

ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18



TECH NOTE

Introduction:

This document has been prepared to address questions related to spacing requirements of headed bars found in ACI 318-14.

Background:

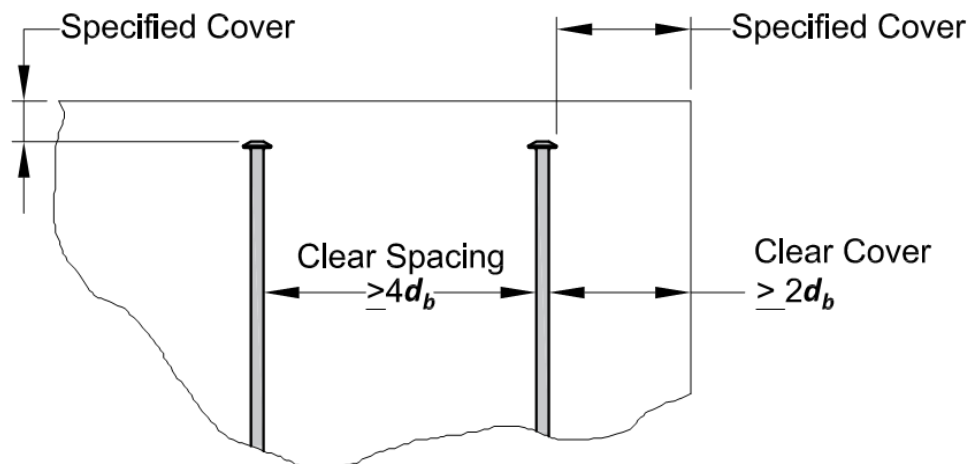
Spacing Requirements in Section 25.4.4.1:

Prescriptive requirements for clear cover and clear spacing of headed bars are defined in section 25.4.4.1 of ACI 318-14. They are quite restrictive, but are based on the limited test data available at the time they were adopted by ACI Committee 318.

- 25.4.4.1(f) states that *Clear cover for bar shall be at least $2d_b$*
- 25.4.4.1(g) states that *Clear spacing between bars shall be at least $4d_b$*

The commentary section R25.4.4.1 goes on to explain that:

- *The clear cover and clear spacing requirements are based on dimensions measured to the bar, not to the head.*
- *The head is considered to be part of the bar for the purposes of satisfying the specified cover requirements in 20.6.1.3 and aggregate size requirements of 26.4.2.1(a)(4).*
- *To avoid congestion, it may be desirable to stagger the heads.*



Plan view of ACI 25.4.4.1 spacing requirement

The intent of this section is to prevent group effects for shallow embedment applications (pullout cone capacity). Essentially there is no difference between the pullout cone capacity of a group of hooked bars and a group of headed bars with the same development length and installation parameters. Based on all known research, if substituting heads for standard hooks of the same installation parameters, headed bars are considered equal or conservative.

ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18

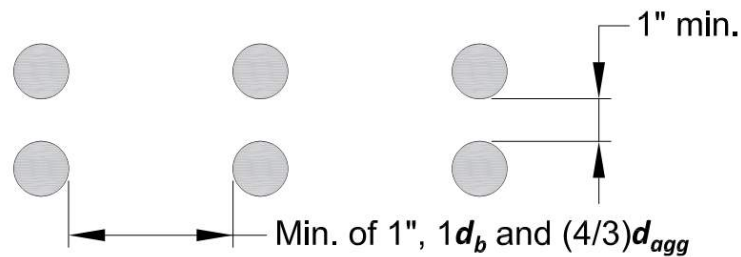


TECH NOTE



Picture (plan view) of headed bars in a foundation, meeting the general requirements outlined above

For reference, clear spacing requirements between straight and/or hooked bars in a horizontal layer and also between parallel bars in 2 or more layers are clearly defined in sections 25.2.1 and 25.2.2 of ACI 318-14 respectively.



