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PSC 교량의 시공이음부 종방향 응력 분포

Longitudinal Stress Distributions around Construction Joints of PSC Bridge Girders

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Abstract

There exist many construction joints in segmentally constructed bridge girders. It is required coupling of tendons or overlapping of tendons to introduce continuous prestress through several spans of bridges. Even though tendon coupling method is easier to use in practice, some cracking problems around construction joints have been reported and complicated stress states around construction joints in PSC girders is not clearly investigated.

The purpose of this paper is to investigate in detail the complicated longitudinal stress distributions around the construction joints in prestressed concrete girders with tendon couplers. To this end, a comprehensive experimental program has been set up and a series of specimens have been tested to identify the effects of tendon coupling and segmental construction of bridge sections.

The present study indicates that the longitudinal stress distributions of PSC girders with tendon couplers are quite different from those of PSC girders without tendon couplers. The longitudinal compressive stresses introduced by prestressing are greatly reduced around coupled joints according to tendon coupling ratios.

Key words : construction joint, prestressed concrete bridge, tendon coupler

요 지

다양한 공법으로 널리 시공되고 있는 프리스트레스트 콘크리트(PSC) 연속 교량의 단면에는 시공이음이 발생하게 된다. 이러한 시공이음부에서 연속적인 프리스트레스 하중을 도입하기 위해서는 텐던을 겹침이음(overlapping)하거나 텐던 커플러를 사용하는 방법이 사용되며, 후자의 경우는 시공이음의 정착부 배근의 단순화와 효율적으로 텐던을 사용할 수 있는 장점이 있다. 본 연구의 목적은 텐던 커플러를 사용한 PSC 교량의 시공이음부의 종방향 응력 분포를 규명하는 데 있으며, 이를 위해 텐던 연속과 단면의 분할 시공 효과를 고려한 실험과 유한요소·해석을 수행하였다. 연구결과 텐던 커플러를 사용한 시공이음부의 응력 상태는 텐던 커플러를 사용하지 않은 경우에 비해 종방향 응력 상태와 다르게 나타나고 있다. 특히 구조적으로 문제가 되는 종방향 압축응력은 시공이음부에서 텐던 연결비율이 증가함에 따라 크게 감소한다.

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1. INTRODUCTION

Prestressed concrete bridges with a number of continuous spans has been segmentally built in many countries. These methods include incremental launching method, movable scaffolding method, full staging method and balanced cantilever method. The procedure for construction of prestressed concrete bridge by incremental launching method is briefly described. All sections of the bridge superstructures are cast segment-by-segment at the starting point of the bridge under factory-produced conditions. Each segment is then pushed into the bridge longitudinal direction over the previously constructed piers, led by launching nose in the front. The subsequent segments are match-cast in the same construction pit, coupled to the previous segments and pushed continuously segment- by-segment.

For span-by-span erection by movable scaffolding system(MSS) as shown in Fig. 1, all the bridge sections are cast in-situ on a movable support system installed on the existing piers and post-tensioned to resist its selfweight before the scaffolding system moves to next span. Scaffolding is then moved to next span and subsequent section is continuously cast.

There exist many construction joints in segmentally constructed bridge girders. It requires a continuity of adjacent segments to introduce continuous prestress through superstructure of bridges. Two methods are generally used to introduce continuous prestress at construction joints. The first method is to couple the tendons at construction joints with tendon coupler as shown in Fig. 2 and the second one is overlapping the tendons around construction joints.

Overlapping tendon requires large cross section to accommodate the anchorage devices and also longer tendon length to develop the prestress force

