Appendix C

Anchorage Data

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Appendix C
Anchorage Data

INTRODUCTION

The purpose of this appendix is to:

- Provide generic information on the various equipment classes for use in anchorage evaluations,
- Provide nominal allowable capacities for certain types of anchors, and
- Describe anchor-specific inspection checks and capacity reduction factors.

A general description of the anchorage evaluation procedure is included in Section 4.4. Only those specific inspection checks or evaluations which apply to a particular type of anchor are described in this appendix.

[1]The criteria in the GIP may be applied to modifications or repair of existing anchorages (e.g., anchor bolts or welds) including one-for-one component replacements (e.g., replacing bolts in one-for-one component replacements). For new installations and newly designed anchorages in modifications or replacements, the USI A-46 (GIP) criteria and procedures may also be applied, except that the factor of safety currently recommended for new nuclear plants in determining the anchorage capacities shall be met.

This appendix is organized with the generic equipment characteristics for anchorage evaluations given first and the remaining information grouped by anchor type as follows:

C.1 Generic Equipment Characteristics for Anchorage Evaluations
C.2 Expansion Anchors
C.3 Cast-In-Place Bolts and Headed Studs

C.4 Cast-In-Place J-Bolts

C.5 Grouted-In-Place Bolts

C.6. Welds to Embedded or Exposed Steel

The first section in this appendix contains generic equipment characteristics for anchorage evaluations for use when equipment-specific data is not available for equipment mass, natural frequency, or damping.

The remaining sections of this appendix contain a table of nominal allowable load capacities along with anchor-specific inspections which should be performed. In some cases a capacity reduction factor is given which may be used to lower the nominal allowable load capacities if the inspection check reveals that the installation does not meet the minimum guidelines.

The material in this appendix is based on the information contained in Reference 7 and Reference 36.

Note: The Seismic Capability Engineers should not use the material contained in this appendix unless they have thoroughly reviewed and understand Reference 7 and Reference 36.

C.1 GENERIC EQUIPMENT CHARACTERISTICS FOR ANCHORAGE EVALUATIONS

This section of the appendix contains estimates of equipment mass, natural frequency, and damping for the various classes of equipment listed in Table 3-l for anchorage evaluations. Note that an expanded discussion of equipment natural frequency and damping is included in Section 4.4.3, Step 1, Input Seismic Accelerations. The purpose of the discussion is to describe generic characteristics which may be used during anchorage evaluations in place of equipment-specific data. These generic characteristics typically result in larger than actual loadings on the anchorages. However, for unusual items of equipment, e.g., motor control center weighing 800 pounds with an additional 100 pounds external weight, an independent check should be made of the reasonableness of the values contained in Table C.l-1.

The equipment mass contained in Table C.l-1 is based on the heaviest item found in each of the classes covered during a survey of equipment. Note that these masses are the same as those used in the screening tables given in the EPRI Anchorage Report (Reference 7) except for the motor control centers which use 625 pounds per cabinet in the Reference 7 screening tables instead of the 800 pounds given in Table C.l-1.

Equipment lowest natural frequency is given as a relative rigidity of either “rigid” or “flexible” in Table C.l-1. Equipment with a lowest natural frequency of the overall structural mode greater than about 20 Hz is considered rigid[1]. Equipment with natural frequencies below about 20 Hz [2]is considered flexible[1].

The relative rigidities given in Table C.l-1 are for “typical” equipment in nuclear power plants. These generic categories of rigid or flexible should be checked when performing the seismic evaluation, noting particularly the rigidity or flexibility of the base support system for the equipment and the rigidity of the anchorage itself. In particular, the estimate for natural

[1] Note that the “rigid” and “flexible” categories of equipment in Table C.1-1 apply only to anchorage evaluations. These categories are different than the 8 Hz natural frequency limitation discussed in Section 4.2 and Table 4-1. The 8 Hz limitation applies to comparison of equipment seismic capacity to ground response spectra and includes internal panel modes and device modes where applicable.

frequency of equipment secured with expansion anchors should take into account the potential for slippage of these types of anchors. This would be necessary, for example, when natural frequency estimates of equipment secured with expansion anchors are based on analytical models which used fixed anchor points or when shake table test results are used in which the equipment was welded to the table.

For rigid equipment, the seismic demand on the equipment can be determined by using the Zero Period Acceleration (ZPA) of the appropriate floor response spectrum. For flexible equipment, the peak of the floor response spectrum (for the damping value given in Table C.l-1) should be used.

Table C.1-1
Generic Equipment Characteristics for Anchorage Evaluations

Equipment Class Number[a] and Name		Typical Maximum Mass		Typical Natural Frequency[c] and Damping
#1	Motor Control Centers	800 lb per cabinet[e]		Flexible 5% Damping
#2	Low Voltage Switchgear	35 lb/ft^3		Flexible 5% Damping
#3	Medium Voltage Switchgear[b]	31 lb/ft^3		Flexible 5% Damping
#4	Transformers	Rating (kVA) 3,000 2,500 2,000 1,000 100	Mass (lb) 15,000 11,050 9,400 6,300 975	Flexible 5% Damping
#5	Horizontal Pumps with Motors	Power (HP) 1,000 600 500 400 200 100	Mass (lb) 20,000 16,500 12,000 8,600 6,000 3,600	Rigid 5% Damping[d]
#6	Vertical Pumps with Motors	Power (HP)	Mass (lb)	
	a. Vertical Immersion	150	4,000	Flexible 3% Damping
	b. Centrifugal	500 2,000	9,000 48,000	Rigid 5% Damping[d]
	c. Deep-Well	500	9,000 (motor) 14,000 (pump)	Flexible 3% Damping

(a) The equipment class numbers given in this table correspond to the numbers given in Table 3-1.

(b) Medium voltage switchgear [2]is called “Metal-Clad Switchgear” in Reference 7.

(c) The lowest natural frequencies of the overall structural mode are given as either Rigid (> about 20 Hz) or Flexible (< about 20 Hz) and apply only to anchorage evaluations. (Note that the 8 Hz natural frequency limitation discussed in Section 4.2 applies to comparison of equipment seismic capacity to ground response spectra.)

(d) A damping value of 5% can be used for rigid equipment since the seismic accelerations can be taken from the ZPA which is not affected significantly by damping level.

(e) Note: When using the screening tables in the EPRI Anchorage Report (Reference 7), an average weight per MCC section of 625 pounds was used rather than the 800 pounds shown in this table.

