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TENNESSEE VALLEY AUTHORITY

CHATTANOOGA, TENNESSEE 37401

400 Chestnut Street Tower II

TERA

July 5, 1979

Mr. James P. O'Reilly, Director
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Region II - Suite 3100
101 Marietta Street
Atlanta, Georgia 30303

Dear Mr. O'Reilly:

OFFICE OF INSPECTION AND ENFORCEMENT BULLETIN 79-02 - RII:JOP 50-327, -328, -390, -391, -438, -439, -518, -519, -520, -521, -553, -554, -566, -567 - SEQUOYAH, WATTS BAR, BELLEFONTE, HARTSVILLE, PHIPPS BEND AND YELLOW CREEK NUCLEAR PLANTS

In response to your March 8 and June 21, 1979 letters which transmitted OIE Bulletin 79-02 and Revision I to Bulletin 79-02, respectively, we are enclosing the results of our investigations for Sequoyah, Watts Bar, Bellefonte, Hartsville, Phipps Bend and Yellow Creek Nuclear Plants. If you have any questions concerning this matter, please get in touch with Tish Jenkins at FTS 854-2014.

Very truly yours,

TENNESSEE VALLEY AUTHORITY

L. M. Mills

L. M. Mills, Manager
Nuclear Regulation and Safety

Enclosure
cc: U.S. Nuclear Regulatory Commission (Enclosure)
Office of Inspection and Enforcement
Division of Reactor Operations Inspection
Washington, DC 20555

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ENCLOSURE

RESPONSE TO OIE BULLETIN 79-02
DATED MARCH 8 AND JUNE 21, 1979
FROM JAMES P. O'REILLY TO H. G. PARRIS

PIPE SUPPORT BASE PLATE DESIGNS USING CONCRETE EXPANSION ANCHOR BOLTS

NRC-OIE Bulletin 79-02, issued March 8, 1979, identified four action items associated with pipe support base plate designs using concrete expansion anchor bolts for holders of construction permits and operating licenses for nuclear power plants. The items were as follows:

For pipe support base plates that use concrete expansion anchor bolts in seismic category I systems as defined by Regulatory Guide 1.29, "Seismic Design Classification" Revision 1, dated August 1973, or as defined in the applicable FSAR.

1. Verify that pipe support base plate flexibility was accounted for in the calculation of anchor bolt loads. In lieu of supporting analysis justifying the assumption of rigidity, the base plates should be considered flexible if the unstiffened distance between the member welded to the plate and the edge of the base plate is greater than twice the thickness of the plate. If the base plate is determined to be flexible, then recalculate the bolt loads using an appropriate analysis which will account for the effects of shear-tension interaction, minimum edge distance, and proper bolt spacing. This is to be done prior to testing of anchor bolts. These calculated bolt loads are referred to hereafter as the bolt design loads.

2. Verify that the concrete expansion anchor bolts have the following minimum factor of safety between the bolt design load and the bolt ultimate capacity determined from static load tests (e.g., anchor bolt manufacturer's) which simulate the actual conditions of installation (i.e., type of concrete and its strength properties):

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   a. Four - For wedge and sleeve type anchor bolts.

   b. Five - For shell type anchor bolts.

3. Describe the design requirements if applicable for anchor bolts to withstand cyclic loads (e.g., seismic loads and high cycle operating loads).

4. Verify from existing QC documentation that design requirements have been met for each anchor bolt in the following areas:

   a. Cyclic loads have been considered (e.g., anchor bolt preload is equal to or greater than bolt design load). In the case of the shell type, assure that it is not in contact with the back of the support plate prior to preload testing.

   b. Specified design siz... correctly installed (e.g. proper embedment dep...

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If sufficient documentation does not exist, then initiate a testing program that will assure that minimum design requirements have been met with respect to subitems a. and b. above. A sampling technique is acceptable. One acceptable technique is to randomly select and test one anchor bolt in each base plate (i.e., some supports may have more than one base plate). The test should provide verification of subitems a. and b. above. If the test fails, all other bolts on that base plate should be similarly tested. In any event, the test program should assure that each category I system will perform its intended function.

The following TVA response addressing the action items is comprised of the following parts:

1. Generic Response
2. Sequoyah Response
3. Watts Bar Response
4. Bellefonte Response
5. Hartsville and Phipps Bend Response
6. Yellow Creek Response

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GENERIC RESPONSE TO NRC-OIE BULLETIN 79-02

Action Item 1 - Flexible Plates

Shear-Tension Interaction - There is a distinct difference in the distribution of stress in transferring load from flexible plates to anchors depending on the method of attachment. In bolted connections the oversize hole in the plate generally provides space for the lateral plate movement needed to accommodate longitudinal plate deflection. When the space between bolt and plate is closed at installation or by plate movement the plate transmits shear to the bolt through bearing on the back side of the bolt (see figure 2). The hole oversize also provides space for rotation between bolt and plate effectively reducing the bending stresses in the bolt which would otherwise be induced by the rotation of the plate at the anchor. Both plate rotation and anchor displacement are exaggerated in the attached sketches in order to clearly demonstrate the location and direction of principal anchor loads. In the bolted connection "VR" is the horizontal component of the resultant force of the plate on the nut and "VS" is the shear induced in the bolt due to plate movements in excess of the installed space between bolt and plate. VS acts on the compression face of the bolt and can vary in magnitude without effecting significantly the rotation of the bolt. The rotation "ϕ" of the plate depends on the type of load application as well as plate flexibility. For tensile loading (without bending) the plate deflects essentially as a cantilever and the maximum plate rotation at the anchor can be expressed as:

$$\phi = \left(\frac{fs}{Es}\right)\left(\frac{e}{t}\right)$$

where: "e" is the distance from attachment to bolt
"t" is the plate thickness
"fs" is the bending stress in the plate
"Es" is the modulus of elasticity of steel

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Graphically (see figure 3) it can be shown that for approximately the same anchor displacement and plate bending configuration (anchor tensile stress) that any rotation of the attachment due to applied moments will directly reduce plate rotation at the anchor. It also shows a reduced overall displacement (ΔM versus ΔT) and reduced shear in the anchor (ΔSM versus ΔST). It thus appears that for flexible plates the combined tensile, shear, and bending stresses in the anchor are more severe under direct tensile loading than with attachments subjected to bending.

The combined stress condition in anchors is more severe in welded connections than in bolted connections because there is no oversize hole to reduce shear in the anchor and maximum stresses for both shear and tension occur at the same location as shown on the attached sketch. Results of tensile tests with welded stud anchors attached to flexible plates are shown in figure 4. They indicate a reduced capacity for plate flexibility of the following:

$$\left(\frac{12t-e}{10t}\right)$$

where: "e" is the shortest distance from the centerline of the anchor to the edge of the attachment
"t" is the thickness of the attachment plate.

Similar tensile tests have not been performed to date with bolted connections; however, comparative performance of bolted connections and welded connections of cantilever attachments shows a distinct difference in failure tendencies at anchor stresses approaching or exceeding minimum tensile strength requirements. When the angle of rotation at the anchor is large, due to plate yielding, the displacement of the anchor is a significant factor in the ductility of the anchor and its ability to develop maximum tensile capacity. Anchors with large displacement capacities do not appear to be effected by the stress combinations.

Prying Action - Prying action is dependent on (1) anchor displacement, (2) plate rotation at the anchor, (3) plate thickness, and (4) the distance from anchor to edge of plate. From the previous discussion and the attached calculations (Attachment 1), it is evident that prying action is more severe in direct tensile attachments than in moment attachments. If the plate has been proportioned in thickness to meet normal AISC allowables, and the edge distance is restricted to approximately two plate thicknesses or two anchor diameters then prying action will be so small as to be inconsequential in the calculation of anchor stress. For a given anchor displacement, plate rotation, and plate thickness maximum prying action is associated with a specific edge distance. This edge distance may be varied one to two plate thicknesses, however, without significantly effecting prying action.

Compression Transfer - The location of the resultant compressive force in a moment connection controls the resisting moment arm of the anchorage. It is, in turn, controlled by base rotation and plate flexibility. Base rotation is affected primarily by displacement of the anchor and secondly by plate flexibility as long as plate stresses remain elastic. If plate yielding in the compression zone precedes anchor yielding then the center of gravity (CG) of the compressive force will shift toward the compressive flange of the attachment. If anchor yielding, or inelastic displacement, precedes plate yielding, then the CG will move toward the compressive edge of the plate.

The calculations (Attachment 1) for location of the CG of the compressive force assume the location occurs at the point where the plate rotation balances the rotation of the attachment without regard to any compressive deformation of the concrete. (The confined state of the concrete will limit compressive deformation in the plane of the anchorage to extremely small values and can be conservatively ignored.)

Anchor Displacement - Anchor displacement is dependent on strains in the concrete as well as in steel and on any slip characteristics associated with a specific type and size of expansion anchor. In the elastic stress range the effective tensile modulus of elasticity of anchors appears to be less than half of the steel modulus. All expansion anchors produce plastic or inelastic concrete strains in the process of setting expansion mechanisms during installation. Inelastic strains may also occur at the heads of embedded bolts as a result of high installation torques. This plasticity on inelasticity does not effect the elastic displacement properties of the anchor under load; however, because a higher load than the setting load or installation torque load must occur before any additional plastic displacement of the concrete occurs. The plastic deformation associated with installation does however effect the amount of preload remaining in the system. All anchor systems exhibit a short term installation stress loss of 25 to 30 percent during the first day or two following installation and a permanent stress loss of approximately 50 percent.

The strain characteristics of the concrete during installation torque or setting of expansion anchors are affected by the strength of concrete at installation, the depth of anchor head or expansion mechanism below the surface and the local density of the concrete at that point. Measurements of torque versus anchor stress for embedded bolts, grouted-in bolts, and wedge bolts in two distinctly different concretes clearly show that torque and anchor load vary significantly with the concrete and anchor type (see figure 5).

Shell-type expansion anchors cannot be effectively preloaded by torque because the attachment plate limits the anchor displacement. For these anchors the maximum load they see prior to service loading is the installation load created by setting the expansion mechanism. There is, therefore, considerable variation in the load producing nonlinear displacements with these anchors; however, the general level of service load allowables is established to produce elastic displacements with nominal concrete strength under service load conditions.

When the applied load exceeds the installation setting or torque load in the anchor, then nonlinear displacement will occur. The slope of the load-displacement curve in the nonlinear range depends on the type of anchor and strain characteristics of the concrete.

Since anchor displacement directly affects the location of the CG of the compression, the type of anchor has a direct effect on anchor stress. The ultimate capacity is also directly related to the displacement capacity of the anchor.

Bolt Spacing - Load transfer through flexible plates produces maximum anchor stress in the first line of anchors beyond the tensile flange of the attachment. This contrasts with load transfer through rigid plates which produces maximum stress in farthest line of anchors. With flexible plates, load transfer to the second and third lines of anchors depends on the displacement of each preceding line of anchors, the spacing of anchors, and plate stiffness. Anchor spacing is limited by anchor depth and capacity to preclude failure of the concrete. (See anchorage requirements in TVA Design Standard DS-C6.1 for Concrete Anchorages, Attachment 2.) A flexible plate analysis of an anchorage with more than one line of tensile anchors must balance plate deflection at each anchor line with anchor displacement.

Anchorage Design - Most anchorages have essentially been designed as rigid connections. Plate flexibility has generally been considered only to the extent of proportioning plate thicknesses to meet AISC stress allowables. The following comparisons have been made between rigid analysis and flexible analysis to determine the effect of plate flexibility on anchor stress. Plate flexibility has no influence on the calculated load of anchorages subjected to tensile loading without bending and, therefore, the following comparison is made for moment connections only.

In most cases anchorages are standardized to be typical for a number of different size attachments of varying cantilever spans. (Practically all moment connections are of the cantilever type.) Designs are, therefore, based on maximum loading conditions and maximum attachment size to be utilized with the typical anchorage. In this (or any other type anchor), the concern for underestimating anchor load by rigid analysis should be for the maximum attachment size corresponding to a given anchorage configuration.

If both attachment and anchorage are designed for the same loading conditions, then the stress allowables in the anchorage should be based on full development of the attachment. If the anchor has sufficient displacement capacity at ultimate loading then plate flexibility will not reduce capacity and will actually increase capacity where there are two lines of tensile anchors beyond the attachment by allowing for equal anchor displacements at both lines of anchors. Since designs are based on service load or factored load allowables and not on ultimate capacity, full development of the attachment requires that the safety factor of the anchors equals or exceeds that of the attachment.

Plate flexibility will effect ultimate capacity if the displacement capacity of the anchors is not sufficient to provide the needed base rotation to move the CG of the compressive force to the outside edge of the plate. Shell-type expansion anchors generally fall into this classification. For this type anchors, full development of the attachment requires that the safety factor for anchor service loading and factored loading be increased to compensate for the reduced capacity of the anchorage. A conservative minimum ultimate displacement capacity for shell-type expansion anchors is 0.2 inch. For this displacement capacity there is no reduction in moment capacity because of plate flexibility for anchorages meeting the maximum conditions outlined in the following table.

