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EVALUATION OF THE STRENGTHENING EFFECT ASSESSMENT OF A DETERIORATED BRIDGE VIA TESTING VIA THE EXTERNAL PRE-STRESSING METHODOLOGY

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Abstract:
In the research article with the goal to increase the load bearing capacity of concrete bridges harmed by ageing or other external environmental variables, the external pre-stressing technique was created. As a result, it is essential to assess the structure's performance both before and after strengthening, and it is best to verify and validate the strengthening impact in advance. However, the strengthening impact of an actual bridge is seldom evaluated due to many factors, including the need to secure deteriorating bridges and the lack of design data. Therefore, a series of material property tests and four-point loading tests were performed in this research before and after strengthening of an actual bridge that had been in use for more than 45 years in order to verify the strengthening impact. Because the external pre-stressing method has a negligible effect on stiffness, it was concluded that it is difficult to confirm the strengthening effect prior to cracking; on the other hand, the effect of increasing the crack load of the external pre-stressing method was experimentally verified. It is anticipated that the study's findings will aid in estimating the load bearing capability and quantity of reinforcing needed to repair steel girder bridges that are actually in existence.
Keywords: strengthening method; strengthening effect; external pre-stressing; deteriorated bridge.

1.0 Introduction

Concrete buildings degrade over time owing to material degradation, heavy loads, and environmental conditions, leading to a decline in their original performance, which impacts their usage and safety [1-3].Specifically, in the context of pre-stressed concrete (PSC) bridges, instances of bridge collapse caused by internal tendon corrosion have been documented, highlighting the need of maintaining [4-6].

Bridges deteriorate over time owing to increased use and degrade faster because of environmental changes like higher traffic flow and more heavy cars. Hence, several reinforcement techniques are used to enhance and enhance the efficiency of these bridges while also increasing knowledge about the significance of structural upkeep [10–16].

Exterior prestressing is a procedure used to reinforce degraded bridges by putting tendons on the outside tensile zone of the structure and applying direct tensioning force to enhance the load bearing capacity of the existing structure. This procedure is often used because to its benefits, which include avoiding corrosion of reinforcing bars and repairing deflection by sealing fractures in the tensile zone [17].

Several research investigations have confirmed the reinforcing impact of the external prestressing approach, however there is little evidence of its effectiveness on existing old bridges. The lack of adhesion between the exterior tendon and the concrete foundation material makes it challenging to accurately forecast the bridge's behaviour due to the absence of strain compatibility. Moreover, the external prestressing strengthening approach is challenging to verify its effectiveness due to the lack of noticeable stiffness change before breaking.

While this was going on, researchers looked at the external pre stressing approach for assessing preexisting structures, analysing bridge behaviour, and studying the consequences of bridge strengthening. The assessment of the current structure's behaviour is crucial for confirming the accurate strengthening effect, since this is defined as the performance difference between the structure before and after strengthening. In analysing the behaviour of prestressed concrete structures, the value of the prestressing force is crucial. For this reason, in order to assess the current structures, several investigations on prestressing force losses have been carried out. There have been research on prestress loss in unattached continuous beams [22], effective prestressing force estimate in PSC girders [23–25], stress in non-adherent tendons under harsh circumstances [26], and prestressing force losses with time [5,27].

Shenoy et al. [23] performed tests for structural integrity on PSC girders utilised over 27 years to study their behaviour and effects, while Tabatabai et al. [25] evaluated the ultimate load-bearing capacity of long-term common bridges by performing structural and load-bearing tests on old PSC girders used for 34 years. Ramos et al. [28] examined the performance of PSC bridges reinforced with external steel wires undergoing repeated deflections, whereas Harajli et al. [29] investigated the behaviour of continuous bridges using external prestressing. Aparicio et al. [21] and Chun et al. [30] conducted a load test on concrete bridges reinforced with external steel wires to assess the bridge's behaviour and load-bearing capability under typical loads. Several research have been carried out to verify the maximum stress and bending strength of external tendons that are not adhered [26,28,30–33]. Generally, there are few cases where the strengthening effect before and after actual strengthening has been systematically confirmed. Most studies have primarily focused on evaluating the condition of existing members needed for strengthening PSC girder bridges and verifying the performance required after strengthening.

The present investigation employed the exterior the prestressing process approach on a bridge that had been in service for 45 years and was subsequently dismantled. A loading experiment was conducted before and after strengthening to analyse the behaviour after the strengthening process and verify its effectiveness.

