

## INTRODUCTION

This report has been prepared by members of the ACI 349 Sub-Committee on Steel Embedments to provide examples of the application of the ACI 349 Code to the design of steel embedments. The ACI 349 Committee was charged in 1973 with preparation of the code covering concrete structures in nuclear power plants. At that time, it was recognized that design requirements for steel embedments were not well defined and a special working group was established to develop code requirements. After much discussion and many drafts, Appendix B was approved and issued in the 1978 Supplement of ACI 349 covering the design of steel embedments. Subsequently, the Sub-Committee has continued to monitor on-going research and testing and to incorporate experience of applying the Code. Periodic revisions have been made to the Code and Appendix B.

The underlying philosophy in the design of embedments is to attempt to assure a ductile failure mode. This is similar to the philosophy of the rest of the concrete building codes wherein, for example, flexural steel for a beam is limited to assure that the reinforcement steel yields before the concrete crushes. In the design of an embedment for direct loading, the philosophy leads to the requirement that the concrete pull-out strength must be greater than the tensile strength of the steel.

This report includes a series of design examples starting with simple cases and extending to more complex cases for ductile embedments. The format for each example follows the format of the Strength Design Handbook, SP-17, and provides a reference back to the code paragraph for each calculation procedure.

## NOTATION

$a$	=	depth of equivalent stress block, in.
$A_{cp}$	=	effective stress area defined by the projected area of the 45 degree stress cone radiating towards the attachment from the bearing edge of the anchor, sq. in.
$A_c$	=	effective stress area of anchor, sq. in.
$A_h$	=	area of anchor head, sq. in.
$A_s$	=	area of steel, sq. in.
$A_{st}$	=	area of steel required to resist tension, sq. in.
$A_{sv}$	=	area of steel required to resist shear, sq. in.

$A_r$	=	reduction in effective stress area to account for limited depth of concrete beyond the bearing surface of the embedment, sq. in.
$A_{vf}$	=	area of shear friction reinforcement, sq. in.
$b$	=	width of embedded or surface mounted plate, or width of an anchor group, measured out to out of bearing edges of the outermost anchor heads, in.
$B$	=	overlapping stress cone factor (see Appendix A)
$c$	=	spacing or cover dimension, in.
$C$	=	compressive reaction
$d_b$	=	nominal diameter of reinforcing bar, in.
$d_h$	=	diameter of anchor head or reinforcing bar, in.
$d_s$	=	diameter of tensile stress component, in.
$F_y$	=	specified yield strength of steel plate, psi
$f'_c$	=	specified compressive strength of concrete, psi
$f_{ut}$	=	specified tensile strength of steel, psi
$f_y$	=	specified yield strength of steel, psi
$h$	=	overall thickness of concrete member, in.
$k_{tr}$	=	transverse reinforcement index
$l_d$	=	development length, in.
$L_d$	=	embedment depth of anchor head measured from attachment of anchor head to tensile stress component, to the concrete surface, in.
$M_n$	=	nominal moment strength
$M_u$	=	factored moment load on embedment
$M_y$	=	elastic moment capacity of steel plate
$n$	=	number of threads per inch
$P_d$	=	design pullout strength of concrete in tension
$P_n$	=	nominal axial strength
$P_u$	=	factored external axial load on the anchorage
$R$	=	radius of 45 degree stress cone, in. (see $A_{cp}$ )
$S$	=	spacing between anchors, in.
$t$	=	thickness of plate, in.
$T$	=	tension force
$T_h$	=	thickness of anchor head, in.
$V_n$	=	nominal shear strength
$V_u$	=	factored shear load on embedments
$\alpha$	=	reinforcement location factor
$\beta$	=	coating factor
$\gamma$	=	reinforcement size factor
$\mu$	=	coefficient of friction
$\phi$	=	strength reduction factor



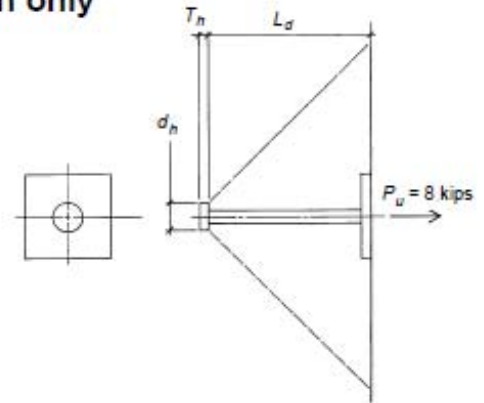
### Example A1—Single stud, tension only

Design an embedment using a stud welded to an embedded plate.

