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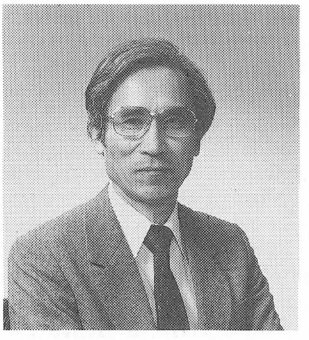
MODERNIZATION OF THE DECK WORKS AND PRESTRESSED CONCRETE PANEL COMPOSITE SLAB METHOD



Akira WATANABE*

SYNOPSIS

Recently in Japan, as large scale construction are increasing, while skilled labors are seriously in shortage, it is necessary to elaborate the form work construction.

If the forms, which are made of precast prestressed concrete and will not be removed later, have enough strength to support the weight of concrete placed on them, staging or intermediate supports can be neglected. This method is commonly called PCC SLAB Method and the characteristics of the slab with less crackings and small deflection for short and long terms loading is noteworthy. The problems regarding its applications have been clarified through various experiments carried out by the author and others.

Engineering progress of the deck works are briefly reviewed and many kinds of the PCC Form Panels and their applications to both civil and architectural engineering constructions are shown in this paper.

A. WATANABE is a professor of civil engineering at Kyushu Institute of Technology, Kitakyushu, Japan. He received his Doctor of Engineering Degree from Kyushu University in 1965. He is a chairman of JSCE Committee on the PC Composite Slab Method. His research interests include repairs of concrete structures, fatigue properties of PC composite slabs, connecting technique of precast concrete members in water for sea structures and design and construction method of PC cable-stayed bridge. He is a member of JSCE, JCI, JSMS, AIJ, and PCI.

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1. INTRODUCTION

Japanese technology has developed in constructing high level infra-structures under unfavorable conditions such as earthquakes, typhoons and also having poor foundation, since the end of world war II. The reputation for the Japanese technology in the civil engineering field is high in the world. The amount of concrete structures built within ten years of highly developed time in Japan is almost equal to that of 100 years in Europe. Now the defects due to the rapid and abundant construction has surfaced recently. No one can deny that the concrete construction based on elaborate placing, vibrating and curing has been made light of, because of procurement difficulties of construction sites. This purchasing matter has a famous saying that "the construction is almost over if the procurement of land is successful". Another difficulty is rapid and economic execution for limited construction period and environmental pollution controls. It was a heavy blow that the steel corrosion due to chlorides of sea sand and the deterioration due to Alkali-Aggregate reaction have exposed in concrete structures. Furthermore, NOx, SOx and acid rain can be an another causes of deterioration of concrete structures.

The deck slab of road bridge is a member which is subjected to remarkable frequency of complicated repeating loads. Reinforced concrete deck slabs of steel bridges of Tomei and Hanshin highways which were constructed with design condition of slab thickness 16–18 cm and less amount of distribution re-bars before 1973 were reported to be much damaged.

The road network in European countries and America were arranged actively in 1950–1970 era and also many bridges were constructed. Most of the engineers engaged to the bridge construction were less experience for the construction of new bridges and the maintenance and rehabilitation of old bridges. As the rapid execution was of much importance in those days, consideration for long term planning was not made. The corrosion of re-bars are due to the usage of salt for the protection of freezing and thawing on road surface and especially, worsening conditions came from large-sized heavy weighted vehicles. The above circumstances have shortened the normally expected life of bridges. The net work of freeways in which the United States is proud of, develops serious symptoms of deterioration. The Ministry of Transport of the United States reported four years ago that the structural defects was admitted in 250,000 bridges corresponding to 45% of the total, which means they have rushed into the era of deterioration.

In Japan, boat people ashored in succession, and this has caused political problems seriously. Mass media reported that these boat people are fake refugees with an intention of working in Japan. The magazine "NIKKEI CONSTRUCTION" reported that the salaries of construction workers in Japan are getting very high because of aging (average 50 years). Also reported in the same magazine, a cause of labor shortage in construction is flowing of workers to the large manufacturing industries such as automobile, electrical plants where they recruit labors with higher bonuses and fringe benefits.

So far, the Japanese construction industries have achieved satisfactory results such as construction of "Shinkansen" (super express railway), Honshu-Shikoku Bridges and high rise Intelligent Buildings. However, under the basic constitution, the Japanese construction industries are still depending strongly on human resources. Upon their constitution of receiving the contract order, they must admit that they are facing the serious labor shortage situation.

Photo 1 showed an example of slab construction by conventional method, this intricate supporting system brings negative impact to the construction. The ACI committee has pointed out ever that the expense of staging and form work have reached to 35–60% of the total cost in construction. To solve the above mentioned factors it is necessary to rationalize and modernize the conventional slab method.

A composite slab method is the new one to improve the conventional slab method. This method adopts the following concepts: (1) the slab is separated into two parts, precast part and cast-in-place concrete part. (2) the precast part is used as support as well as form-work, for the cast-in-place concrete. (3) finally the composite member (precast part + cast-in-place concrete part), resists the external force.

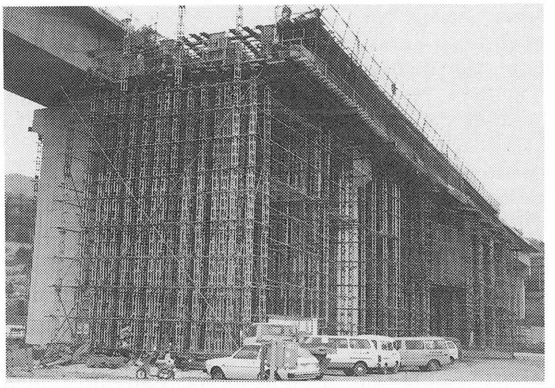

Photo. 1 Conventional Complicated Staging and Form Work

In this paper, firstly, the road bridge's damage patterns are shown and their damage mechanism are analyzed, then review on various composite slab method made. The Prestressed Concrete Panel Composite Slab Method is treated exhaustively.

2. PATTERNS AND MECHANISM OF DAMAGE IN ROAD BRIDGE DECK SLABS[2)]

(1) Type of slab damage

There are four major types of deterioration:

a) Turtle shell type crack propagation and followed by spalling
b) Delamination of top cover of concrete
c) Damage at construction joint
d) Defects due to poor execution of works and other causes

Focusing upon the development and propagation of cracks and examining in the case of one way slab, in which the main re-bars are placed at right angle to the traffic direction, the following patterns are pointed out (ref. to Fig. 1).

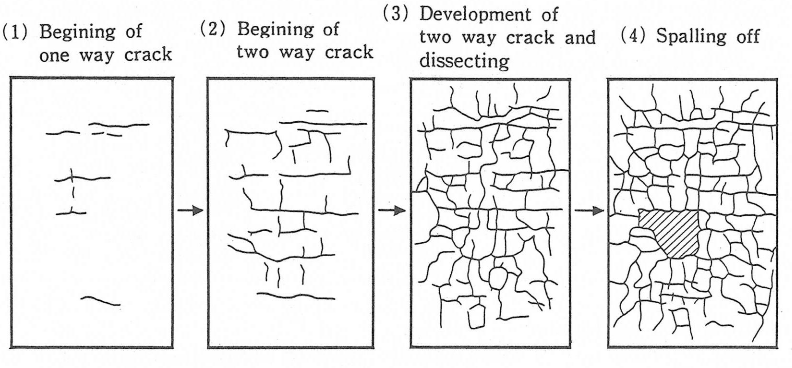

Fig. 1 Development of Cracks (serial)

1) Cracking in the direction of main re-bar
2) Cracking in the direction of distribution re-bar (anisotropic nature)
3) Cracks extend to both direction all over the slab
4) Crack width and depth increases respectively. Corner failure and abrasion accompanied
5) Cracks penetrate throughout the slab, water percolate into the cracks produces dissolve carbonates extrusion
6) Fixing of crack density after hexagonal shape cracks of 20 to 30 cm are formed (crack density = the total length of crack having width greater than 0.1 mm per unit meter square)
7) Powder from abrasion inside cracks extrude, re-bar separating from concrete, sectional shear resistance looses and finally patch delamination.

