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Project Title: Development of Headed Bar Reinforcement

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Development of Headed Bar Reinforcement

Anchorage tests on No. 14 and 18 headed bars to establish design specifications for tension development length of headed bars.

WHAT WAS THE NEED?

Large-diameter reinforced concrete bridge columns and piles often have No. 11 or larger bars as longitudinal reinforcement. These bars extend into the bent cap and footing connected to the column with an embedment length that is sufficient to develop the tension capacity of the bars in the plastic hinge regions of the column in the event of a major earthquake. Compared to bars that have straight ends or are ended with standard hooks, headed bars (bars with a T head) allow a significant reduction of the required development length. A shorter development length allows a smaller depth for the cap beams and footings. Compared to bars with 90-degree hooks, the use of headed bars can significantly reduce congestion in the joint regions, improving the constructability, the quality of concrete placement, and the cost efficiency in construction. However, development length requirements in current ACI (American Concrete Institute) and AASHTO (American Association of State Highway and Transportation Officials) design specifications for headed reinforcing bars are limited to No. 11 and smaller bars due to lack of experimental data on larger size bars. In order to be able to use headed bars larger than No. 11, it was necessary to carry out experimental studies to generate data that were needed to establish development length specifications for the larger diameter bars.

WHAT WAS OUR GOAL?

The main aims of this study were to investigate experimentally the anchorage capacities of No. 14 and No. 18 headed bars, including the influence of the embedment length, concrete strength, head size, parallel tie reinforcement, and bar group on the anchorage strength, evaluate the applicability of the development length requirements for No. 11 and smaller headed bars in ACI 318-19 and the 10th Edition of AASHTO LRFD Bridge Design Specifications to larger diameter bars, and develop a rational method for determining development lengths required for headed bars of any diameters and the reinforcement required for the joint regions. The ultimate goal of the project was to develop guidelines that could be eventually implemented in design specifications for headed bars of any size.

WHAT DID WE DO?

Bar anchorage tests were conducted on No. 14 and No. 18 headed bars, which were anchored in concrete beams reinforced with longitudinal bars and rectangular stirrups that had the size and spacing representative of those used in the cap beams of bridge structures. A total of thirteen specimens were tested, of which eleven had single bars and two had double side-by-side bars. The influence of the head size, namely, heads with net bearing areas of 4 and 9 times the bar area, on the anchorage capacity was investigated. The target compressive strengths of the concrete used were 4,000, 6,000, and 8,000 pounds per square inch. The specimens had bar embedment lengths equal to 70% or 100% of the minimum according to the ACI 318-19 formula, which is intended for smaller bars. The test data and observations were used to determine the load resisting mechanisms developed in the bar anchorage regions and support the development of design recommendations that could be used for No. 14 and 18 bars. Based on the test data, a method based on the anchorage bolt provisions in ACI 318-19 was developed to determine the anchorage capacity and the minimum development length required for headed bars of any size.

WHAT WAS THE OUTCOME?

This study provided a fundamental understanding of the anchorage mechanisms of headed bars to support the development of a rational method to determine the minimum development length required for headed bars of any size. The test results obtained show that the anchorage failure of a headed bar is normally initiated by concrete breakout but eventually governed by bar pullout when the bearing strength of the concrete at the T head has been weakened by the opening of breakout cracks. Without breakout cracks, pullout failure is unlikely because the concrete above the T head is normally highly confined by the surrounding concrete, which can result in a very high compressive strength. The test results also show that the bar force at which concrete breakout occurs is approximately proportional to the square of the embedment length, rather than the embedment length to the power of 1.5 as specified in ACI 318-19 for embedded anchor bolts.

When breakout failure cannot be avoided due to the lack of adequate embedment length, sufficient concrete bearing strength can be developed at the T head to prevent bar pullout failure provided sufficient parallel tie reinforcement is present to restrain the cracks from opening. The importance of parallel tie reinforcement is recognized in ACI 318-19 and AASHTO LRFD Bridge Design Specifications (10th Edition), which allow a reduction of the required development length if sufficient parallel tie reinforcement is provided within a distance of 8 times the bar diameter from the center of the anchored bar.

The test data obtained here show that the specimens that satisfied the development length formula in ACI 318-19 performed satisfactorily. Nevertheless, two specimens that satisfied the AASHTO development length formula and had a head size of 9 times the bar area had anchorage failures, while three specimens that did not meet the AASHTO requirement and had a head size of 4 times the bar area did not have anchorage failure. This indicates that the AASHTO formula over-estimates the influence of the head size. This could stem from the fact that the formula in AASHTO considers only the bond strength and the bearing resistance at the T head and does not explicitly account for the concrete breakout strength. If anchorage failure is initiated by concrete breakout, the size of the T head will not have a significant influence on the anchorage resistance. This is supported by the data obtained in this study as well as other studies on smaller diameter bars, which have shown that the use of a head size greater than 4 times the bar area will not necessarily improve the anchorage capacity and the benefit is small at best.

While the ACI formula appears to be adequate for No. 14 and 18 headed bars, it is empirical and prescriptive, especially with respect to the parallel tie requirement, and the formula appears to be more conservative for No. 18 than No. 14 bars. This can be attributed to the fact that ACI 318-19 has the development length proportional to the bar diameter to the power of 1.5. To address these issues, a method was proposed in this study to determine the development lengths for headed bars and the required parallel tie reinforcement. It is based on the anchor bolt provisions in ACI 318-19, which was improved in this study to account for the influence of the bar embedment length and the contribution of the parallel tie reinforcement in an accurate and rational manner. Even though the method was only verified by the test data on No. 14 and 18 bars obtained in this study, it is believed to be applicable to smaller diameter bars as well based on the fact that it is more physics based.

However, the proposed method is based on data from single and double bar tests. In an actual bridge structure, there are many longitudinal bars extending from a column into a cap beam or footing for anchorage. The stress state in the column section next to the cap beam or footing is more complicated compared to the condition in the bar anchorage tests where one or two bars were subjected to tension. Hence, the proposed method needs to be further evaluated with trial applications to realistic joints that reflect the loading and reinforcement in actual bridge structures. This will entail the testing of large-scale column-to-cap beam assemblies in future studies to evaluate and improve the proposed method as necessary.

WHAT IS THE BENEFIT?

This research produced test data and design recommendations that will allow efficient use of large diameter headed bars in bridge columns. The use of headed bars can improve the constructability, the quality of concrete placement, and the cost efficiency in bridge construction. The findings of this research have a broad impact on improving current code provisions on the tension development of headed bars, allowing the use of No. 14 and 18 headed bars in a safe and efficient manner.

LEARN MORE

Details of this study can be found in the following report:

Asgharpour, N., Raman, R., and Shing, P.B. (2025). "Experimental investigation of development length required for large diameter headed reinforcing bars in tension." SSRP – 25/01, Department of Structural Engineering, University of California, San Diego, CA.

IMAGES

Image 1: Setup for a bar anchorage test

Image 2: Breakout cracks developed in a concrete beam specimen due to the tensile force exerted on the headed bar (the portion of the bar above the top face of the beam was cut off after the test)