Guide to the Design of Anchor Bolts and Other Steel Embedments

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Preface

There has been little published on the design of steel embedments. Many designers looking for guidance have found the work of ACI Committee 349, Concrete Nuclear Structures, extremely helpful. Because there may be designers who are not aware of this information, which is an appendix to the Code prepared by Committee 349, a modified version is offered here which can be applied outside the design of nuclear structures.

Appendix B, "Steel Embedments" of "Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-76)" was adopted by the American Concrete Institute in August 1979. The authors of this article were principal authors of Appendix B. The appendix was ballotted and revised extensively several times before being accepted by ACI Committee 349. Additionally, the document was extensively reviewed by the ACI Technical Activities Committee (TAC). Following revision and ballotting by ACI 349 and further review by TAC, the document was accepted for ballotting by the general membership of the Institute and published in the August 1978 ACI JOURNAL Proceedings *of the American Concrete Institute. It was adopted as part of the Code in June 1979.*

Appendix B is, for the most part, directly applicable to concrete structures in general, not only to nuclear safety related structures. The parts of this article presented in italic-type represents modifications which the authors feel transform Appendix B into a general guide for designing steel embedments. For the most part, the changes fall into one of three categories:

1. 1980 proposed revisions to Appendix B.

2. Deleting references to ACI 349-76 and inserting references to ACI 318-77.

3. Technical changes which the authors feel constitute an improvement in the content of Appendix B.

It is important to emphasize that the regular-type portions of this article have been subjected to a rigorous evaluation by ACI Committee 349, TAC, and the general membership of the Institute.

This guide defines minimum requirements for design of steel embedments used to transmit loads from attachments into reinforced concrete structures. Loads may be transmitted into structures by means of tension, bearing, shear, friction, or any combination thereof. The design limits have been established using both analytical and test methods. The commentary provides background information on the provisions.

Keywords: anchorage (structural); anchor bolts, **anchors (fasteners);** building codes; composite construction (concrete and steel); **embedment;** grouting; **inserts;** loads (forces); reinforced concrete; shear properties; structural design; **studs.**

1.0 — Notation

a = dimension out to out of bearing edges (see Fig. 5-2), in.
A_r = reduction in projected area, *sq in.*
A_1 = loaded area, *sq in.*
A_2 = maximum area of the portion of the supporting surface that is geometrically similar to and concentric with loaded area, *sq in.*
b = dimension, out to out of bearing edges (see Fig. 5-2), in.
D = major thread diameter of threaded anchor or nominal diameter of anchor, in.
f'_c = specified compressive strength of concrete, psi
f_{ut} = minimum specified tensile strength of anchor steel, psi
f_y = minimum specified yield strength of embedment steel, psi
h = overall thickness of member, in.
L_d = embedment depth for tensile anchorage measured from anchorage bearing surface to concrete surface, in.
m = minimum side cover distance from the center of an anchor to the edge of the concrete (see Fig. 5-1), in.
n = number of threads per in.
P_d = *design pullout strength of* concrete in tension, lb
U = required strength *to resist factored loads or related internal moments and forces*
ϕ = *strength* reduction factor, dimensionless

2.0 — Scope

2.1 — This *guide* provides minimum requirements for design and anchorage of steel embedments used to transmit loads from attachments into reinforced concrete structures by means of tension, bearing, shear, friction, or any combination *permitted by this guide.*

Typical embedment details and concepts as referenced in this *guide* are shown in Fig. *2-1* and *2-2*.

In addition to meeting these requirements consideration shall be given to the effect of the forces applied to the embedment on the behavior of the overall structure.

2.2 — The requirements for the attachment to the embedment shall be in accordance with applicable codes and are beyond the scope of this *guide.*

2.3 — Design limits less conservative than those specified in this *guide* may be used by the engineer if substantiated by experimental or detailed analytical investigation.

