Study on monitoring technology focused on reinforcement cable for a fail-safe system

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ABSTRACT: Recently, fractures of PC steel bars on expressway bridges in Japan have been reported. PC steel breakages weaken the load bearing capacity of PC bridges and could, in a worst-case scenario, lead to bridge collapse. To deal with this problem, outer reinforcement cables are installed on PC girders that have apparent PC steel bar breakages to improve the stress condition of the concrete member and recover the load bearing capacity of bridges. This reinforcement cable is also installed as a fail-safe measure against bridge collapse when insufficient grouting or deformation of PC steel rods is suspected. In general, when the PC steel rod is fractured, it loses its prestress. As a result, the PC bridge's load bearing capacity lowers, which increases the tension of the reinforcement cable. In this paper, we focused on whether the progress in the deterioration of PC girders may be estimated by monitoring the changes in the tension of the fail-safe reinforcement cable, and carried out experiments to that end.

In the experiments, prestress-changeable PG girders were used. We installed fail-safe reinforcement cables on both sides of the PC girder and measured the tension of the reinforcement cables as the prestress of the PC girder was lowered. Tests showed that when the design stress of the PC girder is lowered from 100% (490kN) to 0% (0kN), the tension of the reinforcement cable increased a maximum of 17.6kN. This increase is 3% of the design prestress of the PC girder, indicating that the increase in the cable tension is minute compared with the amount of reduced prestress. But an actual bridge is composed of multiple girders, and even though the PC steel rod of a PC girder is only partially fractured, it may be difficult to understand how much the load bearing capacity of the entire bridge lowered just by looking at the changes in the tensile strength of the reinforcement cable. Therefore, in monitoring PC steel rods, it is recommended not only to focus on the changes in the tensile strength of the reinforcement cable but look at its oscillation characteristics, and use the AE method and various other monitoring methods to examine from various angles and evaluate the condition comprehensively.

1 INTRODUCTION

Of the total 18,306 expressway bridges in Japan, 7,133 are PC bridges, which is 39% of the total number. Of these PC bridges, 2,330 are more than 30 years old, and maintaining these bridges appropriately will become very important in the future. Recently, fractures of PC steel rods on expressway bridges in Japan have been reported. These breakages are mainly caused by rainwater entering un-grouted parts and eroding the PC steel rods. When PC steel corrodes, the

PC steel gradually becomes brittle starting from the initially eroded part and then breaks. This means no notable change in the bridge's load bearing capacity can be seen immediately after erosion starts, but the bridge may suddenly collapse when the PC steel rod breaks. In addition, PC steel rods are embedded in concrete, so it is not easy to detect such damages. This is why preventive maintenance is needed for bridges where deformations are either confirmed or suspected. In Japan, to tackle this problem, outer reinforcement cables are installed on bridges with apparent deterioration to enhance the tensile strength of concrete members and recover the load bearing capacity of PC bridges. Fail-safe reinforcement cables are also installed on PC bridges where insufficient grouting or deformation of PC steel is suspected, as a preventive measure against bridge collapse. In general, when a PC steel rod of a PC bridge breaks, it loses the prestress introduced to it. As a result, the load bearing capacity of the bridge lowers, causing tension of the reinforcement cable to increase. In this study, we focused on whether the progress in the deterioration of PC girders may be estimated by monitoring the changes in the tension of the reinforcement cable, installed as a fail-safe measure, and carried out experiments to that end.

2 TEST PIECE

2.1.1 PC girder

Figure 1 describes the test PC girder used in the experiments. The PC girder is 9,000mm long, 400mm wide and 600mm high. This PC girder has one φ32mm PC steel rod, which is typically used in PC structures. The compression strength of the concrete is 36N/mm^2. The compression strength and modulus of static elasticity of the PC girder concrete when the material was 28 days old are shown in Table 1.