TABLE 1
SELF-DRILL EXPANSION ANCHORS

Plate Thickness	Maximum Anchor				Moments		
	Size	Spacing	Number		Service Load[F] Analysis		Ultimate* Capacity
			In Tension	Total	Rigid "Kips	Flexible "Kips	"Kips
Inches	Inches	Inches					
1/2	1/2	9	2	4	34.5	25.5	156
5/8	5/8	10.5	2	4	53	41	239
3/4	3/4	12	2	4	85	68	382
1	7/8	14	3	8	174	146	786
1-1/4	7/8	21	3	8	259	214	1167

*Based on G-32 anchor qualification requirements (Attachment 3).
FBased on TVA Design Standard DS-C6.1 allowables (Attachment 2).

For larger plates a rigid analysis will overestimate capacity of self-drilling anchors as shown in comparison table 2. The anchor displacement capacity of embedded bolts and wedge bolt expansion anchors is sufficient to preclude overestimation of capacity by rigid analysis as shown in the same comparison table.

The use of rigid plate assumptions in the analysis of flexible plate attachments for bending will generally underestimate load in the anchor under service loading conditions by as much as 25 percent. Under factored loads the underestimation will generally be from 15 to 20 percent depending on plate size, anchor type, and displacement characteristics. Any tensile loading which occurs in conjunction with bending will directly reduce the error in calculating anchor load by effecting the net compressive force in the anchorage and by shifting the CG of the compressive force towards the edge of the plate to more nearly coincide with the location resulting from rigid plate assumptions. The above numbers also do not consider the allocation of the shearing force producing the bending moment. Using rigid plate assumptions, this shear is normally divided equally to all anchors resulting in a direct reduction of the service load or factored load allowables. This shear is actually taken by friction in the compressive zone of the anchorage or is entirely carried by the anchors in the compression zone which are significantly stiffer than the tensile anchors.

As long as system capacities are in balance it makes very little difference in attachment performance whether anchor loads in the service load stress range are overestimated or underestimated by the amounts indicated. At most, the result is a very small change in system deflections or displacements which are of a magnitude significantly less than fit up tolerances necessary for system installations. In all cases where flexible plates are used, and a close balance exists between capacities of attachment and anchorages, significant yielding of the plate will precede anchorage failure and provide adequate warning of problems. This balance is assured by TVA's standard design allowables. The use of the relatively simple rigid plate assumptions appears to be fully justified considering the consequences and the many factors affecting anchor loads.

Action Item 2 - Expansion Anchor Factor of Safety

Design allowables for expansion anchors are specified in TVA's Design Standard for Concrete Anchorages DS-C6.1 (Attachment 2). Installation and testing procedures for these anchors are specified in TVA's General Construction G-32 for Bolt Anchors Set in Hardened Concrete (Attachment 3). Qualification tests described in G-32 require that all expansion anchors (each brand, type and size) be tested to failure in job concrete. It further requires that the concrete for qualification testing be between 3000 and 4000 psi at the time of installation and testing. Each size and type of expansion anchor are required to meet minimum specified tensile capacities. These capacities are based on minimum factors of safety applied to the service load design allowables specified in DS-C6.1. If anchors of a given size and type fail to meet the required capacities, then the design allowables for those anchors at that project are reduced to maintain the minimum safety factors. For service load conditions minimum factors of safety of 4 and 4.5 are applied to wedge-type and shell-type expansion anchors, respectively. No increase in design allowables is made for capacities in qualification testing which exceed minimum requirements and no increase in design allowables is made for higher strength concrete. In general, TVA's qualification requirements are approximately 10 percent less for a given size and embedment depth anchor than the quoted capacities of most manufacturers. Actual safety factors are thus generally higher than the minimum specified.

A 60-percent increase in stress allowables is provided for factored load design which incorporates different multiplication factors (individual safety factors) on each type of loading for various combinations of loads. Individual load factors are principally based on probability of occurrence and accuracy of prediction. This increase in stress allowables for unusual loading conditions or loading combinations is consistent with all code approaches.

Action Item 3 - Cyclic Loads (Seismic and High Frequency)

System deflections are controlled by maximum anchor loads. The cycling of loads at lower than installation load levels will not increase system deflections. System deflections will tend to increase on cycling at maximum anchor loads due to creep and fatigue of concrete under high localized stress conditions. At loads equal to maximum design allowables there appears to be no problem in stabilizing deflections for thousands of load cycles. Flexible plates appear to be beneficial in cyclic testing of anchorages by simulating springs in transferring stress reversals to the anchors.

Anchor bolts are not subject to loosening under low frequency seismic vibrations nor is fatigue failure a likely problem because of the relatively low number of cycles involved. No special design requirements, therefore, are specified for seismic loading of anchor bolts.

Bolts are subject to loosening under high frequency vibrations and fatigue failure is dependent entirely on the level of load variation. If the residual load in the anchor resulting from installation torque exceeds the maximum vibration load then no stress change occurs in the anchor due to vibration and no loosening of the bolt or fatigue failure will occur.

Shell-type expansion anchors cannot be effectively preloaded by torque and torquing of the short A307 connecting bolts even to snug tight requirements can result in failure of the installation bolts. For this reason, the tightening of these anchors is restricted to 1/4 turn beyond finger tight. If these anchors are to be subject to vibration then a positive means of fastening is required to prevent loosening.

A minimum torque is required for installation of all wedge type expansion anchors.

Action Item 4 - In-Process Testing of Expansion Anchors

In-process testing of expansion anchors is specified in TVA General Construction Specification No. G-32 which has been in force since September 1972. Testing frequency is specified in terms of lot sizes and varies from a maximum rate of 1 test for lots consisting of less than 5 anchors to a minimum rate of 5 percent of the lot size for lots containing more than 60 anchors. For shell-type anchors a pull test proof load of 1.5 times the maximum specified design factored load is required. Proof load testing of shell anchors is required prior to installation of attachments. Failure by slip is assumed to occur if the gage on the loading device indicates a drop off or lack of advancement of load while the anchor is being strained to the specified proof load. Wedge bolt anchors are tested by torque to verify that minimum installation torques were applied.

The minimum embedment depths of wedge-type expansion anchors is controlled by limiting the minimum length of wedge bolts to the two longest lengths supplied by manufacturers and requiring in purchase specifications that the longer of the two lengths for each size be marked on the ends for visible identification. Depths are then controlled by restricting the projection of each size bolt above the attachment plate.

Records of in-process testing are maintained at all projects and reporting of test results to design is required.

TABLE 2

COMPARISON OF RIGID AND FLEXIBLE PLATE ANALYSIS AT SERVICE LOADING AND AT ULTIMATE CAPACITY

Tube Section			Plate		Anchors							Anchor Overstress at Service Load
	Moments							Moments				
								Service Load		Ultimate Capacity		
Size	Service Load "k	Ultimate Capacity "k	Thick "	Width "	Size "	Number Tensile Anchors	Spacing +	Rigid "k	Flex "k	Rigid "k	Flex "k	Percent
SELF-DRILL EXPANSION ANCHORS												
4x4x1/2	114	342	3/4	16	3/4	3	6.5	141	106	629	551	7
6x6x1/2	324	972	1-1/4	24	7/8	4	7.0	360	276	1581	1406	17
8x8x5/8	710	2130	1-1/2	39	7/8	6	7	876	660	3870	3180	8
10x10x5/8	1214	3642	1-3/4	46	7/8	7	7.0	1219	924	5388	4438	31
10x10x1/2	1040	3120	1-3/4	46	7/8	7	7.0	1219	924	5388	4438	13
EMBEDDED BOLT ANCHORS												
4x4x1/2	114	342	3/4	11	3/4	2	8	119	94	353	353	21
6x6x1/2	324	972	1-1/4	19	3/4	3	8	338	267	1014	1014	21
6x6x1/2	324	972	1-1/4	17	1	2	13	347	273	1023	1023	19
8x8x5/8	710	2130	1-1/2	30	3/4	4	8.67	717	547	2159	2159	30
8x8x5/8	710	2130	1-1/2	24	1	5	10	772	612	2286	2286	16
8x8x5/8	710	2130	1-1/2	23	1-1/4	2	18	763	585	2232	2232	21
10x10x1/2	1214	3642	2	29	1-1/4	3	12	1469	1197	4335	4335	1
WEDGE-BOLT EXPANSION ANCHORS												
4x4x1/2	114	342	3/4	16	3/4	2	13	120	90	474	474	27
4x4x1/2	114	342	3/4	12	1	2	8	121	90	465	465	27
6x6x1/2	324	972	1-1/4	23	1	3	9.5	391	295	1541	1541	10
8x8x5/8	710	2130	1-1/2	33	1	4	9.5	774	600	3068	3000	18
10x10x1/2	1214	3642	1-3/4	40	1-1/4	4	11.67	1220	939	4840	4549	29

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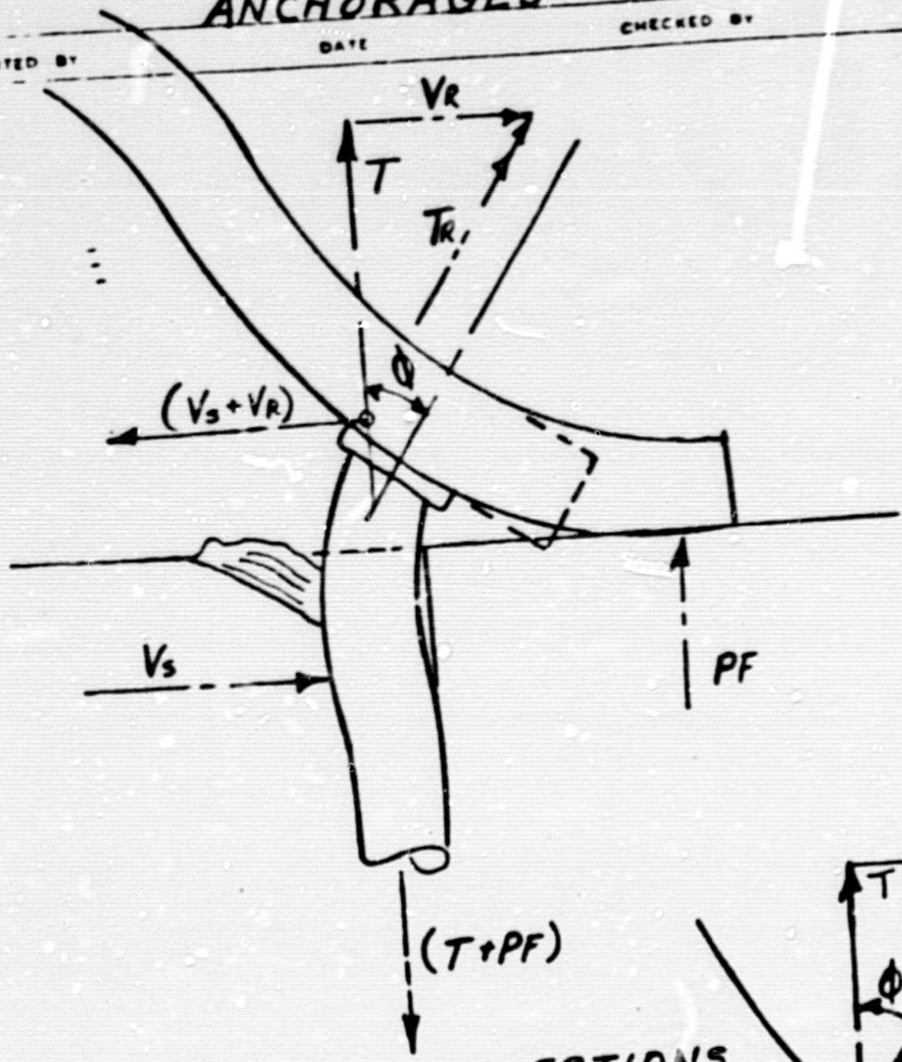
SHEET OF

TVA 400 A (DEC-3-20)