Table C.1-1 (Cont'd)
Generic Equipment Characteristics for Anchorage Evaluations

Equipment Class Number[(a)] and Name		Typical Maximum Mass		Typical Natural Frequency[(c)] and Damping
#12	Air Compressors	Power (HP)	Mass (lb)	Rigid 5% Damping[(d)]
		50	4,000	
		200	10,000	
#13	Motor-Generators	(Not Available)		Rigid 5% Damping[(d)]
#15	Batteries on Racks	0.11 lb/in^3 for batteries, plus weight of racks		Flexible 5% Damping
#16	Battery Chargers and Inverters	45 lb/ft^3		Flexible 5% Damping
#17	Engine-Generators	(Not Available)		Rigid 5% Damping[(d)]
#18	Instrument Racks	20 lb/ft^2 of vertical face		Flexible 3% Damping
#14 & #20	Generic Equipment Cabinets	3 times the weight of cabinet housing		Flexible 5% Damping
#14 & #20	Walk-Through Control Panels	Determine and use weight per foot of length		Flexible 5% Damping

C.2 EXPANSION ANCHORS

The topics covered in this section of the appendix for expansion anchors are as follows. The subsection number of each of these topics is also given.

C.2.1	Nominal Allowable Capacities
C.2.2	Check for Anchor Type
C.2.3	Tightness Check
C.2.4	Embedment Check
C.2.5	Spacing Check
C.2.6	Edge Distance Check
C.2.7	Concrete Strength Check
C.2.8	Check for Concrete Cracks
C.2.9	Check for Essential Relays
C.2.10	Reduced Inspection Alternative
C.2.11	Shear-Tension Interaction

The specific checks described in this section should be performed in conjunction with the generic anchorage installation inspection checks described in Section 4.4.1. (See Table 4-2 for the checks which are applicable for this anchor type.)

The nominal allowable capacities and capacity reduction factors provided in this section should be used in the anchorage capacity equations given in Section 4.4.2.

C.2.1 Nominal Allowable Capacities

The nominal allowable load capacities which can be used for the types of expansion anchors covered by this procedure (i.e., those listed in Table C.2-2) are given in Table C.2-1, below.

Table C.2-1
Nominal Allowable Capacities for Expansion Anchors
($f'_c \geq 4000$ psi for pullout and $f'_c \geq 3500$ psi for shear)[1]

Bolt/Stud Diameter (D, in.)	Pullout Capacity (P_{nom}, kip)	Shear Capacity (V_{nom}, kip)	Minimum Spacing[2] (S_{min}, in.)	Min. Edge Distance[2] (E_{min}, in.)
3/8	1.46	1.42	3.75	3.75
1/2	2.29	2.38	5.00	5.00
5/8	3.17	3.79	6.25	6.25
3/4	4.69	5.48	7.50	7.50
7/8	6.09	7.70	8.75	8.75
1	6.95	9.53	10.00	10.00

Notes:

1. The pullout and shear capacities shown here are for the expansion anchor types included in Section C.2.2 installed in sound, uncracked concrete (i.e., no cracks passing through the anchor bolt installation) with a compressive strength (f'_c) of at least 4000 psi for pullout and 3500 psi for shear.
2. Minimum spacings and edge distances are measured from bolt center to bolt center or concrete edge. Smaller spacings and edge distances less than the minimums given here can be used with the reduction factors given in Sections C.2.5 and C.2.6.

C.2.2 Check for Anchor Type

The specific manufacturers and product names of expansion anchors covered by this procedure are listed in Table C.2-2, below. This table also lists capacity reduction factors (RT_p for pullout and RT_s for shear) which should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.2-1 to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom}\, RT_p$$

$$V_{all} = V_{nom}\, RT_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.2-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.2-1

RT_p = Pullout capacity reduction factor for type of expansion anchor from Table C.2-2

RT_s = Shear capacity reduction factor for type of expansion anchor from Table C.2-2

If the specific manufacturer and product name of an expansion anchor is not known, generic capacity reduction factors as indicated below may be used:

$RT_p = 0.50$ and $RT_s = 0.75$ (for bolt diameter = 3/8-inch)

$RT_p = 0.60$ and $RT_s = 0.75$ (for bolt diameter > 3/8-inch).

Note, however, that these generic capacity reduction factors may only be used for expansion anchors made from carbon steel or better material. Concrete fasteners made from other materials or which use fastening mechanisms which are different than that of expansion anchors should be identified as outliers. This would include fasteners such as lead cinch expansion anchors, chemical anchors, plastic anchors, powder-actuated fasteners, and concrete screws.

“Unknown” anchors should be examined to ensure they are not WEJ-IT Wedge anchor bolts, which can be distinguished from all other bolts by the two vertical slots cut along opposite sides of the bolt, parallel to the longitudinal axis of the bolt.

In general, expansion anchors should not be used for securing vibratory equipment such as pumps and air compressors. If such equipment is secured with expansion anchors, then there should be a large margin between the pullout loads and the pullout capacities; i.e., the loads on these expansion anchors should be primarily shear.

The principal differences between shell- and nonshell-type expansion anchors are explained below.

Table C.2-2
Type of Expansion Anchors Covered by This Procedure
and Associated Capacity Reduction Factors

Manufacturer	Product Name	Type	Capacity Reduction Factors RT_p	RT_s
Hilti	Kwik-Bolt	Nonshell	1.0	1.0
	HDI	Shell	1.0	1.0
	Sleeve (3/8-inch)	Nonshell	0.50	1.0
	Sleeve (1/2 to 5/8-inch)	Nonshell	0.60	1.0
ITW/Ramset	Dynaset	Shell	1.0	1.0
	Dynabolt	Nonshell	0.75	0.75
	Trubolt	Nonshell	0.75	0.75
ITW/Ramset/ Redhead	Multiset Drop-In	Shell	1.0	1.0
	Self Drilling	Shell	1.0	1.0
	Dynabolt Sleeve	Nonshell	1.0	1.0
	Nondrill	Shell	1.0	1.0
	Stud	Shell	0.75	0.75
	TRUBOLT	Nonshell	0.75	0.75
Molly	Parasleeve	Nonshell	1.0	1.0
	MDI	Shell	1.0	1.0
	Parabolt	Nonshell	0.75	0.75
Phillips	Self-Drilling	Shell	1.0	1.0
	Wedge	Nonshell	1.0	1.0
	Sleeve	Nonshell	1.0	1.0
	Multi-Set	Shell	1.0	1.0
	Stud	Shell	1.0	1.0
	Non-Drilling	Shell	1.0	1.0
Rawl	Drop-In	Shell	1.0	1.0
	Stud	Shell	0.75	0.75
	Saber-Tooth	Shell	0.75	0.75
	Bolt	Nonshell	0.75	0.75
Star	Selfdrill	Shell	0.75	0.75
	Steel	Shell	0.60	1.0
	Stud	Shell	0.60	0.75
USE Diamond	Sup-R-Drop	Shell	1.0	1.0
	Sup-R-Stud	Shell	1.0	1.0
	Sup-R-Sleeve	Nonshell	1.0	1.0
	Sup-R-Drill	Shell	0.75	0.75
WEJ-IT	Drop-In	Shell	1.0	1.0
	Sleeve	Nonshell	1.0	1.0
	Wedge	Nonshell	0.50	0.75
	Stud	Shell	0.60	1.0
Unknown*	Unknown* (3/8-inch)	Unknown*	0.50*	0.75*
	Unknown* (> 3/8-inch)	Unknown*	0.60*	0.75*

* See discussion of limitations on use of generic capacity reduction factors of 0.50, 0.60, and 0.75 for "Unknown" concrete fasteners.

