LONG TERM PERFORMANCE OF PRESTRESSED CONCRETE PAVEMENTS IN JAPAN

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ABSTRACT

In Japan, a test section of prestressed concrete (PC) pavement was constructed on a city street in Osaka in 1958, twelve years after the first construction of PC pavement in Europe. From 1961 to 1964, a comprehensive investigation was conducted on a test PC pavement on a yard by Public Work Research Institute, Ministry of Construction and fundamental data were collected. Since then, a number of PC pavements have been widely used in roads, airports and yards. High percentage of the PC pavements are now still in service. Some of them are more than 20 years old and show relatively good performance. This paper summarizes Japanese experiences of design and construction of PC pavement for roads. Results of field survey performed on old PC pavements are also presented and discussed.

INTRODUCTION

Over the last decades, prestressed concrete (PC) pavements have been used in Europe (1) and U.S.A (2). Also in Japan, a number of PC Pavements have been constructed on roads, yards and airports since a test section of PC pavement was constructed on a city street in Osaka in 1958, twelve years after the first construction of PC pavement in Europe. An old PC pavement has been in service for more than 30 years. Although some of Japanese experiences of PC pavement in airports (3,4) have been reported, very little information on highway pavement is available. This paper summarizes Japanese experiences of design and construction of PC pavement for roads. Results of field survey performed on old PC pavements are also presented and discussed. Although several problems have been found in PC pavements, this type of pavement could be a solution to the cases where longer service life is more important than initial cost or a road has to be build on a very soft foundation. Actually, the use of precast PC pavements is increasing for rapid rehabilitation of highway and airport pavements where closure time of traffic is very limited. In order to develop the technology further, the long-term performance should be studied based on the experiences and the results should be reflected in the future improvement of the design and construction.

BRIEF HISTORY OF PC PAVEMENTS IN JAPAN

In Japan, a test section of prestressed concrete (PC) pavement was constructed on a city street in Osaka in 1958. Unfortunately, there remains no published report on that pavement. The first PC pavement appearing in the literature (5) is a test PC pavement constructed on a yard of Public Work Research Institute, Ministry of Construction. Comprehensive investigations were conducted from 1961 to 1964 to make a design and construction guideline for PC pavements. The test pavement consisted of four types of sections with variation of slab thickness, amount of prestress and prestressing method.

Loading tests similar to previous ones (6) were performed on the pavement and loads at surface cracking in PC slabs were obtained. Based on the results of the study, the first Japanese design manual for PC pavements was established.

Next example was a pavement constructed on a bus stop in Taga service area of Meishin Express Highway in 1964 (7). Since this pavement was placed in 320 m long without transverse joint and not enough amount of longitudinal prestress was introduced without transverse prestress, the pavement severely deteriorated and was completely replaced in 1982.

Two large projects of practical PC pavement were constructed in a road on a reclaimed land in Anegasaki, Chiba prefecture (120 mm thick slab, 52,700 m^2) (8) and in another road on a similar reclaimed land in Shinmoji, Kitakyusyu city (150 mm thick slab, 65,700 m^2) (9). Both pavements were placed on a very soft foundation and large settlements had been expected after the construction. Both pre-tensioning and post-tensioning systems with strands were tried in each project.

Since then, over fifty PC pavements have been constructed on roads. Especially, the pavement on Sanbonyanagi-Yuzawa road should be mentioned as a large scale project, where 40,000 m^2 PC pavement was constructed with pre-tensioning and post-tensioning systems in 1974.

Precast PC pavement began to be used in container yards and airports since early 1970's. After the horn joint system was developed (3), the use of precast PC pavement was increasing. In Japan, there are a number of tunnels in the highway networks due to the geographical feature where there are a lot of mountain areas. Concrete pavements are usually adopted in the tunnels because of their light surface color and durability. But it is difficult rehabilitate or replace these concrete pavements because they require a long curing time and large construction spaces. Accordingly, precast PC pavement are supposed to be one of the appropriate alternatives for rapid rehabilitation of existing concrete pavements.

DESIGN AND CONSTRUCTION

Construction methods of PC pavement employed in Japan are pre-tensioning system, post-tensioning system and precast PC pavement as mentioned above. Table 1 summarizes the features of these methods. Brief descriptions of Japanese experiences of each method are given in the following sections.

Post-tensioning System

Table 2 summarizes design and construction data of the PC pavements with the post-tensioning system. Design and construction for some projects of which data are available in the literature are presented below.

Bus stop in Taga Service Area of Meishin Express Highway (7)

Figure 1 shows a relationship between amount of prestress and load at surface cracking which was obtained from loading test performed by Public Work Research Institute, Ministry of Construction. In this experiment, a load was applied at free-edge of a PC pavement with a 120 mm thick slab on a granular subbase with a K-value of 4 kgf/cm^3 (39.2 MN/m^3). Magnitude of the load when cracks appeared on the surface of the PC slab was measured, varying the amount of prestress form 5 to 50 kgf/cm^2 (0.49 to 4.9 MPa). The flexural strength of concrete was 50 kgf/cm^2 (4.9 MPa). Using the average line in the figure and considering the cost, the design effective prestress was determined to be about 5 kgf/cm^2 (0.49 MPa) for the design load of 16 tf (157 kN). Bottom cracks were expected to close after unloading and neglected in the design. Other design variables employed are as follows:

- Coefficient of subbase friction: μ =1.2;
- Coefficient of sheath friction: ν =0.003 /m;
- Elastic modulus of concrete: E=300,000 kgf/cm^2 (29,400 MPa);
- Unit weight of concrete: w=2.41 t/m^3;
- Thickness of concrete slab: h=120 mm;
- Width of concrete slab: B= 4.5 m.

Eight strands with a diameter of 12.4 mm were placed in sheaths. To avoid cracking at early stage of the construction, a force of 6 tf (59 kN) was temporarily applied to each strand when compressive strength of concrete reached 100 kgf/cm^2 (9.8 MPa). Then, when the compressive strength became 300 kgf/cm^2 (29.4 MPa), a force of 12 tf (118 kN) was finally applied to each strand. Amount of prestressing was 17.8 kgf/cm^2 (1.74 MPa) at the end of the slab and reduced to the minimum value of 5 kg/cm^2 (0.49 MPa) at the mid-slab due to friction of subbase and sheath.

Total length of the pavement slab was 320 m and there was no transverse joint in the slab. To minimize the loss of prestressing due to the friction, at first, a center slab of 100 m long was placed and prestressed. Then two 55 m long slabs were added and prestressed at both sides of the center slab. After each prestressing was completed, the strands in sheaths were grouted. During the construction, stresses in the strand and the movements of the slabs were measured and compared with the predicted values. Fairly good agreements were obtained.

A comparison of construction cost between this PC pavement and normal concrete pavements suggested that the cost of the PC pavement is almost the same as a normal concrete pavement with a 250 mm thick slab.

Anegasaki in Chiba Prefecture (8)

A PC pavement was constructed on a major road in a heavy industrial area. This road was upgraded and is now in service as the National Highway, Route 16. The reason why PC pavements were chosen in this project was that the foundation of this area was build by reclaiming a bay and large settlements had been expected to occur.

