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Flexural behavior of precast concrete segmental beams with hybrid tendons and dry joints

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HIGHLIGHTS

- Flexural behavior of precast concrete segmental bridges with hybrid tendons and dry joints was studied.
- Testing parameters include tendons types, load locations and joint numbers.
- It is aimed for accelerated bridge construction.
- Segmental beam specimens show satisfied load capacity and acceptable ductility.

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ABSTRACT

Precast concrete segmental bridges (PCSBs) with hybrid tendons and dry joints might be the most competitive solution for achieving the advantages of rapid construction and favorable structural performance. A series of tests were carried out to investigate the flexural behavior of PCSBs with hybrid tendons and dry joints. Influences of hybrid tendons, load locations and joint numbers were studied. For comparison purpose, a monolithic beam with hybrid tendons was also tested. The deflections, ultimate loads, stresses of prestressing strands and failure modes were investigated. At the ultimate stage, the stresses of all tendons are greater than 1500 MPa. The flexural strength of fully segmental beams with hybrid tendons of S-4 is 30% less than that of the monolithic beam with hybrid tendons of M-1. Due to a high concentration of rotation and deflection at individual joints, the flexural strength of the partially segmental beam with hybrid tendons of S-2 is 12.8% less than that of the fully segmental beam with hybrid tendons of S-4. The segmental beam with hybrid tendons can achieve satisfied flexural capacity and better ductility. The research outcome will help in understanding the roles of types of prestressing tendons and joints numbers on the flexural performance of the segmental bridges.

1. Introduction

Precast concrete segmental bridges (PCSBs) have become more and more popular worldwide for the advantages such as economical cost, rapid construction, and mitigated disturbance to environment. Because internal tendons can improve the ductility of the beam, and the external tendons are convenient for maintenance [1,2], PCSBs with hybrid tendons integrate the use of unbonded internal tendons and external tendons and utilize the advantages of both.

In recent years, PCSBs with hybrid tendons and epoxy joints become increasingly popular. For example, several PCSBs with hybrid tendons and epoxy joints had been completed in China [3–5]. One of the disadvantages with these Chinese projects is that it is time consuming for the resin to polymerize at joints. Weather conditions could be another reason for the delay [6]. On the other hand, PCSBs with hybrid tendons and dry joints are thought to be a competitive alternative for rapid construction. However, due to the stress concentration at the dry joints, the ultimate strength of PCSBs with dry joints could be less than that with epoxy joints. And the existing literature on PCSBs with hybrid tendons and dry joints are very limited.

Hindi et al. [1] discussed the advantages and disadvantages of internal or external tendons and reported testing of a three-span

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reduced-scale bridge model post-tensioned with external tendons, including segmental beam models. The north span of the continuous bridge model had dry joints, and the south and center spans had epoxy joints [1]. The research mainly investigated the effect of varied tendon bonding conditions on the strength and ductility of the segmental beam model. The influence of dry joint numbers on the flexural behavior of PCSBs was not studied.

Romas and Aparicio [7] developed a numerical model for the ultimate analysis of externally prestressed concrete bridges which can analyze simply supported or continuous, monolithic or segmental bridges, with external unbonded prestressing and/or internal bonded prestressing. The numerical model was used to test the structural behavior from beginning until failure. Collected data include displacements, rotations, joint openings, internal forces, and stresses of prestressing steel at each load level. The calculated results by the numerical model showed excellent correlation with the available test results [7].

Aparicio et al. [8] presented the test results of five monolithic and three segmental beams with external tendons in bending and in combined bending and shear. In that test, the precast concrete segmental beam had multi-keyed dry joints. Only three precast concrete segmental simple-supported beam with external tendons and dry joints were tested, comprising of one beam under bending condition, and two beams under shear-bending condition.

Turmo et al. [9] established a validated FEM model to simulate the structural behavior of simply supported bridges. The nonlinear and geometrical model considered the particular behavior of the dry joints, the concrete plasticity and the slipping of the prestressing tendons at deviators. Interesting and original conclusions have been reached regarding the reinforcing criteria and the resistant mechanisms of these structures once the opening of the joint takes place [9].

