Nelson Stud Design Manual

1977

EMBEDMENT PROPERTIES OF HEADED STUDS

INDEX

NOTATIONS

A_{fc} = area of full conical surface (in.^{2}) = π s (R + r)
A_{pc} = area of remaining or partial shear cone (in.^{2})
A_r = area of reduction (in.^{2})
A_s = cross-sectional area of the anchor shank (in.^{2})
C = constant for concrete type
D_e = distance from free edge to center of anchor (in.)
D_{es} = distance from shear edge to center of stud (in.)
D_h = diameter of stud head (in.)
D_s = diameter of shank of anchor (in.)
E_c = modulus of elasticity of concrete (ksi)
f'_c = 28 day concrete compressive strength (psi)
f_s = tensile strength of anchor steel (ksi)
f_y = yield strength of anchor steel (ksi)
H = height of the remaining or partial shear cone (in.)
K = constant equal to 4.0
L_e = length of anchor under the head (in.)
N = number of reductions
P_u = applied tension load
P'_u = tensile capacity of the anchor (kips)
P_{uc} = ultimate concrete tension capacity (lbs.)
P_{ue} = ultimate embedded tension capacity of a headed anchor $\leq 0.9\ A_s f_s$
P'_y = yield strength of the anchor steel (ksi)
r = radius of head of stud (in.)
R = major radius of shear cone (in.)
R_R = radius of remainder of partial cone (in.)
R P_{uc} = reduced tension capacity (kips)
R S_{uc} = reduced shear capacity (kips)
S = length of side of cone — L_e sec (90 — θ) (in.)
S_u = applied shear load
S'_u = shear capacity of the anchor (kips)
S_{uc} = ultimate concrete shear capacity (kips)
S_{ue} = ultimate embedded shear capacity of headed anchor $\leq 0.9\ A_s f_s$
W = unit weight of concrete in lbs./cu. ft.
X = R — D_e
Ø = capacity reduction factor

INTRODUCTION

1.0

Beginning in 1959, Nelson Stud Welding conducted extensive tests on the use of headed studs embedded in concrete.

The test results and design data were originally published in the brochure "Design Data, NELSON® Concrete Anchors."

Increasing use of headed concrete anchors has been made in anchoring steel shapes and plates in concrete with studs welded to the embedded steel items as the anchorage devices.

It became apparent that additional data were needed to adequately predict stud performance in many conditions of use. The "shear cone" or conical section failure of embedded anchors was advanced by such advocates as Mr. Peter Courtois[1] and others.

Explanations of the conical failure concept culminated in the publication of the Prestressed Concrete Institute Design Handbook, Section 6.1.13[2] where anchor strengths were based on theoretically derived, empirically confirmed equations.

Prior to the PCI publication, Nelson Stud Welding had initiated a comprehensive test program at Lehigh University[3], to determine headed anchor behavior and provide sufficient data to reliably forecast the accuracy of the empirically derived equations.

The material published in this manual is test confirmed and provides up-to-date information for engineers involved in designing concrete-steel structures.

2.0 CONNECTION THEORY

It should be noted at the outset of this report that connection design used in concrete construction is governed by American Concrete Institute code[11] criteria. As such, most embedment plate items, weldments, etc. are used with additional reinforcement materials in the form of bar or mesh to develop specified design strengths. Testing for headed anchors used as the basis for this publication was done in plain, unreinforced concrete since the objective was to establish performance criteria for the anchors only. All anchors were tested to failure either in the anchor itself (ductile failure) or failure in the concrete section (brittle failure).

These two modes of failure are part of the basic performance criteria in concrete design. Brittle or abrupt failure when indicated in a connection is generally strictly limited or prohibited in design of concrete structures. Where use of brittle behavior concepts is provided for in a design, it will generally be limited to areas where the structural design is close to ductile (balanced design). Brittle failure is characterized by little or no movement in a connection or structure prior to catastrophic failure. Since there is virtually no warning of failure, codes require a design safety factor considerably in excess of that required where ductile behavior can be demonstrated.

Ductile failure or semi-ductile failure allows for movement, providing warning of impending collapse without sacrificing load carrying capacity. One of the intents of this report is to indicate the areas of ductile, semi-ductile and brittle performance of embedded anchors so that connection designs may be made that limit or, preferably, eliminate any behavior in the anchors that approaches the brittle mode. This design approach results in economies that are achieved through reduced overload factors while structural safety is assured by the behavior criteria which insure increased structural capacity as movement is taking place.

Ductile or semi-ductile behavior in embedded headed anchors can be obtained by using data contained in the report to be sure that the full anchor yield strength is reached in the following areas.

1. **Anchor to embedment plate connection**
   - **A. Weld quality**
   - **B. Plate thickness**

2. **Embedded anchor strengths**
   - **A. Tension capacities**
   - **B. Shear capacities**
   - **C. Effect of stud spacing**
   - **D. Combined shear-tension capacities**

Each part of a full connection design must be analyzed with respect to its overall performance. The failure mechanism should be determined, since failure of one part of the connection before another part has developed its design force may mean the overall connection is unsatisfactory. Progressive failures of this type are sometimes referred to as a "zipper" type collapse pattern. Naturally, brittle connections with no warning prior to catastrophic failure are far more subceptible to "zipper" type structural failure than ductile or semi-ductile connections.

The data presented in this report are arranged so that the behavior of a stud can be readily determined. Connections employing stud sizes that fail before the optimum loading levels should not be used unless adequate subreinforcement is employed to extend their capacity into the ductile range. Ductile or at least semi-ductile embedded anchor behavior should be reached wherever possible regardless of the stress distribution or crack patterns that may be present in the concrete. The reduction in capacity of anchors used in areas of flexural cracking should be taken as approximately 10%. In most cases of full ductile anchor performance shown in this report such a reduction need not be taken.

Table 1. gives the general performance levels of headed anchors as embedded in concrete. Shaded areas should be avoided if at all possible. This table is merely a selection guide to the anchors which fall in the brittle, semi-ductile or ductile behavior modes with and without reinforcement. After selection of an anchor size, analysis of its specific use with regard to spacing, concrete density, loadings, etc. should be undertaken in

accordance with data outlined in the body of this publication.

Following Table 1. are definitions and or explanations of the table itself.

Table 1. — Selection Guide
Suggested Nelson Headed Anchor Sizes(1.)
Connection Type

	Primary Connection(2.)		Secondary Connection		
	Two Way Reinforcing	One Way Reinforcing	Two Way Reinforcing	One Way Reinforcing	No Add. Reinforcing
Failure Mode	"Single Acting"	"Partially Redundant"	"All Types Fully Redundant"		
Brittle	$\frac{1}{2} \times 2\frac{1}{8}$ thru $4\frac{1}{8}$ $\frac{5}{8} \times 2\frac{11}{16}$ $\frac{3}{4} \times 3\frac{3}{16}$ thru $4\frac{3}{16}$ $\frac{7}{8} \times 3\frac{11}{16}$ thru $5\frac{3}{16}$	$\frac{1}{2} \times 2\frac{1}{8}$ and $3\frac{1}{8}$ $\frac{5}{8} \times 2\frac{11}{16}$ $\frac{3}{4} \times 3\frac{3}{16}$ and $3\frac{11}{16}$ $\frac{7}{8} \times 3\frac{11}{16}$ and $4\frac{3}{16}$	$\frac{1}{2} \times 2\frac{1}{8}$ and $3\frac{1}{8}$ $\frac{5}{8} \times 2\frac{11}{16}$ $\frac{3}{4} \times 3\frac{3}{16}$ $\frac{7}{8} \times 3\frac{11}{16}$	$\frac{1}{2} \times 2\frac{1}{8}$ $\frac{5}{8} \times 2\frac{11}{16}$ $\frac{3}{4} \times 3\frac{3}{16}$ and $3\frac{11}{16}$ $\frac{7}{8} \times 3\frac{11}{16}$ and $4\frac{3}{16}$	$\frac{1}{2} \times 2\frac{1}{8}$ $\frac{5}{8} \times 2\frac{11}{16}$ $\frac{3}{4} \times 3\frac{3}{16}$ thru $4\frac{3}{16}$ $\frac{7}{8} \times 3\frac{11}{16}$ thru $5\frac{3}{16}$
Semi-Ductile	$\frac{1}{2} \times 5\frac{5}{16}$ $\frac{5}{8} \times 6\frac{9}{16}$ $\frac{3}{4} \times 5\frac{3}{16}$ and $6\frac{3}{16}$ $\frac{7}{8} \times 6\frac{3}{16}$ and $7\frac{3}{16}$	$\frac{1}{2} \times 4\frac{1}{8}$ $\frac{3}{4} \times 4\frac{3}{16}$ and $5\frac{3}{16}$ $\frac{7}{8} \times 5\frac{3}{16}$ and $6\frac{3}{16}$	$\frac{1}{2} \times 3\frac{1}{8}$ $\frac{3}{4} \times 3\frac{11}{16}$ thru $5\frac{3}{16}$ $\frac{7}{8} \times 4\frac{3}{16}$ thru $6\frac{3}{16}$	$\frac{1}{2} \times 3\frac{1}{8}$ $\frac{3}{4} \times 4\frac{3}{16}$ and $5\frac{3}{16}$ $\frac{7}{8} \times 5\frac{3}{16}$ and $6\frac{3}{16}$	$\frac{1}{2} \times 3\frac{1}{8}$ $\frac{3}{4} \times 5\frac{3}{16}$ $\frac{7}{8} \times 6\frac{3}{16}$
Ductile	$\frac{3}{8} \times 4\frac{1}{8}$ and $6\frac{1}{8}$ $\frac{1}{2} \times 6\frac{1}{8}$ thru $8\frac{1}{8}$ $\frac{5}{8} \times 8\frac{3}{16}$ $\frac{3}{4} \times 7\frac{3}{16}$ and $8\frac{3}{16}$ $\frac{7}{8} \times 8\frac{3}{16}$	$\frac{3}{8} \times 4\frac{1}{8}$ and $6\frac{1}{8}$ $\frac{1}{2} \times 5\frac{5}{16}$ $\frac{5}{8} \times 6\frac{9}{16}$ $\frac{3}{4} \times 6\frac{3}{16}$ thru $8\frac{3}{16}$ $\frac{7}{8} \times 7\frac{3}{16}$ and $8\frac{3}{16}$	$\frac{3}{8} \times 4\frac{1}{8}$ and $6\frac{1}{8}$ $\frac{1}{2} \times 4\frac{1}{8}$ thru $8\frac{1}{8}$ $\frac{5}{8} \times 6\frac{9}{16}$ and $8\frac{3}{16}$ $\frac{3}{4} \times 6\frac{3}{16}$ thru $8\frac{3}{16}$ $\frac{7}{8} \times 7\frac{3}{16}$ and $\frac{7}{8} \times 8\frac{3}{16}$	$\frac{3}{8} \times 4\frac{1}{8}$ and $6\frac{1}{8}$ $\frac{1}{2} \times 4\frac{1}{8}$ thru $8\frac{1}{8}$ $\frac{5}{8} \times 6\frac{9}{16}$ and $8\frac{3}{16}$ $\frac{3}{4} \times 6\frac{3}{16}$ thru $8\frac{3}{16}$ $\frac{7}{8} \times 7\frac{3}{16}$ and $\frac{7}{8} \times 8\frac{3}{16}$	$\frac{3}{8} \times 4\frac{1}{8}$ and $6\frac{1}{8}$ $\frac{1}{2} \times 4\frac{1}{8}$ thru $8\frac{1}{8}$ $\frac{5}{8} \times 6\frac{9}{16}$ and $8\frac{3}{16}$ $\frac{3}{4} \times 6\frac{3}{16}$ thru $8\frac{3}{16}$ $\frac{7}{8} \times 7\frac{3}{16}$ and $\frac{7}{8} \times 8\frac{3}{16}$

Notes: 1. Nelson $\frac{1}{4} \times 2\frac{11}{16}$ and $\frac{1}{4} \times 4\frac{1}{8}$ Headed Anchors while fully ductile under all the above conditions are not frequently used in structural connections.
2. No primary connection should be made without at least one way reinforcing.

Explanation of Table 1.

1. Shaded areas are to be avoided whenever possible. Use of headed anchor sizes listed in the shaded areas under the conditions shown should be subject to vigorous analysis of factors affecting load capacity including spacing, concrete density and type, stress conditions, temperature, volume change and workmanship.
2. **Primary Connections**
   A. **Single Acting** — This connection is one where the failure of the connection would result in the collapse of a member being supported without the benefits of added structural redundant support.

   B. **Partially Redundant** — Failure of the connection would result in a redistribution of loads and stresses accompanied by significant movement and distortion of the structural member but without catastrophic collapse.
3. **Secondary Connections** — Failure of a secondary connection would result in a full redistribution of loads and stresses to adjacent parts of the structure without significant distortions to the member of the structure.
4. **Brittle Behavior** — No noticeable or significant movement in the connection is evident before catastrophic collapse.
5. **Semi-Ductile Behavior** — Movement of approximately $\frac{1}{4}$" in the weld plate position under combined shear-tension loading has no effect in the weldments structural capacity.
6. **Ductile Behavior** — Movement of approximately $\frac{1}{2}$" in the weld plate position under combined shear-tension loading has no effect on the weldments structural capacity.

3.0 MECHANICAL PROPERTIES OF HEADED ANCHORS

3.1 Steel Grades Used in Manufacture

Low Carbon Steel per ASTM Specification A-108 Physical Properties:

Tensile (Minimum) ....60,000 PSI (60 KSI)

Yield (Minimum) ....50,000 PSI (50 KSI) (0.2% Offset)

Elongation (Minimum) 20% in 2"

3.2 Steel Tensile Strength

The ultimate steel strength or tensile strength of a headed anchor may be computed as:

$$P'_u = A_s f_s \qquad \textbf{(Equation 1.)}$$

Where:

P'_u = Tensile capacity of the anchor in Kips.

A_s = Cross sectional area of the anchor shank

f_s = Tensile strength of the anchor steel

3.3 Steel Yield Strength

The yield strength (point at which the steel begins to elongate) of a headed anchor may be computed as:

$$P'_y = A_s f_y \qquad \textbf{(Equation 2.)}$$

Where:

P'_y = Yield strength of anchor in Kips

A_s = Cross sectional area of the anchor shank

f_y = Yield strength of the anchor material

4.0 EMBEDMENT PROPERTIES OF HEADED ANCHORS

4.1 Headed Anchor Ultimate Embedment Strength

Results of tests by Nelson[4][5] on ¼" diameter through ⅞" diameter headed anchors with full embedment are summarized in Table 3. The load displacement curves on several anchors are shown in Figure 1. The shapes of the load displacement curves indicate that a tension load causing 0.01" displacement on a headed anchor represents a reasonable estimate of the yield strength of the embedded anchor. It can be seen that the 0.10" displacement loads are consistently lower than the ultimate embedment loads (P_{ue}) at which the embedded anchors failed, but do not fall lower than 0.9 P_{ue}.

Figure 1. curves show that the load valves at 0.10" displacement represent a point where the load curves approach a flat attitude. Very little increase in loading is required to reach the ultimate embedment strength P_{ue}.

For engineering and design purposes, a conservative valve for the ultimate embedded strength of a headed anchor with sufficient embedment length to develop full strength may be calculated as:

$$P_{ue} = 0.9\, A_s f_s \qquad \textbf{(Equation 3.)}$$

Where:

P_{ue} = Ultimate strength of an embedded headed anchor

A_s = Cross sectional area of the anchor shank

f_s = Tensile strength of the anchor steel

Table 2. Mechanical Properties Of Headed Anchors

Anchor Shank Dia.	A_s-Nominal Area, In.^{2}	Tensile Strength $P'_u = A_s f_s$ Kips	Yield Strength $P'_y = A_s f_y$ Kips
¼	.049	2.95	2.46
⅜	0.110	6.62	5.52
½	0.196	11.78	9.82
⅝	0.307	18.41	15.34
¾	0.442	26.51	22.09
⅞	0.601	36.08	30.07

Table 3. Tensile Capacities Of Headed Anchors — Nelson Test Series[4] [5]

No.	Ds (In.)	A.W.[1] L. (In.)	Dh (In.)	Le (In.)	Le No. Diameters	Failure[2] Mode	Concrete Strength	Load at 0.1" Displacement Kips	Ult. Embedded Strength Pue Kips
A	1/4	2 1/2	1/2	2 5/16	9.25	S	3000 psi	3.6	3.7
B	1/4	2 1/2	1/2	2 5/16	9.25	W	3000 psi	—	3.0
A	3/8	3 7/8	3/4	3.594	9.58	S	3000 psi	8.5	8.5
B	3/8	3 7/8	3/4	3.594	9.58	S	3000 psi	8.6	8.7
A	1/2	5	1	4 11/16	9.38	S	3000 psi	11.9	12.5
B	1/2	5	1	4 11/16	9.38	S	3000 psi	13.8	15.0
A	5/8	6 1/4	1 1/4	5 15/16	9.50	S	3000 psi	22.7	23.7
B	5/8	6 1/4	1 1/4	5 15/16	9.50	S	3000 psi	24.0	25.0
A*	5/8	6 1/4	1 1/8	5 15/16	9.50	S	3000 psi	21.3	22.0
B*	5/8	6 1/4	1 1/8	5 15/16	9.50	S	3000 psi	24.0	25.0
A	3/4	7 1/2	1 1/2	7 1/8	9.50	W	3000 psi	—	33.0
B	3/4	7 1/2	1 1/2	7 1/8	9.50	W	3000 psi	33.8	34.5
A*	3/4	7 1/2	1 1/4	7 1/8	9.50	A	3000 psi	31.2	33.2
B*	3/4	7 1/2	1 1/4	7 1/8	9.50	S	3000 psi	36.1	38.1
A	7/8	7 1/2	1 3/4	7 1/8	8.14	W	3000 psi	48.1	50.5
B	7/8	7 1/2	1 3/4	7 1/8	8.14	A	3000 psi	—	42.5

NOTES: (1) A.W.L. — After weld length.

(2) S — Shank of stud broke; W — Weld at head broke; A — Attachment to testing machine broke

*Tested in Series 5.[4]; all others tested in series 6.[5]

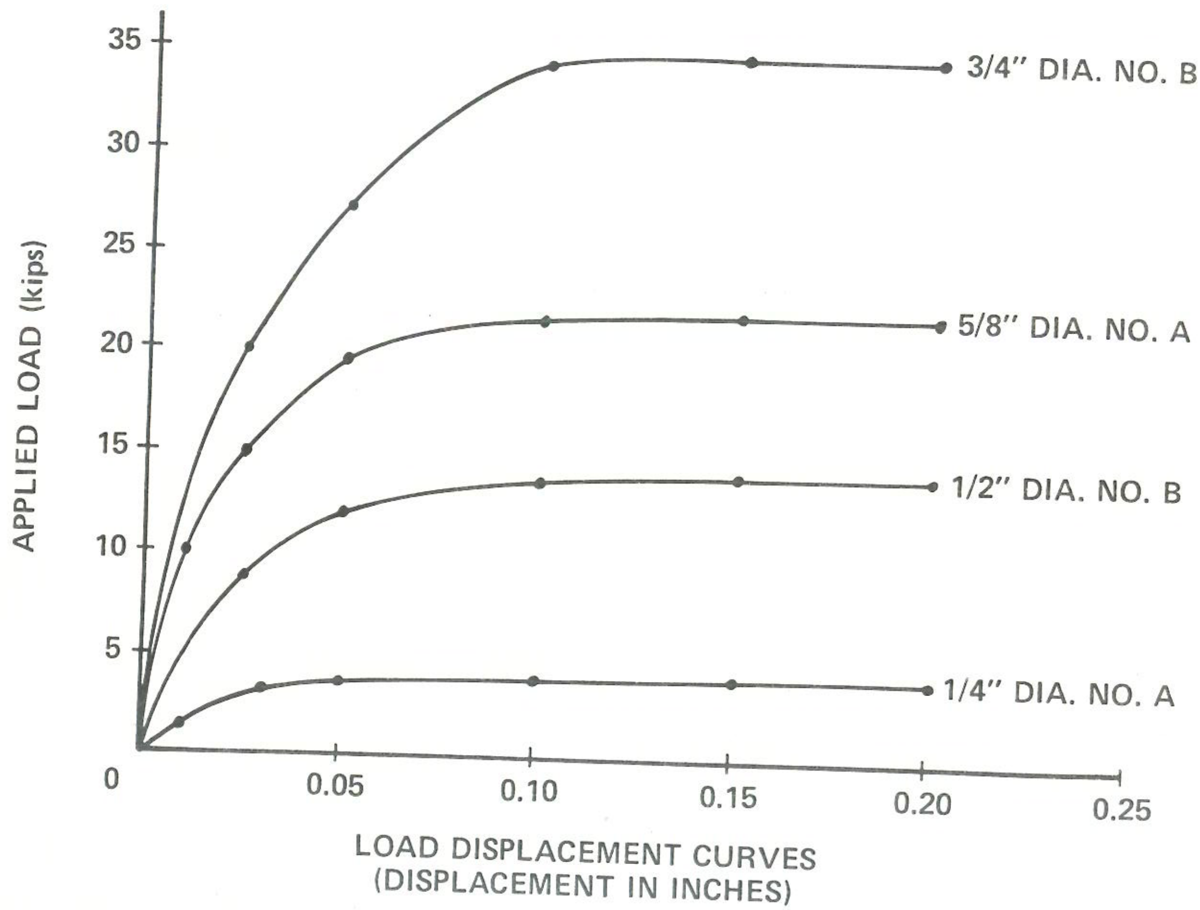


FIGURE 1. — Load Displacement Curves

4.2 Shear Cone Theory

Investigations into the tension capacity of headed anchors and inserts embedded in concrete have shown that when these embedded items do not fail in the anchor steel itself, but pull out of concrete, the geometry of the failed concrete section is conical in section.[1][4] Since the concrete has been subjected to diagonal shear forces, this failure mode is termed a "Shear Cone." The area of this conical section that fails is primarily dependent upon the following factors:

1. **Concrete Compressive Strength**
2. **Concrete Weight**
3. **Headed Anchor Size**
   A. **Length of embedment**
   B. **Head Diameter**
4. **Boundary Conditions**
5. **Anchor Spacing or Grouping**

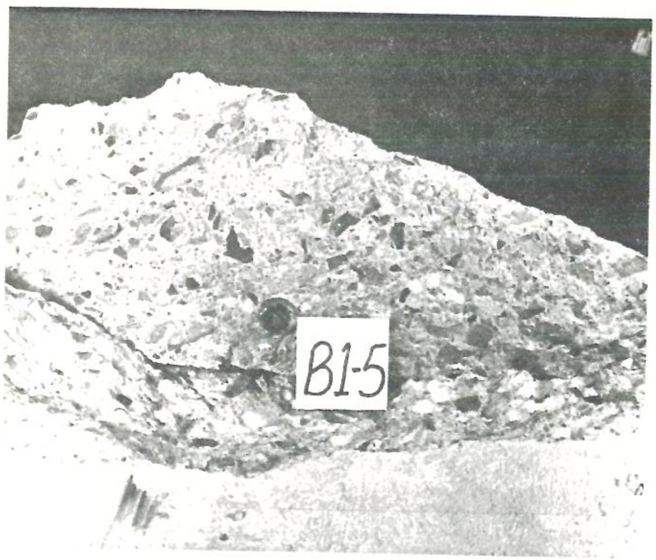


FIGURE 2. — Typical Conical Failure

As the depth of embedment of the headed anchor continues to increase, the area of the conical section that may be pulled out increases proportionately up to the point of full embedment.

At an embedment depth of some 8 to 10 times the anchor shank diameter[6] the capacity of the concrete contained within the conical area exceeds the tensile strength of the steel in the headed anchor. At that area of development, the stud rather than the concrete fails. Beyond the full embedment of 8-10 diameters, conical area failure does not apply since strength is limited by the stud embedment capacity (P_{ue}).

These statements assume that the studs are spaced so that there is sufficient surrounding concrete area for a full shear cone to be developed. Limitations of conical area are covered in a later section.

Figure 3. illustrates the geometrical relationships of a full shear cone.

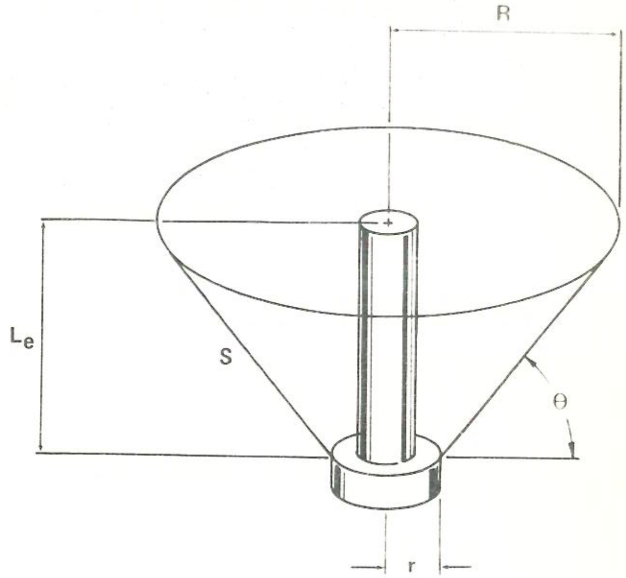


FIGURE 3. — Full Concrete Shear Cone

The **concrete** capacity of a full shear cone may be determined by the formula:

(Equation 4.)

$$Puc = \emptyset C K A_{fc} \sqrt{f'_c}$$

Where

Puc = Ultimate concrete tension capacity (lbs.)
$\emptyset$ = 0.85 Reduction Factor
C = Constant for Concrete type (Per ACI 318-71, Section 11.3.2)
Normal weight concrete C = 1.0
All lightweight concrete C = 0.75
Sand lightweight concrete C = 0.85
K = 4.0
A_{fc} = Area of full conical surface (sq. in.)*
f'_c = 28 day concrete compressive strength
*$A_{fc} = \pi S (R + r)$

4.3 Partial Embedment — Full Shear Cone

This case covers those anchors with insufficient embedment length to develop the anchor embedment strength (Pue), but with adequate space in the surrounding concrete to develop a full shear cone area. Failure occurs in the concrete.

The relationship may be described as:

Puc $\leq$ Pue
or

Concrete Capacity is less than or equal to the anchor embedment strength.

The shear cone failure of an anchor with partial embedment is described geometrically in Figure 4.

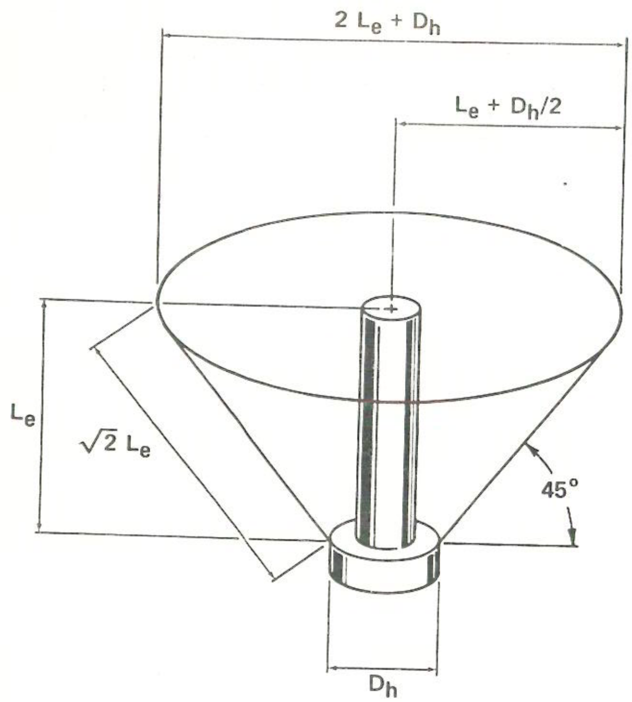


FIGURE 4.—Partial Embedment — Full 45° Shear Cone

Converting Equation 4., Section 4.2 to the partial embedment case, full shear cone area geometry, the following derivations are evolved:

$$Puc = \phi\ CK\ Afc \sqrt{f'_c}$$

$$Puc = (\phi)\ (4)\ (C)\ (Afc) \sqrt{f'_c}$$

$$Afc = \pi \sqrt{2}\ Le\ (Le + Dh/2 + Dh/2) \text{ or}$$
$$\pi \sqrt{2}\ Le\ (Le + dh)$$

$$Puc = \phi\ (C)\ (4)\ [\pi \sqrt{2}\ Le\ (Le + Dh)] \sqrt{f'_c}$$
or
$$Puc = \phi\ 17.77\ C\ (Le)(Le + Dh) \sqrt{f'_c}$$

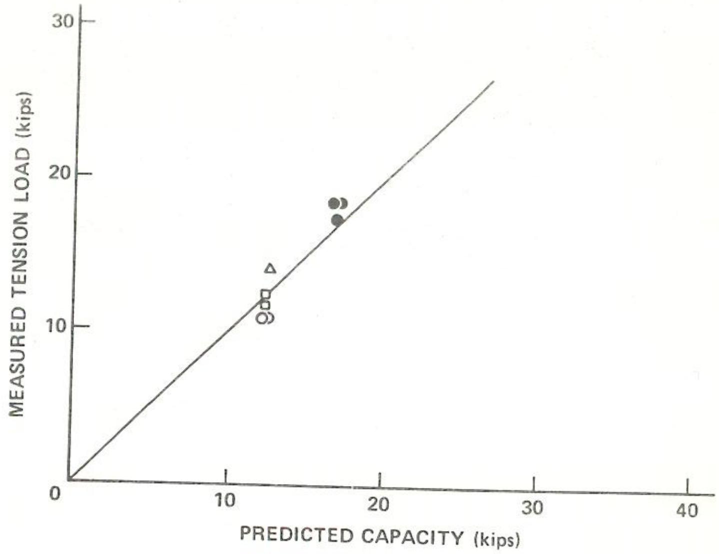
(Equation 5.)

