RESISTANCE AGAINST FATIGUE LOADING OF PRECAST PC DECK SLAB WITH THE IMPROVED LOOP JOINT

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RESISTANCE AGAINST FATIGUE LOADING OF PRECAST PC DECK SLAB WITH THE IMPROVED LOOP JOINT

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ABSTRACT

The loop joint using for precast PC deck slab usually tends to increase the deck slab thickness. If the thickness can be thinner, the dead load of the deck slab can be reduced. So, the authors have developed an improved loop joint which is inclining arrangement of loop joint for the purpose of reducing the deck slab thickness. In previous study, as the static bending test of slab specimens with the new joint, load-carrying behavior and durability satisfied the requirements for highway in Japan. This paper deal with the results of the wheel moving load test to examine the fatigue durability of precast PC deck slab including the improved loop joint. As results, sudden increases in vertical deflection, joint opening, and rebar strain were not confirmed at the load step (250kN × 100,000 times) that caused damage equivalent to 100 years on an actual bridge. Moreover, there was no water leakage from the bottom surface of the deck slab by the water filling test. Therefore, the required fatigue durability, which requires for about 100 years, was exhibited.

Keywords: Loop joint, Precast PC deck slab, Wheel moving load test

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1. INTRODUCTION

Many RC slabs on highway bridges have been deteriorated due to various factors, such as salt damage caused by chlorides of constituent materials in concrete and deicing salt, and increased traffic load due to the increase in vehicle size. From these reasons, it is increasing in recent years to replace RC deck slabs with PC deck slabs which have high durability and are capable of rapid construction. Loop joints are widely used because they are reliable as a deck slab joint structure and do not require special processing. However, loop joint tends to increase the thickness of the deck slab due to the increase in the diameter of the loop bars. Reducing the thickness of deck slab can reduce the dead load and make the reinforcement of main girder unnecessary. Therefore, in this study, the authors have developed an modified loop joint with loop rebars arranged at an angle to reduce the deck slab thickness (Figure 1).

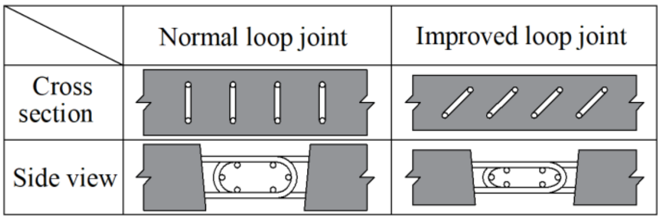


Figure 1. Comparison of normal and improved loop joint.

In previous study [1], a static bending test of RC beam using an improved loop joint was conducted. As a result, it was possible to design by the beam theory even if the loop rebar was inclined to 45 °. The bending load capacity was equivalent to that of a normal loop joint with an angle 90 °.

So as to apply the new joint structure to highway road bridges, the NEXCO design guidelines [2] require that the new joint structure has the required fatigue durability (equivalent to 100 years of durability) to be confirmed appropriately by experiments. Therefore, in order to examine the fatigue durability of the precast PC slab which the improved loop joint was applied, a wheel load moving test using a full-scale precast PC slab specimen was conducted.

2. EXPERIMENT PROCEDURES

2.1. Specimen preparation

Figure 2 shows the specimen dimensions and arrangement of displacement transducers, and Figure 3 shows the cross section in joint position. The specimen consists of three parts: precast PC slabs with improved loop joints and in-situ concrete. For each slab, prestress was introduced in the direction perpendicular to the bridge axis (y-axis), so as to limit tensile stress within 2 N/mm^2 at the bottom edge of the slab against the bending action of the slab during live loading. The parts were connected to form a single one-way PC slab by casting in concrete between them. The specimen was 4,500 x 2,800 mm, with the thickness of 220 mm at the center of span. Loop rebar (D19) were arranged at intervals of 150 mm. The inclination angle of the loop rebar was set to 62.1 °, which is an angle that can reduce the deck slab thickness of 240 mm to 220 mm when using D22 loop rebar. The required deck slab thickness is the sum of the required internal bending diameter of the loop rebar and twice the cover thickness and the reinforcing bar diameter. The required internal bending diameter dB(mm) is calculated by the following Eq. (1) [2], and the cover thickness is 40 mm.

$$dB = \left(1.4 + 2.8 \cdot \frac{\varphi}{e}\right) \cdot \frac{\varphi \cdot \sigma_e}{\sigma_{ck}} \geq 5\varphi \tag{1}$$

Where φ is the diameter of loop rebar, e is the interval of loop rebar, σ_e is reinforcing bar stress at bending start point (= 140 N/mm^2) and σ_{ck} is design strength of concrete.

