프리캐스트 프리스트레스트 콘크리트(PC) 박스거더 교량의 정착부 거동 및 해석

ANCHORAGE ZONE BEHAVIOR AND ANALYSIS OF PRECAST PRESTRESSED CONCRETE BOX-GIRDER BRIDGES

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프리캐스트 프리스트레스트 콘크리트 상자형 교량의 정착부에 프리스트레스 힘이 도입되면, 과다한 국부집중 하중으로 인하여 균열이 발생할수 있으며, 최근 이러한 교량의 건설시 텐던을 따라가며 심각한 균열이 발생한 경우가 있다.

본 논문은 프리캐스트 프리스트레스트 콘크리트 상자형 교량의 정착부에 발생하는 국부집중 응력의 분포 특성을 규명하고, 이를 토대로 파괴기구 고찰함에 목적이 있다. 이를 위하여 정착부 파괴에 직접적인 영향을 미치는 단면의 형상, 텐던의 배치상태, 국부보강 철근의 형태 및 구조보강 철근량 등을 변수로 하는 역학적 거동 실험 및 해석 연구가 수행되었다. 위의 실험 및 해석 연구결과 정착부 파괴양상이 규명되었으며, 프리스트레스 정착부의 새로운 파괴기구 개념이 제시되어, 정착부 파괴과정을 적절히 설명하고 있다.

1. Introduction

A number of problems have occurred in post tensioned applications on both bridge and building field, which indicate that the design prodecures and design criteria for post tensioned anchorage zone tensile stress need futher examination and refinement. In reality, substantial cracking along the tendon path has been experienced in Corpus Cristi precast segmental bridge, in Taxas. Similar cracking was reported in the construction of Olympic Stadium in Montreal and post tensioned slab structures and other thin web applications. And these cracks provide a path for penetration of moisture and salts, thus present potential corrosion and frost damage threats.

The main objectives of this study are to determine the characteristics of the local stress distribution on the anchorage zones, to explore the failure mechanism on the anchorage zones of the precast prestressed box girder bridges. To accomplish these main objectives, a variety of experimental and analytical studies were conducted.

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2. Local Stress Distribution in Anchorage Zones

2.1 The Nature of Anchorage Zone Stresses

When a concentrated load is applied through a bearing plate across the width of a finite rectangular plate, two important tension fields are shown. These two tension fields are as follows: stresses acting along the line of loading, and stresses acting along the loading surface, parallel to it. These are generally called bursting stresses and spalling stresses. In dealing with a specific post-tensioned anchorage, the load must be applied over a finite area, and the compressive stress immediately under the anchor is called bearing stress.

The precise role that each of these stresses plays in the anchorage zone has not been fully understood. And, little information is available on efficiency of reinforcement for controlling cracking caused by these tensile stresses.

2.2 Bursting Stress

Generally, when concentrated load is transferred through finite rectangular plate, high compressive stresses occur at the beneath of loading point, and at a distance from this occur tensile stresses. This distribution of stress acting normally along the line of the load is called by 'bursting stress'.

2.3 Spalling Stress

When prestress forces are transferred in anchorage zones, spalling stress : parallel to the loading surface and away from the point of loading- occurs along the loading surface. The spalling tensile stresses are maximum at the loaded surface and decrease rapidly away from the surface. The peak spalling stress can be very high than bursting stress for the case of inclined tendon members.

2.4 Bearing Stress

The maximum compressive stress developed by a post-tensioning system occurs beneath the anchor. The average bearing stress is equal to the prestress force divided by the net area of the anchor defined as the projected plate area minus the tendon duct area.

3. Tests on the Mechanical Behavior of Anchorage zones

3.1 Test Scheme and Major Variables

The test members in this study are the full scale model selected on the hunch and buttress zone. And a total of 17 prototype model has been made and tested.

The test variables are tendon inclination, type of anchorage rebar, contents of structural steel.

3.2 Test Materials

(1) Concrete

Type III high early strength cement was used in order to obtain high early strength. and 28-day's compressive strength is investigated 520 kg/cm^2. Superplastizer Mighty-150 were used in this concrete. Table 3.1 shows the mix proportion of this concrete.

