International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 5, Issue 4, (July-August) 2017), PP. 63-66

CONTROL OF HORIZONTAL CRACKING AT THE ENDS OF PRETENSIONED HOLLOW TYPE BS12 PC GIRDER UTILIZING FEA

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Abstract— Horizontal end cracking occurs at the end zones of Pre-tensioned prestressed concrete girders where prestress transfer takes place. These cracks are more severe in deeper hollow girders with higher amounts of prestressing. In this study, a BS12 type hollow girder is modeled utilizing FEA to identify the locations of horizontal cracking in terms of vertical principal stresses at the end of the girder. Strand debonding is the proposed method to reduce the principal stresses and this method is used to eliminate horizontal cracks at the end of the girder. With the application of this method, BS12 girder is modeled using FEA with four PC strands debonded and results confirm that debonding four PC strands at the end of a BS12 type hollow girder for the same distance as the transfer length of the PC strands can reduce the principal stresses to a level lower than the tensile strength of concrete. Consequently the horizontal end cracks do not occur.

Keywords— Strand debonding, end zone reinforcement, nonlinear finite element analysis, pretensioned girder, end cracks.

I. INTRODUCTION

Pre-tensioned prestressed girders recently gained popularity over other superstructure members for their ability to efficiently span longer distances due to higher load carrying capacity [1].

Horizontal end cracks in pretensioned bridge girders have been a concern for girder manufacturers and designers [2]. The prestress transfer from the steel strands to concrete at the ends of prestressed concrete girders creates a region of stress concentration often resulting in formation of cracks during detensioning. While end cracking has been observed in pretensioned bridge girders for over fifty years [3]. The cracks appear to be more severe for recently developed heavily prestressed deep girders. Some smaller cracks are considered to be acceptable and can be sealed, while girders with larger cracks pose durability concerns [2].

Pre-tensioned girder end zones, where the prestress transfer takes place often exhibit characteristic cracking during or just after the application of prestressing to the concrete (Fig.1). The prestress force is introduced gradually by bonding between the steel and concrete over a distance known as the transfer length. This force creates compressive stresses that propagate into the member in a curved pattern until a linear stress distribution results [4], the dispersion of the prestress force causes tensile stresses to develop normal to the direction of the prestress force.

End zone cracks have been observed in girders of various shapes, such as box girders, I-shaped girders, hollow slabs , and tee beams [5]. 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 whereas the hollow type girders are very vulnerable to the development of cracks from the prestress force. 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.

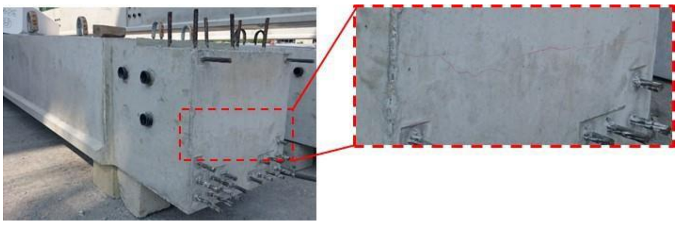


Fig.1. Horizontal cracks at the end of Pretensioned PC hollow girder.

II. FINITE ELEMENT ANALYSIS

In this research, Finite Element Method (FEM) is used to examine how to control horizontal cracking at the ends of pretensioned PC hollow girder. As concrete is a non-linear material so that the use of linear modeling is not capable of yielding a reasonable result. On the other hand, by performing the Non-linear analysis, it is possible to obtain sensible results for concrete and other non-linearly behaving materials. This paper focuses on a non-linear stress analysis of BS12 type girder after the release of prestressing force [6]. Midas FEA is used as Finite Element analysis software.

A. Finite element model of BS12

Detailed finite element model of BS12 girder was created to find out the solution to eliminate horizontal cracking at the ends of BS12 girder. The model is adopted and the properties of girder are taken from JIS standards [6]. The finite element model uses the standard geometry and the standard end zone reinforcement details of the PC girder.

Figure 2 shows cross section of BS12 girder and the location of debonded PC strands. For computational efficiency, only one fourth of the complete girder is modeled by virtue of the symmetry along the girder length and width (Fig.3).

