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The behavior of an in-service plate girder bridge strengthened with external prestressing tendons

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Abstract

In this study the effect of strengthening on a bridge by means of external prestressing tendons was investigated. The target bridge was a plate girder bridge which had been in service for 23 years before the strengthening. The loss of prestressing force with time was investigated while the existing prestressing force was released/re-prestressed after four years of service since the strengthening. Also a field load test was performed using a live-truck load to evaluate the behavior of the bridge before and after the strengthening. An additional numerical model using the finite element method was developed and used in the analysis. From the experiments, it was found that the long term loss of the prestressing force on the external tendons was negligible and that the strengthening did not significantly affect the dynamic responses of the bridge. However, the strengthening reduced the mid-span deflection by 10–24%. The strengthening also reduced the difference in deflection between girders while the truck was riding on the outer girder and this difference arising from the strengthening became more apparent as the truck speed increased. It was also found from the dynamic load test that the strengthening did not significantly influence the natural frequency and impact factor.

Keywords: Strengthening; Prestressing; External tendons; Load test; Natural frequency; Impact factor

1. Introduction

Bridge structures sustain repeated live load, and, accordingly, their structural capacity diminishes continuously as the service period increases. In addition, an increase in traffic load can accelerate the deterioration and can make the load-carrying capacity of the bridge lower. Therefore, a rational strategy for maintenance, rehabilitation and strengthening should be sought and applied in the field as required. In the upgrading process, strategies including construction of a new bridge should be considered in order to minimize cost. Generally the construction of a new bridge will be the most expensive solution not only because of construction cost but also because of other invisible extraneous costs resulting from traffic jams, increase of fuel consumption, etc.

For these reasons, various alternative ways have been suggested to upgrade existing bridges. For steel bridges, strengthening with external prestressing tendons has been known to have great advantages among others: (1) its structural analysis for design is relatively easy and fairly straightforward; (2) its effectiveness has been well recognized through many researches; and (3) this method can economically minimize the disruption of the traffic flow [1,2].

This study used an in-service bridge that had been, after 23 years of service, strengthened with external prestressing tendons for upgrading to a higher rate. After four years of service the prestressing force was released and re-applied for the testing purposes. While the existing prestressing force was released and re-stressed, the behavior of the bridge and the loss of prestressing force were investigated. A field load test utilized a live truck-load for dynamic behavior

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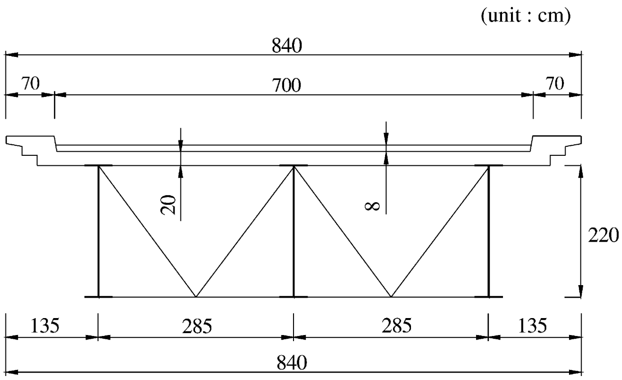

Fig. 1. Geometry of cross section.

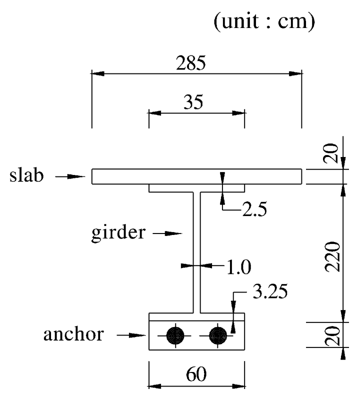

Fig. 2. Geometry of girder.

evaluations. In addition, a numerical analysis was performed for a further in-depth analysis of the static and dynamic behavior.

2. Stiffness of bridge and prestressing force

2.1. General

The target bridge was built in 1973 and strengthened with the external prestressing tendons in 1996 to upgrade its load-carrying capacity. After four years in service, the prestressing force in the external tendons was removed and then re-applied for the purpose of the study herein. The bridge was originally designed for DB-18 design load. DB-18 in Korea is the equivalent bridge design load to HS-18 in US, so that hereinafter DB- will be called HS-. The bridge is a simply supported, three girders, and composite-girder bridge for live load with a span length of 40.0 m and an average width of 8.4 m. Figs. 1 and 2 show the geometry of a cross section of the bridge and a detail of the steel girder, respectively. For the field tests, concrete and steel strain gages and linear variable displacement transducers (LVDTs) were installed, as shown in Fig. 3.

Before the field experiments, the stiffness of the bridge was evaluated through a numerical analysis. In the author's previous study [3–5], a numerical model using the finite element method (FEM) was developed, as shown in Fig. 4. This model used a solid element for the slab, a shell element for the girder, and a beam element for the bracing. The validity of the model was confirmed with an additional scaled-down bridge model tested in a laboratory where the scaled-down bridge model represented a non-damaged condition. The results from the analysis and the laboratory test were in good agreement. This numerical model was applied to the field bridge to compute the stiffness of the bridge. The measured behaviors from the static field load test were also in good agreement, even though the numerical analysis assumed a non-damaged condition. Therefore, it was determined that the bridge considered in the study maintained its originally designed load-carrying capacity [6].

2.2. Determination and introduction of prestressing force

In calculating the prestressing force, the losses of the force due to the movement of anchors and the elastic deformation of composite beam were not taken into consideration since in the field practices they could typically be compensated by adding some more prestressing force than the designed amount. The effect of creep and drying shrinkage was also ignored because of the bridge's age. The friction coefficient due to corrugation was assumed to be 0.0066 m^{-1} with a straight tendon profile and the grease in sheath system utilized. This friction was expected to cause 11.3% of the loss of prestressing force at the mid-span.

As mentioned previously, the bridge has been in service for more than 20 years and was strengthened with the external prestressing tendons for the last four years. Prior to the re-introduction of the prestressing to the bridge, the existing prestressing force was released and re-applied while measuring the strains of the bottom flange at mid-span. This releasing/re-prestressing can provide information about the loss of prestressing with time during the service period. The re-prestressing force was kept at the same level as the released force, which was 44.3 MPa. Table 1 summarizes the measured strains and ratios of the released strains to the re-prestressed ones.

Table 1
Measured strains for examining timely loss of prestressing force

Girder	G1	G2	G3
Compressive strain — released ($\times 10^{-6}$)	212	189	206
Compressive strain — re-prestressed ($\times 10^{-6}$)	218	185	187
Ratio (%)	97.2	102.1	110.2

From Table 1, with the average of the ratios from girder 1 (G1) to 3 (G3) being 103.2%, the loss of prestressing force with time can be said to be negligibly small with a possible scatter from the field installation and measurement. This observation is in good agreement with a study of Ryu and