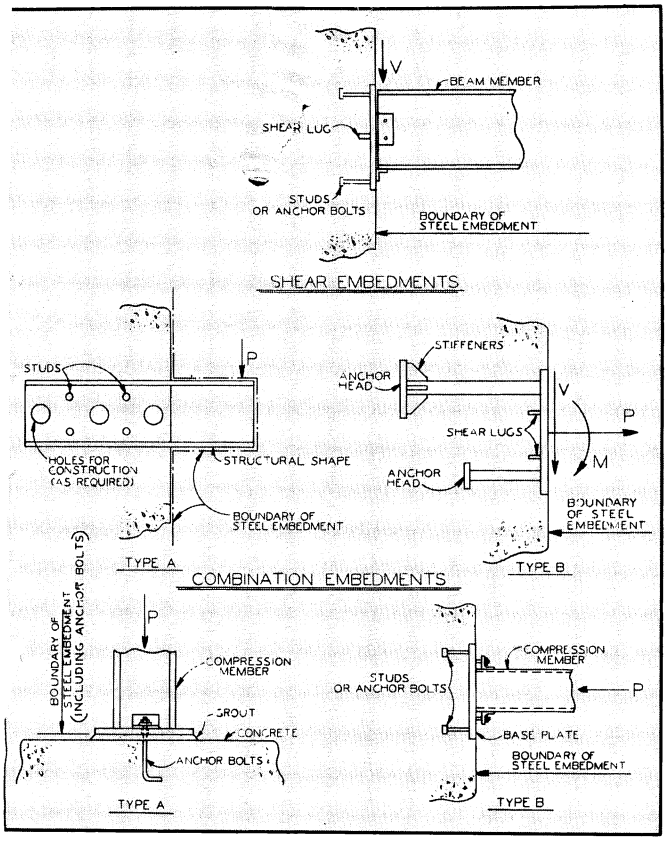

Fig. 2-1 — Bearing embedments — Typical embedment details.

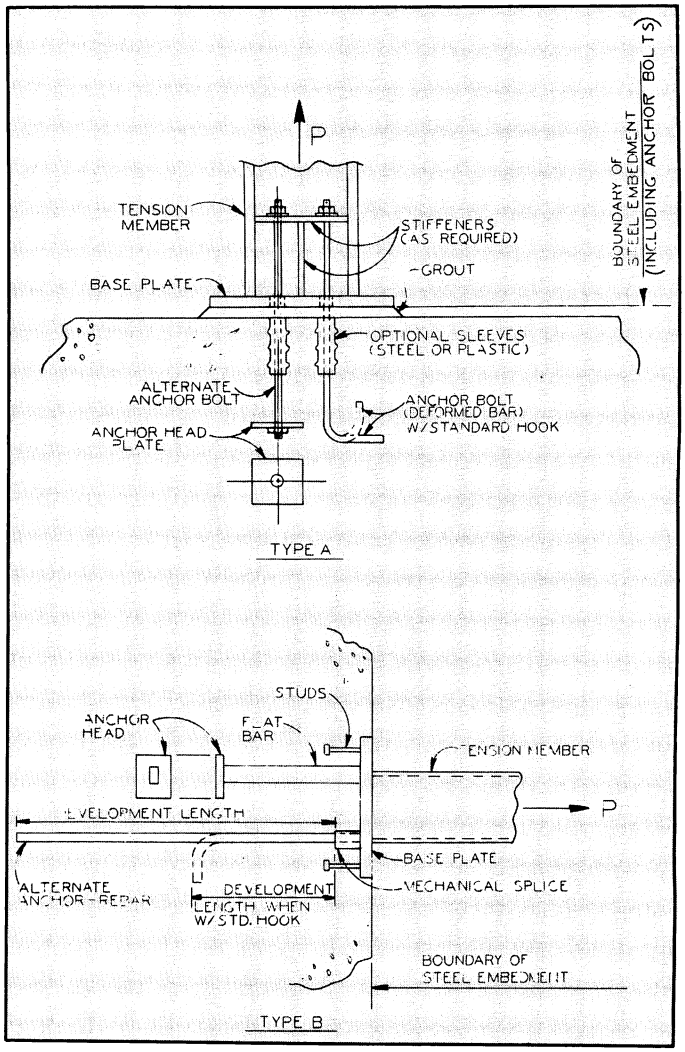

Fig. 2-2 — Tension embedments — Typical embedment details.