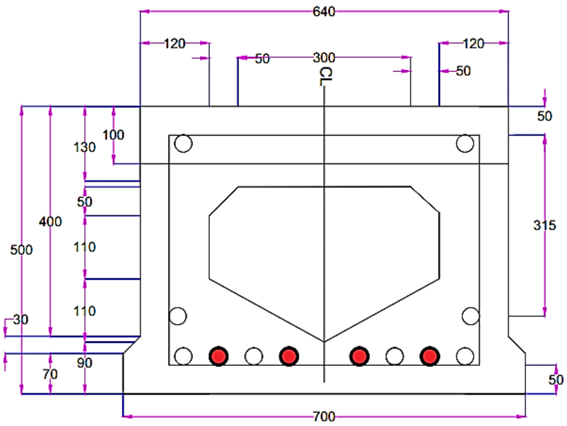


Fig.2. Cross section properties of BS12 girder. (Debonded strands)

B. Material Properties

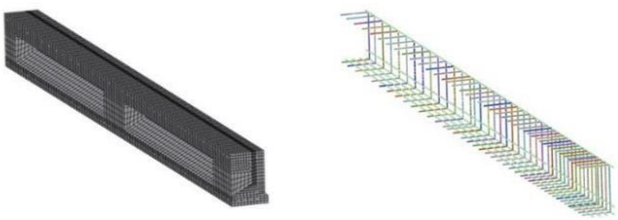
Table 1 shows material properties of concrete at the time of prestressing in which, rebar type is "SD295" and modulus of elasticity is taken as 200GPa and PC strand type is JIS G 3536 SWPR7BL.

Table 1. Concrete material properties used in analyses

Material Properties (N/mm^2)	
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

C. Finite Element Type

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



(a) Concrete model, (b) Stirrup and PC strand model
Fig. 3. Finite element model of PC girder

D. Constitutive laws

Figure 4 shows constitutive laws of materials used in this analysis. Bond stress and threshold value of slipping are assumed to be 5.0 N/mm2 and 0.2mm, respectively.

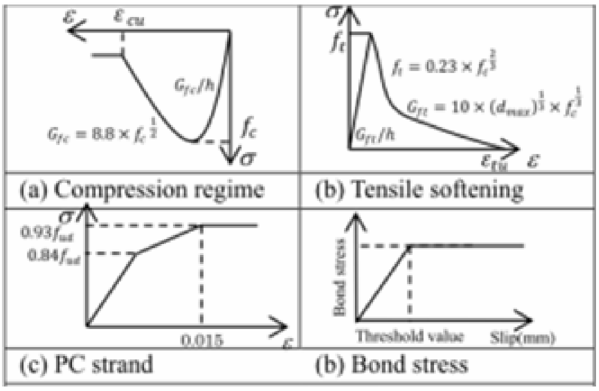


Fig. 4. Constitutive laws

E. Analytical cases

There are several methods to prevent horizontal cracking at the ends of PC girder. In this study, the effect of strand-debonding on horizontal cracking is examined. Three type models are modeled, in case 1, all PC strands are fully bonded to measure the developed vertical principal stresses and to check the condition of horizontal cracking. In case 2, four PC strands are debonded along the transfer length to examine the effects of strand-debonding to reduce the principal stresses and in Case #3, A mesh is placed at the very end of the girder as end reinforcement to examine the effect of end zone reinforcement on horizontal cracks (Fig. 5). Table 2 shows analytical cases of the BS12 model.

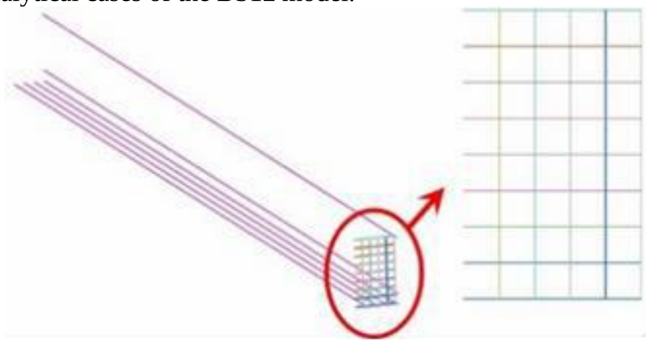


Fig. 5. Mesh adopted at the end cover of girder model

Table 2. Analyzed cases of the girder

Case no	Situations
1	All PC strands are fully bonded
2	Four PC strands are debonded
3	#1 with end mesh

III. FEA RESULTS

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

A. Transfer length of BS12

In pre-tensioned concrete members, the total prestressing force is transferred to the concrete entirely by bond between the prestressing strand and the surrounding concrete. Transfer length is defined as the bond length required to fully transfer the effective prestress from the strand to the concrete [7]. Here for BS12 girder, the transfer length is obtained as 988mm of PC strands according to JRA Specifications for concrete bridges [8]. Effective stress at the centerline of bottom surface of BS12 model, which has been used in this study, is calculated as 16.7N/mm2. Figure 6 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.