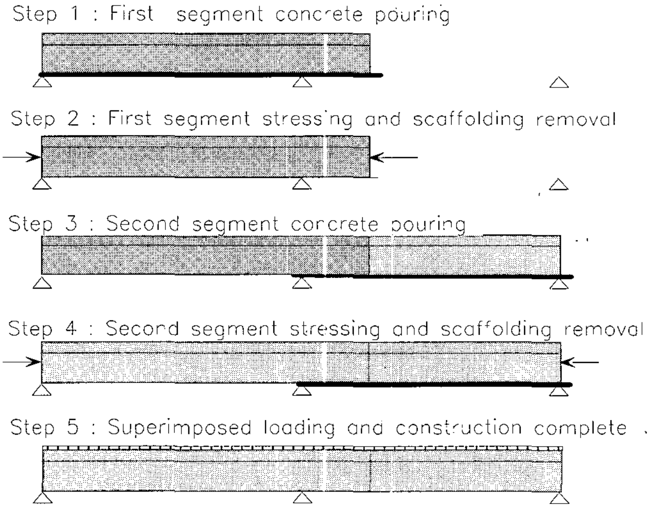


Fig. 1 Bridge construction procedure by movable scaffolding method

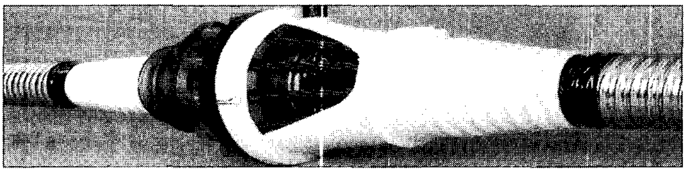
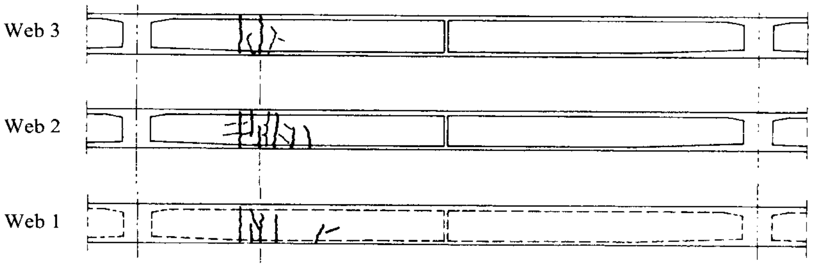
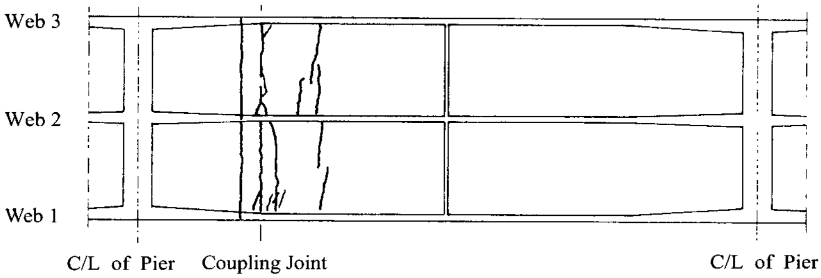


Fig. 2 Detailed configuration of tendon coupler



(a) Elevation view of web



(b) Plan view of bottom flange

Fig. 3 Crack pattern around tendon coupled joints

appropriately. Even though the tendon coupling method is easier to use in practice, some cracking problems around construction joints has been reported.[1,2] Most cracks of 0.1-0.3 mm width around construction joints which occurred in the bottom flanges and web of box girder bridges, caused parallel to the construction joints and limited to the direct vicinity of construction joints as shown in Fig. 3.

The stress distributions around the anchor plate subjected to a concentrated load P is not uniform, but varies greatly, although it becomes uniform at a distance approximately equal to the depth of the bridge section according to the St. Venant principle. Most of literatures are concerned with two important tension stress fields of bursting and spalling stress, around anchorage zones without tendon couplers.[3,4,5] Tendon couplers are used to extend the end of tendon previously installed as shown in Fig. 2. Couplers are functioned as both stressing end anchorage and dead end anchorage. It is expected that the distribution of these longitudinal stresses be changed and become quite different when the represtressing force is applied to anchorage zone by tendon couplers. This may be the major reason that the stress distributions around the construction joints become very complex and the expected uniform compression is not achieved. This may also cause some cracking problems around the coupled construction joints when the tensile stresses from live loads, shrinkage and temperature effects are superimposed.[6,7] The appropriate and realistic design provisions for coupled construction joints are still lacked in current design codes.[8,9,10,11] It is, therefore, necessary to investigate accurate stress distributions around the tendon coupled construction joints due to sequential prestressing at coupling joints.