Shell-type expansion anchors are expanded into the concrete by application of a setting force independent of the load later applied to the bolt or nut by the equipment being anchored. The key feature of this type of expansion anchor is that it relies upon its initial preset for holding it in place. Figure C.2-1 shows the features of several types of shell-type expansion anchors.

Figure C.2-l.a shows a “Self-Drilling Type” of shell-type expansion anchor. This type of anchor is set in place by driving the shell down over the cone expander which is resting against the bottom of the hole.

Figure C.2-l.b shows a “Drop-In Type” which is set in place by driving a cone expander down through the center of the shell thereby causing the lower portion of the shell to expand into the concrete.

Figure C.2-l.c shows a “Phillips Stud Type” which is set in place by driving the stud down over the cone expander which is resting against the bottom of the hole.

Nonshell-type expansion anchors are expanded into the concrete by pulling the stud up out of the hole which causes a sleeve or a split ring to be forced into the concrete. The key feature of this type of expansion anchor is that the more the stud is loaded in tension, the greater the expansion setting force becomes. Figure C.2-2 shows the features of two types of nonshell-type expansion anchors.

Figure C.2-2.a shows a “Sleeve Type” which is set in place by pulling the stud, with its integral cone expander on the bottom, up into the sleeve thereby forcing the lower split portion of the sleeve into the concrete. The sleeve is held in place during this setting process by butting up against the lower surface of the washer.

Figure C.2-2.b shows a “Wedge Type” which is set in place by pulling the stud, with its integral cone expander on the bottom, up though a split ring. Note that the split ring relies on friction against the concrete to stay in place during the setting operation.

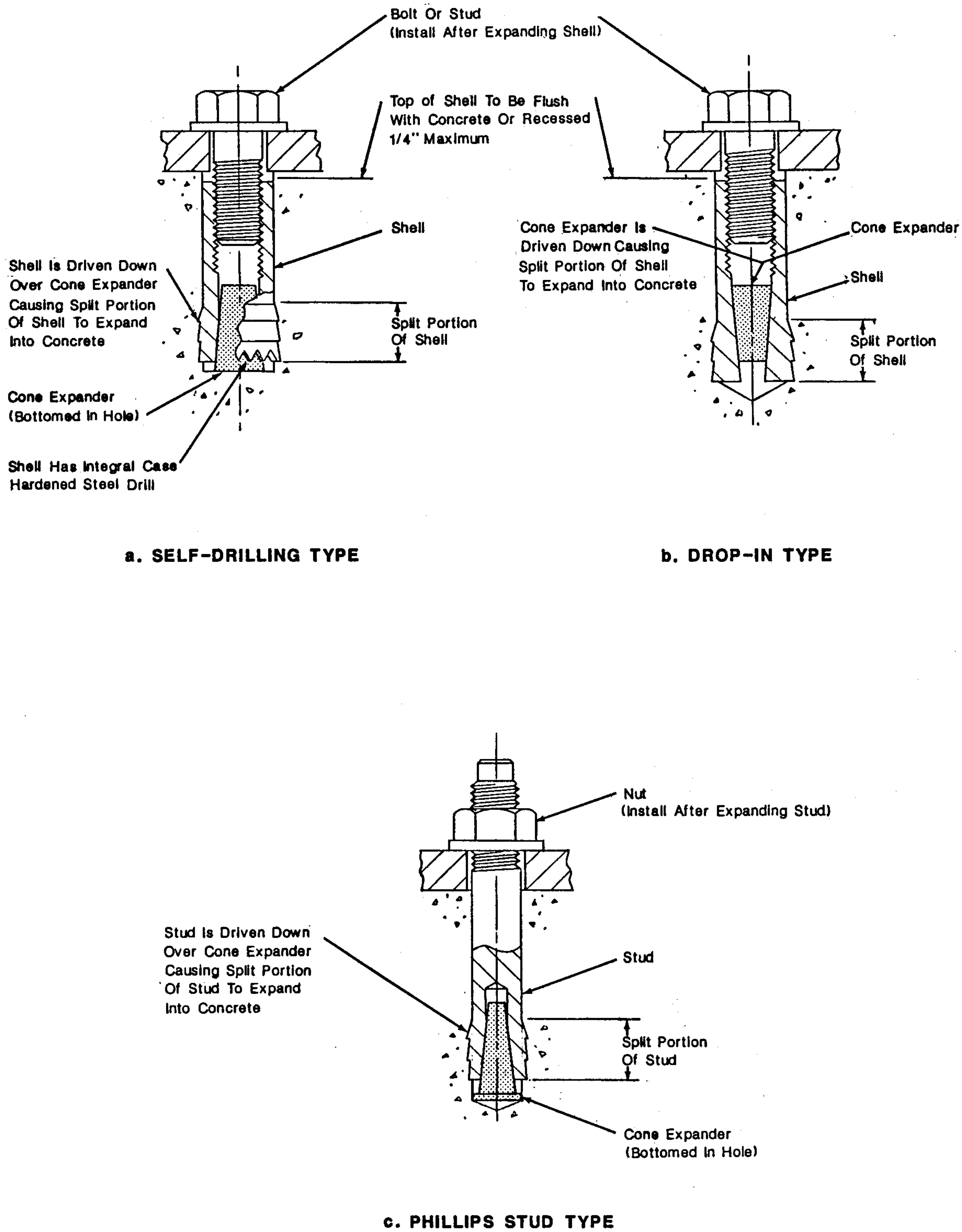
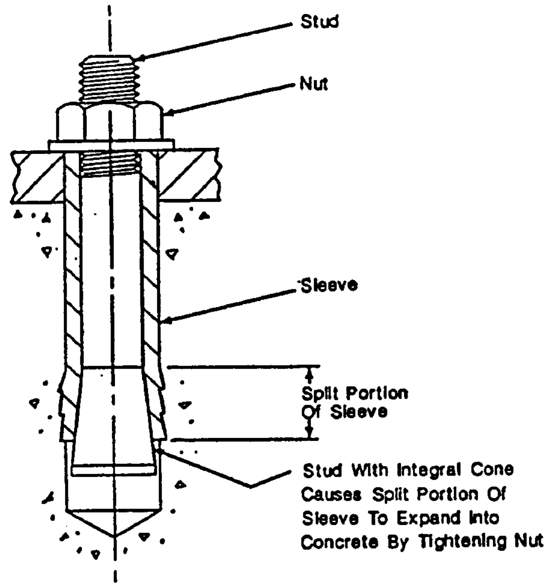
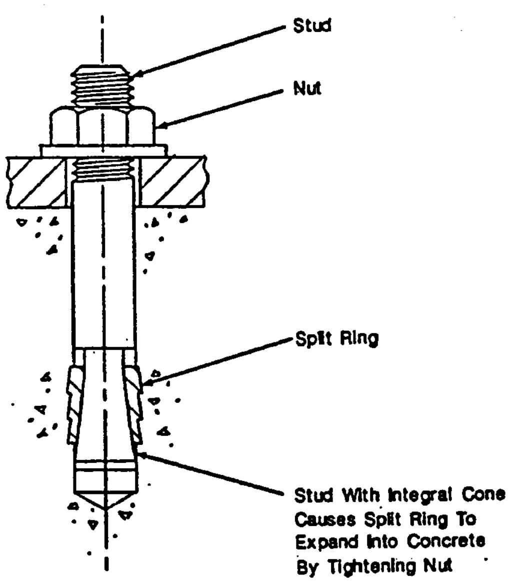


Figure C.2-1. Features of Shell-Type Expansion Anchors
(Source: Reference 7)



a. SLEEVE TYPE



b. WEDGE TYPE

Figure C.2-2. Features of Nonshell-Type Expansion Anchors
(Source: Reference 7)

Distinguishing characteristics of shell- and nonshell-type expansion anchors in their as-installed condition are shown in Figure C.2-3.