Table 3 shows design variables. The thickness of the slab was chosen to be 120 mm with the consideration of the cost and the limitation of construction. Stress in the slab was estimated using Westergaard's equation for edge loading. Assuming a wheel load of 16 tf (157 kN) with a design factor of 2 and a design load of 8 tf (78kN), the design stress was computed to be 117.4 kgf/cm^2 (11.5 MPa). Figure 2 schematically shows a moment distribution along longitudinal slab edge. Then assuming the maximum negative moment for surface cracking to be a fifth of the maximum positive moment for bottom cracking, the maximum stress at the surface became 23.5 kgf/cm^2 (2.34 MPa). Using the lower relationship in Figure 1, the amount of prestress for the design wheel load of 16 tf (157 kN) was determined to be 23.5 kgf/cm^2 (2.34 MPa). Thermal stress was computed to be 6 kgf/cm^2 (0.59 MPa) using the values in Table 3. Accordingly, the amount of effective prestressing in the design was determined as 30 kgf/cm^2 = 23.5 kgf/cm^2 + 6 kgf/cm^2 (2.94 MPa = 2.3 MPa + 0.59 MPa). Since longitudinal cracks, which had never been expected in advance, occurred at early stage of the construction, transverse prestressing was introduced in haste at that time. Assuming a wheel load of 12 tf (118 kN) with a design factor of 1.5, transverse prestress of about 18 kgf/cm^2 (1.76 MPa) was introduced.

Strands with a diameter of 12.4 mm were longitudinally placed at a distance of 50 mm from the bottom surface with a spacing of 250mm. They were put in the sheaths with a diameter of 26 mm. Steel bars with a diameter of 18 mm were transversely placed. To reduce the friction between subbase and concrete slab, a sheet of polyethylene was placed on a 20 mm thick sand layer. The longitudinal prestress was introduced through twice prestressing works. At first, partial prestress was introduced 48 hours after placing of concrete. Finally, each strand was tensioned by a 13.5 tf (132 kN) force at both ends of a 50 m long slab. After each prestressing was completed, strands and bars in the sheaths were grouted.

Figure 3 shows a joint structure between the PC slabs in this pavement. A reinforced concrete slab with a width of 8 m, a thickness of 200 mm and a length of 1.8 m was placed as a sleeper slab beneath the joint. Over the slab, another concrete slabs were placed and transverse prestress was introduced to the slabs by steel bars with a diameter of 18 mm and a spacing of 500 mm. A wood plate and synthetic rubber were put into a gap between the slabs to make a expansion joint.

The construction cost was 1.5 times as high as a normal concrete pavement with a 250 mm thick slab. However, taking the reduction of maintenance costs during the service life into the account, it was supposed to be reasonable.

Pre-tensioning System

Table 4 shows an overview of the PC pavements constructed by the pre-tensioning system which are investigated in this study. Some of them are described in detail below.

Anegasaki in Chiba Prefecture (8)

In this project, PC pavements were constructed with both pre-tensioning and post-tensioning systems. Since the design condition was the same as mentioned earlier, only construction method is presented here.

This pavement which has two lanes with a length of 3 km (total length 6 km) was constructed with 12 subsections with a length of 500 m. Figure 4 shows a subsection of pre-tensioning system. In order to use two slabs at both ends as abutments, they were constructed with post-tensioning system in advance. Large amount of sand was placed on the slabs, as shown in Photo. 1. The average thickness of the sand layer was about 0.8 m. Sleeper slabs with a thickness of 200 mm , a width of 8 m and a length of 2 m were constructed every 50 m just beneath the expansion joints. 4 m wide concrete slabs were placed and longitudinal joint was installed between the lanes.

The strands with a diameter of 12.4 mm were longitudinally placed with a spacing of 250 mm and a length of 500 m between the abutment slabs and were prestressed all together. The prestressing force was 13.5 tf (132 kN) per a strand and the total force of prestressing reached 216 tf (2119 kN) per a slab. However, the horizontal movements of the abutment slabs were less than 1 mm. Since the amount of expansion of one strand due to tensioning was about 3.5 m, a winch was used to tension the strand at first and a jack was used for the final prestressing. Steel bars with a diameter of 20 mm were transversely placed in the sheaths with a spacing of 1 m and prestressed after the longitudinal prestressing was finished. Photo. 2 shows an arrangement of the strands and steel bars.

After the longitudinal and transverse prestressings were completed, concrete was placed with a length of 50 m from the center slab. When the concrete had hardened, strands were cut at each joint and prestress was introduced. It was reported that the construction cost of the pre-tensioning system was a little lower than that of the post-tensioning system.

Shinmoji in Kitakyusyu City (9)

This pavement was also constructed on a very soft reclaimed land. Figure 5 shows the total section of this PC pavement. This section was 831 m long consisting of 11 subsections with a length of 65 m and abutment slabs at both ends (65 m long and 50 m long slabs). Based on the experience of Anegasaki project, the thickness of PC slab was increased from 120 mm to 150 mm. Another design variables were the same as Anegasaki project.

Figure 6 shows a expansion joint of this pavement. Instead of constructing the sleeper slabs, the thickness of the slab was increased at the joint and dowel bars with a diameter of 22 mm and a length of 600 mm were inserted at mid-depth of the slab with a spacing of 300 mm. The dowel bars substantially reduced the deflections at the joint, leading to the tremendous reduction of subbase damage.

Route 8 in Fukui City (10)

Figure 7 shows the plan of the section in this project. This section had a curve alignment with a radius of 150 m. The section was constructed by 5 m wide slab and 3.5 m wide slab with a thickness of 150 mm. At every joint, the thickness of the slab was increased to 200 mm and dowel bars with a diameter of 12.7 mm and a length of 700 mm were inserted at mid-depth of the slab.

Strands with a diameter of 12.7 mm were longitudinally placed with a spacing of 300 mm and tensioned by 14.5 tf (142 kN) force per a strand. The steel bars with a diameter of 14 mm in the sheath were transversely placed with a spacing of 600 mm and prestressed. In the curve section, steel bars with a diameter of 10 mm were transversely installed with a spacing of 150 mm but they were not prestressed.

The most interesting aspect of the project was how the longitudinal force could be applied in the curved section. Simple anchors were installed along the outer edge of the curve. Then the forces were applied radially using the anchors as shown in Photo.3. This method worked very well and longitudinal prestress in the curved section was introduced much easier than expected.

Precast PC Slab Method (4, 11, 12, 13, 14)

Table 5 summarizes precast PC pavement projects investigated in this study. Thickness of precast PC slab for roads varies from 170 mm to 200 mm. Size of the slab varies from 1.3 m to 2 m wide and from 4 m to 10 m long depending on the lane width and site conditions. Since the design and construction of precast PC pavement for airports were already reported (4) and the same for the roads, they are not repeated here. Figure 8 shows an example of a precast PC slab for a road pavement. The steel bars were transversely placed but not prestressed.

Figure 9 shows an example of arrangement of the slabs for a road pavement. Figure 10 shows the two types of the expansion joint. Type A (Figure 10 (a)) is earlier model using curved steel bar like a horn. The example of Figure 9 used Type B (Figure 10 (b)) which is the revised version of Type A. In this type, straight steel bars are inserted after the PC slabs are placed and leveled.

PERFORMANCE

Tables 2, 4 and 5 review evaluations of performance and comments on distress condition for each pavement project. Table 6 shows the classification of the traffic condition referred in the tables, which follows the Japanese manual for asphalt pavement (15). Each traffic class has a wheel load distribution as shown in Table 7. As can be recognized from Table 7, frequency of heavy wheel loads is very high in traffic classes of C and D. Thus, the pavements in these traffic conditions may have been subjected to large load repetitions. Table 8 shows the performance rating which was given for each PC pavement in these tables based on the author's observations .

In the following, two projects: Taga and Chigasaki, are examined as the typical examples of long-term performance of PC pavement in Japan.