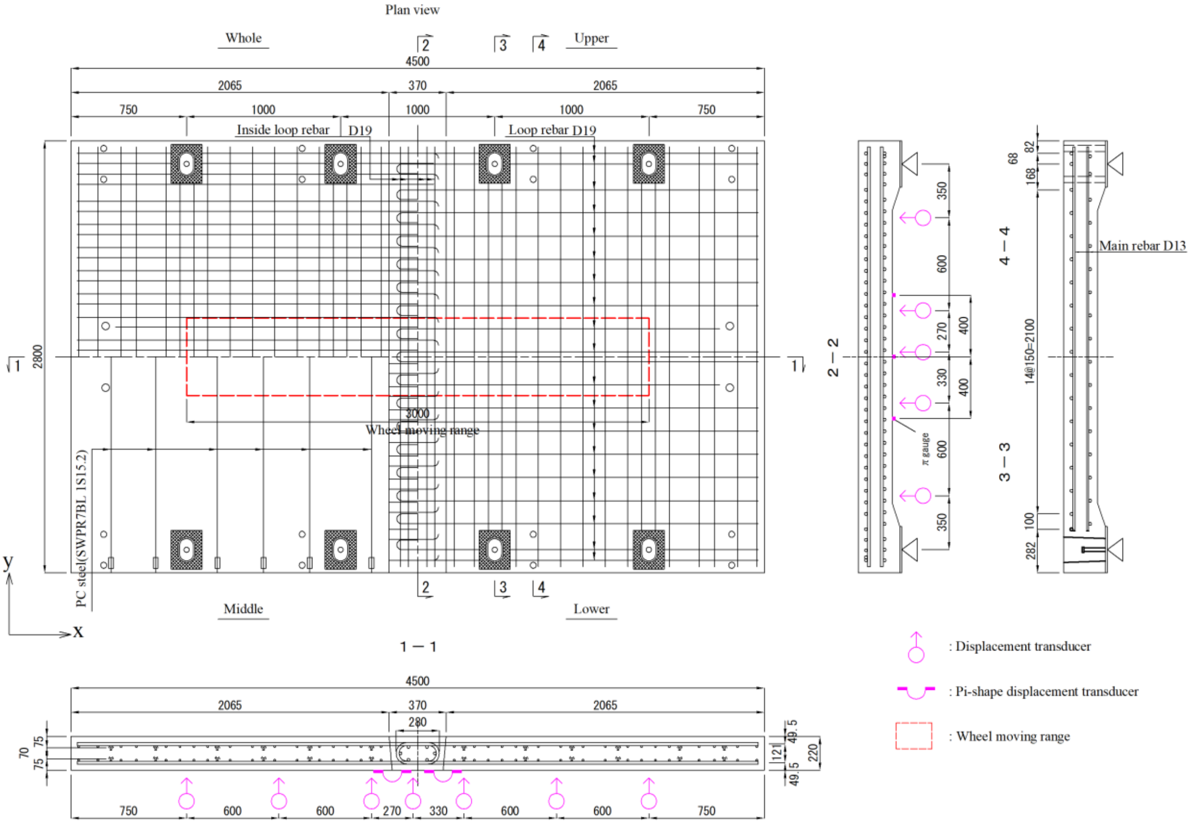


Figure 2. Specimen dimensions and arrangement of displacement transducers.

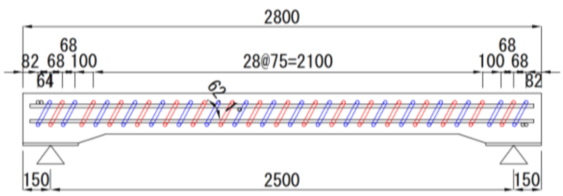


Figure 3. Cross section in joint position.

Table 1. Material property values.