Section view of clear spacing requirements in ACI 318-14 Section 25.2.1 and 25.2.2

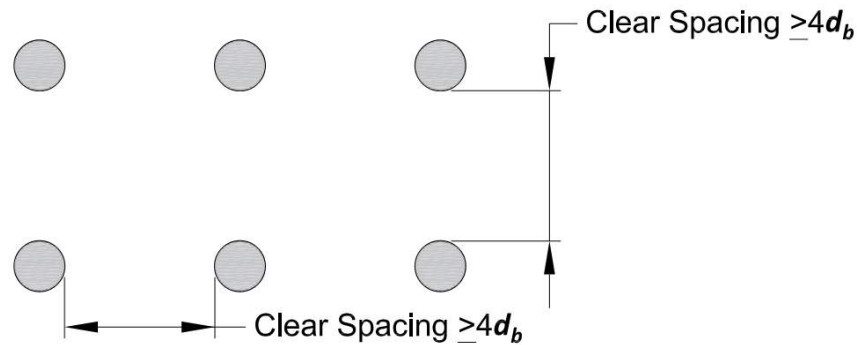
ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18

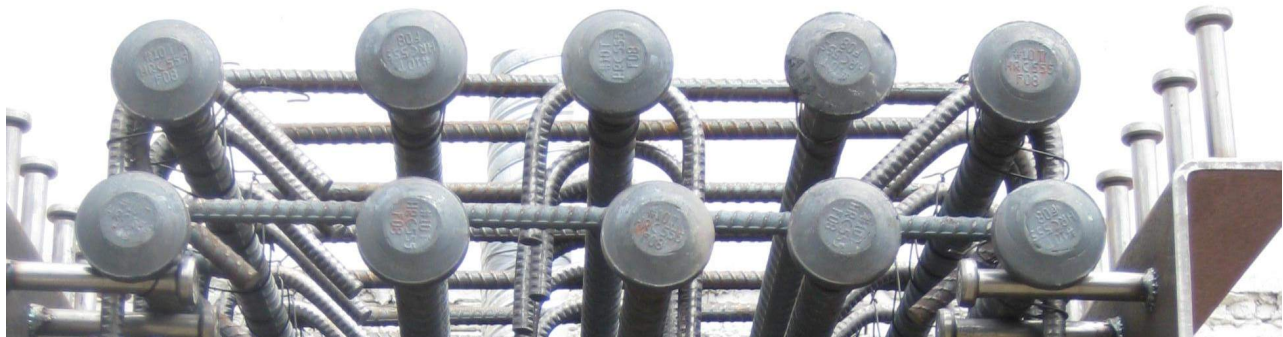


TECH NOTE

The $4d_b$ minimum clear spacing limit as written in the code is ambiguous with respect to headed bars that are placed parallel in 2 or more layers such as is common in foundations, slabs, beams, etc. However, at this point in time, it is generally interpreted/accepted that the $4d_b$ minimum clear spacing applies to headed deformed bars when considered both horizontally and vertically.



Section view of ACI 25.4.4.1 spacing requirements (heads not shown for clarity)



Picture of headed bars within link beam as top longitudinal reinforcement, placed in 2 parallel layers
(Note the importance of measuring the clear spacing to the bar, not the head)
(These parallel layers meet the $4d_b$ min. clear spacing requirement both horizontally and vertically.)

ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18



TECH NOTE

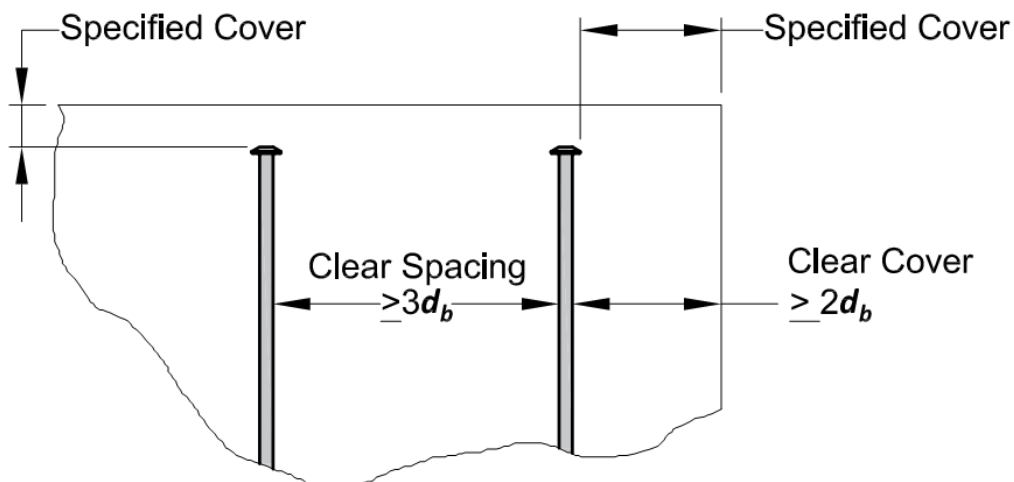
Spacing Requirements in Section 18.8.5.2:

