Center for Transportation Infrastructure and Safety

Adding Faculty in Transportation Areas - Year 2 & 3: Research Progress on Behavior and Design of Concrete Structures

by

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16. Abstract The NUTC provides funds to help departments build up their faculty in the transportation field over the next five years. Broad areas will be considered as listed in the UTC mission or other areas that relate to State Departments of Transportation and MoDOT in particular as stated in their goals, interests, and objectives.		
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Adding Faculty in Transportation Areas

Research Progress on Behavior and Design of Concrete Structures

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Dr. Sneed was supported by NUTC Faculty Support Funds between 2008 to 2011. During this period, she continued her research from her Ph.D. study and made notable progress in research related to the behavior of reinforced and prestressed concrete structures. During the period, one journal paper, one ACI Special Publication, two conference papers, and one technical report were published. This final report includes the abstracts of these publications.

Sneed, L.H. and Ramirez, J.A., 2010, "Influence of Effective Depth on the Shear Strength of Concrete Beams – Experimental Study," *ACI Structural Journal*, American Concrete Institute, Farmington Hills, MI, pp. 554-562.

Laboratory tests of reinforced concrete beams without shear reinforcement have shown that the shear strength (in terms of average shear stress) decreases as the size (depth) of the member increases. This paper discusses the results of experimental research performed to test the hypothesis that the effective depth influences the shear strength of reinforced concrete flexural members that do not contain web reinforcement in the range of overall depth between 12 to 36 in. (610 to 900 mm) where ACI 318-08 does not require skin reinforcement. The results of tests on eight simply supported reinforced concrete beams without shear and skin reinforcement are described, discussed, and correlated herein. The longitudinal reinforcement ratio was approximately 1.25%. The target concrete compressive strength was 10,000 psi (70 MPa). The beam width varied between 8 and 24 in. (203 and 610 mm). All of the beams were simply supported and monotonically loaded in increments at midspan up to destruction. The shear span-depth ratio was maintained at 3.0. Test results show a reduction in shear strength with increasing effective depth; however, significant differences in behavior were observed between the 12 in. (305 mm) specimens and the larger specimens in terms of the amount of flexural cracking, crack progression, load-displacement, and load-strain measurements despite holding other traditionally considered influential parameters constant. These differences suggest that the reduction in shear strength was influenced not only by a size effect but also by differences in behavior and mode of shear transfer at failure (beam action versus arch action). For the beams tested in this study, flexural crack spacing did not scale with beam size. The change in ACI 318-08 restricting isolated beams without minimum shear reinforcement to heights not greater than 10 in. (250 mm) is supported by the findings of this study.

Sneed, L.H. and Ramirez, J.A., 2009. "Evaluation of Minimum Shear Reinforcement Requirements in Nonprestressed Beams Without Distributed Horizontal Reinforcement," *Thomas T.C. Hsu Symposium on Shear and Torsion in Concrete Structures*, SP-265, American Concrete Institute, Farmington Hills, MI, pp. 405-426.

This paper presents an evaluation of the minimum shear reinforcement requirements in the ACI 318 code for nonprestressed concrete beams exempt from distributed horizontal reinforcement requirements. A total of 34 tests performed by different researchers on reinforced concrete beams with heights in the range of 24 to 36 in. (600 to 900 mm) are used to examine the reserve shear strength defined as the shear strength in excess of the nominal shear strength provided by the concrete, *Vc*, calculated in accordance with ACI 318. Additionally, the design shear force limitations for these beams containing minimum shear reinforcement are examined. Tests evaluated in this study include beams without shear reinforcement as well as beams with shear reinforcement levels that are less than ACI 318-08 minimum requirements. From the evaluation conducted in this study, it is concluded that the addition of low amounts of shear reinforcement, even less than the minimum amount required by ACI 318-08, *Vs,min*, provide a reserve strength beyond *Vc* calculated in accordance with the code. Results also show that low amounts of shear reinforcement tend to eliminate the trend of decreasing shear strength with increasing height. When low levels of shear reinforcement are taken into account in the strength calculation (that is, *Vn=Vc+ Vs,min*), however, specific concerns are raised regarding the reliance on minimum shear reinforcement to mitigate low values of the concrete contribution to the shear strength as well as provide shear resistance above *Vc* without the use of the strength reduction f factor. Modifications to the minimum shear reinforcement requirement exceptions for beams in ACI 318-08 are also examined.