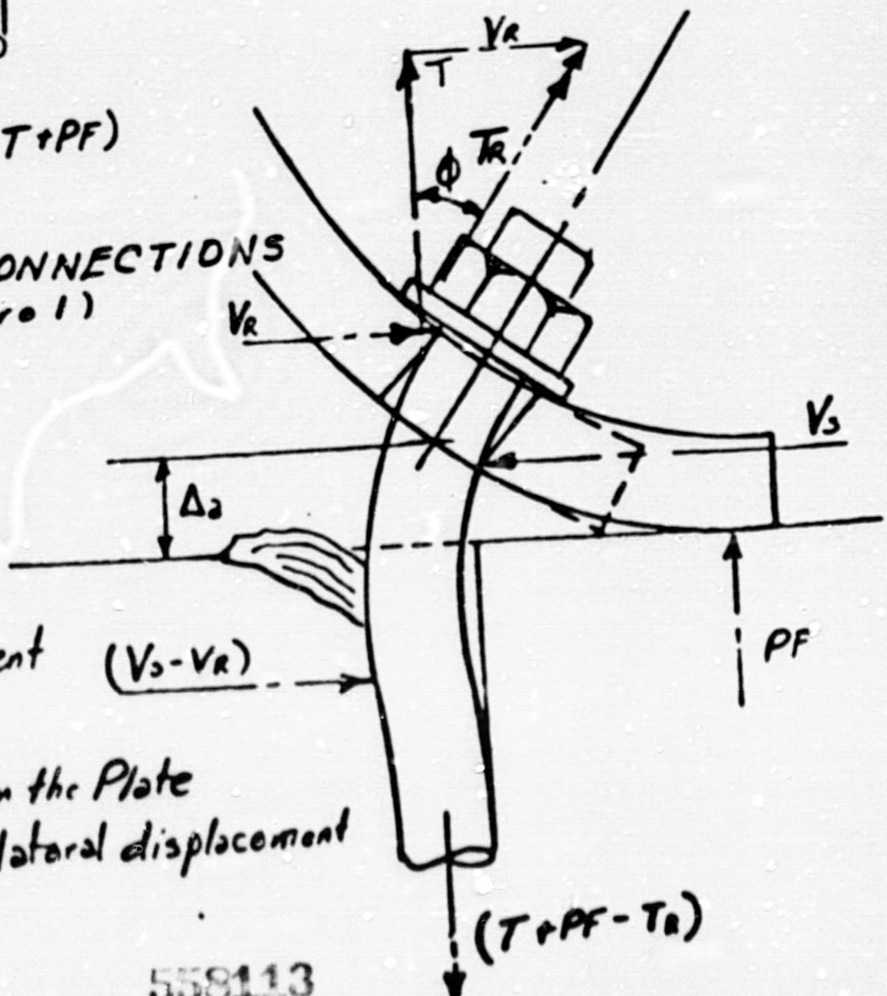
SUBJECT FLEXIBLE PLATE ANCHORAGES

PROJECT

COMPUTED BY DATE CHECKED BY DATE



WELDED CONNECTIONS
(Figure 1)



Δ_a = Anchor Displacement

PF = Prying Force

T = Tensile Load from the Plate

V_s = Shear producing lateral displacement

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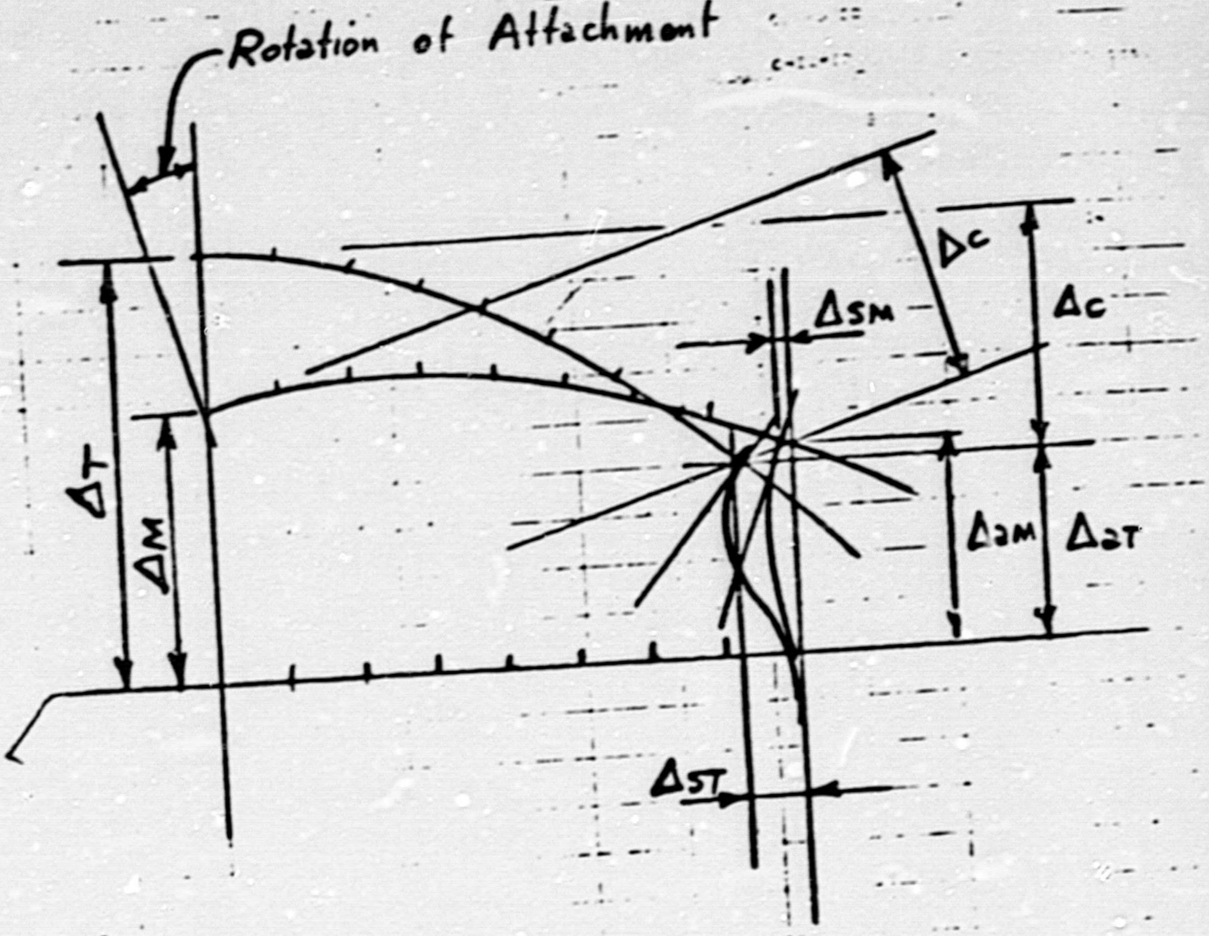
BOLTED CONNECTIONS

Anchor Displacement
Tension Loading vs Bending Moment



(Figure 3)

Δc = Cantilever deflection of plate
ΔT = Vertical displacement of tensile loaded attachment
ΔM = " " " attachment in bending.
ΔaM = " " " anchor due to bend mom.
ΔaT = " " " " " " tensile load
Δsm = Horizontal " " " " " bend mom.
Δst = " " " " " " tensile load

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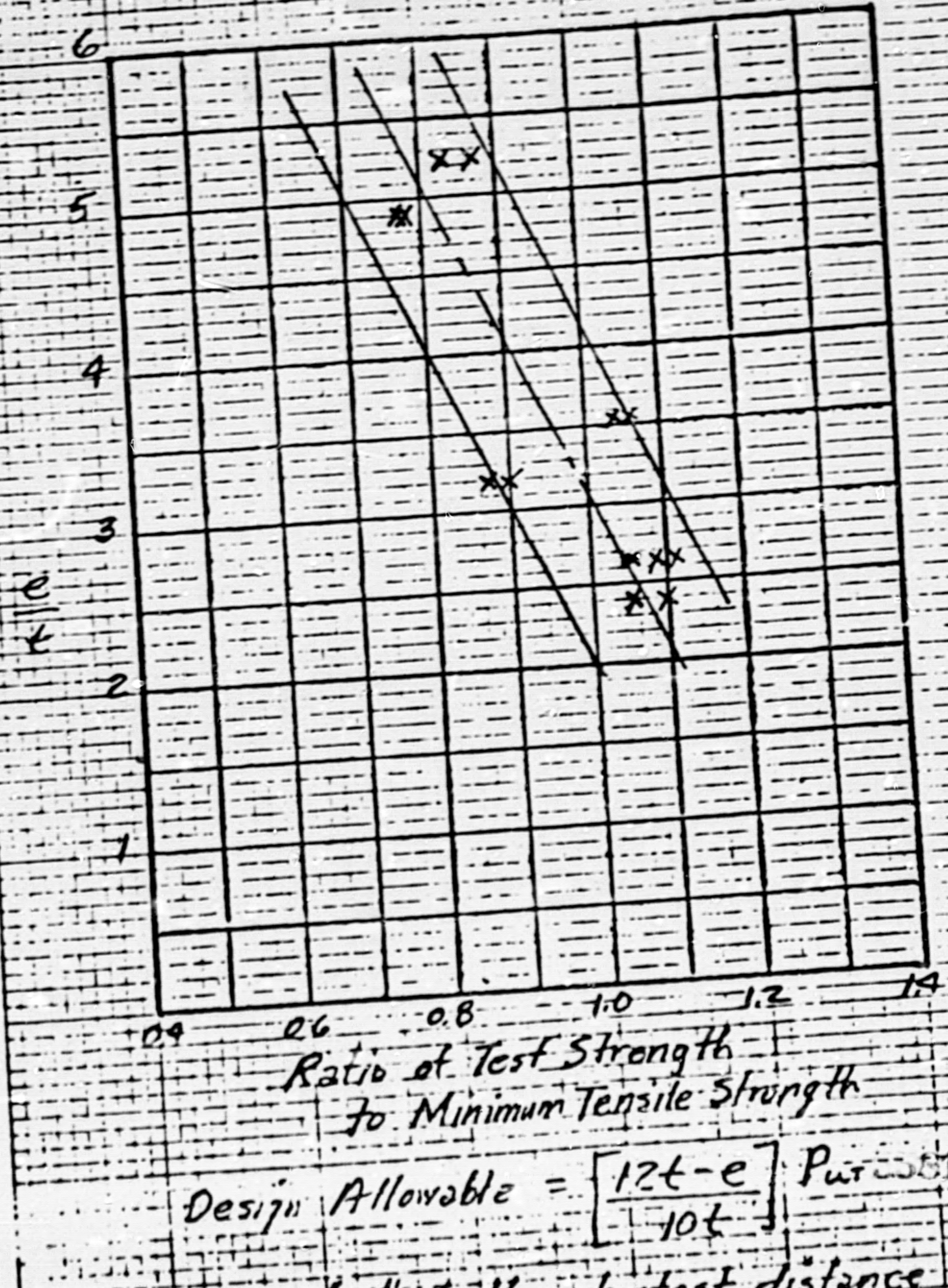
Welded Stud Anchors
Tensile Loading



Ratio of Test Strength to Minimum Tensile Strength

$$\text{Design Allowable} = \left[\frac{12t - e}{10t}\right] P_{UT}$$

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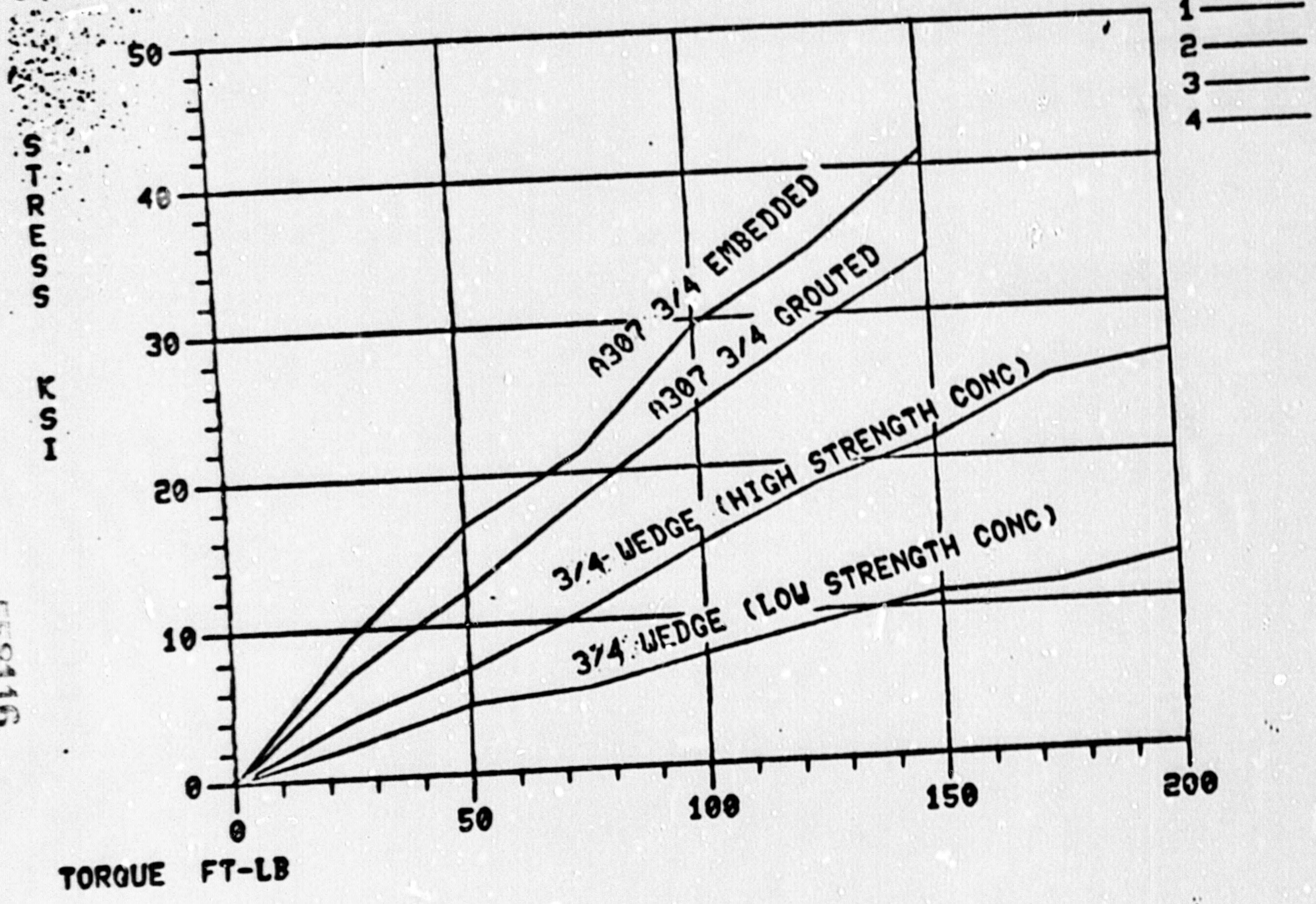
Where "e" is the shortest distance from anchor to attachment
"t" equals plate thickness

