A fundamental study on horizontal cracking at the ends of pretensioned PC girders utilizing FEA

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1. Introduction

Horizontal cracks at the ends of pretensioned prestressed concrete girders have been reported on numerous occasions in recent years. Pre-tensioned girder end zones, where the prestress transfer takes place, often exhibit characteristic cracking during or just after the application of prestress to the concrete as shown in Fig.1.

End zone cracks have been observed in girders of various shapes, such as box girders, I-shaped girders, hollow slabs, and tee beams [1]. Several studies have been conducted to control horizontal cracking at the ends of aforementioned type girders. But, there are few researches on hollow type girders. The purpose of this study is to examine how to control horizontal cracking at the ends of pretensioned PC hollow girder through finite element method.

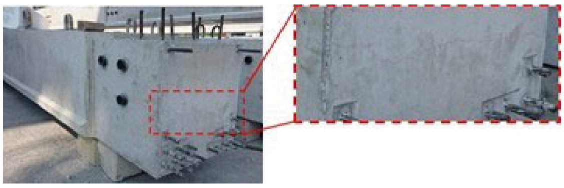


Fig.1: Horizontal cracks at the end of Pretensioned PC hollow girder

2. Finite element analysis

In this research, Finite Element Method (FEM) is used to examine how to control horizontal cracking at the end of pretensioned PC hollow girder. This paper focuses on a non-linear stress analysis of BS12 type girder (JIS A 5373-2010) [2] after the release of prestress. Midas FEA [3] is used as Finite Element analysis software.

2.1 Finite element model of BS12

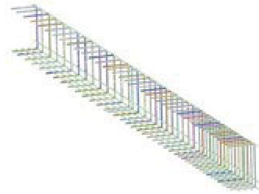
Figure 2 shows cross section and side section of BS12 girder.

Fig.3 shows a finite element model of BS12 girder. For computational efficiency, only a quarter of the full girder is modeled by virtue of the symmetry along the girder length and width. Table 1 shows material properties of concrete at the time of prestressing. Rebar type is "SD295" and modulus of elasticity is taken as 200GPa. PC strand is JIS G 3536 SWPR7BL type strands.

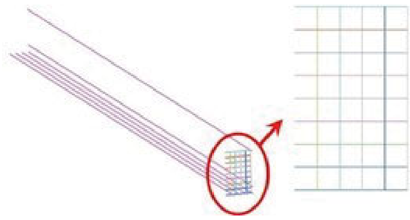
Hexahedron element and embedded rebar element are adopted for concrete and reinforcing bars, respectively. PC strands are modeled by truss elements and compressive forces are applied to truss element as prestress forces.

Fig. 4 shows constitutive laws of materials used in this analysis. Bond stress and threshold value of slipping are assumed to be 5.0 N/mm^2 and 0.2mm, respectively.

(a) Concrete model



(b) Stirrup and PC strand model



(c) Mesh adopted at the end cover of girder model

Fig.3: Finite element model of PC girder (BS12)

Table 1 Material properties used in analyses

Young modulus (E_c)	29500 N/mm^2
Compressive strength (f_c)	35 N/mm^2
Tensile strength (f_t)	2.46 N/mm^2

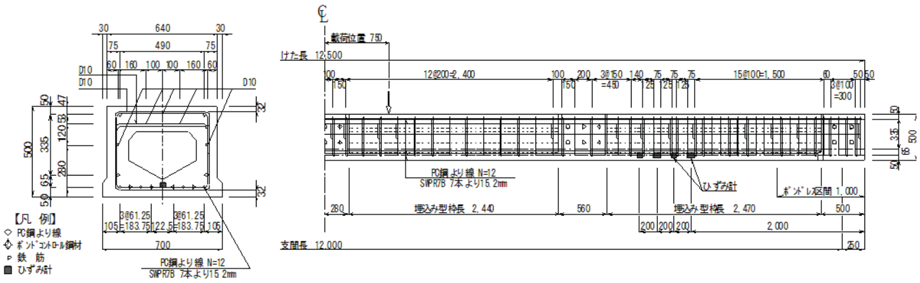


Fig.2: Cross and Side section properties (from JIS A 5373-2010)