(2) Factors of crack development in deck slab and its damage mechanism

a) Insufficient amount of distribution re-bar
In spite of the fact that considerable amount of bending moment are distributed in the direction of bridge axis the amount of distribution re-bar required was only 25% of main re-bar, according to the specification made before 1967. In the year the Director-General of Japan Road Bureau issued the guidance to increase the amount of distribution re-bar (Table-1). Cracks are formed in the direction of right angle to the bridge axis, then cracks followed in the direction of bridge axis due to an anisotropic nature. This is the reason why cracks are propagated in both directions.

Table 1 Transition of the Standards for Design of Reinforced Concrete Floor Slab of Steel Bridge

Subject \ Date of Enf.		March. 1958	October. 1964	Sept. 9. 1967	May. 1968	August. 1968	Jan. 1970	Mar. 18. 1971	Apr. 25. 1972	February.1973	Apr. 13. 1978
Standards and Specifications		Design Manual for Welded Girder Bridge (Provisional application of specification)	Design Manual	Guidance on the distribution bars in RC floor slab of steel highnay bridge-Dir.Gen.Road Bureau	Provisional standard on desigh of floor slab of steel highway bridge (draft)	Prans of structure IV (steel highway bridge)	Design Mannal part 2	Design of RC floor slab of steel highway bridge. Dir. Gen. Road Burean	Design Manual Part 2 Revised edition	Specification of highway bridge	Design of RC floor slab of steel highway bridge. Guidance by Dir. Street Div. & Dir. Road Plan Div.
Details	wheel load (tf)	8	→	→	→	→	→	9.6	→	→	→
Details	impact coeff.(i)	20/(50+l)	→	→	→	→	→	Bending moment due to impact is included in design moment			
Details: allowable stress	concrete (kgf/cm²)	$\sigma_{28}/3$ 60	→	→	→	80	80	→	$\sigma_{ck}/3.5=68.5$ specitication highway $\sigma_{ck}=240$	→	→
Details: allowable stress	re-bar (kgf/cm²)		SD30…1 800	→	SD30…1 400	SD30…1 500	SD30…1 500	SD30…1 400	igwa →	→	→
Details	minimum thickness of slab (cm)	14	→	→	16	16	16	$3l+11\geqq16$	18	→	$d=k_1\cdot k_2 d_0$ 18
Details: bending moment due to LL at mid span	main re-bar (tf-m)	$\frac{0.4P(1+i)(l-1)}{l+0.4}$	→	→	→	→	→	$(0.12l+0.07)\times P\times0.8$	→	→	→
Details: bending moment due to LL at mid span	dist: re-bar (tf-m)	25% of amount of main re-bar	→	70% mid-span 35% support	→	→	→	$(0.10l+0.04)\times P\times0.8$	→	→	→
Remarks			·Establishments of Manuals on deformed bars	·Increment of amount of distribution re-bar	·Reduction of allowable stress of SD 30	·Increment of allowable stress of concrete, ·Establishment of allowable stress of SD 30		·Increment of wheel load considering traffic amount Change of calculation method for bending moment (increase of design mom.)	·Reduction of allowable stress of ·concrete Increment of slab thickness		·Supplement of traffic amount and additional bending moment

b) Insufficient stiffness of main girder
The moment due to the deflection of main girder is added to the primary moment of the deck slab in the direction of bridge axis. Therefore cracks in the direction of right angle to the bridge axis is likely to be accelerated. In the case of continuous beam and Gerber beam the above phenomenon sometimes causes cracking around the ends of the beams.

c) Insufficient thickness of deck slabs
As the priority was given to be economic in construction of deck slab design during 1955 to 1965, the allowable stress became larger and the dead load was reduced, therefore many slab with smaller thickness appeared. Consequently many cracks developed in the deck slab and leads to its deterioration. Taking the above matter into consideration the decrease of allowable stress and increment of slab thickness were adopted to the design code for road bridge in 1973.

d) General uneven settlement of main girders
In the case when the deck slabs are supported on more than three main girders, bending moment due to the uneven settlement is added to the primary one. Especially in the case of fewer cross beams, additional moments described above causes the structure to have more cracks in the bridge axis direction.

e) Combined effect of torsion and uneven settlement of main girders
When there are few or no cross beams, torsion and uneven settlement may take place easily. Especially in the T-girder bridge, cracks are liable to be occurred along haunch.

f) The effects of alternating shear and percolating water
The Concrete Laboratory of Japan Highway Public Corporation executed the great deal of test on repeated loading with changing loading points. From the test, it was found that the cracks penetrate throughout the slab then rain water pass into it, weakened the section by alternating shear hence abrasion is accelerated. This is thought to be the main reason of shear resistance reduction of the very section.

Dr. Sonoda, K.[3] carried out the test on the above matter with special apparatus which he devised, for repeated loading with changing loading point. From the experiment the crack patterns after the static loading and cyclic loading are shown in Fig. 2 (a) and (b) respectively. From the figures it is found that the cracks for the former case, propagates radially and that for the latter, developed grid and turtle-shell shapes.

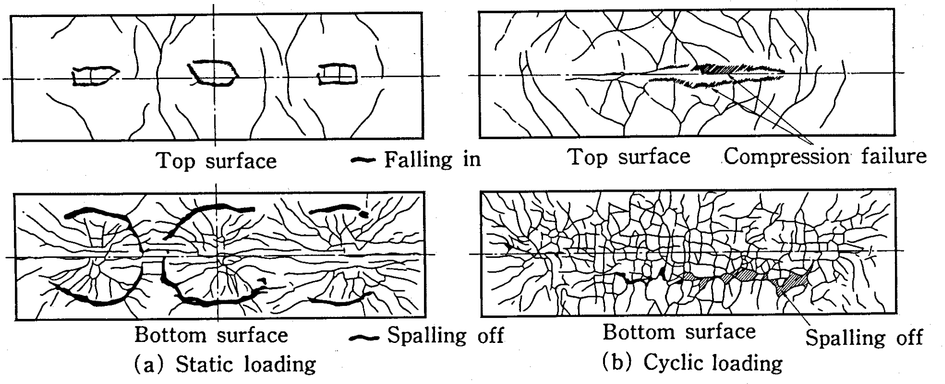

Fig. 2 Crack and Failure Mode

The authors also carried out similar test and confirmed that cracks can penetrate through the slab even under a few repeated loading.