(2) Post Tensioning Anchor

Used anchors were EC 5-19 bearing type anchor with a light-weight trumpet manufactured by VSL. The anchors were rated for 19-0.5"ϕ strands. Tendon duct is made by steel and it's diameter is 9cm. Also, anchor head(diameter=180 cm) by VSL was used.

(3) PC-Strand

In this test, seven wire strand were used. It's tensile strength is 18.6t, and it's diameter is 1.27 cm. This seven wire strand satisfy the criteria of the ASTM-416.

(4) Structural and Anchorage Reinforcement Steel

All the structural steel used in test are H13, H19, H25, and the tensile strength of steel is 400 N/mm^2. H13-steel was used for the anchorage reinforcing steel and it's diameter is φ13, and tensile strength is 400 N/mm^2.

3.3 Design and Fabrication of Test Members

As mentioned earlier, the test members in this study are the full scale model size selected on the hunch and buttress zone of the precast segment.

Table 3.1 Mix proportion of concrete

Water-Cement ratio(%)	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)	Migthy150 (kg/m^3)
38	196	516	612	1,082	5.16

To investigate local stress distribution by prestress force, concrete strain gage were inserted in concrete. As shown in Fig.1 to determine internal tensile bursting strain, the embedment concrete gage inserted along the tendon path to the transverse direction of prestress load. And, as the tangential bursting strain of tendon may be different from radial bursting strain - it may be the determinant factor for determining the failure mechanism of concrete, concrete strain gages are embeded on upper and side face of tendon in turn.

3.4 Test Procedures

The anchors were loaded by stressing of tendon passing through the members, as in the actual usage.

Prior to loading zero readings were taken for all the gages. The load was then increased in 20 ton increments up to 160t. And at the higher load, the load increased by 5 ton. At each load stage, the values from inserted and attached stain gages were taken by UCAM.

4. Test Results

4.1 The Modes of Failure on Anchorage Zones

In spite of the many variables investigated in this experimental study, the post-tensioned anchors tend to exhibit a generally consistent behavior in sequence of failure.

The basic stages, when there are no supplementary reinforcement, are as follows:

(a) Initial cracking along the tendon path, beginning at a distance about the bearing plate width in front of anchor.

(b) With increased load, the crack extends both towards the loaded face and away from it.

(c) Formation of diagonal cracks on the end face, emanating from the corners of the bearing plate.

(d) Propagation of the diagonal cracks on the side faces.

(e) A generally sudden explosive-type failure, with complete destruction of the side face and a noticeable formation of a con of crushed concrete ahead of the anchor.

These failure modes are shown in Fig.2.

4.2 Effects of Tendon Inclination

Fig.3 shows the normalized cracking load as a function of tendon inclination. When the members reinforced by ordinary structural reinforcement, there were strength reduction of 26.8% with no anchorage reinforcement, 25.7% reduction with orthogonal anchorage reinforcement, 24.7% reduction of spiral reinforcement.

From these results, spiral reinforcement is more effective in controlling cracks in the case of inclined tendon.

4.3 Effects of Anchorage Local Reinforcement

To examine the effects of local reinforced anchorage, the members with spiral, orthogonal and no reinforced members were made with the variables of tendon shape and structural reinforcement.

Fig.4 shows the normalized cracking load as a case of local reinforced type.

4.4 Effects of Closely-Spaced Anchorage

Table 4.1 illustrates the increase in the cracking loads between the mono anchorage and closely spaced member.

As seen in this table, a gain in cracking load of 1.3% is evident between double and single straight anchorage member. But for the curved tendon members, a gain in cracking load of 6.7% was obtained. These results show that previously stressed, closely-spaced anchorage do not increase the tensile splitting stress but actually tend to reduce it. This favorable result is due to precompression. In the next section, it will be discussed the variations of internal stress in detail.

From this results, closely-spaced anchorage for curved tendon member is more effective than for straight tendon series.