This expression may be restated as in the Lehigh Report[3] by:

$$Puc = 0.475\ C\ (Le + Dh)\ Le \sqrt{f'_c}$$

which simply converts Puc from pounds to kips.

Confirmation of the concrete capacity formula accuracy is shown in Figure 5. where partial embedment, full shear cone test specimens are graphed on a measured (tested) versus theoretical (predicted) basis.



Symbol	Beam	Stud Size D x Le	f'c (psi)	Concrete Type
• †	Beam C	¾" x 4"	5180	NWC
○	7 SH a, b	¾" x 4"	3000	NWC
△ *	7 DH b	¾" x 3 13/16"	3000	NWC
□	7 STH a, b	¾" x 4"	3000	NWC

Note:
†These values obtained from Table 5.
*These Values Obtained from Nelson Stud Project No. 802, Report No. 1966-5 Test No. 7[7.]

FIGURE 5.—Partial Embedment Capacity

4.4 Full Embedment Condition

Where the anchor embedment length is in the range of 8 to 10 times the anchor shank diameter, the relationship of concrete capacity to stud embedment capacity may be described as:

$$Puc \geq Pue$$
or

Concrete Capacity is equal to or greater than the anchor embedment strength.

In these cases, the stud will fail rather than the concrete.

McMackin, Slutter and Fisher have reported[3] that tension capacity near a free edge in 5000 psi normal weight concrete can be determined by the formula.

$$R\ Puc = \frac{2\ De}{9\ Ds}\ (Puc)$$

where:

R Puc = Reduced concrete tension capacity

De = Distance from a free edge to the center of the anchor

Puc = Concrete capacity $\leq P_{ue}$

Ds = Anchor shank diameter

Since the concrete capacity (Puc) and conical area is limited to the maximum value of anchor embedment strength (Pue) setting the values of R Puc and Puc in this equation as Pue and adding constants for the effect of concrete type and density the following is derived.

(Equation 6.)

$$R\,P_{uc} = \left[\frac{2\,De}{9\,Ds}\,(C)\,\sqrt{\frac{f'c}{5000}}\right] Pue$$

where:

$R\,P_{uc}$ = Reduced concrete capacity

De = Distance from a free edge to the center of the anchor

C = Constant for concrete type
Normal weight concrete C = 1.0
Sand Lightweight concrete C = 0.85
All lightweight concrete C = 0.75

Ds = Anchor shank diameter

When the function $\left[\frac{2\,De}{9\,Ds}\,(C)\,\sqrt{\frac{f'c}{5000}}\right]$ reaches unity, the edge distance (De) is adequate for full potential shear cone area development, and the reduced capacity ($R\,P_{uc}$) is equal to the full capacity (P_{uc}). In this case, the radius (R) of the potential shear cone represents the spacing necessary to develop the anchor capacity (P_{ue}). $R\,P_{uc}$ or reduced capacity cannot exceed the full capacity (P_{ue}).

4.5 Headed Anchor Tension Capacities

Table 4. shows the embedded tension capacities for **stock size** Nelson headed anchors. Note that the concrete capacity (Puc) is shown only for those anchors where the concrete capacity governs.

Anchors with full embedment where anchor capacity controls show the value (Pue) for anchor embedment capacity.

In confirmation of the data contained in Table

Table 4. Design Embedded Tension Capacities of Stock Size Headed Anchors — Full Shear Cone Area Development

(1.) Anchor Size	(2.) A.W. Length	Head Diameter	Head Thickness	Le (In.)	Ultimate Embedded Strength of Anchor (Pue) Kips	Tension Capacity (Puc)* — Kips (3.) f'c = 3000 psi NWT	(3.) f'c = 4000 psi NWT	(3.) f'c = 5000 psi NWT	(4.) f'c = 3000 psi SLWT	(4.) f'c = 4000 psi SLWT	(4.) f'c = 5000 psi SLWT	(5.) f'c = 3000 psi ALWT	(5.) f'c = 4000 psi ALWT	(5.) f'c = 5000 psi ALWT
1/4 x 2 11/16	2 9/16	.500	.187	2 3/8	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65
1/4 x 4 1/8	4	.500	.187	3 13/16	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65
3/8 x 4 1/8	4	.750	.281											
3/8 x 6 1/8	6	.750	.281	3 23/32	5.96	5.96	5.96	5.96	5.96	5.96	5.96	5.96	5.96	5.96
				5 23/32	5.96	5.96	5.96	5.96	5.96	5.96	5.96	5.96	5.96	5.96
1/2 x 2 1/8	2	1.00	.312	1 11/16	10.60	3.75	4.33	4.84	3.18	3.68	4.11	2.81	3.25	3.63
1/2 x 3 1/8	3	1.00	.312	2 11/16	10.60	8.20	9.46	10.58	6.97	8.04	8.99	6.15	7.10	7.94
1/2 x 4 1/8	4	1.00	.312	3 11/16	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60
1/2 x 5 5/16	5 3/16	1.00	.312	4 7/8	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60
1/2 x 6 1/8	6	1.00	.312	5 11/16	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60
1/2 x 8 1/8	8	1.00	.312	7 11/16	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60	10.60
5/8 x 2 11/16	2 1/2	1.250	.312	2 3/16	16.56	6.22	7.18	8.00	5.29	6.10	6.80	4.66	5.39	6.00
5/8 x 6 9/16	6 3/8	1.250	.312	6 1/16	16.56	16.56	16.56	16.56	16.56	16.56	16.56	16.56	16.56	16.56
5/8 x 8 3/16	8	1.250	.312	7 11/16	16.56	16.56	16.56	16.56	16.56	16.56	16.56	16.56	16.56	16.56
3/4 x 3 3/16	3	1.250	.375	2 5/8	23.86	8.41	9.71	10.86	7.15	8.25	9.23	6.31	7.28	8.15
3/4 x 3 11/16	3 1/2	1.250	.375	3 1/8	23.86	11.31	13.05	14.60	9.61	11.09	12.41	8.48	9.79	10.95
3/4 x 4 3/16	4	1.250	.375	3 5/8	23.86	14.62	16.87	18.87	12.43	14.34	16.04	10.97	12.65	14.15
3/4 x 5 3/16	5	1.250	.375	4 5/8	23.86	22.48	23.86	23.86	19.11	22.05	23.86	16.86	19.46	21.76
3/4 x 6 3/16	6	1.250	.375	5 5/8	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86
3/4 x 7 3/16	7	1.250	.375	6 5/8	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86
3/4 x 8 3/16	8	1.250	.375	7 5/8	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86	23.86
7/8 x 3 11/16	3 1/2	1.375	.375	3 1/8	32.47	11.63	13.43	15.01	9.89	11.42	12.76	8.72	10.07	11.26
7/8 x 4 3/16	4	1.375	.375	3 5/8	32.47	15.00	17.30	19.35	12.75	14.71	16.45	11.25	12.98	14.51
7/8 x 5 3/16	5	1.375	.375	4 5/8	32.47	22.96	26.49	29.63	19.52	22.52	25.19	17.22	19.87	22.22
7/8 x 6 3/16	6	1.375	.375	5 5/8	32.47	32.47	32.47	32.47	27.68	31.95	32.47	24.43	28.19	31.53
7/8 x 7 3/16	7	1.375	.375	6 5/8	32.47	32.47	32.47	32.47	32.47	32.47	32.47	32.47	32.47	32.47
7/8 x 8 3/16	8	1.375	.375	7 5/8	32.47	32.47	32.47	32.47	32.47	32.47	32.47	32.47	32.47	32.47

NOTES: (1.) Stock Anchor Sizes
(2.) A.W. — Length overall after welding to plate
(3.) NWT — Normal weight concrete (C = 1.0)
(4.) SLWT — Sand Lightweight Concrete (C = 0.85)
(5.) ALWT — All Lightweight Concrete (C = 0.75)

*Puc — From equation 5., Section 3.1 (where Puc > Pue, Pue controls.)

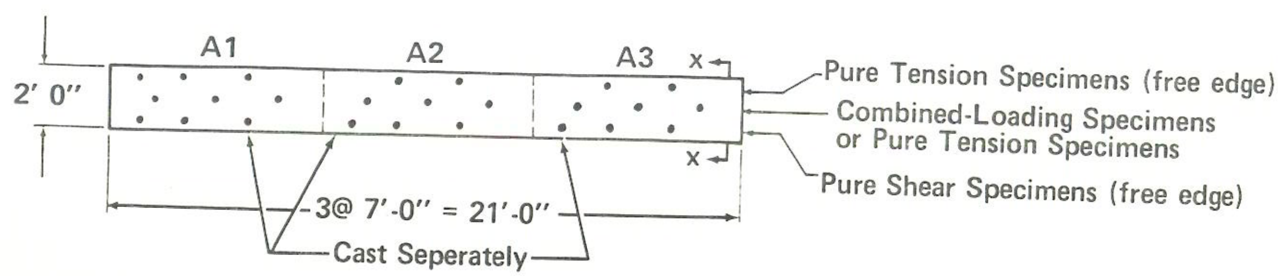
4., one part of the Lehigh tests[3] was tension-loading of headed anchors embedded in normal weight and all lightweight concrete beams. The beams were 2' x 2' and the full shear cone development confirmation test specimens were placed in the center of the beam so that no boundary conditions would influence the results. Table 5. summarizes the results of the tested specimens versus theoretical values from Table 4.

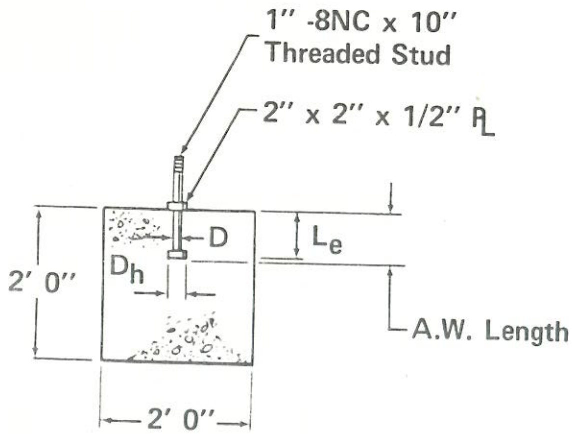
Note that specimens 5., 6. and 7., while exceeding the design embedment capacity (Pue) did not fail in the stud but in the concrete. If the value of concrete capacity (Puc) were to govern according to Equation 5., Section 4.3. failure of the concrete would be calculated as being some 73 kips for specimen 5. and 55 kips for specimens 6. and 7. Obviously, failure in the concrete at much lower values indicates that design embedment strength (Pue) for full embedment specimens not concrete strength (Puc) controls. A typical test beam, anchor arrangement and anchor test schedule are shown in Figure 6.

Table 5. Predicted Versus Actual Embedded Tension Capacity

Anchor Size (A.W. Length)	Concrete Type and Strength	Actual Load	Calculated Load*	Actual Failure Mode	Predicted Failure Mode
(1) ¾ x 7	NWT-5200 psi	28.3 Kips	23.86 Kips	Stud	Stud
(2) ¾ x 7	"	28.5	23.86	Stud	Stud
(3) ¾ x 7	"	28.0	23.86	Stud	Stud
(4) ¾ x 7	ALWT-5300	28.7	23.86	Stud	Stud
(5) ⅞ x 8	NWT-4900	43.0	32.47	Concrete	Stud
(6) ¾ x 8	ALWT-5300	30.1	23.86	Concrete	Stud
(7) ¾ x 8	"	31.5	23.86	Concrete	Stud
(8) ¾ x 4	NWT-5180	18.5	18.87	Concrete	Concrete
(9) ¾ x 4	"	18.5	18.87	Concrete	Concrete
(10) ¾ x 4	"	17.3	18.87	Concrete	Concrete

*For full embedment specimens, the ultimate design embedded strength of the anchor (Pue) is shown rather than the concrete capacity (Puc) since Puc > Pue.





Section X-X

Schedule of Anchor Sizes

Number Tested	D (in.)	A.W. Length (in.)	Le (in.)	D_h (in.)	Shank Area (in.)
28	¾	4	3⅝	1¼	.442
23	¾	7	6⅝	1¼	.442
6	¾	8	7⅝	1¼	.442
3	⅞	8	7⅝	1⅜	.601

FIGURE 6.—Typical Test Beam and Anchor Test Schedule

4.6 Spacing for Full Tension Capacity of Partially Embedded and Fully Embedded Anchors

The shear cone areas for partially embedded anchors are calculated with a 45° cone, making the surface area radius (R) equal to Le + Dh/2 in all cases. Spacing for a single anchor, between anchors or from the center of an anchor to a free edge are based on this fact.

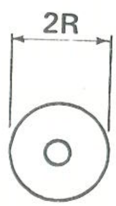
Spacings for full embedment anchors are based on calculating the surface area radius (R) according to Equation 6., Section 4.4. by setting the term

$$\frac{2\,De}{9\,Ds}(c)\sqrt{\frac{f'c}{5000}} = 1 \text{ and solving for De}$$

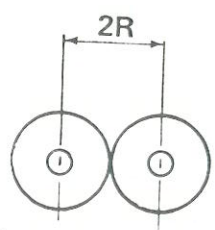
Table 6. shows the minimum spacing required for full shear cone development capacity for stock size anchors in various concrete types and densities.

Table 6. Spacing For Full Tension Capacity Development Of Stock Size Headed Anchors Anchor Spacing (R) In Inches

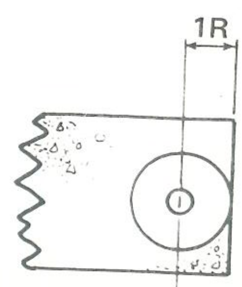
Anchor Size	Normal Weight Concrete 3000 psi	4000 psi	5000 psi	Sand Lightweight Concrete 3000 psi	4000 psi	5000 psi	All Lightweight Concrete 3000 psi	4000 psi	5000 psi
$\frac{1}{4} \times 2\frac{11}{16}$	1.535 in.	1.330 in.	1.190 in.	1.808 in.	1.566 in.	1.401 in.	2.047 in.	1.774 in.	1.587 in.
$\frac{1}{4} \times 4\frac{1}{8}$	1.535	1.330	1.190	1.808	1.566	1.401	2.047	1.774	1.587
$\frac{3}{8} \times 4\frac{1}{8}$	2.305	1.997	1.786	2.712	2.348	2.100	3.073	2.662	2.381
$\frac{3}{8} \times 6\frac{1}{8}$	2.305	1.997	1.786	2.712	2.348	2.100	3.073	2.662	2.381
$\frac{1}{2} \times 2\frac{1}{8}$	2.188	2.188	2.188	2.188	2.188	2.188	2.188	2.188	2.188
$\frac{1}{2} \times 3\frac{1}{8}$	3.188	3.188	3.188	3.188	3.188	3.188	3.188	3.188	3.188
$\frac{1}{2} \times 4\frac{1}{8}$	3.070	2.661	2.380	3.613	3.131	2.800	4.096	3.548	3.174
$\frac{1}{2} \times 5\frac{5}{16}$	3.070	2.661	2.380	3.613	3.131	2.800	4.096	3.548	3.174
$\frac{1}{2} \times 6\frac{1}{8}$	3.070	2.661	2.380	3.613	3.131	2.800	4.096	3.548	3.174
$\frac{1}{2} \times 8\frac{1}{8}$	3.070	2.661	2.380	3.613	3.131	2.800	4.096	3.548	3.174
$\frac{5}{8} \times 2\frac{11}{16}$	2.813	2.813	2.813	2.813	2.813	2.813	2.813	2.813	2.813
$\frac{5}{8} \times 6\frac{9}{16}$	3.843	3.327	2.976	4.520	3.914	3.500	5.122	4.436	3.968
$\frac{5}{8} \times 8\frac{3}{16}$	3.843	3.327	2.976	4.520	3.914	3.500	5.122	4.436	3.968
$\frac{3}{4} \times 3\frac{3}{16}$	3.250	3.250	3.250	3.250	3.250	3.250	3.250	3.250	3.250
$\frac{3}{4} \times 3\frac{11}{16}$	3.750	3.750	3.750	3.750	3.750	3.750	3.750	3.750	3.750
$\frac{3}{4} \times 4\frac{3}{16}$	4.250	4.250	4.250	4.250	4.250	4.250	4.250	4.250	4.250
$\frac{3}{4} \times 5\frac{3}{16}$	5.250	3.992	3.571	5.250	5.250	5.250	5.250	4.250	4.250
$\frac{3}{4} \times 6\frac{3}{16}$	4.610	3.992	3.571	5.424	4.697	4.201	5.250	5.250	5.250
$\frac{3}{4} \times 7\frac{3}{16}$	4.610	3.992	3.571	5.424	4.697	4.201	6.147	5.323	4.761
$\frac{3}{4} \times 8\frac{3}{16}$	4.610	3.992	3.571	5.424	4.697	4.201	6.147	5.323	4.761
$\frac{7}{8} \times 3\frac{11}{16}$	3.813	3.813	3.813	3.813	3.813	3.813	6.147	5.323	4.761
$\frac{7}{8} \times 4\frac{3}{16}$	4.313	4.313	4.313	4.313	4.313	4.313	3.813	3.813	3.813
$\frac{7}{8} \times 5\frac{3}{16}$	5.313	5.313	5.313	5.313	5.313	5.313	4.313	4.313	4.313
$\frac{7}{8} \times 6\frac{3}{16}$	5.377	4.657	4.167	6.313	6.313	4.901	5.313	5.313	5.313
$\frac{7}{8} \times 7\frac{3}{16}$	5.377	4.657	4.167	6.326	5.479	4.901	6.313	6.313	6.313
$\frac{7}{8} \times 8\frac{3}{16}$	5.377	4.657	4.167	6.326	5.479	4.901	7.169	6.210	5.555



Minimum spacing for single anchor = 2R



Minimum spacing between anchors = 2R



Minimum spacing, center of anchor to free edge = 1R

4.7 Reduced Anchor Tension Capacity — Partial Shear Cone

The case of an anchor having sufficient concrete area surrounding it to develop a full shear cone or optimum capacity is not frequently found in practice due to the configuration of the concrete member in which the anchor is embedded.

More frequently, the physical dimensions of the member cause a reduction in anchor capacity for two primary reasons.

A. **Boundary Conditions** — Reduction in shear cone area due to one or more edge conditions can occur as shown in Figure 7.

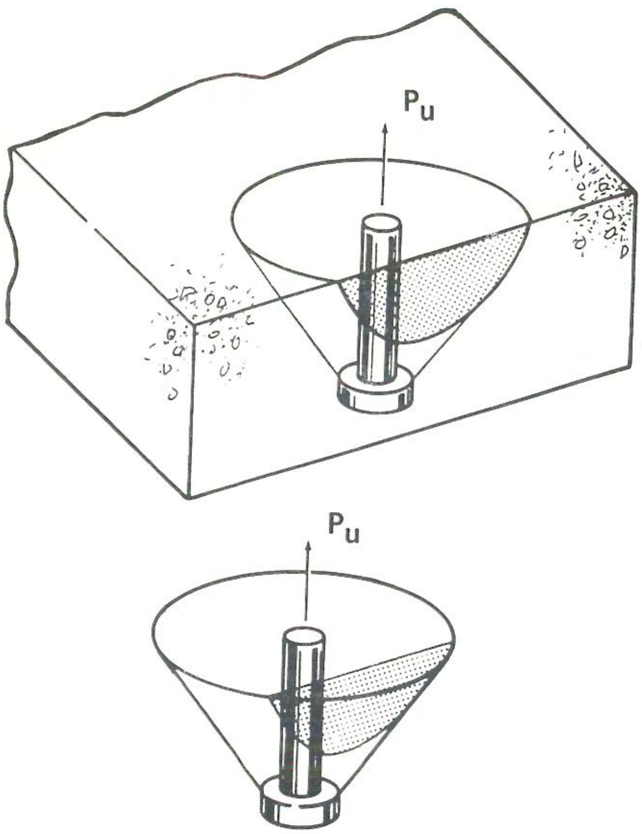


FIGURE 7. — Boundary or Free Edge Condition

B. **Spacing Conditions** — To meet loading requirements, headed anchors may be grouped or clustered. Again, due to physical limitations, the distance between anchors may not be sufficient to allow full shear cone area development. Essentially, the cone areas overlap, producing a reduced area similar to that of a free edge as shown in Figure 8.

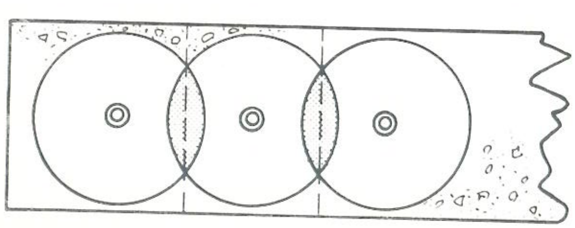


FIGURE 8. — Overlapping Spacing Condition

Overlapping Spacing Condition

Common reduction cases are shown in Figures 9, 10 and 11.

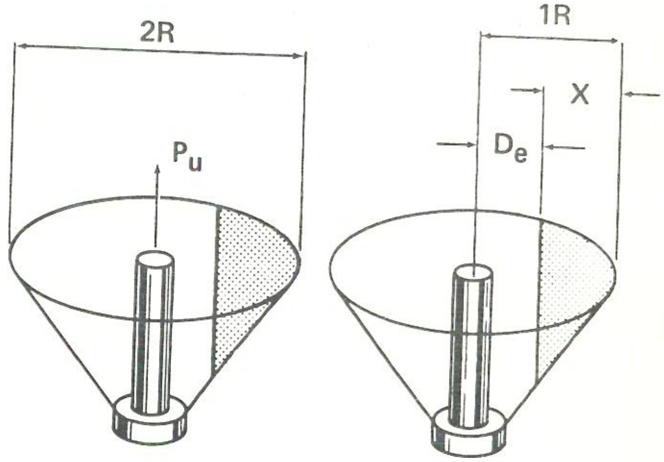


FIGURE 9.—One Reduction to Full Shear Cone.

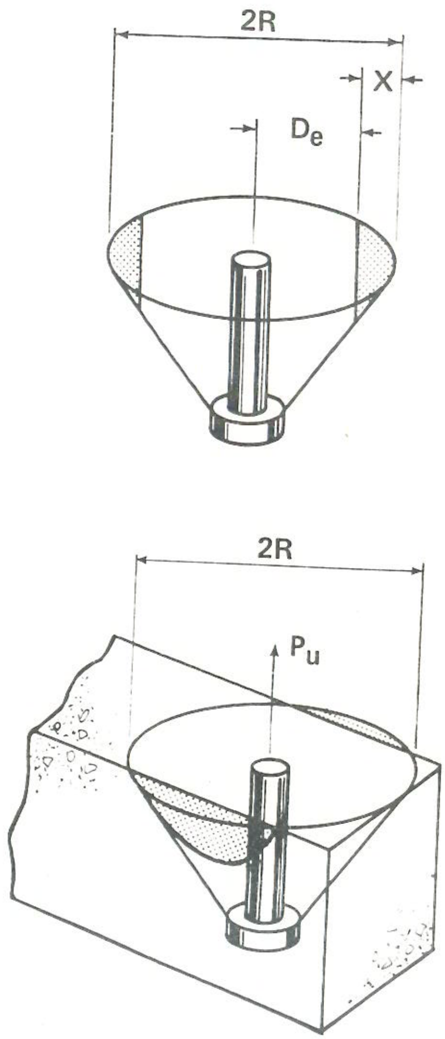


FIGURE 10.—Two Reductions to Full Shear Cone

CONE A - THREE REDUCTIONS

CONE B - FOUR REDUCTIONS

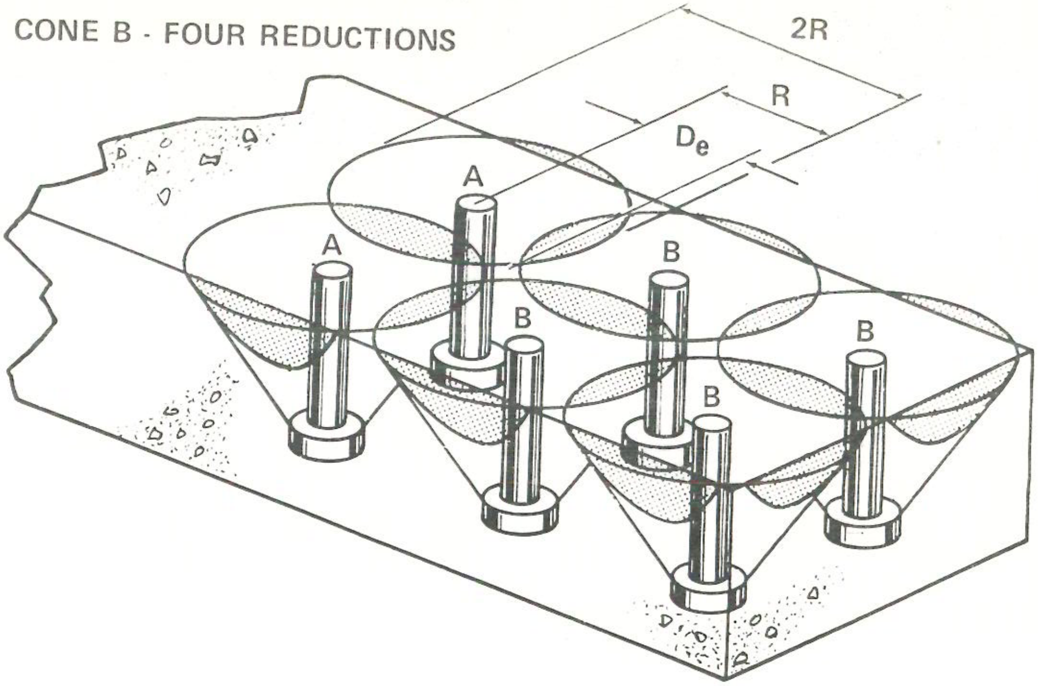


FIGURE 11.—Three and Four Reductions to Full Shear Cone

Finally, in the infrequent case where full cones overlap with very tight spacing, the areas of reduction may also overlap. Figure 12. shows such an example. In calculating the reduced capacity of each anchor, the overlapping areas of reduction may normally be ignored.

