



20-21 SEISMIC REQUIREMENTS FOR HEADED BAR REINFORCEMENT

Introduction

A headed bar is a deformed steel bar with a head attached to one, or both ends of the bar. Headed bars can be used as a replacement for straight or hooked bars in concrete members and connections. Testing by the University of California at San Diego (UCSD) of slab column assemblies has shown that headed bar reinforcement is effective in reducing rebar anchorage length, congestion, and construction time. Further testing is needed for anchorage in other types of superstructures. At this time, Caltrans approves the use of full size (9A_b) headed bars, only. The use of headed bars with head size smaller than full-size is not currently approved until more testing can be done. This memo describes the properties, uses, and detailing requirements for headed bar reinforcement, especially for seismic applications in bridges.

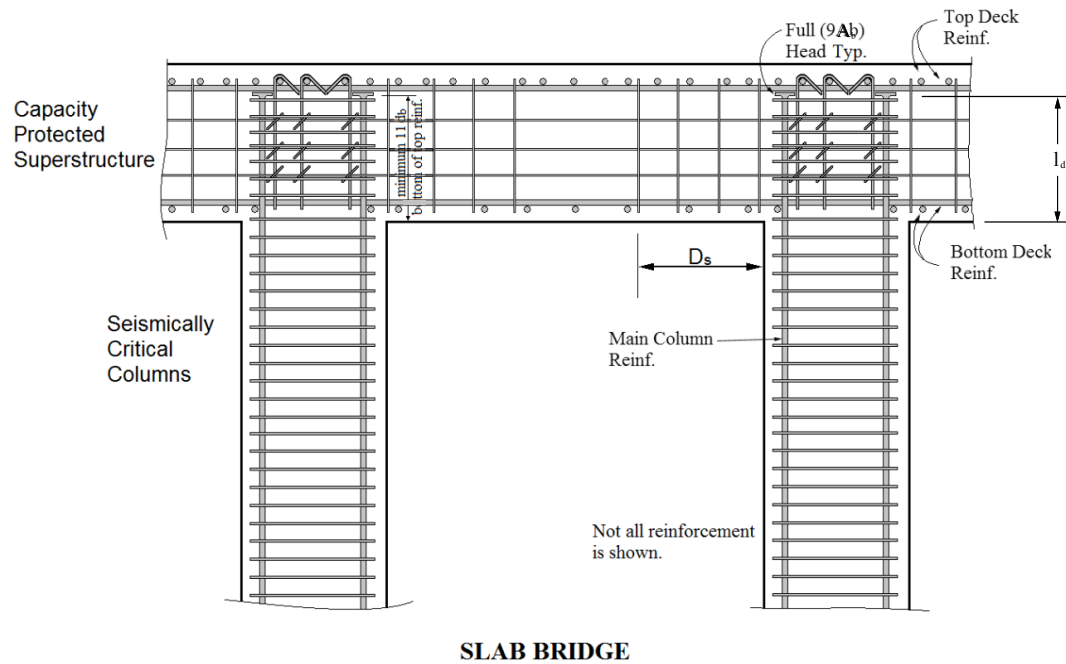
Properties Of Headed Bar Reinforcement

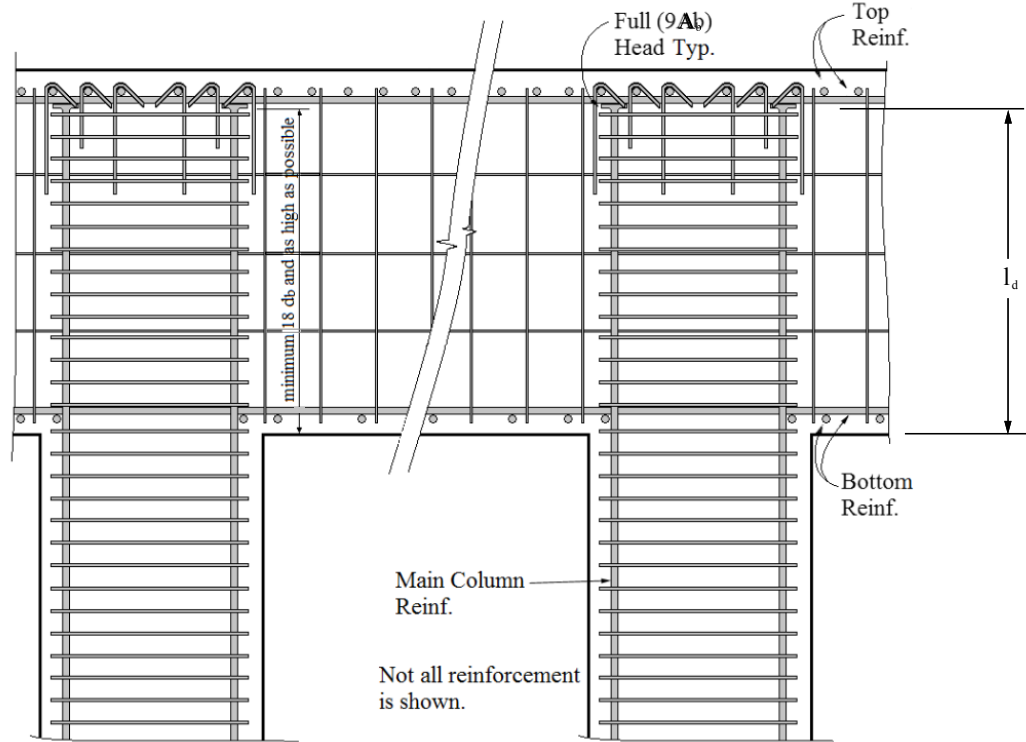
Headed bar reinforcement is usually formed by friction welding of plates, by forging an upset bearing surface at the end of a reinforcing bar, or by forging threads into the end of the bar, which are then used to attach the plate. Caltrans Standard Specifications Section 52-5.02 states that “Headed bar reinforcement must have full size heads and must be on the Authorized Materials List.” Headed bar reinforcement must comply with ASTM requirements, which include tensile tests that confirm that necking occurs at least one diameter away from the affected zone. Headed bar reinforcement must be A706-Grade 60 steel that meets the stress and strain requirements in Caltrans Seismic Design Criteria (SDC). Full size heads have a net bearing area that is at least nine times the area of the bar (A_b). The head shape may be square, rectangle, round, or oval.

Uses Of Headed Bar Reinforcement