Material	Application	Code	Characteristic value (N/mm^2)	Remark
Concrete	Precast deck slab	f'_c	76.8	79 days after placing
		E_c	39200	
	Cast in place	σ_c	60.3	39 days after placing (expansive concrete)
		E_c	33700	
Reinforcing bar	D13 D19	f_u	550	Epoxy resin coating
		f_y	400	
		E_s	200000	
PC steel strand	1S15.2	σ_u	1962	
		σ_y	1812	
		E_s	191000	

Because the PC steel is prestressed by the pre-tension method, the prestress force decreases in the 65φ section from the end of the specimen. Therefore, in this test, a compression grip as shown in Photo 1 was installed at the end of the PC steel to reduce the development length.

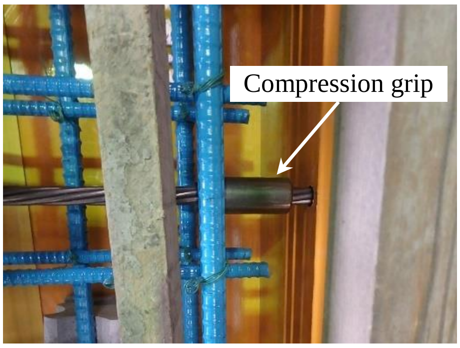


Photo 1. Compression grip.

2.2. Test setup

2.2.1. Wheel moving load test machine

The test was conducted using a wheel moving load test machine shown in Photo 2. The iron wheel of the test machine having a diameter of 0.7m and a width of 0.5m supplies reciprocating motion. The maximum load during running was 490kN. The reciprocation speed was a maximum of 15 reciprocations / minute, and the test was performed at a speed of 10-15 reciprocations / minute.

Photo 2. Wheel moving load test machine.

2.2.2. Condition and instrumentation

The support condition was simple support with a span length of 2,500 mm, and the load travel repeatedly within the range of 500 mm in width and 3,000 mm in length (shown by the red dashed line in Figure 2). Figure 4 shows the load step diagram. In this test, 250 kN x 100,000 times were conducted referring the paper [3] to investigate the durability equivalent to 100 years. After that, a water filling test was conducted to check water leakage from the joint between the precast part and the in-situ part. The water filling test is shown in Photo 3. In the water filling test, the water depth was 10 mm and the water was left for 6 hours. After the water filling test, the water was removed, and the load was increased by 50 kN for every 40,000 times as shown in Figure 4 to investigate the fatigue fracture properties of the specimen. The load was increased upto 490kN which is the maximum load of the machine. The total number of loadings at each loading stage is 460,000. The number of converted loading time N_{eq} running under this condition is approximately 440 billion times calculated from Eq. (2).

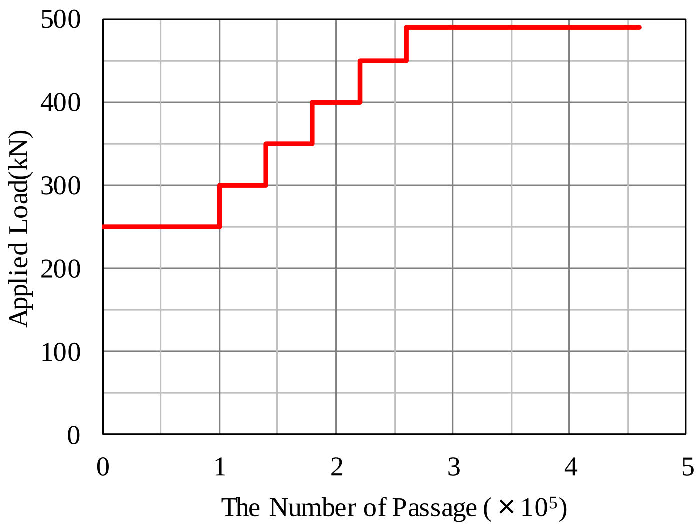


Figure 4. Load step diagram.