Figure C.2-3.a shows a nonshell-type expansion anchor in which the visible portion is characterized by a smoothly cut or mechanically finished threaded stud with a nut holding the base of the equipment in place.

Figure C.2-3.b shows the most common type of shell-type expansion anchor in which the visible portion is characterized by a head of a bolt.

Figures C.2-3.c and C.2-3.d show other types of shell-type expansion anchors in which the visible portion is characterized by a rough cut or a raised knob on the end of the threaded rod. Careful inspection is necessary to distinguish these two types of shell expansion anchors from the nonshell-type shown in Figure C.2-3.a.

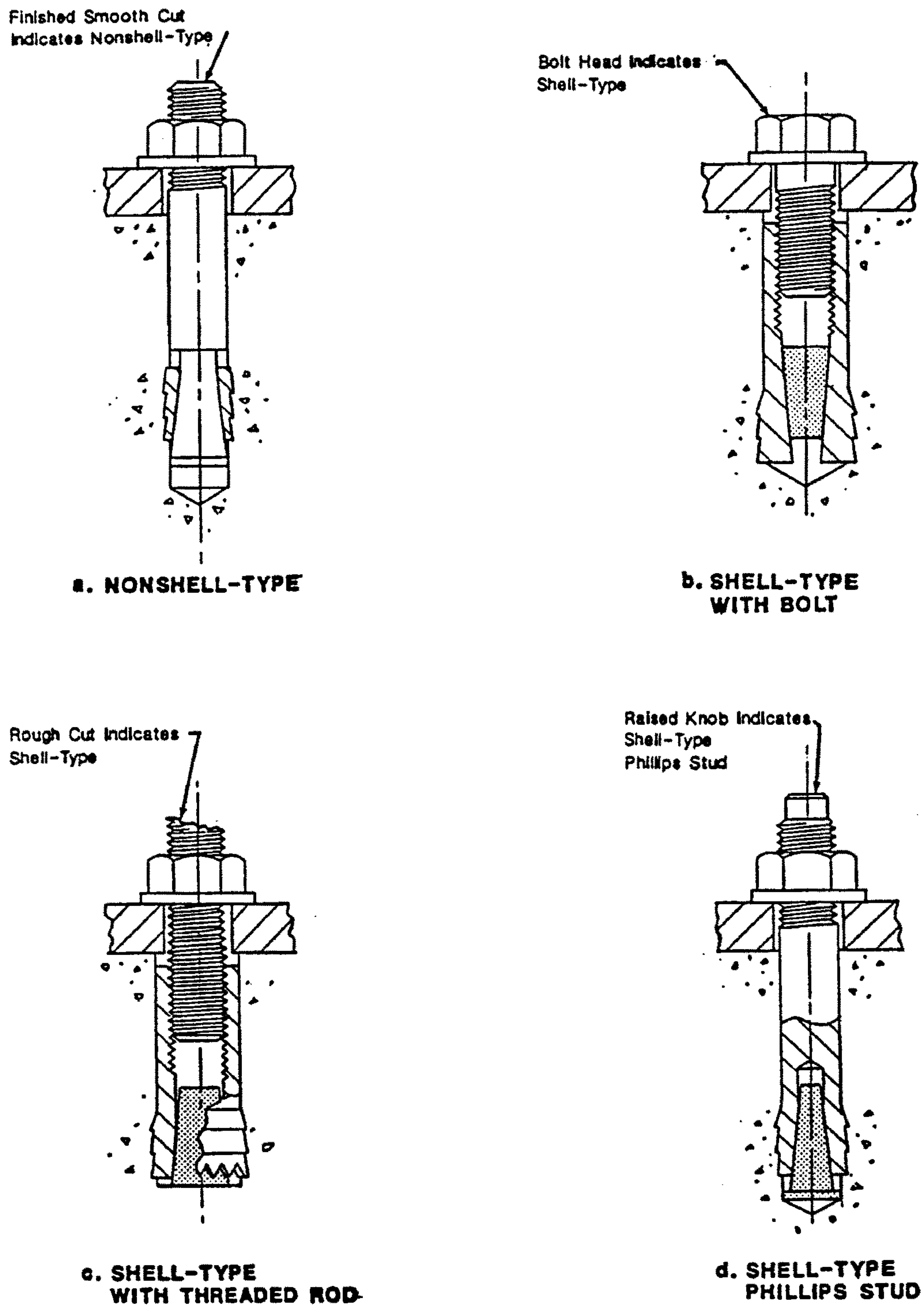


Figure C.2-3. Distinguishing Characteristics of Installed Shell- and Nonshell-Type Expansion Anchors
(Source: Reference 7)

C.2.3 Tightness Check

(Note: This inspection check is not needed if the Reduced Inspection Alternative is chosen, as described in Section C.2.10.)

The tightness check can be performed by using a standard size box or open-end wrench on the bolt head or nut and applying a torque by hand until the bolt or nut is “wrench tight”; i.e., tightened without excessive exertion. For those cases where specific torque values must be used (e.g., for maintenance work orders), the “Tightness Check Torque” values given in Table C.2-3, below, can be used for this expansion anchor tightness check. These values correspond to about 20% of the normal installation torques.

Table C.2-3
Recommended Torque Values for Expansion Anchor Tightness Check

Anchor Diameter (in.)	Installation Torque (ft-lbs)	Tightness Check Torque (ft-lbs)
3/8	25-35	5-7
1/2	45-65	9-13
5/8	80-90	16-18
3/4	125-175	25-35
7/8	200-250	40-50
1	250-300	50-60

A well-installed expansion anchor should not rotate under this applied torque. A small amount of initial rotation (about l/4 turn) is acceptable provided the nut or bolt will tighten and resist the applied torque. If a bolt turns more than about l/4 turn, but does eventually resist the torque, it should be re-torqued to the manufacturer's recommended installation torque and then considered acceptable.

A sampling program can be used to check the tightness of expansion anchors provided it achieves 95% confidence that no more than 5% of the expansion anchors fail to meet the tightness guidelines given above. This 95/5 criterion can be met using the guidelines given below for sample size, homogeneous population, allowable number of nonconforming anchors, and use of initial tightness test results.