Longitudinal column reinforcement must be fully developed in the joints with adjacent members to allow plastic hinges to form in the column during earthquakes. Achieving adequate development is of particular concern for slab bridges, where the depth available for the development of the column or pile extension reinforcement is limited. Research (Papadopoulos, 2015) has shown that for column longitudinal reinforcement with full size heads, an embedment length of $11d_b$ into a slab superstructure is adequate to force plastic hinging in the column. Headed bar reinforcement is also a good choice for reducing

congestion in column to bent cap connection of box girder bridges. Figure 1 shows the proper use of headed bars in slab and box girder bridges. Headed bar reinforcement may also be beneficial in column to footing connections, superstructure in-span hinges, abutment stem walls, shear keys, etc. Bundling of headed bars is not usually possible because of the large size of the heads.





BOX GIRDER BRIDGE

Figure 1. Slab and Box Girder Bridges with Headed Column Reinforcement.

Research

Anchorage tests of headed bar reinforcement in locations other than slab bridges is limited. While recent research has shown that $11d_b$ is an adequate development length for column reinforcement with full size heads in slab bridges, the development length requirements for headed bars into bent caps of other types of bridge superstructures have not yet been established by experimental testing.

The enhanced anchorage capacity of headed bar reinforcement is due to the head bearing against the concrete as well as from the bond between the bar and the surrounding concrete. Past research (Figure 2) has shown that the anchorage failure of headed rebar can occur due to a side-faced blowout of the concrete close to the surface (Derives, 1996), breakout when the reinforcement isn't sufficiently embedded (Derives, 1996), and a punching failure through the bridge deck when the head is too close to the surface and not properly blocked by the top deck reinforcement (Papadopoulos, 2015).

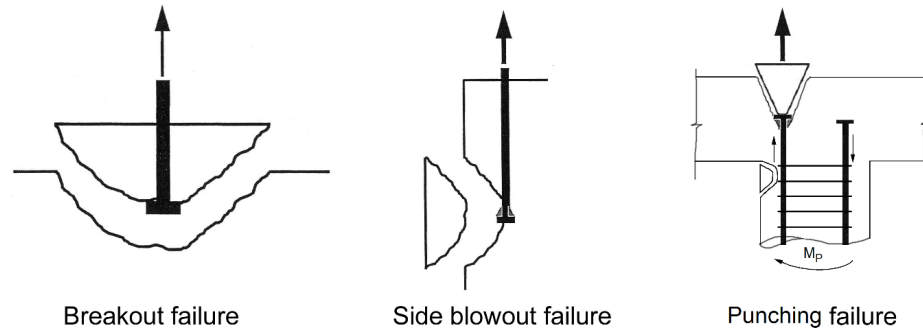


Figure 2. Failure of headed reinforcement based on past research.