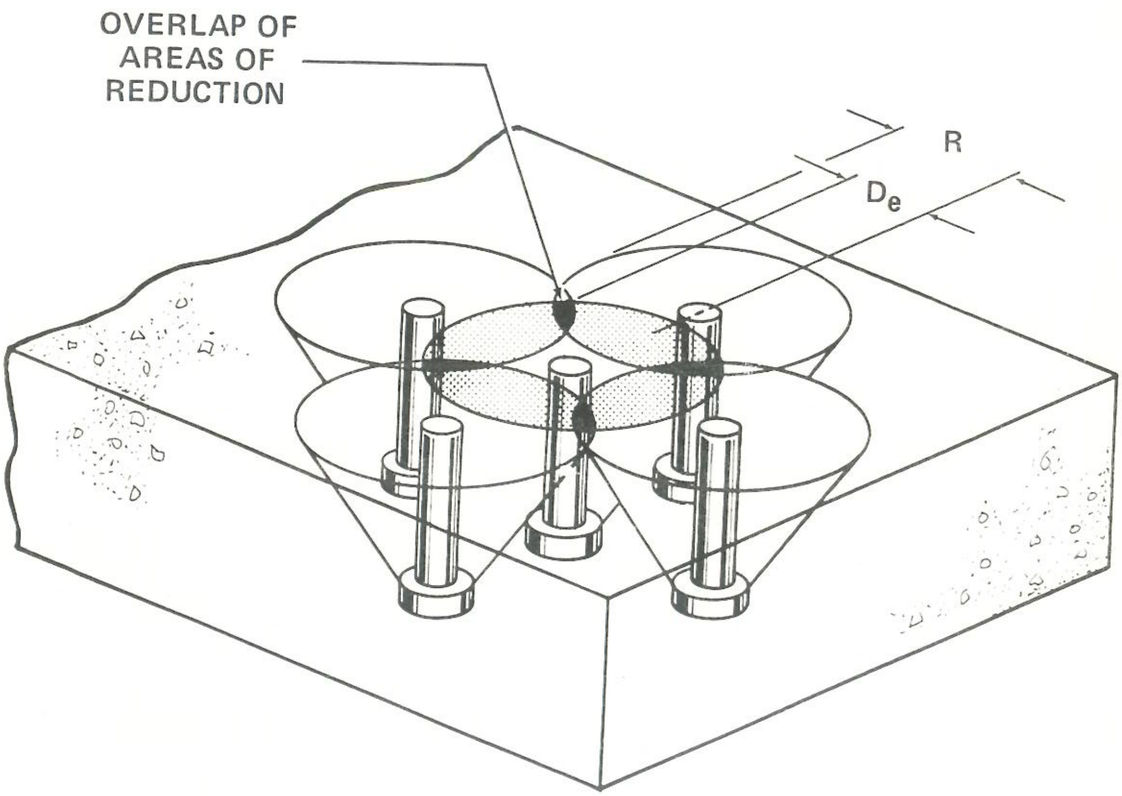


FIGURE 12.—Overlapping Areas of Reduction (Ar)

4.8 Calculating Reduced Tension Capacity

In calculating the reduced capacity of a headed anchor shear cone influenced by boundary conditions, the extent of reduction is dependent upon whether the anchor is long enough to develop its full embedment strength (Pue) or whether the concrete capacity (Puc) controls.

4.8.1 Partial Embedment — Reduced Shear Cone

When the headed anchor is of insufficient length to develop full anchor embedment capacity, Puc or concrete capacity controls. From Section 4.2 Puc or concrete capacity may be calculated as:

$$Puc = \phi\, CK\, Afc \sqrt{f'c}$$

When subject to reduction, the reduced capacity may be stated as:

$$R\,Puc = \phi\, CK\, (A_{fc} - Ar)\sqrt{f'c}$$

or

$$R\,Puc = \phi\, CK\, (A_{pc})\sqrt{f'c}$$

(Equation 7.)

where

$R\,Puc$ = Reduced tension capacity in kips

ϕ, C, K as previously defined

A_{fc} = Area of the full shear cone in square inches

A_r = Area of reduction in square inches

A_{pc} = Area of the remaining or partial cone in square inches

A_{fc} or the full shear cone area of a partial embedment anchor may be calculated as:

$$A_{fc} = \pi S\,(R + r)$$

since partially embedded anchors pull a 45° shear cone in tension, full shear cone area is:

$$A_{fc} = \pi\sqrt{2}\,Le\,(Le + Dh)$$

Full shear cone areas (A_{fc}) for partial embedment, stock size anchors are shown in Table 7. along with partial cone areas (A_{pc}) for various single edge distances.

The area of the remaining or partial cone (A_{pc}) following reductions by boundary conditions may be calculated as:

$$A_{pc} = \pi\, R_R \sqrt{R_R^{2} + H^{2}}$$

where:

R_R = Radius of the remaining or partial cone

H = Height of the remaining or partial cone Depth and embedment Le

where more than one reduction to the cone is necessary, the reduced capacity may be described as:

$$R\,Puc = Puc - \left[\frac{A_{fc} - A_{pc}}{A_{fc}}(P_{uc})\right]_1 + \left[\frac{A_{fc} - A_{pc}}{A_{fc}}(Puc)\right]_2 \ldots\ldots \text{etc.}$$

(Equation 8.)

Table 7. Partial Shear Cone Areas For Partial Embedment Anchors

Anchor Size	AFC	Apc For Distance To Free Edge Of: 0.5 in.	1.0 in.	1.5 in.	2.0 in.	2.5 in.	3.0 in.	3.5 in.	4.0 in.	4.5 in.	5.0 in.	5.5 in.	6.0 in.
½ x 2⅛	20.14	9.12	11.63	14.48	17.70	—	—	—	—	—	—	—	—
½ x 3⅛	44.00	18.89	22.43	26.27	30.48	34.98	39.86	—	—	—	—	—	—
⅝ x 2¹¹⁄₁₆	33.29	—	17.44	20.90	24.69	29.59	—	—	—	—	—	—	—
¾ x 3³⁄₁₆	45.16	—	22.69	26.55	30.74	35.30	40.22	—	—	—	—	—	—
¾ x 3¹¹⁄₁₆	60.70	—	29.41	33.80	38.49	43.57	48.96	54.68	—	—	—	—	—
¾ x 4³⁄₁₆	78.46	—	37.05	41.93	47.15	52.68	58.56	64.78	71.37	—	—	—	—
¾ x 5³⁄₁₆	120.64	—	54.98	60.88	67.11	73.64	80.52	87.72	95.29	103.19	111.39	—	—
⅞ x 3¹¹⁄₁₆	62.44	—	29.92	34.34	39.08	44.18	49.61	55.43	—	—	—	—	—
⅞ x 4³⁄₁₆	80.48	—	37.61	42.54	47.79	53.37	59.34	65.60	72.17	—	—	—	—
⅞ x 5³⁄₁₆	123.21	—	55.70	61.62	67.88	74.46	81.37	88.68	96.20	104.13	112.40	—	—
⅞ x 6³⁄₁₆	174.83	—	77.28	84.22	91.50	99.10	107.03	115.26	123.87	132.76	141.99	151.58	161.62

4.8.2 Full Embedment — Reduced Shear Cone

In calculating the reduced capacity of a full embedment anchor where Puc ≥ Pue and the anchor embedment strength controls, Equation 6., section 4.4 provides a conservative estimate.

Restated, this formula to calculate individual reductions is:

$$R\,P_{ue} = P_{ue} - \left[Pue - \left(\frac{2\,De}{9\,Ds} C \sqrt{\frac{f'c}{5000}} \right) Pue \right]_1 + \text{etc.}$$

(Equation 9.)

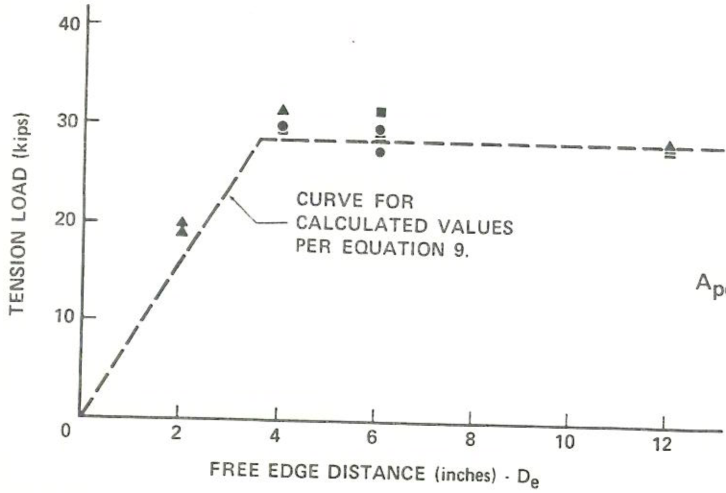
With both partial embedment and full embedment anchors, the reduced tension capacity of a shear cone subject to boundary or edge conditions is equal to the full tension capacity Pue or Puc minus the sum of the number of reductions. Under no condition can the anchor design capacity (Pue) be exceeded.

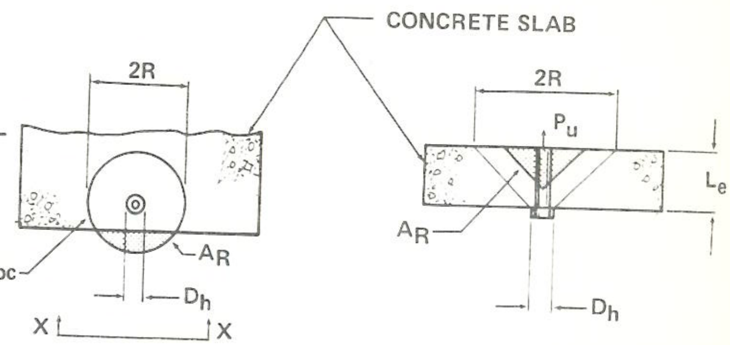
Tables 9. through 14. follow. These tables show the amount of a single reduction (in kips) to the tension capacities of stock size anchors for various edge distances. Tables 9, 10. and 11. are for normal weight concrete of 3, 4 and 5 Ksi compressive strength. Tables 12., 13. and 14. are for all lightweight concrete of the same compressive strengths.

Approximate reduction values for sand lightweight concrete may be calculated by interpolating between the values shown for normal and lightweight concretes.

Several specimens subject to edge condition reduction were tested in the Lehigh study[3]. Figure 13., shows the tested results plotted against the calculated curve for 3/4 x 7-3/16" full embedment specimens.

One specimen tested was a partial embedment anchor, 3/4 x 4-3/16" in 5000 psi normal weight concrete at a distance from the center of the anchor to the free edge of 2.0". Table 8. includes the calculated versus tested results for this case.





Symbol	Beam	Stud Size	fc (psi)	Concrete Type
△	A	3/4" x 7-3/16"	5270	Normal
■	B	3/4" x 7-3/16"	4900	"
O	C	3/4" x 7-3/16"	5180	"

FIGURE 13. — Tension Reduction

Table 8.

Specimen Size	Concrete Density	Tested Value	Calculated Value
3/4" x 4-3/16"	5000 psi Normal	11.0 Kips	11.34 Kips [1.]

Note: [1.] Value obtained from Table 9.

Table 8: 3/4" x 4-3/16" Headed Anchor with 2.0" Free Edge Distance in 5000 psi Normal Weight Concrete.

Table 9. Single Reduction Values For Various Edge Distances in 3000 Psi Normal Weight Concrete

Anchor Size	Radius N.W.C.(1.)	Tension Capacity(2.) Kips	Afc	Reduction To Tension Capacity (Kips) Distance From Center Of Anchor To Free Edge (Inches) De 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
1/4 x 2 11/16	1.535 in.	2.65	14.2	1.18	.73	.24	0	0	0	0	0	0	0
1/4 x 4 1/8	1.535	2.65	14.2	1.18	.73	.24	0	0	0	0	0	0	0
3/8 x 4 1/8	2.305	5.96	32.0	3.02	2.32	1.65	.92	0	0	0	0	0	0
3/8 x 6 1/8	2.305	5.96	32.0	3.02	2.32	1.65	.92	0	0	0	0	0	0
1/2 x 2 1/8	2.188	3.75	20.1	—	1.58	1.05	.46	0	0	0	0	0	0
1/2 x 3 1/8	3.188	8.20	44.0	—	4.02	3.30	2.52	1.68	.78	0	0	0	0
1/2 x 4 1/8	3.070	10.60	56.9	—	4.72	3.85	2.94	1.97	.96	0	0	0	0
1/2 x 5 5/16	3.070	10.60	56.9	—	4.72	3.85	2.94	1.97	.96	0	0	0	0
1/2 x 6 1/8	3.070	10.60	56.9	—	4.72	3.85	2.94	1.97	.96	0	0	0	0
1/2 x 8 1/8	3.070	10.60	56.9	—	4.72	3.85	2.94	1.97	.96	0	0	0	0
5/8 x 2 11/16	2.813	6.22	33.3	—	2.95	2.31	1.60	.69	0	0	0	0	0
5/8 x 6 9/16	3.843	16.56	88.9	—	7.89	6.82	5.72	4.57	3.38	2.13	0	0	0
5/8 x 8 3/16	3.843	16.56	88.9	—	7.89	6.82	5.72	4.57	3.38	2.13	0	0	0
3/4 x 3 3/16	3.250	8.41	45.2	—	—	3.47	2.69	1.84	.92	0	0	0	0
3/4 x 3 11/16	3.750	11.31	60.7	—	—	5.01	4.14	3.19	2.19	1.12	0	0	0
3/4 x 4 3/16	4.250	14.62	78.5	—	—	6.81	5.84	4.81	3.71	2.55	1.33	0	0
3/4 x 5 3/16	5.250	22.48	120.6	—	—	11.14	9.98	8.76	7.48	6.13	4.72	3.25	1.72
3/4 x 6 3/16	4.610	23.86	128.1	—	—	10.61	9.32	7.99	6.61	5.17	3.69	2.15	0
3/4 x 7 3/16	4.610	23.86	128.1	—	—	10.61	9.32	7.99	6.61	5.17	3.69	2.15	0
3/4 x 8 3/16	4.610	23.86	128.1	—	—	10.61	9.32	7.99	6.61	5.17	3.69	2.15	0
7/8 x 3 11/16	3.813	11.63	62.4	—	—	5.24	4.36	3.40	2.40	1.31	0	0	0
7/8 x 4 3/16	4.313	15.00	80.5	—	—	7.07	6.09	5.05	3.94	2.77	1.55	0	0
7/8 x 5 3/16	5.313	22.96	123.2	—	—	11.48	10.32	9.09	7.80	6.44	5.04	3.56	2.02
7/8 x 6 3/16	5.377	32.47	174.4	—	—	15.18	13.70	12.18	10.61	9.00	7.33	5.62	3.84
7/8 x 7 3/16	5.377	32.47	174.4	—	—	15.18	13.70	12.18	10.61	9.00	7.33	5.62	3.84
7/8 x 8 3/16	5.377	32.47	174.4	—	—	15.18	13.70	12.18	10.61	9.00	7.33	5.62	3.84

Notes: (1.) Radius Or R From Table 6., Section 4.6.
(2.) Tension Capacity Puc Or Pue From Table 4., Section 4.5.

Table 10. Single Reduction Values For Various Edge Distances In 4000 Psi Normal Weight Concrete

Anchor Size	Radius N.W.C.(1.)	Tension Capacity(2.) Kips	Afc	Reduction To Tension Capacity (Kips) Distance From Center Of Anchor To Free Edge (Inches) De 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
1/4 x 2 11/16	1.330 in.	2.65	12.3	1.15	.65	0	0	0	0	0	0	0	0
1/4 x 4 1/8	1.330	2.65	12.3	1.15	.65	0	0	0	0	0	0	0	0
3/8 x 4 1/8	1.997	5.96	27.7	2.92	2.22	1.47	0	0	0	0	0	0	0
3/8 x 6 1/8	1.997	5.96	27.7	2.92	2.22	1.47	0	0	0	0	0	0	0
1/2 x 2 1/8	2.188	4.33	20.1	—	1.82	1.22	.53	0	0	0	0	0	0
1/2 x 3 1/8	3.188	9.46	44.0	—	4.64	3.81	2.91	1.94	.89	0	0	0	0
1/2 x 4 1/8	2.661	10.60	49.3	—	4.59	3.63	2.62	1.55	0	0	0	0	0
1/2 x 5 5/16	2.661	10.60	49.3	—	4.59	3.63	2.62	1.55	0	0	0	0	0
1/2 x 6 1/8	2.661	10.60	49.3	—	4.59	3.63	2.62	1.55	0	0	0	0	0
1/2 x 8 1/8	2.661	10.60	49.3	—	4.59	3.63	2.62	1.55	0	0	0	0	0
5/8 x 2 11/16	2.813	7.18	33.3	—	3.41	2.66	1.85	.80	0	0	0	0	0
5/8 x 6 9/16	3.327	16.56	77.0	—	7.75	6.58	5.36	4.09	2.76	0	0	0	0
5/8 x 8 3/16	3.327	16.56	77.0	—	7.75	6.68	5.36	4.09	2.76	0	0	0	0
3/4 x 3 3/16	3.250	9.71	45.2	—	—	4.00	3.10	2.12	1.06	0	0	0	0
3/4 x 3 11/16	3.750	13.05	60.7	—	—	5.78	4.77	3.68	2.52	1.29	0	0	0
3/4 x 4 3/16	4.250	16.87	78.5	—	—	7.85	6.73	5.54	4.28	2.94	1.52	0	0
3/4 x 5 3/16	3.992	23.86	111.0	—	—	10.35	8.92	7.44	5.91	4.33	0	0	0
3/4 x 6 3/16	3.992	23.86	111.0	—	—	10.35	8.92	7.44	5.91	4.33	0	0	0
3/4 x 7 3/16	3.992	23.86	111.0	—	—	10.35	8.92	7.44	5.91	4.33	0	0	0
3/4 x 8 3/16	3.992	23.86	111.0	—	—	10.35	8.92	7.44	5.91	4.33	0	0	0
7/8 x 3 11/16	3.813	13.43	62.4	—	—	6.04	5.02	3.92	2.76	1.51	0	0	0
7/8 x 4 3/16	4.313	17.30	80.5	—	—	8.15	7.03	5.83	4.54	3.20	1.79	0	0
7/8 x 5 3/16	5.313	26.49	123.2	—	—	13.24	11.90	10.49	8.99	7.43	5.81	4.10	2.32
7/8 x 6 3/16	4.657	32.47	151.0	—	—	14.88	13.24	11.55	9.82	8.03	6.19	4.29	0
7/8 x 7 3/16	4.657	32.47	151.0	—	—	14.88	13.24	11.55	9.82	8.03	6.19	4.29	0
7/8 x 8 3/16	4.657	32.47	151.0	—	—	14.88	13.24	11.55	9.82	8.03	6.19	4.29	0

Notes: (1.) Radius Or R From Table 6., Section 4.6.
(2.) Tension Capacity Puc or Pue From Table 4., Section 4.5.

In 5000 Psi Normal Weight Concrete

Anchor Size	Radius N.W.C.(1.)	Tension Capacity (2.) Kips	Afc	Reduction To Tension Capacity (Kips) Distance From Center Of Anchor To Free Edge (Inches) De									
				0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
1/4 x 2 11/16	1.190 in.	2.65	11.0	1.11	.58	0	0	0	0	0	0	0	0
1/4 x 4 1/8	1.190	2.65	11.0	1.11	.58	0	0	0	0	0	0	0	0
3/8 x 4 1/8	1.786	5.96	24.8	2.89	2.12	1.30	0	0	0	0	0	0	0
3/8 x 6 1/8	1.786	5.96	24.8	2.89	2.12	1.30	0	0	0	0	0	0	0
1/2 x 2 1/8	2.188	4.84	20.1	—	2.04	1.36	.59	0	0	0	0	0	0
1/2 x 3 1/8	3.188	10.58	44.0	—	5.19	4.26	3.25	2.17	1.00	0	0	0	0
1/2 x 4 1/8	2.380	10.60	44.1	—	4.46	3.42	2.32	0	0	0	0	0	0
1/2 x 5 5/16	2.380	10.60	44.1	—	4.46	3.42	2.32	0	0	0	0	0	0
1/2 x 6 1/8	2.380	10.60	44.1	—	4.46	3.42	2.32	0	0	0	0	0	0
1/2 x 8 1/8	2.380	10.60	44.1	—	4.46	3.42	2.32	0	0	0	0	0	0
5/8 x 2 11/16	2.813	8.00	33.3	—	3.81	2.98	2.07	.89	0	0	0	0	0
5/8 x 6 9/16	2.976	16.56	68.9	—	7.60	6.33	5.00	3.62	0	0	0	0	0
5/8 x 8 3/16	2.976	16.56	68.9	—	7.60	6.33	5.00	3.62	0	0	0	0	0
3/4 x 3 3/16	3.250	10.86	45.2	—	—	4.48	3.47	2.37	1.19	0	0	0	0
3/4 x 3 11/16	3.750	14.60	60.7	—	—	6.47	5.34	4.12	2.82	1.45	0	0	0
3/4 x 4 3/16	4.250	18.87	78.5	—	—	8.79	7.53	6.20	4.79	3.29	1.71	0	0
3/4 x 5 3/16	3.571	23.86	99.2	—	—	10.04	8.49	6.88	5.22	3.50	0	0	0
3/4 x 6 3/16	3.571	23.86	99.2	—	—	10.04	8.49	6.88	5.22	3.50	0	0	0
3/4 x 7 3/16	3.571	23.86	99.2	—	—	10.04	8.49	6.88	5.22	3.50	0	0	0
3/4 x 8 3/16	3.571	23.86	99.2	—	—	10.04	8.49	6.88	5.22	3.50	0	0	0
7/8 x 3 11/16	3.813	15.01	62.4	—	—	6.76	5.62	4.39	3.09	1.69	0	0	0
7/8 x 4 3/16	4.313	19.35	80.5	—	—	9.12	7.86	6.52	5.08	3.58	2.00	0	0
7/8 x 5 3/16	5.313	29.63	123.2	—	—	14.81	13.31	11.73	10.06	8.31	6.50	4.59	2.60
7/8 x 6 3/16	4.167	32.47	135.0	—	—	14.55	12.76	10.92	9.04	7.09	5.09	0	0
7/8 x 7 3/16	4.167	32.47	135.0	—	—	14.55	12.76	10.92	9.04	7.09	5.09	0	0
7/8 x 8 3/16	4.167	32.47	135.0	—	—	14.55	12.76	10.92	9.04	7.09	5.09	0	0

Notes: (1.) Radius Or R From Table 6., Section 4.6.
(2.) Tension Capacity Puc or Pue From Table 4., Section 4.5.

Table 12. Single Reduction Values For Various Edge Distances In 3000 Psi All Lightweight Concrete

Anchor Size	Radius ALWT(1.)	Tension Capacity (2.) Kips	Afc	Reduction To Tension Capacity (Kips) Distance From Center Of Anchor To Free Edge (Inches) De												
				0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
1/4 x 2 11/16	2.05 in.	2.65	19.0	1.21	.84	.42	0	0	0	0	0	0	0	0	0	0
1/4 x 4 1/8	2.05	2.65	19.0	1.21	.84	.42	0	0	0	0	0	0	0	0	0	0
3/8 x 4 1/8	3.07	5.96	42.7	2.97	2.44	1.87	1.26	.61	0	0	0	0	0	0	0	0
3/8 x 6 1/8	3.07	5.96	42.7	2.97	2.44	1.87	1.26	.61	0	0	0	0	0	0	0	0
1/2 x 2 1/8	2.19	2.81	20.1	—	1.19	.79	.35	0	0	0	0	0	0	0	0	0
1/2 x 3 1/8	3.19	6.15	44.0	—	3.02	2.48	1.89	1.26	.59	0	0	0	0	0	0	0
1/2 x 4 1/8	4.10	10.60	75.9	—	4.82	4.09	3.33	2.53	1.68	.79	0	0	0	0	0	0
1/2 x 5 5/16	4.10	10.60	75.9	—	4.82	4.09	3.33	2.53	1.68	.79	0	0	0	0	0	0
1/2 x 6 1/8	4.10	10.60	75.9	—	4.82	4.09	3.33	2.53	1.68	.79	0	0	0	0	0	0
1/2 x 8 1/8	4.10	10.60	75.9	—	4.82	4.09	3.33	2.53	1.68	.79	0	0	0	0	0	0
5/8 x 2 11/16	2.81	4.66	33.3	—	2.21	1.73	1.20	.52	0	0	0	0	0	0	0	0
5/8 x 6 9/16	5.12	16.56	118.6	—	7.96	7.08	6.16	5.26	4.20	3.16	2.07	.94	0	0	0	0
5/8 x 8 3/16	5.12	16.56	118.6	—	7.96	7.08	6.16	5.26	4.20	3.16	2.07	.94	0	0	0	0
3/4 x 3 3/16	3.25	6.31	45.2	—	—	2.60	2.02	1.38	.69	0	0	0	0	0	0	0
3/4 x 3 11/16	3.75	8.48	60.7	—	—	3.76	3.11	2.39	1.64	.84	0	0	0	0	0	0
3/4 x 4 3/16	4.25	10.97	78.5	—	—	5.11	4.38	3.61	2.78	1.91	1.00	0	0	0	0	0
3/4 x 5 3/16	5.25	16.86	120.6	—	—	8.69	7.49	6.57	5.61	4.60	3.54	2.44	1.29	0	0	0
3/4 x 6 3/16	6.15	23.86	170.8	—	—	10.84	9.76	8.65	7.49	6.29	5.05	3.77	2.44	1.07	0	0
3/4 x 7 3/16	6.15	23.86	170.8	—	—	10.84	9.76	8.65	7.49	6.29	5.05	3.77	2.44	1.07	0	0
3/4 x 8 3/16	6.15	23.86	170.8	—	—	10.84	9.76	8.65	7.49	6.29	5.05	3.77	2.44	1.07	0	0
7/8 x 3 11/16	3.81	8.72	62.4	—	—	3.93	3.27	2.55	1.80	.98	0	0	0	0	0	0
7/8 x 4 3/16	4.31	11.25	80.5	—	—	5.30	4.57	3.79	2.96	2.08	1.16	0	0	0	0	0
7/8 x 5 3/16	5.31	17.22	123.2	—	—	8.61	7.74	6.82	5.85	4.83	3.78	2.67	1.52	0	0	0
7/8 x 6 3/16	6.31	24.43	174.8	—	—	12.66	11.65	10.59	9.48	8.32	7.12	5.88	4.59	3.25	1.85	0
7/8 x 7 3/16	7.17	32.47	232.5	—	—	15.37	14.14	12.86	11.55	10.20	8.81	7.37	5.90	4.38	2.81	1.20
7/8 x 8 3/16	7.17	32.47	232.5	—	—	15.37	14.14	12.86	11.55	10.20	8.81	7.37	5.90	4.28	2.81	1.20

Notes: (1.) Radius Or R From Table 6., Section 4.6.
(2.) Tension Capacity Puc Or Pue From Table 4., Section 4.5.