- Sample Size. The number of expansion anchors selected for tightness checking should be at least as large as given in Table C.2-4, below, for "Sample Size".

Table C.2-4
Sample Size for Expansion Anchor Tightness Check

Condition	Sample Size[1]
Expansion Anchors Securing Equipment Which Contains Essential Relays	100%
Total Size of Homogeneous Anchor Population is Less Than 40 Anchors	100%
Total Size of Homogeneous Anchor Population is Between 40 and 160 Anchors	40 Anchors
Total Size of Homogeneous Anchor Population is More Than 160 Anchors	25%

1. Note: The sample sizes provided in this table are for accessible bolts. See Section 4.4.1, Check #4 for a discussion on how to handle inaccessible bolts.

- Homogeneous Population. The sample size is based on the total population of expansion anchors being homogeneous. Factors such as installation specifications, quality assurance procedures used in the installation specifications, quality assurance procedures used during installation, bolt manufacturer, installation contractor, etc., should be considered when judging whether or not the total population is homogeneous. If there is more than one homogeneous set of expansion anchors, then the sample size limitations given above and the allowable number of nonconforming anchors given below apply to each individual population.

- Allowable Number of Nonconforming Anchors. The criterion of 95% confidence that there are no more than 5% nonconforming anchors can be met if the number of expansion anchors which fails the tightness check does not exceed the limitations given in Table C.2-5, below. If more than these number of anchors fail the tightness check, then the sample size should be increased until the failure rate does not exceed the limitations in this table.

- Use of Initial Tightness Test Results. The results of the initial torque tightness check on each expansion anchor should be used to establish the failure rate for the purposes of the sampling program. For example, if out of a total population of 400 expansion anchors 100 were tightness checked and 4 of these failed the initial check, then the sample size should be expanded. (Table C.2-5 only allows 3 anchors to fail for 100 tests on a population of 400.) The sample size should be expanded even if all 4 of the failed anchors were able to be fully tightened up to their installation torque requirements.

Table C.2-5
Allowable Number of Expansion Anchors Which Need Not Pass Tightness Check

Total Population	Number of Anchors Which Need Not Pass Tightness Check for Test Sample Size, (n):											
Size (N)	**40**	**60**	**80**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
100	1	2	3	5	---	---	---	---	---	---	---	---
200	N/A	1	2	3	6	10	---	---	---	---	---	---
300	N/A	N/A	2	3	5	7	10	15	---	---	---	---
400	N/A	N/A	N/A	3	5	7	9	12	15	20	---	---
500	N/A	N/A	N/A	N/A	5	7	9	12	14	17	20	25
600	N/A	N/A	N/A	N/A	5	7	9	11	14	16	19	22
700	N/A	N/A	N/A	N/A	N/A	7	9	11	13	16	18	21
800	N/A	N/A	N/A	N/A	N/A	6	9	11	13	16	18	21
900	N/A	N/A	N/A	N/A	N/A	N/A	8	11	13	15	18	20
1000	N/A	N/A	N/A	N/A	N/A	N/A	8	11	13	15	17	20

If certain expansion anchors are not accessible due to such things as high radiation, concrete poured over the anchorages, equipment disassembly or removal being required, etc., then other methods may be used to assess the tightness of the expansion anchors as discussed in Section 4.4.1, Check #4 and summarized below.

- Use the Reduced Inspection Alternative (Section C.2.10) to verify the anchorage adequacy (the reduced inspection does not require a tightness check).
- Delay the tightness checks until a later refueling outage when radiation hazards are less.
- Use engineering judgment to assess the anchorage adequacy based on other considerations, e.g., tightness checks on similar anchors elsewhere in the plant, which show that

installation practices produced consistently tight installation. This method should be used as a last resort. The basis for the engineering judgment should be documented.

C.2.4 Embedment Check

(Note: This inspection check is not needed if the Reduced Inspection Alternative is chosen, as described in Section C.2.10.)

The manufacturer's recommended minimum embedments listed in Table C.2-6, below, are from the catalogs of each of the vendors listed in Reference 7, Page E-27. (These were the most recent catalogs available when Reference 7 was published.) Expansion anchors with less than the minimum embedment should be documented as outliers.

These minimum embedments can be verified by performing the following inspection checks for shell- and nonshell-type expansion anchors. Note that these checks should be performed after the tightness check (described in Section C.2.3) has been performed.

Table C.2-6
Manufacturer's Recommended Minimum Embedment
for Expansion Anchors Covered by This Procedure

		Minimum Embedment (L) [in.] for Bolt/Stud Diameter:					
Manufacturer	**Product Name (S=Shell, N=Nonshell)**	**3/8"**	**1/2"**	**5/8"**	**3/4"**	**7/8"**	**1"**
Hilti	Kwik-Bolt (N)	1.63	2.25	2.75	3.25	---	4.50
	HDI (S)	1.56	2.00	2.56	3.19	---	---
	Sleeve (N)	1.50	2.00	2.00	---	---	---
ITW / Ramset	Dynaset (S)	1.63	2.00	2.63	3.25	---	---
	Dynabolt (N)	2.00	2.25	2.25	---	---	---
	Trubolt (N)	1.50	2.25	2.75	3.38	4.00	4.50
ITW / Ramset / Redhead	Multiset Drop-In (S)	1.63	2.00	2.50	3.19	---	---
	Self Drilling (S)	1.53	2.03	2.47	3.25	---	---
	Dynabolt Sleeve (N)	1.88	2.00	2.25	---	---	---
	Nondrill (S)	1.56	2.06	2.56	3.19	---	---
	Stud (S)	1.63	1.88	2.38	2.88	---	---
	TRUBOLT (N)	1.50	2.25	2.75	3.25	3.75	4.50
Molly	Parasleeve (N)	1.50	2.00	2.00	---	---	---
	MDI (S)	1.56	2.00	2.50	3.19	---	---
	Parabolt (N)	1.50	2.25	2.75	3.25	4.00	4.50
Phillips	Self-Drilling (S)	1.53	2.03	2.47	3.25	3.69	---
	Wedge (N)	1.75	2.13	2.63	3.25	3.75	4.50
	Sleeve (N)	1.88	2.00	2.25	---	---	---
	Multi-Set (S)	1.38	1.75	2.25	2.50	---	---
	Stud (S)	1.63	1.88	2.38	2.88	---	---
	Non-Drilling (S)	1.56	2.06	2.56	3.19	---	---
Rawl	Drop-In (S)	1.88	2.38	3.00	3.50	---	---
	Stud (S)	1.75	2.25	2.88	3.38	4.00	4.50
	Saber-Tooth (S)	1.53	2.03	2.47	3.25	3.69	---
	Bolt (N)	2.00	2.50	2.75	3.00	---	---
Star	Selfdrill (S)	1.53	2.03	2.47	3.25	3.69	---
	Steel (S)	1.44	1.94	2.38	3.00	---	---
	Stud (S)	1.63	1.75	2.38	2.88	---	---
USE Diamond	Sup-R-Drop (S)	1.56	2.00	2.53	3.19	---	---
	Sup-R-Stud (S)	2.16	2.81	3.31	4.25	4.72	5.56
	Sup-R-Sleeve (N)	1.50	2.00	2.50	3.00	---	---
	Sup-R-Drill (S)	1.53	2.03	2.47	3.27	---	---
WEJ-IT	Drop-In (S)	1.63	2.00	2.50	3.25	---	---
	Sleeve (N)	1.50	1.88	2.00	2.25	---	---
	Wedge (N)	1.50	2.00	3.00	3.00	4.50	5.50
	Stud (S)	1.75	2.13	3.63	3.25	---	4.50

Shell-Type Expansion Anchors. The embedment length of shell-type expansion anchors is predetermined by the length of the shell and how it is installed in the concrete. The appropriate shell length is assured if the expansion anchor is one of the types listed in Table C.2-6. An appropriate installation is assured if the shell of these anchors does not protrude above the surface of the concrete.