Bus stop in Taga Service Area of Meishin Express Highway

Since most traffic in this area was bus, magnitude and volume of wheel load were not so large. This pavement was constructed in 1963 and was replaced in 1982. According to maintenance staffs, it was observed that transverse cracks occurred at relatively early stage and soon later longitudinal cracks began to appear. Eventually, cracks connected with each other and became alligator cracks. The following causes of the distress are expected:

1. The total length of 320 m was too long and the amount of prestress of 5 kgf/cm^2 (0.5 MPa) was too low.
2. The amount of transverse prestress was also too low.
3. The thickness of the slab of 120 mm was too thin.

Anegasaki in Chiba Prefecture

A brief history of performance of this pavement is presented below:

1. Just after the construction, brow-up of the subbase surface due to volume expansion of the steel slag began to appear. The blow-up reached 100 to 300 mm in height and resulted in the surface unevenness and the transverse cracks in the PC slabs. Furthermore, voids formed under the slabs at the joints. Surprisingly, these voids did not lead to any critical distress of the slabs. After these voids were filled, the pavement has continued to be in service.

2. Next problem was the missing of sealing materials of the joints. It was due to the large movements at the slab ends which reached 15 mm under the temperature change of 30 °C. Various materials for joint sealing including preformed joint filler and asphalt materials were tried but all failed, as shown in Photo. 4.

3. Pumping phenomena appeared and voids beneath the slab developed along the free edge of the slab, as shown in Photo. 5. When a wheel passed near the place of the void, large deflection of the slab was observed. However, even such large deflection did not result in cracking in the PC slabs.

4. Distress of the joints was also a problem. Spalling of the joints began to appear relatively early but did not seem so critical. Photo. 6 shows a patching due to joint distress in a pre-tensioning section. However this distress has never developed further.

5. Asphalt overlay with a thickness of 100 mm was placed 15 to 20 years after the construction. After the overlaying, reflection cracks appeared at the joints, as shown in Photo. 7.

6. Since rutting and cracking became severe in the asphalt overlay layer, this pavement was completely replaced in 1994. Before the replacement, several PC slabs were partially removed to investigate the conditions of the slabs and subbase, as shown in Photo. 8. Although some unevenness of the PC slab and little corrosion of the steel bars were observed, the total condition of the slabs seemed to be fairly sound.

SUMMARY AND CONCLUSIONS

The experiences of the PC pavements in Japan can be summarized as follows:

1. Thickness design:
   - PC pavement slabs with the enough prestress as designed have high bearing capacity. Longitudinal cracks were observed in the pavements where amount of transverse prestress was not enough.
   - The minimum thickness of the PC pavement slab is 150 mm with respect to the construction.

2. Expansion joint:
   - Since the movement at the ends of long PC slab is very large, joint sealing materials are easily removed and unwelcome foreign matters fall into the joint opening. However there is no appropriate material for joint sealing which can follow the movement and have enough durability. One solution to this problem may be to employ less long slab, such as 20 to 35 m.
   - Increasing the slab thickness at joint is a good method to reduce the deflection due to wheel loads.
   - In post-tensioning system, a space between the slabs is required for prestressing works. This space should be filled after the prestressing works. This make the joint structure more complex and, in certain situations, make a weak point in the pavement.
   - In pre-tensioning system, there is possibility that prestress substantially decreases at the ends of the slab after cutting strands.

3. Pumping:
   Since the thickness of the PC pavement slab is relatively thin, the deflection due to wheel load tends to be large. In addition, we have large amount of rainfall (average annual precipitation is about 1500 mm). This would lead to pumping of the subbase in a short period. To prevent this phenomena, subbase should be build with high quality and unerodable materials. It might be uneconomical to increase the slab thickness to 170 or 200 mm.

4. Settlement:
   Even if large unevenness occurs in the PC pavement due to settlement of soft foundation or deformation of subbase, PC slabs can follow the settlement or deformation without any crack in the slabs. This means that the PC pavement could be one of the best alternatives for roads on very soft foundation.

5. Tensioning system:
   If a length of the pavement section is long, the pre-tensioning system would be more easy to build and more economical than the post-tensioning system.

6. Precast PC pavement:
   It is too early to evaluate long-term performance of precast PC pavement. But we believe that this method is a promising technology for rapid rehabilitation of existing concrete pavements.

7. Costs:
   It is understandable that the initial cost tends to be high because of complex prestressing works. In addition, special structures required at the expansion joints increases the cost further. This could be compensated only by longer service life and less joint maintenance costs.

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TABLE 1 Advantages and Disadvantages of Construction Methods

Construction Method	Advantage	Disadvantage
Post-tensioning	• Applicable to short and/or curved sections • Ability to start from any part in a section • Ability to avoid early cracking by partial prestressing • Use of large diameter bars	• Requiring a number of procedure steps • Much loss of prestress due to friction
Pre-tensioning	• Less loss of prestress due to friction • Ability to place bars and prestress at once • Ability to improve construction efficiency in a large scale project	• Troublesome in a curved section • Requiring abutments • Requiring careful curing to avoid early cracking • Requiring long time closure of long section
Precast Slab	• Ability of rapid placement • Immediate opening to traffic • Ability of partial replacement • Ability of recycling of slabs • High quality control • Requiring less large machines to place	• Requiring a special crane to place because of heavy weight of the slabs • High cost

TABLE 2 Design and Performance of Post-tensioning PC Pavements

No.	Location	Area (m^2)	Age (Year)	Traffic[1)]	Slab Thickness (mm)	Joint spacing (m) and Structure	Longitudinal Force[2)] (tf/m)	Transverse Force[2)] (tf/m)	Performance Rating[3)]	Remarks on Conditions
1	Bus stop at Taga service area	1538	15	B	120	320 without joint	21.3	0.0	E	Replaced due to alligator cracking 15 years after construction.
2	Road at Arigasaki in Chiba prefecture	16000	31	D	120	50 with sleeper slab	48.0	24.0	C	Overlaid with a 100 mm thick asphalt layer 15 years after construction. Faulting at joints were observed. PC slabs are still fairly sound.
3	Road at Shinmoji in Kitakyusyu city	20000	30	D	150	50 with sleeper slab	51.4	25.0	B,C	Partially overlaid with an asphalt layer due to faulting at joints. All joints were distressed. Uneven settlements were observed.
4	Road at Sanbonyanagi-Yuzawa line in Iwate prefecture	?	22	C	150	60 with sleeper slab	44.5	22.5	A	Only one joint was distressed. Several small patches were done. PC slabs were quite sound.
5	Road at Kohase in Hukuoka prefecture	10481	22	B	150	50 with sleeper slab	45.5	22.5	A	Most joints were distressed. PC slabs were sound. There was no uneven settlement
6	Road for tanks at Chitose in Hokkaido	12770	19	B	150	60 with sleeper slab	46.5	22.5	B	Longitudinal cracks near the shoulder were observed. They were caused by sliding of embankment.

Note: 1)Refer to Table 7; 2)At slab end, just after prestressing; 3) Refer to Table 8.