3. REVIEW ON VARIOUS COMPOSITE SLAB METHOD[4)]

In composite slab method, precast part encountered two cases, one with the case of steel members, another with concrete members. Especially the latter is called commonly as "Half Slab Method" and recently used widely. Now the merits of the half slab method are as follows:

a) This method is more economical because the upper portion uses ready mixed concrete. (the concrete for precast portion is more expensive)
b) The unevenness in setting of precast panels is naturally adjusted while placing cast-in-place concrete.
c) The cover thickness can be secured by the use of precast slab and the higher durability can be attained.
d) As this method is carried out simply and repeatedly, the effect of proficiency can rise. A safe and rapid execution is possible consequently.

Precast panels in the half slab method are, Shütahl panel, Omnia panel, prestressed concrete panel, spancrete panel, Picos panel and the improved one using double "T" shaped etc.

(1) The case, when precast part is made of steel

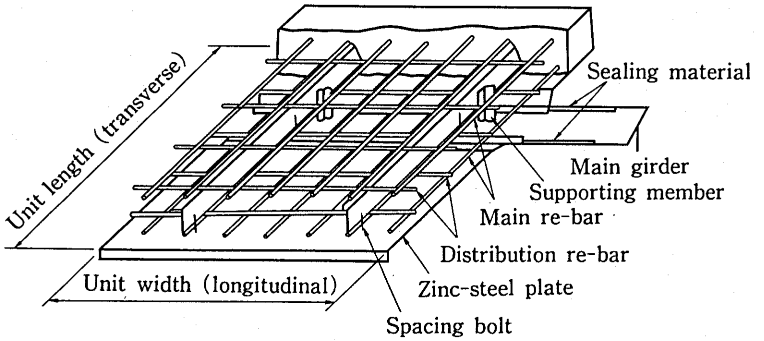

Fig. 3 Steel Form Unit Slab

Fig. 3 shows the steel form unit slab developed by the Japanese Ministry of Construction research fund. By the use of this slab, most of work at construction site can be reduced remarkably. So the work at site is only setting the grillage unit and placing concrete.

Fig. 4 shows the example of steel grid slab. Fig. 5 shows the deck plate slab using corrugated typed steel plate as dead-form (no dismantling) which is mainly used in architectural field. To increase the fire proofing asbestos and lath lining are commonly used. (NOTE) In the case that steel plate is used both as form and tension reinforcement, as explained in Para 2.(2)f and shown in Photo 2, steel plates at the bottom are likely to be corroded by the rain water seeping through cracks. For instance, to increase the resisting moment of the deck slab of formerly constructed bridges of Highways in Japan, plates are fixed at the bottom but these plates were also corroded due to the same reason as described above. This is the very reason why half-slab method is widely used.

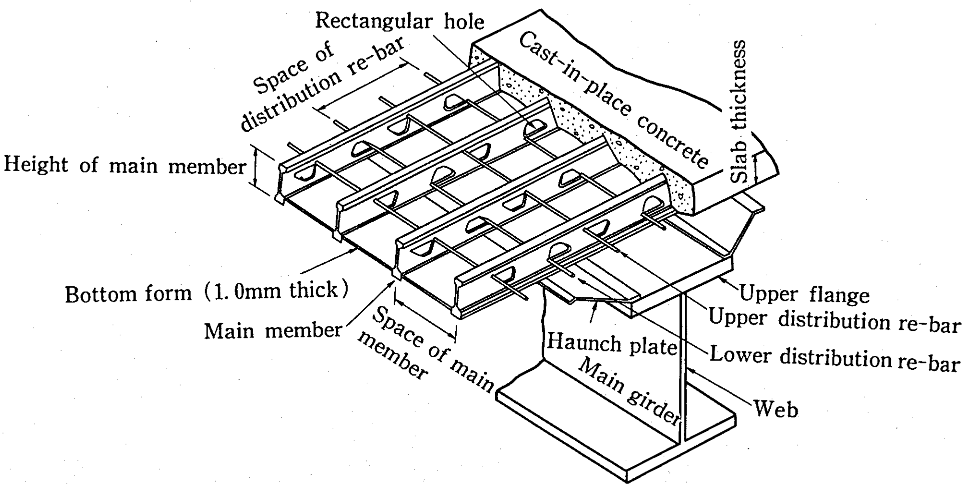

Fig. 4 Steel Grid Slab

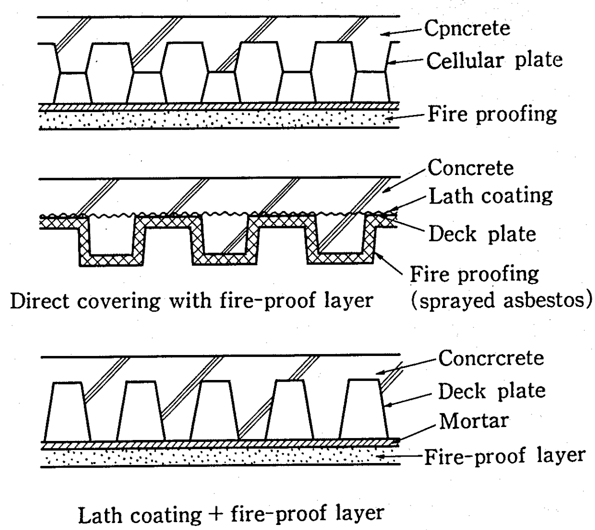

Fig. 5 Deck Plate Slab

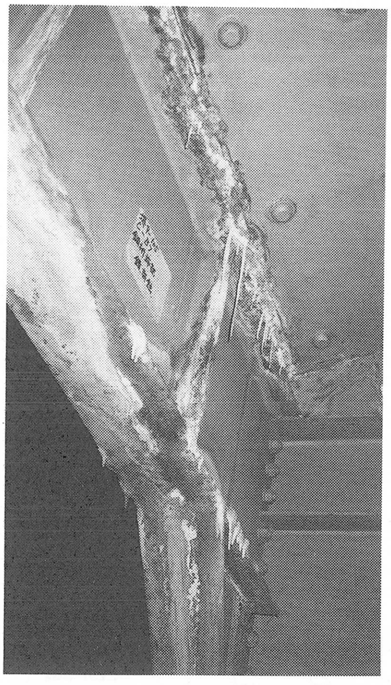

Photo. 2 Example of Leakage and Corrosion of Steel Girder at the Bottom

(2) The case when precast part is made of concrete

a) Shütahlton Slab Method

It is said that the weight of an ordinary reinforced concrete slab is more than 22% of the total weight of a building. Since the demand for reducing the weight of slab was high, the Shütahlton slab method, developed in Switzerland came into use. In this method multigrooved plates made of kiln dried clay and hollow tiles were used. In the grooves prestressing wires were inserted and filled with concrete mortar later. After hardening of mortar prestressing was done. The prestressed unit and hollow tiles were arranged as shown in Fig. 6, and finally cast-in-place concrete work was done. This method had been widely used in Europe.