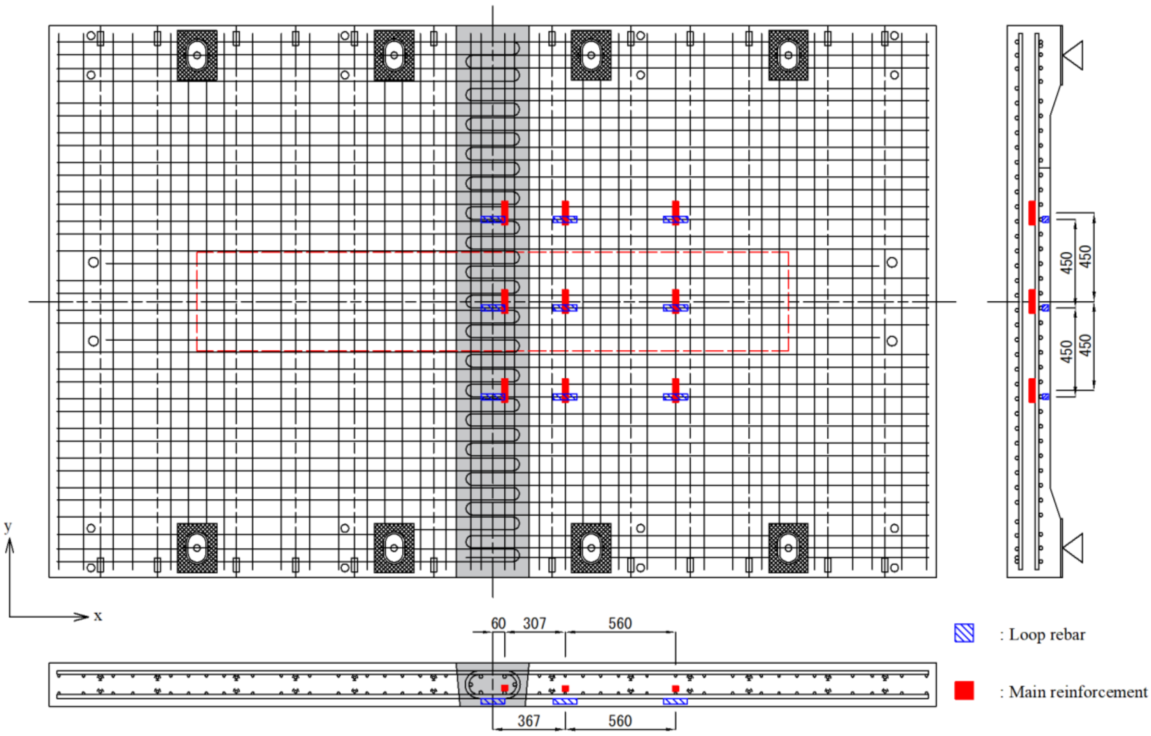


Figure 5. Strain gauge position.

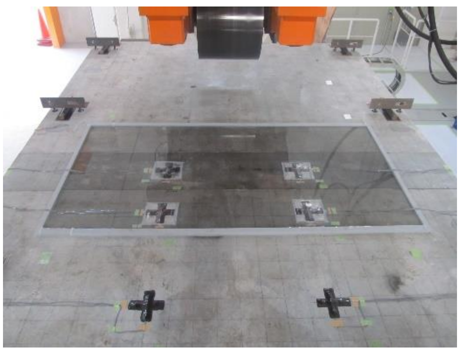


Photo 3. Water filling test.

$$N_{eq} = \sum \left(\frac{P_i}{P_0}\right)^m \times N_i \tag{2}$$

Where P_o [3] is the basic axle load (= 157 kN), P_i is wheel load (kN), m is absolute value of reciprocal of SN curve slope (= 12.76) proposed by Matsui et al. [4], the deck slab surface condition is dry and N_i is number of loadings at wheel load P_i.

Static loading was performed in the center part of the deck slab after loading a predetermined number of times. At that time, the deflection of the slab, the strain of the reinforcing bar, and the amount of joint opening at the interface between the precast part and the in-situ part were measured. The deflection of the slab was measured using a vertical displacement transducers (LVDTs), the strain of the reinforcing bar was measured using a strain gauge, and the joint opening was measured using Pi-shape displacement transducers (Pi gauge). The arrangement of LVDTs and Pi gauges is shown in Figure. 2, and the strain gauge position is shown in Figure. 5 respectively.