2. TEST PROGRAM SET-UP

The tendons are generally coupled at the webs in prestressed concrete girders as shown in Fig. 4. Web member has been therefore selected to make the full-scale test members. During the tests, the strains of concrete and steel bar in the test members have been measured to figure out the effects of coupling of tendons and segmental

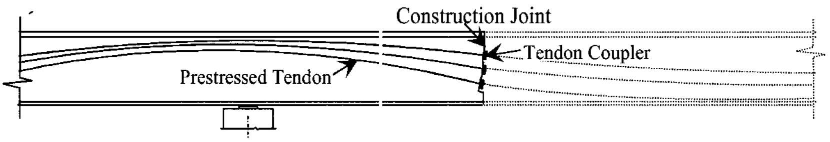


Fig. 4 Coupled construction joint in segmental bridge constructions

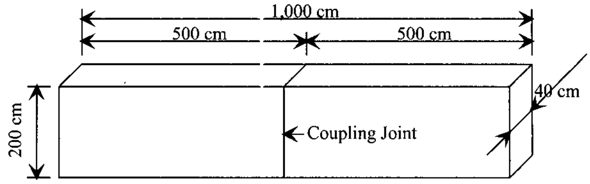
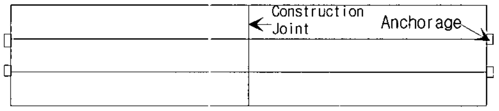
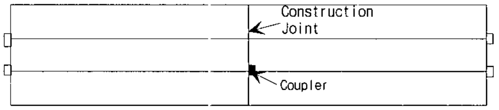


Fig. 5 Dimensions of test specimens

Specimen1(SP1) Tendon coupling Ratio 0%



Specimen2(SP2) Tendon coupling Ratio 50%



Specimen3(SP3) Tendon coupling Ratio 100%

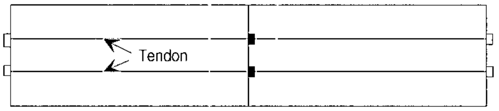


Fig. 6 Arrangements of test members

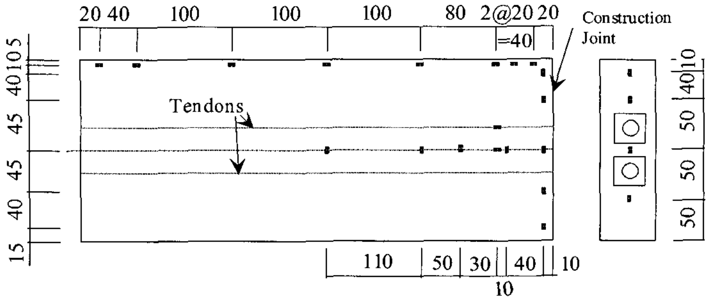
construction of bridge members.

The concentrically post-tensioned test members were designed to represent segmentally erected prestressed concrete bridge girders under a uniform compression. The cross section of test members is 40 cm wide and 200 cm high. The longitudinal length of each segment is 5 m which is designed to introduce the uniform compression in the middle part of a segment. The overall specimen length coupled at the construction joint by tendon couplers is 10 m as shown in Fig. 5.

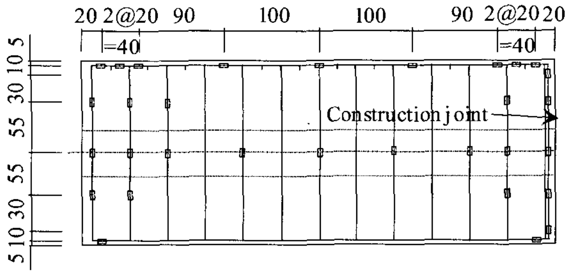
The nominal concrete compressive strength for the test members is designed to be 45 MPa at 28 days. The seven wire strand with the diameter of 15.2 mm has been used and each tendon consists of 12 strands. The tensile strength of strand is 1890 MPa.

Tendon arrangements of test specimens are shown in Fig. 6. The specimen 1(SP1) has no tendon couplers at the construction joint, continuous prestressing, which represents uniform compression as a reference case. The specimen 2(SP2) has one tendon coupler among two tendons at the construction joint and the other tendon is continuous at the joint. The two tendons are all coupled at the joint in test specimen 3(SP3) to see the effects of full tendon coupling.