Table 13. Single Reduction Values For Various Edge Distances In 4000 Psi All Lightweight Concrete

Anchor Size	Radius ALWT (1.)	Tension Capacity (2.) Kips	Afc	Reduction To Tension Capacity (Kips) — Distance From Center Of Anchor To Free Edge (Inches) De: 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
1/4 x 2 11/16	1.77 in.	2.65	16.4	1.20	.79	.34	0	0	0	0	0	0	0	0	0	0
1/4 x 4 1/8	1.77	2.65	16.4	1.20	.79	.34	0	0	0	0	0	0	0	0	0	0
3/8 x 4 1/8	2.66	5.96	37.0	2.98	2.40	1.78	1.12	.41	0	0	0	0	0	0	0	0
3/8 x 6 1/8	2.66	5.96	37.0	2.98	2.40	1.78	1.12	.41	0	0	0	0	0	0	0	0
1/2 x 2 1/8	2.19	3.25	20.1	—	1.37	.92	.40	0	0	0	0	0	0	0	0	0
1/2 x 3 1/8	3.19	7.10	44.0	—	3.48	2.86	2.18	1.46	.67	0	0	0	0	0	0	0
1/2 x 4 1/8	3.55	10.60	65.7	—	4.79	4.00	3.17	2.29	1.36	.39	0	0	0	0	0	0
1/2 x 5 5/16	3.55	10.60	65.7	—	4.79	4.00	3.17	2.29	1.36	.39	0	0	0	0	0	0
1/2 x 6 1/8	3.55	10.60	65.7	—	4.79	4.00	3.17	2.29	1.36	.39	0	0	0	0	0	0
1/2 x 8 1/8	3.55	10.60	65.7	—	4.79	4.00	3.17	2.29	1.36	.39	0	0	0	0	0	0
5/8 x 2 11/16	2.81	5.39	33.3	—	2.56	2.00	1.39	.60	0	0	0	0	0	0	0	
5/8 x 6 9/16	4.44	16.56	102.7	—	7.96	7.00	5.99	4.95	3.86	2.72	1.54	0	0	0	0	0
5/8 x 8 3/16	4.44	16.56	102.7	—	7.96	7.00	5.99	4.95	3.86	2.72	1.54	0	0	0	0	0
3/4 x 3 3/16	3.25	7.28	45.2	—	—	3.00	2.33	1.59	.80	0	0	0	0	0	0	0
3/4 x 3 11/16	3.75	9.79	60.7	—	—	4.34	3.58	2.76	1.89	.97	0	0	0	0	0	0
3/4 x 4 3/16	4.25	12.65	78.5	—	—	5.89	5.05	4.16	3.21	2.21	1.14	0	0	0	0	0
3/4 x 5 3/16	5.25	19.46	120.6	—	—	9.64	8.64	7.58	6.47	5.31	4.09	2.82	1.49	0	0	0
3/4 x 6 3/16	5.32	23.86	147.9	—	—	10.78	9.61	8.39	7.13	5.83	4.47	3.07	1.63	0	0	0
3/4 x 7 3/16	5.32	23.86	147.9	—	—	10.78	9.61	8.39	7.13	5.83	4.47	3.07	1.63	0	0	0
3/4 x 8 3/16	5.32	23.86	147.9	—	—	10.78	9.61	8.39	7.13	5.83	4.47	3.07	1.63	0	0	0
7/8 x 3 11/16	3.81	10.07	62.4	—	—	4.53	3.77	2.94	2.07	1.13	0	0	0	0	0	0
7/8 x 4 3/16	4.31	12.98	80.5	—	—	6.11	5.27	4.37	3.41	2.40	1.34	0	0	0	0	0
7/8 x 5 3/16	5.31	19.87	123.2	—	—	9.93	8.93	7.87	6.74	5.57	4.36	3.08	1.74	0	0	0
7/8 x 6 3/16	6.31	28.19	174.8	—	—	14.61	13.44	12.21	10.93	9.60	8.22	6.79	5.29	3.75	1.79	0
7/8 x 7 3/16	6.21	32.47	201.3	—	—	15.34	13.99	12.61	11.18	9.71	8.19	6.62	5.01	3.35	1.64	0
7/8 x 8 3/16	6.21	32.47	201.3	—	—	15.34	13.99	12.61	11.18	9.71	8.19	6.62	5.01	3.35	1.64	0

Notes: (1.) Radius Or R From Table 6., Section 4.6.
(2.) Tension Capacity Puc Or Pue From Table 4., Section 4.5.

Table 14. Single Reduction Values For Various Edge Distances In 5000 Psi All Lightweight Concrete

Anchor Size	Radius ALWT (1.)	Tension Capacity (2.) Kips	Afc	Reduction To Tension Capacity (Kips) — Distance From Center Of Anchor To Free Edge (Inches) De: 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
1/4 x 2 11/16	1.587 in.	2.65	14.7	1.18	.75	.26	0	0	0	0	0	0	0	0	0	0
1/4 x 4 1/8	1.587	2.65	14.7	1.18	.75	.26	0	0	0	0	0	0	0	0	0	0
3/8 x 4 1/8	2.381	5.96	33.1	2.97	2.35	1.68	.97	0	0	0	0	0	0	0	0	0
3/8 x 6 1/8	2.381	5.96	33.1	2.97	2.35	1.68	.97	0	0	0	0	0	0	0	0	0
1/2 x 2 1/8	2.188	3.63	20.1	—	1.53	1.02	.44	0	0	0	0	0	0	0	0	0
1/2 x 3 1/8	3.188	7.94	44.0	—	3.89	3.20	2.44	1.63	.75	0	0	0	0	0	0	0
1/2 x 4 1/8	3.174	10.60	58.8	—	4.74	3.89	2.99	2.05	1.06	0	0	0	0	0	0	0
1/2 x 5 5/16	3.174	10.60	58.8	—	4.74	3.89	2.99	2.05	1.06	0	0	0	0	0	0	0
1/2 x 6 1/8	3.174	10.60	58.8	—	4.74	3.89	2.99	2.05	1.06	0	0	0	0	0	0	0
1/2 x 8 1/8	3.174	10.60	58.8	—	4.74	3.89	2.99	2.05	1.06	0	0	0	0	0	0	0
5/8 x 2 11/16	2.813	6.00	33.3	—	2.86	2.24	1.55	.67	0	0	0	0	0	0	0	0
5/8 x 6 9/16	3.968	16.56	91.8	—	7.90	6.87	5.79	4.67	3.49	2.27	0	0	0	0	0	0
5/8 x 8 3/16	3.968	16.56	91.8	—	7.90	6.87	5.79	4.67	3.49	2.27	0	0	0	0	0	0
3/4 x 3 3/16	3.250	8.15	45.2	—	—	3.36	2.60	1.78	.89	0	0	0	0	0	0	0
3/4 x 3 11/16	3.750	10.95	60.7	—	—	4.85	4.01	3.09	2.12	1.09	0	0	0	0	0	0
3/4 x 4 3/16	4.250	14.15	78.5	—	—	6.59	5.65	4.65	3.59	2.47	1.28	0	0	0	0	0
3/4 x 5 3/16	5.250	21.76	120.6	—	—	10.78	9.66	8.48	7.24	5.94	4.58	3.15	1.67	0	0	0
3/4 x 6 3/16	4.761	23.86	132.3	—	—	10.66	9.40	8.09	6.74	5.33	3.89	2.38	0	0	0	0
3/4 x 7 3/16	4.761	23.86	132.3	—	—	10.66	9.40	8.09	6.74	5.33	3.89	2.38	0	0	0	0
3/4 x 8 3/16	4.761	23.86	132.3	—	—	10.66	9.40	8.09	6.74	5.33	3.89	2.38	0	0	0	0
7/8 x 3 11/16	3.813	11.26	62.4	—	—	5.07	4.22	3.29	2.32	1.27	0	0	0	0	0	0
7/8 x 4 3/16	4.313	14.51	80.5	—	—	6.84	5.90	4.89	3.81	2.69	1.50	0	0	0	0	0
7/8 x 5 3/16	5.313	22.22	123.2	—	—	11.11	9.98	8.80	7.55	6.23	4.88	3.44	1.95	0	0	0
7/8 x 6 3/16	6.313	31.53	174.8	—	—	16.34	15.03	13.66	12.23	10.74	9.19	7.59	5.92	4.19	2.38	0
7/8 x 7 3/16	5.555	32.47	180.1	—	—	15.22	13.78	12.29	10.75	9.17	7.54	5.86	4.13	2.34	0	0
7/8 x 8 3/16	5.555	32.47	180.1	—	—	15.22	13.78	12.29	10.75	9.17	7.54	5.86	4.13	2.34	0	0

Notes: (1.) Radius Or R From Table 6., Section 4.6.
(2.) Tension Capacity Puc Or Pue From Table 4., Section 4.5.

4.8.3 Use of Tables 9. through 14.

An example calculation for reduced capacity of a headed anchor follows.

Case: Insert plate with 6 anchors, ½ x 6⅛, embedded in 5000# normal weight concrete for Figure 14. Find the reduced capacity of the end anchors, A. and the full plate capacity.

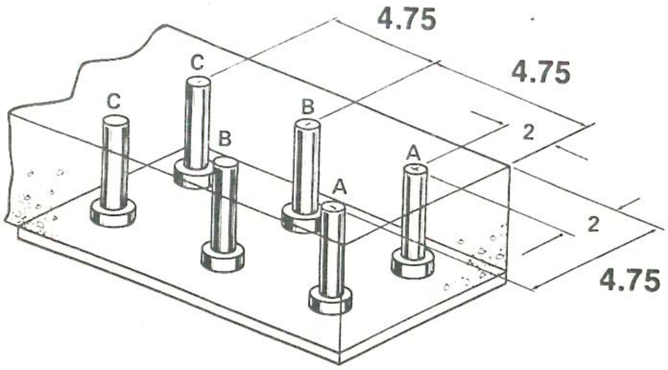
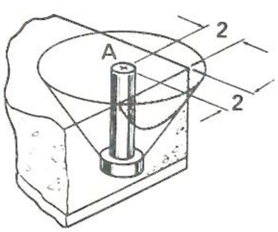


FIGURE 14.— Insert Plate With 6 Anchors



A. From Table 4., section 4.5 tension capacity of ½ x 6⅛" anchor in 5000# concrete — 10.60 kips

B. From Table 6., section 4.6 spacing for ½ x 6⅛ anchor in normal weight concrete = R = 2.38 in. Min. spacing between anchors = 4.76" = 2R. Min. spacing to free edge = 2.38" = R.

C. Spacing between anchors in Figure 14 is 4.75" or sufficient for full tension capacity.

D. Spacing to edge in Figure 14., is 2.0" not adequate for full capacity.

E. From Table 11., reduction values in 5000# concrete, 2.0" distance to free edge, A anchors with 2 reductions.

R Pue = Pue — (2.32 + 2.32)
R Pue = 10.60 — 4.64
R Pue = 5.96 kips = capacity of A anchors

F. Total capacity of insert in tension.
1. Two anchors (A) with 2 reductions = 2 x 5.96 = 11.92 Kips.
2. Four anchors (B. & C.) with 1 reduction = 4 (10.60 — 2.32) = 33.12 kips

Total insert plate capacity = 45.04 kips

Allowable load = $\frac{45.04}{2}$ = 22.52 Kips.

For additional sample problem see Section 7.0.

4.9 Anchors In Groups — A Note Of Caution

In some connection designs, the use of groups of headed studs is quite prevalent. These anchor groups use large numbers of studs spaced so closely that full conical areas cannot be developed. Examples of such grouping of headed anchors are seen in turbine mounting plates, column-beam connections, shelf angles, nuclear containment liner base rings, etc.

In these cases, whether the anchor is subject to a **shear** or **tension** load, there is a possibility that large numbers of headed anchors of the same embedment length may cause the establishment of a shear plane in the concrete. Failure then occurs in the concrete in the form of a truncated pyramid as shown in figure 15.

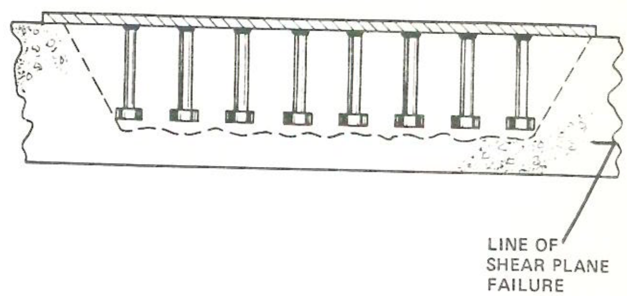


FIGURE 15. — Shear Plane Failure

Usually, calculation of the anchor group on the basis of individual anchors and their reductions yields a low allowable load for the connection. Calculation of the allowable shear or tension load by using the **surface area** of the truncated pyramid as Afc in the formula $Puc = \theta\ CK\ Afc\sqrt{f'c}$ should be made as a check on the anchor group performance. Problem No. 2 in the sample problem Section 7.0, shows this procedure. A higher allowable load value using the truncated pyramid area calculation is acceptable, provided that sufficient secondary reinforcement in the form of bars and/or mesh is employed to increase the connection performance into the ductile range.

It is far better to avoid the possibility of shear planes and reduced connection performance by applying the following corrective measures.

1. Change in anchor size
2. Change in anchor spacing
3. Placement of longer or shorter embedment length headed anchors in the stud pattern to disrupt the potential shear plane effect.

Finally, a confirming calculation based on group performance should be made on any cluster of anchors where the spacing between anchors approaches the 2R minimum suggested for tension in Table 6. and for shear in Table 16.

5.0 EMBEDMENT PROPERTIES OF HEADED ANCHORS IN SHEAR

5.1 Ultimate Embedded Shear Capacity

Shear capacities of embedded anchors have been the subject of numerous investigations. One study of Driscoll and Slutter[8] observed that a height-to-diameter ratio (H/Ds) of 4 or more for headed anchors embedded in normal weight concrete is sufficient to develop full shear capacity. The stud height is measured, after welding, from the top of the head to the weld plate as the entire stud resists the shear force.

Recently, Ollgaard, Slutter and Fisher[9] conducted a detailed investigation of the shear capacities of headed anchors in both normal and lightweight concrete. This report concluded that the ultimate shear capacity of a headed, stud welded anchor can be calculated as:

$S_{uc} = 1.106\ As\ f'c^{0.3}\ Ec^{0.44}$

Restated in terms of psi as used throughout this publication, the following is derived:
$Suc = 6.66 \times 10^{-3}\ As\ f'c^{0.3}\ Ec^{0.44}$

Where: **(Equation 10.)**

Suc = Concrete Shear Capacity of Headed anchor in kips.

f'c = 28 day concrete compressive strength, psi

Ec = modulus of elasticity, psi, which may be calculated as:
$Ec = W^{1.5}\ 33\ \sqrt{f'c}$ (ACI 318-71 Section 8.3.1)

where:
W = unit weight of concrete in pcf

A typical load slip curve based on ¾" diameter studs from the referenced report is shown in figure 16.

For engineering purposes, an ultimate strength design equation representing a conservative value for the embedded shear capacity of a headed anchor may be stated as:

$Suc = \phi\ 6.66 \times 10^{-3}\ As\ f'c^{0.3}\ Ec^{0.44} \leq Sue$

where $\phi = 0.85$

$Suc = 5.66 \times 10^{-3}\ As\ f'c^{0.3}\ Ec^{0.44} \leq Sue$

(Equation 11.)

where:

Sue = The ultimate embedded shear capacity of a headed anchor which cannot exceed 0.9 As fs.

Basically, the embedded shear capacity of a headed anchor is dependent upon the following:

1. **Concrete Properties**
   - **A. Weight**
   - **B. Compressive Strength**
   - **C. Modulus of elasticity**
2. **Headed Anchor Size**
   - **A. Shank area (As)**
   - **B. Height to diameter ratio (H/Ds)**
3. **Boundary Conditions**
4. **Anchor Spacing or Grouping**

Table 15. shows stock anchor sizes and their shear capacities in 145 pcf normal weight concrete and 110 pcf sand lightweight concrete of various densities.

These capacities are based on sufficient surrounding concrete so that the full shear strength may be developed.

The concrete weights chosen for use in Table 15. are among those most commonly used in normal and lightweight calculations. Actual shear capacities for concrete weights other than shown may be calculated by using Equation 11.

Shear capacity values for anchors embedded in all lightweight concrete will be slightly less than these shown in Table 15. The difference is slight enough, however, that the use of the values shown for headed anchor shear capacity in all types of lightweight concrete are acceptable.

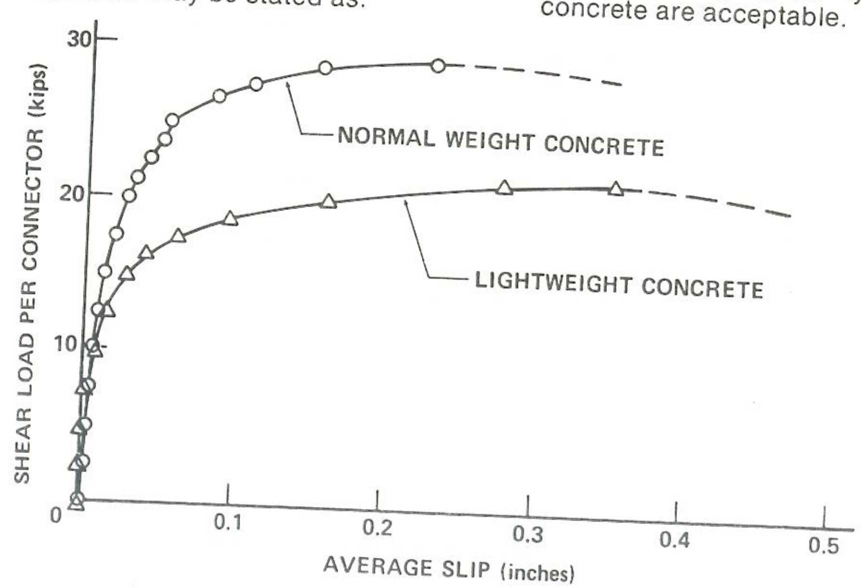


FIGURE 16. — Average Slip, Inches

Table 15. Full Embedment Shear Capacities Of Headed Anchors

Anchor (1.) Size	A.W. (2.) Length (In.)	H/Ds (No. of Dia.)	Sue (3.) (Kips)	Concrete Shear Capacity (Suc) Kips — Normal Concrete (145 pcf) f'c 3000 psi	f'c 4000 psi	f'c 5000 psi	Lightweight Concrete (110 pcf) f'c 3000 psi	f'c 4000 psi	f'c 5000 psi
1/4 × 2 11/16	2 9/16	10.25	2.65	2.22	2.59	2.65	1.85	2.16	2.41
1/4 × 4 1/8	4	16.00	2.65	2.22	2.59	2.65	1.85	2.16	2.41
3/8 × 4 1/8	4	10.67	5.96	4.98	5.79	5.96	4.14	4.83	5.41
3/8 × 6 1/8	6	16.00	5.96	4.98	5.79	5.96	4.14	4.83	5.41
1/2 × 2 1/2	2	4.00	10.60	8.87	10.33	10.60	7.39	8.61	9.64
1/2 × 3 1/8	3	6.00	10.60	8.87	10.33	10.60	7.39	8.61	9.64
1/2 × 4 1/8	4	8.00	10.60	8.87	10.33	10.60	7.39	8.61	9.64
1/2 × 5 5/16	5 3/16	10.37	10.60	8.87	10.33	10.60	7.39	8.61	9.64
1/2 × 6 1/8	6	12.00	10.60	8.87	10.33	10.60	7.39	8.61	9.64
1/2 × 8 1/8	8	16.00	10.60	8.87	10.33	10.60	7.39	8.61	9.64
5/8 × 2 11/16	2 1/2	4.00	16.56	13.89	16.19	16.56	11.57	13.49	15.10
5/8 × 6 9/16	6 3/8	10.20	16.56	13.89	16.19	16.56	11.57	13.49	15.10
5/8 × 8 3/16	8	12.80	16.56	13.89	16.19	16.56	11.57	13.49	15.10
3/4 × 3 3/16	3	4.00	23.86	19.99	23.3	23.86	16.67	19.42	21.73
3/4 × 3 11/16	3 1/2	4.67	23.86	19.99	23.3	23.86	16.67	19.42	21.73
3/4 × 4 3/16	4	5.33	23.86	19.99	23.3	23.86	16.67	19.42	21.73
3/4 × 5 3/16	5	6.67	23.86	19.99	23.3	23.86	16.67	19.42	21.73
3/4 × 6 3/16	6	8.00	23.86	19.99	23.3	23.86	16.67	19.42	21.73
3/4 × 7 3/16	7	9.33	23.86	19.99	23.3	23.86	16.67	19.42	21.73
3/4 × 8 3/16	8	10.67	23.86	19.99	23.3	23.86	16.67	19.42	21.73
7/8 × 3 11/16	3 1/2	4.00	32.47	27.19	31.69	32.47	22.66	26.41	29.55
7/8 × 4 3/16	4	4.57	32.47	27.19	31.69	32.47	22.66	26.41	29.55
7/8 × 5 3/16	5	5.71	32.47	27.19	31.69	32.47	22.66	26.41	29.55
7/8 × 6 3/16	6	6.86	32.47	27.19	31.69	32.47	22.66	26.41	29.55
7/8 × 7 3/16	7	8.00	32.47	27.19	31.69	32.47	22.66	26.41	29.55
7/8 × 8 3/16	8	9.14	32.47	27.19	31.69	32.47	22.66	26.41	29.55

NOTES (1.) Stock Anchor Sizes
(2.) A.W. Length — Length After Welding
(3.) Sue = Ultimate Stud Embedded Shear Strength
Sue = .9 $A_s f_s$, where Suc > Sue, Sue Controls

5.2 Spacing For Development Of Full Shear Capacity.

There are two basic failure modes for studs subject to pure shear forces. In the first, the concrete capacity exceeds the anchor capacity and failure occurs in the anchor. The second failure mode occurs when the anchor capacity exceeds the concrete capacity. From the Ollgaard, Slutter and Fisher investigation[9.], failure occurs in a wedge shaped section pulled from the concrete and is preceeded by localized crushing ahead of the stud, bending in the stud and cracking extending at an angle from under the stud head behind the stud to the concrete — steel interface.

This failure is somewhat different from the large conical type failures that occur in tension loading, and is relatively unaffected by stud length or stud spacing as compared with tension loading.

Spacing to develop full shear capacity is influenced by the following factors with Case B. assuming higher relative importance.

A. Spacing between anchors in a group or with regard to boundary conditions on anchors without a free edge in the direction of the shear force.

B. Spacing between anchors and distance from a free edge of anchors at an edge subject to shear force.

As long as the anchor has no free edge in the direction of the shear force, Case A. applies, and spacings are governed by the H/Ds ratio. A spacing equal to the ratio of 4.0 is satisfactory to develop the full potential shear capacity of a headed anchor. Table 16., which follows, shows the full spacing requirements.

Free edge conditions in the direction of the shear force are covered in Section 5.3.2.

Table 16. Spacing For Full Shear Capacity Development Of Stock Size Headed Anchors Anchor Spacing (R) In Inches

Anchor Size	Ratio H/Ds	Normal, Sand Lightweight or All Lightweight Concrete 3000 psi	4000 psi	5000 psi
1/4 x 2 11/16	10.25	0.5	0.5	0.5
1/4 x 4 1/8	16.00	0.5	0.5	0.5
3/8 x 4 1/8	10.67	0.75	0.75	0.75
3/8 x 6 1/8	16.00	0.75	0.75	0.75
1/2 x 2 1/8	4.00	1.00	1.00	1.00
1/2 x 3 1/8	6.00	1.00	1.00	1.00
1/2 x 4 1/8	8.00	1.00	1.00	1.00
1/2 x 5 5/16	10.37	1.00	1.00	1.00
1/2 x 6 1/8	12.00	1.00	1.00	1.00
1/2 x 8 1/8	16.00	1.00	1.00	1.00
5/8 x 2 11/16	4.00	1.25	1.25	1.25
5/8 x 6 9/16	10.20	1.25	1.25	1.25
5/8 x 8 3/16	12.80	1.25	1.25	1.25
3/4 x 3 3/16	4.00	1.50	1.50	1.50
3/4 x 3 11/16	4.67	1.50	1.50	1.50
3/4 x 4 3/16	5.33	1.50	1.50	1.50
3/4 x 5 3/16	6.67	1.50	1.50	1.50
3/4 x 6 3/16	8.00	1.50	1.50	1.50
3/4 x 7 3/16	9.33	1.50	1.50	1.50
3/4 x 8 3/16	10.67	1.50	1.50	1.50
7/8 x 3 11/16	4.00	1.75	1.75	1.75
7/8 x 4 3/16	4.57	1.75	1.75	1.75
7/8 x 5 3/16	5.71	1.75	1.75	1.75
7/8 x 6 3/16	6.86	1.75	1.75	1.75
7/8 x 7 3/16	8.00	1.75	1.75	1.75
7/8 x 8 3/16	9.14	1.75	1.75	1.75

Note:
R = Radius

1. Minimum spacing for single anchor = 2R.
2. Minimum spacing between anchors = 2R.
3. Minimum spacing, center of anchor to free edge not subject to shear = 1R.

5.3 Reduced Shear Capacity of Headed Anchors

5.3.1. Case A.—Boundary Conditions and Spacing Between Anchors Not Subject to a Free Edge Shear Force.

While the failure mode or geometry is different, anchors under applied shear force may be subject to reductions as are anchors subject to tension. Shear capacity may have one, two, three or four reductions due to spacing between anchors in a group or due to spacing to a free edge NOT in the direction of the shear force.

Figures 17., 18. and 19. illustrate the reductions that may take place. Again, the concrete failure geometry in shear is not conical, but is most conveniently illustrated by the use of drawings similar to those used with tension forces.

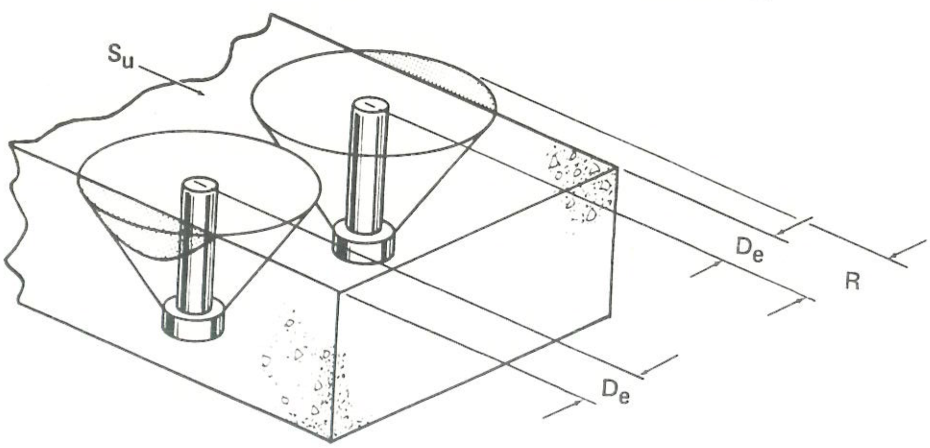


FIGURE 17.—One Reduction To Shear Capacity.

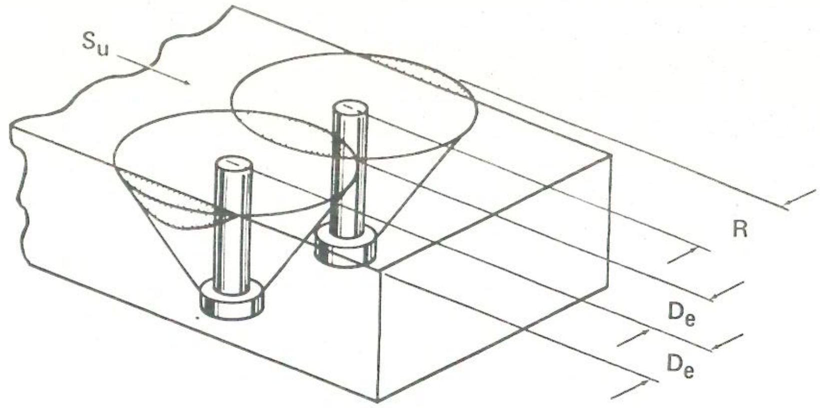


FIGURE 18.—Two Reductions to Shear Capacity.

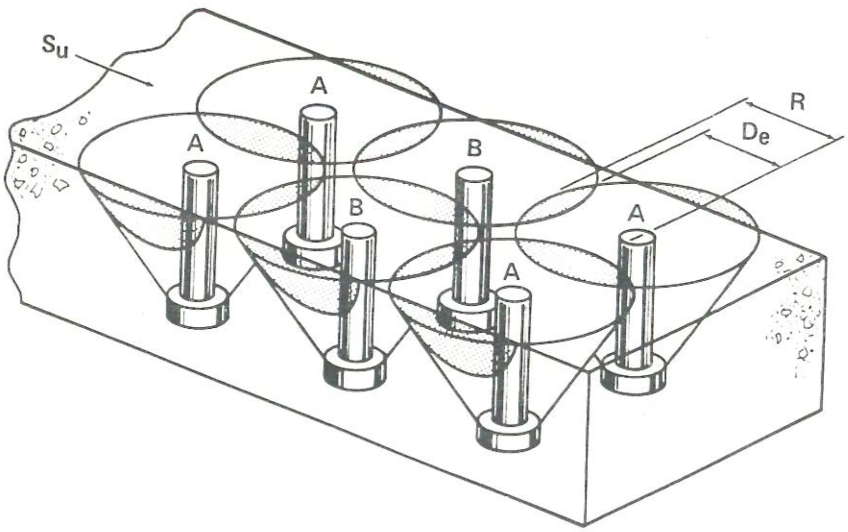


FIGURE 19.—Three and Four Reductions to Shear Capacity.

