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Headed-stud connections

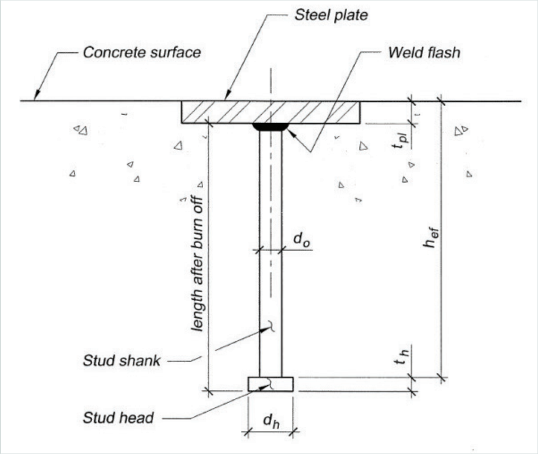
Donald Meinheit and Andrew Osborn

The theme of this issue of *PCI Journal* is Connections, so it seems appropriate to discuss a PCI research and development project that pertains to the precast concrete workhorse: the headed-stud connection.

In the precast concrete industry, welding headed studs to steel plates and embedding the assembly into the formwork provides an economical means of making connections. After stripping and component erection, other connecting hardware is attached to complete the structural connection in the field. The geometric design of the headed stud closely follows the characteristics of a structural bolt with its hex head or a heavy hex-headed nut embedded in concrete. Headed-stud anchorages can be found in column corbels, spandrel beams, dapped-end members, wall panels, tee beams, and a host of other precast concrete structural components.

The PCI Design Handbook: Precast and Prestressed Concrete editions 1 through 5,[1–5] published between 1971 and 1999, relied on test data and design procedures derived from tests on single-headed studs and wire loop/coil nut inserts in tension. The development of the 45-degree cone breakout model originated from tests on wire loop inserts in the mid-1960s sponsored by Superior Concrete Products, now Dayton Superior. Dayton Superior also proposed a simple shear breakout equation for the first edition of the *PCI Design Handbook*. The second and third editions of the *PCI Design Handbook* used the 45-degree cone breakout model for shear. The design model in the early editions of the *PCI Design Handbook* for tension failure of studs in groups may have influenced the current code design model provisions.

Starting in the late 1980s, extensive research conducted at the University of Stuttgart[6–9] became the basis for design provisions on headed-stud connections presented in the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)*.[10] The design model used in the ACI 318-02 code provisions proposed a square breakout model for single anchors and a rectangular model, like that in the *PCI Design Handbook*, for anchor groups in tension. The Stuttgart research[6–9] focused on the behavior of studs and other anchor types used as single anchors and in groups in tension. Because the 45-degree cone breakout model did not correctly take into account edge distance and spacing effects, the 45-degree cone model was eventually abandoned.



This general geometry is used to define the headed-stud anchor. Source: Reproduced from Anderson and Meinheit (2006), Fig. 1.1.1.

The *PCI Design Handbook* design equations for studs in tension and shear were unconservative when edges and spacing were considered, although PCI placed a connection load factor on connection design that compensated for some for the unconservative nature of the design model. PCI recognized this design model deficiency and, in 1996, funded a major research project to study the shear behavior (phase 1) and then the tension behavior and combined tension/shear behavior (phase 2).[11,12]

ACI 318-02[10] and ACI 318-05[13] "Appendix D: Anchoring to Concrete" did not recognize the failure mode where the concrete breakout in shear is controlled by the rear studs. In 2008, the code commentary[14] references the fifth edition of the *PCI Design Handbook*.[5] If shear breakout capacity is controlled by the rear studs, the front studs could be removed and the shear breakout would not change.

The ACI 318-02[10] Appendix D code provisions were 29 pages long. In chapter 17 of ACI 318-19,[15] they have grown to 50 pages. The ACI 318-19 code has adopted several results from PCI research, primarily related to the shear provisions.

Shear failure of the stud group is controlled by the distance of the rear stud(s) from the free edge. Source: Reproduced from Anderson, Tureyen, and Meinheit (2007), Fig. 7.4.1.

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