In the experiment, we focused on the increased tension of the reinforcement cable when the prestress of the PC girder was lowered. And so, the PC steel rod and girder were not bonded together so that the amount of prestress introduced to the PC steel rod may be changed even after grouting. As shown in Figure 2, Vaseline was applied on the steel rod as a lubricant and then the rod was covered with a heat-shrinkable tubing. This will prevent the grout from adhering to the steel rod when grout is injected into the sheath, and therefore, prestress may be changed with the PC steel rod and PC girder integrated.

As for the prestress introduced to the PC steel rod, an amount of prestress that will make the tensile strain of the PC girder's lower end concrete 0 was set as 100%. Prestress 100% is 490kN.

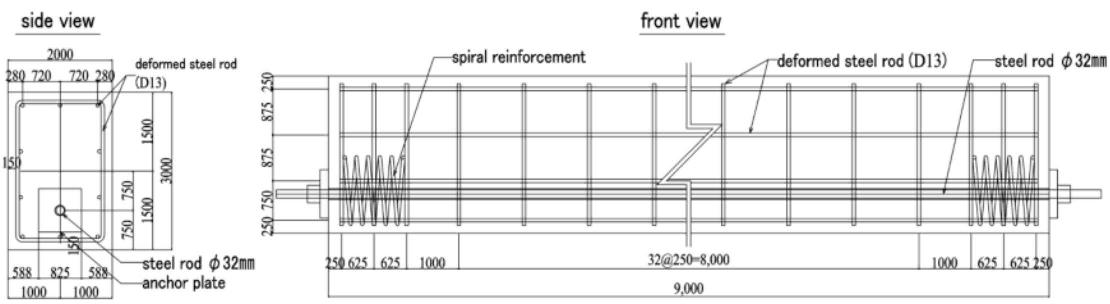


Figure 1. Details of PC girder

2.1.2 Fail-safe reinforcement cable

In the experiment, two types of PC steel cables were used as fail-safe reinforcement cables. As described in Table 2, they were large-capacity F100TS cable and mid-to-small capacity ECF strand cable. One cable was installed symmetrically each on the left and right sides of the PC girder. Figure 3 shows the cables installed on the girders. The reinforcement cables were attached in two ways: linear layout -- in a straight line parallel to the girder; and deflected layout -- with deflection parts.

Table 1. Compression strength and modulus of static elasticity of concrete (material age: 28 days)

Compression strength (N/mm2)	Modulus of static elasticity (kN/mm2)
50.6	28.2

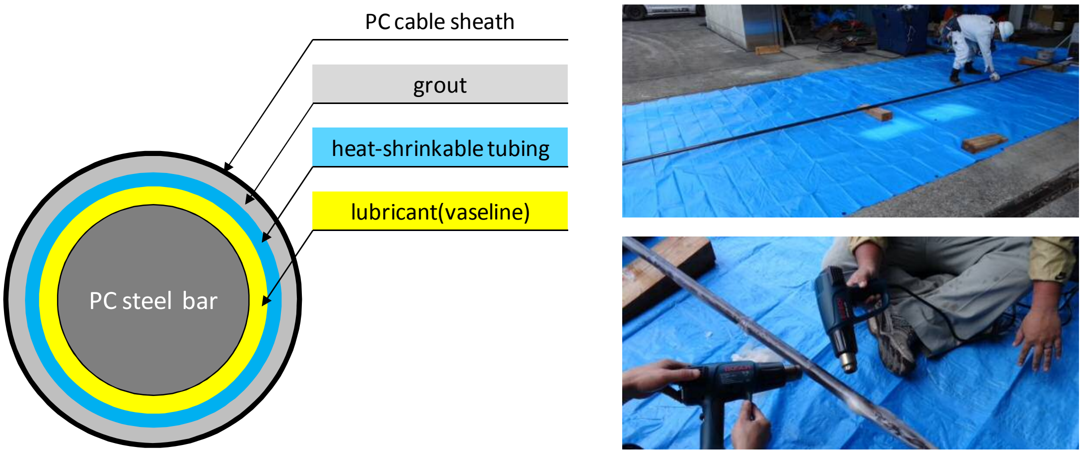


Figure 2. Un-bonded PC girder

Table 2. Fail-safe reinforcement cable specifications

Name	Specifications	Py(kN) Load against 2% permanent elongation	Pu(kN) Tensile load
F100TS	7× ϕ 11.1mm	≧826	≧966
ECF strand	1× ϕ 15.2mm	≧222	≧261