Wieberg, K., **Sneed, L.,** Belarbi, A., and Anderson, N., 2010. "Spalling of Partial-Depth Precast-Prestressed Bridge Deck Panel Investigation Using GPR." *2010 fib Congress/PCI Convention and Bridge Conference Proceedings*, Washington, D.C., 16 pp.

This paper presents research in progress on spalling of partial-depth precast-prestressed concrete bridge deck panels. Recently it has been observed that several bridges in Missouri with this type of construction have experienced spalling of concrete at the edges of the panels revealing an extreme condition of corrosion in the prestressing tendons, some to the point of rupture. Ground penetrating radar (GPR) was used to assess the condition of an existing bridge deck experiencing severe spalling of concrete and corrosion of reinforcement, as well as to determine the reasons for spalling. The GPR technique of non-destructive evaluation was well-suited for determining the relative condition of the prestressing tendons as well as the relative condition of the concrete throughout the deck in order to identify areas of cracking and corrosion. The GPR method was also used in an attempt to identify areas of delamination at the interface between the precast panel and cast-in-place topping slab. Measurements were taken from the top and bottom surfaces of the bridge deck to obtain a better image of the cross section because the deck consists of two layers of concrete as well as multiple layers of reinforcement. The data obtained from the top of the bridge deck indicated less concrete degradation in areas with increased amounts of longitudinal reinforcement provided for negative moment. GPR was able to provide locations of deterioration, but it was unable to distinguish the type of deterioration.

Grelle, S. and **Sneed, L.**, 2011, "An Evaluation of Anchorage Systems For Fiber-Reinforced Polymer (FRP) Laminates Bonded to Reinforced Concrete Elements." *Proceedings, ASCE Structural Congress: 2011*, ASCE, Las Vegas, NV, 12 pp.

Many studies have shown that fiber-reinforced polymer (FRP) laminates are an effective alternative for structural retrofit and repair of insufficiently reinforced concrete members; however, achieving the full tensile capacity of the externally bonded FRP is often very difficult. This is especially true when FRP is used on elements where there is inadequate length to develop the full tensile strength of the FRP laminate, leading to premature debonding failure. Anchorage systems attempt to mechanically restrain the FRP or improve the FRP-to-concrete bond, thus reducing the length required to develop its full design strength. Many types of anchorage systems have been tested by different investigators, but mixed and inconclusive results have been presented. Additionally, no evidence exists to show that one particular type of anchorage system is completely effective in developing the full tensile strength of FRP. The lack of conclusive results is exacerbated by the absence of a consistent testing procedure for evaluating anchorage strength and a system for categorizing the purpose of the anchorage system, despite the current design guide's recommendation that anchorage testing should precede the strengthening of a structure with FRP. An overview of previously tested anchorage systems is presented along with applicable testing procedures from existing literature. The limitations of each anchorage system are mentioned with respect to specific structural strengthening applications. The existing anchorages are then categorized according to their specific application to FRP anchorage, and the applicability of testing procedures to each anchorage category is discussed. Finally, the need for systematic testing is discussed and potential research topics are explored.

Sneed, L.H., Belarbi, A., and You, Y-M. 2010. "Spalling Solution of Precast Prestressed Bridge Deck Panels," Report OR11-005, Missouri Department of Transportation, Jefferson City, MO.

This research has examined spalling of several partial-depth precast prestressed concrete (PPC) bridge decks. It was recently observed that some bridges with this panel system in the MoDOT inventory have experienced rusting of embedded steel reinforcement and concrete spalling issues in the deck panels. The objectives of this research were to investigate the causes of spalling in precast-prestressed panels and propose cost-effective alternative solutions including improved design options for new construction, as well as suggest mitigation methods for existing deteriorated bridge decks.

A survey of transportation agencies and a series of bridge deck investigations were conducted to determine the nature and causes of spalling. Panel deck system modifications were proposed and evaluated for potential use in new construction. These modifications were investigated in terms of structural performance and serviceability with respect to the current design. Panel deck system modifications evaluated included an increase in tendon side cover, the addition of fibers or corrosion inhibitor to the panel concrete mixture, an increase in reinforcement in the cast-in-place concrete topping, and the substitution of edge tendons with epoxy-coated steel or carbon fiber reinforced polymer tendons. Efficiency of the proposed solutions was examined and validated through fundamental laboratory studies and numerical simulations using finite element modeling. Finally, recommendations are provided for new and existing construction to mitigate the spalling problem.