TABLE 3 Design variables for Chigasaki Project

Variable	Value
Joint Spacing	50 m
Total Width of Lanes	8 m
Slab Thickness	120 mm
Design Wheel Load	8 tf
Contact Radius of Wheel Load	200 mm
K-value	3 kgf/cm^3 (0.29 MPa)
Coefficient of Friction of Subbase	1.0
Temperature Change	30 °C
Compressive Strength of Concrete	300 kgf/cm^2 (29.4 MPa) at 28 day 240 kgf/cm^2 (23.5 MPa) at prestressing
Poisson ratio of concrete	0.15
Thermal expansion of concrete	10-5/°C
Creep coefficient of concrete	2.0
Dry shrinkage	12.010^{-5}
Elastic modulus of concrete	200000 kgf/cm^2 (19600 MPa)
Relaxation coefficient	3 %

TABLE 4 Design and Performance of Pre-tensioning PC Pavements

No.	Location	Area (m^2)	Age (Year)	Traffic[1]	Slab Thickness (mm)	Joint Spacing (m) and Structure	Longitudinal Force[2] (tf/m)	Transverse Force[2] (tf/m)	Performance Rating[3]	Remarks on conditions
1	Road at Arigasaki in Chiba prefecture	48000	30	D	120	50 with sleeper slab	48.0	24.0	C	Overlaid with a 100 mm thick asphalt layer 15 years after construction. Faulting at joints were observed. PC slabs are still fairly sound.
2	Road at Shinmoji in Kitakyusyu city	35000	29	D	150	50 with 25cm slab thick and dowel	51.4	25.0	B,C	Partially overlaid with an asphalt layer due to faulting at joints. All joints were distressed. Uneven settlements were observed.
3	Road in Sanbonyanagi-Yuzawa line in Iwate prefecture	?	22	C	150	60 with 25cm slab thick and dowel	44.5	22.5	A	Only one joint was distressed. Several small patches were done. PC slabs were quite sound.
4	Tsukinoki by-pass of National Highway, Route 4	2100	25	D	150	50 with 25cm slab thick and dowel	45.5	22.5	C	Overlaid with a asphalt layer due to raveling by studded tires and joint faulting. Overlaid layer is still sound.
5	Hukui by-pass of National Highway, Route 8	6222	24	D	150	60 with 25cm slab thick and dowel	44.5	22.5 and 0(curved section)	C	Overlaid with a asphalt layer due to raveling by studded tires. Reflection cracks are observed.

Note: 1)Refer to Table 7; 2)At slab end, just after prestressing; 3) Refer to Table 8.

TABLE 5 Design and Performance of Precast PC Pavements

No.	Location	Area (m^2)	Age (Year)	Traffic1)	Slab Thickness (mm)	Slab Size (W x L) (m)	Longitudinal Force[2] (tf/m)	Joint Structure[3]	Performance Rating[4]	Remarks on Conditions
1	Wanatsu, National Highway, Rout 8 in Nigata prefecture	343	13	D	170	1.75 x 7.0	31.0	Horn	C	Partially overlaid or patched due to raveling by studded tires and joint faulting.
2	Kotsunagi tunnel, Highway Route 4	1193	13	D	200	1.95 x 8.5	36.9	Horn	B	Partially overlaid or patched due to raveling by studded tires and joint faulting.
3	Inage intersection, National Highway, Route 14	990	12	D	170	2.25 - 3.0 x 10.0	33.9	Horn (?)	B	Partially patched. Reconstruction of under seal
4	Kayatsugi tunnel, National Highway, Route 8	900	11	C	170	1.4 x 7.0	32.0	Horn (?)	B	Overlaid on wheel paths with a thin asphalt layer due to raveling by studded tires.
5	Takao intersection, National Highway, Route 20	498	11	D	170	2.5 - 3.0 x 11.0	32.0	Dowel	A	Although small spalling at joint are observed, PC slabs are sound.
6	Shinamagatsuji tunnel, National Highway, Route 168	289	10	B	170	2.5 - 3.0 x 4 - 4.65	32.8	Dowel	B	It is required to repair joints. PC slabs are sound.
7	Higashiyama tunnel, National highway, Route 1	3618	9	D	170	1.67 x 10.0	30.8	Dowel	A	Quite sound.

Note: 1)Refer to Table 7; 2)At slab end, just after prestressing; 3) Refer to Figure 10; 4) Refer to Table 8.

TABLE 6 Traffic Classification

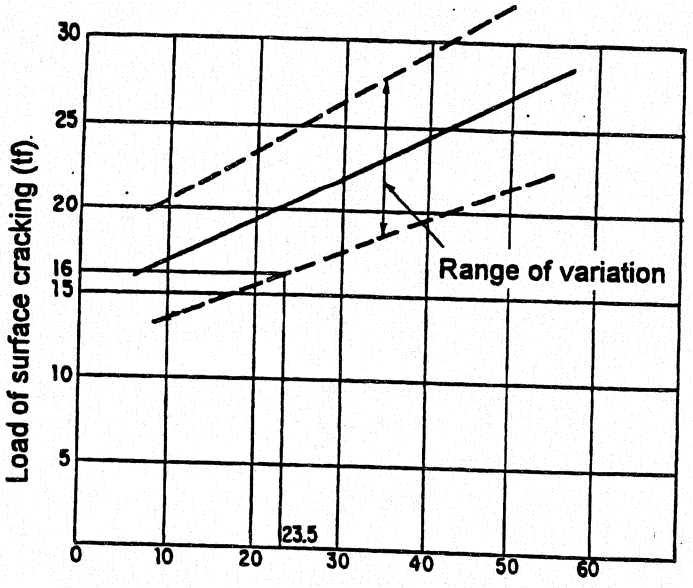
Class	Heavy Commercial Vehicles (Vehicles/Day/Lane)
L	~ 100
A	100 ~ 250
B	250 ~ 1000
C	1000 ~ 3000
D	3000 ~

TABLE 7 Wheel Load Distribution (/Day/Lane)

Traffic Class	Vehicle /Day/lane	Wheel Load (tf) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-	Total
A	1600	2833	214	89	46	24	18	12	9	4	4	3	3257
B	4986	8371	810	420	229	119	79	45	27	15	7	5	10124
C	8915	13934	1855	1210	620	335	208	118	59	30	13	10	18391
D	12714	16610	3611	3091	1978	1005	623	378	176	86	36	21	27614

TABLE 8 Performance Rating

	Rating	Condition
A	Very Good	No distress. All slabs are sound.
B	Good	Quite few distress. Most slabs are sound.
C	Fair	Partially repaired due to raveling and joint spalling. Slabs are fairly sound.
D	Poor	Overlaid due to cracking in the slabs.
E	Very Poor	Completely replaced or will be replaced soon.



(1tf = 9.81 kN, 1kgf/cm² = 0.098 MPa)

FIGURE 1 Relationship between Load at Surface Cracking and Amount of Prestress

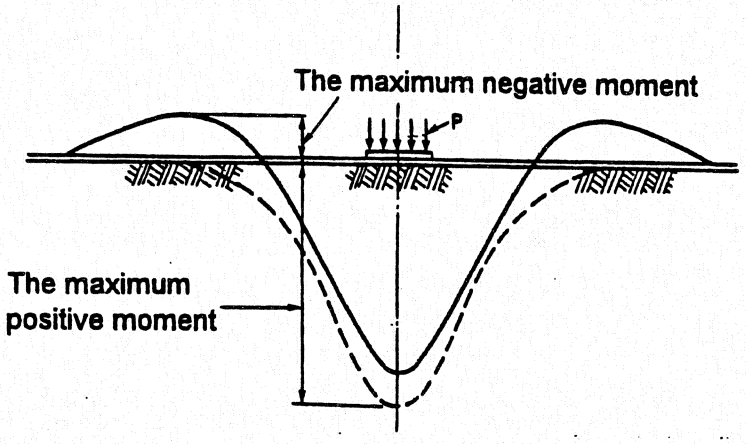


FIGURE 2 Bending Moment Distribution along the Slab Edge.