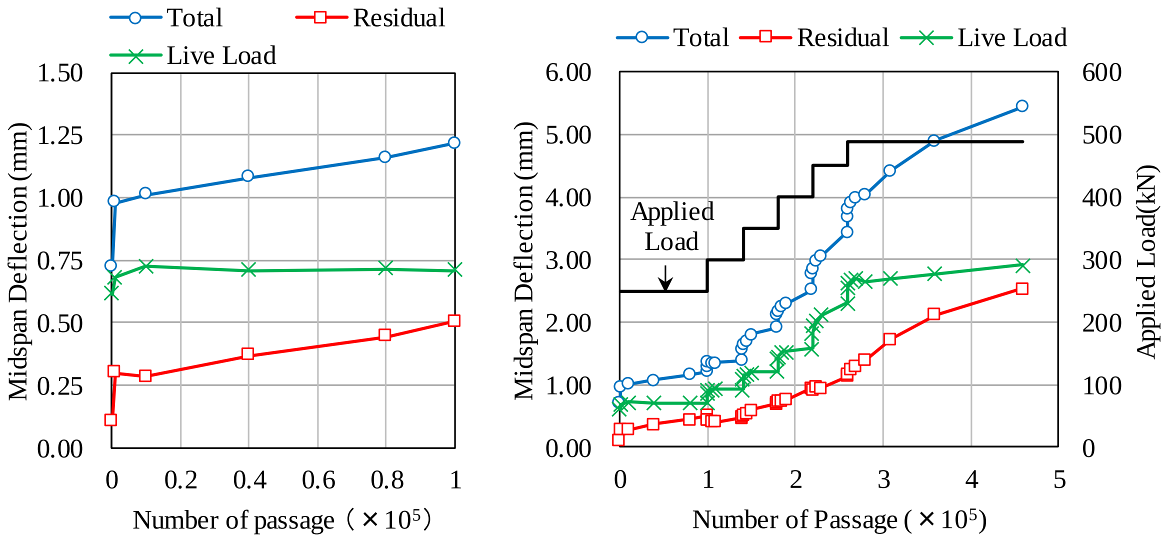
3. RESULTS AND DISCUSSIONS

3.1. Deflection at midspan

Figure 6 shows the changes in deflection in the center of the slab. Figure 6 (a) shows the details of 250kN x 100,000 times, which is equivalent to 100 years, and Figure 6 (b) shows results in total load steps. The live load deflection δ_{live} is calculated by Eq. (3)

$$\delta_{live} = \delta_{total} - \delta_{residual} \tag{3}$$

Where δ_{total} is total deflection which is measured by LVDT at the maximum load in each load stage, $\delta_{residual}$ is residual deflection which is measured at unloading. Total deflection and residual deflection gradually increased with increasing loading, and the deflection after 490kN tended to increase more than before. On the other hand, the live load deflection was almost constant at any load stage. The same tendency was observed at the other LVDTs, and drastic changes in deflection due to the loop joint were not observed.



(a) Until 100,000 times (250 kN)

(b) Total

Figure 6. Changes of midspan deflection.

3.2. Deflection distribution

Figure 7 shows the deflection distribution in live load. Figure 7 (a) shows the y-axis direction (between the slab supports), and Figure 7 (b) shows the x-axis direction (perpendicular to the slab supports). The value indicates the live load deflection at the final loading in each load stage. It can be confirmed that the deflection of the live load increases at any measurement position as the applied load increases, and that the deflection difference between the steps increases as the load step increases. In Figure 7, when comparing the left and right deflections centered on the center of the span, it was confirmed that the values were roughly the same at all loading stages. From this, it is considered that there is no difference in the flexural behavior in both x and y-axis direction even if the loop reinforcement is placed at an angle.