Prescriptive requirements for clear spacing of headed bars in Earthquake-Resistant Structures are defined in section 18.8.5.2 of ACI 318-14.

- 18.8.5.2 states that *Clear spacing between bars shall be permitted to be at least $3d_b$*
 - Note that this spacing requirement allows headed bars to be spaced closer than section 25.4.4.1

The commentary section R18.8.5.2 goes on to explain that:

- *The $3d_b$ spacing limit is based on studies of joints confined by transverse reinforcement consistent with special moment frame requirements in this chapter (Kang et al. 2009).*
- *To avoid congestion, it may be desirable to stagger the heads.*



Plan view of ACI 18.8.5.2 spacing requirements

ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18



TECH NOTE

Alternative Mechanical Anchorage in ACI 318-14 Section 25.4.5.1:

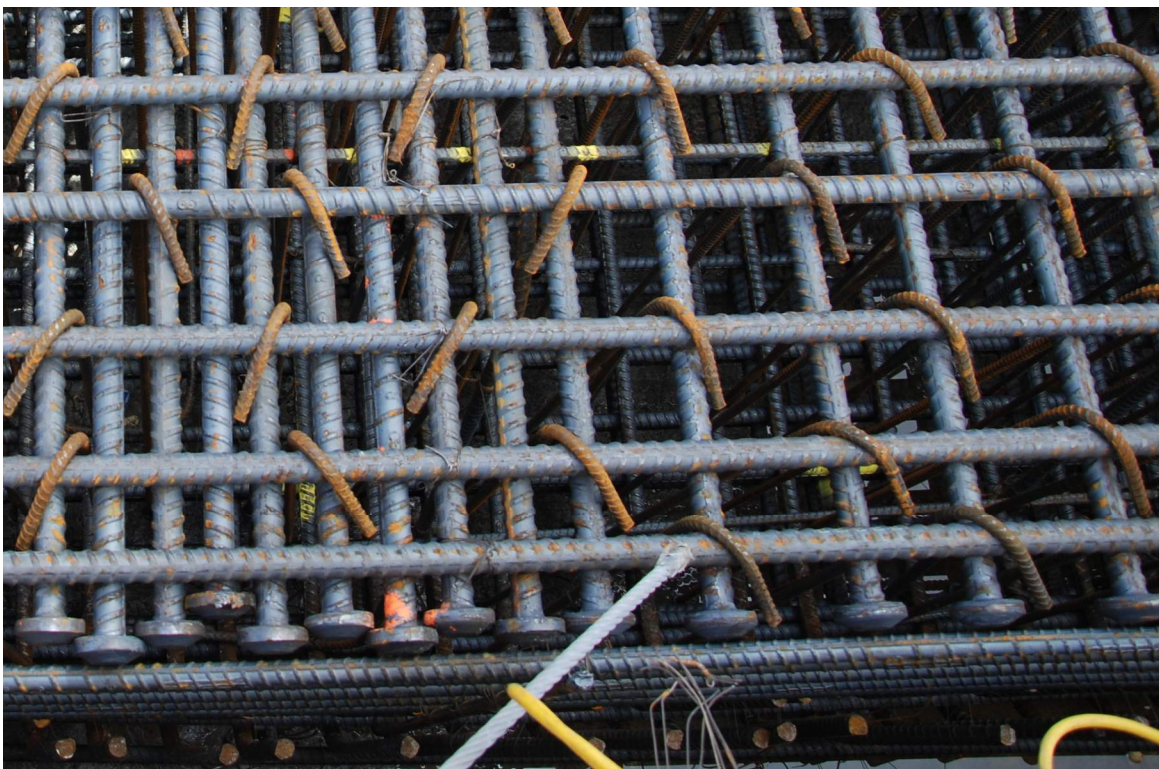
The current spacing limitations are restrictive and frequently questioned by design and construction professionals since similar requirements do not exist for straight bars or hooked bars. Headed bars are commonly and successfully used in many situations with closer spacing that does not meet the spacing requirements outlined in section 25.4.4.1 of ACI 318-14.