2. The Experimental Technique

2.1. Deteriorated Bridge

As demonstrated in The bridge used in the experiment was built in 1975 and removed after about 45 years of usage. The bridge is a two-span continuous PSC girder with specifications of 60.9 m in length, 30.5 m maximum span, and 11.7 m in width. However, the lack of design data is mostly owing to the extended service duration. Furthermore, the design drawing's poor resolution hinders the precise inspection of requirements. The parameters of the bridge were checked by measuring. Figure 2 displays the bridge's cross-section. The girder's compressive strength is 27 MPa. Tendons with a diameter of 8 mm and tensile strength of 1560 MPa were placed into seven ducts using 12 strands, based on the current engineering information.

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Figure 1. Front view of the deteriorated bridge

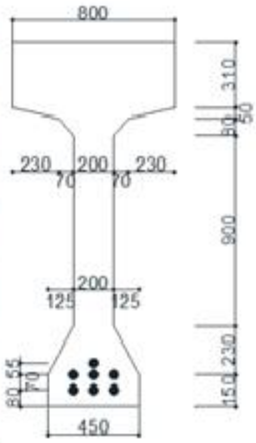

Figure 2. Cross section of the deteriorated bridge (unit: mm).

2.2. Material Properties

Materials properties testing were carried out on the concrete and tendons of the degraded bridge to determine the material qualities of the bridge. Approximately 50 cores were taken from different locations of the girder, as seen in Figure 3, and subjected to a compressive strength test. The test showed that the concrete compressive strength was 33 MPa, which was 22% greater than the starting strength of 27 MPa. It was unable to ascertain whether the strength was changed since there was no value for experimentation available during its manufacture. A tensile strength test was conducted on five tendons taken from the specified bridge. The test revealed a tensile strength of 1660 MPa, indicating a 6% increase compared to the original design data of 1560 MPa. Thus, it may be inferred that there was no notable impact on the performance of the tendons inside the grout, even after 45 years.

Figure3. Core sampling

The interior tendon's functional elasticity was assessed to verify the genuine bridge's performance. Figure 4 displays the process of removing the grout to expose the internal tendon, which was then tugged in the transverse direction to assess the effective tensile strength based on the force-displacement relationship. The pre-stressing force was determined using a load cell placed in the anchoring. An effective tension ranging from 25.1 to 32.7 kilonewtons was observed in this test. This figure represents 32–43% of the tensile strength of the tendon. It is estimated that over 50% of the tension has been lost, leaving roughly 40–53% of the effective tension compared to the maximum tension force recommended by ACI 318 [34]. As seen in Table 1, the deviation of each tendon was significant, and several tendons experienced total tension release. It was challenging to determine whether the losses of the prestressing force happened during the bridge's usage or during its destruction for testing. Furthermore, the removal of the grout may have impacted the performance of

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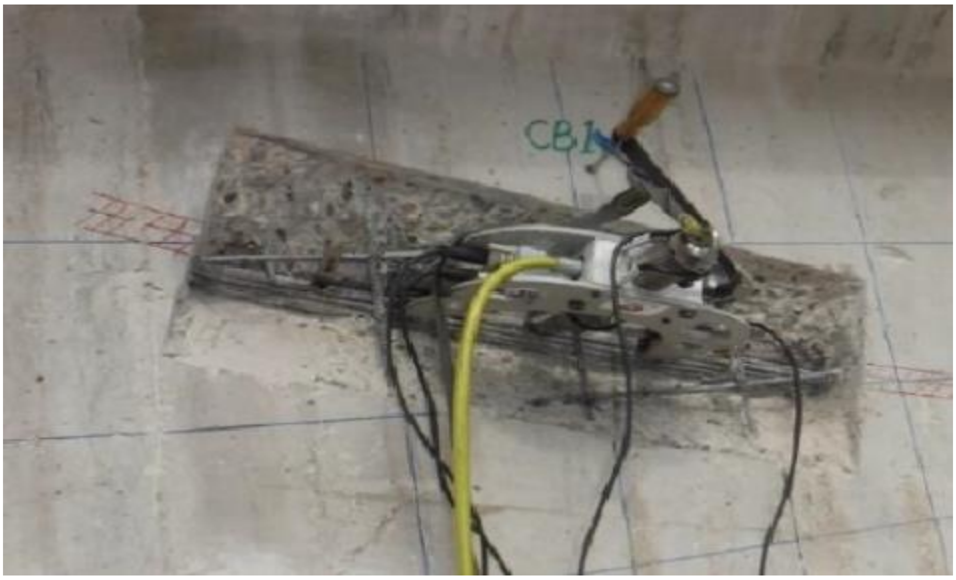
the existing structure due to the exposed internal tendon or deviations from the tension force of each tendons.