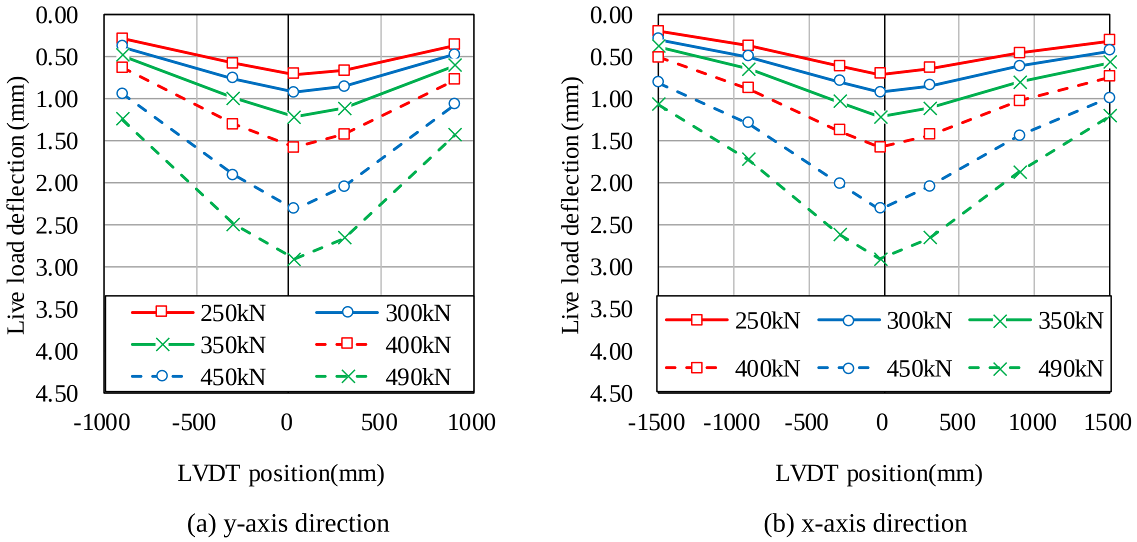


Figure 7. Deflection distribution in live load.

3.3. Crack width between PC deck slab and in-situ part

Figure 8 shows the changes of crack width between PC deck slab and in-situ part. The figure shows the values below the loading point, which showed the largest value among all six locations. The display format of each value is the same as in Figure 6. As shown in Figure 8 (b), crack width at each load stage fluctuated and did not show a constant value, unlike the case of deflection. It can be inferred that a small

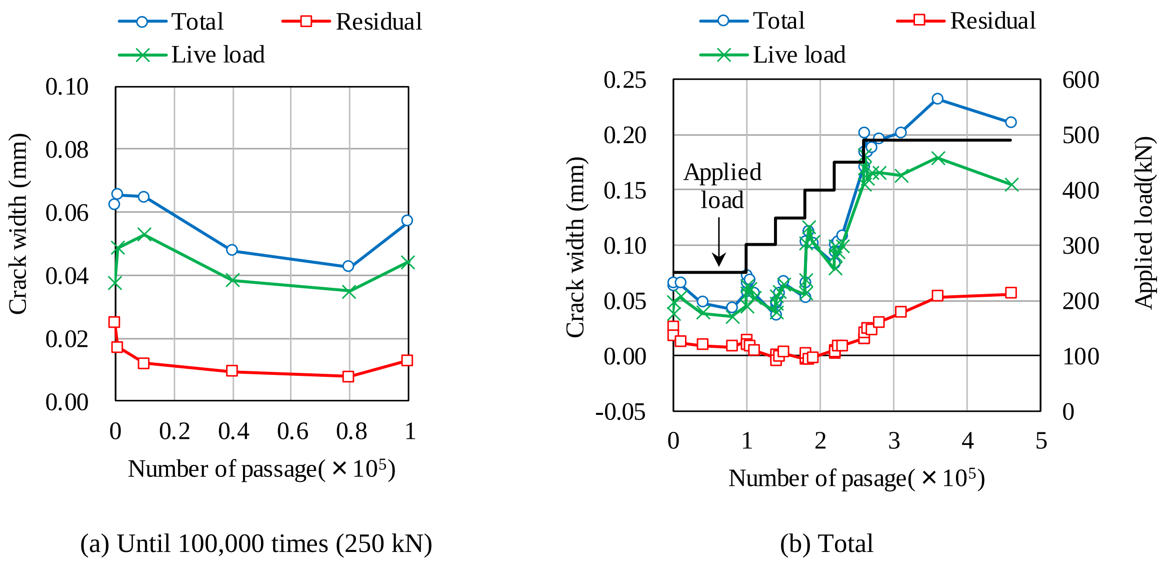


Figure 8. Changes of crack width between deck slab and in-situ part.