Section 25.4.5.1 of ACI 318-14 allows the use of headed bars which do not meet the spacing requirements outlined in section 25.4.4.1 provided that:

- *They are approved by the building official*
- *Test demonstrate the ability of the head and bar system to develop or anchor the desired force (f_y tension) in the bar.*

This section is currently used to justify headed bar applications where the clear spacing (measured horizontally and/or vertically) is closer than $4d_b$. In many cases, particularly with flexural reinforcement, closer spacing will improve overall performance of the reinforcement by providing better confinement for the section.

Example 1:



Picture (plan view) showing a band of closely-spaced headed bars in a foundation
(The staggering of the heads is not required)

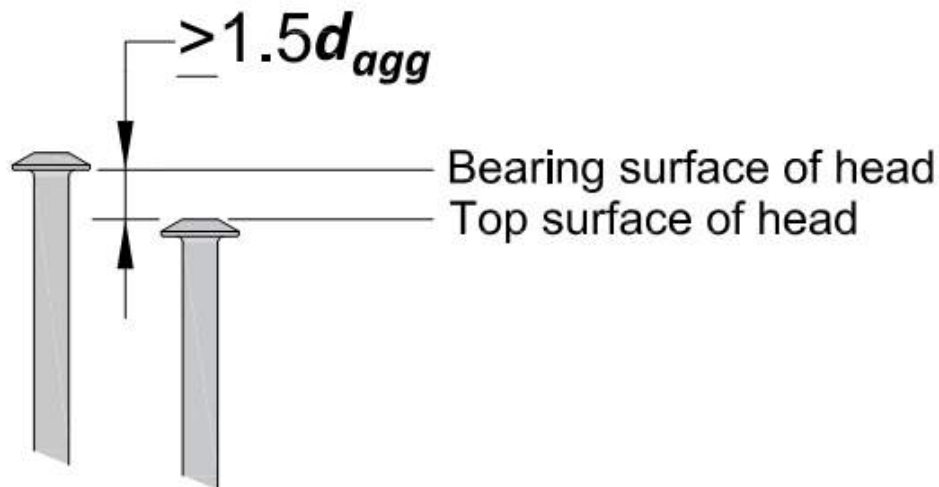
ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18

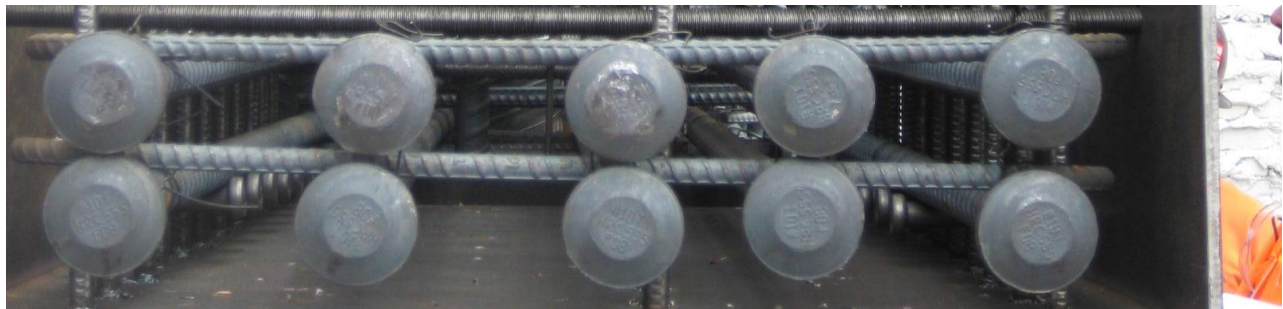


TECH NOTE

If heads are staggered during placement, the stagger should allow for adequate concrete flow & consolidation around the heads. The stagger (measured from bearing face of one head to the top of the next head) should be at least $1.5d_{agg}$ to allow for adequate concrete flow & consolidation.