5. Analysis with Non-Linear Finite Element Method.

The analysis with non-linear finite element method is conducted by ABAQUS. A three dimensional isoparametric solid finite element defined by twenty nodal points having three degrees of

Table 4.1 Cracking load between mono anchorage and closely spaced anchor

Case / Members	Mono anchorage	Closely-spaced anchorage
Straight tendon member	300	304(200)
Curved tendon member	226	240(200)

translational freedom at each node is used. To define concrete properties beyond elastic range, "CONRETE" option was used. To define the values of stress and strain at ultimate strength, "FAILURE RATIOS" option were also used. Local anchorage steel and shear reinforcements have been included in this finite element model. These reinforced steel have been modeled by truss element.

For the case of inclined tendon members, tendon curvature are required, and by multiple strand effects, the curvature forces directed to the center of curvature are generated. These curvature forces are calculated exactly by making programs, and this calculated forces are applied to the nodal point by concentrated loads. By these modeling, moments and forces are equilibriumed at any points.

Fig.5 shows the cracking loads compared with test data as a function of tendon inclination. As shown in this figure, there were a drop in cracking loads of 1.9% as increasing 1 degree increase of tendon inclination. This reduction values are slightly lower than test data-1.3%.

6. Concept of anchorage Zone Failure Mechanism

In this study, the bursting stress are classified into radial and tangential bursting stress as noticed earlier. One measure of bursting stress design criteria is peak tensile bursting stress for a given load. As the analytically computed bursting strains were in general agreement with test data, it can be discussed by 3D-FEM analytical solution results.

From these all results, tendon path crack is caused by tangential bursting stresses, and the exposed crack is induced by the tangential bursting stress at the side face of tendon. And the maximum tangential tensile busting stresses are revealed at 20-30cm distance from the loaded face, for straight tendon members, and this point is in accordance with the external first tendon path crack.

Most previous researchers focused on the radial bursting stress, but they did not explain the mechanism of tendon path crack. After generation of first tendon crack, cracks are formed by spalling stresses and eventually sudden explosive failure with complete destruction on the anchorage zones is occured.

7. Conclusions

From this study, the following conclusions can be drawn.

1. The failure of the anchorage zones is initiated by the cracks along the tendon path, and this crack is generated at a distance about the bearing plate width from the loaded face. As prestress load increases, diagonal cracks are formed, and eventually sudden explosive failure with complete destruction on the anchorage zones is occured.

2. Tendon-path cracks can occur at points well remote from the loaded face where the tendon profile has significant curvature and multiple-strands are used. This is due to the curvature force, and this force creates lateral forces sufficiently high to cause not only cracking but side face rupture as well. Thus, for inclined-curved tendon members, careful attention must be paid to avoid the possibility of cracking along the tendon path at the point of maximum curvature.

3. A realistic concept of failure mechanism on the anchorage zone is suggested.

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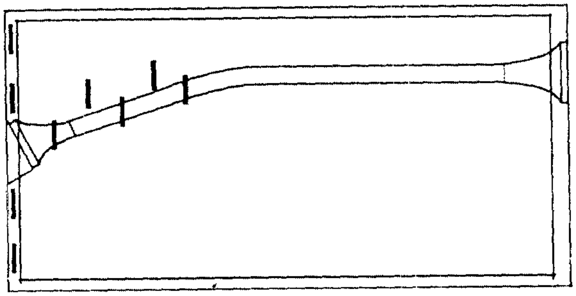

