Project Summary Report 0-1855-S
Explore New Uses for T-Headed Bars in Structural Concrete Reinforcement Applications

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Behavior and Design of Headed Reinforcement in Concrete Structures

PROJECT SUMMARY REPORT

In structural concrete, the provisions for anchorage of straight bars and hooks occasionally present detailing problems due to the long development lengths and large bend diameters that are required, particularly when large-diameter reinforcing bars are used. In many cases, the requirements for straight bar anchorage and lap splices cannot be provided within the available dimensions of elements. Hooked bars can be used to shorten anchorage length, but in many cases, the bend of the hook will not fit within the dimensions of a member or the hooks create congestion and make an element difficult to construct. Similarly, mechanical anchorage devices can be used to shorten lap splice lengths, but they frequently require special construction operations and careful attention to tolerances.

To address the problems that arise in conventional reinforcing bar anchorage, headed bars were developed for use in the construction of concrete platforms for the offshore oil industry. Headed bars (sometimes referred to as "T-heads" - Figure 1) are formed by the attachment of a plate or the forging of an upset bearing surface at the end of a straight reinforcing bar. Such bars are anchored by a combination of bond along the straight bar length and direct bearing at the head. Like a hooked bar, they can develop within a short distance, but they do not create as much congestion. Although used extensively in offshore concrete oil production platforms, headed bars have not been widely used in other types of concrete construction. There is little guidance currently available for the design of headed bar anchorage either in the form of code provisions or published research.

Headed bars can potentially simplify the design and construction of complex bridge details. Realizing this potential, the Texas Department of Transportation (TxDOT) through The University of Texas at Austin's Center for Transportation Research, funded project 0-1855, "Explore New Uses for T-Headed Bars in Structural Concrete Reinforcement Applications." The primary objectives of the study were to: 1) determine suitable bridge applications in which the use of headed reinforcement could improve the design and constructability of the structure, 2) develop and implement a test program based on such applications, 3) analyze the results of the test program and develop a basis for design using headed reinforcement, and 4) document and deliver the findings to TxDOT.

Figure 1: Headed Bars

What We Did...

Test Program

Following several meetings between the research team and TxDOT bridge design engineers to identify bridge details for which headed bars showed the most promise, two details were selected. The use of headed bars to reduce lap

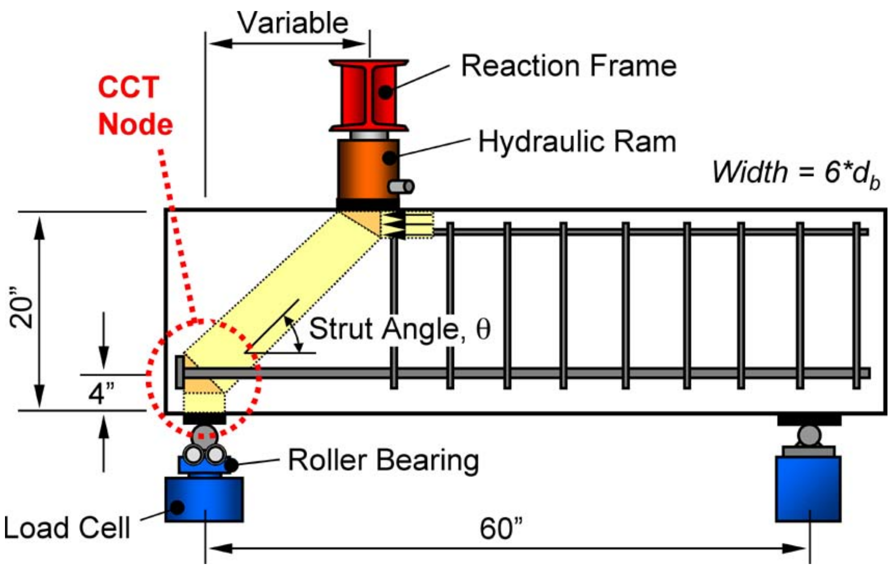

Figure 2 - Typical CCT Node Test Setup

lengths and replace hooked bars in congested discontinuity regions were of most interest to TxDOT engineers. Two test programs were pursued simultaneously: lap splice tests and compression-compression-tension (CCT) node tests. Specimens were designed to be as general as possible so that the behavior of the headed bars in these details could be extrapolated to a variety of specific applications in which lap splices and CCT nodes occur.

The basic CCT node specimen is shown in Figure 2. Variables of the test program included the angle of the compression strut, head size and shape, bar size, and the presence of confinement in the nodal zone. Companion specimens with non-headed and hooked bars were tested for comparison. A total of 64 CCT node specimens were tested. In addition to studying the anchorage performance of headed bars, these specimens were used to examine the behavior of CCT nodes. Current code provisions related to strut-and-tie modeling (STM) were evaluated against the test results. This phase of the research is discussed in Report 0-1855-2, "*Anchorage of Headed Reinforcement in CCT Nodes*."