Example 2:



Picture of headed bars within link beam as bottom longitudinal reinforcement, placed in 2 parallel layers (These parallel layers may meet the 4db min. clear spacing requirement when measured horizontally, but are stacked and do not comply with the 4db min. clear spacing when measured vertically)

If bars terminating with standard hooks are being replaced with bars terminating with heads, and the installation parameters are the same, the clear spacing requirements for hooked bars should still be applicable. Based on all known research, if substituting heads for standard hooks of the same installation parameters, headed bars are considered equal or conservative.

ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18



TECH NOTE

Current Challenges with Spacing Requirements:

The most contested spacing requirement in the Code is the $4d_b$ minimum clear spacing. There have been numerous examples of congested rebar details where headed deformed bars were placed much closer than this limit, yet, still provided superior structural performance and ease of construction. These situations often include joints, such as beam to column connections, vertical bar terminations in column/wall tops of pile caps, corbels or similar elements with high force demands. This clear spacing limit has also been investigated by prominent researchers and very specifically addressed in a few state-of-the-art reports. The reports demonstrate that the $4d_b$ minimum clear spacing limit can and should be relaxed.

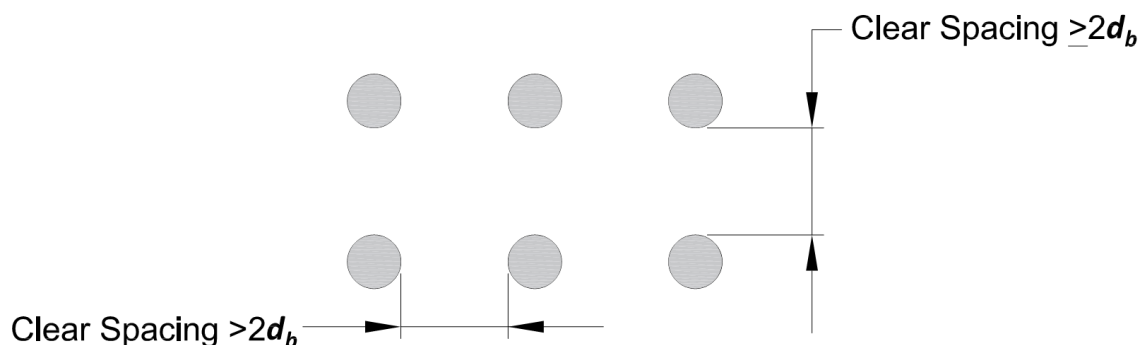
Prominent Research:

ACI Structural Journal paper by Kang, T. H.-K. et al. (2009)

In the seminal ACI Structural Journal paper by Kang, T., H.-K. et al. (2009) a comprehensive review of headed bar related experimental investigations was performed, where the authors examined a very large number of independent test results from many countries and manufacturers. This study aimed to document the tests in a unified format and to propose design guidelines to enhance the existing ACI provisions. This unification of database and in-depth review was prompted by the acknowledgement in the ACI Commentary pertaining to Section 12.6 (ACI 318-08) that the code development process on this subject was impeded by the very few reviewed tests.

This ACI journal paper took a close look at hundreds of tests, most focusing on congested applications. It made numerous recommendations to alter the current code limitations. Key recommendations include:

- *For beam-column joint design, the minimum clear spacing between headed bars can be reduced to $2d_b$*
- *Multiple layers of headed bars can be used for beam-column joints with minimum clear spacing of $2d_b$ between the layers.*



Section view of clear spacing recommendations

ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18



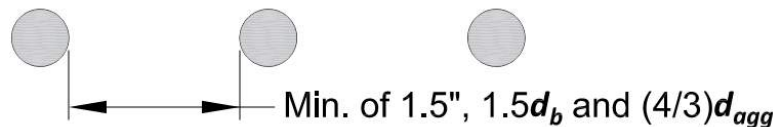
TECH NOTE

ACI 352R-02 Committee Report (Reapproved in 2010)

Another key document on this topic is the ACI 352 Committee Report. This ACI committee issued an extensive state-of-the-art report on monolithic beam-column connections and addressed the terminations of both hooked and headed bars. Their report recommends in Section 4.5.3 not only a shorter development length compared to the present 318 Code, but also makes statements supporting the relaxation of the currently prescribed ACI 318 limits for clear spacing and concrete cover.