3.0 — Definitions

Anchor head — A nut, washer, plate, stud, or bolt head or other steel component used to transmit anchor loads to the concrete by bearing.

Attachment — The attachment is that structure external to the surfaces of the embedment which transmits loads to the embedment.

Embedment — The embedment is that steel component in contact with the concrete *or grout* used to transmit applied loads to the concrete structures. The embedment may be fabricated of plates, shapes, bolts, reinforcing bars, shear connectors, expansion anchors, inserts, or any combination thereof.

Expansion anchor — A component installed in hardened concrete for the transfer of loads into structural components by direct bearing and/or friction.

***Grouted embedment** — An embedment located in a formed or drilled hole in hardened concrete utilizing a grout to provide load transfer from the embedment to the concrete.*

Inserts — Commercially available, predesigned, and prefabricated embedments installed prior to concrete placement which are specifically designed for attachment of bolted connections.

4.0 — General requirements and loading combinations

4.1 — The embedment and surrounding concrete *or grout* shall be designed for transmitting to the concrete structure all loads used in the design of the attachment.

4.2 — Reactions on the embedment due to individual loads such as dead, live (including vibratory loads), thermal and seismic, loads shall be considered. The loading combinations for embedment design shall be in accordance with Section *9.2* of *ACI 318-77.*

4.3 — Material and testing requirements for embedment steel shall be *specified by the engineer to ensure that the intended function of the embedment and the attachment is compatible.*

4.4 — The strength of embedments as affected by the size and grade of steel, spacing, and depth of embedment and any concrete dimensions which limit or restrict the transfer of loads from steel to concrete shall be considered as defined in Sections *5.0, 6.0,* and *7.0.*

4.5 — Shear lugs that meet the requirements of Sections *5.5 and 6.*1.2(b) shall be considered effective only when located in a concrete compression zone developed between the embedment and the concrete and transverse to the direction of the shear force for a given load combination *unless adequate reinforcement is provided.*

4.6 — A combination of bearing and shear friction mechanisms shall not be used to develop the required

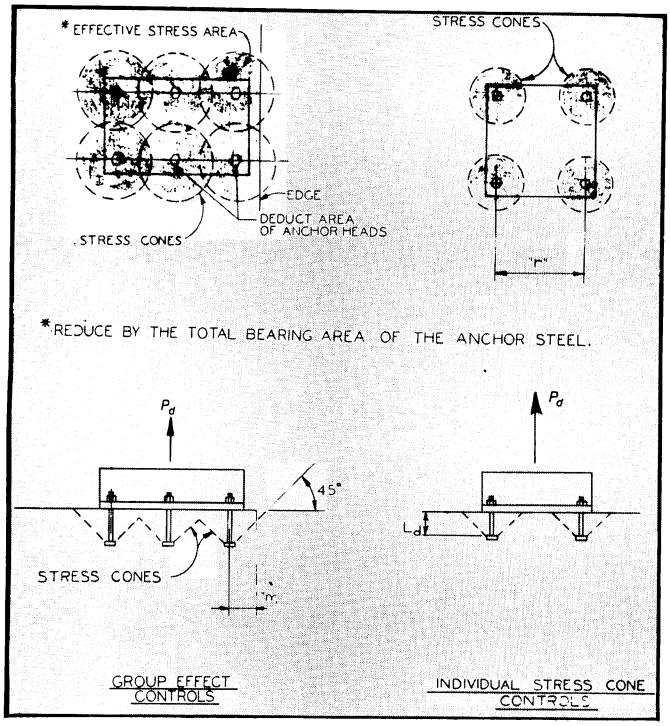

Fig. 5-1 — Effective stress area for anchorage pullout.