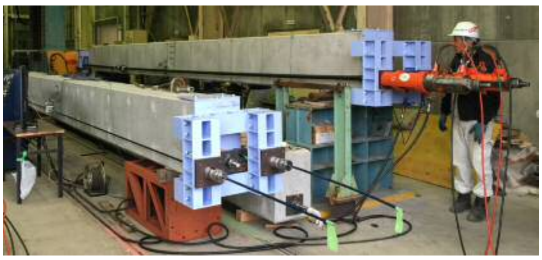


Figure 3. Installing fail-safe reinforcement cable

3 EXPERIMENT WITH PC GIRDER

3.1.1 Gaging method

A load cell was attached to the end of the PC steel rod and reinforcement cable to manage the amount of prestress introduced to the PC girder and measure the increase in tension of the reinforcement cable. A displacement sensor and strain gage were also installed on the PC girder. The displacement sensor and strain gage were installed on the bottom face of the test piece: at the center of span between fulcrums, L/2 (L: span); at 2 points at span L/4; and at 2 points, 100mm from the fulcrum in the center of span direction. Figure 4 shows the positions of the instruments.

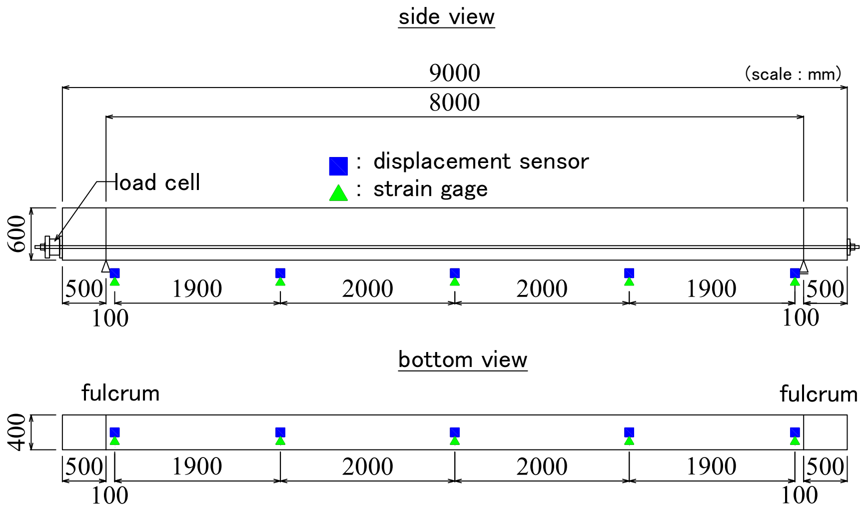


Figure 4. Position of measuring apparatus

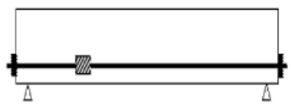
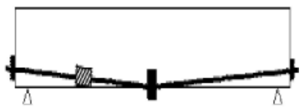
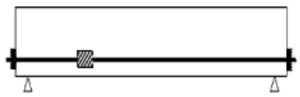
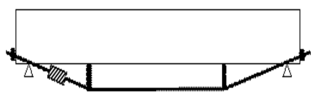
3.1.2 Experiment conditions

An experiment case is described in Table 3. Full-prestress, 0.6σpu (490kN), was introduced to the PC girder, and from there prestress was lowered 10% at a time, and the changes in the tension of the reinforcement cable was measured each time. The reinforcements cables were installed on both sides of the PC girders in two ways: in a linear layout and in a deflected layout.