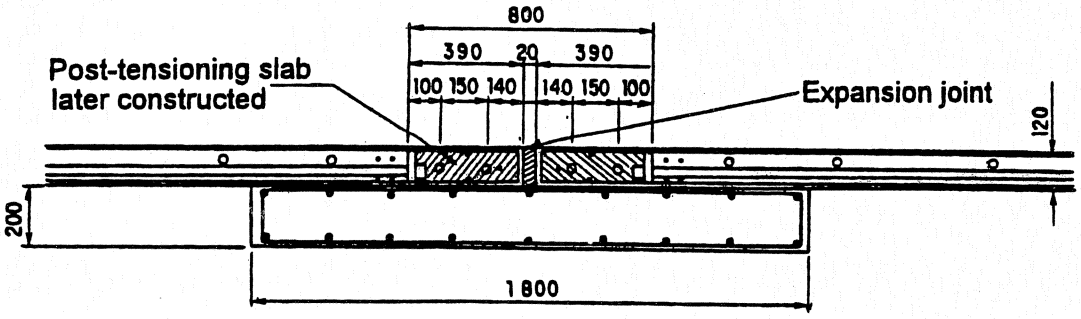


FIGURE 3 Cross Section of Expansion joint in Post-tensioning System.

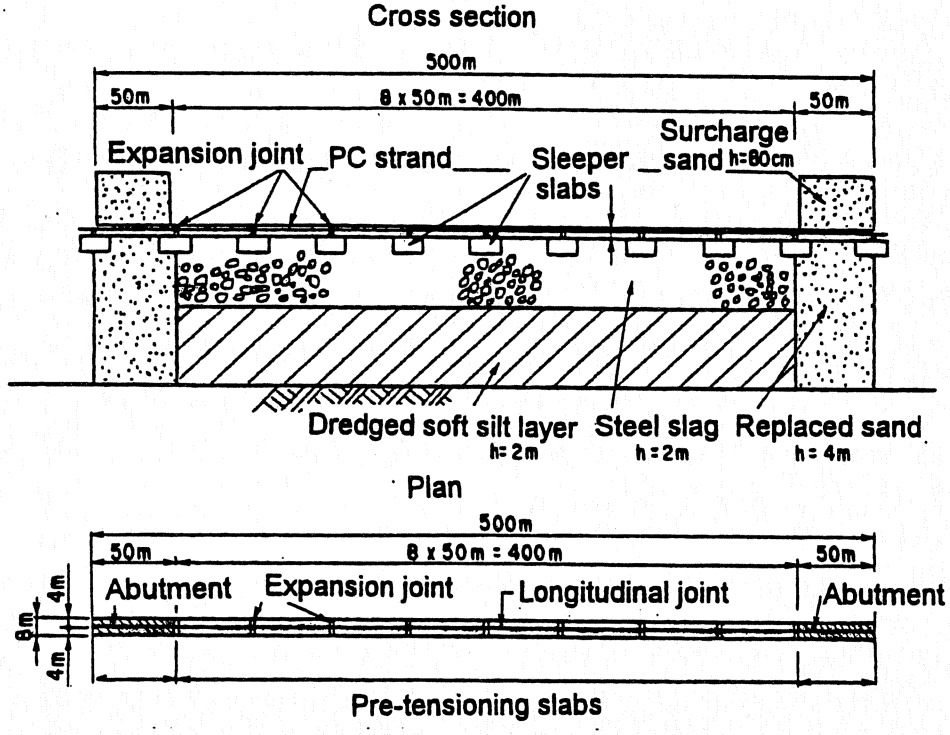


FIGURE 4 General View of Anegasaki PC Pavement with Pre-tensioning System

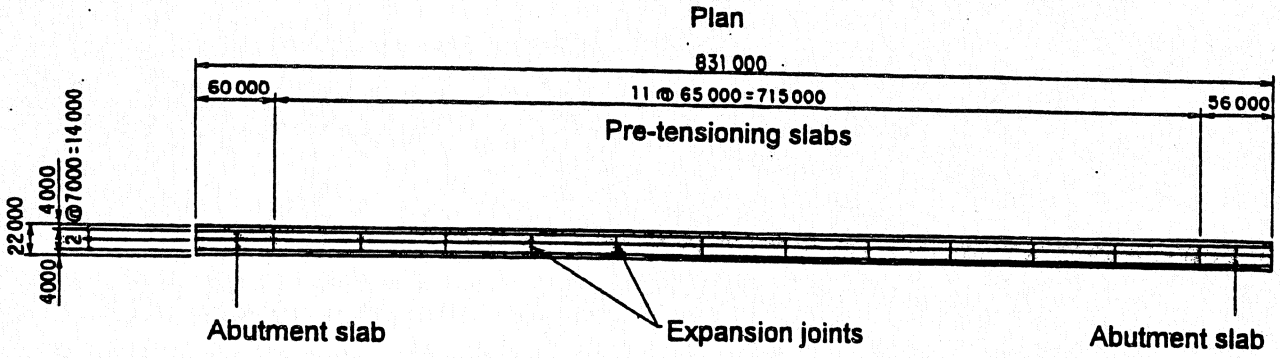


FIGURE 5 Plan of Shinmoji PC Pavement

