - (8) Others

3.2.3 Differences and comparisons among standards

3.2.3.1 Qualities of grout

(1) Materials: Standards for water, cement, and chemical admixtures

(2) Fluidity: Standards, assessment test methods

(3) Chloride ion content: Standards, concepts, assessment test methods

(4) Bleeding ratio: Standards, concepts, assessment test methods

(5) Volume change ratio: Standards, concepts, assessment test methods

(6) Compressive strength: Standards

3.2.3.2 Quality control and inspection of PC grout

(1) General practice for quality control and inspection (quality and grouting work)

(2) Inspection frequency and quality control methods

(3) Inspection methods (before, during, and after grouting): Inspection techniques after grouting

3.2.4 Strength of PC grout

(1) Compressive strength

(2) Tensile strength

(3) Young's modulus

(4) Bond strength

3.2.5 Representative PC grouts (products) in Japan

(1) Types and characteristics

- High viscosity types
- Low viscosity types
- Ultra-low viscosity types
- Intermediate types
- Highly thixotropic types, etc.

3.2.6 PC grout for various structures

Ground anchors, prestressed concrete containers, shields, etc.

3.3 Durability

3.3.1 Design and verification against chloride attack

Current state of design and verification regarding durability, particularly against chloride attack, in architectural and civil engineering fields

3.3.2 Policies and strategies for ensuring durability in prestressed concrete civil structures

3.3.3 Policies for ensuring durability in prestressed concrete building structures

3.3.4 Multilayer protection

Introduction of the concept of multilayer protection and problems of quantitative evaluation

3.3.5 Trends in *fib*

Background to Commission 9, proposal of protection levels and Japan's points of view

3.4 Fire resistance

3.4.1 Concept of fire resistance of prestressed concrete members

Residual prestressing tensile forces and residual load-bearing capacity of prestressed concrete members after fire

3.4.2 Mechanical properties of prestressing steel at high temperatures

3.4.2.1 Yield strength

3.4.2.2 Young's modulus

3.4.2.3 Creep and relaxation

3.4.3 Mechanical properties of concrete at high temperatures

3.4.3.1 Compressive strength

3.4.3.2 Modulus of elasticity

3.4.4 Fire resistance of prestressed concrete members

3.5 Crack width

3.5.1 Crack width and deformability of prestressed concrete beams

3.5.2 Crack properties of prestressed concrete beam-column joint panels

3.6 Load - deformation characteristics

3.6.1 Load - deformation characteristics of prestressed concrete members with bonded tendons

Identification of the characteristic points of cracking, normal rebar yielding, prestressing steel yielding, crush of cover concrete, crush of core concrete, buckling and rupture of normal rebars, (rupture of prestressing steel), etc.

3.6.1.1 Beam members in architectural engineering

Assessment of flexural load-bearing capacity incorporating the bond of prestressing steel

3.6.1.2 Bridges in civil engineering

3.6.2 Evaluation of residual deformation in prestressed concrete beams

3.6.3 Comparison of load - deformation hysteresis models for prestressed concrete beams

3.6.4 Load - deformation characteristics of prestressed concrete members with unbonded tendons

3.6.5 Energy absorbing capacity (equivalent viscous damping factor)

3.6.6 Mechanical properties of precast prestressed concrete columns

Flexural strength, skeleton curves, ultimate shear capacity

3.6.7 Comparison of load - deformation idealization of prestressed concrete members in the architecture and civil engineering fields

3.7 Bond

3.7.1 Bond properties of complicated systems comprising prestressing steel, grout, sheaths, and concrete

Bond stress-slip relationship of prestressing steel and ordinary rebars

Required bond performance

Bond strength and bond stress - slip relationship

3.7.2 Bond properties of prestressed reinforced concrete featuring fatigue

3.8 Future subjects and problems to be solved

Performance requirements for bond of sheaths and prestressing steel

Problems in inspection in the civil engineering field

The above-mentioned table of contents clarifies that architectural and civil engineerings are headed in different directions. Whereas the prestressing technique as such is regarded as having been nearly established in the civil engineering field, with the focus on durability, it is in the process of expanding the forms of use in the architectural field, with new structural systems being developed and precast systems being adopted. At the current stage, seismic resistance is particularly emphasized in the architectural field. PC grout has been attracting attention in the architectural field as well, due to reported prestressing steel rupture accidents. However, much of the discussion centers on the ease of secure grouting work rather than its long-term durability.