When making this embedment check, a check should also be made (as described in Section 4.4.1, Check #4) to confirm that the top of the shell is not touching the bottom of the base plate of the item of equipment being anchored. This check should be performed after the tightness check has been done. This will assure that the expansion anchor is tight in the hole and not just tight up against the base of the equipment.

If it is necessary to remove the bolt or nut from the anchorage to make the above two checks, then it is only necessary to spot check the embedment of a few anchors. If this spot check indicates that these types of bolts may not be properly installed, then this inspection check should be expanded accordingly. When re-installing the anchor, it should be re-tightened to a “wrench tight” condition or to the recommended tightness check torque values using the guidelines given in Section C.2.3, above.

Nonshell-Type Expansion Anchors. The embedment length of nonshell-type expansion anchors is predetermined by the length of the stud and the installation of the anchor. The appropriate overall length of nonshell studs is dependent upon the manufacturer, the model, and the thickness of the equipment base plate for which the anchor is designed. Table C.2-7, below, can be used as a generic screen for assessing whether a nonshell expansion anchor has adequate embedment. A range of projections is given in Table C.2-7 since there are differences in acceptable projections depending upon the make and model of the anchor. If a nonshell stud projects more than the lower value of this range, then anchor-specific information should be used to determine the embedment length of the anchor.

Table C.2-7
Maximum Stud Projections Above Concrete for Nonshell-Type Expansion Anchors

Stud Diameter (in.)	Maximum Stud Projections Above Concrete (in.)
3/8	1/2 – 3/4
1/2	1/2 – 3/4
5/8	1/2 – 7/8
3/4	7/8 – 1-1/2
7/8	1-1/2 – 2
1	1-1/2 – 2

Note that careful evaluation is needed when checking the projections since larger projections than those given above may be needed if the base plate is relatively thick or if, at the time of installation in the plant, a particular bolt length may not have been available. Also, for bolts made by some manufacturers, the bolt projections may be larger than those given in the above table even for their shortest bolts. Thus, while this check need only be visual, a careful evaluation should be made to determine whether the stud projection is reasonable, given the bolt diameter, base plate thickness, and whether a grout pad is used. When projections are larger than those given in Table C.2-7, adequate embedment should be verified by consulting design and construction documents and vendor catalogs. Alternately, ultrasonic inspection techniques may be used to compare the measured bolt/stud length to the manufacturer's recommended minimum embedment given in Table C.2-6.

This embedment check should be performed on wedge- and sleeve-type, nonshell expansion anchors after the tightness check has been done as described in Section C.2.3. This is to ensure that the tightness check does not pull the expansion anchor partially out of the hole beyond the required minimum embedment.

For bolts with deeper embedments than the minimum values given in Table C.2-6, manufacturer's catalog data may be used, if it is available, to establish the nominal allowable capacities instead of those given in Table C.2-1. As an alternative, plant-specific testing may be performed to establish the strength of the more deeply embedded expansion anchors.

C.2.5 Spacing Check

If the spacing (S) between an expansion anchor and another anchor is less than the minimum value (S_{min}) given in Table C.2-1, then a pullout capacity reduction factor (RS_p) and a shear capacity reduction factor (RS_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.2-1 to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom} RS_p$$

$$V_{all} = V_{nom} RS_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.2-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.2-1

RS_p = Pullout capacity reduction factor for closely spaced expansion anchors

= 1.0 for $S \geq 10D$

= $\frac{S}{10D}$ for $10D > S \geq 5D$

= 0.5 for $5D > S \geq 2.5D$

= Outlier for $S < 2.5D$

S = Spacing between anchors measured center-to-center

D = Diameter of anchor bolt/stud

RS_s = Shear capacity reduction factor for closely spaced expansion anchors

= 1.0 for $S \geq 2D$

= 0.5 for $S < 2D$

A reduction factor should be applied for <u>each</u> nearby anchor, whether it is another expansion anchor or a different type of anchor. The spacings (S) given above are defined in terms of multiples of the anchor bolt/stud diameter (D), measured from anchor centerline to centerline.

C.2.6 Edge Distance Check

If the distance (E) from an expansion anchor to a free edge of concrete is less than the minimum value (E_{min}) given in Table C.2-1, then a pullout capacity reduction factor (RE_p) and a shear capacity reduction factor (RE_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.2-1 to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom}\,RE_p$$

$$V_{all} = V_{nom}\,RE_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.2-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.2-1

RE_p = Pullout capacity reduction factor for near edge expansion anchors

= 1.0 for $E \geq 10D$

= $\dfrac{E}{10D}$ for $10D > E \geq 4D$

= Outlier for $E < 4D$

E = Edge distance from centerline of anchor to free edge

D = Diameter of anchor bolt/stud

RE_s = Shear capacity reduction factor for near edge expansion anchors

= 1.0 for $E \geq 10D$

= $\left[\dfrac{E}{10D}\right]^{1.5}$ for $10D > E \geq 4D$

= Outlier for $E < 4D$

A reduction factor should be applied for each nearby edge; e.g., if an anchor is near a corner, then two reduction factors apply. The edge distance (E) given in the tables above are in terms of multiples of the anchor bolt/stud diameter (D), measured from the anchor centerline to the edge.

C.2.7 Concrete Strength Check

If the concrete compressive strength (f'_c) is less than 4000 psi for pullout loads or 3500 psi for shear loads, then a pullout capacity reduction factor (RF_p) and a shear capacity reduction factor (RF_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}), given in Table C.2-1, to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom}\,RF_p$$
$$V_{all} = V_{nom}\,RF_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.2-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.2-1

RF_p = Pullout capacity reduction factor for expansion anchors in low strength concrete

= 1.0 for $f'_c \geq 4000$ psi

= $\dfrac{f'_c}{4000}$ for 4000 psi $> f'_c \geq 2000$ psi

= Outlier for $f'_c < 2000$ psi

f'_c = Concrete compression strength (psi)

RF_s = Shear capacity reduction factor for expansion anchors in low strength concrete

= 1.0 for $f'_c \geq 3500$ psi

= $\dfrac{f'_c}{10{,}000} + 0.65$ for 3500 $> f'_c \geq 2000$ psi

= Outlier for $f'_c < 2000$ psi

C.2.8 Check for Concrete Cracks

If there are significant structural cracks in the concrete where expansion anchors are installed, then a pullout capacity reduction factor (RC_p) should be multiplied by the nominal pullout capacity (P_{nom}), given in Table C.2-1, to obtain the allowable pullout capacities (P_{all}) as follows.