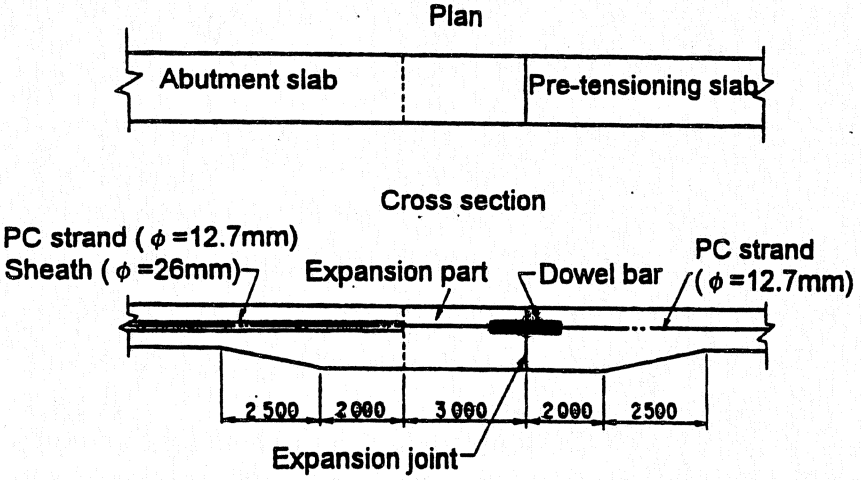


FIGURE 6 Expansion Joint at Slab End in Shinmoji PC Pavement

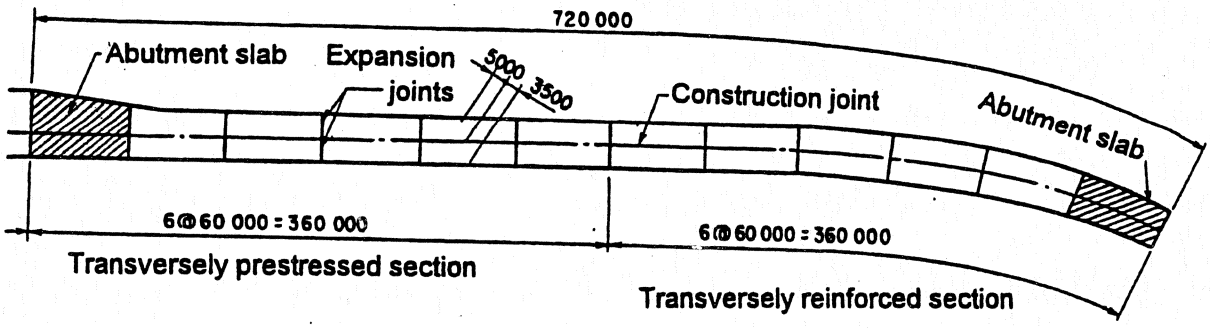


FIGURE 7 Plan of Fukui Bypass PC pavement

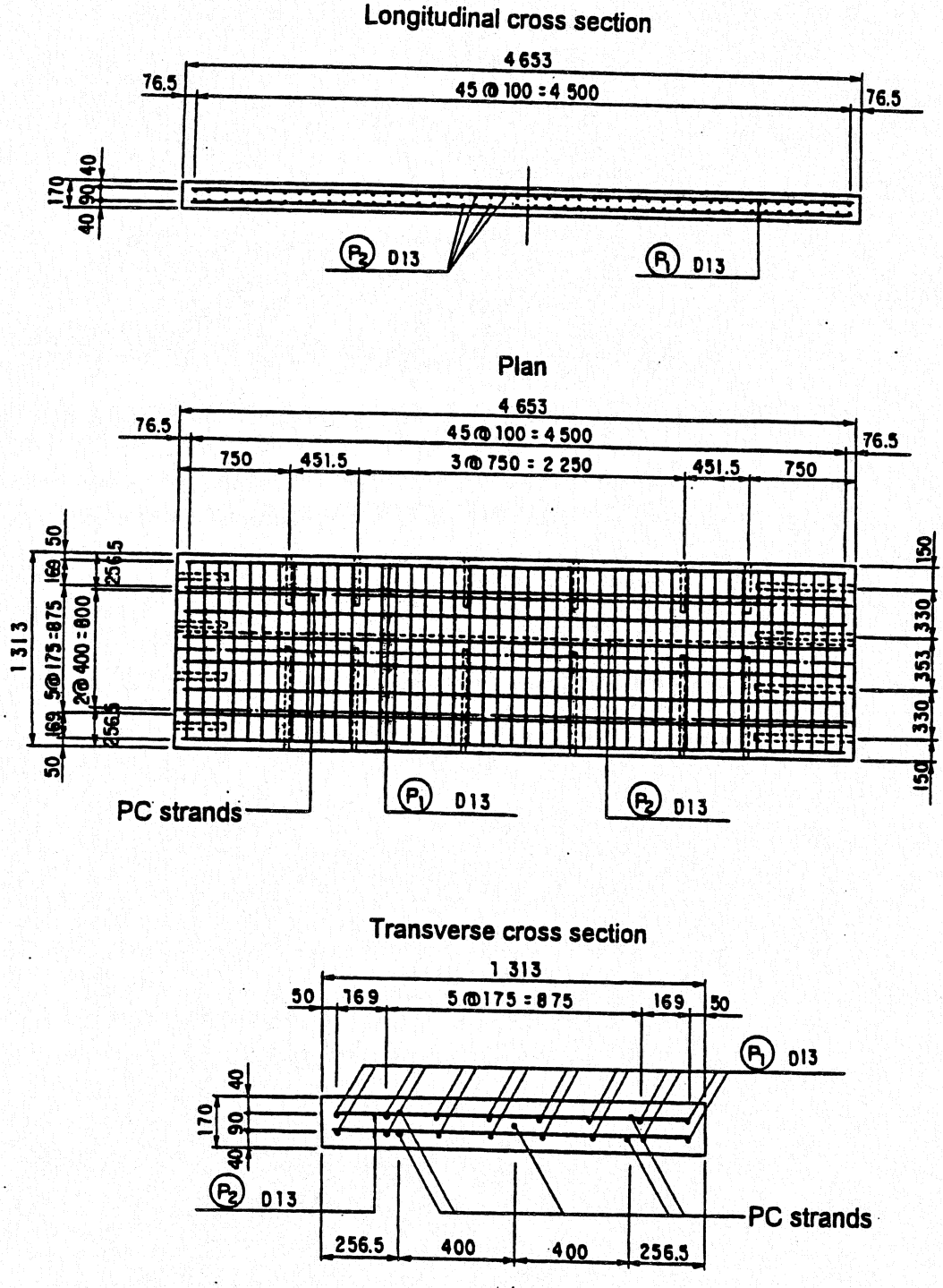
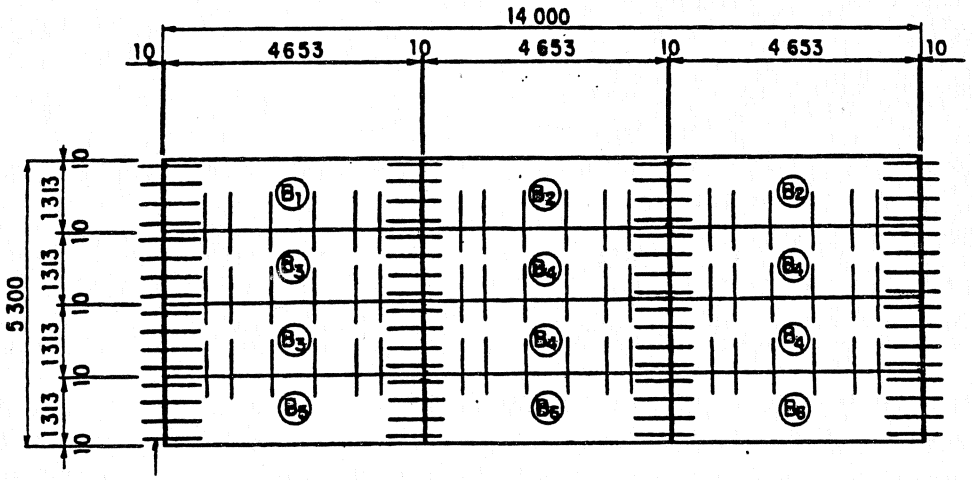


FIGURE 8 An Example of Precast PC Pavement Slab.