7. Next-generation technology WG's report

The Next-generation technology WG collected innovative next-generation technologies involving prestress. It also clarified fundamental technologies to serve as the foundations for next-generation technologies and summarized their linkages. The WG also formulated a database of representative structures constructed with prestressing techniques.

Chapter 4 of the report, which the Next-generation technology WG works on, is described under the table of contents (draft) given below. The database of representative structures involving prestressing techniques is included in Chapter 5.

4.1 Materials: New materials, HSC, HPC, HSS

4.1.1 Use of high strength/high performance concrete for prestressed concrete construction

4.1.2 High strength prestressing steel

4.1.3 New materials for prestressed concrete construction

(1) Coated prestressing steel

(2) Continuous fiber tendons

(3) Pretensioned prestressing steel units

(4) Other prestressing steel: Stainless prestressing steel, etc.

4.2 Construction methods

4.2.1 Precast prestressed concrete construction

(1) Erection and points of member connection

(2) Pretensioned members

4.2.2 Prestressed concrete with unbonded tendons

4.2.3 Precast prestressed concrete with unbonded tendons

(1) A project for office buildings to be designed and constructed of precast prestresssed concrete with unbonded tendons

(2) Prestressed concrete buildings to be designed and constructed of re-usable precast units

4.2.4 Prestressed concrete beams having large openings

4.3 Seismic resistance

Earthquake-resisting systems using prestress (structural systems achieving both small residual displacement and hysteretic energy absorption, such as the hybrid system of PRESSS)

4.4 Durability and maintenance

4.5 Environmental performance

4.6 Seismic retrofitting

4.6.1 Seismic retrofitting techniques in civil engineering

4.6.2 Seismic retrofitting techniques in architectural engineering

(1) External steel braces attached by post-tensioning

(2) External precast prestressed concrete frames installed by post-tensioning

(3) Precast concrete braces connected by post-tensioning

(4) Strengthening by wrapping of prestressing steel wire around columns

(5) Special strengthening methods

4.7 Cost-reducing effect

Instead of the "better but more expensive than reinforced concrete" argument, a more forward-looking discussion should be promoted, emphasizing that the use of prestressed concrete reduces the overall cost of structures.

4.8 Hybrid construction for bridges

4.8.1 Classification of hybrid bridges

(1) Corrugated steel web bridge

(2) Composite truss bridge

(3) Steel composite girder bridge

(4) Mixed bridge

4.8.2 Background to the development of hybrid bridges

(1) History of hybrid bridges

(2) Background to the development of corrugated steel web bridges

(3) Background to the development of composite truss bridges

4.8.3 Future hybrid bridges

(1) Hybrid bridges combining steel plates and steel pipes

(2) Hybrid bridges using steel plates like a butterfly

(3) Prestressed hybrid bridge piers

4.8.4 Subjects and future prospects of hybrid bridges

The Committee report will be distributed at the symposium scheduled for October.

8. Education of prestressed concrete construction

To answer the question how many universities teach prestressed concrete structure, committee member Prof. Ichizo Kishimoto and others surveyed the course syllabuses of major universities and technical colleges made public on the Intemet. As a result, three out of 37 universities and technical colleges were found to provide a course titled "Prestressed concrete structure" solely for prestressed concrete construction. Several others teach prestressed concrete as part of reinforced concrete structure or one of the structural systems. It was thus revealed that not many universities and technical colleges provide classes on prestressed concrete construction.

Not only activities to educate and raise awareness of structural engineers but also education at universities and technical colleges are essential to popularize prestressed concrete construction.

9. Summary

The goal of the Committee was to summarize and review the progress of prestressing techniques over the last 20 years since the Technical Committee on the Applicability of Prestressed Concrete summarized its report in 1990. As described in Section **3**, few points have been improved among the issues pointed out 20 years ago. The superiority of a technology is one thing and whether it becomes widespread is another. The research activities of the present committee may be examined 20 years later. The committee hopes that improvements will be achieved by then in even the slightest terms.

References

1) H. Shiohara, O. Chiba et al. : Development of a Large-Span Precast Concrete Structural System with Ease of Construction using Prestressed Connections (Part 1: Objectives and the Research Program ~ Part 11: Verification by Dynamic Response Analysis(2)), Summaries of Technical Papers of AIJ Annual Meeting (Chugoku), pp.651-672, September 2008 (in Japanese)