Note that in all the cases shown, the anchors are placed sufficiently far back from the free edge in the direction of the shear force that the shear edge condition may be ignored. This edge condition is covered in Section 5.3.2.

Using conical area calculations for shear as used in Section 4.8 conservatively approximates the reductions to shear capacity according to the following formula.

$$RSuc = Suc - \left[\left(\frac{A_{fc} - A_{pc}}{A_{fc}} \right) \left(Suc \right)_1 + \left(\frac{A_{fc} - A_{pc}}{A_{fc}} \right) \left(Suc \right)_2 + \ldots \text{etc.}) \right]$$

(Equation 12.)

Tables 17. through 22. show reduction values for single reductions to shear capacities of stock size headed anchors for various edge distances in 145 pcf normal weight concrete of 3000, 4000 and 5000 psi compressive strengths and 110 pcf lightweight concrete of the same strengths.

Where: RSuc = Reduced shear capacity in kips.

Suc = Shear Capacity of Headed Anchor in kips.

Afc = Area of full cone

Apc = Area of partial cone

Table 17. Single Reduction Values To Shear Capacity For Various Edge Distances In 145 pcf Normal Weight Concrete f'c = 3000 psi

Anchor Size	Radius (1.) (In.)	Afc (Sq. In.)	Shear (2.) Capacity Kips	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge In Inches (DE)			
				0.5	1.0	1.5	2.0
1/4 x 2 11/16	0.5	2.4	2.22	0	0	0	0
1/4 x 4 1/8	0.5	2.4	2.22	0	0	0	0
3/8 x 4 1/8	0.75	5.5	4.98	2.09	0	0	0
3/8 x 6 1/8	0.75	5.5	4.98	2.09	0	0	0
1/2 x 2 1/8	1.00	9.7	8.87	4.27	0	0	0
1/2 x 3 1/8	1.00	9.7	8.87	4.27	0	0	0
1/2 x 4 1/8	1.00	9.7	8.87	4.27	0	0	0
1/2 x 5 5/16	1.00	9.7	8.87	4.27	0	0	0
1/2 x 6 1/8	1.00	9.7	8.87	4.27	0	0	0
1/2 x 8 1/8	1.00	9.7	8.87	4.27	0	0	0
5/8 x 2 11/16	1.25	15.2	13.89	—	5.04	0	0
5/8 x 6 9/16	1.25	15.2	13.89	—	5.04	0	0
5/8 x 8 3/16	1.25	15.2	13.89	—	5.04	0	0
3/4 x 3 3/16	1.50	20.9	19.99	—	7.78	0	0
3/4 x 3 11/16	1.50	20.9	19.99	—	7.78	0	0
3/4 x 4 3/16	1.50	20.9	19.99	—	7.78	0	0
3/4 x 5 3/16	1.50	20.9	19.99	—	7.78	0	0
3/4 x 6 3/16	1.50	20.9	19.99	—	7.78	0	0
3/4 x 7 3/16	1.50	20.9	19.99	—	7.78	0	0
3/4 x 8 3/16	1.50	20.9	19.99	—	7.78	0	0
7/8 x 3 11/16	1.75	28.0	27.19	—	11.42	8.06	0
7/8 x 4 3/16	1.75	28.0	27.19	—	11.42	8.06	0
7/8 x 5 3/16	1.75	28.0	27.19	—	11.42	8.06	0
7/8 x 6 3/16	1.75	28.0	27.19	—	11.42	8.06	0
7/8 x 7 3/16	1.75	28.0	27.19	—	11.42	8.06	0
7/8 x 8 3/16	1.75	28.0	27.19	—	11.42	8.06	0

Notes: 1. Radius Or R From Table 16., Section 5.2.
2. Shear Capacity Suc Or Sue From Table 15., Section 5.1.

Table 18. Single Reduction Values To Shear Capacity For Various Edge Distances In 145 pcf Normal Weight Concrete f'c = 4000 psi

Anchor Size	Radius (1.) (In.)	Afc (Sq. In.)	Shear (2.) Capacity (Kips)	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge In Inches (De)			
				0.5	1.0	1.5	2.0
1/4 x 2 11/16	0.5	2.4	2.59	0	0	0	0
1/4 x 4 1/8	0.5	2.4	2.59	0	0	0	0
3/8 x 4 1/8	0.75	5.5	5.79	2.43	0	0	0
3/8 x 6 1/8	0.75	5.5	5.79	2.43	0	0	0
1/2 x 2 1/8	1.00	9.7	10.33	4.97	0	0	0
1/2 x 3 1/8	1.00	9.7	10.33	4.97	0	0	0
1/2 x 4 1/8	1.00	9.7	10.33	4.97	0	0	0
1/2 x 5 5/16	1.00	9.7	10.33	4.97	0	0	0
1/2 x 6 1/8	1.00	9.7	10.33	4.97	0	0	0
1/2 x 8 1/8	1.00	9.7	10.33	4.97	0	0	0
5/8 x 2 11/16	1.25	15.2	16.19	—	5.66	0	0
5/8 x 6 9/16	1.25	15.2	16.19	—	5.66	0	0
5/8 x 8 3/16	1.25	15.2	16.19	—	5.66	0	0
3/4 x 3 3/16	1.50	20.9	23.30	—	9.06	0	0
3/4 x 3 11/16	1.50	20.9	23.30	—	9.06	0	0
3/4 x 4 3/16	1.50	20.9	23.30	—	9.06	0	0
3/4 x 5 3/16	1.50	20.9	23.30	—	9.06	0	0
3/4 x 6 3/16	1.50	20.9	23.30	—	9.06	0	0
3/4 x 7 3/16	1.50	20.9	23.30	—	9.06	0	0
3/4 x 8 3/16	1.50	20.9	23.30	—	9.06	0	0
7/8 x 3 11/16	1.75	28.0	31.69	—	13.30	9.39	0
7/8 x 4 3/16	1.75	28.0	31.69	—	13.30	9.39	0
7/8 x 5 3/16	1.75	28.0	31.69	—	13.30	9.39	0
7/8 x 6 3/16	1.75	28.0	31.69	—	13.30	9.39	0
7/8 x 7 3/16	1.75	28.0	31.69	—	13.30	9.39	0
7/8 x 8 3/16	1.75	28.0	31.69	—	13.30	9.39	0

Notes: 1. Radius Or R From Table 16., Section 5.2.
2. Shear Capacity Suc Or Sue From Table 15., Section 5.1.

Table 19. Single Reduction Values To Shear Capacity For Various Edge Distances In 145 pcf Normal Weight Concrete f'c = 5000 psi

Anchor Size	Radius[1] (In.)	Afc (Sq. In.)	Shear [2] Capacity (Kips)	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge In Inches (De) 0.5	1.0	1.5	2.0
1/4 x 2 11/16	0.5	2.4	2.65	0	0	0	0
1/4 x 4 1/8	0.5	2.4	2.65	0	0	0	0
3/8 x 4 1/8	0.75 .	5.5	5.96	2.50	0	0	0
3/8 x 6 1/8	0.75	5.5	5.96	2.50	0	0	0
1/2 x 2 1/8	1.00	9.7	10.60	5.10	0	0	.0
1/2 x 3 1/8	1.00	9.7	10.60	5.10	0	0	0
1/2 x 4 1/8	1.00	9.7	10.60	5.10	0	0	0
1/2 x 5 5/16	1.00	9.7	10.60	5.10	0	0	0
1/2 x 6 1/8	1.00	9.7	10.60	5.10	0	0	0
1/2 x 8 1/8	1.00	9.7	10.60	5.10	0	0	0
5/8 x 2 11/16	1.25	15.2	16.56	—	5.80	0	0
5/8 x 6 9/16	1.25	15.2	16.56	—	5.80	0	0
5/8 x 8 3/16	1.25	15.2	16.56	—	5.80	0	0
3/4 x 3 3/16	1.50	20.9	23.86	—	9.28	0	0
3/4 x 3 11/16	1.50	20.9	23.86	—	9.28	0	0
3/4 x 4 3/16	1.50	20.9	23.86	—	9.28	0	0
3/4 x 5 3/16	1.50	20.9	23.86	—	9.28	0	0
3/4 x 6 3/16	1.50	20.9	23.86	—	9.28	0	0
3/4 x 7 3/16	1.50	20.9	23.86	—	9.28	0	0
3/4 x 8 3/16	1.50	20.9	23.86	—	9.28	0	0
7/8 x 3 11/16	1.75	28.0	32.47	—	13.64	9.61	0
7/8 x 4 3/16	1.75	28.0	32.47	—	13.64	9.61	0
7/8 x 5 3/16	1.75	28.0	32.47	—	13.64	9.61	0
7/8 x 6 3/16	1.75	28.0	32.47	—	13.64	9.61	0
7/8 x 7 3/16	1.75	28.0	32.47	—	13.64	9.61	0
7/8 x 8 3/16	1.75	28.0	32.47	—	13.64	9.61	0

Notes: 1. Radius Or R From Table 16., Section 5.2.
2. Shear Capacity Suc Or Sue From Table 15., Section 5.1.

Table 20. Single Reduction Values To Shear Capacity For Various Edge Distances In 110 pcf Lightweight Concrete f'c = 3000 psi

Anchor Size	Radius[1] (In.)	Afc (Sq. In.)	Shear [2] Capacity (Kips)	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge In Inches (De) 0.5	1.0	1.5	2.0
1/4 x 2 11/16	0.5	2.4	1.85	0	0	0	0
1/4 x 4 1/8	0.5	2.4	1.85	0	0	0	0
3/8 x 4 1/8	0.75	5.5	4.14	1.74	0	0	0
3/8 x 6 1/8	0.75	5.5	4.14	1.74	0	0	0
1/2 x 2 1/8	1.00	9.7	7.39	3.55	0	0	0
1/2 x 3 1/8	1.00	9.7	7.39	3.55	0	0	0
1/2 x 4 1/8	1.00	9.7	7.39	3.55	0	0	0
1/2 x 5 5/16	1.00	9.7	7.39	3.55	0	0	0
1/2 x 6 1/8	1.00	9.7	7.39	3.55	0	0	0
1/2 x 8 1/8	1.00	9.7	7.39	3.55	0	0	0
5/8 x 2 11/16	1.25	15.2	11.57	—	4.05	0	0
5/8 x 6 9/16	1.25	15.2	11.57	—	4.05	0	0
5/8 x 8 3/16	1.25	15.2	11.57	—	4.05	0	0
3/4 x 3 3/16	1.50	20.9	16.67	—	6.48	0	0
3/4 x 3 11/16	1.50	20.9	16.67	—	6.48	0	0
3/4 x 4 3/16	1.50	20.9	16.67	—	6.48	0	0
3/4 x 5 3/16	1.50	20.9	16.67	—	6.48	0	0
3/4 x 6 3/16	1.50	20.9	16.67	—	6.48	0	0
3/4 x 7 3/16	1.50	20.9	16.67	—	6.48	0	0
3/4 x 8 3/16	1.50	20.9	16.67	—	6.48	0	0
7/8 x 3 11/16	1.75	28.0	22.66	—	9.52	6.71	0
7/8 x 4 3/16	1.75	28.0	22.66	—	9.52	6.71	0
7/8 x 5 3/16	1.75	28.0	22.66	—	9.52	6.71	0
7/8 x 6 3/16	1.75	28.0	22.66	—	9.52	6.71	0
7/8 x 7 3/16	1.75	28.0	22.66	—	9.52	6.71	0
7/8 x 8 3/16	1.75	28.0	22.66	—	9.52	6.71	0

Notes: 1. Radius Or R From Table 16., Section 5.2.
2. Shear Capacity Suc Or Sue From Table 15., Section 5.1.

Table 21. Single Reduction Values To Shear Capacity For Various Edge Distances In 110 pcf Lightweight Concrete f'c = 4000 psi

Anchor Size	Radius[1.] (In.)	Afc (Sq. In.)	Shear [2.] Capacity (Kips)	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge In Inches (De)			
				0.5	1.0	1.5	2.0
1/4 x 2 11/16	0.5	2.4	2.16	0	0	0	0
1/4 x 4 1/8	0.5	2.4	2.16	0	0	0	0
3/8 x 4 1/8	0.75	5.5	4.83	2.03	0	0	0
3/8 x 6 1/8	0.75	5.5	4.83	2.03	0	0	0
1/2 x 2 1/8	1.00	9.7	8.61	4.14	0	0	0
1/2 x 3 1/8	1.00	9.7	8.61	4.14	0	0	0
1/2 x 4 1/8	1.00	9.7	8.61	4.14	0	0	0
1/2 x 5 5/16	1.00	9.7	8.61	4.14	0	0	0
1/2 x 6 1/8	1.00	9.7	8.61	4.14	0	0	0
1/2 x 8 1/8	1.00	9.7	8.61	4.14	0	0	0
5/8 x 2 11/16	1.25	15.2	13.49	—	4.72	0	0
5/8 x 6 9/16	1.25	15.2	13.49	—	4.72	0	0
5/8 x 8 3/16	1.25	15.2	13.49	—	4.72	0	0
3/4 x 3 3/16	1.50	20.9	19.42	—	7.55	0	0
3/4 x 3 11/16	1.50	20.9	19.42	—	7.55	0	0
3/4 x 4 3/16	1.50	20.9	19.42	—	7.55	0	0
3/4 x 5 3/16	1.50	20.9	19.42	—	7.55	0	0
3/4 x 6 3/16	1.50	20.9	19.42	—	7.55	0	0
3/4 x 7 3/16	1.50	20.9	19.42	—	7.55	0	0
3/4 x 8 3/16	1.50	20.9	19.42	—	7.55	0	0
7/8 x 3 11/16	1.75	28.0	26.41	—	11.09	7.82	0
7/8 x 4 3/16	1.75	28.0	26.41	—	11.09	7.82	0
7/8 x 5 3/16	1.75	28.0	26.41	—	11.09	7.82	0
7/8 x 6 3/16	1.75	28.0	26.41	—	11.09	7.82	0
7/8 x 7 3/16	1.75	28.0	26.41	—	11.09	7.82	0
7/8 x 8 3/16	1.75	28.0	26.41	—	11.09	7.82	0

Notes: 1. Radius Or R From Table 16., Section 5.2.
2. Shear Capacity Suc or Sue From Table 15., Section 5.1.

Table 22. Single Reduction Values To Shear Capacity For Various Edge Distances In 110 pcf Lightweight Concrete f'c = 5000 psi

Anchor Size	Radius[1.] (In.)	Afc (Sq. In.)	Shear [2.] Capacity Kips	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge In Inches (De)			
				0.5	1.0	1.5	2.0
1/4 x 2 11/16	0.5	2.4	2.41	0	0	0	0
1/4 x 4 1/8	0.5	2.4	2.41	0	0	0	0
3/8 x 4 1/8	0.75	5.5	5.41	2.27	0	0	0
3/8 x 6 1/8	0.75	5.5	5.41	2.27	0	0	0
1/2 x 2 1/8	1.00	9.7	9.64	4.64	0	0	0
1/2 x 3 1/8	1.00	9.7	9.64	4.64	0	0	0
1/2 x 4 1/8	1.00	9.7	9.64	4.64	0	0	0
1/2 x 5 5/16	1.00	9.7	9.64	4.64	0	0	0
1/2 x 6 1/8	1.00	9.7	9.64	4.64	0	0	0
1/2 x 8 1/8	1.00	9.7	9.64	4.64	0	0	0
5/8 x 2 11/16	1.25	15.2	15.10	—	5.29	0	0
5/8 x 6 9/16	1.25	15.2	15.10	—	5.29	0	0
5/8 x 8 3/16	1.25	15.2	15.10	—	5.29	0	0
3/4 x 3 3/16	1.50	20.9	21.73	—	8.45	0	0
3/4 x 3 11/16	1.50	20.9	21.73	—	8.45	0	0
3/4 x 4 3/16	1.50	20.9	21.73	—	8.45	0	0
3/4 x 5 3/16	1.50	20.9	21.73	—	8.45	0	0
3/4 x 6 3/16	1.50	20.9	21.73	—	8.45	0	0
3/4 x 7 3/16	1.50	20.9	21.73	—	8.45	0	0
3/4 x 8 3/16	1.50	20.9	21.73	—	8.45	0	0
7/8 x 3 11/16	1.75	28.0	29.55	—	12.41	8.75	0
7/8 x 4 3/16	1.75	28.0	29.55	—	12.41	8.75	0
7/8 x 5 3/16	1.75	28.0	29.55	—	12.41	8.75	0
7/8 x 6 3/16	1.75	28.0	29.55	—	12.41	8.75	0
7/8 x 7 3/16	1.75	28.0	29.55	—	12.41	8.75	0
7/8 x 8 3/16	1.75	28.0	29.55	—	12.41	8.75	0

Notes: 1. Radius Or R From Table 16., Section 5.2.
2. Shear Capacity Suc Or Sue From Table 15., Section 5.1

In many installation cases, the placement of anchors close to a free edge subject to shear forces cannot be avoided. Naturally, the force on the anchor in the direction of the free edge causes failure of the concrete around the anchor at loads less than the full shear capacity (Suc) of the anchor.

Various sources[2,10] have suggested that the capacity of an anchor under such conditions may be calculated as:

$R\ Suc = \emptyset\ (2.5\ Des - 3.5)$

where:

R Suc = Reduced Concrete shear capacity

$\emptyset$ = .85 reduction factor

Des = distance from free edge in the direction of load

This relationship provides a conservative estimate of the anchor balance, as is stated in the literature cited.

McMackin, Slutter and Fisher[3.] found that reduced shear capacity in 5000 psi normal weight concrete is better described by the formula:

$$R\ Suc = Suc\ \frac{(Des-1)}{8\ D_s} \leq 0.9\ Asfs$$

(Equation 13.)

where:

R Suc = Reduced concrete shear capacity (kips)

Suc = Concrete shear capacity (kips)

Des = distance shear edge (inches) to center of stud

D_s = stud shank diameter (inches)

A_s = stud shank area (inches^2)

f_s = tensile strength of anchor steel

Figure 20. shows the plotted curves of both formulas against test data. Equation 13. represents a more reliable estimate of actual capacity.

5.3.3 Distance From Free Edge for Full Developm of Shear Capacity.

Equation 13., Section 5.3.2 must be modifi to reflect concrete compressive strength a type as follows:

$$R\ Suc = Suc \left[\frac{Des-1}{8\ D_s}\ (C)\ \sqrt{\frac{f'c}{5000}} \right] \leq Su$$

(Equation 14

where all functions remain the same and:

C = Constant for concrete type

Normal weight concrete C = 1.0

Sand lightweight concrete C = 0.85

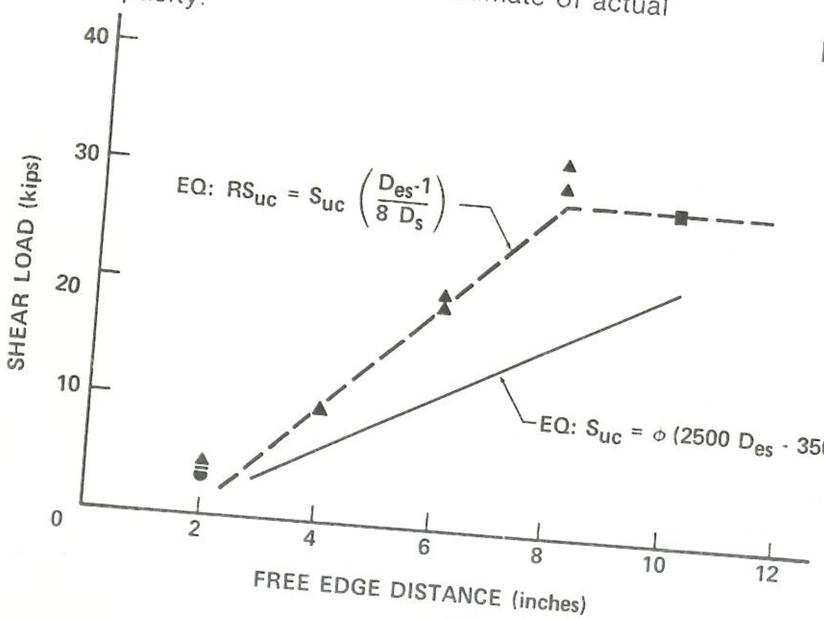
All lightweight concrete C = 0.75

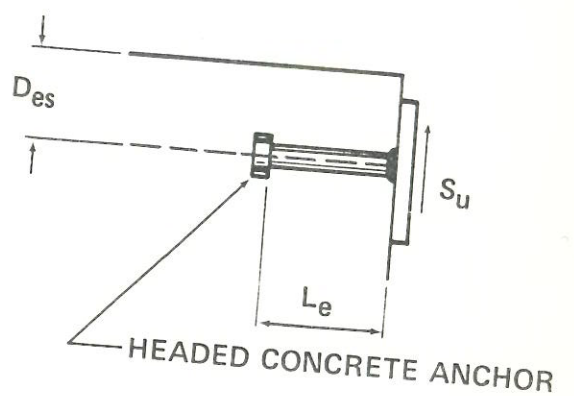
f'_c= 28 day concrete compressive strength PSI

when the function $\left[\frac{Des-1}{8\ D_s} (C) \sqrt{\frac{f'c}{5000}} \right]$ reaches unity, the distance from the free edge subject to shear force (Des) is adequate for the full shear capacity of the anchor to be developed.

Table 23., shows thé minimum distance (Des) from a free edge subject to shear force that an anchor should be placed for full shear capacity development.

When the distance an anchor is placed from a free edge subject to shear force is less than the full capacity distance shown in Table 23., the shear capacity of the embedded anchor is reduced accordingly. Tables 24. through 29. show the amount of reduction to full capacity in kips for various distances to an edge subject to shear force in 3, 4 and 5 ksi concretes of normal and lightweight density.





Symbol	Beam	Stud Size	f'c (psi)	Concrete Type
▲	A	3/4" x 4 3/16"	5270	NWT
■	B	3/4" x 4 3/16"	4900	NWT
●	C	3/4" x 4 3/16"	5180	NWT

FIGURE 20.—Reduced Shear Capacity — Free Edge Condition Subject to Shear Force

Table 23. Distance From A Free Edge In The Direction Of A Shear Force Required For Full Shear Capacity Development

Anchor Shank Diam. (Ds.)	(Des) Distance from Center of Anchor to Free Edge — Concrete Type and Strength: 3000 psi NWT	4000 psi NWT	5000 psi NWT	3000 psi LWT	4000 psi LWT	5000 psi LWT
1/4" Diam.	3.58 in.	3.24 in.	3.00 in.	4.44 in.	3.98 in.	3.67 in.
3/8" Diam.	4.87	4.36	4.00	6.16	5.47	5.00
1/2" Diam.	6.16	5.48	5.00	7.88	6.96	6.33
5/8" Diam.	7.45	6.60	6.00	9.60	8.45	7.67
3/4" Diam.	8.74	7.72	7.00	11.42	9.94	9.00
7/8" Diam.	10.03	8.84	8.00	13.04	11.43	10.33

Table 24. Reduction Values To Shear Capacity For Various Edge Distances For Anchors Subject to Free Edge Shear Force f'c = 3000, Normal Weight Concrete

Anchor Size	Shear (1) Capacity Kips	Reduction to Shear Capacity (Kips) — Distance from Center of Anchor To Free Edge (Des) in Inches: 1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
1/4 x 2 11/16	2.22	1.79	1.37	0.94	0.51	.09													
1/4 x 4 1/8	2.22	1.79	1.37	0.94	0.51	.09													
3/8 x 4 1/8	4.98	4.34	3.73	3.05	2.41	1.76	1.12	0.48											
3/8 x 6 1/8	4.98	4.34	3.73	3.05	2.41	1.76	1.12	0.48											
1/2 x 2 1/8	7.48	6.76	6.03	5.31	4.58	3.86	3.13	2.41	1.68	0.96	0.23								
1/2 x 3 1/8	8.87	8.01	7.15	6.30	5.43	4.57	3.71	2.86	2.00	1.14	0.28								
1/2 x 4 1/8	8.87	8.01	7.15	6.30	5.43	4.57	3.71	2.86	2.00	1.14	0.28								
1/2 x 5 5/16	8.87	8.01	7.15	6.30	5.43	4.57	3.71	2.86	2.00	1.14	0.28								
1/2 x 6 1/8	8.87	8.01	7.15	6.30	5.43	4.57	3.71	2.86	2.00	1.14	0.28								
1/2 x 8 1/8	8.87	8.01	7.15	6.30	5.43	4.57	3.71	2.86	2.00	1.14	0.28								
5/8 x 2 11/16	12.15	11.21	10.27	9.33	8.38	7.45	6.50	5.56	4.62	3.68	2.73	1.79	0.85						
5/8 x 6 9/16	13.89	12.81	11.74	10.66	9.58	8.51	7.43	6.35	5.28	4.20	3.13	2.05	0.97						
5/8 x 8 3/16	13.89	12.81	11.74	10.66	9.58	8.51	7.43	6.35	5.28	4.20	3.13	2.05	0.97						
3/4 x 3 3/16	17.41	16.29	15.16	14.04	12.91	11.79	10.66	9.54	8.41	7.29	6.17	5.04	3.92	2.79	1.67	0.54			
3/4 x 3 11/16	19.99	18.70	17.41	16.12	14.83	13.53	12.24	10.95	6.66	8.37	7.08	5.79	4.50	3.21	1.92	0.63			
3/4 x 4 3/16	19.99	18.70	17.41	16.12	14.83	13.53	12.24	10.95	6.66	8.37	7.08	5.79	4.50	3.21	1.92	0.63			
3/4 x 5 3/16	19.99	18.70	17.41	16.12	14.83	13.53	12.24	10.95	6.66	8.37	7.08	5.79	4.50	3.21	1.92	0.63			
3/4 x 6 3/16	19.99	18.70	17.41	16.12	14.83	13.53	12.24	10.95	6.66	8.37	7.08	5.79	4.50	3.21	1.92	0.63			
3/4 x 7 3/16	19.99	18.70	17.41	16.12	14.83	13.53	12.24	10.95	6.66	8.37	7.08	5.79	4.50	3.21	1.92	0.63			
3/4 x 8 3/16	19.99	18.70	17.41	16.12	14.83	13.53	12.24	10.95	6.66	8.37	7.08	5.79	4.50	3.21	1.92	0.63			
7/8 x 3 11/16	24.27	22.93	21.59	20.24	18.90	17.56	16.21	14.87	13.52	12.18	10.83	9.49	8.11	6.80	5.46	4.12	2.77	1.43	0.09
7/8 x 4 3/16	27.19	25.68	24.18	22.67	21.17	19.66	18.16	16.69	15.15	13.64	12.14	10.63	9.13	7.62	6.12	4.61	3.11	1.60	0.10
7/8 x 5 3/16	27.19	25.68	24.18	22.67	21.17	19.66	18.16	16.69	15.15	13.64	12.14	12.14	9.13	7.62	6.12	4.61	3.11	1.60	0.10
7/8 x 6 3/16	27.19	25.68	24.18	22.67	21.17	19.66	18.16	16.69	15.15	13.64	12.14	12.14	9.13	7.62	6.12	4.61	3.11	1.60	0.10
7/8 x 7 3/16	27.19	25.68	24.18	22.67	21.17	19.66	18.16	16.69	15.15	13.64	12.14	12.14	9.13	7.62	6.12	4.61	3.11	1.60	0.10
7/8 x 8 3/16	27.19	25.68	24.18	22.67	21.17	19.66	18.16	16.69	15.15	13.64	12.14	12.14	9.13	7.62	6.12	4.61	3.11	1.60	0.10

1. Shear Capacity (Suc) from Table 15., Section 5.1; where Suc > Sue, Sue Controls

Example: Reduced Shear Capacity of a 3/8 x 6 1/8" Headed Anchor 3.0" from a shear edge in 3000 psi NWT Concrete = 4.98 — 2.41 = 2.57 Kips

Table 25. Reduction Values To Shear Capacity For Anchors Subject To Free Edge Shear Force f'c = 4000, Normal Weight Concrete

Anchor Size	Shear (1) Capacity (Kips)	Reductions to Shear Capacity (Kips) Distance from Center of Anchor to Free Edge (Des) in Inches														
		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5
1/4 x 2 11/16	2.59	2.01	1.44	0.85	0.27											
1/4 x 4 1/8	2.59	2.01	1.44	0.85	0.27											
3/8 x 4 1/8	5.79	4.93	4.07	3.20	2.34	1.48	0.61									
3/8 x 6 1/8	5.79	4.93	4.07	3.20	2.34	1.48	0.61									
1/2 x 2 1/8	8.72	7.75	6.77	5.80	4.82	3.85	2.87	1.90	0.92							
1/2 x 3 1/8	10.33	9.17	8.03	6.87	5.71	4.56	3.40	2.25	1.09							
1/2 x 4 1/8	10.33	9.17	8.03	6.87	5.71	4.56	3.40	2.25	1.09							
1/2 x 5 5/16	10.33	9.17	8.03	6.87	5.71	4.56	3.40	2.25	1.09							
1/2 x 6 1/8	10.33	9.17	8.03	6.87	5.71	4.56	3.40	2.25	1.09							
1/2 x 8 1/8	10.33	9.17	8.03	6.87	5.71	4.56	3.40	2.25	1.09							
5/8 x 2 11/16	14.17	12.90	11.64	10.37	9.10	7.84	6.57	5.30	4.04	2.77	1.50	0.24				
5/8 x 6 9/16	16.19	14.74	13.29	11.85	10.41	8.95	7.51	6.06	4.61	3.16	1.72	0.27				
5/8 x 8 3/16	16.19	14.74	13.29	11.85	10.41	8.95	7.51	6.06	4.61	3.16	1.72	0.27				
3/4 x 3 3/16	20.39	18.77	17.35	15.84	14.33	12.79	11.28	9.76	8.24	6.72	5.20	3.68	2.16	0.64		
3/4 x 3 11/16	23.3	21.56	19.83	18.09	16.36	14.62	12.88	11.15	9.41	7.68	5.94	4.21	2.47	0.73		
3/4 x 4 3/16	23.3	21.56	19.83	18.09	16.36	14.62	12.88	11.15	9.41	7.68	5.94	4.21	2.47	0.73		
3/4 x 5 3/16	23.3	21.56	19.83	18.09	16.36	14.62	12.88	11.15	9.41	7.68	5.94	4.21	2.47	0.73		
3/4 x 6 3/16	23.3	21.56	19.83	18.09	16.36	14.62	12.88	11.15	9.41	7.68	5.94	4.21	2.47	0.73		
3/4 x 7 3/16	23.3	21.56	19.83	18.09	16.36	14.62	12.88	11.15	9.41	7.68	5.94	4.21	2.47	0.73		
3/4 x 8 3/16	23.3	21.56	19.83	18.09	16.36	14.62	12.88	11.15	9.41	7.68	5.94	4.21	2.47	0.73		
7/8 x 3 11/16	28.28	26.47	24.67	22.86	21.06	19.25	17.44	15.64	13.83	12.02	10.22	8.42	6.61	4.80	3.00	1.19
7/8 x 4 3/16	31.69	29.67	27.64	25.62	23.60	21.57	19.55	17.53	15.51	13.48	11.45	9.43	7.41	5.38	3.36	1.34
7/8 x 5 3/16	31.69	29.67	27.64	25.62	23.60	21.57	19.55	17.53	15.51	13.48	11.45	9.43	7.41	5.38	3.36	1.34
7/8 x 6 3/16	31.69	29.67	27.64	25.62	23.60	21.57	19.55	17.53	15.51	13.48	11.45	9.43	7.41	5.88	3.36	1.34
7/8 x 7 3/16	31.69	29.67	27.64	25.62	23.60	21.57	19.55	17.53	15.51	13.48	11.45	9.43	7.41	5.88	3.36	1.34
7/8 x 8 3/16	31.69	29.67	27.64	25.62	23.60	21.57	19.55	17.53	15.51	13.48	11.45	9.43	7.41	5.38	3.36	1.34

Notes: 1. Shear Capacity (Suc) from Table 15., Section 5.1; Where Suc > Sue, Sue Controls.