The basic lap splice specimen is shown in Figure 3. Variables of the lap splice test program included the lap length, the head size and shape, the bar spacing, contact versus non-contact laps, and the presence of confinement in the lap zone. Companion specimens with non-headed bars were also tested. A total of 27 lap splice tests were performed. This phase of the research is discussed in Report 0-1855-3, "*Anchorage Behavior of Headed Reinforcement,*" Part A.

In addition to the experimental work, an extensive literature review of closely related topics was performed. The important findings of the literature review are summarized in Report 0-1855-1, "*Anchorage Behavior of Headed Reinforcement: Literature Review*."

What We Found...

Overview of Results

The results of both test programs indicated that headed bars could provide superior anchorage to non-headed and hooked bars. Additionally, the CCT node tests provided much needed information on the process of truss formation in discontinuity regions and the stress-state of the concrete in and around a nodal region. The lap splice tests provided information about the nature of stress transfer between lapped bars. The combined data from both test programs were used to develop a model for headed bar anchorage capacity that could be used in design.

An example of typical data collected from a CCT node test is

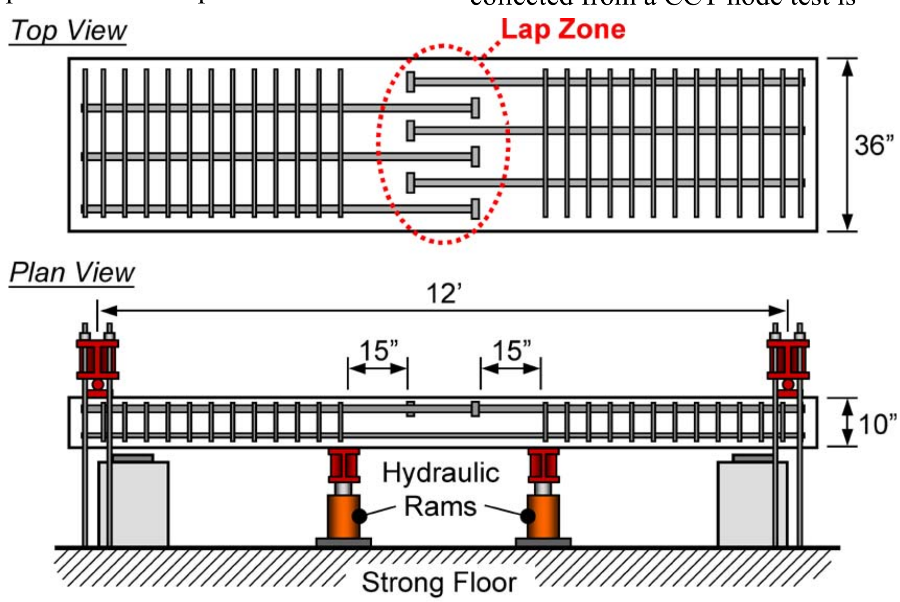

Figure 3 - Typical Lap Splice Test Setup

provided in Figure 4. Stresses along a #8 headed tie bar anchored at a CCT node are shown. Stress profiles from several load stages are shown. The profiles can be related to the extent of cracking during each load stage. At a load of 19.4 kips, the point of maximum bar stress coincides with the location of crack 1, the only crack present at that load point. With increased load (P = 29.8 kips), crack 2 formed and the point of maximum bar stress shifted to the location of that crack. This process continued with the formation of crack 3 at a load of 39.4 kips. Finally, no new cracks formed and the point of maximum bar stress remained constant at about a distance of 7 bar diameters ($7d_b$) from the head. The anchorage contribution from the head can clearly be seen as the stress of the bar at $1d_b$ from the head was about 54 ksi. Bond over the short anchorage length contributed about another 15 ksi.

Average stresses along headed and non-headed lapped bars are shown in Figure 5. The superior capacity of the headed bars over non-headed bars can be readily observed. Non-headed bars reached a maximum stress of about 40 ksi at the ends of the lap zone, whereas the headed bars exceeded 60 ksi. The heads increased capacity of the lapped bars by about 20%.

Stress data as shown in Figures 4 and 5 allowed the contributions from head bearing and bond to be separated. Head bearing data was combined with a database of previously published results from studies of headed bars, deeply embedded anchor bolts, and bearing tests of rigid plates on concrete. This collection of data was used to determine an equation for the contribution of head bearing to anchorage capacity. The variables which most affect head bearing capacity are the size of the head relative to bar size, the cover dimensions to the head relative to the bar size, and the concrete strength. A simple formula for the bar stress provided by the head was developed using these variables.