ACI 352R-02 recommendations do not provide specific guidelines for clear spacing between headed bars; therefore, the clear bar spacing specified for straight and/or hooked reinforcing bars as defined in Section 25.2.3 of ACI 318-14 would also be used for headed bars.

- *For longitudinal reinforcement in columns, pedestals, struts, and boundary elements in walls, clear spacing between bars shall be at least the greatest of 1.5 in., $1.5d_b$, and $(4/3)d_{agg}$.*



Section view of clear spacing requirements in ACI 318-14 Section 25.2.3

University of Kansas SM Report No. 117 (2016)

David Darwin and his colleagues at The University of Kansas have completed a multi-year research program on the anchorage of headed reinforcing bars in concrete. This study evaluated the anchorage capacity of high-strength headed bars cast in normal and high-strength concrete. The test results were compared with the provision for development length in the ACI Building Code (ACI 318-14). Expressions were developed that characterize the anchorage capacity of headed bars as a function of embedment length, concrete compressive strength, bar diameter, bar spacing, and confining transverse reinforcement. These expressions were compared with the test results in the current and previous studies and used to develop design provisions for headed bar development length.

Key recommendations include:

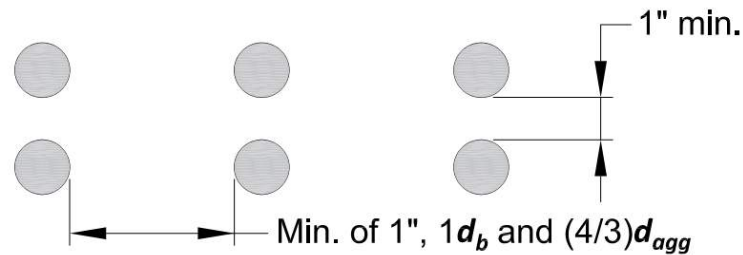
- *Code provisions that apply to headed bars with yield strengths up to 120,000 psi and to concrete with compressive strengths up to 16,000 psi and account for the effects of confining reinforcement and bar spacing on anchorage strength of headed bars.*
- *New development length equation that accounts for closely spaced headed bars.*
- *Reducing the current limit on bar clear spacing to $1d_b$, allowing for use of more closely spaced headed bars and making the spacing considerations the same for straight, hooked and headed bars.*

ACI 318-14 Spacing Requirements for Headed Deformed Bars in Tension

V1 10/5/18



TECH NOTE



Section view of clear spacing recommendations in University of Kansas SM Report No. 117 (2016)

Summary:

Based on the comprehensive research documents described above, and positive feedback from actual applications, HRC believes that headed bars replacing hooked bars can be used conservatively with the same installation parameters, regardless of the clear spacing and the other limitations of ACI 318-14 Section 25.4.4.1. HRC has no knowledge of any negative experience with such close spacing. HRC also recommends increasing the bar size while reducing the number of bars to alleviate very close spacing and ensure reliable concrete consolidation.

References:

American Concrete Institute – ACI Committee 318 (2014), Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14), American Concrete Institute, Farmington Hills, Michigan, 519 pp.

American Concrete Institute – ACI Committee 352 (2002, reapproved 2010), Recommendations for Design of Beam-Column Connections in Monolithic Reinforced Concrete Structures--Joint ACI-ASCE (ACI 352R-02), American Concrete Institute, Farmington Hills, Michigan, 38 pp.

Thomas H.-K. Kang, Myoungsu Shin, Nilanjan Mitra, and John F. Bonacci, (2009), Seismic Design of Reinforced Concrete Beam-Column Joints with Headed Bars, American Concrete Institute, Farmington Hills, MI, ACI Structural Journal, V. 106, No. 6, November-December.

Yun Shao, David Darwin, Matthew O'Reilly, Remy Lequesne, Krishna Ghimire and Muna Hano, (2016), Anchorage of Conventional and High-Strength Headed Reinforcing Bars, The University of Kansas Center for Research, Inc., Lawrence, KS, Structural Engineering and Engineering Materials SM Report No. 117, August 2016, 334 pp.