(Figure 4)

STRESS-RELAXATION TESTS



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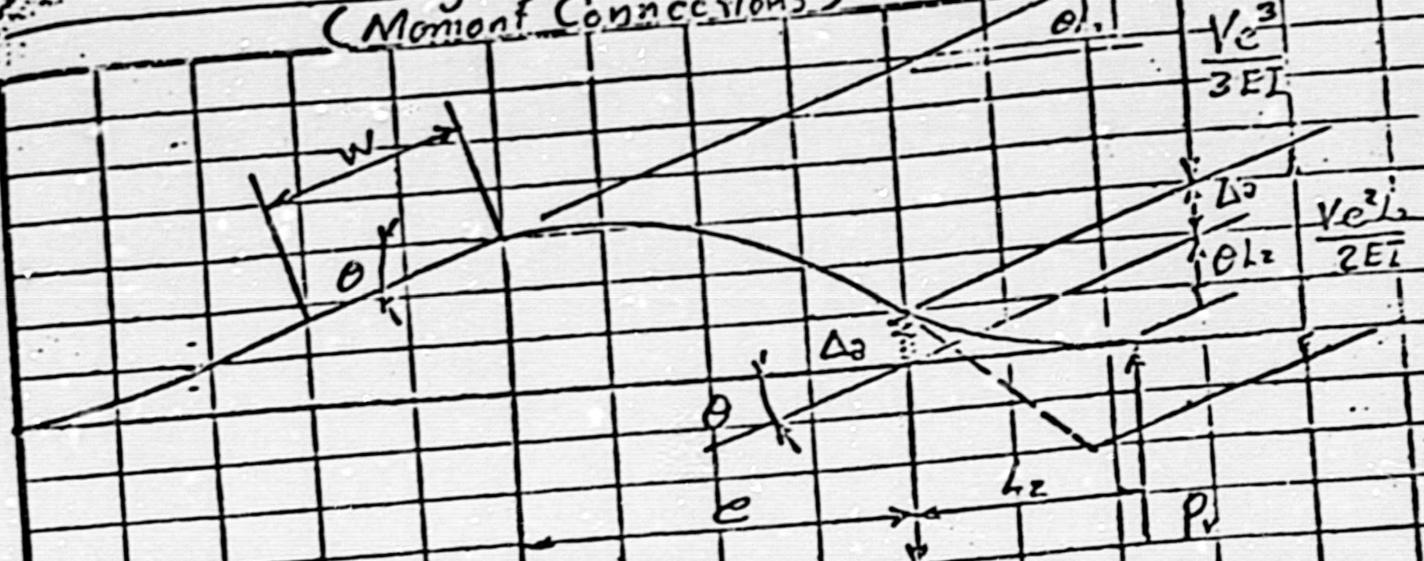
(Figure 5)

Prying Action
(Moment Connections)



$T = (V + P_v)$

D = Anchor Bolt Diameter

V = Plate shear

θ = Base Rotation

P_v = Prying Action Force

T = Total Anchor Load

$$\frac{Ve^3}{3EI} + \frac{Ve^2L_2}{2EI} - \left(\frac{L}{2} + w + e + L_2\right)\theta = \frac{P_v L_2^3}{3EI}$$

$$\left(\frac{L}{2} + w + e\right)\theta = \frac{Ve^3}{3EI} + \Delta_2$$

$$\therefore \frac{P_v L_2^3}{3EI} = \frac{Ve^2L_2}{2EI} - L_2\theta - \Delta_2$$

Divide by V.

$$\frac{P_v}{V} = \frac{3}{2}\left(\frac{e}{L_2}\right)^2 - \frac{3EI}{VL_2^3}\left(\Delta_2 + L_2\theta\right)$$

$$\theta = \frac{\Delta_2 + Ve^3/3EI}{\left(L/2 + w + e\right)}$$ from sheet 1.

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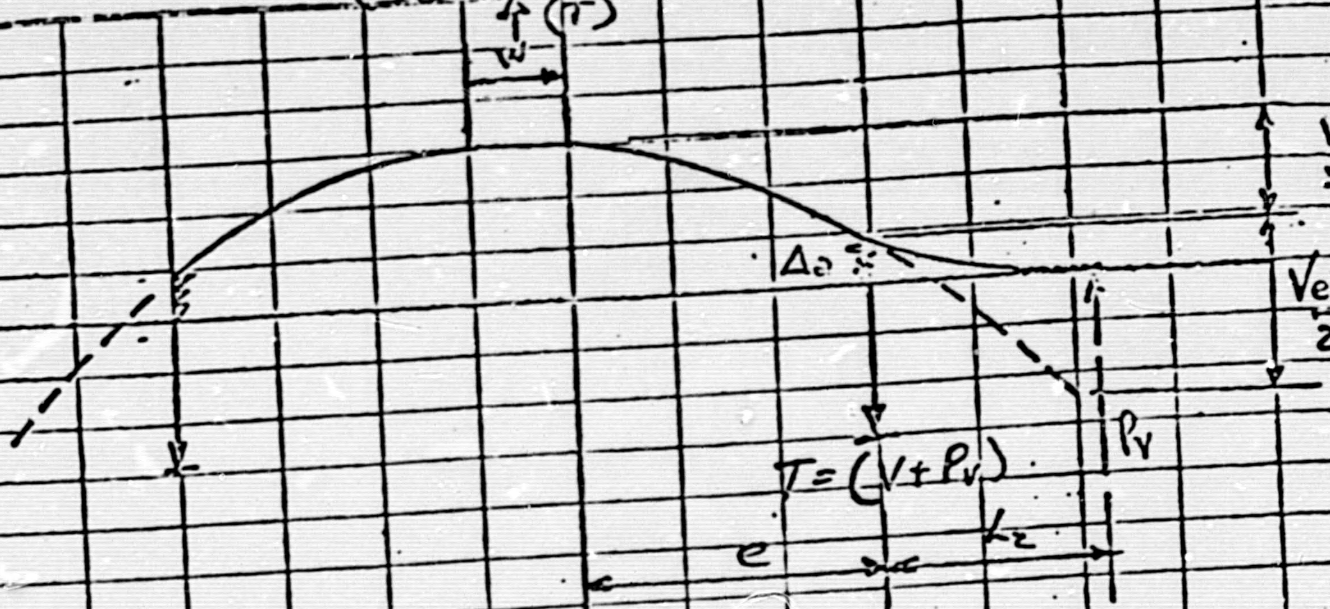
Minimum Plate thickness for anchor spacing "s" = w + 2e, L = 2D, V = T

$$t_{min} = \sqrt{\frac{3T(s-w)}{(s+4D)f_{s2}}}$$

Prying Action (Tension Connection)

COMPUTED ______ DATE ______
CHECKED ______ DATE ______



$$\frac{P_v L_2^3}{3EI} = \frac{V e^2 L_2}{2EI} - \Delta_2$$

$$\left[\frac{P_v}{V}\right] = \frac{3}{2}\left(\frac{e}{L_2}\right)^2 - \frac{3EI\Delta_2}{V L_2^3}$$

Note: The basic difference difference in prying action ~~for~~ between moment connections and tension connections is the added reduction of $\frac{3EIL_2\theta}{VL_2^3}$ for moment connections.

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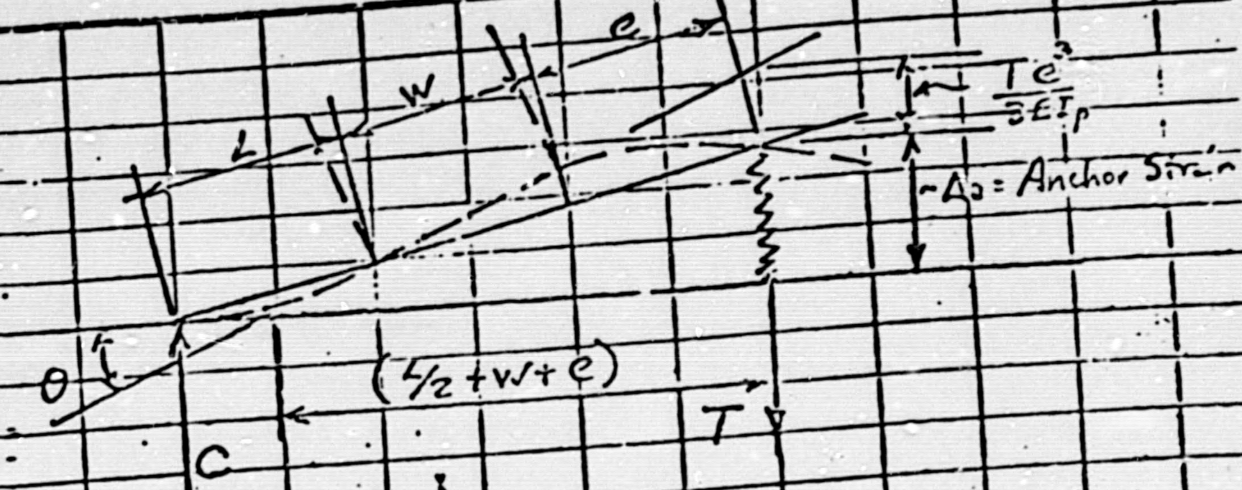
Note: Calculate plate stress for the full range of prying action shown in Figure 7 would exceed 0.9 fy For A36 Plate.



Base rotation $\theta = \dfrac{\Delta_a + \frac{Te^3}{3EI}}{(L/2 + w + e)}$

Cantilevered plate rotation $\theta = \dfrac{CL^2}{2EI_{cp}}$

Minimum $I_{cp} = (w + 2L)t^3/12$

For plate rotation equal to base rotation and T = C:

$$\frac{TL^2}{2EI_{cp}} = \frac{\Delta_a + \frac{Te^3}{3EI_p}}{(L/2 + w + e)}$$

$$\frac{L^2(L/2 + w + e)}{(w + 2L)} = \frac{Et^3}{6T}\left[\Delta_a + \frac{Te^3}{3EI_p}\right]$$

Find the relationship of Δ_a and T from stress-strain measurements of the anchor in question and solve for "L" for any attachment width "w", eccentricity 'e' and plate thickness "t"

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Attachment 2

TVA

CONCRETE ANCHORAGES
General

CIVIL DESIGN
STANDARD DS-C6.1

1.0 General

1.1 This standard[1] governs the design of steel components which transmit forces to concrete. Wherever possible ductility of the anchorage is assured by limiting capacities such that the failure mechanism will be controlled by the properties of the steel rather than concrete. When capacities are limited by the tensile strength of the concrete, a working load safety factor of at least four is used.

1.1.1 Where loads are limited by the properties of the steel, applicable provisions of the AISC Specifications and Commentary are used. Where loads are limited by properties of the concrete, applicable provisions of the ACI Standard Building Code are used. Anchorages to concrete have some peculiarities which differ from the usual design provisions of either standard.

1.1.2 All concrete anchorages are single-shear connections involving shear transfer through relatively large plates whose dimensions are controlled by bending stresses, whereas the usual steel connection is a double-shear connection involving shear transfer through relatively small plates sized for tensile loading. The effect of "long" and "short" connections and "single" or "double" shear on the shear strength of bolts is discussed in the AISC Commentary. Research testing by TVA confirms the AISC Commentary recommendations for short, single-shear connections.

1.1.3 Bearing provisions of the ACI Building Code are concerned with bearing restrictions on exterior concrete surfaces. Research testing clearly demonstrates those restrictions should not apply to bearing stresses at the embedded heads of anchor bolts.

1.2 Bolts with heads or nuts, or similar studs or bars, embedded in the concrete when the concrete is placed, or grouted into holes drilled in hardened concrete, are termed standard anchors. Anchors which are expanded laterally against the sides of a hole drilled in hardened concrete are termed expansion anchors. Design load provisions of this standard apply only to expansion anchors listed in tables II and III. Commercially available, predesigned and prefabricated embedments installed prior to concrete placement and which are especially designed for attachment of bolted connections are termed concrete inserts. Provisions of this standard apply only to the insert types listed in section 2.3.3. R1

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[1] This design standard was prepared by CEB's R&D staff in coordination with CDB's R&D staff. The requirements of this standard may be supplemented or altered for a given project by written instructions from the engineer in charge.