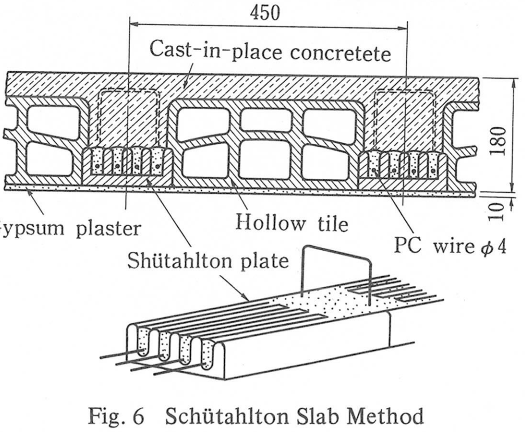

Fig. 6 Schütahlton Slab Method

b) Omnia Slab Method and its Improved Method

Omnia slab method developed in West Germany is old and historical, it is used internationally in the field of architecture (ref. Fig. 7). Omnia slab is produced by embedding the lower chord of omnia truss made of re-bar into concrete with the thickness of 4–6 cm and unifying with cast-in-place concrete. This Omnia slab has achieved satisfactory results in fire-proofing and durability. Prestress is sometimes introduced to the section, to cope with long-term deflection and crack, in two ways. The former is done by prestressing PC strands embedded in the precast slab, and the latter is by giving pre-camber to the Omnia truss.

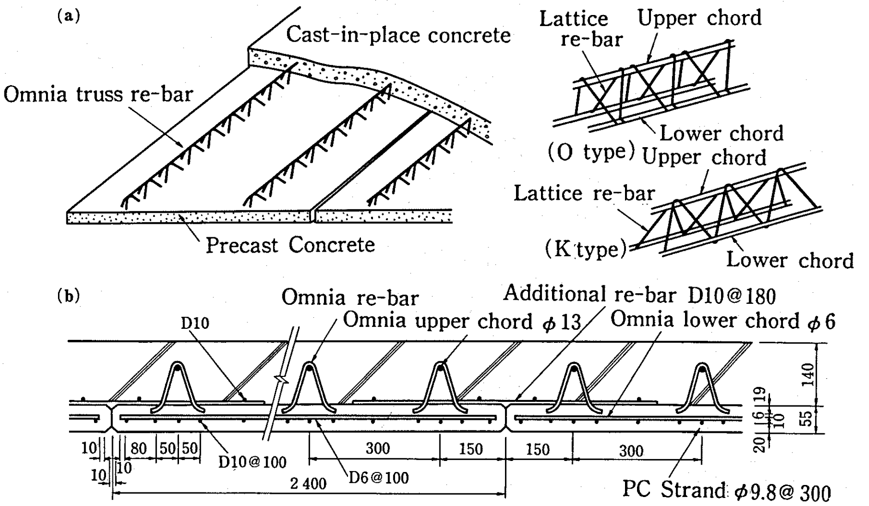

Fig. 7 Omnia Slab Method

c) Spancrete Slab Method

Spancrete member is one of the hollow-typed PC plates. This method is executed by laying the spancrete member with circular shear cotter (ϕ25x7 mm, 600/m^2) on a beams and placing cast-in-concrete (Fig. 8). Since it is a hollow type section, the dead weight is reduced and the merits against long term deflection and cracking can be obtained.

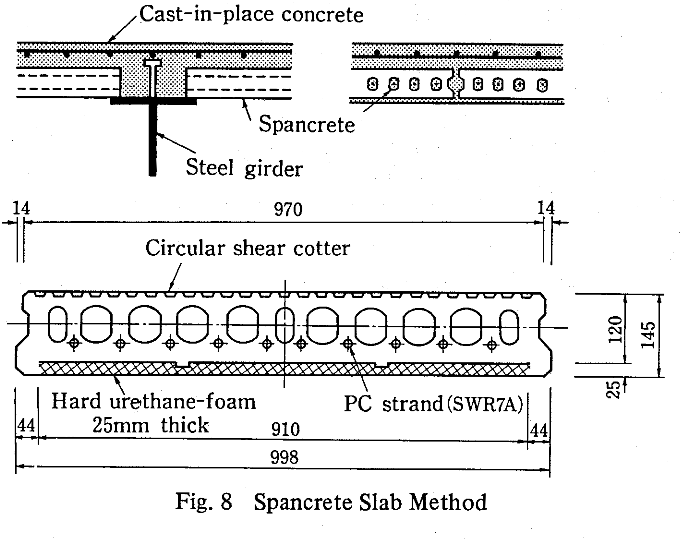

Fig. 8 Spancrete Slab Method

d) PICOS Method[18)]

PICOS method is the abbreviation of Precast Insiteplaced Concrete Slab Method. This is not the method of unifying many small precast concrete panels and cast-in-place concrete as described above. This is executed on the basis of "one grid-one panel system" as shown in Fig. 9. This PICOS panels (reinforced concrete, with shear cotter of 80x80x8 mm) are made in the construction sites and stocked in layers. Installation is done by traveling cranes having sucking-disk.

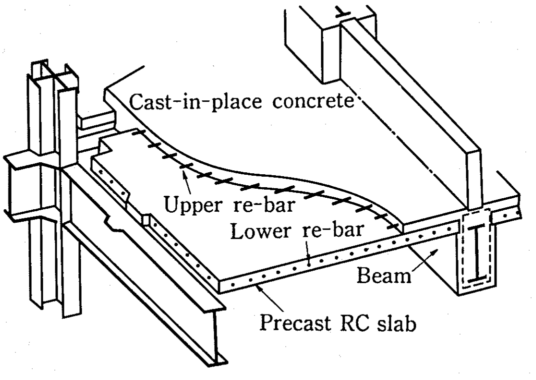

Fig. 9 PICOS Method

4. PRESTRESSED CONCRETE PANEL COMPOSITE SLAB METHOD

(1) Methodology and the Establishment of Specifications

Fig. 10[5)] shows the typical cross-sections of Flat Panel, Rib Panel, Hollow Panel, Channel Panel etc., Responding to the required span, the selection is made from sections shown in the same figure.

First, these prestressed concrete (PC) panels are laid on the main girders, then the distribution re-bars are placed on them and concreting is made. Then the PC panels and cast-in-place concrete formed the composite slab section and resist load as an unit body. This is the basic principle of this method. Now, these slabs are used as bridge decking and floor slab in building. The general concept of application to bridge and building are shown in Figs. 11, 12 respectively.

The author's research on PC composite slab embarked from the test of PC composite beam which he carried out in 1956. Another thrust was to cope with the strong demand for the modernization of the deck works which was to be done rapidly under the condition of decreasing construction workers. The reason[6)] why the author named this method "Stagingless Live Form Method" was to express the real indentity of omitting staging and using the forms as working member.

In order to promote the wide use of this method, "The Recommendations[7)] for design and Construction on Prestressed Concrete Panel Composite Slab Method" was made in February, 1987 by the concrete research sub committee of JSCE. (chairman, A. Watanabe)

