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Experiment and numerical modeling of prestressed concrete curved slab with spatial unbonded tendons

Nan Zhang [a,1], Chung C. Fu [b,*], Huimin Che [c]

[a] College of Civil Engineering, Nanjing University of Technology, Nanjing 210009, China
[b] The Bridge Engineering Software and Technology Center, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742, USA
[c] College of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China

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ABSTRACT

Curved prestressed concrete structures with unbonded tendons are widely used in highway interchanges and industrial cooling towers, etc. In engineering practice, there is a demand to establish calculating methods for analyzing and designing these prestressed concrete curved structures with unbonded tendons. However, there are some difficulties in calculating the ultimate strength of these curved structures. The major difficulty is to calculate the ultimate stress in unbonded tendons. The assumption of a plane cross-section cannot be adopted here because of the slip between unbonded tendon and concrete. Thus, many formulas for calculating the ultimate stress in unbonded tendons were mainly based on experimental data fitting. In order to obtain the ultimate stress in unbonded tendons from mechanical principles, instead of using experimental data fitting formula, an advanced nonlinear analysis method to calculate ultimate stress in unbonded tendons is developed. The analysis model is established by using the Reissner–Mindlin medium thickness plate theory allowing for the influence of the transverse shear deformation. The orthotropic increment constitutive model of concrete is extended to solve the medium thickness plate problem. The tension stiffening of the cracked concrete is considered in the nonlinear analysis model. The numerical formulation of calculating the stress increment in an unbonded tendon is established by using the spatial displacement relationship. Instead of using general-purpose programs such as ANSYS and ABAQUS, a computer program specifically for predicting the nonlinear response of a prestressed concrete curved slab structure with unbonded tendons and calculating the ultimate stress in unbonded tendons is developed by authors. Six test models of prestressed concrete curved slabs with unbonded tendons are reported. The calculated results using this program are compared with test results, where their relative deviation is less than 3.0%, which validates the proposed method. These study results can be used for analysis, especially to design the strength of prestressed concrete curved structures with unbonded tendons. And, this research work also proposes a new approach, which can be customized to fit into general purposed FEM programs, such as APDL (ANSYS Parametric Design Language), for analyzing the nonlinear structural behavior of these curved structures.

1. Introduction

In the engineering practice of designing prestressed concrete curved structures, structural engineers need to calculate the load-carrying capacity of prestressed concrete curved structures. Many common analysis methods can be used in calculating the load-carrying capacity of prestressed concrete curved structures with bonded tendons. But, because the assumption of a plane cross-section cannot be adopted to calculate the ultimate stress in unbonded tendons due to the slip between unbonded tendon and concrete, there is a difficulty in calculating the strength of these curved structures. So, many formulations for calculating the ultimate stress in unbounded tendons have been mainly based on experimental data fitting. Many researchers studied the ultimate strength of a prestressed concrete beam or slab with unbonded tendons from experimental test results, such as Mattock et al. [1], Tam and Pannell [2], Cook et al. [3], Du and Tao [4], Naaman and Alkhairi [5], Wu et al. [6], Barbieri et al. [7], ACI Committee 318 [8] and AASHTO LRFD Bridge Design Specifications [9].

In ACI-318 [8], the stress in unbonded prestressing steel at nominal strength in S.I. units is simplified as

* Corresponding author.
E-mail address: ccfu@eng.umd.edu (C.C. Fu).
1 Formerly Visiting Professor, BEST Center, University of Maryland, College Park, MD 20742, USA.

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