Turmo et al. [10] presented a study of the structural behavior of segmental concrete beams with external prestressing and dry joints, focusing on the response of these structures under shear. Moreover, potential benefits of using of steel fiber reinforced concrete (SFRC) were investigated [10]. It should be noted although PCSBs with external tendons and dry joints were investigated in Hindi et al. [1], Aparicio et al. [8], and Turmo et al. [10]'s research, the flexural behavior of PCSBs with dry joints combined with hybrid tendons were not studied in their tests.

Li et al. [11–13] conducted a series of experiments mainly focusing on precast concrete segmental bridges with external tendons. Li [11] reported the tests of 13 monolithic and 14 segmental simply-supported externally prestressed concrete model beams including only two testing beams with external tendons and dry joints. Li et al. [12] designed a series of cantilever beam specimens including two specimens with hybrid tendons and epoxy joints and one beam with external tendons and dry joints to simulate the negative moment regions in continuous beams. Li et al. [13] experimentally analyzed the mechanism of combined shear and bending resistance for precast concrete segmental beams with external tendons and dry or epoxy joints. There were five experimental beams with external tendons and dry joints subjected to pure bending, combined shear and bending, and direct shear. These studies did not consider PCSBs with hybrid tendons and dry joints.

Yuan et al. [6] experimentally investigated the behavior of segmental concrete box beams with hybrid tendons and epoxy joints. Saibabu et al. [14] presented experimental investigations on a scaled model of a simply supported precast externally post-tensioned box-girder bridge deck that was cast using a segmental construction method. Performance of box-girders with dry and epoxy joints was evaluated under static and cyclic loading. It was observed from the aforementioned studies that none of the previous studies has examined PCSBs with hybrid tendons and dry joints.

The principal goal of this study is to highlight the flexural behavior of precast concrete segmental bridges with hybrid tendons and dry joints. In this paper, four specimens of precast concrete segmental beams and one specimen of monolithic beam have been tested. The ratio of internal tendons to external tendons, the location of loads, and the number of segments are the main parameters for the experiment. Details of test specimens, instrumentation setup and test procedure are described followed by the structural responses comprised of deflection, strain and failure modes. The results will provide a better understanding of the flexural behavior of the PCSBs with hybrid tendons and dry joints.

2. Experimental program

2.1. Design of specimens

A total of four segmental beams and one monolithic beam with a T-shape cross section of 0.4 m in height, 0.6 m in width and 3.5 m in length were tested under flexure. The thickness of the specimen web and top flange are 0.11 m and 0.06 m respectively. The segmental beams have interlocking dry joints with four shear keys of 0.50 m in height at each joint. Geometric details of testing beams are shown in Fig.1.

The tests were divided into three groups. The first group includes three simply-supported segmental beams with three segments, which are divided by two dry joints (J5 and J6 for S-1 and S-2 beams, J4 and J5 for S-3 beam) as shown in Fig. 1. Experimental parameters of the first group are the external tendons or hybrid tendons, the location of loads and the numbers of segments. The following nomenclature was used in this group:

(1) three-segment specimen "S-1" with four external prestressing strands (EX1, EX2, EX3, and EX4 in Fig.1) in which two strands are draped profile and two strands are straight. Three wires of straight prestressing strand with seven wires had been cut off to adjust the section areas to be approximately equal to the areas of other beams. The shear span, which defines as the distance from the vertical load to the near support, is 816 mm, and the distance between the first joint to the support is 650 mm;

(2) three-segment specimen "S-2" with two external prestressing strands with draped profile, one internal straight prestressing strands (EX1, IN1, and EX4 in Fig.1). The shear span is 816 mm, the distance between the first joint to the support is 650 mm;

(3) three-segment specimen "S-3" with two external prestressing strands with draped profile, one internal straight prestressing strands. The shear span is 1100 mm, and the distance between the first joint to the support is 1050 mm;

The second group has only one simply-supported segmental beam with seven segments. The main objective is to investigate the effect of joint numbers. The nomenclature used in the test group was S-4, which has two external prestressing strands with draped profile, one internal straight prestressing strand. The shear span is 816 mm, and the distance between the first joint to the support is 650 mm.

The third group includes one simply-supported monolithic beam for comparison purpose, which has two external prestressing strands with draped profile, one internal straight prestressing strand, and the shear span is 816 mm. The identifier of monolithic beam is M. The experimental parameters are summarized in Table 1.

2.2. Fabrication

The formwork for the monolithic and segmental concrete beams was fabricated from wood panels. The monolithic concrete beam was cast at one time, and the segmental concrete beams