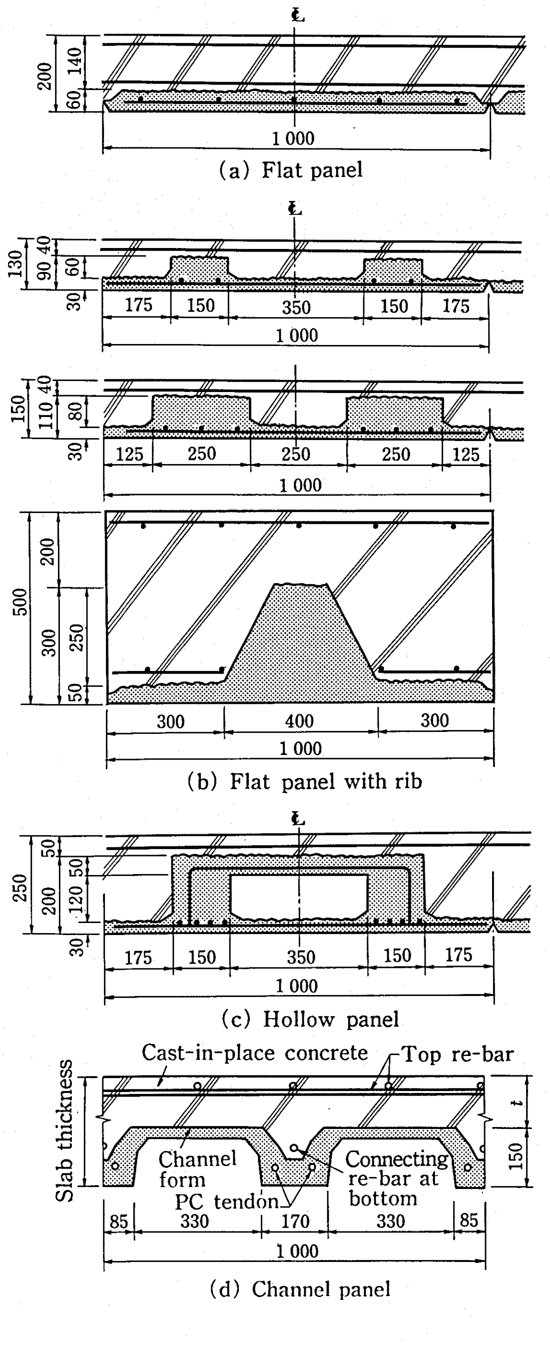

Fig. 10 Type of PC Panels

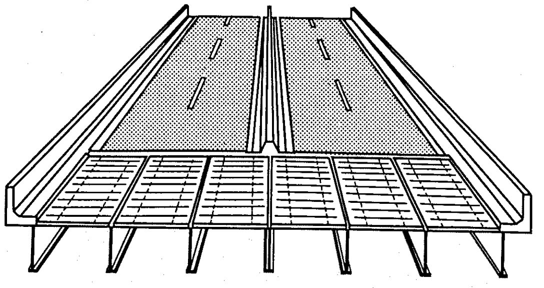

Fig. 11 General Layout of PCC Slab Method to Bridge

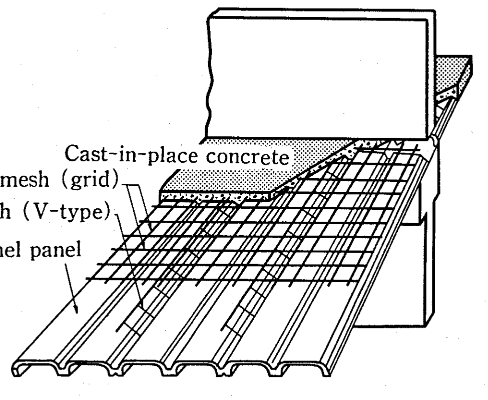

Fig. 12 General Layout of PCC Slab Method to Building Floor

(2) Major Problems Encountered in this Method and its Solution

[1]: Whether shear resistance of the interface between panel and cast-in-place concrete is sufficient or not. [2]: Whether this slab can be analyzed as an isotropic one in spite of having butt-joint between PC panels or not. [3]: In the case when precast panels are laid on the continuous girder at support, in the anchorage zone of PC wire of panel, the tensile stress due to negative moment is added to the primary hoop tensile stress, whether these stresses will cause cracking or not.

The above [1], [2] and [3] problems were studied theoretically and experimentally and the following results were obtained.

Research and results on the problem [1]

The PCC beam test specimens were made with prestressed concrete panel and cast-in-place concrete, RC beam test specimens were made using only cast-in-place concrete and their sections are shown in Fig. 13. Types and number of specimen are shown in Table 2. Horse shoe shaped dowels of ϕ13 mm were embedded at the both ends distance of 30 cm in series B, C and E.

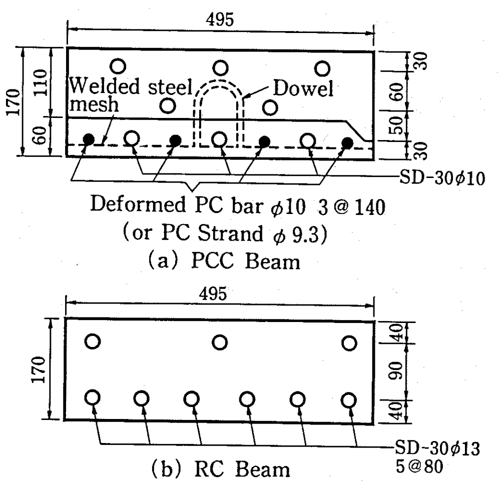

Fig. 13 Cross-section of Beam

Table 2 Series of Beam Specimen

Sym.	Number of specimen	PC Tendon	Number of dowels	Construction joint
A	7	PC deformed bar	0	common
B	7	PC strand	2	common
C	7	PC deformed bar	2	mould oil sprayed
D	7	Reinforced concrete		
E	7	PC deformed bar	2	common

In "C" series specimen, mold oil was sprayed over the PC panels a day before placing cast-in-place concrete. This was made to investigate the shear resistance under the possible worst condition in construction site.

Two point equally spaced loading was applied to the specimen which was simply supported. In the fatigue test, the maximum and minimum applied load were (45% to 80%) and 8% of the static failure load respectively.

The cracking load of PCC beam was four times that of RC beam and was also double the design load 3.2 tf, 2.1 tfm/m).

"A" and "B" series of PCC specimen failed by yielding of PC tendon at the load of 22 tf without any defect in bond and horizontal shear.

"C" series of PCC specimen failed by delamination of the interface between precast and cast-in-place parts at 8 tf (about 5.6 times the design load) and finally dowels were uprooted. In the RC specimen the yielding of re-bar started at 11.5 tf and followed the successive deflection and failed at 13.5 tf. The fatigue test results are shown in Fig. 14.

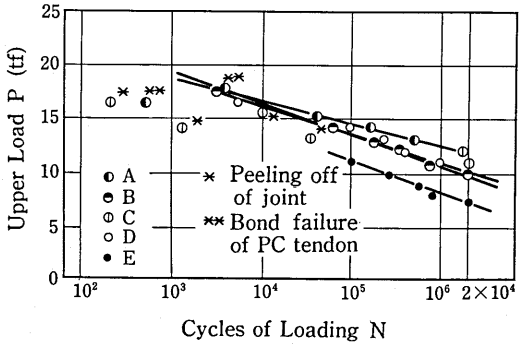

Fig. 14 Fatigue Test Results of Composite Beams

"A" series specimen applied with upper limit load of 17.5 tf (80%) and 16.4 tf (75%) failed due to slippage of tendons. "C" series specimen with 13.2 tf (60%) failed by delamination. "B" and "E" series specimens failed by fatigue fracture of re-bar and that of PC tendon followed.

All of "D" series (RC) specimen failed by fatigue fracture of re-bar. Fatigue limit for 2 million cycles of PCC beam specimen was (10–11.5 tf, 6.6–7.7 tf m/m). This load was 1.4 times the fatigue limit load of 7.4 tf (4.9 tf m/m) of RC specimen and about 3.5 times the design load.