Figure 4 Evaluation of internal tendon force.
Table1. Result of internal tendon force measurement

Duct No.	Distance [1] (m)	Tendon No.	Measured	
			Force (kN)	Stress (MPa)
1	5	1 2	30.8 32.7	613 650
2	9	1 2 3	Tension released 33.4 25.1	 664 499
3	23	1 2	Tension released Tension released	

2.3: A Load as well as Assessment Strategy
The investigation was conducted in three parts. An assessment was undertaken to evaluate the performance of the existing bridge before strengthening the destroyed bridge. The second phase involves using the external pre-stressing approach to reinforce the structure using external tendons. After reinforcement, a loading test was conducted to confirm the performance. Figures 5 and 6 show the use of two actuators with a capacity of 5000 kN. A four-point loading test was conducted for safety purposes using a displacement control technique at a speed of 2 mm/min. The boundary condition for the beam was established with a hinge and roller located 250 mm from both ends. The load was adjusted to create a pure bending section with a length of 6 m and a breadth of 3 m on each side from the centre of the specimen. In the pre-strength phase, the force was applied until the fracture appeared, whereas in the post-strength phase, the weight was applied until the structure was torn apart.

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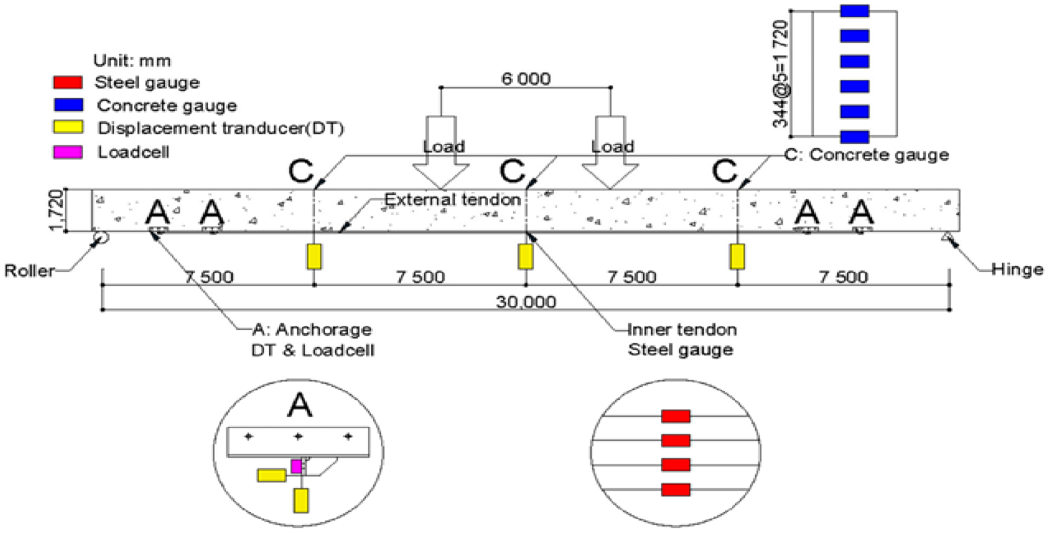

Figure 5 Experimental setting.