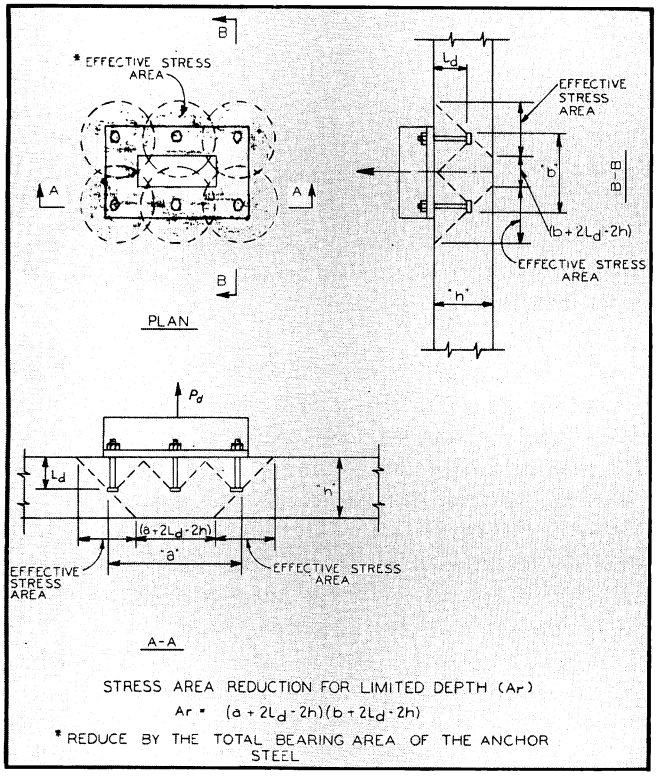

Fig. 5-2 — Stress area reduction for limited depth A_r.

shear strength defined in accordance with Section 9.2 of *ACI 318-77.*

5.0 — Design requirements for concrete

5.1 — The design provisions of this *guide* are based on the strength design method. The assumptions, principles, and requirements of *ACI 318-77* are applicable for all load combinations except as modified herein.

***5.2* — Tension** — The *design* pullout strength of concrete P_d for any anchorage shall be based on a uniform tensile stress of $4\phi\sqrt{f'_c}$ acting on an effective stress area which is defined by the projected area of stress cones radiating toward the attachment from the bearing edge of the anchors. The effective area is limited by overlapping stress cones, by the intersection of the cones with concrete surfaces, by the bearing area of anchor heads, and by the overall thickness of the concrete (see Fig. *5*-1 and *5*-2). The inclination angle for calculating projected areas shall be 45 deg. The ϕ factor shall be taken as 0.65 for an embedded anchor head unless the anchor head is beyond the far face reinforcement. In such cases a ϕ factor of 0.85 may be used.

***5.3* — Shear** — The *design shear* strength of anchors subject to shear shall satisfy the requirements of Sections *6*.1.2 and *7*.2.2.

***5.4* — Reinforcement** — If the requirements of Section *6*.1 are not satisfied, reinforcement shall be provided to develop the required *strength.* Reinforcement requirements shall be in accordance with applicable sections of *ACI 318-77* and placed to prevent failure of the concrete in tension.

5.5 — Bearing

5.5.1 — The bearing *requirements* of Sections 10.*16* or 18.*13 of ACI 318-77* shall apply to the maximum *bearing* stress *at a shear lug or* anchor head *except as permitted by Section 5.5.2.*

5.5.2 — *The bearing requirements of Section 5.5.1 do not have to be met if the anchor head at the base of the tensile stress component satisfies the following conditions:*

(a) The bearing area of the anchor head (excluding the area of the tensile stress component) is at least 1.5 times the area of the tensile stress component.

(b) The thickness of the anchor head is at least 1.0 times the greatest dimension from the outer most bearing edge of the anchor head to the face of the tensile stress component.

(c) The bearing area of the anchor head is approximately evenly distributed around the perimeter of the tensile stress component.

6.0 — Anchorage requirements

6.1 — Anchorage design shall be controlled by the strength of embedment steel unless otherwise specified in this *guide.*

***6*.1.1 — Tension.** Steel strength controls when the *design* pullout strength of the concrete P_d as determined in Section *5*.2 exceeds the minimum specified tensile strength of the tensile stress component of the embedment steel and full load transfer is accomplished from steel to concrete within the depth of the anchorage by one of the following methods:

(a) A mechanical anchor at the base of the tensile stress components *which satisfies the requirements of Section 5.5.2.* To prevent failure due to lateral bursting forces at an anchor head, the side cover dis-