Next, a fatigue test was carried out keeping the upper and lower limit load of 3.2 tf (corresponding to the design load) and 0.5 tf, respectively. Consequently, after running 600,000 cycles with 8 tf (corresponding to 3.5 times the design load), the relationship of the load-deflection was found to be non linear. From the above result[5,6], this PCC beam showed favorable behavior in cracking. Prestress of the panel was working effectively in the PCC beam. Therefore it was concluded that PCC beam behaved like a PC beam and its resisting capacity was practically enough to the design load.

The analysis was done on hypothetical slab models with sides ratio 1:3 and three different thickness of cast-in-place concrete, in the case of shear force dominated loading. The analytical results of maximum horizontal shear stress at interface was 4.01 to 6.74 kgf/cm^2.

On the other hand it was experimentally found[8] that the horizontal shear strength was more than 10 kgf/cm^2 in the case when mesh-type deformations on the PC panel were made and more than 19.6 kg/cm^2 in the case when identations with 4 mm transverse ditches on the panel. From the above results it was concluded that PCC slab was sound for fatigue in the case of deformation with 4 mm transverse ditches.

Concerning the horizontal shear capacity, some reports[9] stated that PCC beam showed no failure after 5 million cyclic loading on two span continuous beam specimen. AASHTO also stated that there was no problem[10] at all in horizontal shear capacity under cyclic loading in the case just by roughening the top surface of PC panel.

Research and results on the problem [2][11,12]

The dimension of the test specimen was determined as 2 m span, 1.8 m wide and 17 cm thick and was designed as one way slab in 2nd class bridge. The details of its cross-section is shown in Fig. 15. The PCC slab was made with 4 PC panels of two 50 cm and two 40 cm width, to investigate the effect of existing lateral butt-joint. The plan view of the specimen with its loading position were shown in Fig. 16. The loading was applied in sequence as numbered to resemble the alternating shear loading. The load of 8.0 tf, corresponding to T-20 type vehicle rear wheel load was applied on 20 cm

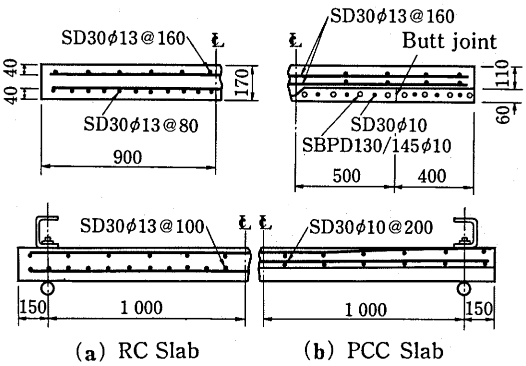

Fig. 15 Cross Section of Slab Specimen

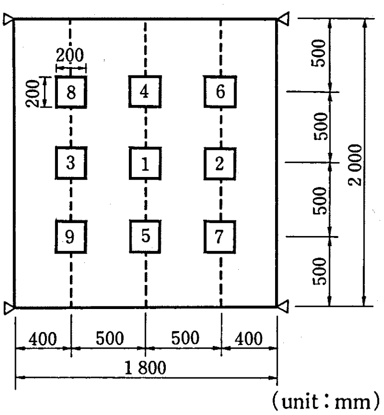

Fig. 16 Repeated Loading Test with Changing Loading Point

square on the top of slab specimens, keeping the lower limit load at 0.5 tf. Cyclic loading of 10,000 was applied to every position in sequence. This was continued until the accumulated cycles reached 2 million.

As the results of this experiment, it was found that the residual deflection of PCC and RC slab was 0.8 mm and 3.8 mm respectively, after 2 million cycles of sequential loading. Again the mid span loading of 8.0 tf was done and its deflection curves were shown in Fig. 17. From this figure, it is clear that deflections of PCC slab in both longitudinal and transverse directions were about one-half that of RC slab. It is also cleared that there was no problem on existence of butt-joint between panels.

With the aim to investigate the effect of lateral butt-joint at the bottom surface of PCC slab, the deflection of the specimen at span center was calculated theoretically by FEM method assuming it as isotropic and was compared with the experimental one after 2 million cycles of loading of 8 tf. When coinciding the corresponding values at mid-span, it was found that the both deflections agreed well as shown in Fig. 18. This result also shows that butt-joint can be ignored.

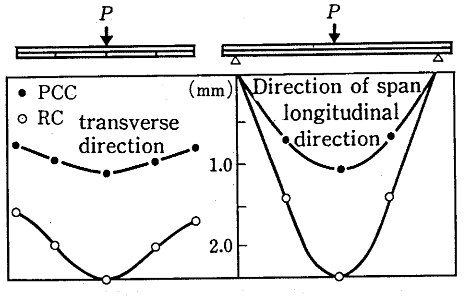

Fig. 17 Deflections after 2 Million Cycles of Loading

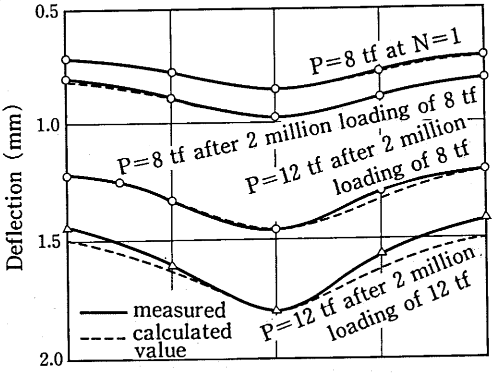

Fig. 18 Comparison between calculated Values by FEM Method and Measured Values (central loading)

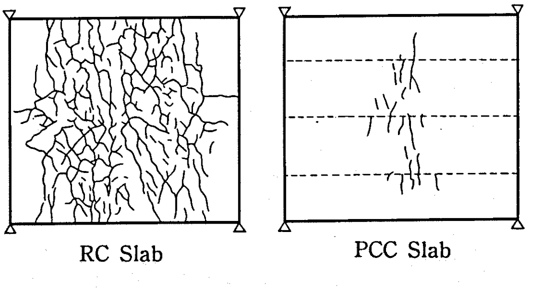

Fig. 19 Comparison of Cracks at the Bottom of Slab

Fig. 19 shows the crack at the bottom surface of RC and PCC slabs. Obviously PCC slab had much lesser cracks than RC.

Further more, to investigate the least possible thickness of cast-in-place concrete part of PCC slab, the slab specimen having PC panel and cast-in-place concrete of equal thickness (7 cm) was fabricated and tested[13].

