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CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

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Research Results

Geotechnical / Structures

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Project Title:

Assessment and Shear Strengthening Of Existing Cast-In-Place and Precast Concrete Bridge Girders

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Enhancing Shear Resistance of Existing Concrete Bridges

Utilizing Near-Surface-Mounted (NSM) bars and Partially Embedded Bars (PEB) in the web of the girder to enhance the shear capacity of existing concrete bridges was evaluated through large-scale testing.

WHAT WAS THE NEED?

It is estimated that several hundred bridges on state highways in California are structurally inadequate to carry many of the permit loads that are routinely requested for transport on California Department of Transportation (Caltrans) roadways. This results in time consuming and costly detours for many vehicles carrying these loads. Most of these deficient bridges have pre-cast concrete "T", "I" or cast-in-place concrete box girder superstructures. They are primarily deficient in shear in terms of their ability to carry permit loads. One of the goals of Caltrans is to strengthen all of these bridges to adequately carry AASHTO LRFD "P-15" loading. There is presently no established procedure to increase the shear capacity of typical girders found in the majority of the deficient bridges. The only alternatives available at this time are complete bridge replacement or possibly the replacement of the superstructure only. Both of these alternatives are costly, time consuming and disruptive to the traveling public and the transportation of goods. Many methods have been proposed by various researchers for shear strengthening of reinforced concrete girders. However, it is necessary to carefully assess the pros and cons of existing approaches and to select methods that are suitable for California bridges.

WHAT WAS OUR GOAL?

The primary objective of the proposed research is to assess the feasibility of two shear-strengthening techniques and to evaluate their effectiveness in enhancing the shear capacity of existing reinforced concrete bridges through large-scale testing.

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WHAT DID WE DO?

Two shear-strengthening techniques to enhance the shear capacity of existing reinforced concrete girder bridges was investigated: the first scheme consisted of using Near-Surface-Mounted (NSM) bars while the second scheme comprised Partially Embedded Bars (PEB) in the web of the girder. The NSM-based approach is an existing method that has been studied by other researchers though some unresolved issues remain and the present testing was expected to contribute to the existing literature on NSM strengthening. In contrast, PEB is a variation of an existing method referred to as Embedded Through Section (ETS) where the bar is embedded through the full depth of the section. In the proposed PEB method, shear strengthening is achieved by inserting steel or FRP bars into holes bored through the partial depth of the girder web and then bonded with an epoxy adhesive. The research objectives were accomplished through the following tasks:

- A prototype bridge was first identified following a review of the Caltrans bridge inventory. The selection was based on the ability of the UC Davis strong floor and reaction system to test a specimen whose cross-section represents either a full-scale or near full-scale bridge girder. Reinforcing details of the specimen were modified so as to induce shear failure prior to flexural yielding of the specimen.
- A preliminary series of pull-out tests were carried out to establish the most suitable anchorage scheme (for NSM) and bar material and bonding agent for PEB.
- The experimental testing was conducted in different phases: two control tests were conducted on unstrengthened specimens cast with different batches of concrete; the next phase consisted of three tests using NSM CFRP bars; and the final phase involved strengthening of the specimens using PEB.

WHAT WAS THE OUTCOME?

The primary findings from the NSM strengthening is summarized below:

- The NSM shear strength contribution varied widely between the phase 1 and phase 2 results ranging from 5 kips - 45 kips (2% - 25% increase compared to the respective control tests). The phase 1 results showed the only meaningful improvement in the shear strength while the phase 2 results were ineffective at changing the shear strength of the specimen.
- The primary failure mode of all 3 NSM tests was side cover detachment. This was marked by the crack angle following a steeper path passing vertically between the NSM bars and then wrapping behind them at the top face of the web. At the bottom edge of the web face, the typical side cover crack was prevented from fully forming due to presence of the fillets between the beam flange and web.
- Stirrups adjacent to the major shear cracks yielded in all tests, meaning the NSM rods do not negatively impact the performance of stirrups, which is consistent with previous test results.
- Though f_c' is a main parameter in determining the bond strength of NSM reinforcement, the difference in f_c' between test phases cannot fully account for the difference in the NSM shear contribution between phase 1 and phase 2. It is therefore likely that there is an inverse relationship between the amount of transverse reinforcement and the shear contribution of the NSM reinforcement.
- Doubling the amount of NSM reinforcement used in phase two was not effective at increasing the NSM shear contribution. This was due to the limit state controlled by side cover detachment.

Conclusions from the PEB strengthening are as follows:

- Results from the pull-out testing demonstrated that, regardless of the bonding material, sandcoated CFRP bars provided the highest pull-out force capacity compared to other tested bars. Smooth CFRP bars had the least resistance to the applied pull-out force due to premature bar-slip. Traditional Grade 60 bars and high-strength steel (Grade 80) bars failed by yielding and rupture of the bars, respectively. Finally, all of bonding materials – either the adhesives (epoxy) or cementitious material (grout) – exhibited good performance regardless of the embedded bar material.