Table 26. Reduction Values To Shear Capacity For Anchors Subject To Free Edge Shear Force f'c = 5000, Normal Weight

Anchor Size	Shear (1) Capacity (Kips)	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge (Des) In Inches												
		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
1/4 x 2 11/16	2.65	1.99	1.32	0.66										
1/4 x 4 1/8	2.65	1.99	1.32	0.66										
3/8 x 4 1/8	5.96	4.97	3.97	2.98	1.99	0.99								
3/8 x 6 1/8	5.96	4.97	3.97	2.98	1.99	0.99								
1/2 x 2 1/8	9.75	8.53	7.31	6.09	4.87	3.66	2.44	1.22						
1/2 x 3 1/8	10.60	9.27	7.95	6.62	5.30	3.97	2.65	1.32						
1/2 x 4 1/8	10.60	9.27	7.95	6.62	5.30	3.97	2.65	1.32						
1/2 x 5 5/16	10.60	9.27	7.95	6.62	5.30	3.97	2.65	1.32						
1/2 x 6 1/8	10.60	9.27	7.95	6.62	5.30	3.97	2.65	1.32						
1/2 x 8 1/8	10.60	9.27	7.95	6.62	5.30	3.97	2.65	1.32						
5/8 x 2 11/16	15.86	14.27	12.69	11.10	9.52	7.93	6.34	4.76	3.17	1.59				
5/8 x 6 9/16	16.56	14.90	13.25	11.59	9.94	8.28	6.62	4.97	3.31	1.66				
5/8 x 8 3/16	16.56	14.90	13.25	11.59	9.94	8.28	6.62	4.97	3.31	1.66				
3/4 x 3 3/16	22.82	20.92	19.02	17.12	15.21	13.31	11.41	9.51	7.61	5.70	3.80	1.90		
3/4 x 3 11/16	23.86	21.87	19.88	17.89	15.91	13.92	11.93	9.94	7.95	5.96	3.98	1.99		
3/4 x 4 3/16	23.86	21.87	19.88	17.89	15.91	13.92	11.93	9.94	7.95	5.96	3.98	1.99		
3/4 x 5 3/16	23.86	21.87	19.88	17.89	15.91	13.92	11.93	9.94	7.95	5.96	3.98	1.99		
3/4 x 6 3/16	23.86	21.87	19.88	17.89	15.91	13.92	11.93	9.94	7.95	5.96	3.98	1.99		
3/4 x 7 3/16	23.86	21.87	19.88	17.89	15.91	13.92	11.93	9.94	7.95	5.96	3.98	1.99		
3/4 x 8 3/16	23.86	21.87	19.88	17.89	15.91	13.92	11.93	9.94	7.95	5.96	3.98	1.99		
7/8 x 3 11/16	31.65	29.39	27.13	24.87	22.61	20.35	18.09	15.82	13.56	11.30	9.04	6.78	4.52	2.26
7/8 x 4 3/16	32.47	30.15	27.83	25.51	23.19	20.87	18.55	16.23	13.92	11.60	9.28	6.96	4.64	2.32
7/8 x 5 3/16	32.47	30.15	27.83	25.51	23.19	20.87	18.55	16.23	13.92	11.60	9.28	6.96	4.64	2.32
7/8 x 6 3/16	32.47	30.15	27.83	25.51	23.19	20.87	18.55	16.23	13.92	11.60	9.28	6.96	4.64	2.32
7/8 x 7 3/16	32.47	30.15	27.83	25.51	23.19	20.87	18.55	16.23	13.92	11.60	9.28	6.96	4.64	2.32
7/8 x 8 3/16	32.47	30.15	27.83	25.51	23.19	20.87	18.55	16.23	13.92	11.60	9.28	6.96	4.64	2.32

Notes: 1. Shear Capacity (Suc) From Table 15., Section 5.1. Where Suc > Sue, Sue Controls

Table 27. Reduction Values To Shear Capacity For Anchors Subject To Free Edge Shear Force f'c = 3000, Lightweight

Anchor Size	Shear Capacity (Kips) [1]	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge (Des) In Inches																							
		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
1/4 x 2 11/16	1.85	1.58	1.31	1.04	0.78	0.51	0.24																		
1/4 x 4 1/8	1.85	1.58	1.31	1.04	0.78	0.51	0.24																		
3/8 x 4 1/8	4.14	3.74	3.34	2.94	2.54	2.14	1.74	1.34	0.94	0.53	0.13														
3/8 x 6 1/8	4.14	3.74	3.34	2.94	2.54	2.14	1.74	1.34	0.94	0.53	0.13														
1/2 x 2 1/8	6.24	5.79	5.33	4.88	4.43	3.97	3.52	3.07	2.61	2.16	1.71	1.26	0.80	0.35											
1/2 x 3 1/8	7.39	6.85	6.32	5.78	5.24	4.71	4.17	3.63	3.10	2.56	2.02	1.49	0.95	0.41											
1/2 x 4 1/8	7.39	6.85	6.32	5.78	5.24	4.71	4.17	3.63	3.10	2.56	2.02	1.49	0.95	0.41											
1/2 x 5 5/16	7.39	6.85	6.32	5.78	5.24	4.71	4.17	3.63	3.10	2.56	2.02	1.49	0.95	0.41											
1/2 x 6 1/8	7.39	6.85	6.32	5.78	5.24	4.71	4.17	3.63	3.10	2.56	2.02	1.49	0.95	0.41											
1/2 x 8 1/8	7.39	6.85	6.32	5.78	5.24	4.71	4.17	3.63	3.10	2.56	2.02	1.49	0.95	0.41											
5/8 x 2 11/16	10.12	9.53	8.94	8.36	7.77	7.18	6.59	6.00	5.42	4.83	4.24	3.65	3.06	2.48	1.89	1.30	0.71	0.13							
5/8 x 6 9/16	11.57	10.90	10.23	9.55	8.88	8.21	7.54	6.86	6.19	5.52	4.85	4.18	3.50	2.83	2.16	1.49	0.81	0.14							
5/8 x 8 3/16	11.57	10.90	10.23	9.55	8.88	8.21	7.54	6.86	6.19	5.52	4.85	4.18	3.50	2.83	2.16	1.49	0.81	0.14							
3/4 x 3 3/16	14.59	13.88	13.18	12.47	11.76	11.06	10.35	9.65	8.94	8.23	7.53	6.82	6.11	5.41	4.70	3.99	3.29	2.58	1.87	1.17	0.46				
3/4 x 3 11/16	16.67	15.86	15.06	14.25	13.44	12.63	11.83	11.02	10.21	9.41	8.60	7.79	6.98	6.18	5.37	4.56	3.76	2.95	2.14	1.33	0.53				
3/4 x 4 3/16	16.67	15.86	15.06	14.25	13.44	12.63	11.83	11.02	10.21	9.41	8.60	7.79	6.98	6.18	5.37	4.56	3.76	2.95	2.14	1.33	0.53				
3/4 x 5 3/16	16.67	15.86	15.06	14.25	13.44	12.63	11.83	11.02	10.21	9.41	8.60	7.79	6.98	6.18	5.37	4.56	3.76	2.95	2.14	1.33	0.53				
3/4 x 6 3/16	16.67	15.86	15.06	14.25	13.44	12.63	11.83	11.02	10.21	9.41	8.60	7.79	6.98	6.18	5.37	4.56	3.76	2.95	2.14	1.33	0.53				
3/4 x 7 3/16	16.67	15.86	15.06	14.25	13.44	12.63	11.83	11.02	10.21	9.41	8.60	7.79	6.98	6.18	5.37	4.56	3.76	2.95	2.14	1.33	0.53				
3/4 x 8 3/16	16.67	15.86	15.06	14.25	13.44	12.63	11.83	11.02	10.21	9.41	8.60	7.79	6.98	6.18	5.37	4.56	3.76	2.95	2.14	1.33	0.53				
7/8 x 3 11/16	20.22	19.38	18.54	17.70	16.86	16.02	15.19	14.35	13.51	12.67	11.83	10.99	10.15	9.31	8.47	7.63	6.79	5.95	5.12	4.28	3.44	2.60	1.76	0.92	0.08
7/8 x 4 3/16	22.66	21.72	20.78	19.84	18.90	17.96	17.02	16.08	15.14	14.20	13.26	12.32	11.38	10.43	9.49	8.55	7.62	6.67	5.73	4.79	3.85	2.91	1.97	1.03	0.09
7/8 x 5 3/16	22.66	21.72	20.78	19.84	18.90	17.96	17.02	16.08	15.14	14.20	13.26	12.32	11.38	10.43	9.49	8.55	7.62	6.67	5.73	4.79	3.85	2.91	1.97	1.03	0.09
7/8 x 6 3/16	22.66	21.72	20.78	19.84	18.90	17.96	17.02	16.08	15.14	14.20	13.26	12.32	11.38	10.43	9.49	8.55	7.62	6.67	5.73	4.79	3.85	2.91	1.97	1.03	0.09
7/8 x 7 3/16	22.66	21.72	20.78	19.84	18.90	17.96	17.02	16.08	15.14	14.20	13.26	12.32	11.38	10.43	9.49	8.55	7.62	6.67	5.73	4.79	3.85	2.91	1.97	1.03	0.09
7/8 x 8 3/16	22.66	21.72	20.78	19.84	18.90	17.96	17.02	16.08	15.14	14.20	13.26	12.32	11.38	10.43	9.49	8.55	7.62	6.67	5.73	4.79	3.85	2.91	1.97	1.03	0.09

Notes 1 Shear Capacity (Suc) From Table 15 , Section 5 1 , Where Suc > Sue, Sue Controls

Table 28. Reduction Values To Shear Capacity For Anchors Subject To Free Edge Shear Force f'c = 4000, Lightweight

Anchor Size	Shear Capacity (Kips) [1]	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge (Des) In Inches																			
		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0
1/4 x 2 11/16	2.16	1.80	1.44	1.07	0.71	0.35															
1/4 x 4 1/8	2.16	1.80	1.44	1.07	0.71	0.35															
3/8 x 4 1/8	4.83	4.29	3.75	3.21	2.67	2.13	1.59	1.05	0.51												
3/8 x 6 1/8	4.83	4.29	3.75	3.21	2.67	2.13	1.59	1.05	0.51												
1/2 x 2 1/8	7.26	6.65	6.04	5.43	4.83	4.22	3.61	3.00	2.39	1.78	1.17	0.56									
1/2 x 3 1/8	8.61	7.89	7.17	6.44	5.72	5.00	4.28	3.55	2.83	2.11	1.39	0.67									
1/2 x 4 1/8	8.61	7.89	7.17	6.44	5.72	5.00	4.28	3.55	2.83	2.11	1.39	0.67									
1/2 x 5 5/16	8.61	7.89	7.17	6.44	5.72	5.00	4.28	3.55	2.83	2.11	1.39	0.67									
1/2 x 6 1/8	8.61	7.89	7.17	6.44	5.72	5.00	4.28	3.55	2.83	2.11	1.39	0.67									
1/2 x 8 1/8	8.61	7.89	7.17	6.44	5.72	5.00	4.28	3.55	2.83	2.11	1.39	0.67									
5/8 x 2 11/16	11.80	11.01	10.22	9.43	8.63	7.84	7.05	6.26	5.47	4.67	3.88	3.09	2.30	1.51	0.72						
5/8 x 6 9/16	13.49	12.58	11.67	10.77	9.87	8.96	8.06	7.15	6.25	5.34	4.44	3.53	2.63	1.72	0.82						
5/8 x 8 3/16	13.49	12.58	11.67	10.77	9.87	8.96	8.06	7.15	6.25	5.34	4.44	3.53	2.63	1.72	0.82						
3/4 x 3 3/16	16.99	16.04	15.09	14.14	13.19	12.24	11.29	10.34	9.39	8.44	7.49	6.54	5.59	4.64	3.69	2.74	1.79	0.84			
3/4 x 3 11/16	19.42	18.33	17.25	16.06	15.08	13.99	12.90	11.82	10.73	9.65	8.56	7.47	6.39	5.30	4.22	3.13	2.05	0.96			
3/4 x 4 3/16	19.42	18.33	17.25	16.06	15.08	13.99	12.90	11.82	10.73	9.65	8.56	7.47	6.39	5.30	4.22	3.13	2.05	0.96			
3/4 x 5 3/16	19.42	18.33	17.25	16.06	15.08	13.99	12.90	11.82	10.73	9.65	8.56	7.47	6.39	5.30	4.22	3.13	2.05	0.96			
3/4 x 6 3/16	19.42	18.33	17.25	16.06	15.08	13.99	12.90	11.82	10.73	9.65	8.56	7.47	6.39	5.30	4.22	3.13	2.05	0.96			
3/4 x 7 3/16	19.42	18.33	17.25	16.06	15.08	13.99	12.90	11.82	10.73	9.65	8.56	7.47	6.39	5.30	4.22	3.13	2.05	0.96			
3/4 x 8 3/16	19.42	18.33	17.25	16.06	15.08	13.99	12.90	11.82	10.73	9.65	8.56	7.47	6.39	5.30	4.22	3.13	2.05	0.96			
7/8 x 3 11/16	23.57	22.44	21.31	20.18	19.05	17.92	16.79	15.66	14.53	13.40	12.27	11.14	10.01	8.88	7.75	6.62	5.40	4.37	3.24	2.11	0.98
7/8 x 4 3/16	26.41	25.14	23.88	22.61	21.35	20.08	18.82	17.55	16.28	15.02	13.75	12.49	11.22	9.95	8.69	7.42	6.16	4.89	3.63	2.36	1.09
7/8 x 5 3/16	26.41	25.14	23.88	22.61	21.35	20.08	18.82	17.55	16.28	15.02	13.75	12.49	11.22	9.95	8.69	7.42	6.16	4.89	3.63	2.36	1.09
7/8 x 6 3/16	26.41	25.14	23.88	22.61	21.35	20.08	18.82	17.55	16.28	15.02	13.75	12.49	11.22	9.95	8.69	7.42	6.16	4.89	3.63	2.36	1.09
7/8 x 7 3/16	26.41	25.14	23.88	22.61	21.35	20.08	18.82	17.35	16.28	15.02	13.75	12.49	11.22	9.95	8.69	7.42	6.16	4.89	3.63	2.36	1.09
7/8 x 8 3/16	26.41	25.14	23.88	22.61	21.35	20.08	18.82	17.55	16.28	15.02	13.75	12.49	11.22	9.95	8.69	7.42	6.16	4.89	3.63	2.36	1.09

Notes: 1. Shear Capacity (Suc) From Table 15., Section 5.1.; Where Suc > Sue, Sue Controls.

Anchors Subject To Free Edge Shear Force
f'c = 5000, Lightweight

Anchor Size	Shear[1] Capacity (Kips)	Reduction To Shear Capacity (Kips) Distance From Center Of Anchor To Free Edge (Des) In Inches																	
		1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
$\frac{1}{4} \times 2\frac{11}{16}$	2.41	1.96	1.51	1.05	0.60	0.15													
$\frac{1}{4} \times 4\frac{1}{8}$	2.41	1.96	1.51	1.05	0.60	0.15													
$\frac{3}{8} \times 4\frac{1}{8}$	5.41	4.73	4.06	3.38	2.71	2.03	1.35	0.68											
$\frac{3}{8} \times 6\frac{1}{8}$	5.41	4.73	4.06	3.38	2.71	2.03	1.35	0.68											
$\frac{1}{2} \times 2\frac{1}{8}$	8.13	7.37	6.61	5.84	5.08	4.32	3.56	2.79	2.03	1.27	0.51								
$\frac{1}{2} \times 3\frac{1}{8}$	9.64	8.74	7.83	6.93	6.02	5.12	4.22	3.31	2.41	1.51	0.60								
$\frac{1}{2} \times 4\frac{1}{8}$	9.64	8.74	7.83	6.93	6.02	5.12	4.22	3.31	2.41	1.51	0.60								
$\frac{1}{2} \times 5\frac{5}{16}$	9.64	8.74	7.83	6.93	6.02	5.12	4.22	3.31	2.41	1.51	0.60								
$\frac{1}{2} \times 6\frac{1}{8}$	9.64	8.74	7.83	6.93	6.02	5.12	4.22	3.31	2.41	1.51	0.60								
$\frac{1}{2} \times 8\frac{1}{8}$	9.64	8.74	7.83	6.93	6.02	5.12	4.22	3.31	2.41	1.51	0.60								
$\frac{5}{8} \times 2\frac{11}{16}$	13.21	12.22	11.23	10.24	9.25	8.26	7.27	6.27	5.28	4.29	3.30	2.31	1.32	0.33					
$\frac{5}{8} \times 6\frac{9}{16}$	15.10	13.97	12.83	11.70	10.57	9.44	8.30	7.17	6.04	4.91	3.77	2.64	1.51	0.38					
$\frac{5}{8} \times 8\frac{3}{16}$	15.10	13.97	12.83	11.70	10.57	9.44	8.30	7.17	6.04	4.91	3.77	2.64	1.51	0.38					
$\frac{3}{4} \times 3\frac{3}{16}$	19.01	17.82	16.63	15.45	14.26	13.07	11.88	10.69	9.51	8.32	7.13	5.94	4.75	3.56	2.38	1.19			
$\frac{3}{4} \times 3\frac{11}{16}$	21.73	20.37	19.01	17.66	16.30	14.94	13.58	12.22	10.87	9.51	8.15	6.79	5.43	4.07	2.72	1.36			
$\frac{3}{4} \times 4\frac{3}{16}$	21.73	20.37	19.01	17.66	16.30	14.94	13.58	12.22	10.87	9.51	8.15	6.79	5.43	4.07	2.72	1.36			
$\frac{3}{4} \times 5\frac{3}{16}$	21.73	20.37	19.01	17.66	16.30	14.94	13.58	12.22	10.87	9.51	8.15	6.79	5.43	4.07	2.72	1.36			
$\frac{3}{4} \times 6\frac{3}{16}$	21.73	20.37	19.01	17.66	16.30	14.94	13.58	12.22	16.87	9.51	8.15	6.79	5.43	4.07	2.72	1.36			
$\frac{3}{4} \times 7\frac{3}{16}$	21.73	20.37	19.01	17.66	16.30	14.94	13.58	12.22	10.87	9.51	8.15	6.79	5.43	4.07	2.72	1.36			
$\frac{3}{4} \times 8\frac{3}{16}$	21.73	20.37	19.01	17.66	16.30	14.94	13.58	12.22	10.87	9.51	8.15	6.79	5.43	4.07	2.72	1.36			
$\frac{7}{8} \times 3\frac{11}{16}$	26.37	24.96	23.54	22.13	20.72	19.31	17.89	16.48	15.07	13.66	12.24	10.83	9.42	8.01	6.59	5.18	3.77	2.35	0.94
$\frac{7}{8} \times 4\frac{3}{16}$	29.55	27.97	26.38	24.80	23.22	21.63	20.05	18.47	16.89	15.30	13.72	12.14	10.55	8.97	7.39	5.80	4.22	2.64	1.06
$\frac{7}{8} \times 5\frac{3}{16}$	29.55	27.97	26.38	24.80	23.22	21.63	20.05	18.47	16.89	15.30	13.72	12.14	10.55	8.97	7.39	5.80	4.22	2.64	1.06
$\frac{7}{8} \times 6\frac{3}{16}$	29.55	27.97	26.38	24.80	23.22	21.63	20.05	18.47	16.89	15.30	13.72	12.14	10.55	8.97	7.39	5.80	4.22	2.64	1.06
$\frac{7}{8} \times 7\frac{3}{16}$	29.55	27.97	26.38	24.80	23.22	21.63	20.05	18.47	16.89	15.30	13.72	12.14	10.55	8.97	7.39	5.80	4.22	2.64	1.06
$\frac{7}{8} \times 8\frac{3}{16}$	29.55	27.97	26.38	24.80	23.22	21.63	20.05	18.47	16.89	15.30	13.72	12.14	10.55	8.97	7.39	5.80	4.22	2.64	1.06

Notes: 1. Shear Capacity (Suc) From Table 15., Section 5.1.: Where Suc · Sue, Sue Controls.

5.3.4 Spacing Between Anchors at A Free Edge Subject to Shear Force.

Section 5.3.3. outlined the distances from a free edge subject to shear force that an anchor should be placed for full shear capacity development. The distances (Des) are summarized in Table 23. Should the anchor be placed closer to the edge than the distance indicated, the shear capacity is reduced by amounts shown in Tables 24. through 27.

Figure 21., below, shows a typical concrete failure mode for an anchor with an edge distance less than required for full capacity development.

FIGURE 21.—Specimens A2-7 and A2-8(3), $\frac{3}{4}$ x $4\frac{3}{16}$" Anchors, Subject to Pure Shear, 6" From Free Edge.

Note that the failure geometry remains roughly conical in nature. The surface area of the failure approximates an isosceles triangle, so that the spacing needed between headed anchors along a free edge is equal to twice the depth of embedment of the anchor.

Figure 22. shows the geometrical relationship for headed anchors with insufficient edge distance to develop full shear capacity.

Accordingly, the spacing between .headed anchors at a free edge subject to shear force may be described as:

$$\text{Shear Edge Stud Spacing} = 2\left(\text{Des} + \frac{D_S}{2}\right)$$

where:

Des = Distance from free edge to center of anchor in inches

Ds = Stud diameter in inches

Table 30. which follows shows the required spacing between anchors placed at a free edge so that their full potential shear capacity may be obtained.

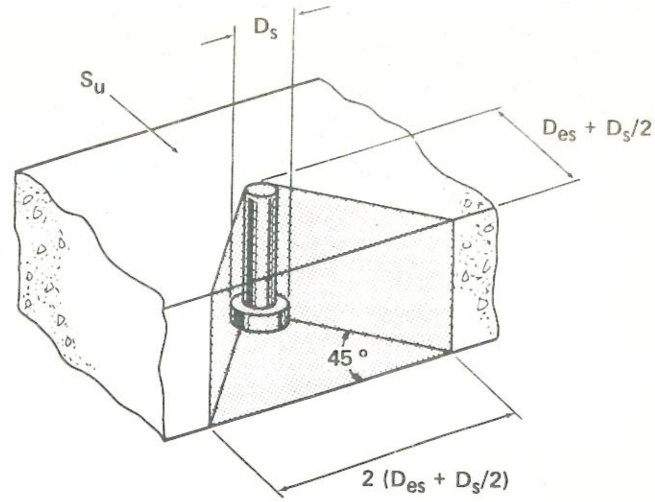


FIGURE 22.—Geometry of Free Edge Shear Failure.

Table 30. Spacing Required Between Headed Anchors At A Free Edge For Development Of Potential Shear Capacity

Distance From Center Of Anchor To Free Edge (Des) In Inches	Center-to-Center Spacing of Anchors In Inches — Anchor Diameter (Ds)					
	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"
1.5	3.25	3.38	3.50	3.62	3.75	3.88
2.0	4.25	4.38	4.50	4.62	4.75	4.88
2.5	5.25	5.38	5.50	5.62	5.75	5.88
3.0	6.25	6.38	6.50	6.62	6.75	6.88
3.5	7.25	7.38	7.50	7.62	7.75	7.88
4.0	8.25	8.38	8.50	8.62	8.75	8.88
4.5		9.38	9.50	9.62	9.75	9.88
5.0		10.38	10.50	10.62	10.75	10.88
5.5		11.38	11.50	11.62	11.75	11.88
6.0		12.38	12.50	12.62	12.75	12.88
6.5			13.50	13.62	13.75	13.88
7.0			14.50	14.62	14.75	14.88
7.5			15.50	15.62	15.75	15.88
8.0				16.62	16.75	16.88
8.5				17.62	17.75	17.88
9.0				18.62	18.75	18.88
9.5				19.62	19.75	19.88
10.0					20.75	20.88
10.5					21.75	21.88
11.0					22.75	22.88
11.5						23.88
12.0						24.88
12.5						25.88
13.0						26.88

5.3.5. Reduction in Shear Capacity Due to Free Edge Spacing.

From Table 30., Section 5.3.4, it becomes obvious that the spacings between anchors at a free edge subject to shear force can easily exceed the spacings required between studs for shear capacity development when they are not influenced by the free edge shear condition.

In most applications, the anchors are spaced more closely together than required by the free edge, shear force condition. Accordingly, a reduction to the shear capacity must be taken. This reduction is directly proportional to the reduction in surface area.

Figure 23. & 24. shows typical reductions to free edge shear capacity.

