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RESEARCH ARTICLE

Experimental monitoring of the strengthening construction of a segmental box girder bridge and field testing of external prestressing tendons anchorage

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ABSTRACT Prestressed concrete segmental box girder bridges are composed of short concrete segments that are either precast or cast in situ and then joined together by longitudinally post-tensioning internal, external, or mixed tendons. The objectives of this study are to monitor the construction process of the external prestressing tendons to strengthen the bridge structure and perform a field load test to measure the strain and the deflection of the anchorage devices of the external prestressing tendons to determine the state of these devices after tension forces are applied. The monitoring process of the external prestressing tendons construction includes inspecting the cracks in the diaphragm anchorage and the deviation block devices before the tension forces are applied to the external tendons; measuring the deformation of the steel deviation cross beam during the tension process; measuring the deformation of the box girder after different levels of tension forces are applied; measuring the elongation of the external tendons in each level of the tension; and measuring the natural frequency of the external tendons after the tension process is complete. The results of the monitoring process show that the measured values of the deformation, the elongation, and the natural frequency meet the requirements. Therefore, there is no damage during the construction and the tensioning of the external prestressing tendons. A field load test is performed to the anchorage beam, the steel deviation block devices, and the steel deviation cross beam. The field load test results of the anchorage devices show that the values of the strains, the stresses, and the deflection are less than the respective allowable limit values in the requirements. Therefore, the anchorage devices have sufficient strength, and the working state is good after the tension forces are applied to the external prestressing tendons.

KEYWORDS prestressed concrete, box girder, monitoring, external tendons, strain, deflection

1 Introduction

Prestressed concrete segmental box girder bridges with externally post-tensioned tendons are one of the main new developments in bridge engineering construction in recent years. The many advantages of this type of structure include its fast and versatile construction, no disruption at the ground level, a highly controlled quality and its associated cost savings. Therefore, this type of structure is the preferred solution for many long, elevated highway bridges [1].

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Prestressed concrete segmental box girder bridges are composed of short concrete segments that are either precast or cast in situ and then joined together by longitudinally post-tensioning internal, external, or mixed tendons. The cross-sectional geometry of the concrete segments has varied widely, ranging from single to multiple cells with straight or sloping webs. Prestressed box girder bridges typically exhibit small deflections during the first years of service and then continue to deflect excessively [2–4].

The concrete structure strengthening involves upgrading the strength and the stiffness of the structural members, and the repairing process involves re-establishing the strength and the function of the damaged members. The number of factors dictates which method is appropriate for the strengthening and the repairing of the bridge structural members. These factors include the type and the age of the structure, the importance of the structure, the magnitude of the strength (which increases) required, the type and the degree of the damage, the available materials, the cost, the feasibility, and the aesthetics. The strengthening and the repairing of the bridge structure can be both an effective and an economic solution in the appropriate situation [5–9].

External prestressing refers to a post-tensioning method in which the tendons are placed on the outside of a structural element to facilitate flexural resistance. It may be efficiently utilized in the construction of segmental box-girder bridges and the strengthening of existing concrete beams. External prestressing was first used in the late 1920s and has been widely used recently in bridges, both for new construction and the strengthening of existing structures to increase their load carrying capacity. The prestressing force is transferred to the member section through end anchorages, deviators saddles. The use of external post-tensioning became popular in the last two decades, after the corrosion protection of external tendons was improved by methods such as epoxy and grease coating [10–16].

External post-tensioning restores the serviceability of an existing bridge by relieving the dead load-bending effects and thus reducing deflections or eliminating cracking. The additional post-tensioning material will also increase the ultimate limit state capacity in bending and shear [17].

The main objectives of this study are to monitor the construction process of the external prestressing tendons used to strengthen a bridge structure and apply a field load test to measure the strain and the deflection of the anchorage devices of the external prestressing tendons to determine the state of these devices after the tension forces are applied to the external tendons.

2 Description of the bridge structure

The Sanguxian viaduct prestressed concrete bridge is a continuous segmental box girder T-shape rigid frame bridge that is located in the Mudanjiang-Harbin Highway within the Heilongjiang Province of north-east China. The bridge is 280-m long and 12-m wide. It has a slope of 2.2% along the length of the spans. The bridge was constructed using the cast-in-place cantilever method. There are two separate T-shaped cantilever beams. Each side of the T structure consists of 10 segments. The length of segment No. 0, which is on the top of the pier, is 7.0 m. Segment Nos. 1 and 2 are cast in situ. The 8 remaining cantilever segments are cast in place. The bridge was open to traffic in 1997. Figure 1 shows the longitudinal layout of the bridge structure, Fig. 2 shows the general view of the bridge, and Fig. 3 shows the pier and the span of the prestressed box girder.

3 Strengthening process of the bridge structure

The Sanguxian Bridge suffers from many damages, including serious cracks within the web, the top, and the bottom of the box girders, spalling and cracks in the bridge deck pavement, and damage of the expansion devices. Therefore, the damaged structural members of the bridge need to be strengthened to improve the stiffness of the bridge structure. The strengthening process of the bridge structure consists of six stages. In the first stage, the bridge structure spans are longitudinally strengthened by installing the external prestressing tendons, the diaphragm anchorage, and the deviation blocks devices. In the second stage, the grouting method is used to close the cracks in the web, the top, and the bottom of the box girders. In the third stage, the inclined webs of the box girders, which suffer from serious cracks that result from their sticking to the steel plates, are strengthened. In this stage, steel plates are pasted to the floor of the box girders in the middle and the side spans of the bridge to strengthen it. In the fourth stage, the connection rigidity of the closed end of the box girders is improved by attaching steel plates to the joints of that end's sides. In the fifth stage, the bridge deck pavement is reconstructed and the expansion devices are replaced. In the sixth stage, the box girder of pier No. 3 is repaired using epoxy concrete after the concrete surface, which has been frozen, is chiseled. This study investigates the strengthening process using external prestressing tendons. Figure 4 shows the external prestressing tendons that are located near pier box girder.

4 Monitoring of the external prestressing tendons construction

The monitoring process of the construction of external prestressing tendons consists of five stages. In the first stage, the cracks in diaphragm anchorage and the deviation block devices are inspected before the tension forces are applied to the external tendons. In the second stage, the deformation of the steel deviation cross beam is measured as the tension forces are applied to the external tendons. In the third stage, the deformation of the box girder is measured after different levels of tension forces are applied. In the fourth stage, the elongation of the external tendons is measured for each tension level. In the fifth stage, the natural frequency of the external tendons is measured after the tension process is completed. Four tension force levels, 30% σ_k, 60% σ_k, 80% σ_k, 100% σ_k, are applied to the external tendons. Figure 5 shows the steel deviation devices in the box girder.