Dowel bar or Horn bar

FIGURE 9 Arrangement of Precast PC Slabs

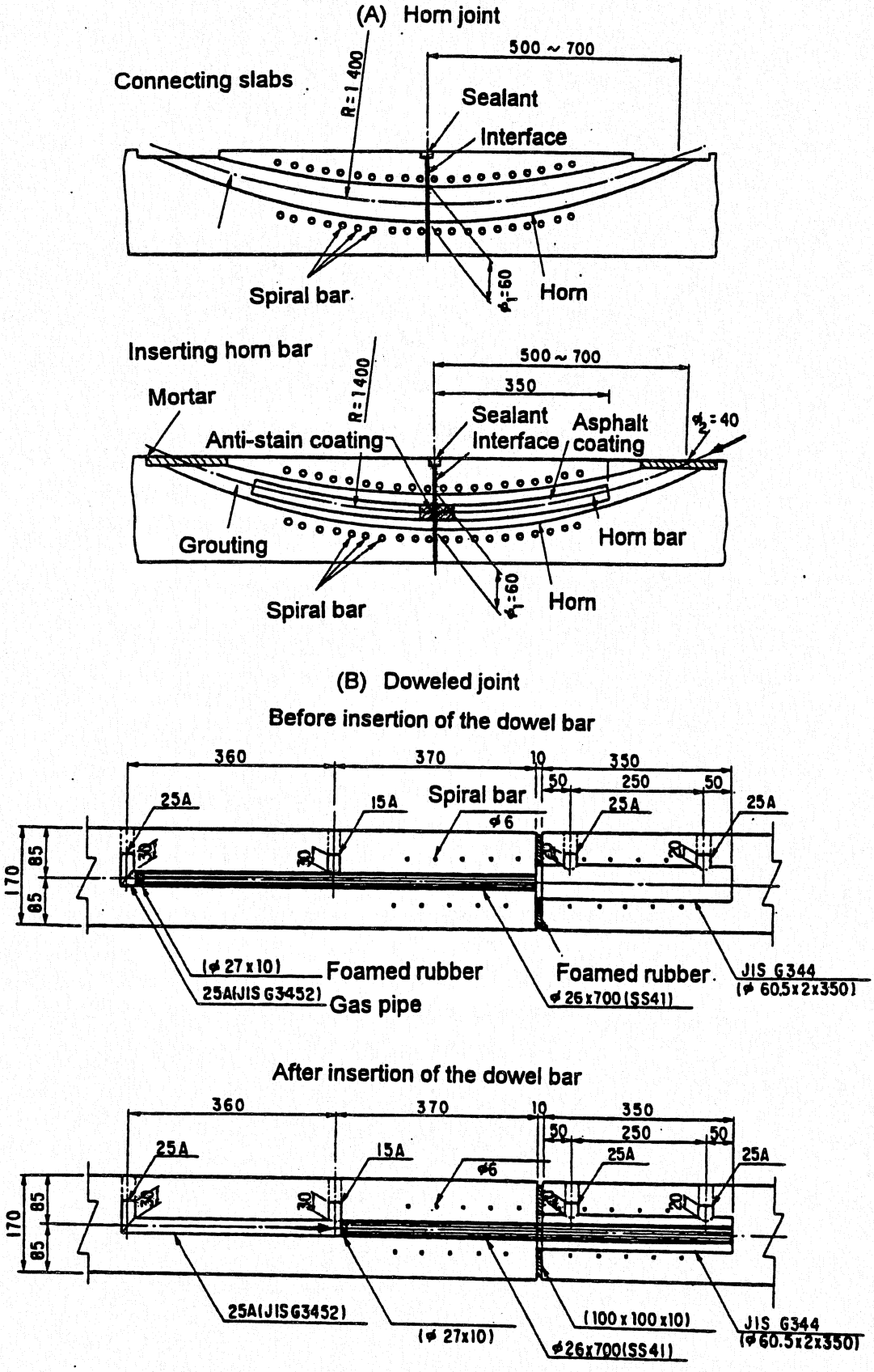


FIGURE 10 Joints for Precast PC Pavement

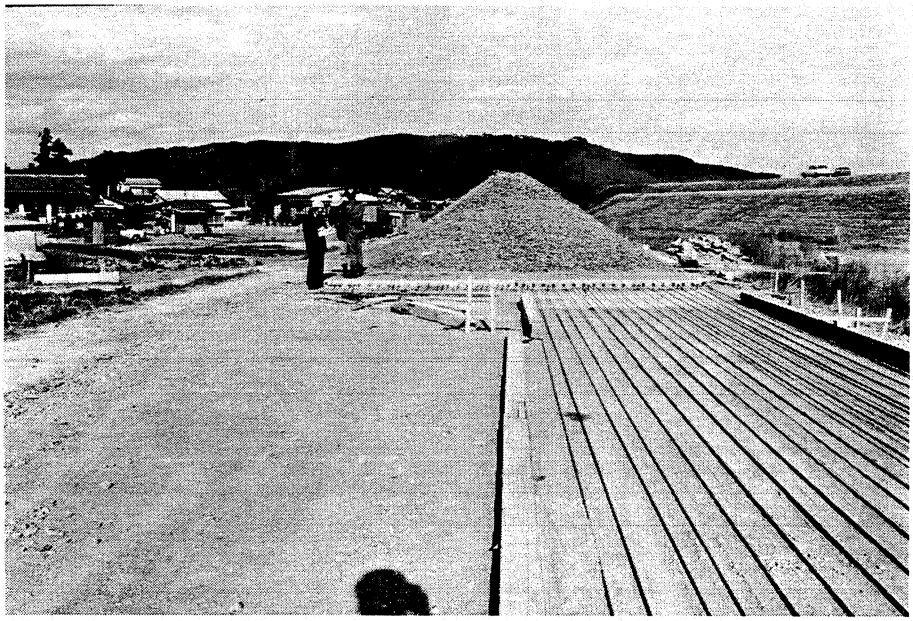


PHOTO. 1 Abutment Slab on Which Large Amount of Sand Was Placed (Anegasaki Project)

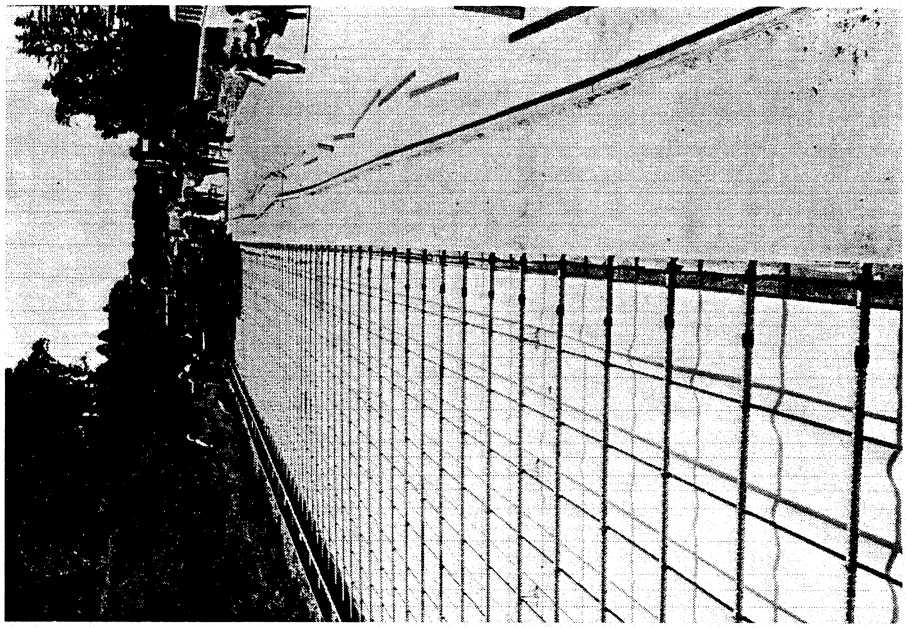


PHOTO. 2 Placement of Concrete on the Strands and Transverse Bars (Anegasaki Project)