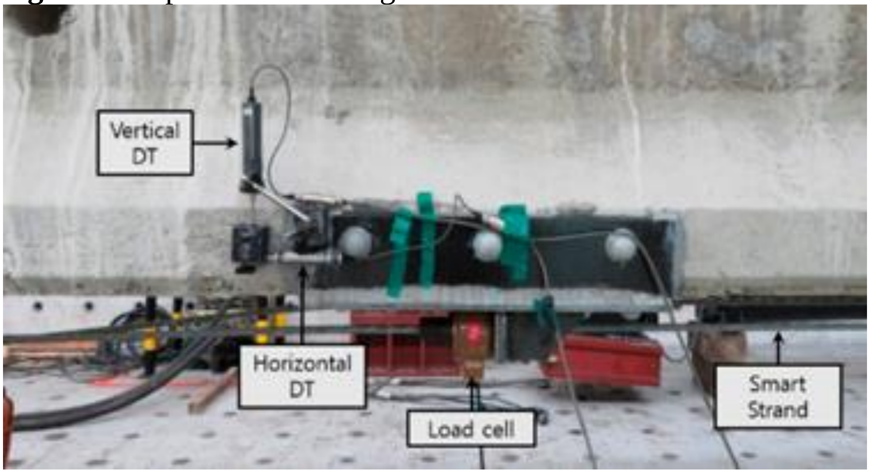

Figure 6. Anchorage sensor setting.

Sensors were placed at strategic points around the displacement transducer to monitor the structural response and anchoring activity under loading conditions. Stress gauges were set up on both the internal tendons and the concrete surface. A displacement transducer was put to assess the anchorage's activity during and after reinforcement. Additionally, a load cell was inserted at the end of the external tendon to monitor the change in the applied tension.

2.4. Strengthening Deteriorated Bridge

The anchorage's effectiveness is crucial in the external the prestressing process procedure to provide a significant strengthening impact. In several instances, the verification of the strengthening effect was hindered by the premature removal of the anchoring. This occurs when the anchoring is planned based on the tensile strength of the external tendons or the stress they bear at the structure's failure point, resulting in an overly large anchorage. It was verified that the anchoring was constructed with prestressing force applied in some areas. Thus, this research employed the tensile strength of the external tendon as the design strength for developing the anchoring and anchor bolt spacing in accordance with standards.

Early deterioration of the anchoring was avoided by taking into account side anchor bolts that were overlooked during the planning phase of the building.

A leaflet-type anchoring with placed anchor bolts was used to sustain all loads. Two strands were dispersed and fastened for anchorage performance, as seen in Figure 5.

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Each external tendon was built with a prestressing force of 180 kN. The maximum tension forces recorded using the load cell for the four external tendons were 184.8, 180.0, 179.5, and 181.5 kN, as shown in Table 2.

Table 2. Tendon force and anchorage displacement.

	Jacking Order	Tendon Force (kN)			Anchorage Displ. (mm)	
		Jacking Force	Setting Loss	Elastic Loss	Horizontal	Vertical
T1	3	184.8	172.8	172.0	0.06	0.05
T2	2	180.0	171.0	168.3	0.03	0.01
T3	1	179.5	169.3	164.5	0.02	0
T4	4	181.5	175.5	175.5	0.02	0.02

The injected tension was decreased as a result of the slip produced during connecting the tendon to the fastening device and the loss of elasticity caused by the following tension in the tendon. The anchorage's activity increased by 0.06 mm when the tension force was supplied to the individual tendon, demonstrating that the anchoring provided sufficient safety against the imposed tension. At the midpoint of the span, a vertical movement of 11.5 mm (upward) occurred once all pre-stressing forces were activated. Figure 7 illustrates the girder's displacement caused by the exterior tendons' pre-stressing.