To investigate the longitudinal stress dis-



a) Locations of concrete strain gages



b) Locations of steel strain gages

Fig. 7 Locations of strain gages in each segment(unit cm)

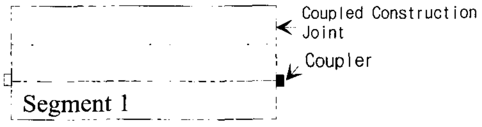
tributions around the coupled construction joints due to sequential prestressing at tendon couplers, the strain gages in concrete and steel reinforcement are installed as shown in Fig. 7.

3. TEST RESULTS AND FINITE ELEMENT ANALYSIS

The segmental construction sequence of test members is depicted in Fig. 8. Post-tensioning operation has been done with same procedure of the actual bridge construction practice. The jacking and initial prestress forces for all test members are summarized in Table 1. The longitudinal strains have been measured during the prestressing of tendons.

The test members which simulate the segmental construction of prestressed concrete girder bridges have been modeled for the finite element(FE) analysis. Fig. 9 represents the finite element models for test members according to the sequential

Step 1 : Cast of segment 1 and first prestressing



Step 2 : Cast of segment 2 and second prestressing

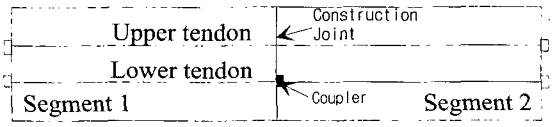


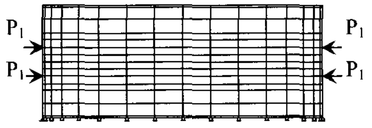
Fig. 8 Construction and prestressing sequence of test members SP 2

Table 1. Determination of Lock-in Force

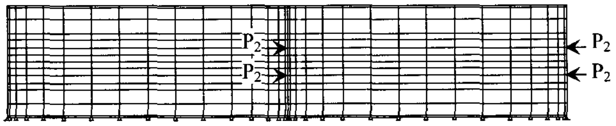
test member	coupling ratio	1st PT	Jacking force(ton)	loss(%)	initial force(ton)	2nd PT	Jacking force(ton)	loss(%)	initial force(ton)
SP1	0	upper	-	-	-	upper	201.5	9.4	182.6
		lower	-	-	-	lower	201.5	8.8	183.8
SP2	50%	upper	221.4	12.1	194.6	upper	221.4	8.3	203.0
		lower	-	-		lower	201.5	8.8	183.8
SP3	100%	upper	221.4	12.3	194.2	upper	221.4	12.5	193.7
		lower	221.4	15.6	186.9	lower	221.4	10.0	199.3

prestresssing operation. Fig. 9(a) shows the model for the first segment prestressing(Case1). Fig. 9(b) represents the model for the second segment prestressing (Case 2) after the second segment has been installed. The final stress states may be obtained by superposing the results of two cases.

The strain distribution obtained from finite element analysis has been compared with measured test data. Fig. 10 shows the comparison of analysis results with measured data on the longitudinal strain distributions along the edge of test members. It is shown that the analytic results correlates fairly well with test data. Fig. 10(a) gives the longitudinal strain values for the test member SP1 without any tendon couplers. It is shown that uniform compression is achieved in the middle part(construction joint region) due to prestressing, because it has no tendon couplers in the joint. It has been applied to continuous prestressing through the full length of test memeber. Fig. 10(b) and (c) show the strain distribution along the edge of test member SP2 and SP3 with tendon coupler at the joint. Fig. 10(b) shows the longitudinal strain distributions along the edge line of test member SP2 which has only one tendon coupler at the middle joint(coupling rate 50%). It is shown that the uniform compression is not achieved. The compressive strains are reduced by about 35 % in the local region of segment 1 at a distance approximately equal to 0.2h from the middle joint of test member. Fig. 10(c) summarizes the similar results of longitudinal strain distribution for the test member SP3, which has two tendon couplers at the joint(coupling ratio 100 %). This figure again shows the reduction of compressive strains at the tendon coupling joint. The reduction of compression reaches up to about 70 % in the case of fully coupled joint (100 % coupling