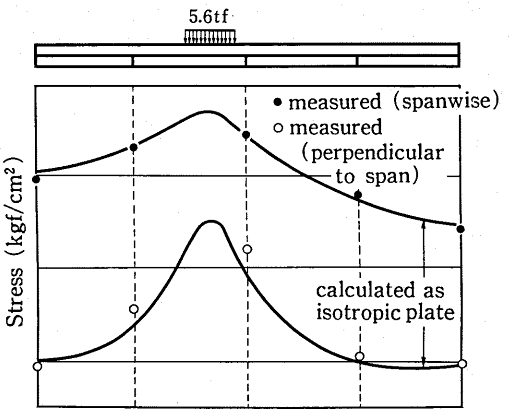

Fig. 20 Stress Distribution on the Top Surface of PCC Slab

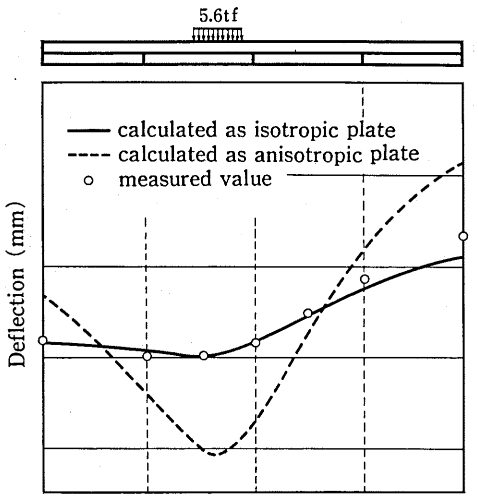

Fig. 21 Deflection of PCC Slab (perpendicular to span, butt joints exist)

Fig. 20 and 21 show the stress distribution on the top surface and deflection curves respectively. When 5.6 ton (corresponding to rear wheel load of T-14) was acting near the center of the specimen. In Fig. 21, calculated deflection values in the direction at right angle to the span assuming PCC slab as an isotropic plate and using the overall thickness of 14 cm, are shown in solid line. And the calculated values assuming PCC slab as an anisotropic plate and neglecting the thickness of PC panel were also shown in dotted line. Young's modulus and Poison's ratio of concrete used in this calculation were taken as 3.0×10^5 kgf/cm² and 0.17 respectively. From the results, it was found that the calculations made as an isotropic plates can be practically used. According to the recommendations on PCC slab method, the minimum thickness of cast-in-place concrete is required to be 1.5 times that of PC panels of PCC slab.

From the above results, designing the PCC slab as an isotropic plate was satisfactory. In United States, large scale prototype tests were carried out in Texas[14], and reported as follows:

1. The bond at interface between the prestressed precast panels and the cast-in-place concrete performed without any indication of distress under the cyclic design loads and static failure loads.
2. Wheel loads were transferred and distributed across transverse panel joints in a satisfactory manner.

Research and results on the problem [3]

Hoop tension due to anchoring of tendon for various diameter was calculated and added them the tensile stress produced by negative moment at support section of continuous girder. Then this was compared with the tensile strength of concrete, and it was found that when using PC tendon up to 9.3 mm diameter, by the help of sandwich effect due to negative re-bars and main girder, there were no problem.

On the other hand, lateral bending test executed by The Japan Society of Material Science clarified that cracks formed suddenly in the case of using more than ϕ10.8 mm tendon. They concluded that tendons more than ϕ10.8 mm should be avoided.

(3) Design for PCC Slab Method[7,15]

a) Check Method on Serviceability of PC Panels
The provisions are as follows just after prestressing:

(i) the axial compressive stress due to prestress shall be less than 10 kgf/cm^2.
(ii) in the case when prestress and own weight of panel are superimposed, the minimum value of flexural compressive stress shall be more than 3/5 times the maximum value in the same section. In the case when effective prestress, own weight of panel, own weight of cast-in-place concrete and temporary load during constructions are super-imposed, the flexural compressive stress shall be less than 200 kgf/cm^2 and also flexural tensile stress shall not take place in concrete.

Generally higher prestressing force and larger eccentricity of PC tendon are recommended to the portion where flexural tensile stress acts under the working load, precompressive stress is required. The above provisions represent limiting conditions considering the protection against excessive camber and buckling in thin PC panels.

b) Check Method on Serviceability Limit and Fatigue Limit States of PCC Slab
There are three methods and one of them can be chosen.

A Method: This is the method which calculate precisely the stress of concrete, considering how precast panel and cast-in-place concrete can resist loads at each construction stage. This method allows the flexural crack of PC panel under working load and the check on flexural crack and fatigue of PC tendon shall be made. This method is more economical than other methods. However, the design calculation is the most complicated among them.

B Method. The calculating method of concrete stress is the same as A method. This method shall not allow the tensile stress of PC panel and can design the PC composite slab with excellent durability, consequently, the check on flexural crack of PC panel is not necessary. Also "no check on fatigue" is needed because the stress change in PC panel becomes small. And in a region where the positive bending moment acts, the required reinforcement which is enough to overcome tensile stresses in concrete is arranged. Calculations can be made considering that the gross area of PCC slab is effective according to the provision 11.3.1(3) of Standard Specification for Concrete, Part 1 (Design). But, in a region where the negative bending moment acts, the check on fatigue of PC tendon and flexural crack in cast-in-concrete should be done.

C Method: This is the simple calculating method, using the assumption different from the actual stress state. This method ignores the compressive stress remained in PC panel after the completion of slab construction. So this method assumes that all the compressive stresses in PCC slab before acting live load are null. Comparing to A Method, this may not be economical, but the design calculation is simpler.

c) Check Method on Ultimate Limit State of PCC Slab
The ultimate limit state for bending moment, axial force and shear force shall be examined in accordance with the concept described in chapter (6.2) (6.3) of Standard Specification for Concrete, part 1 (Design). And the ratio of design sectional resisting capacity against design moment, design shear force and design punching shear force shall not be lesser than structure factor γ_i (1.15), respectively.

(4) Applied Examples of PCC Slab Method[16)]

The Japan Highway Public Corporation applied PCC slab method with flat panel for the first time to Onitaka steel girder bridge in Keiyo highway and also Akechi continuous steel girder bridge in Chuo highway. The Laboratory of Concrete Section of the Corporation conducted the all-round investigation of Akechi Bridge which had been built 13 years ago and had 30,000 average vehicle per day. According to report, no discrepancy has been found. For reference, the size of PC panel used in this bridge was 2,450 mm long, 398 mm wide and 50 mm thick. And the prestress introduced was 40 kgf/cm^2 and 114 kgf/cm^2 to the top and the bottom fiber, respectively. The thickness of cast-in-place concrete was 180 mm, making the total thickness of 230 mm. Longitudinal re-bars of D-16 were placed with 120 mm pitch for the upper and 240 mm pitch for the lower in cast-in-place concrete. In those days, design concept was as follows. PC panel supported its own weight. But against the live load, the remaining section after neglecting the PC panel's resisted as reinforced concrete.

Then after, this method was applied to some bridges such as Konakadai[17)] bridge of East Kanto Highway (PC composite girder bridge, six main girders). This method succeeded recovering much delay resulted from the foundation work in residential area. PC panel used in this bridge was 1,000 mm wide. The effective prestress was 46 kgf/cm^2 using PC strand (6xϕ9.3 mm) and the design concept type II was adopted for temporary load under construction.

Generally, after joint pads (called joint filler) are attached to the edge of main girders in advance, PC panels are laid on them. And cement mortar of non shrinkage type is poured to butt-joint between PC panels.

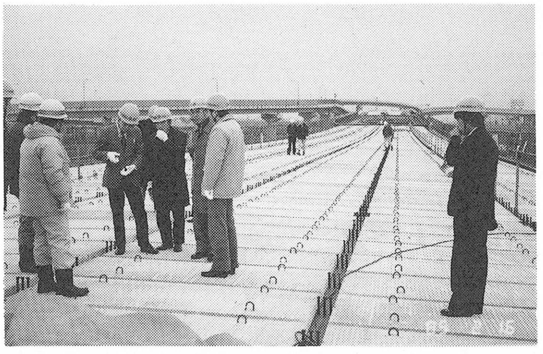

Photo. 3 Application of PCC Panel to Steel Composite Bridge

Photo 3 shows the members of PCC slab research committee visiting the construction site of the East Osaka Line of Hanshin Expressway. Hanshin Expressway Public Corporation adopted the PCC slab method in this construction. This method also has received high reputation from the view point of easier construction management. Normally, traveling cranes and universal track cranes are used in laying PC panels as shown in Fig. 22.