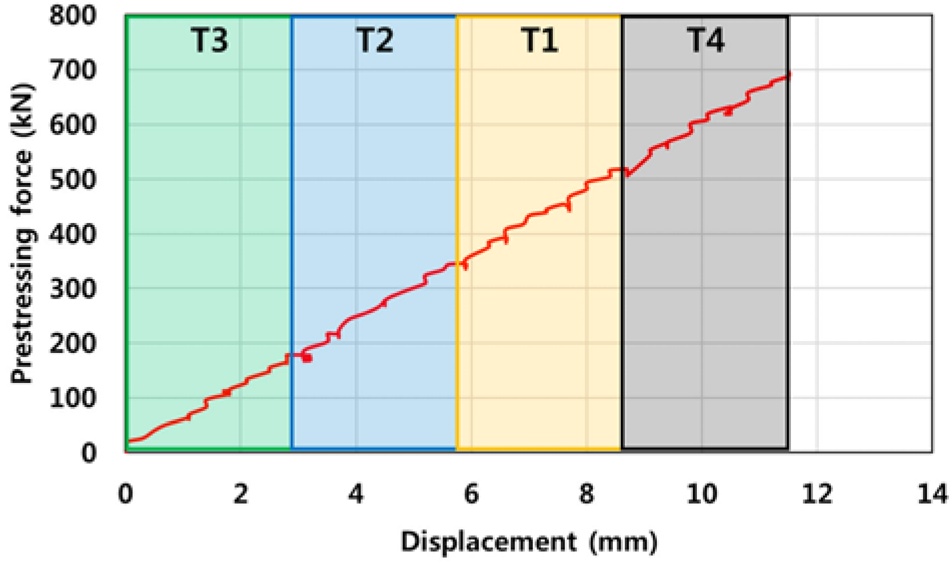

Figure 7. Displacement according to pre-stressing

3. Experiment Result and Analysis

In Figure 8, you in can see the way the mooring moved. Where "number" is the tendon number, "H" is the horizontal displacement, and "V" is the vertical displacement. As shown in Figure 8, the biggest movement that happened was 0.5 mm, and the grounding stayed safe even when the load went up.

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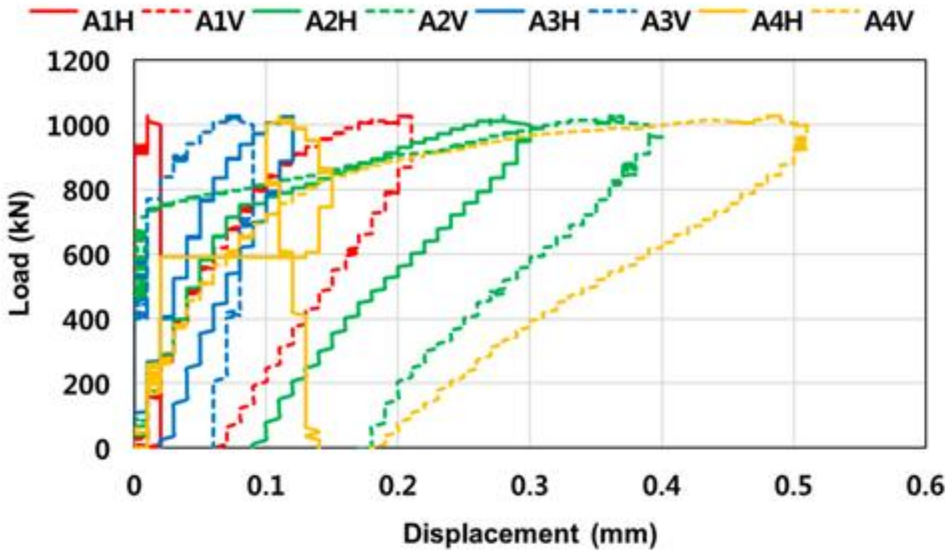

Figure 8. Anchorage displacement.

As the load goes up, Figure 9 shows how the stress on the external muscle changes. The exterior tendon has a width of 15.2 mm, a surface area of 138.7 mm2, a yield load of 222 kN, and a tension load of 261 kN. According to the test data, the yield was proven at around 210 kN, and the external tendon broke at around 230 kN. This is not the same as the supposed mechanical qualities, and it is thought to be a mistake in the experiment because the loadcell wasn't lined up with the muscle when it was put in place.

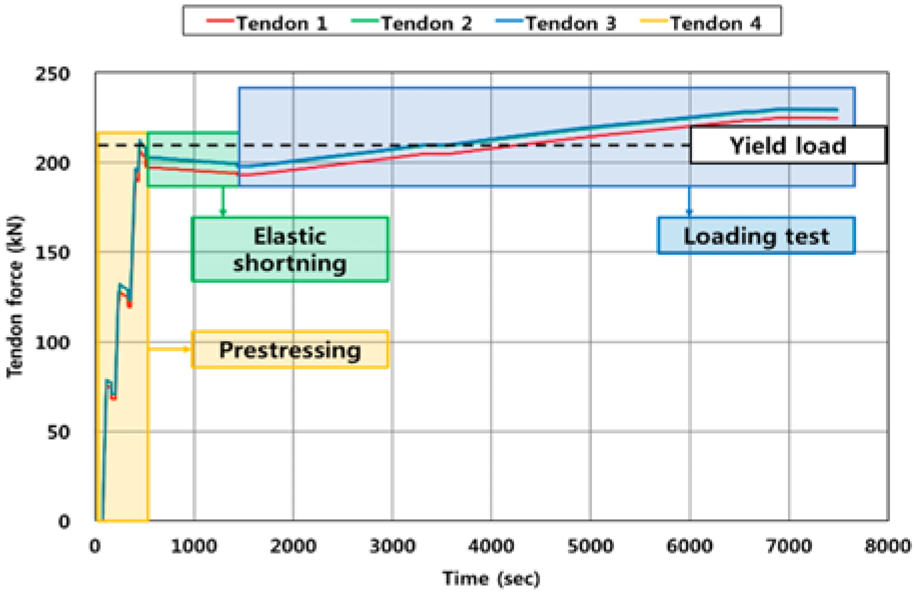

Figure 9. External tendon force.