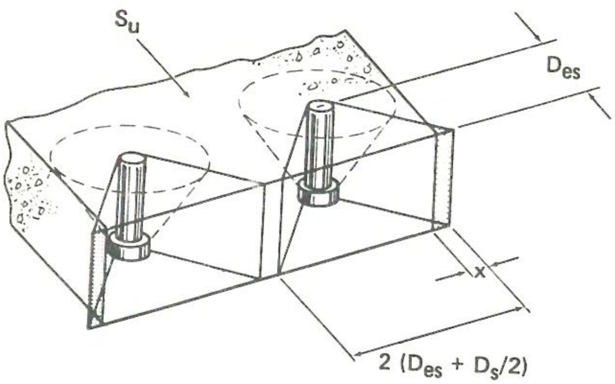


FIGURE 23.—Single Reduction to Free Edge Shear Spacing.

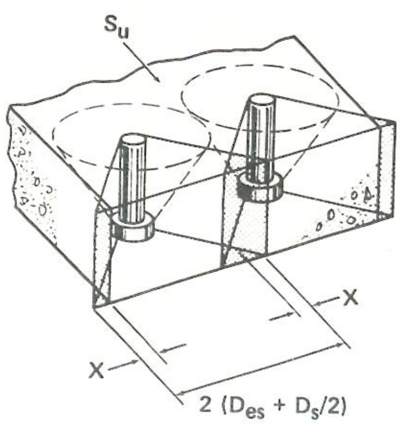


FIGURE 24.—Double Reduction to Free Edge Shear Spacing.

There can be a maximum of two reductions to free edge shear capacity. The reduction to free edge shear capacity may be expressed as:

$$R\ Suc = Suc - Suc\left[\frac{0.5\ x^2}{(De_s + D_s/2)^2}\right]N$$

(Equation 15.)

where:

R Suc = Reduced shear capacity, kips
Suc = Free edge shear capacity, kips from Tables 24. through 29.

X = Distance reduced from full center-to-center spacing, inches.

De_s = Distance from shear edge to center of stud, inches
D_s = Diameter of stud shank, inches
N = Number of reductions (one or two)

When headed anchors are placed close enough to a free edge so that the conical development area overlaps the free edge, reduction in capacity due to spacing along the free edge may be ignored. **The reduction in shear capacity due to cone overlap governs.** Figure 25. illustrates such a case.

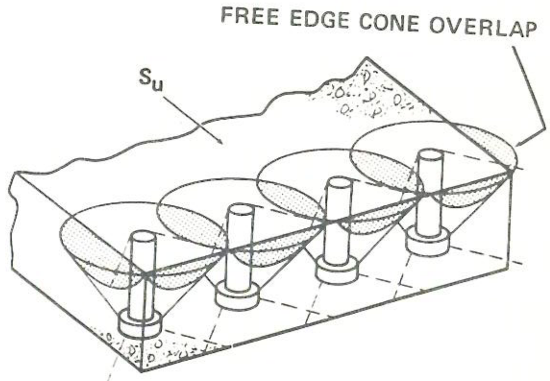


FIGURE 25.—Reduced Shear Capacity at Free Edge Due to Cone Overlap.

EXAMPLE: Determine the shear capacity of an embedment plate with four (4) ½ x 6⅛ headed anchors attached, anchors spaced on 4" centers, 3" from free edge and sides of concrete member. Concrete compressive strength: 4000 psi normal weight. No sub-reinforcement used.

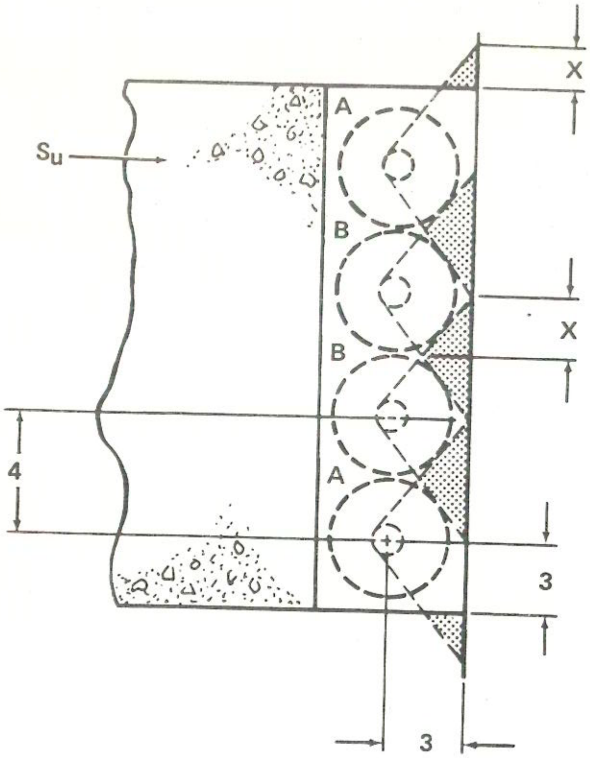


FIGURE 26. — Top View

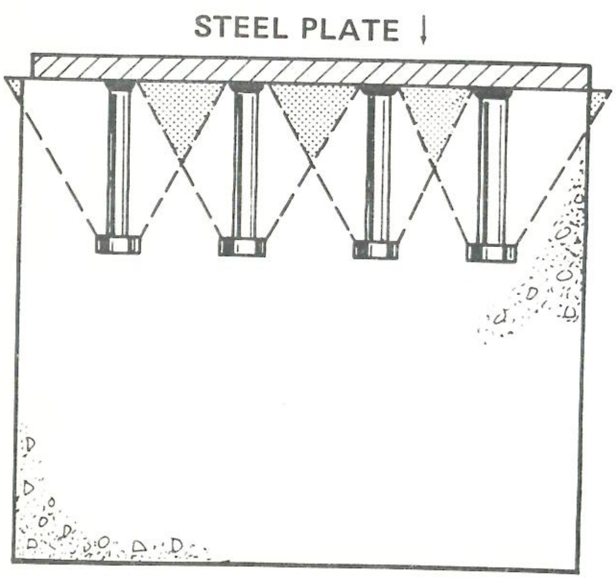


FIGURE 27. — Front View.

STEP 1. Full shear capacity per anchor
Table 15. 4000 psi N.W. concrete

10.33 kips/anchor
4 anchors
41.32 kips

STEP 2. Spacing required between anchors
Table 16. Spacing required = 2R

$R = \frac{1.0}{2}$
2.0" (4.0" Actual)
(No overlap condition exists)

No Reduction

STEP 3. Distance required from center of anchor to free edge subject to shear force.

Table 23. 5.48" required, 3.0" actual, reduction necessary.

Table 25. Reduction for 3" edge distance = 5.71 kips/anchor.

Total reduction = 4 x 5.71 = 22.84 kips

STEP 4. Spacing between anchors along a free edge subject to shear force.

Table 30. Required spacing = 6.50", actual spacing — 4.0.

A. Anchors, spacing to side of member — 3", required = $\frac{6.50}{2}$ or 3.25

X reduction = 0.25" one side.
Spacing to adjacent anchor = 4.00", required = 6.50", reduction X =
$\frac{6.50 - 4.00}{2} = 1.25''$

B. Anchors, 2 reductions, X = 1.25".

Calculation: Equation 15., Amount of reduction =

A. Anchors, $10.33\ \frac{0.5\,(.25)^2}{(3.0 + .25)^2} +$

$10.33\ \frac{0.5\,(1.25)^2}{(3.0 + .25)^2} =$

.794 kips/A. Anchor

B. Anchors, $10.33\ \frac{0.5\,(1.25)^2}{(3.0 + .25)^2} +$

$10.33\ \frac{0.5\,(1.25)/_4}{(3.0 + .25)^2} -$

1.53 kips/B. Anchor

Total Reduction 2 x .794 = 1.588
2 x 1.53 = 3.06
4.548

STEP 5. Total Capacity of Connection

Full Capacity	41.32 kips
Step 2. Reduction	0 kips
Step 3. Reduction	-22.84 kips
Step 4. Reduction	-4.65 kips
Capacity =	13.83 kips
Allowable load = $\frac{13.83}{2}$ =	6.92 kips

Failure mode predicted: Concrete. The need for sub-reinforcement at the free edge to increase connection capacity is indicated to prevent failure.

This connection should also be calculated using the anchors as a group. For a typical example of a group calculation see example problem No. 2., Section 7.

Recommendation: Add edge reinforcement.

6.0 EMBEDMENT PROPERTIES OF ANCHORS — COMBINED SHEAR — TENSION LOADING.

In many cases, headed anchors embedded in concrete are subject to combined shear and tension forces. These loadings may be deliberately applied or may be the result of a resolution of forces acting upon the anchors.

As is evident from the preceeding sections of this publication, the embedment spacings for tension are the most critical and will control the insert plate design in most cases of combined loading.

One of the prime objectives of the Lehigh report[3.] was the determination of anchor performance when subject to combined loadings. Details on the method of force application, results, etc. are available in that report as published in the A.I.S.C. JOURNAL. Copies are available from Nelson Stud Welding. Both full embedment and partial embedment anchors were investigated with loadings in pure shear, pure tension, 30° shear-tension and 60° shear-tension.

All of the anchors tested exhibited excellent ductility prior to failure either in the stud or failure of the concrete. Figure 28. shows typical specimen ductility.

The test results are summarized in Table 31.

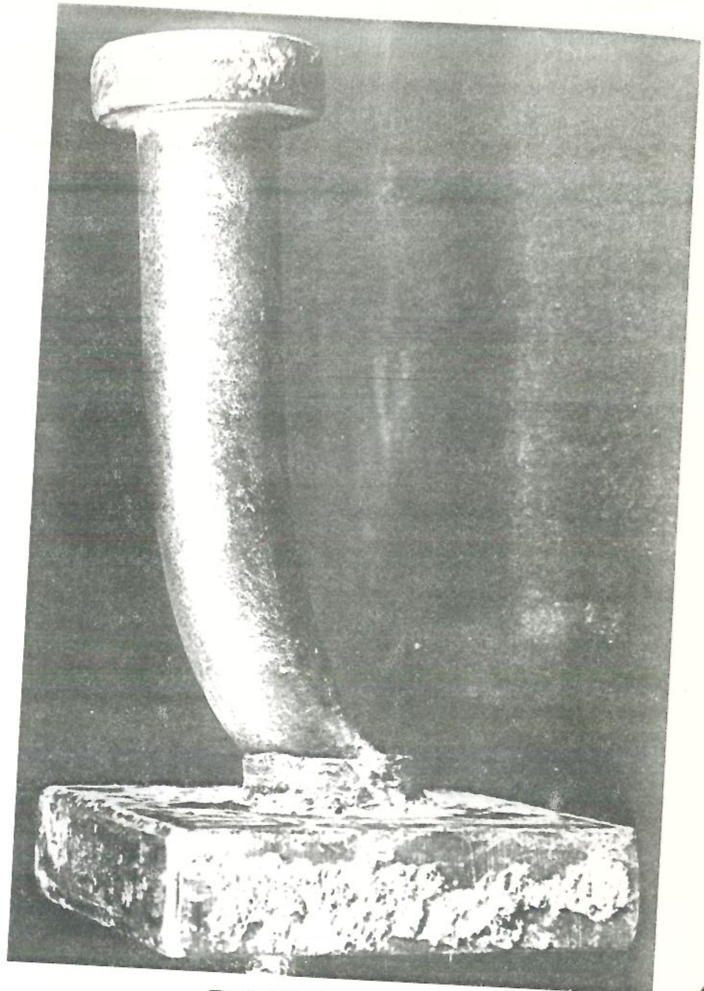


FIGURE 28.— Beam C
Partial Embedment Specimen, Combined Loading at 60°, Normal Weight Concrete.

Table 31. Combined Loading Test Results

Symbol	Beam	Stud Size	Concrete Type	f'c (psi)	Type of Loading Pure Tension = o°	Ultimate Load (Kips) Tension	Ultimate Load (Kips) Shear	Failure Mode
▲	A	¾ x 7	Normal Weight	5270	Tension	28.3		Stud
▲	A	¾ x 7	Normal Weight	5270	Tension	28.5		Stud
▲	A	¾ x 7	Normal Weight	5270	Tension	28.0		Stud
▲	A	¾ x 7	Normal Weight	5270	Combined 30°	23.7	13.6	Stud
▲	A	¾ x 7	Normal Weight	5270	Combined 30°	23.7	13.75	Stud
▲	A	¾ x 7	Normal Weight	5270	Combined 60°	12.9	21.3	Stud
▲	A	¾ x 7	Normal Weight	5270	Combined 60°	11.7	21.2	Stud
▲	A	¾ x 7	Normal Weight	5270	Combined 60°	13.4	23.6	Stud
■	B	⅞ x 8	Normal Weight	4900	Tension	43.0		Concrete
■	B	⅞ x 8	Normal Weight	4900	Combined 30°	33.0	19.5	Stud
■	B	⅞ x 8	Normal Weight	4900	Combined 60°	17.3	30.6	Stud
△	D	¾ x 7	All Lightweight	5300	Tension	28.7		Stud
△	D	¾ x 7	All Lightweight	5300	Combined 30°	25.6	15.4	Concrete
△	D	¾ x 7	All Lightweight	5300	Combined 60°	10.8	19.4	Stud
□	D	¾ x 8	All Lightweight	5300	Tension	30.1		Concrete
□	D	¾ x 8	All Lightweight	5300	Tension	31.5		Concrete
□	D	¾ x 8	All Lightweight	5300	Combined 30°	21.6	12.4	Stud
□	D	¾ x 8	All Lightweight	5300	Combined 30°	19.8	11.8	Concrete
□	D	¾ x 8	All Lightweight	5300	Combined 60°	12.6	22.0	Stud
□	D	¾ x 8	All Lightweight	5300	Combined 60°	13.3	23.6	Concrete
■	B	¾ x 4	Normal Weight	4900	Combined 30°	17.7	10.8	Concrete
■	B	¾ x 4	Normal Weight	4900	Combined 30°	17.6	10.8	Concrete
■	B	¾ x 4	Normal Weight	4900	Combined 30°	17.4	10.6	Concrete
■	B	¾ x 4	Normal Weight	4900	Combined 60°	12.6	22.8	Stud
■	B	¾ x 4	Normal Weight	4900	Combined 60°	10.4	18.4	Concrete
■	B	¾ x 4	Normal Weight	4900	Combined 60°	10.0	18.0	Concrete
•	C	¾ x 4	Normal Weight	5180	Tension	18.5		Concrete
•	C	¾ x 4	Normal Weight	5180	Tension	18.5		Concrete
•	C	¾ x 4	Normal Weight	5180	Tension	17.3		Concrete
•	C	¾ x 4	Normal Weight	5180	Combined 30°	13.8	8.4	Concrete
•	C	¾ x 4	Normal Weight	5180	Combined 30°	15.5	9.6	Concrete
•	C	¾ x 4	Normal Weight	5180	Combined 30°	16.4	9.6	Concrete
•	C	¾ x 4	Normal Weight	5180	Combined 60°	12.6	22.2	Stud
•	C	¾ x 4	Normal Weight	5180	Combined 60°	13.0	23.6	Concrete
•	C	¾ x 4	Normal Weight	5180	Combined 60°	12.0	21.2	Stud

Pure shear force loadings were taken from a previous report by Ollgaard, Slutter and Fisher.[9.] Both concrete and anchors had comparable properties to those used in this study.

The formulae found to provide the best fit for the test data are:

Full Embedment

$$\left(\frac{Pu/A_s}{P'u/As}\right)^{5/3} + \left(\frac{Su/A_s}{S'u/As}\right)^{5/3} = 1$$

where:

Pu = Applied tension load

Su = Applied shear load

P'u = Tensile capacity of the anchor = $A_s f_s$ (Area x tensile strength)

S'u = Shear capacity of the anchor $6.6 \times 10^{-3} A_s f'_c{}^{0.3} Ec^{0.44}$ $\leq$ Sue

where:

A_s = area of the headed anchor

f'_c = 28 day concrete compressive strength, Psi

E_c = concrete modulus of elasticity, psi

Partial Embedment

$$\left(\frac{P_u}{P_{u_c}}\right)^{5/3} + \left(\frac{S_u}{S'u}\right)^{5/3} = 1$$

where: Pu and Su have been defined above and Puc = ultimate concrete tension capacity, kips and Suc = shear capacity kips.

$Puc = C\,A_{fc}\sqrt{f'_c} =$

$0.55\ CLe\ (Le + D_h)\ \sqrt{f'c} \leq P'u$

(See Equation 5.)

Curves derived from the formulae and plotted against test data are shown in Figure 29.

Essentially, the curves show that the formulae for full and partial embedment provide a reasonable fit to the test data.

Providing a better design relationship to the curves shown in Figure 29., a reduction factor for ultimate strength design of 0.9 for full embedment anchors and 0.85 for partial embedment anchors yields the following design formulae and design curves.

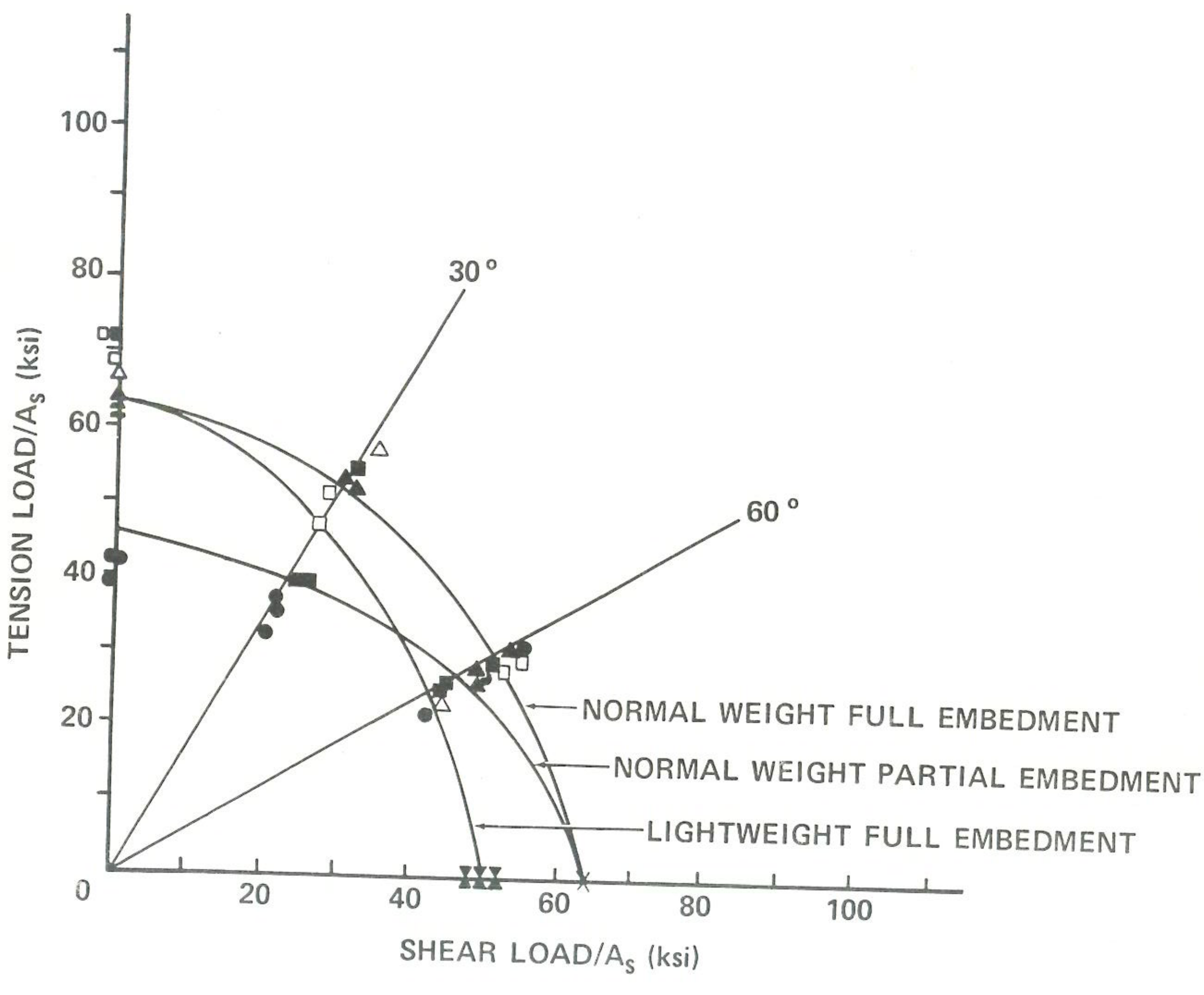


FIGURE 29.—Combined Loading — Formulae Versus Test Data.

6.1 Full Embedment — Combined Loading Design Data.

$$\left(\frac{P_u}{P'_u}\right)^{5/3} + \left(\frac{S_u}{S'_u}\right)^{5/3} \leq 1$$

(Equation 16.)

where:
P_u = Applied tension load
S_u = Applied shear load
$P'u$ = Tensile capacity of the anchor = $0.9\ A_s f_s$

$S'u$ = Shear capacity of the anchor = $0.9 \times 6.66 \times 10^{-3}\ A_s\ f'_c\ Ec^{0.44} \leq 0.9\ A_s\ f_s$

Terms as previously defined.

Equation 16. is the formula which provides the best ultimate strength design under all conditions of combined loading for **full embedment** anchors in both normal and lightweight concrete.

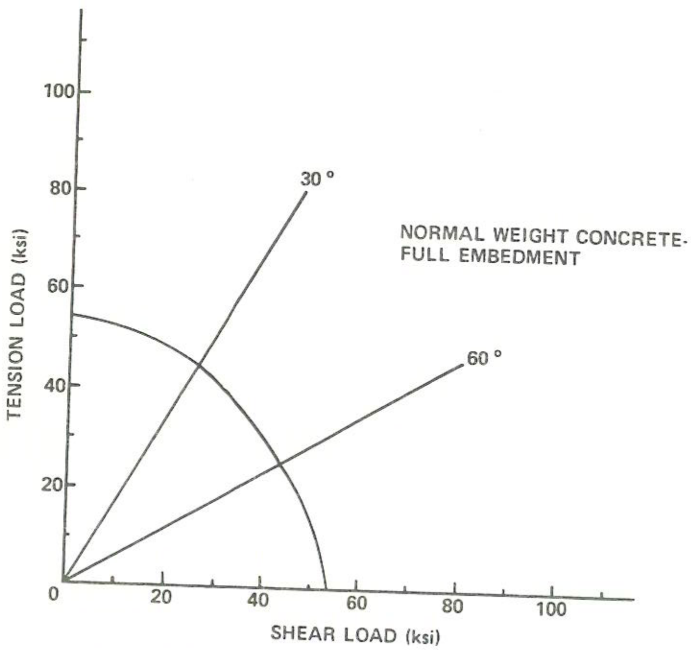


FIGURE 30.— Interaction Design Curve. Combined Loading of Full Embedment Anchors in Normal Weight Concrete

6.2 Partial Embedment — Combined Loading Design Data.

Applying an ultimate strength design reduction factor of 0.85 to the **partial embedment** case, the design formula for this case may be taken as:

$$\left(\frac{P_u}{P_{uc}}\right)^{5/3} + \left(\frac{S_u}{S_{uc}}\right)^{5/3} \leq 1$$

(Equation 17.)

where:
P_u = Applied tension load
S_u = Applied shear load
P_{uc} = Ultimate concrete tension capacity, kips = $0.475\ C\ Le\ (Le + D_h)\sqrt{f'c} \leq 0.85\ A_s f_s$
Suc = Concrete shear capacity of the anchor, kips = $5.66 \times 10^{-3}\ A_s\ f'c^{0.33}\ Ec^{0.44} \leq 0.85\ A_s\ f_s$

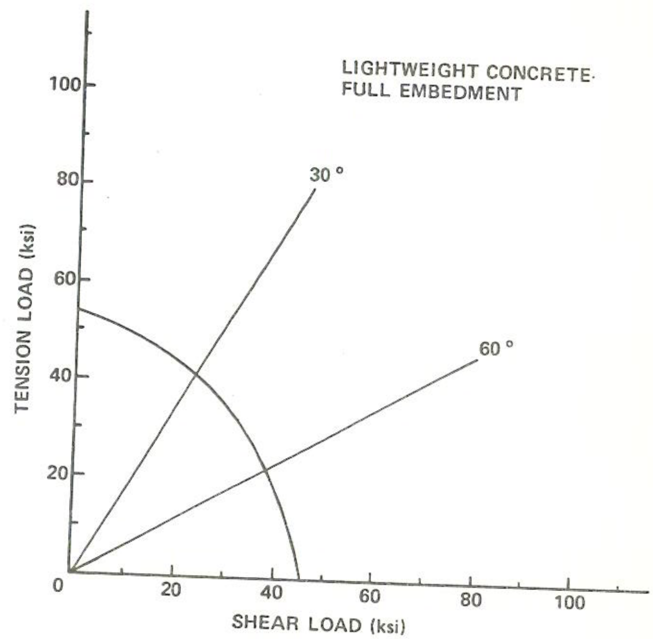


FIGURE 31.— Interaction Design Curve. Combined Loading of Full Embedment Anchors in Lightweight Concrete

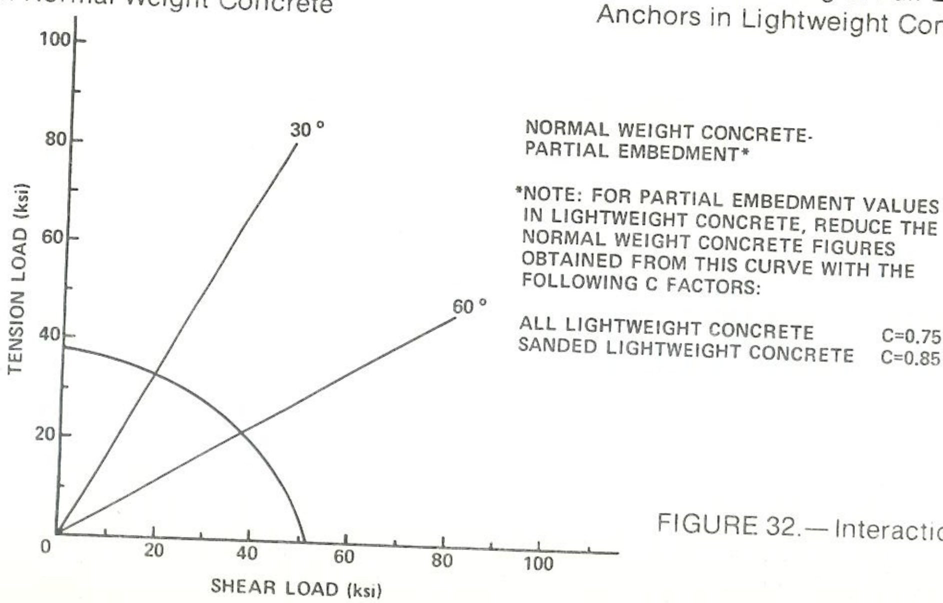


FIGURE 32.— Interaction Design Curve.

6.3 Use of Design Curves for Combined Loading

In order to use the design curves (figures 30., 31., and 32.), tension and shear loads should either be stated in terms of kips per square inch (KSI) as they are on the curves or converted to actual loadings in terms of Pounds (KIPS). The following table is for conversion purposes.