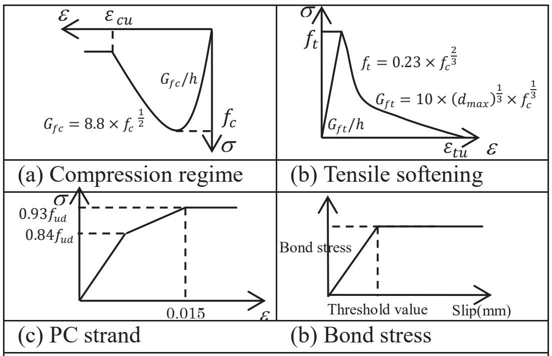


Fig.4: Constitutive laws

2.2 Analytical cases

There are several methods to prevent horizontal cracking at the end of PC girder. In this study, the effect of strand-debonding on horizontal cracks is examined. In Case #3, a mesh is placed at the very end of girder as end reinforcement. Table 2 shows analytical cases.

Table 2: Analyzed cases

Case	Situations
#1	All PC strands are fully bonded
#2	Four PC strands are debonded
#3	#1 with mesh

3. FEA Results

This section describes the investigations on the transfer length and the state of maximum principal stress distributions at the end of girder.

3.1 Transfer length of BS12

Effective stress at the centerline of bottom surface of BS12 model, which has been used in this study, is calculated as 16.7N/mm^2. The transfer length is obtained as 988mm of PC strands [4]. Fig.5 shows effective axial stress of concrete at the centerline of lower surface. It is found that the numerical results are in accordance with designed values.

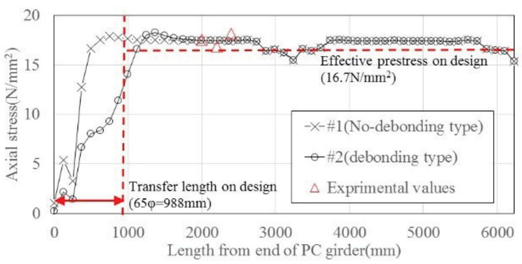


Fig.5: Effective stress in concrete

3.2 Maximum principle stress at the end of girder

It is considered that horizontal cracks at the end of girder occur when maximum principal stress reaches tensile strength of concrete at the time of prestress release. Here, at the end of PC girder, maximum principal stress has been examined on a side edge. After the prestress force was transferred to the concrete, the magnitudes of the maximum principal stresses in the concrete of BS12 girder are shown in Fig.6.

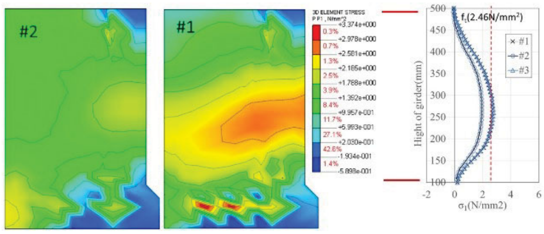


Fig.6: Maximum Principal stress contours in concrete at a cross section at the end of girder.

The computational results are obtained for BS12 girder with 12 PC strands. The girder represents the cracking problem as it exhibits horizontal end cracking. However, debonding four strands (#2), eliminates horizontal cracking at the girder end. The trends and results are applicable to all similar girders.

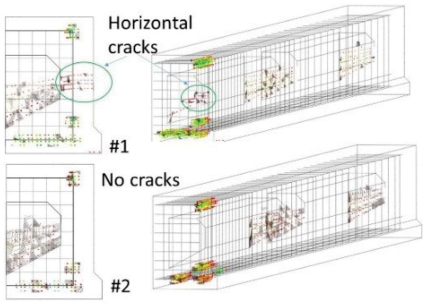


Fig.7: Cracking map of the girder

4. Conclusion and future works

The principal tension stress at the end of BS12 girder with four PC strands debonded is less than the tensile strength of concrete (2.46N/mm^2) as seen in Fig.6. Therefore, we can conclude that horizontal end cracking does not occur in BS12 type hollow girder if four strands debond at the ends of girder for the length equivalent to transfer length according to JRA Specifications for concrete bridges as the principal tensile stresses at the end of girder become less than tensile strength of concrete.

Reference

1. Christie J. Hasenkamp, Sameh S. Badie, Christopher Y. Tuan, Maher K. Tadros, "*Sources of End Zone Cracking of Pretensioned Concrete Girders*" Civil and Environmental Engineering Commons, 2008
2. Japanese Industrial Standards (JIS A 5373- 2010)
3. Midas IT HP: http://jp.midasit.com/midasit/
4. Japan Road Association (JRA). (2012). Specification of Highway Bridges, part 3, Concrete Bridges