Partially-Repaired Reinforced Concrete Beams with Exposed Reinforcement

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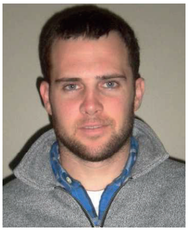

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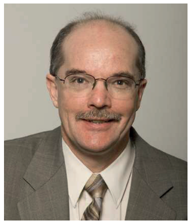

Michael Bartlett, born 1957, received civil engineering degrees from Queens University (B.Sc.), the University of Waterloo (M.A.Sc.) and the University of Alberta (PhD). His research interests include the evaluation and rehabilitation of bridge and building infrastructure.

Summary

Deteriorated reinforced concrete highway bridge girders are regularly repaired by replacing existing concrete with new concrete, temporarily exposing the reinforcement. At this stage the capacity of the girder is uncertain because, while plane sections remain plane at each cross section, the requirement of compatible strains in the reinforcement and the adjacent concrete no longer holds. This paper presents an experimental study of five 4-metre concrete T-section specimens with exposed reinforcement loaded with a simulated uniformly distributed load and a concurrent single-point load to realistically simulate the loading applied to a typical girder. These results are used to validate an analytical approach developed to assist practicing engineers in checking the safety of girders with exposed reinforcement during rehabilitation.

Keywords: Bridges, Concrete, Exposed Reinforcement, Assessment/Repair, Rehabilitation

1. Introduction

Reinforced concrete (RC) highway bridge girders are susceptible to deterioration caused primarily by corrosion of the reinforcing steel from the use of deicing salts. Their repair involves removing the contaminated concrete, exposing the reinforcement, and replacing it with new concrete. Loss of the steel-concrete bond eliminates the requirement that strains in the reinforcement and the adjacent concrete are compatible and the flexural capacity of the girder is difficult to compute [1, 2].

Eight previous investigations involved either single- or two- point loading and, because RC girders resist substantial uniformly distributed dead loads, are not realistic. Thus an investigation of five 4 metre T-sections loaded with a simulated distributed load and a point load was undertaken. This paper presents the strain compatibility analysis developed and its validation by tests.

2. Strain Compatibility Analysis of Specimens with Exposed Reinforcement

Previous researchers [2] concluded that a girder with exposed reinforcement can exhibit a ductile failure with no reduction in yield capacity if: the bond between the concrete and the reinforcement at the support is sufficient; a concrete compression failure does not occur at the end of the exposed length; and, the reinforcement yields before the concrete crushes in compression. The longest exposed length of reinforcement, ℓ_{exp}, that satisfies all three of these conditions is defined as the critical length of exposed reinforcement, ℓ_c. The current Strain Compatibility Analysis was developed to predict ℓ_c for the third condition, the most predominant failure mode previously observed [2]. The procedure involves incrementally increasing ℓ_{exp} for a girder subjected to a given

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loading until the horizontal force and moment equilibrium and strain compatibility between the concrete and reinforcement requirements are exactly satisfied.

3. Experimental Testing of Specimens with Exposed Reinforcement

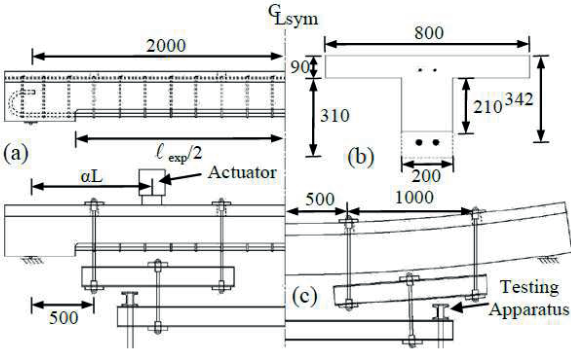

Fig. 1: (a) Elevation of Test Specimen (b) Cross-section, (c) Testing Apparatus: Unloaded (Left) and Loaded (Right)

To evaluate the accuracy of the analysis, five T-section specimens with exposed reinforcement, including Control Specimen, as shown in Fig. 1 were designed and tested. A testing apparatus was designed to apply a simulated distributed load using four equal point loads applied by a system of whiffle trees and a concurrent point load applied by an actuator, as shown in Fig. 1(c).

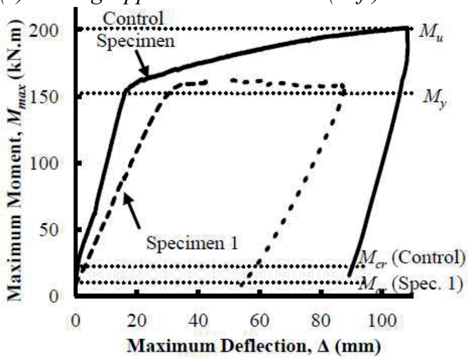

Fig. 2: Moment-Deflection for Control Specimen and Specimen 1, with M_{cr}, M_y and M_u

The moment-deflection relationships for the Control Specimen and Specimen 1 and their respective predicted values of the cracking, M_{cr}, yield, M_y, and ultimate, M_u, moments for an otherwise identical specimen with no reinforcement exposed are shown in Fig. 2. Specimen 1, unlike the Control Specimen, exhibited a small increase in flexural capacity after yield before ductile behaviour with no strain hardening was observed. All specimens failed by crushing of the concrete compression flange at a moment above the predicted M_y but below M_u.

The Strain Compatibility Analysis was used to predict the failure moment, M_{SCA}, of the five specimens. The procedure was altered slightly by incrementally changing the maximum lever arm, jd_{max}, to predict M_{SCA} because ℓ_{exp} was predetermined. These M_{SCA} correlate well with the M_u observed, with a mean M_u/M_{SCA} ratio of 1.00 and a standard deviation of 0.068. The failure modes were also consistent with those predicted.

4. Conclusions

There are no code criteria to analyze RC girders with exposed reinforcement to determine the maximum ℓ_{exp} that does not reduce the flexural capacity. This paper rectifies this knowledge gap by developing a strain compatibility analysis. The research has yielded the following conclusions:

1. RC T-section specimens with long ℓ_{exp} can reach the original flexural capacity and exhibit a ductile failure. All test specimens failed by crushing of the concrete flange at a moment greater than the predicted M_y and less than M_u. With the reinforcement exposed, strain hardening does not occur and does not allow the capacity of the specimen to increase.
2. A Strain Compatibility Analysis using an accurate stress-strain concrete relationship was developed, and been validated by the test results. The analysis can be used for any length and location of ℓ_{exp}, moment distribution or cross section. It is an important tool to assist practitioners evaluating a RC bridge with exposed reinforcement.