Fig. 1 Inserted concrete strain gage

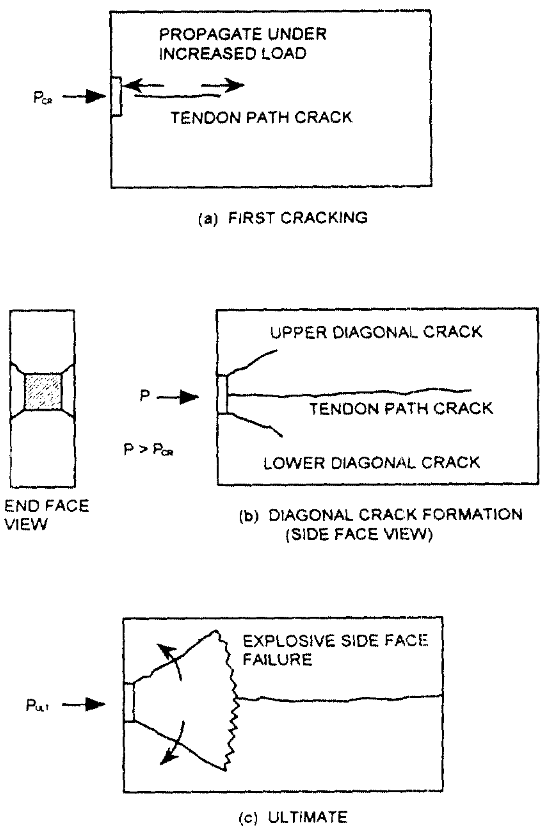

Fig. 2 Failure modes

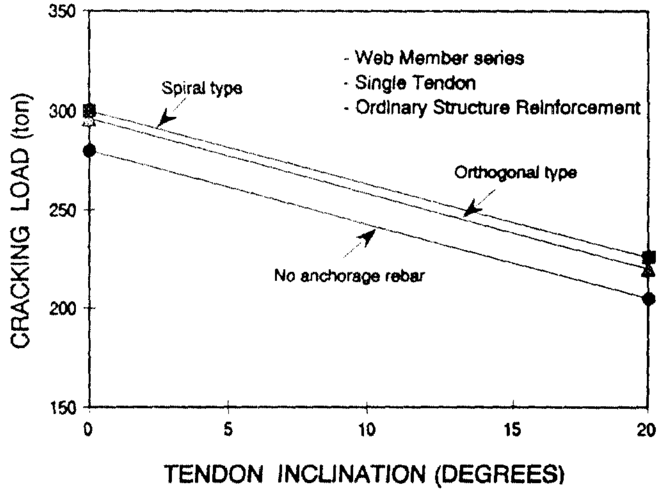

Fig. 3 Cracking load as a function of tendon inclination.

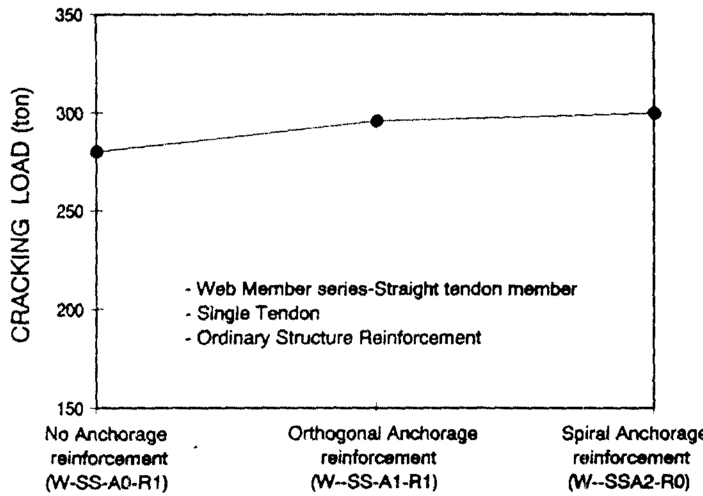

Fig. 4 Cracking load as a case of local reinforced type.

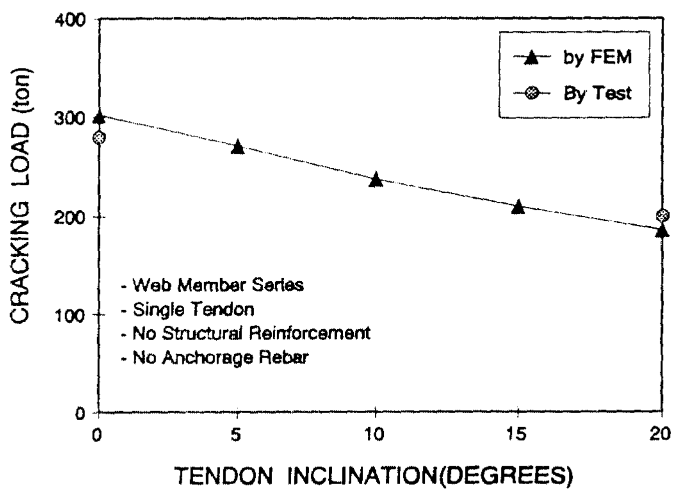

Fig. 5 Cracking loads compared with test data as a function of tendon inclination(by FEM)