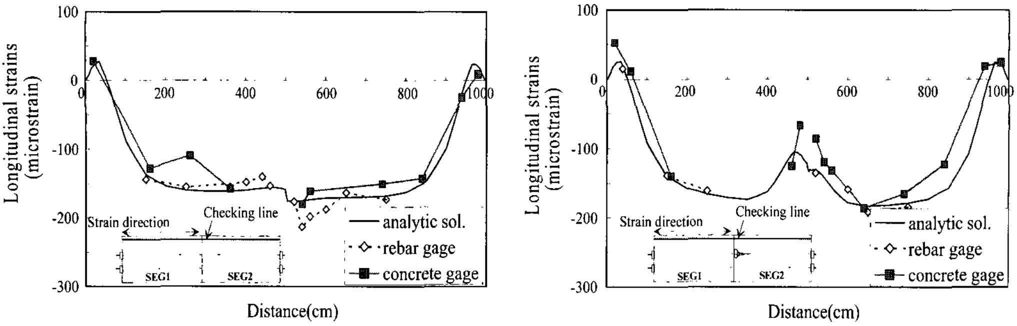


(a) Post-tensioning of Segment 1(Case 1)



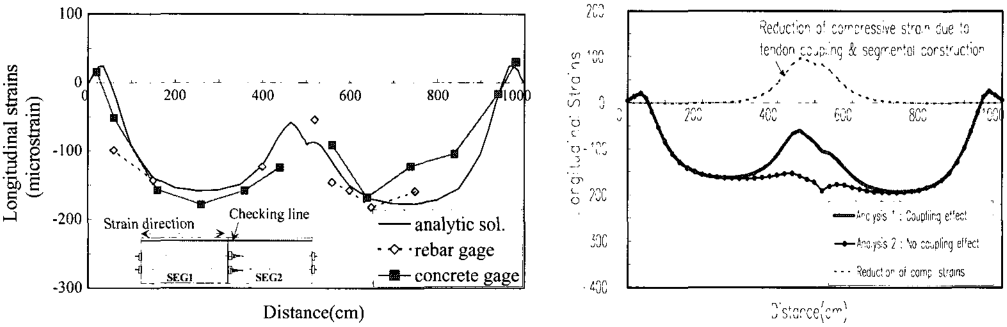
(b) Post-tensioning of Segment 2(Case 2)

Fig. 9 Finite element models for test members according to prestressing sequence



(a) Longitudinal strain state (SP1)

(b) Longitudianl strain state (SP2)



(c) Longitudinal strain state (SP3)

(d) Reduction of compressive strains

Fig. 10 Comparison of analysis with test results on the longitudinal strain distributions along the edge of test members

ratio) at the same region location as test member SP 2.

Fig. 10(d) shows the compressive strain distributions of both SP1 and SP3, which represents a continuous prestressing at the middle joint and fully coupled joints respectively. Fig. 10(d) shows a large reduction of compressive strains along longitudinal edge of test member. This is due to the effect of tendon coupling and segmental construction at the middle joint. This large amount of reduction of compressive stresses at the coupled joints may cause serious cracking problems in PSC girder bridges due to tensile stresses when live loads, shrinkage and temperature effects are superimposed. Therefore, the realistic and safe design must include the effects of tendon coupling in the construction joints of prestressed concrete structures.

4. CONCLUSIONS

Thre exist many construction joints in egmentally constructed prestress concrete bridges, These construction joints usually require coupling of tendons to introduce continuous prestress. It is expected that the stress states around coupled joints are very complicated and the uniform compression may not be achieved at these joints due to tendon coupling, which may cause serious cracking problems when live loads, shrinkage and temperature effects are superimposed.

The purpose of the present study is therefore to investigate throughly the complex stress behavior around the coupled construction joints in prestressed concrete bridge structures. The following conclusions have been drawn from the present paper.

1. Longitudinal stress distributions of pre-

stressed concrete(PSC) girders with tendon couplers at construction joints are quite different from those of PSC girders without tendon couplers.

2. The compressive stresses in concrete introduced by prestressing are reduced by about 35 % around the coupling joints for the coupling ratio of 50 percent. This reduction of compressive stresses at the tendon coupling joints reaches up to 70 percent in the case of fully coupled joints(i.e., coupling ratio 100 %).
3. Large reduction of compressive stresses around the coupling joints may cause serious cracking problems in PSC girder bridges due to tensile stresses when live loads, shrinkage, and temperature effects are superimposed. This result indicates that appropriate amount of reinforcements are required in the vicinity of coupling joints to avoid deleterious cracking.

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