

Evaluation of Strand Debonding as a Method for Controlling End-Region Damage in Pretensioned Concrete Girders

Fatemeh Ranjbar, Hossein Yousefpour*, Javad Vaseghi-Amiri

Faculty of Civil Engineering, Babol Noshirvani University of Technology, Mazandaran, Iran.

ABSTRACT

Prestressed concrete is an effective solution for construction of flexural members under significant service loads, which can be pretensioned or posttensioned. In pretensioned concrete members, the transfer of prestressing force relies on direct contact between the prestressing steel and concrete. Modern pretensioned concrete girders employ thin webs and high levels of prestress. The transfer of large stresses from strands to concrete in such cross sections results in cracking at the ends of the girders and causes concerns about their durability and load-carrying capacity, specially under shear-critical loading. This paper presents a numerical evaluation of pretensioned beams in which end-region cracking is mitigated by means of strand debonding. Nonlinear models of prestressed girders are developed to simulate the conditions of the member at the time of transfer and under loading until failure. The model was validated using strains and load-displacement curves obtained from experimental studies on full-scale girders. The structural behavior of the pretensioned girders was investigated using the validated model for debonding of all strands in lengths between 250 and 1000 mm or half of the strands for lengths between 250 and 3000 mm. Results showed that debonding of all strands up to a length of 250 mm or half of strands for up to 1000 mm would control cracking in the end region areas without affecting the load-carrying capacity. Greater debonding lengths cause serious damage to the girder under shear-critical loading and necessitate additional transverse reinforcement at the beginning of the fully bonded zone.

KEYWORDS

Prestressed concrete, Pretensioning, Finite Element Analysis, Debonding, End-Region Cracking.

* Corresponding Author: Email: hyousefpour@nit.ac.ir

1. Introduction

One of the promising methods to reduce end-region cracking in pretensioned elements is debonding of strands at the end of the member. As a result, the bond between steel and concrete starts at regions far from the end of the member, leading to smaller end-region stresses [1, 2].

A few previous studies [3-10] have examined end-region stresses and cracking in pretensioned elements. These studies have not established a relationship between end-region damage and observed failure modes in pretensioned elements. Moreover, they have not addressed methods such as debonding in a way that is useful to the design practice.

This paper presents a numerical study on the effect of debonding on the end-region damage and shear strength of pretensioned concrete elements using experimentally validated FE models of bridge girders with the objective of helping design engineers choose the debonding plan.

2. Methodology

A 3-D finite element model of a bridge girder was developed in Abaqus [11] based on the series of specimens fabricated and tested by Yousefpour et al. [12-14]. The sectional geometry of the specimens, which had a length of 9.1 m, are shown in "Figure 1". A summary of the mechanical properties for the specimens is provided in "Table 1".

The model incorporated nonlinear material properties for steel and concrete as well as concrete compressive and tensile damage, as summarized in "Table 2".

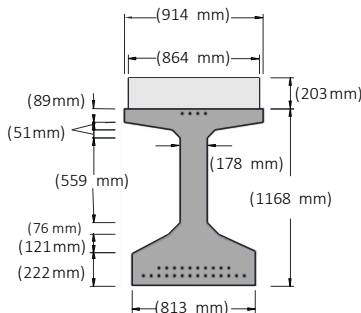


Figure 1. Cross-sectional dimensions of the bridge girder

Concrete and prestressing steel were modeled using 3-D eight-node reduced integration (C3D8R) elements. The 3-D linear truss (T3D2) elements were used for modeling reinforcing bars.

The interaction properties between concrete and prestressing steel were defined as follows: Hard contact with allowance for separation after contact was used in the normal direction. In the tangential direction,

a combination of Coulomb friction and cohesive behavior was employed.

Table 1. Mechanical properties used in the model

Property	Assumption
Compressive strength of concrete	52.4 MPa
Modulus of Elasticity of concrete	33854 MPa
Direct tensile strength of concrete	4.43 MPa
Yield strength of shear reinforcement	418 MPa
Yield strength of prestressing steel	1600 MPa
Ultimate strength of prestressing steel	1904 MPa

Table 2. FE Model properties

Property	Model Assumption
Compressive stress-strain model	Minh et al. [15]
Tensile stress-strain model	Cornelissen et al. [16]
Concrete damage plasticity	
Dilation angle	45 degrees
Viscosity parameter	0.0055

3. Results and Discussion

The model was successfully validated against experimental data reported by Yousefpour et al. [12-14] in terms of strain distribution along the strand, stress in transverse reinforcement, and load-deformation behavior, examples of which are presented in "Figures 2, 3, and 4", respectively.

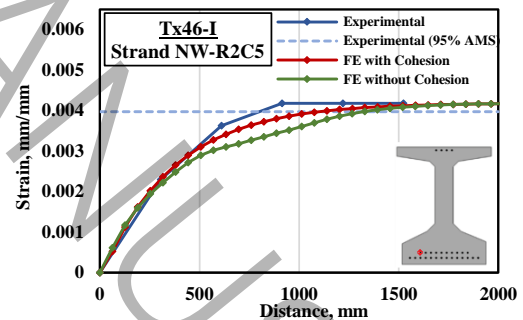


Figure 2. Typical distribution of longitudinal strains along the strand in comparison with experimental data