Table 32. Conversion Table — KSI To KIPS

KSI	KIPS					
	Anchor Diameter (Ds) and Area (As)					
Kips/Sq. In.	**Ds = ¼″ As = .0491**	**Ds = ⅜″ As = .1104**	**Ds = ½″ As = .1964**	**Ds = ⅝″ As = .3068**	**Ds = ¾″ As = .4418**	**Ds = ⅞″ As = .6013**
2	0.10	0.22	0.39	0.61	0.88	1.20
4	0.20	0.44	0.79	1.23	1.77	2.41
6	0.29	0.66	1.18	1.84	2.65	3.61
8	0.39	0.88	1.59	2.45	3.53	4.81
10	0.49	1.10	1.96	3.07	4.42	6.01
12	0.59	1.32	2.36	3.68	5.30	7.22
14	0.69	1.58	3.75	4.30	6.18	8.42
16	0.78	1.77	3.14	4.91	7.07	9.62
18	0.88	1.99	3.54	5.52	7.95	10.82
20	0.98	2.21	3.93	6.14	8.84	12.03
22	1.08	2.43	4.33	6.75	9.72	13.23
24	1.18	2.65	4.71	7.36	10.60	14.43
26	1.27	2.87	5.11	7.98	11.49	15.63
28	1.37	3.09	5.50	8.59	12.37	16.84
30	1.47	3.31	5.89	9.20	13.25	18.04
32	1.57	3.53	6.28	9.82	14.14	19.24
34	1.67	3.75	6.68	10.43	15.02	20.44
36	1.76	3.97	7.07	11.04	15.90	21.65
38	1.86	4.20	7.46	11.66	16.79	22.85
40	1.96	4.42	7.86	12.27	17.67	24.05
42	2.06	4.64	8.25	12.89	18.56	25.25
44	2.16	4.86	8.64	13.50	19.44	26.46
46	2.25	5.08	9.03	14.11	20.32	27.66
48	2.35	5.30	9.43	14.73	21.21	28.86
50	2.45	5.62	9.82	15.34	22.09	30.07
52	2.55	5.74	10.21	15.95	22.97	31.27
54	2.65	5.95	10.60	16.56	23.86	32.47

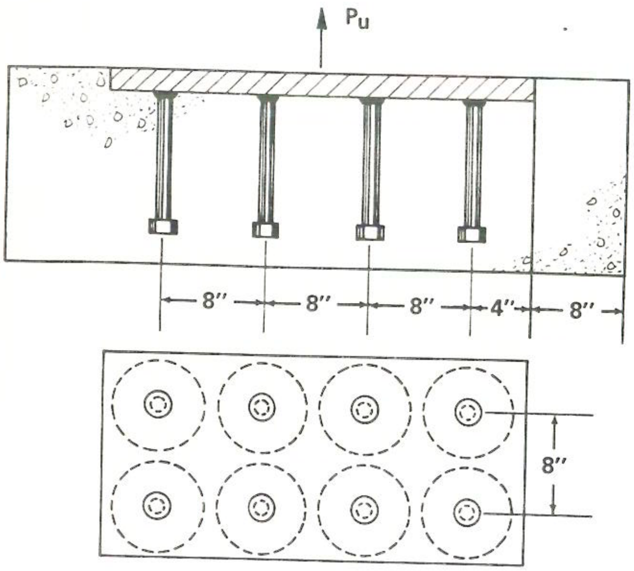
7.0 Example Problems

Problems showing applications involving shear, tension and combined shear-tension are included in this section. While background data and formulae constitute a large portion of this publication, actual problems may be readily solved after familiarization by reference to the examples given and to important design tables and/or curves.

7.1 Index To Design Tables And Design Curves.

Problem 1.
Determine the allowable **tension load** for an embedment plate with 8 anchors, spaced as shown.

Anchors = $\frac{3}{4}'' \times 7\frac{3}{16}''$
Concrete = f'c = 4000 psi
Normal Weight



Anchor Capacity from Table 4 = 23.86 = Pue

Anchor Spacing Required from Table 6. =
R = 3.992''

$$\frac{2}{7.984''}\ \text{Dia.}$$

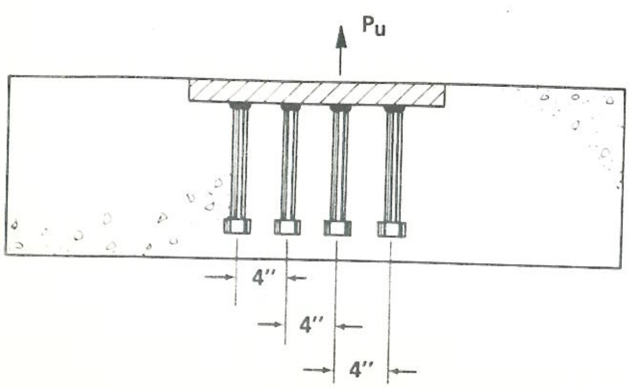
Spacing shown exceeds requirements.

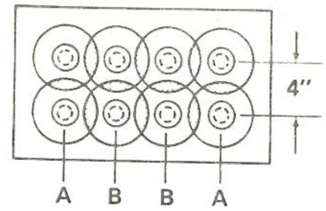
Capacity = 8 Anchors x 23.86 Kips/Anchor = 190.9 Kips

Using a load factor of 2.0
Allowable Load Pu = $\frac{190.9}{2}$ = 95.4 Kips

Problem 2.
Determine the allowable **tension load** for a plate similar to that in Problem 1., with anchor spacing reduced as shown.

Anchors = $\frac{3}{4}'' \times 7\frac{3}{16}''$
f'c = 4000 psi
Normal weight





Anchor Capacity from Table 4. = 23.86 = Pue

Anchor Spacing Required from Table 6. =
R = 3.992''

$$\frac{2}{7.984''}\ \text{Call 8.00'' Dia.}$$

Spacing shown does **not** meet requirements.

4 Corner Anchors (Anchor A.) Have two reductions.
4 Interior Anchors (Anchor B.) Have three reductions.

De
(Distance to edge) = $\frac{4''}{2}$ center spacing = 2.00''

From Table 10. Reduction due to edge distance of 2.00'' = 8.92 Kips.

$$\begin{aligned} \text{R Puc} &= 4[23.86-2\ (8.92)] = 24.08\ \text{Kips} \\ &\quad + \\ &\quad 4[23.86-3\ (8.92)] = -11.60\ \text{Kips} \\ &\quad = \qquad\qquad\qquad\quad 12.48\ \text{Kips} \end{aligned}$$

Allowable Load = $\frac{12.48}{2}$ = 6.24 Kips

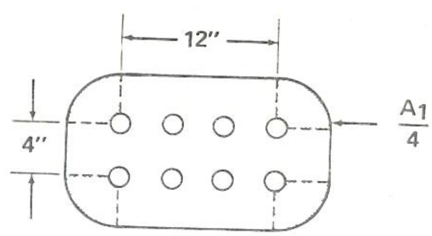
Any group of anchors with spacing less than or equal to the minimum shown should be checked by a group calculation using Equation 5. as follows.

Problem 2. — Check tension load by group calculation:

Area = $A_1 + 2A_2 + 2A_3 + A_4$

$\frac{A_1}{4}$ $\quad A_1$ = AFC (Area of Full Cone)

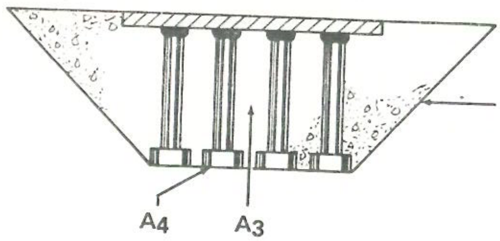
from Table 10. AFC = 111.0 sq. in.



A_2 = Area of end between end anchors

$(2)\ (4)\ \sqrt{(R-r)^2 + Le^2}$

$(2)\ (4)\ \sqrt{(3.992-.625)^2 + 6.625^2} = 59.5$ sq. in.



A_3 = Area of side

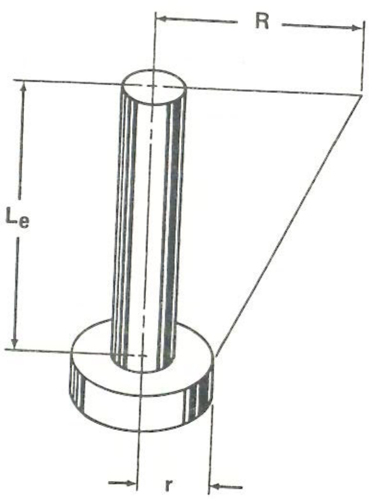
$(2)\ (12)\ \sqrt{(R-r)^2 + Le^2}$

$2\ (12)\ \sqrt{(3.992-.625)^2 + 6.625^2} = 178.4$ sq. in.

A_4 = Area of base

4 (12) = $\underline{48}$ sq. in.

Area = 396.9 sq. in.



Solution: Full cone for ¾" x 7³⁄₁₆" anchor in 4000 psi normal weight concrete from Table 10. = 111 sq. in.

$\underline{\quad 8}$ anchors on plate
888 sq. in. Theoretical Area

$\dfrac{396.9 \text{ Actual Area}}{888 \text{ Theoretical Area}} =$

.447 (8 anchors x 23.86 Kips/Anchor) =

$\dfrac{85.32}{2}$ Kips = 42.7 Kips Allowable Load

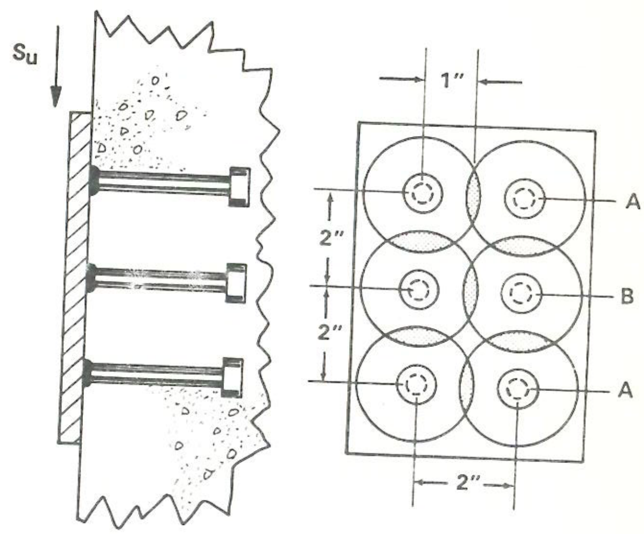
This is 55 ksi on concrete in Bear's in the Head!

Note: The use of a group area calculation should be made in tension capacity problems whenever the anchors in the group have areas less than or equal to the minimum acceptable spacing of R or 2R as listed in Table 6.

The use of a larger capacity if calculated by the group area method is acceptable **only** when sufficient reinforcement in the form of bars or mesh is used to assure the group area development.

Problem 3.
Determine the allowable **shear load** for an embedment plate with 6 anchors spaced as shown. Eccentricity is negligible.

Anchors = ¾" x 4³⁄₁₆"
Concrete = f'c = 3000 psi
Normal weight



Anchor Capacity from Table 15. Suc = 19.99 Kips
Spacing for Full Capacity from Table 16. R = 1.50"

$\underline{\quad 2}$
3.00"

Spacing shown does **not** meet requirements.

4 Corner Anchors (Anchor A.)
Have 2 reductions.

2 Interior Anchors (Anchor B.)
Have 3 reductions.

Reduced Capacity due to an edge distance of 1" from Table 17. = 7.78 Kips

RSuc = 4 (19.99-2 (7.78)) = 17.72

+

2 (19.99-3 (7.78)) = $\underline{-6.70}$

= 11.02 Kips

Allowable load = $\dfrac{11.02}{2}$ = **5.51 Kips**

Anticipated failure mode = Concrete (secondary reinforcement needed)

The behavior of this group of anchors should be checked by a group calculation.

Using the same area approach as used with the tension group in Problem 2., the following shear group calculation can be made.

Area = $A_1 + 2A_2 + 2A_3 + A_4$

A_1 = Area of corners (4) = Afc
from Table 17. for 3000 psi normal weight
Afc = 20.9 sq. in.

A_2 = Area of end between anchors
(2) (1) $\sqrt{(1.5-.625)^2 + 3.0^2}$ = 6.25 sq. in.
Note: 3.0" = Le = Maximum of 4 x Dia. Stud

A_3 = Area of side
(2) (4) $\sqrt{(1.5-.625)^2 + 3.0^2}$ = 25.0 sq. in.

A_4 = Area of Base
4 x 1 = 4.0 sq. in.
56.15 sq. in.

Solution: Actual Area = 56.15 sq. in.
Theoretical Area = 6 anchors x Afc
6 x 20.9 =
125.4 sq. in.

$\frac{56.16}{125.4} = .448$

.448 (6 anchors x 19.99 kips/anchor) =
53.73 Kips

Allowable Load = $\frac{53.73}{2}$ = 26.87 Kips

The larger figure arrived at by group calculation can only be acceptable when sufficient reinforcement in the form of bars or mesh is used to assure the group area development.

Problem 4. Combined loading
Determine the allowable load on the bracket shown.

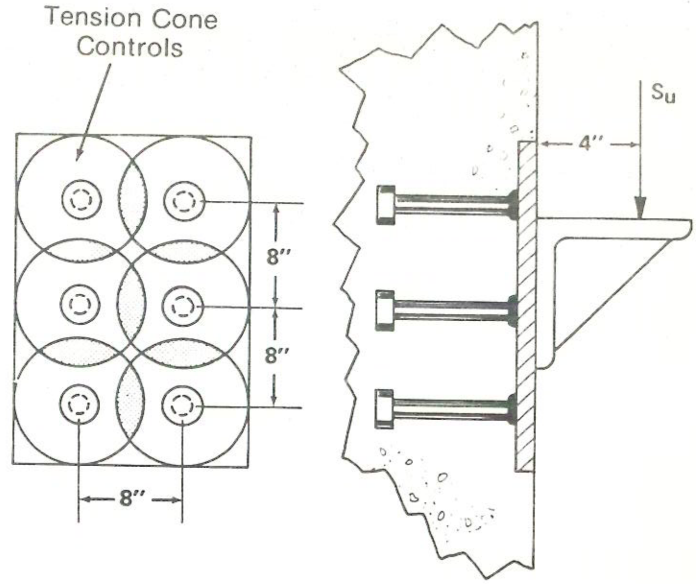
Anchors = 3/4" x 7 3/16"
Concrete = f'c = 3000 psi
Normal weight

Shear force taken by each anchor = $\frac{Su}{6}$

Bending taken only by the outside anchors
Moment = 4 Su = 16 (2) Pu, where Pu is the tension component on the outside anchors,
Pu = $\frac{Su}{8}$

from Table 6., spacing
for full tension capacity = 4.610R
2
9.220"

De = 4.0"
from Table 9., tension reductions = 3.69 Kips
RPuc = [23.86-(2) 3.69] = 16.48 Kips
from Table 17., shear reductions = 0 Kips
RSuc = [19.99-0] = 19.99 Kips



(Since interior anchors are not stressed in tension, they are considered to have the same value as the outside anchors).

Equation 16.

$$\left(\frac{Pu}{Puc}\right)^{5/3} + \left(\frac{Su}{Suc}\right)^{5/3} = 1$$

$$\left(\frac{Su/8}{16.48}\right)^{5/3} + \left(\frac{Su/6}{19.99}\right)^{5/3} = 1$$

$$Su^{5/3} (7.59 \times 10^{-3})^{5/3} + (8.34 \times 10^{-3})^{5/3} = 1$$

$$Su^{5/3} = \frac{1}{.000293 + .000344}$$

$$Su^{5/3} = 1569.86$$

Su = 82.8 Kips

Allowable Load = $\frac{82.8}{2}$ = 41.4 Kips

Failure mode indicated: Concrete. Additional reinforcement to bring the connection into the ductile failure range is indicated.

Problem 5. Combined Loading
Determine the allowable load on the bracket shown.

Anchors = 3/4" x 7 3/16"
Concrete = f'c = 3000 psi
Normal weight

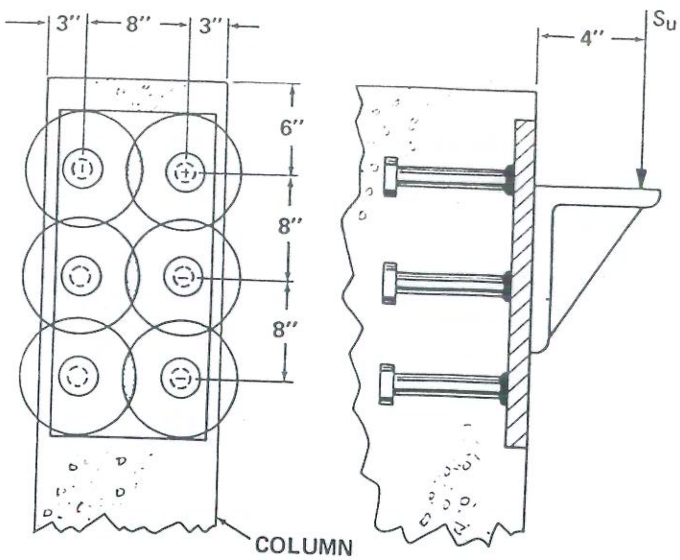
Shear force taken by each anchor = $\frac{Su}{6}$

Bending taken only by the outside anchors

Moment = 4 Su = 16 (2) Pu, where Pu is the tension component on the outside anchors,
Pu = $\frac{Su}{8}$

Reduced edge distance on sides. Tension anchors, 2 reductions, De = 4.0", De = 3.0"

From Table 6. spacing for full tension capacity 4.610" = R



From Table 9., tension reductions
De = 4.0, 3.69 Kips
De = 3.0, 6.61 Kips
RPuc = [23.86-(3.69 + 6.61)] = 13.56 Kips

From Table 17., shear reductions (none)
De = 4.0, 0 Kips
De = 3.0, 0 Kips
RSuc = [Suc] = 19.99 Kips

Equation 16.

$$\left(\frac{Pu}{Puc}\right)^{5/3} + \left(\frac{Su}{Suc}\right)^{5/3} = 1$$

$$\left(\frac{Su/8}{13.56}\right)^{5/3} + \left(\frac{Su/6}{19.99}\right)^{5/3} = 1$$

$$Su^{5/3}\,(9.22 \times 10^{-3})^{5/3} + (8.34 \times 10^{-3})^{5/3} = 1$$

$$Su^{5/3} = \frac{1}{.000405 + .000344}$$

$$Su^{5/3} = 1335.11$$
$$Su = 75.2 \text{ Kips}$$

Allowable load = $\frac{75.2}{2}$ = **37.6 Kips**

Failure mode indicated: Concrete. Additional reinforcement to bring the connection into the ductile failure range is indicated.

8.0 STANDARD SPECIFICATIONS

Short Form Specification — Embedment anchors shall be Nelson headed anchors with fluxed ends (or approved equal). Studs shall be automatically end welded with suitable Nelson Stud Welding equipment in the shop or field on spacings indicated on the drawings. All welds shall be made in accordance with recommendations of the Nelson Stud Welding Company, Lorain, Ohio.

Welding Specifications — All weld plate materials shall be clean, dry and free of paint, rust, oil or other contaminants. Plating, if required should be done after completion of welding. Two studs should be welded to plate material of the same type and thickness being used for embedment at the start of each shift to check for proper weld setup procedure. Test welding should be done in the same position being used for production. Test welds, after cooling, should be bent by hammer 45° from the vertical position without failure. Non-failure of both studs indicates that the weld setup is satisfactory and production welding may be started.

Inspection Requirements — After welding, the ceramic ferrule should be removed from each stud and the weld fillet visually inspected. A fillet of less than 360° is cause for further inspection. Such studs should be hammer tested, bending the stud 15° from the vertical toward the closest end of the embedment plate or steel member. Bending without failure indicates a satisfactory weld. Bent studs may be left bent.

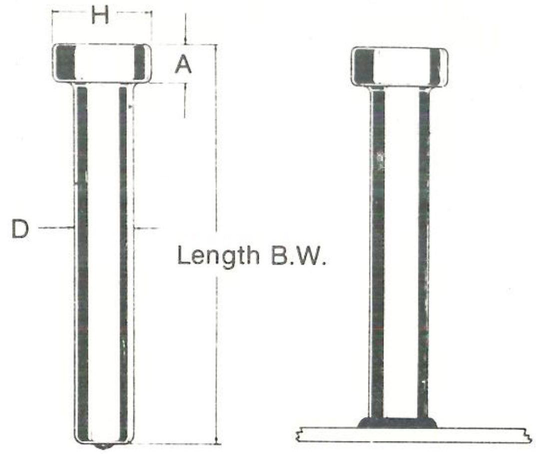
When studs are welded to steel plates or members with temperatures below 32° F., one stud in each 100 should be tested by bending 15° from the vertical. **Warning** — Welding should not be attempted when the base metal temperature is below 0° F. or when the steel surface is wet or exposed to falling rain or snow.

TABLE 33.

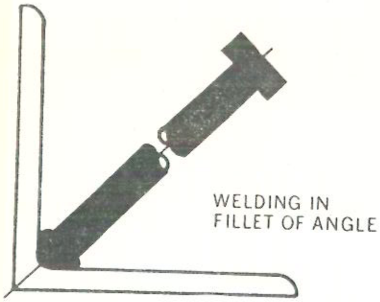
Steel Plate

Weld Base Diameter	Plate Thickness
.250	1/8 (.125)
.375	3/16 (.187)
.500	3/16 (.187)
.625	1/4 (.250)
.750	5/16 (.318)
.875	3/8 (.375)

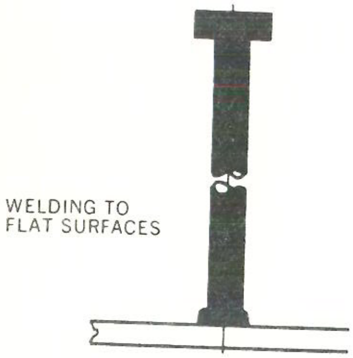
Minimum Plate Thickness Required For Full Strength Stud Weld (12.)



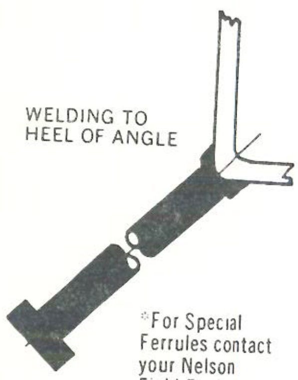
Part No.	Description	Stud Dia. D	A	H	Length, B.W. (Before Weld)	Length, A.W. (After Weld)	Le
101-053-031	$\frac{1}{4}$ x $2\frac{11}{16}$ H4L	$\frac{1}{4}$	.187	.500	$2\frac{11}{16}$	$2\frac{9}{16}$	$2\frac{3}{8}$
101-053-033	$\frac{1}{4}$ x $4\frac{1}{8}$ H4L				$4\frac{1}{8}$	4	$3\frac{13}{16}$
101-053-043	$\frac{3}{8}$ x $4\frac{1}{8}$ H4L	$\frac{3}{8}$	.281	.750	$4\frac{1}{8}$	4	$3\frac{23}{32}$
101-053-045	$\frac{3}{8}$ x $6\frac{1}{8}$ H4L				$6\frac{1}{8}$	6	$5\frac{23}{32}$
101-053-047	$\frac{1}{2}$ x $2\frac{1}{8}$ H4L	$\frac{1}{2}$	.312	1.000	$2\frac{1}{8}$	2	$1\frac{11}{16}$
101-053-002	$\frac{1}{2}$ x $3\frac{1}{8}$ H4L				$3\frac{1}{8}$	3	$2\frac{11}{16}$
101-053-003	$\frac{1}{2}$ x $4\frac{1}{8}$ H4L				$4\frac{1}{8}$	4	$3\frac{11}{16}$
101-053-005	$\frac{1}{2}$ x $5\frac{5}{16}$ H4L				$5\frac{5}{16}$	$5\frac{3}{16}$	$4\frac{7}{8}$
101-053-008	$\frac{1}{2}$ x $6\frac{1}{8}$ H4L				$6\frac{1}{8}$	6	$5\frac{11}{16}$
101-053-010	$\frac{1}{2}$ x $8\frac{1}{8}$ H4L				$8\frac{1}{8}$	8	$7\frac{11}{16}$
101-053-012	$\frac{5}{8}$ x $2\frac{11}{16}$ H4L	$\frac{5}{8}$	.312	1.250	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{3}{16}$
101-053-019	$\frac{5}{8}$ x $6\frac{9}{16}$ H4L				$6\frac{9}{16}$	$6\frac{3}{8}$	$6\frac{1}{16}$
101-053-023	$\frac{5}{8}$ x $8\frac{3}{16}$ H4L				$8\frac{3}{16}$	8	$7\frac{11}{16}$
101-098-003	$\frac{3}{4}$ x $3\frac{3}{16}$ S3L	$\frac{3}{4}$	Min. $\frac{3}{8}$	1.250	$3\frac{3}{16}$	3	$2\frac{5}{8}$
101-098-007	$\frac{3}{4}$ x $4\frac{3}{16}$ S3L				$4\frac{3}{16}$	4	$3\frac{5}{8}$
101-098-011	$\frac{3}{4}$ x $5\frac{3}{16}$ S3L				$5\frac{3}{16}$	5	$4\frac{5}{8}$
101-098-015	$\frac{3}{4}$ x $6\frac{3}{16}$ S3L				$6\frac{3}{16}$	6	$5\frac{5}{8}$
101-098-019	$\frac{3}{4}$ x $7\frac{3}{16}$ S3L				$7\frac{3}{16}$	7	$6\frac{5}{8}$
101-098-023	$\frac{3}{4}$ x $8\frac{3}{16}$ S3L				$8\frac{3}{16}$	8	$7\frac{5}{8}$
101-098-029	$\frac{7}{8}$ x $3\frac{11}{16}$ S3L	$\frac{7}{8}$	Min. $\frac{3}{8}$	1.375	$3\frac{11}{16}$	$3\frac{1}{2}$	$3\frac{1}{8}$
101-098-031	$\frac{7}{8}$ x $4\frac{3}{16}$ S3L				$4\frac{3}{16}$	4	$3\frac{5}{8}$
101-098-035	$\frac{7}{8}$ x $5\frac{3}{16}$ S3L				$5\frac{3}{16}$	5	$4\frac{5}{8}$
101-098-039	$\frac{7}{8}$ x $6\frac{3}{16}$ S3L				$6\frac{3}{16}$	6	$5\frac{5}{8}$
101-098-043	$\frac{7}{8}$ x $7\frac{3}{16}$ S3L				$7\frac{3}{16}$	7	$6\frac{5}{8}$
101-098-047	$\frac{7}{8}$ x $8\frac{3}{16}$ S3L				$8\frac{3}{16}$	8	$7\frac{5}{8}$



Stud Diameter	Fillet Radius	Use Ferrule Number	Grip	Foot	Chuck
1/4	.125R	100-106-001	501-004-003	502-002-001	500-001-014
3/8	.250R	100-106-002	501-004-006	502-002-001	500-001-018
1/2	.250R	100-103-009	501-004-008	502-002-001	500-001-085
	.375R	100-103-011	501-004-008	502-002-001	500-001-085
5/8	.375R	100-106-005	501-004-009	502-002-002	500-001-088
	.375R	100-106-004	501-004-014	502-002-002	500-001-088
3/4	.375R	100-106-004	501-004-014	502-002-002	500-001-088
	.750R	100-103-012	501-004-014	502-002-002	500-001-088



Stud Diameter	Use Ferrule Number	Grip	Foot	Chuck
1/4	100-101-006	501-004-003	502-002-001	500-001-014
3/8	100-101-008	501-004-006	502-002-001	500-001-018
1/2	100-101-010	501-004-008	502-002-001	500-001-085
5/8	100-101-012	501-004-009	502-002-002	500-001-088
3/4	100-101-043	501-004-019	502-002-009	500-001-088
7/8	100-101-140	501-004-020	502-002-009	500-001-091



*For Special Ferrules contact your Nelson Field Engineer.

Stud Diameter	Use Ferrule Number	Grip	Foot	Chuck
1/4	*Special			
3/8	100-105-001	501-003-008	502-002-001	500-001-018
1/2	100-105-002	501-003-010	502-002-001	500-001-085
5/8	100-105-003	501-004-009	502-002-002	500-001-008

RECOMMENDED EQUIPMENT & ACCESSORIES:

For Studs 1/4'' through 5/8'' Diameter	NELSON NS-20-Stud Welding Unit (Part No. 799-015-000) OPTIONAL TRANQUIL-ARC Kit is recommended for use with 799-015-000 system when welding 1/2" and 5/8" diameter
For Studs 3/4'' & 7/8'' Diameter	NELSON NS-20A HD Stud Welding Unit (Part No. 799-340-000)

POWER RECOMMENDATIONS:

For Welding 1/4, 3/8 or 1/2 Dia. Studs to Flat Surfaces	400 Ampere N.E.M.A. Rated Generator or NELSON Battery Unit
For Welding 1/2'' thru 7/8'' Dia. Studs in Fillet Heel or Flat of Angle	NELSON 2000-A Power Unit or Equal
For Welding 3/4" Dia. Studs in Fillet or Heel of Angle	600 Ampere N.E.M.A. Rated Generator or Equal