In Figure 10, you can see how the girder's load and movement changed before and after it was strengthened. Before it was strengthened, the beam was loaded with only 570 kN. The beam was loaded with 1028 kN based on how far along the bending crack it was after being strengthened with all external tendons jacked. After being strengthened, the trial stopped when the external tendon failed, not when the anchoring fell out. The anchorage did not come loose or crack until the experiment was over. This suggests that the tensile strength of the strands was good enough if the connection was designed.

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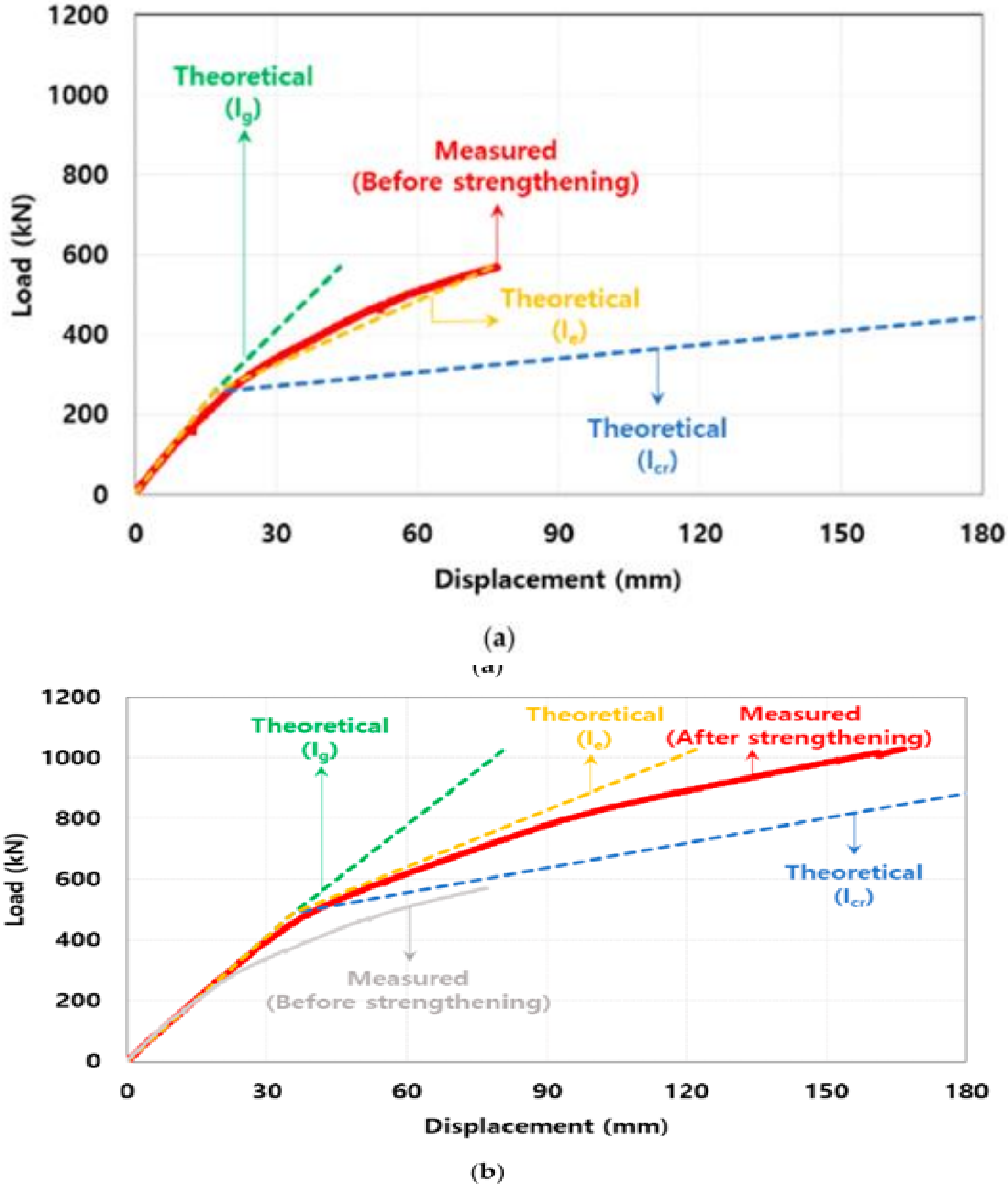

Figure 10. Load-displacement relationship: (a) Before strengthening; (b) After strengthening.