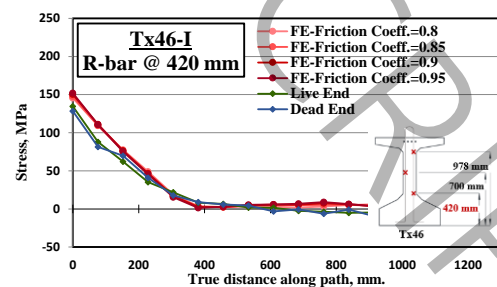


Figure 3. Typical comparison between numerical and experimental strains in transverse reinforcement

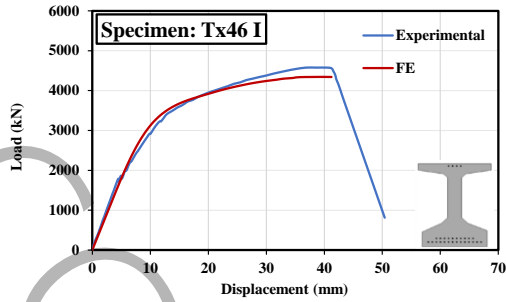


Figure 4. Typical comparison between numerical and experimental load-deflection data

The validated model was then employed to assess the effects of debonding the strands within the end regions in two general conditions: a) debonding all strands over a distance of 250, 500, 750, or 1000 mm; and b) debonding half of the strands over a distance of 500, 1000, 1500, or 3000 mm from the end face.

Typical transverse steel stresses for the case of debonding all strands are shown in "Figure 5", which exhibit a significant reduction in the stresses at the end face for all debonded lengths except 1 m. On the other hand, contours of end-region damage in "Figure 6" show that if all strands are debonded over a distance greater than 250 mm, greater end-region transverse reinforcement would be needed to prevent additional damage at the end of the debonded region under shear-critical loading.

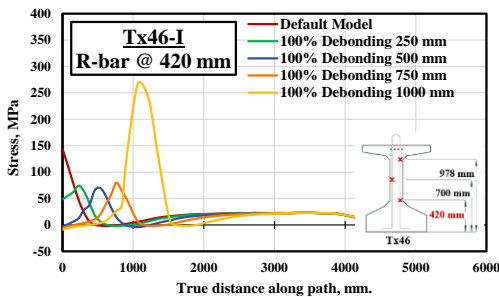


Figure 5. Stress in transverse steel reinforcement assuming debonding of all strands

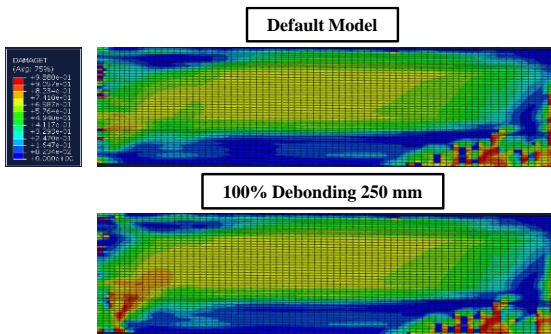


Figure 6. Contours of end-region tensile damage at peak load assuming debonding of all strands

Debonding half of the strands was found to be a more practical approach, especially for lengths between 500 and 1000 mm from the girder end, for which the end-region damage would be minimized with no additional hear-induced damage (as shown in "Figure 7"), nor negatively affecting the load-deformation behavior (as shown in "Figure 8").

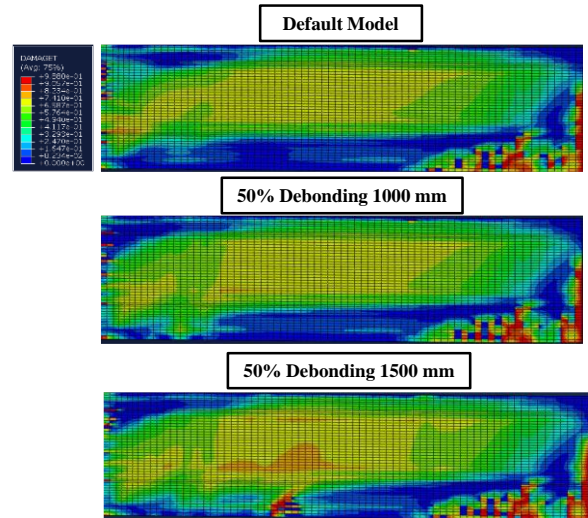


Figure 7. Typical contours of end-region tensile damage at peak load assuming debonding half of the strands

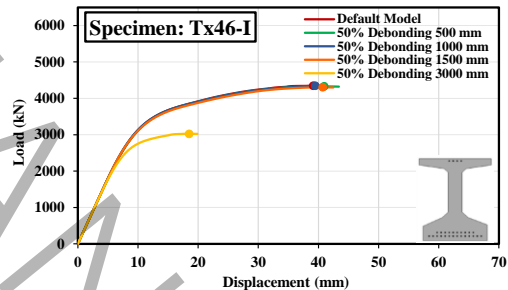


Figure 8. Typical load-deflection behavior assuming debonding half of the strands

4. Conclusion

In this study, a three-dimensional nonlinear FE model was developed and validated against experimental data to examine the end-region damage and load-carrying capacity of a pretensioned concrete girder assuming different debonding scenarios.

Results from the model showed that debonding of the strands is an effective method to control end-region cracks in pretensioned girders. However, only a limited distance of strands may be entirely debonded without negatively affecting the shear strength. Debonding half of the strands over 500-1000 mm from the girder end was found to be a practical solution for the girder under investigation.

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