A methodological approach for finite element modeling of pretensioned concrete members at the release of pretensioning

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This paper presents a methodological approach for finite element simulation of pretensioned concrete members. The three-dimensional analysis presented in this paper involves a rectangular [150 mm (6 in.) tall × 150 mm (6 in.) wide × 2440 mm (96 in.) long] concrete member hosting one 15-mm (0.6 in.) diameter 7-wire low-relaxation Grade 1860 MPa (270 ksi) prestressing strand. The finite element models are divided into two general classifications: (i) concentrically pretensioned, and (ii) eccentrically pretensioned. The finite element models are analyzed based on elastoplastic material behaviors as well as mesh sensitivity. Two approaches are examined for finite element modeling of the pretensioned concrete specimens: (i) the extrusion technique utilizing friction-based contact simulations, and (ii) the embedment technique simulating equivalent responses while being a computationally less expensive solution. A comparative analysis is presented to measure the validity as well as accuracy of the findings by the finite element techniques against the commonly used closed-form solutions based on elastic beam theory. The validity of the finite element approach is further verified by comparative analysis of the analytical data against the experimental findings. The paper concludes that the embedment technique provides an accurate and numerically efficient alternative in comparison with the extrusion method for the simulation of the pretensioned concrete members. While the extrusion technique provides more detailed information corresponding to the regions located immediately around the prestressing strands, including the interface overstresses and bond slippage, the embedment technique appears to have the ability to simulate the overall response of the concrete members with comparable accuracy.

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1. Objective

The current state of analysis and design of pretensioned concrete members indicates a serious lack of unified and practical guidelines for analytical simulation of precast prestressed concrete members. There is a need for development of a validated methodological approach to analytically simulate the behavior of pretensioned concrete members during various stages of construction and service life. This paper includes modeling methodologies which primarily focus on the response of the members immediately after the release of the pretensioning.

The main objective of this research is to propose modeling approaches that can adequately simulate the pretensioning mechanism and predict the inelastic response of a pretensioned member immediately after the release of the pretensioning.

Once a reliable analytical method is developed and confirmed against the available closed form solutions, a series of comparative analyses are conducted to verify the simulation of concentrically pretensioned concrete prisms against experimental data. The comparative analyses not only show conformance of the analytical results with the test data, they also indicate the sensitivity of the simulated models to passive confinement in the form of close stirrups along the length of the member. It is important to note that availability of analytical procedures to simulate the pretensioning mechanism can have direct impact on future research in the area of precast/prestressed concrete considering the costly laboratory experiments using full or scaled specimens.

2. Literature review

In the past 30 years, many attempts have been made to propose finite element models which can capture the response of pretensioned concrete members. Dating back to 1978, Mirza and Tawfik [1] presented a one-dimensional mathematical modeling which included a stiffness analysis for the detensioning (release) process. This model required the system stiffness matrix and load vectors to be updated upon the releasing of each individual strands, resulting in a time consuming process.