Given:

$$\begin{aligned} f'_c &= 4000 \text{ psi} \\ f_y &= 50,000 \text{ psi} \\ f_{ut} &= 60,000 \text{ psi} \\ P_u &= 8 \text{ kips} \end{aligned}$$

where  $P_u$  is the required factored external load as defined in Section 9.2 of the Code.



CODE SECTION	DESIGN PROCEDURE	CALCULATION
<b>STEP 1: Determine required steel area of the stud</b>		
B.6.5.1	<p>Assume that the load is applied directly over the stud and that a plate size of 3 in. × 3 in. × 3/8 in. has been established by requirements of the attachment.</p> <p>Equate the external (required strength) and internal (design strength) forces and solve for the required steel area for the stud.</p>	$P_u = \phi P_n = \phi A_s f_y$ $A_s = 8 / [(0.9)(50)] = 0.18 \text{ in.}^2$ <p>Use one 1/2 in. diameter stud,</p> $A_s = 0.196 \text{ in.}^2 > 0.18 \text{ in.}^2$ <p style="text-align: right;">OK</p>
<b>STEP 2: Check anchor head bearing</b>		
B.5.1.1(a) B.4.5.2	<p>a) Area of the anchor head (<math>A_h</math>) (including the area of the tensile stress component) is at least 2.5 times the area of the tensile stress component.</p> <p>b) Thickness of the anchor head (<math>T_h</math>) is at least 1.0 times the greatest dimension from the outer most bearing edge of the anchor head to the face of the tensile stress component.</p> <p>c) Bearing area of head is approximately evenly distributed around the perimeter of the tensile stress component.</p>	<p><math>A_h = \pi(d_h/2)^2 = 0.79 \text{ in.}^2</math> (per manufacturer's data, <math>d_h = 1 \text{ in.}</math>)</p> <p><math>A_h/A_s = 0.79/0.196 = 4 &gt; 2.5</math> OK</p> <p><math>T_h = 0.312 \text{ in.}</math> (per manufacturer's data) (<math>d_h - d_s)/2 = 0.25 \text{ in.}</math></p> <p><math>T_h = 0.312 &gt; 0.25</math> OK</p> <p>Head and tensile stress component are concentric. OK</p>
<b>STEP 3: Determine required embedment length for the stud to prevent concrete cone failure</b>		
B.5.1.1 B.4.2	<p>The design pullout strength of the concrete, <math>P_d</math>, must exceed the minimum specified tensile strength (<math>A_s f_{ut}</math>) of the tensile stress component.</p> <p><math>P_d &gt; A_s f_{ut}</math></p> <p><math>P_d = \phi 4 \sqrt{f'_c} A_{cp}</math></p> <p><math>A_{cp} = \pi[(L_d + d_h/2)^2 - (d_h/2)^2]</math></p> <p>Compute <math>L_d</math> from the equation:</p> <p><math>\pi[(L_d + d_h/2)^2 - (d_h/2)^2] \phi 4 \sqrt{f'_c} \geq A_s f_{ut}</math></p>	<p><math>A_s f_{ut} = 0.196 \times 60 = 11.8 \text{ kips}</math></p> <p><math>\phi 4 \sqrt{f'_c} = 0.65 \times 4 \times \sqrt{(4000)}</math> <math>= 165 \text{ psi}</math> (see Note 2)</p> <p><math>\pi[(L_d + 0.5)^2 - 0.5^2] 0.165 \geq 11.8</math></p> <p><math>L_d(L_d + 1.0) \geq 22.8</math></p> <p><math>L_d^2 + L_d - 22.8 \geq 0</math></p> <p><math>L_d \geq 4.30 \text{ in.}</math></p> <p>Use 1/2 in. diameter stud 1-5/16 in. long, which has an effective length of 4.87 in. giving <math>L_d = 4.87 + 0.38 = 5.25 \text{ in.}</math></p>

## Example A1, continued

CODE SECTION	DESIGN PROCEDURE	CALCULATION
<b>STEP 4: Check plate thickness</b>		
	Since the load is applied directly over the stud, the only requirement on plate thickness is that it satisfy the minimum thickness required for stud welding.	Stud welding of $1/2$ in. diameter studs is acceptable on $3/8$ in. thick plate per manufacturer. OK

- NOTE: 1) In the above example, the embedment length  $L_d$  is taken to the face of the concrete. If the plate were larger than the stress cone, then the embedment length would exclude the thickness of the embedded plate.
- 2) In all design examples, the strength reduction factor  $\phi$  for concrete pullout is taken as 0.65 per Category (d) of Section B.4.2.