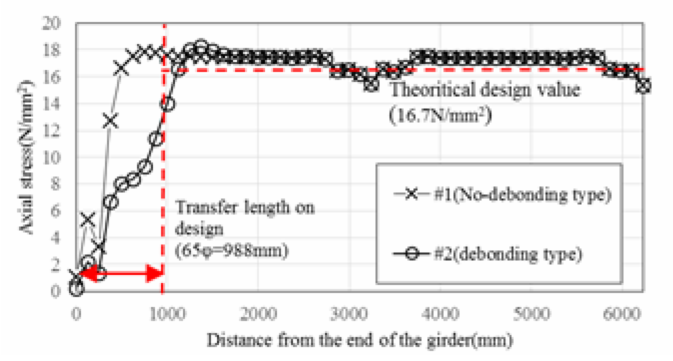


Fig. 6. Effective stresses in the concrete

B. 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 BS12 PC girder, maximum principal stress is 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 the girder are shown in Fig.7.

The computational results are obtained for BS12 girder with 12 PC strands. The girder represents the cracking problem as it exhibits horizontal end cracking in case #1. However, debonding four strands as in case #2 can reduce the principal stresses to the amount less than the tensile strength of concrete and therefore debonding of four strands can eliminates horizontal cracking at the girder ends. The trends and results are applicable to all similar girders.

The analysis of BS12 girder with end zone reinforcement in Case #3 shows the principal stresses same as in the case #1 and the horizontal cracking are likely to occur. Thus it shows that only end mesh cannot eliminate horizontal cracking at the ends of BS12 girder.

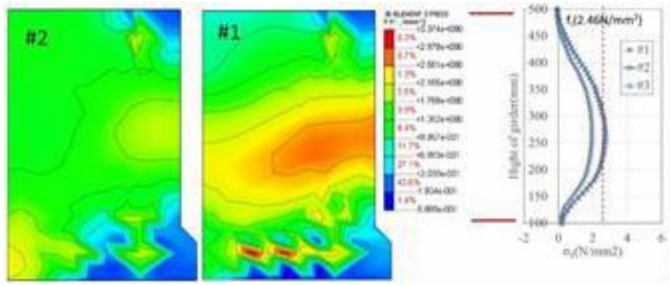


Fig. 7. Maximum Principal Stress contours in concrete at a cross section at the end of girder.

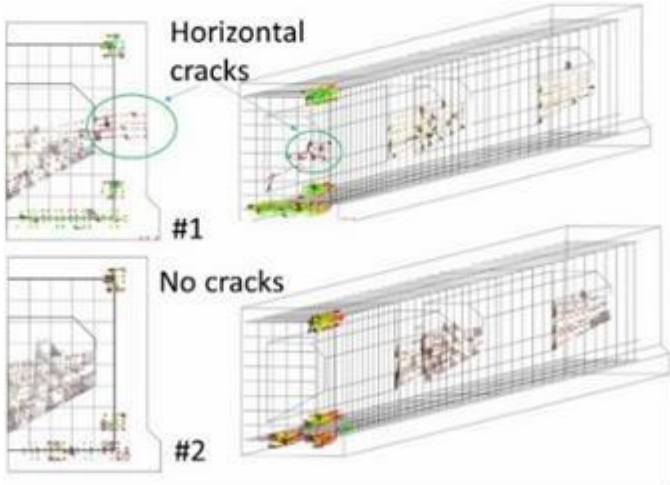


Fig. 8. Cracking map of the girder

CONCLUSION AND FUTURE WORK

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) Therefore, we can conclude that horizontal end cracking does not occur in BS12 type hollow girder if four strands are debonded at the ends of girder for the length equivalent to transfer length according to JRA Specifications for concrete bridges, because as the principal tensile stresses at the end of girder diminishes than tensile strength of concrete.

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