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1.2.1 For standard anchors the heads of studs and bolts provide full anchorage in the concrete equal to the tensile capacity of the bolt or stud, provided the limitations for the combined effects of spacing, embedment depths, and cover (or edge distances) are not exceeded. Where plain or deformed bars are used, equivalent anchorage may be accomplished by threading the end of the bar and using a standard nut of equal or higher strength steel. Threading of A615 bars is limited to bars of 40,000 psi yield strength. Plain bars of A449 steel may be threaded irrespective of yield strength.

1.2.2 Anchorages for expansion anchors and concrete inserts are limited by anchor size and the design values herein specified.

1.3 Shear bars shall not be used to transmit shear to any concrete anchorage subject to tensile loading. Shearing forces shall be distributed to bolts, studs, etc., in accordance with their ability to transmit the combined shear and tensile loads as herein described.

1.3.1 In compression members, prestressed anchorages, or anchorages with a substantial minimum compression zone, shearing forces may be transmitted through friction (see section 2.2) or by distribution to bolts, studs, etc. (see section 2.3).

1.4 Steel plates are necessary for transfer of loads at the attachment surface to anchor bolts, bars, or studs. They should not be used at the embedded head of anchors for the purposes of reduced bearing stresses since their inclusion at this point reduces the tensile capacity of the concrete and does not affect anchorage capacity. R1

1.5 The basic procedure for design is: (1) determine the total area of bolts, bars, or studs required for a given configuration of anchors in accordance with section 2.0, (2) determine the embedment requirements to limit the tensile stresses in the concrete in accordance with section 3.0, (3) check bearing stress on the concrete surface in accordance with section 4.1, and (4) in the case of flexural members, check shear in the concrete.

1.5.1 Design by this standard may be made under either working stress design criteria or ultimate strength design criteria by use of an appropriate Ø factor or as herein described. Load factors and loading combinations for use in ultimate strength (or factored load) design are specified by the controlling code or project design criteria.

2.0 Determination of Embedded Steel Area

2.1 Using conventional "straight line" theory for distribution of stress and strain, proportion the anchorage for the combined bending and direct loads on the base plate, ignoring shear, limiting maximum tensile stresses to ϕf_y (or the maximum allowable tensile load per anchor), and limiting bearing stresses as herein prescribed.

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2.1.1 Determine the resultant tensile load (T) in the anchorage and the resultant compressive force (C_F) under the base plate which are required to balance the imposed loads.

2.2 If the total shear load (V) acting in conjunction with the imposed bending and direct loads is equal to or less than 0.5 C_F for the shear plane between steel and concrete or 0.25 C_F for the shear plane between two steel plates, no additional anchorage steel other than that required for tensile loads is required for shear.

2.3 If the total shear load is greater than described above, determine the total area of embedded steel required for combined tension and shear in accordance with sections 2.3.1, 2.3.2, or 2.3.3.

2.3.1 Standard Anchors

2.3.1.1 The total area of steel required for combined tension and shear.

$$A_{st} = \frac{CV + T}{\phi f_y}$$

where:

A_{st} = The total area of steel required. [The area of steel shall be the stress area of threaded bolts or bars (see table I of the Appendix) and the full cross-sectional area of welded bars and studs.]

T = The total tensile load in the anchorage as a result of combined bending and direct load stresses.

V = The total shear load.

f_y = The minimum yield strength of the steel.

f_y = 33 ksi for A307 bolts.

f_y = 44 ksi for welded stud anchors (headed).

ϕ = 0.90, where V and T represent ultimate or factored loading conditions.

ϕ = 0.55, where V and T are working loads.

C = 1.10 for embedded plates with the exposed surface of the steel plate coincidental with the concrete surface.

C = 1.25 for plates with recessed grout pads with the contact surface of the plate coincidental with the concrete surface. R1

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C = 1.50 for plates fastened to hardened concrete with bolts preloaded to yield.

C = 1.85 for plates supported on a pad of grout or mortar with the contact surface of the plate exterior to the concrete surface. R1

2.3.1.2 Where shear is directed toward an edge, consult section 3.3 for design requirements.

2.3.1.3 Requirements for Tightening Standard Bolts

The following requirements for tightening bolts shall be specified on drawings where applicable.

(a) No standard bolted connections shall be tightened less than "snug tight." For bolts larger than 5/8-inch diameter, "snug tight" is herein described as the tightness attained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. For smaller bolts "snug tight" is herein described as 1/4-turn-of-the-nut after finger tightening or after the surfaces of attachment plate and concrete are in contact. R1

(b) All standard bolted connections subject to vibrating loads shall be preloaded to yield by an additional 2/3-turn-of-the-nut after an initial tightening as described in (a). Where this cannot be accomplished, some positive means of fastening the nut must be devised.

2.3.1.4 Sleeved connections must be completely filled with grout or mortar prior to installation of the attachment. R1

2.3.2 Expansion Anchors

2.3.2.0 Design of expansion anchors is herein limited to the design values and expansion anchors listed in tables II and III. The anchors divide essentially into two basic types: (1) expansion shell anchors and (2) wedge bolt anchors. The design values are primarily influenced by anchor size and embedment depth. The "shell" anchors are further divided into self-drilling and predrilled types. The anchor type and size must be specified in accordance with section 2.3.2.5.1. R1

The engineer in charge may authorize the use of other types of anchors or manufacturers other than those listed in tables II and III, provided the results of tests performed in accordance with ASTM E 488-76 using concrete strengths less than 4000 psi are more than 4 times the service load design values of tables II and III for the same size anchor and minimum embedment depth.

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2.3.2.1 Expansion shell anchors typically fail the concrete in tension because of the relatively shallow anchor depths, but failure by slip may occur at approximately the same loading. Load-deflection measurements indicate a progressive splitting of the concrete along the failure cone.

Expansion wedge bolt anchors typically fail by anchor slip. The pullout force is essentially resisted by steel-on-steel friction of the restraining wedge. The resultant wedge pressure creates tensile stresses in the concrete, and anchor slip is the result of progressive splitting and spallage of the concrete into the open space below the wedge. The restraint of the concrete against splitting is primarily a function of the location of the wedge with respect to the concrete surface. R1

Tables II and III provide the allowables for tension (T) and shear (V_o) for both factored load and service load design. For anchors spaced farther apart than the minimum spacing given, use the tabular values for T_o in applying section 2.1. For anchors spaced closer than the minimums, determine T_o in accordance with section 3.2.

2.3.2.2 For combined loading determine the tensile load (T_1) in each individual anchor under section 2.1 and distribute shear to each anchor (V_1) by:

$$\frac{V_1}{V_o} = \frac{T_o - T_1}{T_o}$$

$$\sum V_1 \geq V$$

2.3.2.3 Where shear is directed toward an edge consult section 3.3 for design requirements.

2.3.2.4 Requirements for Tightening Expansion Anchor Bolts

The following requirements for tightening expansion bolts shall be specified on the drawings.

(a) All bolt connections to "shell" type expansion anchors shall be tightened by 1/4-turn-of-the-nut after finger tightening or after the surfaces of the attachment plate and concrete are in contact. R1

(b) All shell type expansion anchors subject to vibrating loads must be tightened as above and provided with a positive means to prevent loosening by vibration.

(c) All wedge type expansion anchors shall be torqued within the range of values specified in table III unless tests performed on project concrete establish a more desirable range of values for controlling deflections under service load conditions. R1

2.3.2.5 Requirements for Testing and Designation of Expansion Anchors

2.3.2.5.1 Designation

The following letter designations shall be used on drawings and in specifications to identify the required anchor type. They are given in the order of descending strength requirements. Any anchor type of higher strength requirements may be used in place of a lower strength requirement anchor without consulting the engineer. R1

WB	Wedge Bolt Anchor
SSD	Expansion Shell Anchor (self-drilling type)
SPD	Expansion Shell Anchor (predrilled type)
EA	Unspecified type

2.3.2.5.2 Testing

(a) In nuclear plant Category I structures all expansion anchors designated SSD and SPD shall require proof load testing in accordance with General Construction Specification No. G-32.

(b) In nuclear plant Category I structures, expansion anchors designated WB shall be tested in accordance with General Construction Specification No. G-32. The installation shall be considered satisfactory if lift-off (turn-of-the-nut) does not occur at the minimum torque specified in table III. R1

(c) Anchor designation EA shall only be given to "approved" anchors whose design loads do not exceed 2/3 of the minimum allowable values of table II. Proof testing is not required of anchors designated as EA irrespective of location.

2.3.3 Concrete Inserts

2.3.3.0 Design of concrete inserts herein designated as "standard" apply only to continuous inserts of "Unistrut" series P 3200 channel or its equivalent. R1

Design of concrete inserts herein designated as "heavy-duty" apply only to continuous inserts of "Unistrut" series channel P 1000 with 3/8- by 4-inch long Nelson studs welded to the channel web and spaced 4 inches on centers. R1

They do not apply to any other size channel or type of insert.

2.3.3.1 Failure is limited by either the steel properties of the connecting holts or by the steel properties of the Modified "Unistrut" except (or slip resistance of shearing forces acting along the longitudinal axis of the Unistrut channel.

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2.3.3.1.1 The design of "standard" inserts is limited to one single 1/2-inch bolt connection per foot of channel length. R1

For combined tensile and shear forces use the allowable tensile values (T_o) as given below in applying section 2.1 and determine the number of 1/2-inch connecting bolts (N_b) by:

$$N_b = \frac{T}{T_o} + \frac{V}{V_o}$$

2.3.3.1.2 Tensile loading is limited by the strength of the channel "lip" for single or double bolt connections of 1/2-inch bolts preloaded to a minimum torque of 50 foot-pounds.

T_o = 2 kips/bolt for service loads

T_o = 3.6 kips/bolt for factored loads

2.3.3.1.3 Tensile loading is limited by the strength of the 12-gauge metal at the "stud" connection for multiple bolt connections of 3 or more 1/2-inch preloaded bolts at 3-inch ± spacing.

T_o = 5 kips/foot of channel for service loads

T_o = 9 kips/foot of channel for factored loads

2.3.3.1.4 Shear loading is limited by the shear strength of the 1/2-inch bolt in a transverse direction to the longitudinal axis of the channel.

V_{OT} = 2 kips/bolt for service loads

V_{OT} = 3.6 kips/bolt for factored loads

2.3.3.1.5 Shear loading is limited by the slip resistance of the preloaded connecting bolts in the longitudinal direction of the channel.

V_{OL} = 1 kip/bolt for service loads

V_{OL} = 1.8 kip/bolt for factored loads

2.3.3.1.6 For shear acting at any angle "θ" from the longitudinal axis of the channel:

$$V_{OA} = \frac{1}{\cos\theta} \leq 2 \text{ kips/bolt for service load}$$

$$V_{OA} = \frac{1.8}{\cos\theta} \leq 3.6 \text{ kips/bolt for factored loads}$$

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2.3.3.2 Requirements for Tightening Bolts R1

The following requirements for tightening bolts shall be specified on the drawings.

All connecting bolts for concrete inserts shall be tightened by a minimum torque load of 50-foot pounds or until a distinct yielding of the lip is detected by decreased resistance to the applied torque.

3.0 Determination of Embedment Requirements

3.1.0 Standard Anchors

Minimum embedment lengths of bolts and bars shall be based on developing 1.25 times the minimum required ultimate tensile strength of the embedded steel by assuming an allowable uniform concrete tensile stress of $3.4 \sqrt{f'_c}$ acting on a projected area bounded by the intersection of 45-degree lines radiating from the heads of the bolts or anchors with the surfaces of the concrete (see figure 4). When the concrete area beyond the outside perimeter of the bolts is limited, the full tensile capacity of the anchorage may be developed in concentrically located, fully developed reinforcing steel of equal capacity. Under no conditions shall the lap distance between the bolt head and the mechanical anchorage or the return leg of the reinforcing bars be less than the embedment length requirements for the bolts without an edge condition (see figure 6). R1

The tensile strength of concrete in a slab or wall is limited by the thickness of the concrete and the out-to-out dimensions of the anchors. If 45-degree lines extending from the heads of exterior anchors toward the compression face do not intersect within the concrete, then the effective stress area is limited as shown in figure 5.

3.1.0.1 These embedment requirements may also be applied to grouted-in bolts using either sanded Portland cement or epoxy grouts, provided the drilled hole is approximately 2 times the bolt diameter and the sides of the hole have been roughened and cleaned prior to grouting.

3.1.1 For bolts or anchors spaced further apart than 16 anchor diameters, the minimum embedment length (L_d) can be determined conservatively by the following:

$$(L_d + m) = 14d \sqrt{\frac{Fut}{60}}$$

where: R1

L_d = Embedded length (inches) equal to or greater than $8d \sqrt{\frac{Fut}{60}}$.

m = Edge distance (inches) equal to or greater than $3d \sqrt{\frac{Fut}{60}}$.

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d = Bolt diameter (inches).

F_{ut} = The minimum ultimate tensile strength of the anchors in ksi corresponding to specification requirements.