4 EXPERIMENT RESULTS

The findings of the experiment are shown in Figure 5. Test results show that tension of the reinforcement cable increases as the prestress introduced to the PC girder decreases. But the maximum tension increase of the reinforcement cable was 17.6kN even when the PC girder prestress was lowered to 0% (0kN) from the design prestress of 100% (490kN). Because 17.6kN is about 3% of the design prestress, we can say that changes in tension is minute compared with the lowered amount of prestress.
When the tension of the PC steel rod lowers, deflection of the PC girder increases together with strain in the axial direction. When the reinforcement cables are arranged along the PC girder in a linear layout, the increase in tension of the reinforcement cable is small. However, it was confirmed that by providing a deflection at the reinforcement cable and letting it follow the geometric change of the PC girder, the change in the cable tension may be doubled, which improves sensitivity for measuring tension fluctuations.

Table 3. Experiment conditions

Test case	Outer cable type	Outer cable tension	Outer cable position	Outer cable deflection angle	Layout
1-1	F100TS	0.2 σ pu	—	—	
1-2	F100TS	0.05 σ pu	Under girder center	1.7°	
2-1	ECF strand	0.2 σ pu	—	—	
2-2	ECF strand	0.2 σ pu	Under girder 300mm	7.9°	

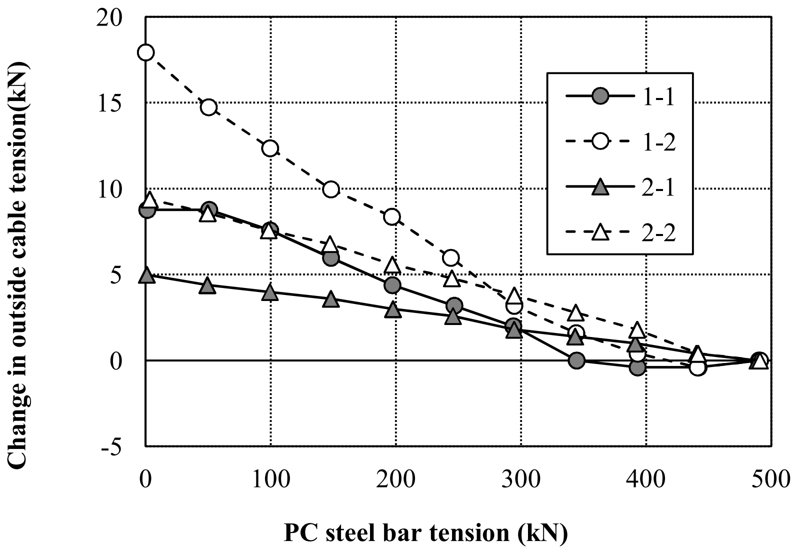


Figure 5.Experiment results

5 CONCLUSION

It was confirmed that tension of reinforcement cables increases as the amount of prestress introduced to the PC girder is reduced. But it was found that tension changes were minute compared with the amount of prestress lowered. In addition, it was confirmed that by providing a defection at the reinforcement cable and letting it follow the geometric change in the PC girder, the sensitivity for measuring tension change in the reinforcement cable improved.

Because PC bridges are composed of multiple PC girders, even if a portion of the PC girder steel rod is fractured, the changes in the entire bridge are thought to be small. Even when a breakage of the PC steel rod is identified, adhesion by grouting at places other than the fractured portion will work to maintain prestress, and therefore, it is possible that prestress would not be lost for the full length of the PC steel rod immediately after it breaks. On the other hand, active load and temperature load may affect the PC steel rod after it breaks, causing a loss of adhesion by grouting and prestress may lower over time. As you can see, prestress of PC bridges cannot be estimated in a simple way. In other words, it is not easy to capture how the load bearing capacity of the entire bridge lowers along with the decrease in the PC girder's prestress just by looking at the changes in the tension of the reinforcement cable. So, as a method to monitor breakages of PC steel rods, it is recommended not only to focus on the changes in the reinforcement cable tensile strength, but also check its oscillation characteristics and use the AE method and other various monitoring technologies and measuring methods and evaluate the damage comprehensively.