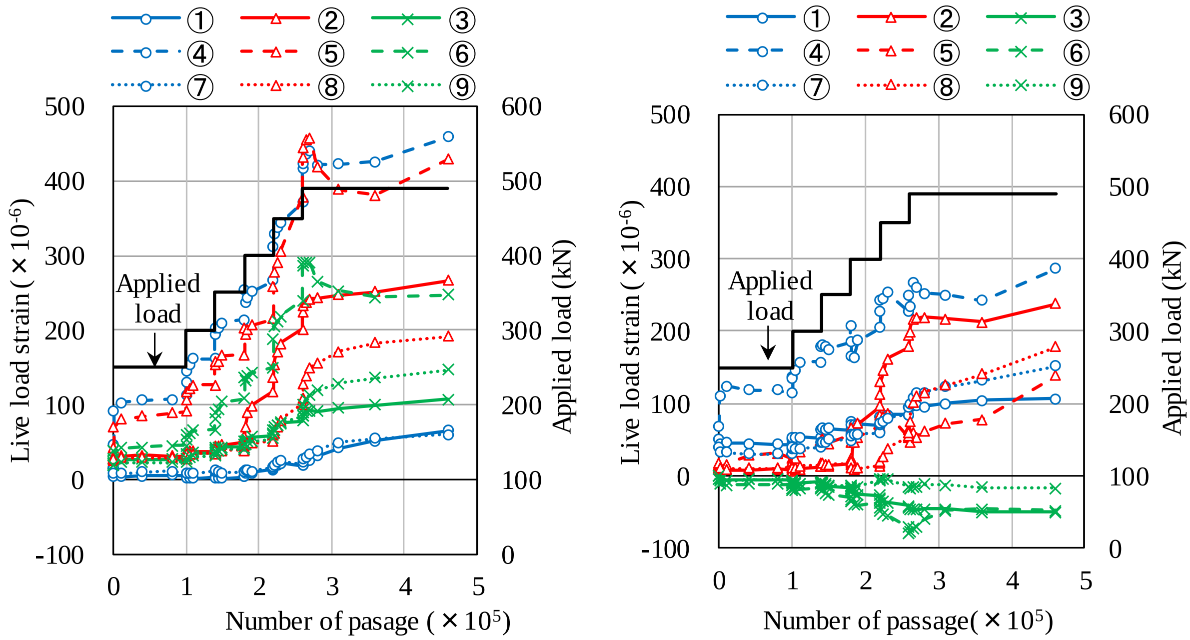
level difference in the vertical direction occurred during each run due to the impact of the wheel load. On the other hand, paying attention to the fatigue durability of 250kN × 100,000 times that is equivalent to 100 years in Figure 8 (a), the largest crack width was 0.07mm, which was very small. In the water filling test after 250kN x 100,000 times, no water leakage from the joints on the lower surface was confirmed. Therefore, it is considered that it has fatigue durability equivalent to 100 years.

3.4. Strain of reinforcing bar

Figure 9 (a) and (b) show the strain on the lower side of the loop reinforcing bar, and the strain on the lower side of the main reinforcing bar, respectively. The numbers in the graph correspond to Figure 5, and the strain indicates the live load strain. The live load strain ε_{live} is calculated by Eq. (4)

$$\varepsilon_{live} = \varepsilon_{total} - \varepsilon_{residual} \tag{4}$$

Where ε_{total} is the total strain which is obtained at the maximum load at each load stage, and $\varepsilon_{residual}$ is the residual strain which is obtained at unloading. As shown in Figure 9 (a), the strain generated in the loop rebar tends to increase as it gets closer to the in-situ part, and in particular, No.4 just below the loading point shows the largest value. For gauges No.3, 6, and 9, the strain showed compression. This is thought that negative bending occurs at this position due to the support conditions of the slab. Looking at the transition of strain upto 100,000 times, no sudden increase in strain is confirmed. In the main rebar shown in Figure 9 (b), the strain tends to increase at the center position of the span (No.4, 5, and 6), which is considered to be the same as the normal slab behavior. Comparing gauges No.1–3, and No.7–9 located 450mm away from the center of the span, all showed almost the same strain up to a loading load of 350kN. On the other hand, after 400kN, paying attention to No.2 and 8, the strain has a difference of about 50 x 10^{-6}. This is thought to be due to the difference in the progress of cracks on the bottom of the slab. Even in the main reinforcing bar, no sudden increase in strain was observed up to 100,000 times.