3.1.2 For bolts or anchors spaced closer together than 16 bolt diameters, the restraining tensile requirements of the concrete of section 3.1 will control the minimum embedment length. For A36 steel and 3000 psi strength concrete, figures 1 thru 3 of the appendix provide a quick method for determining anchor requirements. Figure 1 is based on the condition that no anchors are located closer to an edge than the depth of the anchor. Figure 2 is based on the condition that the principal line of stress anchors is located 3 diameters from a concrete edge. Figure 3 is based on the condition of two perpendicular lines of anchors located 3 diameters from respective edges.

In using figures 1 thru 3 the total number of tension anchors "n" is $\frac{T}{\phi f_y A_b}$.

(a) For higher strength steel, multiply the required embedment L_d of figures 1 thru 3 by $\sqrt{\frac{Fut}{60}}$.

(b) For higher strength concrete, multiply the required embedment L_d of figures 1 thru 3 by $\sqrt[4]{\frac{3000}{f'_c}}$.

(c) The embedment requirement for edge distances "m" less than L_d but greater than 3d can be determined conservatively by interpolation.

3.1.3 When the anchors must be located closer than the minimum "m" distance to an exposed edge, reinforcement must be provided to prevent a blowout cone failure. For standard anchors the side force at the head of the anchor may be assumed as 1/4 of the anchor capacity. Ductility cannot be assured without reinforcement (see figure 7). As an alternative the yield strength to be used in design may be restricted to the following:

$$f_y = 67\sqrt{f'_c}\left(\frac{m}{d}\right)^2$$

3.1.4 Minimum Spacing of Stud Anchors

3.1.4.1 Stud anchors are normally furnished in standard length of approximately 10.5 stud diameters when used for tensile anchorages. Since the ultimate tensile strength of the stud anchors is approximately equal to that of A36 steel, figures 1 thru 3 can be used to limit the spacing of either single depth studs, or double depth studs where studs are welded on studs. For a minimum embedment depth of 10.5d or 21d, the corresponding minimum spacing (r) in terms of stud diameters can be read directly from the figures for a given number of studs (the number of studs "n" should be determined as prescribed in section 3.1.2). For concrete strengths other than 3000 psi the minimum spacing can be obtained by multiplying the above spacing by $\sqrt[4]{\frac{3000}{f'_c}}$.

3.2 Expansion Anchors

The inclination of the concrete tensile failure angle varies with depth of embedment for embedment depths less than 6 inches. For expansion anchors the assumed angle of failure ϕ for determining the concrete tensile capacity is given below corresponding to depth of embedment. The failure surface will be bounded by the concrete surface at which the load is applied, and by any intersecting lateral surfaces or failure surfaces of adjacent anchors. Tensile stresses in the concrete shall be assumed uniform over this projected area and shall be limited to $2.4\sqrt{f'_c}$ for factored loads and $1.5\sqrt{f'_c}$ for service loads. When expansion anchors are spaced closer than the specified minimums of tables II or III, the total limiting tensile anchorage load must be calculated using the above criteria. R1 R1

$$\phi = 28 + 3.4\, L_d \leq 45°$$

3.3 Effect of Edge Distance on Shear Strength

3.3.1 The full strength of bolts, bars, or studs in shear can be utilized when the nearest edge distance "m" is greater than 1.25 times the required embedment "L_d" for full tensile development of standard anchors or greater than 10 diameters for expansion anchors.

$$m \geq 1.25\, L_d$$

3.3.2 Where shear is directed toward an edge located less than above, sufficient reinforcement must be provided to develop the entire shearing force and located to intersect the plane of potential failure (see figure 8). Limit the maximum allowable shear in the anchors such that:

(a) For an anchor spacing (r) less than edge distance "m"

$V_{max} = 4.8\, rm\sqrt{f'_c}$ for factored loads

$V_{max} = 3.0\, rm\sqrt{f'_c}$ for service loads

(b) For an anchor spacing greater than "m"

$V_{max} = 4.8\, m^2\sqrt{f'_c}$ for factored loads

$V_{max} = 3.0\, m^2\sqrt{f'_c}$ for service loads

4.0 Sizing of Base Plates

4.1 Allowable Bearing Stress

4.1.1 Concrete bearing stress limitations are imposed by the ACI Building Code to assure the integrity of both the supporting concrete and the concrete member transmitting load. When the member applying load is not a concrete member, then the only concern for concrete strength is the integrity of the supporting concrete.

4.1.2 When the supporting concrete is wider than the loaded area on all sides, the concrete confines the bearing area and reduces the splitting tendencies of the supporting concrete. For building columns the provisions of the ACI 318 Building Code Sections 10.14 and 11.10 apply. For all other anchorages base plates need only be sized for the shear provisions of Section 11.10 and as outlined below.

4.1.3 When the supporting concrete is a flexural member, then failure is either restricted to a tensile concrete failure acting on a 45-degree line radiating from the loaded area for two-way bending or a diagonal tension failure when one-way bending controls. Bearing is thus limited by the shear provision of Section 11.10 of the Building Code. R1

4.1.3.1 When bearing stress in flexural slabs or walls exceeds the above, then the shear reinforcement must be provided as outlined in Section 11.11 of the Building Code.

4.1.4 There are no bearing restrictions at the heads of standard anchors provided the minimum embedment requirements of section 3.0 are complied with.

4.1.4.1 No bearing restrictions should be applied to the sides of fully anchored bars or bolts subject to shearing forces acting through a steel plate affixed to the bar, bolt, or stud in question.

4.1.4.2 Where anchor plates are used on the back surface of concrete, their only function is to reduce the very high surface bearing stress which would otherwise occur under the head of the bolt. The effective distribution of stress through the anchor plate is approximately twice the thickness of the plate beyond the head of the bolt. Anchor plates may be proportioned by assuming a maximum allowable uniform stress distribution over this area of 6 f'_c.

4.2 Special consideration should be given to the effect of large shearing forces and edge distance on the proportioning of base plates.

4.2.1 When a base plate is located near the edge of a rigid support, shearing forces will reduce the compressive force required to produce failure and the allowable bearing stress should be reduced. The following should be used to determine allowable bearing for a shearing force "V" acting toward a concrete edge:

$$f'_b = 0.6\ f'_c \left(1 - \frac{0.85V}{P}\right)\left(\frac{w+e}{W}\right)^{1/3}\left(\frac{2b+w+e}{2b}\right)\left(1+2.5\sqrt{\frac{A_{sb}}{b}}\right)$$

$$f'_b \geq 0.1f'_c \leq 1.2f'_c$$

Where

A_{sb} = The area of reinforcing steel under the base plate.

b = The base plate dimension parallel to the edge of concrete.

w = The base plate dimension perpendicular to the edge of concrete.

e = The distance from the edge of concrete to the edge of the bearing plate.

p = The total applied compressive load.

When the width of concrete support "W_{cs}" is less than $\frac{2b+w+e}{2}$, change the width modifier $\frac{2b+w+e}{2}$ in the above equation to $\frac{W_{cs}}{b}$.

When $\frac{2e+w}{2}$ w is less than e, modify the above equation by $\frac{(2e+w)w}{18}$.

4.3 Where service load or working stress design is used, the allowable bearing stresses of section 4.0 should be reduced by 50 percent.

4.4 For sleeved bolts the bearing stress on the area projecting past the sleeve shall be limited to a maximum of $6f'_c$. The minimum thickness of the overhanging plate or washer at the base of the sleeve shall be equal to the maximum overhang.

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NOTATIONS

A_b = The tensile stress area of a single bolt or anchor. R1

A_R = Reduced stress area for limited depth.

A_{st} = The total steel area required for anchorage.

A_{sb} = The area of reinforcing steel under the base plate.

b = The width of base plate parallel to a concrete edge.

b_s = The width of slab or wall supporting a bearing plate.

C = The shear coefficient applied to standard anchors which accounts for effects of cutting edges, threads, and strength factors.

C_F = The minimum compressive force expected to occur under the base plate of an anchorage.

d = The nominal diameter of an anchor bolt, bar, or stud.

d_s = The depth or thickness of a slab or wall supporting a bearing plate.

e = The perpendicular distance from the edge of a base plate to the edge of supporting concrete.

f'_b = The allowable average compressive stress (bearing pressure) under a base plate.

f'_c = The specified compressive strength of concrete.

f_y = The specified minimum yield strength of steel.

F_{ut} = The minimum specified tensile strength of steel. R1

h = The thickness of concrete slab or wall.

L_d = The minimum embedded length required to fully develop the tensile strength of an anchorage.

m = The edge distance from the center of an anchor to the edge of concrete.

N = The average dimension of the base plate divided by the depth of slab or the thickness of wall.

N_b = The total number of bolts in an anchorage.

P = The maximum applied compression load on a base plate.

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NOTATIONS (Continued)

r = The spacing of multiple anchors.

T = The total tensile force in an anchorage as a result of combined bending and direct load stresses.

T_1 = The tensile force in an individual anchor.

T_o = The maximum tensile force allowed in an individual anchor.

V = The total shear in an anchorage.

V_b, V_o = The maximum shear value of an individual anchor without edge effects.

V_1 = The shearing force acting on an individual anchor.

$V_{\theta A}$ = The shearing force acting on any angle "ϕ" from the longitudinal axis of an insert.

$V_{\theta L}$ = The shearing force acting along the longitudinal axis of an insert.

$V_{\theta T}$ = The shearing force acting perpendicular to the longitudinal axis of an insert.

W = The base plate dimension perpendicular to the edge of concrete.

W_{cs} = The width of concrete support.

ϕ = The capacity reduction factor, normally taken as 0.9 for factored load design and 0.55 for service load design. Also used to designate the angle of applied load. |R1

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TABLE I

STRESS AREAS OF THREADED BOLTS

(UNC Thread Series)

Bolt Diameter Inches	Net Area (ASN) Sq. Inches	Bolt Diameter Inches	Net Area (ASN) Sq. Inches
1/4	0.032	1-1/2	1.41
5/16	0.052	1-3/4	1.90
3/8	0.078	2	2.50
1/2	0.142	2-1/4	3.25
5/8	0.226	2-1/2	4.00
3/4	0.334	2-3/4	4.93
7/8	0.462	3	5.97
1	0.606	3-1/4	7.10
1-1/8	0.763	3-1/2	8.33
1-1/4	0.969	3-3/4	9.66
1-3/8	1.16	4	11.1

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TABLE II

EXPANSION SHELL ANCHOR DATA

Bolt Size in.	Minimum Depth in. L_d	Factored Load Design kips T_o	Factored Load Design kips V_o	Service Load Design kips T_o	Service Load Design kips V_o	Nominal Minimum Spacing in.
1/4	1-3/32	0.70	0.50	0.45	0.30	2.5
5/16	1-5/16	1.05	0.80	0.65	0.50	3.5
3/8	1-17/32	1.50	1.25	0.95	0.80	4.0
1/2	2-1/32	2.30	2.20	1.45	1.40	5.0
5/8	2-15/32	3.10	[illegible]	1.95	2.25	5.5
3/4	3-1/4	4.40	[illegible]	2.75	3.30	6.5
7/8	3-11/16	5.30	[illegible]	3.30	4.50	7.0

ACCEPTABLE SSD ANCHORS

Phillips Self-Drill
Rawl Self-Drill

ACCEPTABLE SPD ANCHORS

Phillips Non-Drill
Rawl Steel Drop-in
Hilti Hol Hugger

NOTES:

(a) Allowable loads shown above [illegible] only to anchors which are to be proof tested in accordance with Standard Construction Specification No. G-32. Use two-thirds of the above [illegible] in design of anchors which are not to be proof tested.

(b) Allowable loads apply only for anchors in concrete having a compressive strength of 3000 psi or more.

(c) Allowable loads are for predrilled (SPD) anchors. For self-drilled (SSD) anchors the above values for T_o may be increased by 20 percent.

TABLE III

WEDGE BOLT DESIGN DATA

Bolt Size in. D	Min. Length in. L	Min. Depth[1] in. L_d	Max.[2] Attachment Thickness in.	Factored Load Design kips T_o	Factored Load Design kips V_o	Service Load Design kips T_o	Service Load Design kips V_o	Min. Spacing in.	Installation Torque ft.-lbs Min.	Installation Torque ft.-lbs Max.
1/4	3	1-3/4	1	0.95	0.80	0.60	0.50	3.0	5	10
3/8	3-1/2	2-1/4	7/8	1.45	1.90	0.90	1.20	4.0	15	30
1/2	5-1/2	3-1/4	1-1/2	3.35	3.20	2.10	2.00	5.0	40	60
5/8	6	4-1/4	7/8	4.40	4.80	2.75	3.00	7.0	70	100
3/4	8-1/2	6	1-3/4	6.60	6.65	4.20	4.15	8.5	120	180
1	9	7	1	10.00	10.70	6.30	6.70	9.5	240	360
1-1/4	12	9	1-3/4	13.10	15.60	8.20	9.75	10.5	400	500

NOTES: (1) Depth measured to the bottom of the anchor.

(2) Longer bolts which are required for thicker attachments must be color coded for identity.

(3) Maximum projection of the bolt above the attachment after installation should not exceed two bolt diameters.

(4) Allowable loads are based on concrete having a minimum compressive strength of 3000 psi.