While a crack appears on the surface of concrete, the connected strain gauge quickly records a wide range of values. We can't trust the number that was measured after the crack appeared. Following this, to see the differences in behaviour between before and after strengthening, the deflection evaluation result, which shows the overall behaviour, and the strain gauge attached by exposing the internal tendon after crushing the concrete surface were used to compare the two. The cross-sectional second moment analysis method was used to look at the actual results, as shown in Equation (1) [35]. For this, the load–displacement relationship of the cracked part is broken down into two straight lines with slopes of Ig and Icr. When the effective cross-sectional second moment was used instead of the simpler formula, Ie was closer to the number found in the examination.

$$I_e = I_{cr} + \left(\frac{M_{cr}}{M_a}\right)^3 (I_g - I_{cr}) \qquad (1)$$

Ie is the effective section secondary moment, Icr is the crack section secondary moment, Mcr is the bending cracking moment of the section, Ma is the maximum bending moment acting on the member, and Ig is the non-cracked section secondary moment. Ig was determined by calculating the second moment of the whole section, whereas Icr was determined using Equation (2) based on the crack moment. Table 3 displays the slope of the graph obtained using Ig, Ie, and Icr after cracking. Each outcome has a comparable significance regarding stiffness. The slope of the theoretical value in Figure 10 is equivalent to stiffness. Table 3 indicates a little variation based on the crack load, with the theoretical value slope being consistent. Therefore, confirming the real strengthening impact prior to cracking is challenging.

$$M_{cr} = f_r Z_2 + P_e\left(\frac{{Z_2}^2}{A_c} + e_p\right) \quad (2)$$

in which Mcr is the section's bend breaking present, fr is its tensile strength, Z2 is its constant, Pe is its pre-stressing force, Ac is its area, and ep is its distance to the ligament.

Table 3. Comparison of slope

	Slope (kN/mm)		
	I_g	I_e	I_{cr}
Before strengthening	11.7	5.3	1.1
After strengthening	11.9	6.2	2.7

This was proven that the slope of the load–displacement relationship changed at about 240 kN before strengthening and at about 470 kN after strengthening. This caused the concrete to crack and the crack load to rise by about 50%. But, as you can see in Figure 10b, the curve of the link between the pre-crack stress and movement before and after strengthening was the same. Because of this, the stiffness stayed the same, making it hard to see if the strengthening worked by comparing the stiffness before and after. As a result, it is hard to figure out the crack load in a real bridge through an experiment. This means that it would be hard to prove the strengthening effect before the bridge cracked. Also, if you look at Table 4, you can see that the amount of displacement caused by the same load goes down after stiffening. When the force was 400 kN, the bending before strengthening was 39.7 mm. After strengthening, it was 30.3 mm, showing that the effect of strengthening was about 23.7%. Also, at 470 kN, the deflections before and after strengthening were 51.7 mm and 37.2 mm, respectively, and the strengthening effect was found to be 28%. It was also found that the strengthening effect grew as the load did. In the last step of loading, the beam bent 77.1 mm before and after strengthening, and it bent 51.3 mm after strengthening, showing that the effect was 33% stronger. So, with an external prestressing of 180 kN for four tendons, the bridge used in this trial that was in bad shape was able to hold about 33% more weight. Figure 11 shows the relationship between load and strain in the internal muscles before and after they were strengthened. It was hard to tell if the reinforcement worked because the slope was the same before and after the reinforcement. This was because the load–strain relationship of the internal muscles was similar to the load–displacement relationship. However, the strengthening effect shown in Table 4 through the load-displacement relationship and the strengthening effect shown in Table 5 through the load-strain relationship were not exactly the same. Before it got stronger, the internal tendon was under 555 kN of stress. A strain of 366 was created after strengthening, proving a reinforcement effect of about 34.1%. Also, the strains were 741 before and 452 after strengthening at 470kN, which is the stress level where cracks appear. This means that the strengthening effect was 39%.

