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Advances in Concrete Bridges: Design, Construction, Evaluation, and Rehabilitation

SP-333

Editors:
Yail J. Kim, John J. Myers, and Antonio Nanni

American Concrete Institute
Always advancing

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PREFACE

Advances in Concrete Bridges: Design, Construction, Evaluation, and Rehabilitation

Concrete bridges play an important role in the efficiency and reliability of transportation civil infrastructure. Significant advancements have been made over the last decades to enhance the performance and durability of bridge elements at affordable costs. From an application perspective, novel analysis techniques and construction methods are particularly notable, which have led to the realization of more sustainable built-environments. As far as the evaluation and rehabilitation of constructed bridges are concerned, new nondestructive testing approaches provide accurate diagnosis and advanced composites, such as carbon fiber reinforced polymer (CFRP), have become an alternative to conventional materials. This Special Publication (SP) contains nine papers selected from two technical sessions held at The ACI Concrete Convention and Exposition – Spring 2018, in Salt Lake City, UT. The objective of the SP is to present technical contributions aimed to understand the state of the art of concrete bridges, identify and discuss challenges, and suggest effective solutions for both practitioners and government engineers. All manuscripts were reviewed in accordance with the ACI publication policy. The Editors wish to thank all contributing authors and reviewers for their rigorous efforts. The Editors also gratefully acknowledge Ms. Barbara Coleman at ACI for her knowledgeable guidance in the development of the SP.

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SP-333-1

A Numerical Analysis Methodology for the Strengthening of Deep Cap Beams

Rafael A. Salgado, Serhan Guner

Synopsis: A significant number of in-service bridges have been subjected to loads above their original design capacities due to the increase in traffic and transported freight in the past decades. Externally bonded fiber reinforced polymers (FRP) is a non-destructive retrofit technique that has become common for the strengthening of overloaded cap beams of bridges. However, there is a lack of analysis methods for the retrofitted cap beams that can accurately predict the retrofitted structural response while accounting for the critical material behaviors such as bond-slip relationships, confinement effects, and redistribution of stresses. In this study, an analysis methodology using nonlinear finite element models is proposed for cap beams retrofitted with externally bonded FRP fabrics. A two-stage verification of the proposed methodology was employed: a constitutive modeling and critical behavior of materials verification using experimental results available in the literature; and a system-level load capacity determination using a large, in-situ structure. The proposed methodology was able to capture the FRP-concrete composite structural behavior and the experimentally observed failure modes. The FRP retrofit layout created using the results of this study increased the capacity of the initially overloaded cap beam in 27%, granting it a 6% extra capacity under its ultimate loading condition.

Keywords: deep beams; nonlinear analysis; cap beam; structural assessment; FRP; retrofit; analysis methodology

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INTRODUCTION

Externally bonded fiber reinforced polymer (FRP) is a non-destructive and efficient retrofit technique that has been increasingly common for the strengthening of overloaded bridge cap beams. Despite its large applicability, there is still a lack of analytical methods for the retrofitted cap beams that can accurately predict their structural response due to the added FRP fabrics. Despite some simple equations given by codes[1,2] to obtain an estimate of the added flexural and shear capacity due to the FRP fabrics, several material behaviors that are critical to obtain an accurate response of the retrofitted structure such as bond-slip relationships, confinement effects, and redistribution of stresses are not considered. On top of that, due to their small shear spans, cap beams are usually classified as deep elements that form a direct strut action (i.e., a diagonal compressive stress field between the load application point and the supports) and do not satisfy the Euler-Bernoulli theory (i.e., plane sections remain plane). By neglecting these important structural behaviors when performing retrofit studies using FRP fabrics, the calculated FRP retrofit layout is at risk of being ineffective or even detrimental to the original cap beam. Thus, the complexity and uniqueness of each cap beam require an effective analysis approach with an accurate FRP modeling methodology to substitute any 'guess-work' with a better understanding of the structural behavior.

This study proposes an analysis methodology for deep cap beams retrofitted with externally bonded FRP fabrics. The methodology is presented in two stages with respective verifications: constitutive modeling of the critical behavior of materials; and an overall methodology application using a large, in-situ structure. The material behavior models and the modeling procedure proposed are verified using experimental results available in the literature. The overall modeling process is presented to assist in accurately analyzing cap beams using the proposed methodology.

RESEARCH SIGNIFICANCE

FRP fabrics have been commonly used to retrofit deep cap beams of in-service bridges that have become structurally deficient due to the increase in loading condition over the decades. There is a lack of holistic analysis approaches to accurately calculate the load capacity of retrofitted cap beams while accounting for the concrete's deep beam actions and the composite behavior introduced by the FRP fabrics. This study details a finite element approach that aims to provide a holistic understanding of the structural behavior and to accurately calculate the load capacity of FRP retrofitted deep cap beams.

PROPOSED CAP BEAM NUMERICAL MODELING AND SYSTEM-LEVEL ANALYSIS METHODOLOGY

A numerical modeling and system-level analysis methodology for deep cap beams retrofitted with externally bonded FRP is proposed using nonlinear finite element analysis (NLFEA). NLFEA models are suitable for the assessment of deep cap beams due to its implementation of the nonlinear effects that are characteristic of deep elements, such as the nonlinearity of the strain distribution and the effects of cracking on the stress distribution[3,4]. Using NLFEA, the performance of the structure under both the serviceability and ultimate limit state conditions can be verified and it allows for the prediction of the progression of nonlinear events (i.e., concrete cracking, reinforcement yielding, concrete crushing, and the formation of the failure mechanism). Using the proposed methodology, if the NLFEA analysis of an un-retrofitted cap beam calculates an overloaded structural state, then a retrofit study using externally bonded FRP fabrics must be conducted to ensure the adequacy of the cap beam to its ultimate loading condition. In such cases, an NLFEA analysis is essential to get an accurate capacity of the deep beam and to determine an FRP retrofit layout that effectively captures the deficiencies of the beam.