The shear capacity of expansion anchors is not significantly affected by cracks in the concrete.

$$P_{all} = P_{nom} \, RC_p$$

Where:

P_{all}	=	Allowable capacity of anchor
P_{nom}	=	Nominal pullout capacity of anchor from Table C.2-1
RC_p	=	Pullout capacity reduction factor for expansion anchors in cracked concrete
	=	See Table C.2-8 for values

The pullout capacity reduction factor applies only to significant structural cracks which penetrate the concrete mass and pass through the vicinity of the anchor installation. Concrete with surface (craze) cracks or shrinkage cracks which only affect the surface of the concrete should be considered uncracked. It may be necessary to exercise judgment to establish whether cracks in the vicinity of an anchor actually pass through the installation. Inspections for crack width should be visual (i.e., detailed measurement of crack widths is not necessary).

Table C.2-8
Pullout Capacity Reduction Factors for Expansion Anchors in Cracked Concrete

Conditions	Reduction Factor for Pullout Capacity (RC_p)
• No Cracks	1.0
• Crack size < 0.01 in. and the Number of Required Anchors Securing the Equipment Which Are Affected by These Cracks Is:	
≤ 50%	1.0
> 50%	0.75*
• 0.01 in. ≤ Crack Size ≤ 0.02 in.	0.75*
• Crack Size > 0.02 in.	Outlier

* Capacity reduction factor applies to all required anchors securing the item of equipment, not just the anchors which are affected by the cracks.

C.2.9 Check for Essential Relays

If there are essential relays mounted in the item of equipment, then the following pullout capacity reduction factor (RR_p) and shear capacity reduction factor (RR_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.2-1 to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom}\, RR_p$$

$$V_{all} = V_{nom}\, RR_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.2-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.2-1

RR_p = Pullout capacity reduction factor for expansion anchors securing equipment in which essential relays are mounted

= 0.75

RR_s = Shear capacity reduction factor for expansion anchors securing equipment in which essential relays are mounted

= 0.75

The Relay Functionality Review described in Section 6 of the GIP identifies which cabinets and items of equipment contain essential relays.

C.2.10 Reduced Inspection Alternative

A reduced level of inspection can be performed for expansion anchors if additional conservatism is included in the anchorage evaluation. The two inspections which can be deleted for this reduced inspection are:

- Tightness Check (Section C.2.3)
- Embedment Check (Section C.2.4)

However to use this Reduced Inspection Alternative, the following conditions should be met:

- Capacity Reduction Factor Applied. If the Reduced Inspection Alternative is used, then a pullout capacity reduction factor (RI_p) and shear capacity reduction factor (RI_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.2-1 to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom} \, RI_p$$

$$V_{all} = V_{nom} \, RI_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.2-1

V_{all}	=	Allowable shear capacity of anchor
V_{nom}	=	Nominal shear capacity of anchor from Table C.2-1
RI_p	=	Pullout capacity reduction factor for used with Reduced Inspection Alternative
	=	0.75
RI_s	=	Shear capacity reduction factor for use with Reduced Inspection Alternative
	=	0.75

- Other Effects Do Not Reduce Anchor Capacity. None of the other effects which could lower the capacity of the anchor are present. The following anchorage inspection checks, from Section 4.4.1, should show that the anchors have full capacity. The checks and the full capacity values are listed in Section 4.4.1 and in Sections C.2.5 through C.2.9:

Check 6 - Gap Size:	None	(Section 4.4.1)
Check 7 - Spacing:	$S \geq 10D$	(Section C.2.5)
Check 8 - Edge Distance:	$E \geq 10D$	(Section C.2.6)
Check 9 - Concrete Strength:		
• For Pullout:	$f'_c \geq 4000$ psi	(Section C.2.7)
• For Shear:	$f'_c \geq 3500$ psi	(Section C.2.7)
Check 10 - Concrete Cracks:	None	
Check 11 - Essential Relays:	None	

- One Third of Anchors Not Available. The applied seismic and dead loads should be less than the allowable anchor pullout and shear capacities given above when a third of the anchors securing the item of equipment are assumed to be unavailable for carrying loads, i.e., 50% more bolts are used to secure the item of equipment than necessary to meet the allowable loads. There should be at least 6 anchors securing the equipment; 4 assumed to be carrying the load and 2 not.

C.2.11 Shear-Tension Interaction

When expansion anchors are subjected to simultaneous shear and tension, one of the following shear-tension interaction formulations should be used. The linear formulation is conservative. The bi-linear formulation is more realistic. Figure C.2-4 illustrates these formulations.

- Linear Formulation (conservative)

$$\frac{V}{V_{all}} + \frac{P}{P_{all}} \leq 1.0$$

- Bilinear Formulation (more realistic)

$$\frac{P}{P_{all}} \leq 1.0 \qquad \text{for } \frac{V}{V_{all}} \leq 0.3$$

$$0.7\,\frac{P}{P_{all}} + \frac{V}{V_{all}} \leq 1.0 \qquad \text{for } 0.3 < \frac{V}{V_{all}} \leq 1.0$$

Where:
P = Applied pullout loads due to earthquake plus dead loads.
V = Applied shear loads due to earthquake plus dead loads.
P_{all} = Allowable pullout capacity load for the anchor.
V_{all} = Allowable shear capacity load for the anchor.