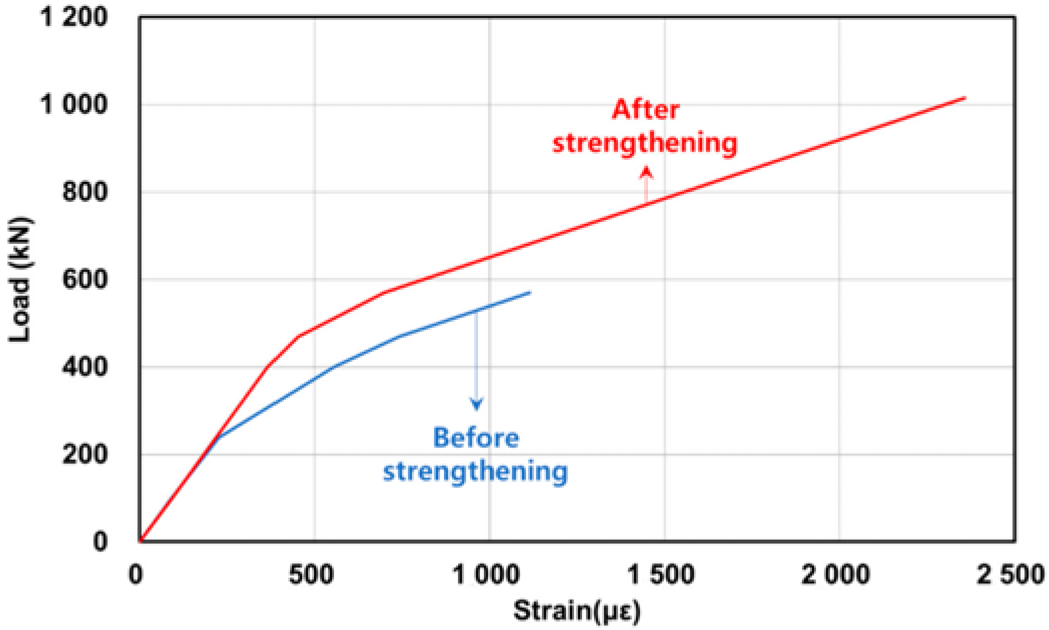

Figure11.Load–strainrelationship.

4. Conclusions

This research examined the material characteristics of 45-year-old PSC girder bridges and confirmed the strengthening impact of using the external pre-stressing approach via experiments. Concrete and tendon material properties, effective tension assessment, and load-carrying ability of a degraded bridge were analyzed in this research. The bridge was subjected to four-point loading tests before and after reinforcement. This experiment's findings are anticipated to help confirm the effectiveness of the current degraded pre-stressed concrete bridge and establish the necessary reinforcing measures.

a. After performing a concrete material test on over 50 cores from the girders of an ancient bridge, it was determined that the compressive strength of the concrete was 33 MPa, which was 22% more than the specified value of 27 MPa. The decrease in compressive strength could not be confirmed since measurements taken by experiment throughout the bridge's construction were not available. The tensile strength test was conducted on five tendons from the deteriorating bridge. The results indicate that the decline in tensile performance was not considerable, even though the tendons had been exposed for 45 years and covered with grout.

b. The inner tendon of the degraded bridge was exposed and then tugged transversely to assess the effective tension of the existing tendon. The effective tension ranges from 25.1 to 32.7 kN. If the maximum introduced tension is assumed, the effective tension measures between 40% and 53%. It is possible that about 50% of the prestressing force is dissipated over time.

c. During the development of the anchoring for strengthening with the outside prestressing, early failure of the anchorage was often verified by just considering the design strength up to the applied tension, rather than the tensile strength of the tendon. However, in this investigation, the anchoring did not fail until the member was destroyed due to the design reflecting the tensile strength of the tendon, the restriction of the anchor bolt spacing, and the stringent consideration of the side anchors not accounted for in the design. It was proven that careful attention is necessary while handling strengthening construction.

d. A four-point stress test was conducted both before and after reinforcement to assess the strengthening impact by measuring the fracture load increase. The bridge's behaviour was anticipated quite correctly by using the effective moment of inertia. It was challenging to assess the strengthening impact prior to breaking due to the external tensioning approach having little influence on stiffness before rupture.

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