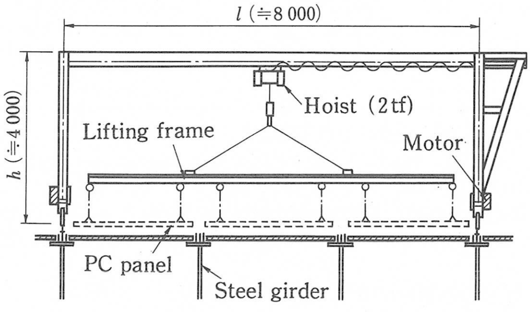

Fig. 22 Travelling Crane Placing PC Panels

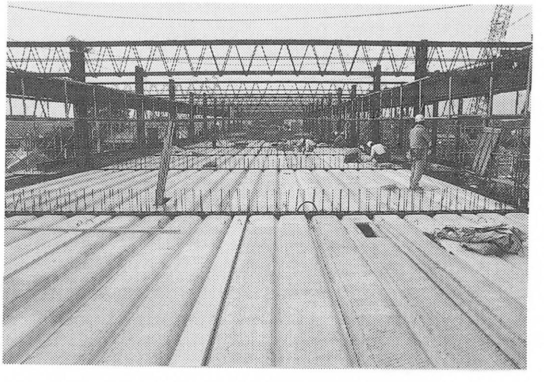

Photo. 4 Application of Channel Panel to Apartment Building (Tokyo)

Photo 4 shows the another example in which channel typed PC panels were applied to an apartment building slab in Tokyo.

It is required to increase the bending capacity of PC panel accompanying with the accommodation of larger span. To achieve this requirement, a ribbed PC panel shown in Fig. 10(b) is quite effective. Needless to say, it is essential to research on the appropriate number and height of the rib. It is possible to reduce the own weight of panel and also to increase the bending capacity of slab by using the hollow typed PC panel as shown in Fig. 10 (c).

Usually the PC panel with ribs are applied to 4–5 m span. Moreover, in order to use this type of panel for the span larger than 4–5 m, the possibility is to increase the height of rib, section modulus and eccentricity of PC tendon gradually towards the span center. (ref. to Fig. 23)

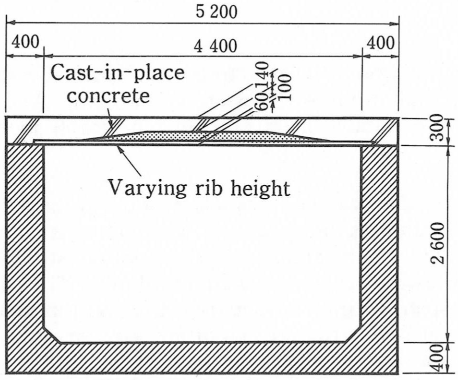

Fig. 23 Cover Construction of Culvert

The covering works of city sewerage system for renovations are subjected to the limitation of construction method due to environmental conditions. And the rapid constructions are normally requested.

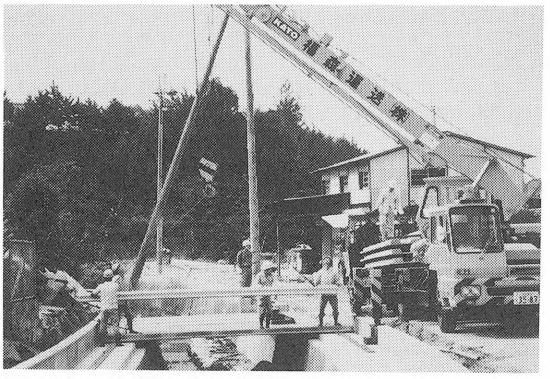
Photo. 5 Cover Construction of Drainage
(Nara City)

Photo 5 shows the example of ribbed panels used to cover the drainage in Nara City. After the completion of construction, this covered place has also been used as parking lot. Fig. 23 shows the another example using ribbed panels to cover the drain, finally forming box culvert in Mihara City.

(5) Present Situation and the Scope for Future

Hanshin Expressway Public Corporation has increased the thickness of deck slab for bridge from 17 cm at the time of commencement to 25 cm[15]. Metropolitan Expressway Public Corporation also increased the thickness by 1.5 times and the steel amount by 1.2 times that at the time of commencement to strengthen the slab.

PC Panel Composite Slab Method is compared to the proverb, "Killing three birds with one stone", by improving considerably the form and support works using precast PC panel as stagingless live form and by resisting to external forces with composite cross section after completion. It is very significant to recognize an excellent deck slab for bridge having good character for deflection and cracks, that is the PCC slab method.

Recently, there is a tendency to choose the structure of an easier maintenance after the completion of construction under traffic limitations with lesser running cost. And also there is a tendency for designing a structure diving into durable members and replaceable members so-called "Life Design Method mixed with different concepts to the part".

The PCC slab method is believed to be the favorable product from the view point of replaceability and the maintenance. The advantages of executing with no staging, rapidly and safely are great. Especially in building, the merits which can execute the floor construction of each level at the same time are remarkable. And the uses of channel panels and double "T" panels makes the construction possible more than 10 meter span, without secondary beams. So this method will be considered more effective for the construction of such structures requiring wide space and heavy duty floor with high concentrated loads as heavy warehouse, nuclear waste storage facilities and others. The research on this slab method will be extended actively in the future, fulfilling the demand for wider space and larger capacity. In the intelligent building with electronic information facility, this slab method used hollowed panels, is believed to be favorable because electrical wiring and communication cables can be placed in the hollow area.

Before the establishment of PCC slab Recommendations, this method was adopted by the design change of execution method with rapid construction. Since the establishment, this method has been widely used in the construction of highway bridge deck and will be adopted more frequently in the future. Further more, there will be several new application to the structures such as partition floor of under water tunnels, covers of open cut tunnels in urban area, landing piers and retaining walls. As mentioned above, the Japan Society of Civil Engineers have given guide lines for the method to be widely used. So far, it was found that the total amount of PCC slab used was 80,000 m^2 (2 billion Yen) and 1.2 million m^2 (18 billion Yen) in bridges and buildings, respectively.

Labor shortage becomes more and more serious every year, PCC slabs are manufactured in high quality, on the back ground described above and the adoption of this method will be also expanded progressively in the field of civil engineering construction in the near future.

ACKNOWLEDGEMENT

PCC Slab Method Research Committee was inaugurated composing of 41 members, in which the author was chairman and Prof. Hajime Okamura was a vice chairman and general secretary and Prof. Manabu Fujii was also a vice chairman. The committee established The Recommendations for Design and Construction of PCC Slab Method, three years after inauguration. The author would like to express the gratitudes to all persons who were related to the committee. And he would like to express the gratitude deeply to Prof. Takaaki Mizuno, Prof. Masatane Kokubu and Prof. Kiyoshi Okada who gave him valuable advice. Finally, he would like to convey his heartfelt gratitudes to the late Mr. Yoshihiko Murakami (former vice president, Fuji PS Co. Ltd.), whose enthusiasm originated this method and supported this research with the author throughout.

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