APPROVED ANCHORS

Hilti Kwik Bolt
Phillips Wedge Anchor
Rawl Stud Bolt
Wej-It

POOR ORIGINAL

5581372

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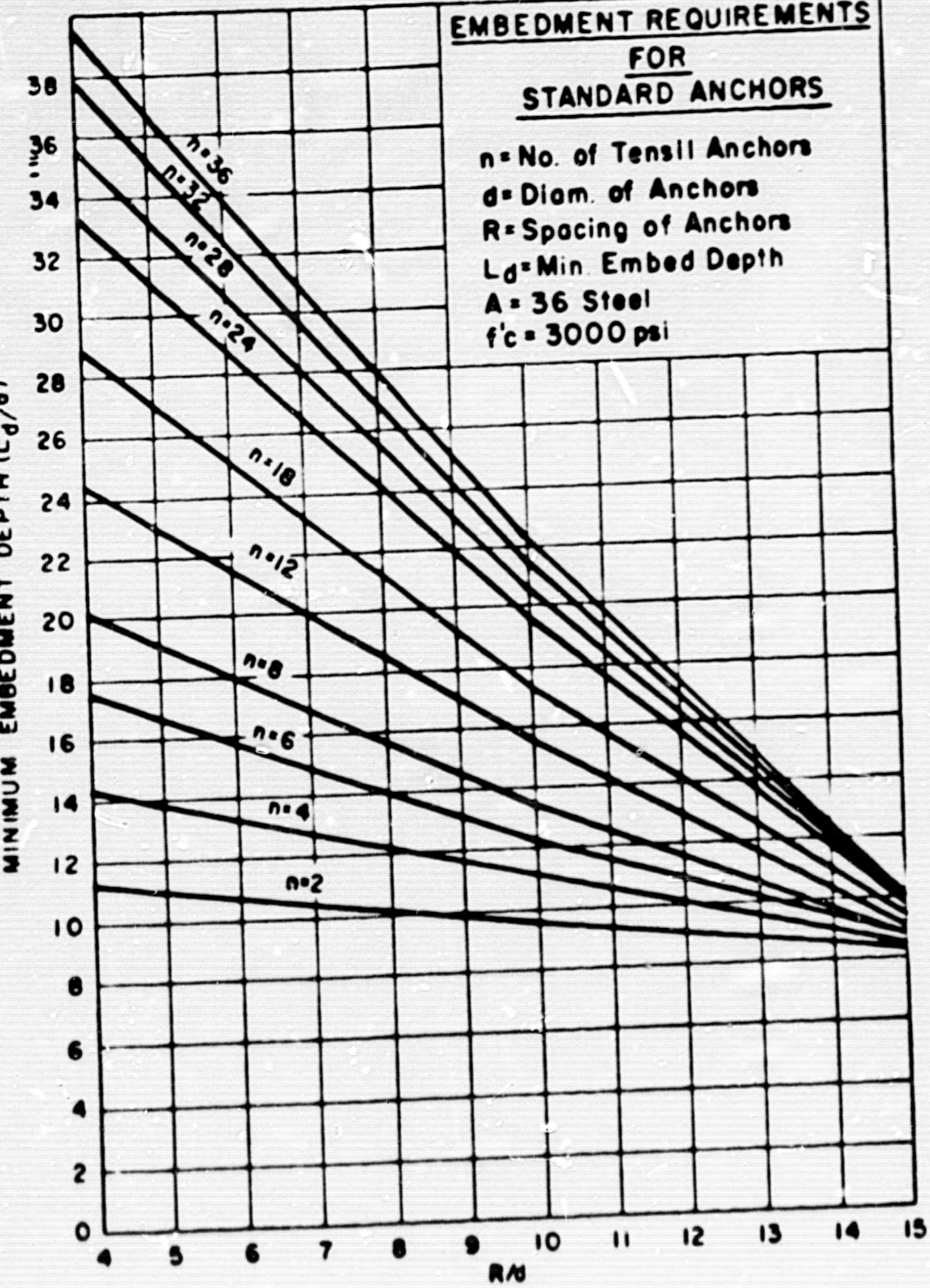

558138

SPACING OF HEADED ANCHORS
EDGE DISTANCE = 1.2 Ld

Figure 1

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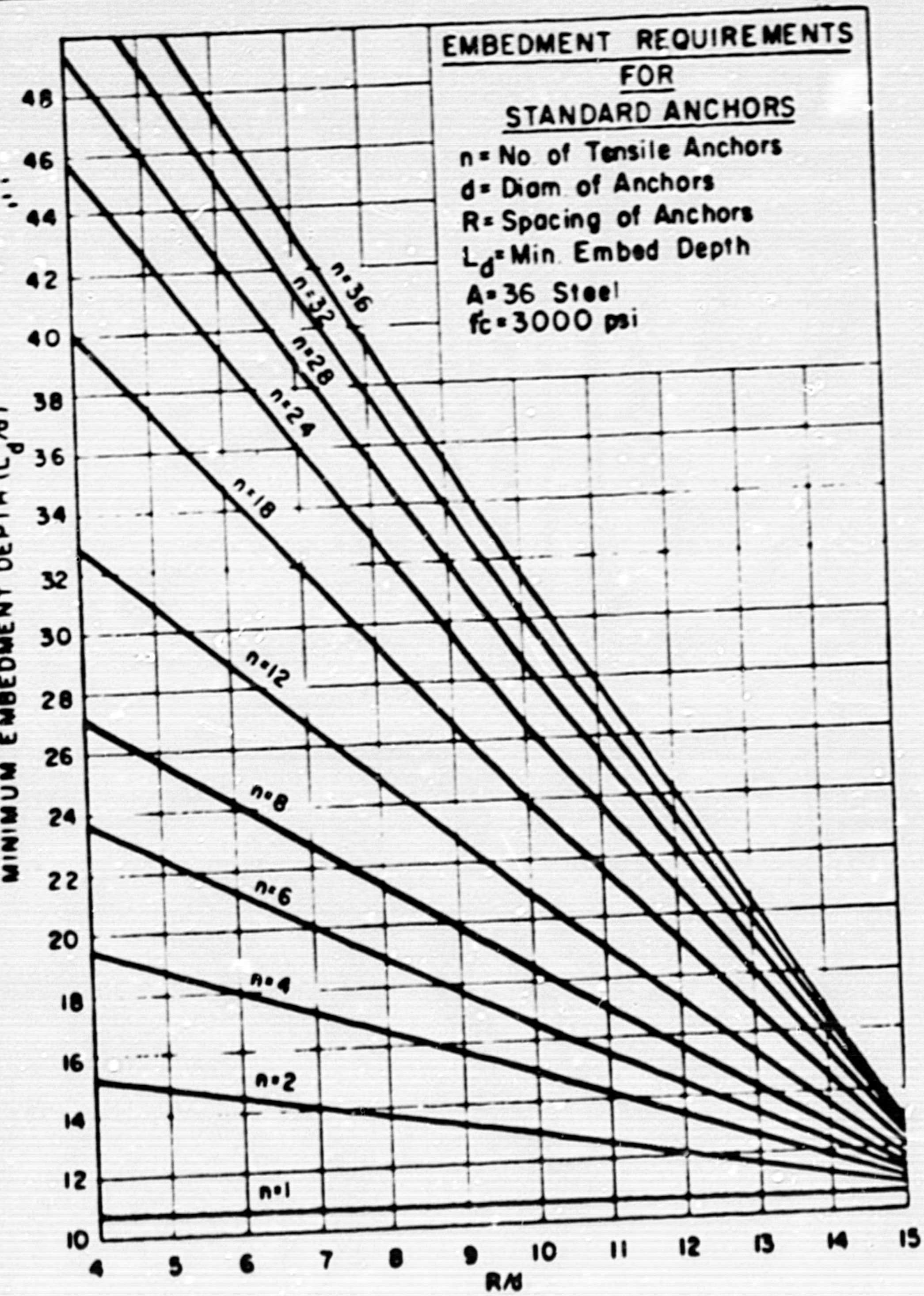

SPACING OF HEADED ANCHORS
EDGE DISTANCE = 3d

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Figure 2

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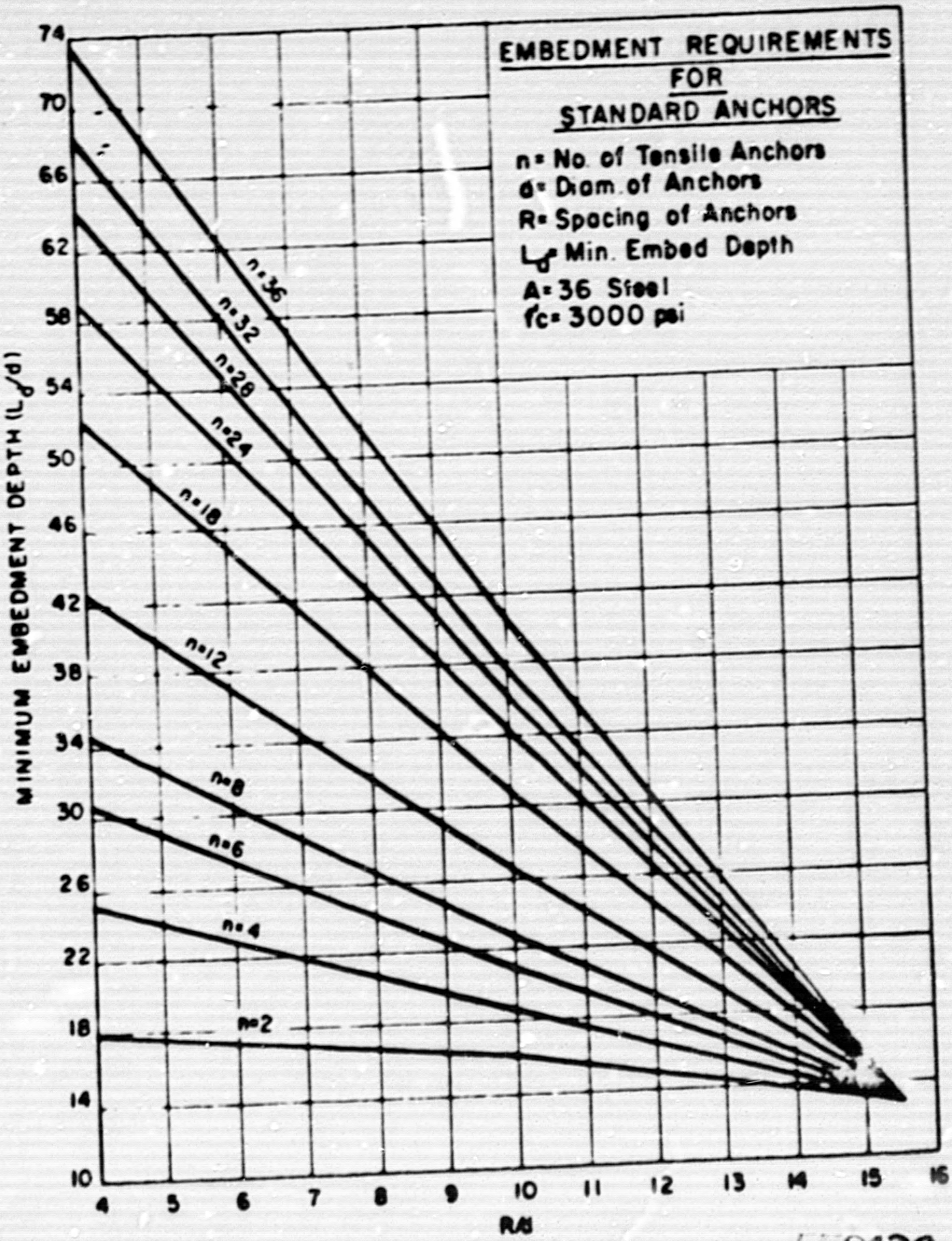