Previous testing by Caltrans (Stoker, 1974), the University of Texas (Devries, 1996) (Bashady, 1996), the University of Kansas (Wright, 1997), and the University of California at Berkeley (Naito, 2001) has shown the improved performance of headed bars over straight and hooked bars. All of the testing through May 2002 is reported in a literature review by the University of Texas (Thompson, 2002), which was also summarized as part of the headed bar research at UCSD (Papadopoulos, 2015). Testing results from the University of Texas were published in the *ACI Structural Journal* (Thompson, 2005) (Thompson, 2006) and were used to establish the current ACI development length equations. However, it is uncertain whether the reinforcement in the Texas tests were pulled until failure of the steel in tension.

In the most recent research performed in 2015 at UCSD, three full-scale slab-column assemblies with full size T-headed main column reinforcement developed into the slab were tested. The three test specimens had embedment lengths of $9.8d_b$, and $8.7d_b$, and $11.0d_b$ into the slab. The study showed that for slab concrete with compressive strength of 4.5 ksi, and Grade 60 steel, main bar development length of $11d_b$ is adequate for headed bars in slab-column joints designed according to Caltrans Memo to Designer 20-7.

Requirements For Headed Reinforcement

Headed bars must be placed as described in Table 1 (without staggering of heads). ACI 318-14 Section 25.4.4.1 (ACI, 2014) requires a minimum clear spacing of $4d_b$ between bars, and a clear cover of $2d_b$.

Caltrans Seismic Design Criteria (SDC) discusses the use of headed bar reinforcement in footings, and abutments in Sections 7.7.1.7, and 7.8.4.1A, respectively. The development length of column longitudinal reinforcement is discussed in SDC Section 8.2.1. It states that straight column bars must be developed into bent caps at least 24 bar diameters (d_b). It also states that it is expected that the use of 'T' heads or hooked bar termination will reduce the anchorage requirements for column reinforcement in tension.



Based on the latest research, bridge designers must provide a minimum of $11d_b$ for the development of headed bars into slabs, $14d_b$ for bars in capacity protected locations, and $18d_b$ for longitudinal bars in seismic critical members developed into adjacent capacity protected members (see Table 1). Note that Caltrans only approves the use of full size heads at this time.

Table 1 shows current Caltrans minimum required development lengths for reinforcement that is straight, hooked, or headed. If future testing shows that the required development length for headed bar reinforcement can be smaller than those shown in Table 1, headed bars would be useful in a greater variety of situations. The required development length for hooked bars in Table 1 was computed using ASHTO LRFD BDS Equation 5.11.2.4.1-1, based on $f'c = 4 \text{ ksi}$.

Tables 2 and 3 show how headed bar reinforcement can be used instead of hooks for stirrups and ties. This could be useful in situations where congestion is a problem. Please note in Table 3 that the headed stirrup takes up more space and may reduce the effective depth of the member.

Table 1. Bar Development Lengths

Development length $l_d = (\text{table value}) \times \text{bar diameter } (d_b)$

C or S	Longitudinal/Main bars in:	Embedded into/ Extended within	STRAIGHT	HOOK	HEADED ¹ (Full size)	INSTRUCTIONS
S	Columns	Bent caps and footings	24	19	18^2	Extend to bottom of top deck reinf. (avoid prestress ducts, etc.)
	Walls	Bent caps, footings	24	19	18^3	-
	Pile Extensions and walls	Slab bridge	24	19	11^4	Touch bottom of top steel in slab
C	Bent Caps	Bent caps	24	19	14	-
C	Footings	Footings	24	19	14	-
C	In-span hinges	In-span hinges	24	19	14	-

C = Capacity Protected

S = Seismic Critical

¹Interim development length based on committee decision using conservative values.

²Extend to top reinforcement in cap.

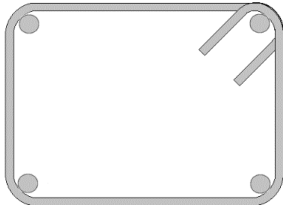
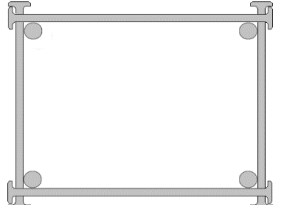



³Extend to bottom reinforcement in footing.

⁴Lower bound value based on tests (Papadopoulos, 2015)

Table 2. Headed Bar Uses for Stirrups and Ties

COMPONENT	APPLICATION	HEADED BAR (Full size)
In span hinges	Stirrups/ties	For 135° and 180° hooks
Walls	Cross ties	For 135° and 180° hooks
Bent caps	Stirrups	For 135° and 180° hooks
Joints	Stirrups	For 135° and 180° hooks
Footings	Stirrups/ties	For 135° and 180° hooks

Table 3. Definitions of Stirrups and Ties

	Conventional	Headed	Conventional + headed
Stirrups			Not applicable
Ties/cross ties			



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