The Researchers Recommend...

Draft code provisions for the use of headed bars were provided in Report 0-1855-3, "*Anchorage Behavior of Headed Reinforcement,*" Part B. In addition to the formula for head capacity, a minimum anchorage length of $6d_b$ was recommended for headed bars. It was also recommended that strut-and-tie models (STM) be constructed to properly identify anchorage points for headed bars. Example problems were provided which detail the use of the recommended provisions for discontinuity regions and lap splices.

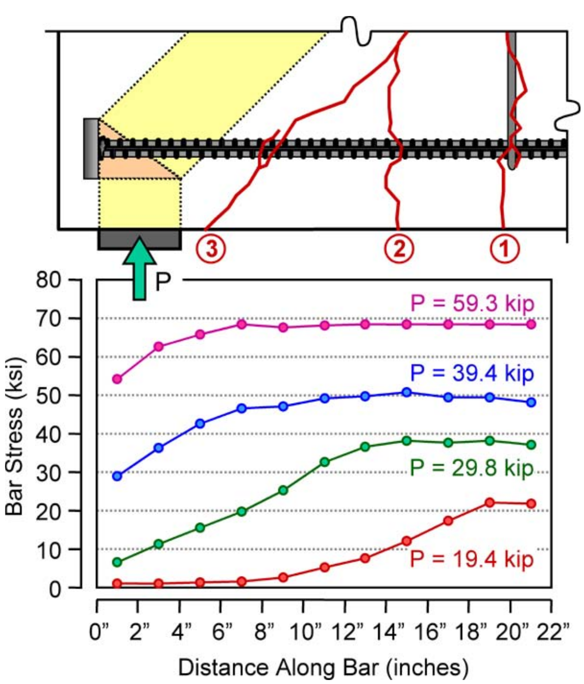

Figure 4 - Tie Bar Stress Profiles from a CCT Node Test

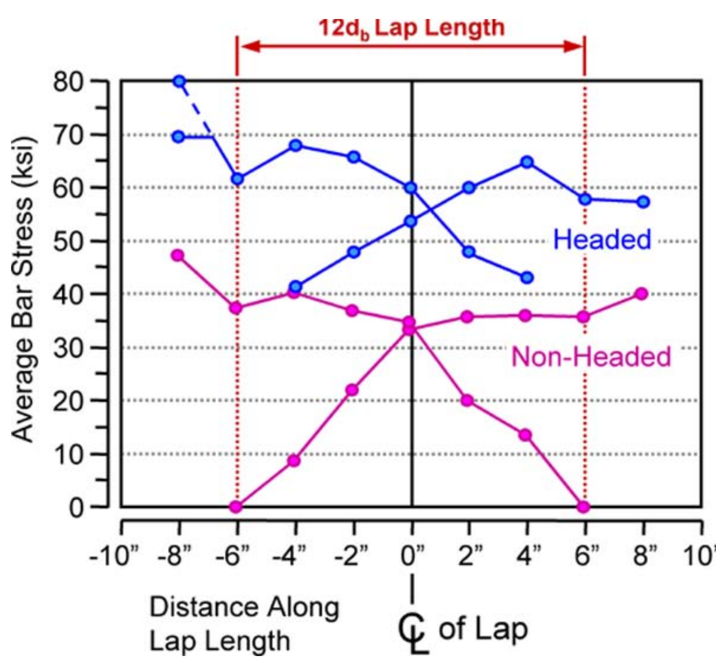

Figure 5 - Stress Profiles for Headed and Non-Headed Lapped Bars

For More Details...

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The research is documented in the following reports:

0-1855-1, *"Anchorage Behavior of Headed Reinforcement: Literature Review,"* May 2002.
0-1855-2, *"Anchorage of Headed Reinforcement in CCT Nodes,"* June 2003.
0-1855-3, *"Anchorage Behavior of Headed Reinforcement,Part A: Lap Splices, Part B: Design Provisions and Summary*," July 2003.

TxDOT Implementation Status Date

In the past, headed bars have been used sparingly by TxDOT, utilizing a very conservative design approach. The results of this research give TxDOT bridge engineers the capability to confidently utilize the benefits of headed bars on a wider basis, simplifying the design and construction of complex bridge details. The research results will be implemented in-house on selected projects within congested areas of heavily reinforced structural members.

National design code provisions incorporating the results of this research will be pursued through the usual AASHTO committee procedures.

For more information please contact Tom Yarbrough, P.E., RTI Research Engineer, at (512) 465-7403 or email at tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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