558139

SPACING OF HEADED ANCHORS
EDGE DISTANCE = 3d
TWO PERPENDICULAR EDGES

Figure 3

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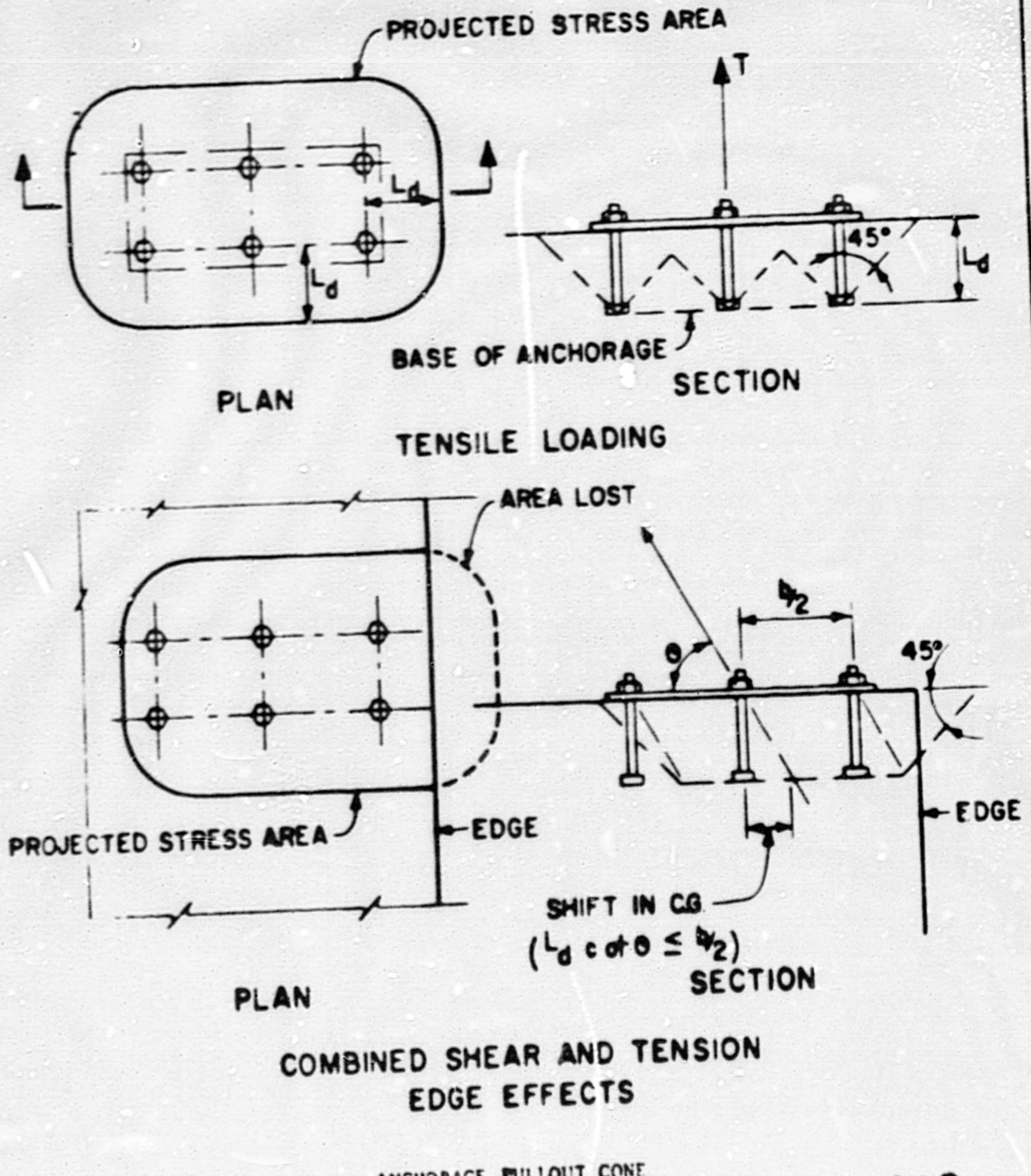

ANCHORAGE PULLOUT CONE
DETAILS

558140

Figure 4

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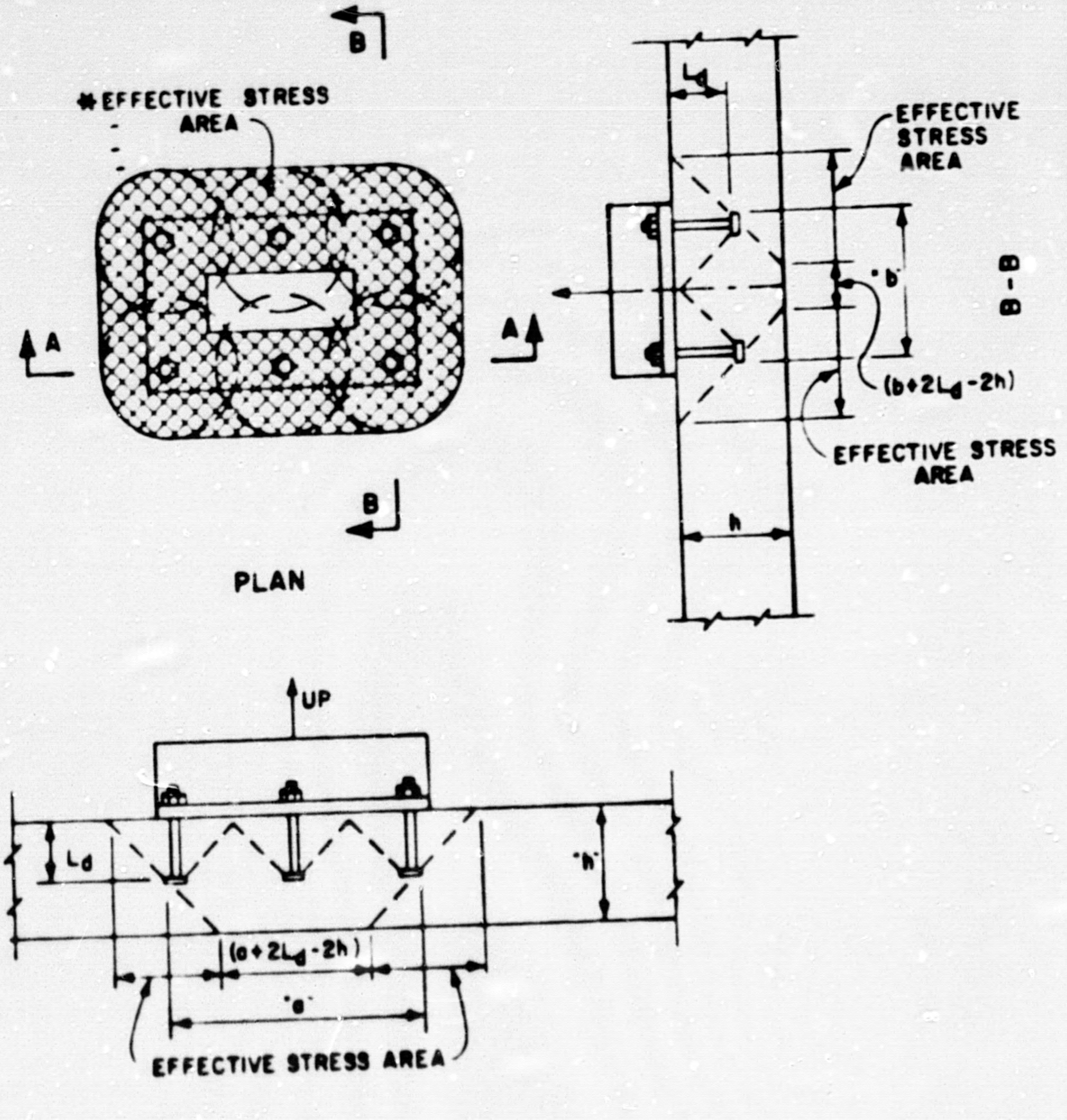

A-A

STRESS AREA REDUCTION FOR LIMITED DEPTH (A_R)

$$A_R = (a + 2L_d - 2h)\ (b + 2L_d - 2h)$$

*REDUCE BY THE TOTAL BEARING AREA OF THE ANCHOR STEEL

Figure 5

558142

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CONCRETE ANCHORAGES
General - Appendix

CIVIL DESIGN
STANDARD DS-[illegible].1

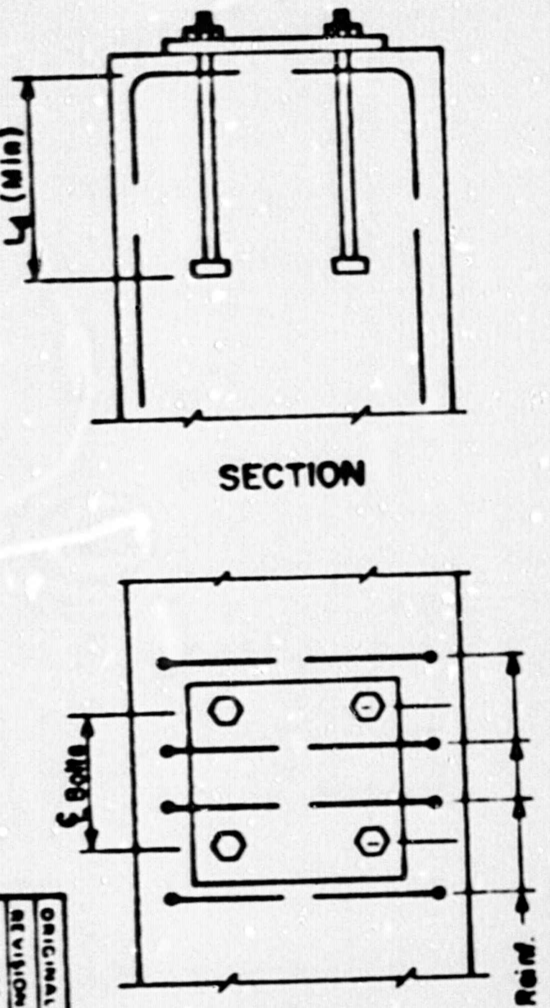

Figure 6
(Ref. Sect. 3.1.0)

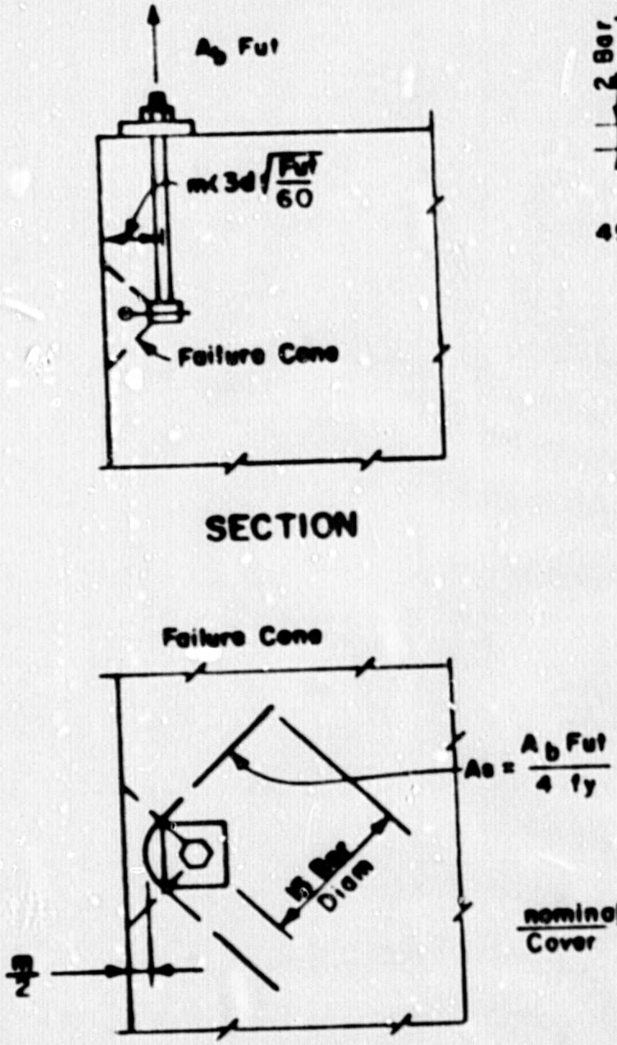

Figure 7
(Ref. Sect. 3.1.3)

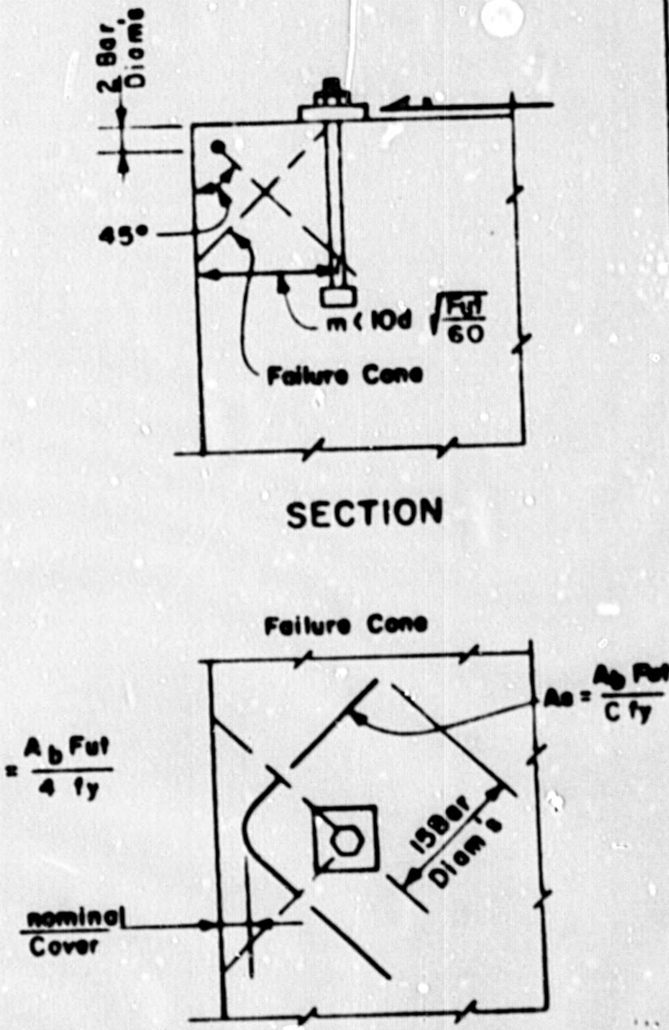

Figure 8
(Ref. Sect. 3.3.2)

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