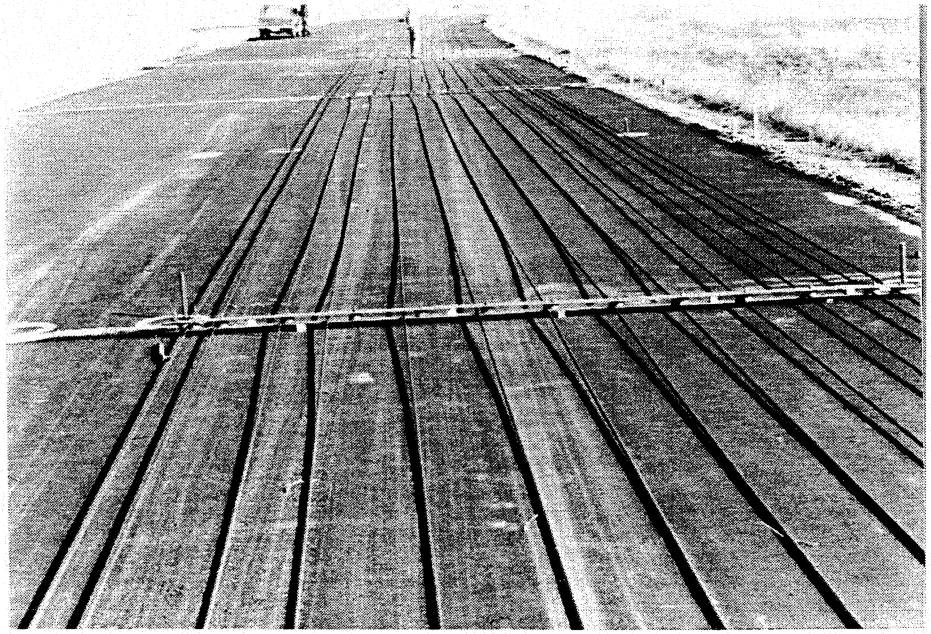


PHOTO. 3 Radially Tensioned Strands in a Curved Section. (Fukui Project)



PHOTO. 4 Condition of a Joint in Pre-tensioning System (Anegasaki Project)

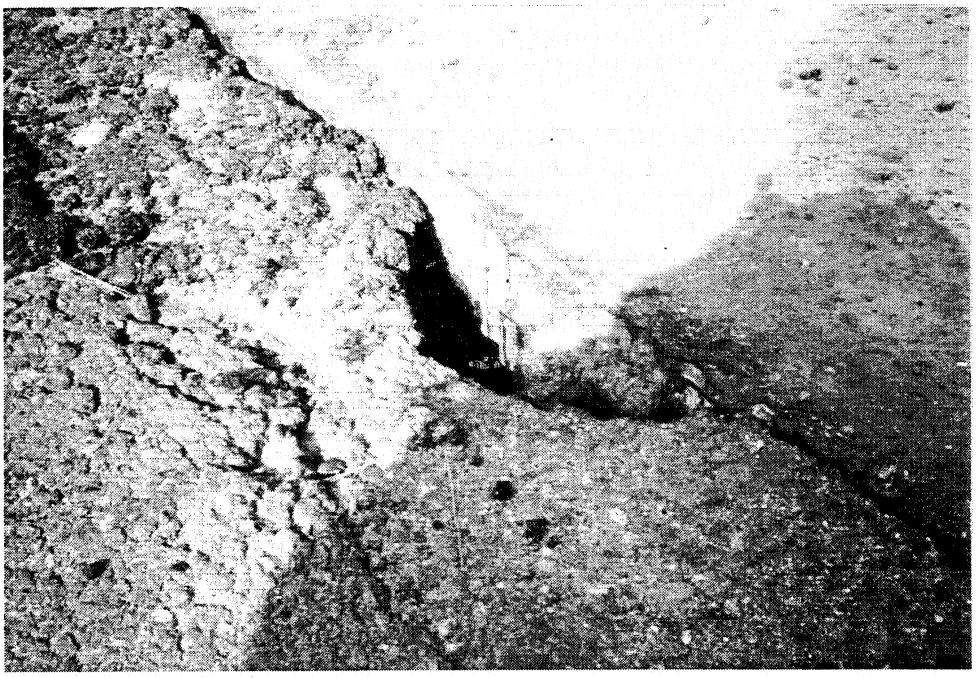


PHOTO. 5 Void due to Pumping at Free-edge of a PC Slab (Anegasaki Project)



PHOTO. 6 Distress at a Joint in Pre-tensioning System (Anegasaki Project)

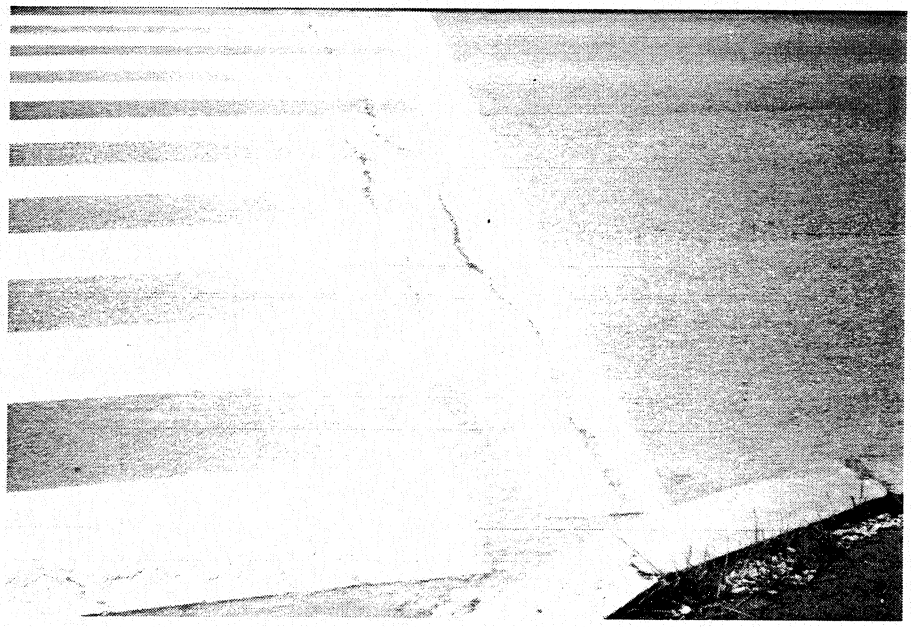


PHOTO. 7 Reflection Cracks in an Asphalt Layer Overlaid on a PC Pavement (Anegasaki Project)

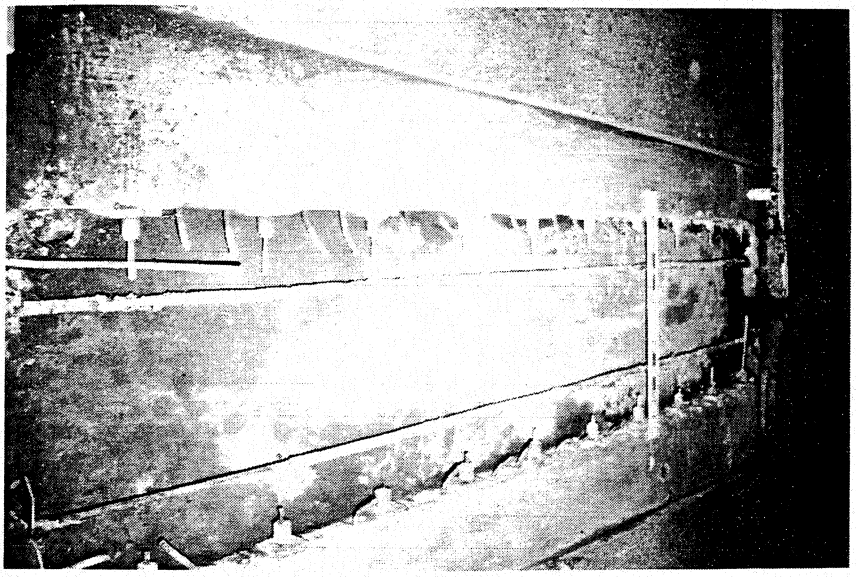


PHOTO. 8 Condition of Old PC Slabs Overlaid with a 10 cm Asphalt Layer and Subbase Surface (Anegasaki Project)

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