(a) Loop rebar bottom side strain

(b) Main rebar bottom side strain

Figure 9. Strain of reinforcing bar.

3.5. Crack progress

Figure 10 shows the crack progress diagram. Up to 250 kN, the cracks of y-axis direction occurred at joint interface and precast parts, respectively. After that, cracks did not occur in the in-situ section in

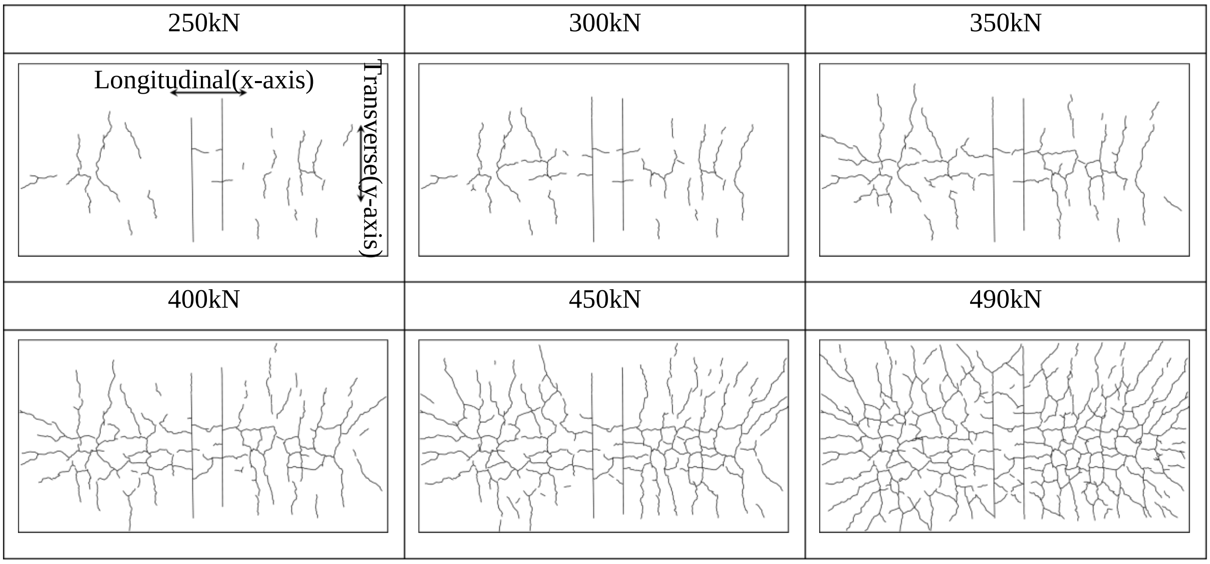


Figure 10. Crack progress.

the x-axis direction. Therefore, it is considered that the fatigue durability of the in-situ part with the loop joints arranged at an inclination is equal to or better than that of the normal joints of PC deck slab. The punching shear failure due to fatigue did not occur even after loading 490kN × 200,000 times, so the improved loop joint is considered to have sufficient fatigue durability.

4. CONCLUSIONS

In order to confirm the fatigue durability of the precast PC slab to which the improved loop joint was applied, a wheel load moving test using a full-scale precast PC slab specimen was conducted. The findings obtained from this study are shown below.

As a result of a wheel moving load test, sudden increases in vertical deflection, joint opening, and rebar strain were not observed at the load step (250kN × 100,000 times) that caused damage equivalent to 100 years on an actual bridge. Moreover, there was no water leakage from the bottom surface of the deck slab by the water filling test.

The cracks in the in-situ part did not occur rapidly, and the final cracking properties were map cracking, which is similar to the general crack growth. Therefore, the effect of the sloping arrangement of the loop reinforcing bars was not confirmed.

Even after loading 490kN × 200,000 times, punching shear failure due to fatigue did not occur.

Based on the above, it is considered that the improved loop joint has enough fatigue durability when the loop rebar angle is in the range of 62.1 ° to 90 °.

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