- The proposed shear-strengthening technique using Partially Embedded Bars (PEB) is an effective shear-strengthening method. An increase in shear strength of 53% and 30% compared to the unstrengthened (control) specimens was obtained for PEB Scheme I and II, respectively.
- Results from the load test on PEB Scheme II specimen highlighted the fact that the existing shear reinforcement ratio has a significant influence on the effectiveness of PEB. Doubling the transverse reinforcement in the PEB Scheme II specimen resulted in a reduction in shear strength of approximately 23%.
- In both Phase I or II specimens, the presence of PEB CFRP strengthening bars resulted in more distributed cracking confirming that the embedded bars helped bridge (controlling the opening) the shear cracks and led to more sections of the shear span participate in resisting the applied shear force.

In summary, the PEB method is significantly more effective than the NSM method at increasing the shear capacity of reinforced concrete T-beams.

WHAT IS THE BENEFIT?

Findings from the project indicate that partially embedding FRP bars in the web can increase the shear capacity of existing reinforced concrete (RC) girders. This technique can be utilized by Caltrans to address shear deficiency in the existing inventory of RC bridges. However, additional testing is warranted to establish the exact amount of partially embedded bars (PEBs) needed as a function of existing shear reinforcement. While numerical simulations can aid in the development of design guidelines for shear strengthening using PEB, additional testing to validate the numerical modeling is essential.

LEARN MORE

Additional information on the project and findings can be obtained directly from the Principal Investigator at skkunnath@ucdavis.edu.

IMAGES

Image 1: Test setup enabling two tests per specimen.

Image 2: Failure of control specimen (Phase I).

Image 3: Failure of strengthened specimens (Phase I): (a) NSM.

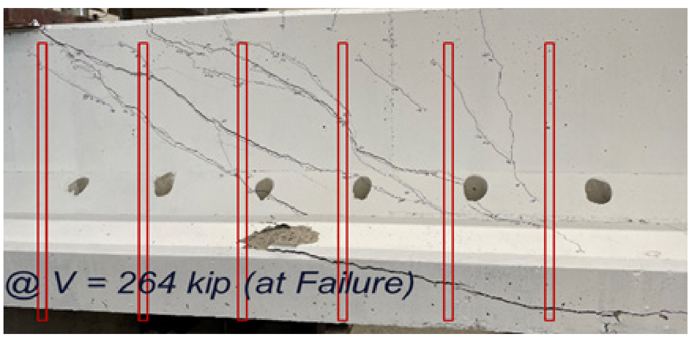

Image 4: Failure of strengthened specimens (Phase I): (b) PEB.

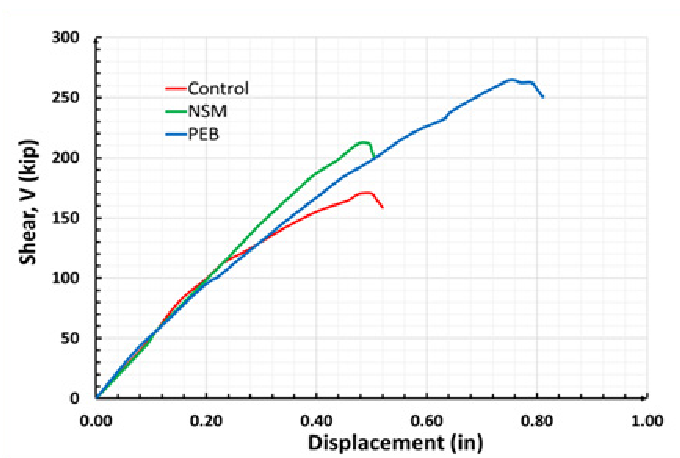

Image 5: Results of Phase I testing.

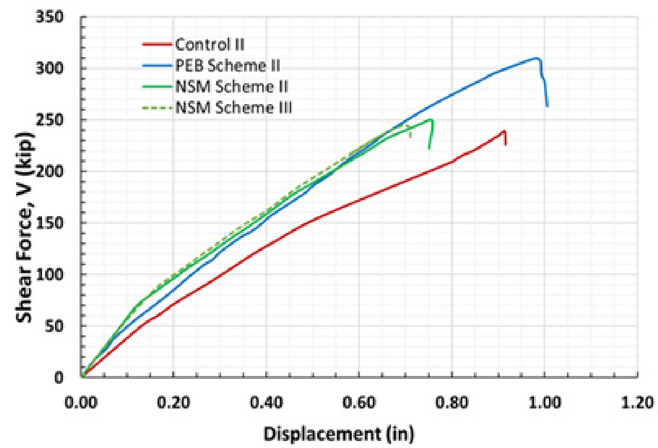

Image 6: Results of Phase II testing.