S/T EXP

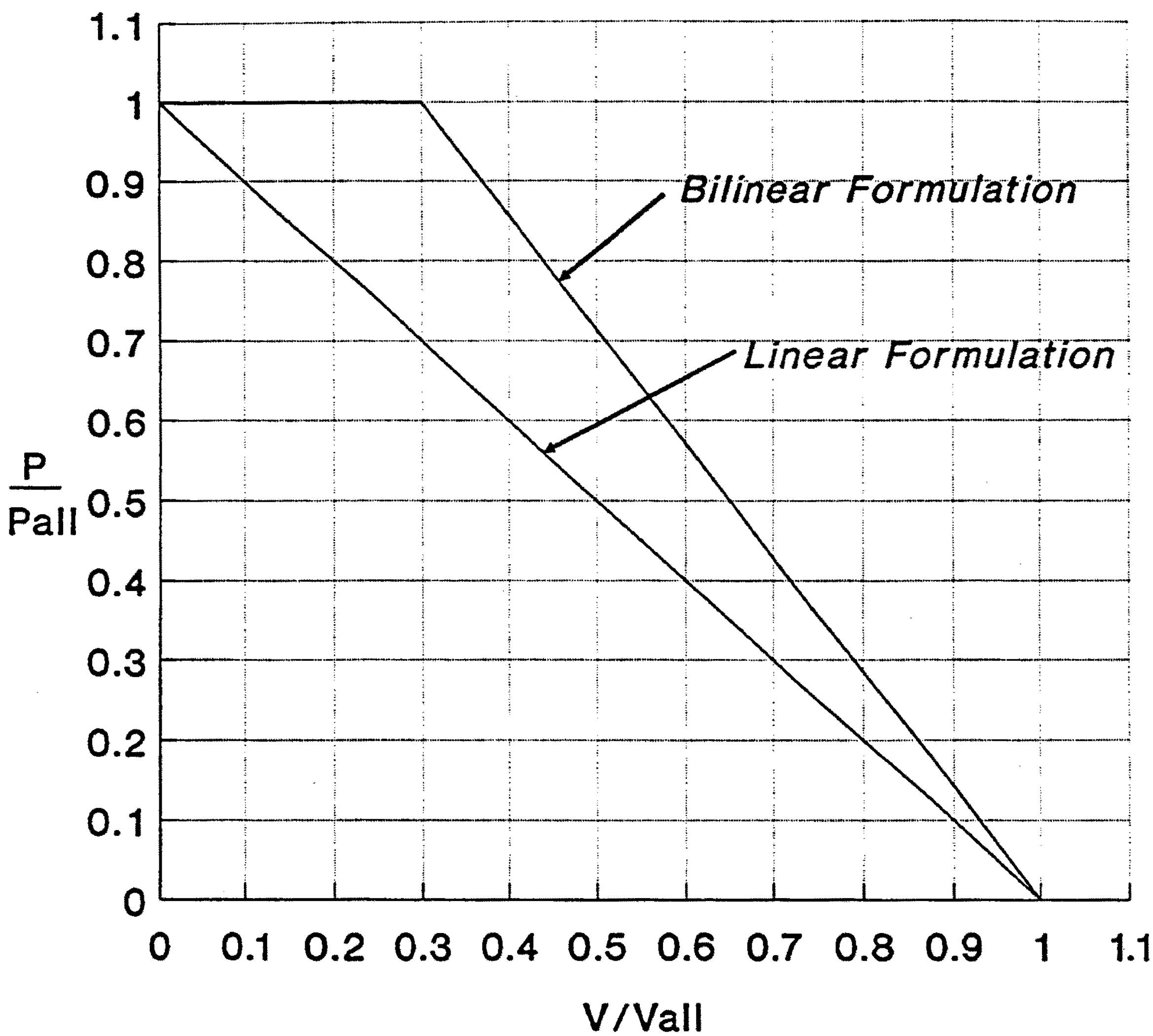


Figure 6.2-4. Shear-Tension Interaction Limitations for Expansion Anchors (Source: Reference 7)

C.3 CAST-IN-PLACE BOLTS AND HEADED STUDS

The topics covered in this section of the appendix for cast-in-place bolts and headed studs are as follows. The [2]subsection number of each of these topics is also given.

The specific checks described in this section should be performed in conjunction with the generic anchorage installation inspection checks described in Section 4.4.1. (See Table 4-2 for the checks which are applicable for this anchor type.)

The nominal allowable capacities and capacity reduction factors provided in this section should be used in the anchorage capacity equations given in Section 4.4.2

C.3.1 Nominal Allowable Capacities

The nominal allowable load capacities which can be used for cast-in-place bolts and headed studs are listed in Table C.3-1, below.

Table C.3-1
Nominal Allowable Capacities for Cast-In-Place Bolts and Headed Studs
($f'_c \geq 3500$ psi)[1]

Bolt/Stud Diameter (D, in.)	Pullout Capacity (P_{nom}, kip)	Shear Capacity (V_{nom}, kip)	Minimum Embedment[2] (L_{min}, in.)	Minimum Spacing[3] (S_{min}, in.)	Min. Edge Distance[3] (E_{min}, in.)
3/8	3.74	1.87	3-3/4	4-3/4	3-3/8
1/2	6.66	3.33	5	6-1/4	4-3/8
5/8	10.44	5.22	6-1/4	7-7/8	5-1/2
3/4	15.03	7.51	7-1/2	9-1/2	6-5/8
7/8	20.44	10.22	8-3/4	11	7-3/4
1	26.69	13.35	10	12-5/8	8-3/4
1-1/8	33.80	16.90	11-1/4	14-1/4	9-7/8
1-1/4	41.72	20.86	12-1/2	15-3/4	11
1-3/8	50.40	25.25	13-3/4	17-3/8	12-1/8

Notes:

1. The pullout and shear capacities shown here are for ASTM A-307 or equivalent strength bolts installed in sound, uncracked concrete (i.e., no cracks passing through the anchor bolt installation) with a compressive strength of 3500 psi or greater. For bolt capacities in lower strength concrete, see Section C.3.5. For bolt capacities in cracked concrete, see Section C.3.6.
2. See Figure C.3-1 for definition of embedment length (L). Smaller embedments than the minimum given here can be used with the reduction factor given in Section C.3.2.
3. Minimum spacings and edge distances are measured from bolt center to bolt center or concrete edge. Spacings and edge distances less than the minimums given here can be used with the reduction factors given in Sections C.3.3 and C.3.4.

C.3.2 Embedment Check

The nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.3-1 are based on the assumption that the embedment length is sufficiently long to preclude failure in the concrete. The minimum embedments (L_{min}) given in Table C.3-1 are equal to 10 times the bolt diameter (D). Figure C.3-1 shows the embedment length (L) for a cast-in-place bolt and a headed stud.

The embedment length should be verified by consulting existing drawings to ensure that the actual embedment length (L) is more than the minimum (L_{min}). If the construction drawings are not available, ultrasonic means or other appropriate methods may be used to verify the actual embedments.

If the embedment length (L) is less than the minimum value (L_{min}) given in Table C.3-1, then a pullout capacity reduction factor (RL_p) and a shear capacity reduction factor (RL_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.3-1 to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom} \, RL_p$$

$$V_{all} = V_{nom} \, RL_s$$

Where:

P_{all}	=	Allowable pullout capacity of anchor	
P_{nom}	=	Nominal pullout capacity of anchor from Table C.3-1	
V_{all}	=	Allowable shear capacity of anchor	
V_{nom}	=	Nominal shear capacity of anchor from Table C.3-1	
$RL_p = RL_s$	=	Pullout (p) and shear (s) capacity reduction factors for cast-in-place anchors with shallow embedment	
	=	1.0	for $L \geq 10D$
	=	$\dfrac{(L + D)\,L}{(L_{min} + D)\,L_{min}}$	for $4D < L < 10D$ and $L > 3$ inches
	=	Outlier	for $L <$ Greater of: 4D or 3 inches
L	=	Length of anchor embedment per Figure C.3-1	
L_{min}	=	Minimum length of anchor embedment from Table C.3-1	
D	=	Diameter of anchor bolt/stud	

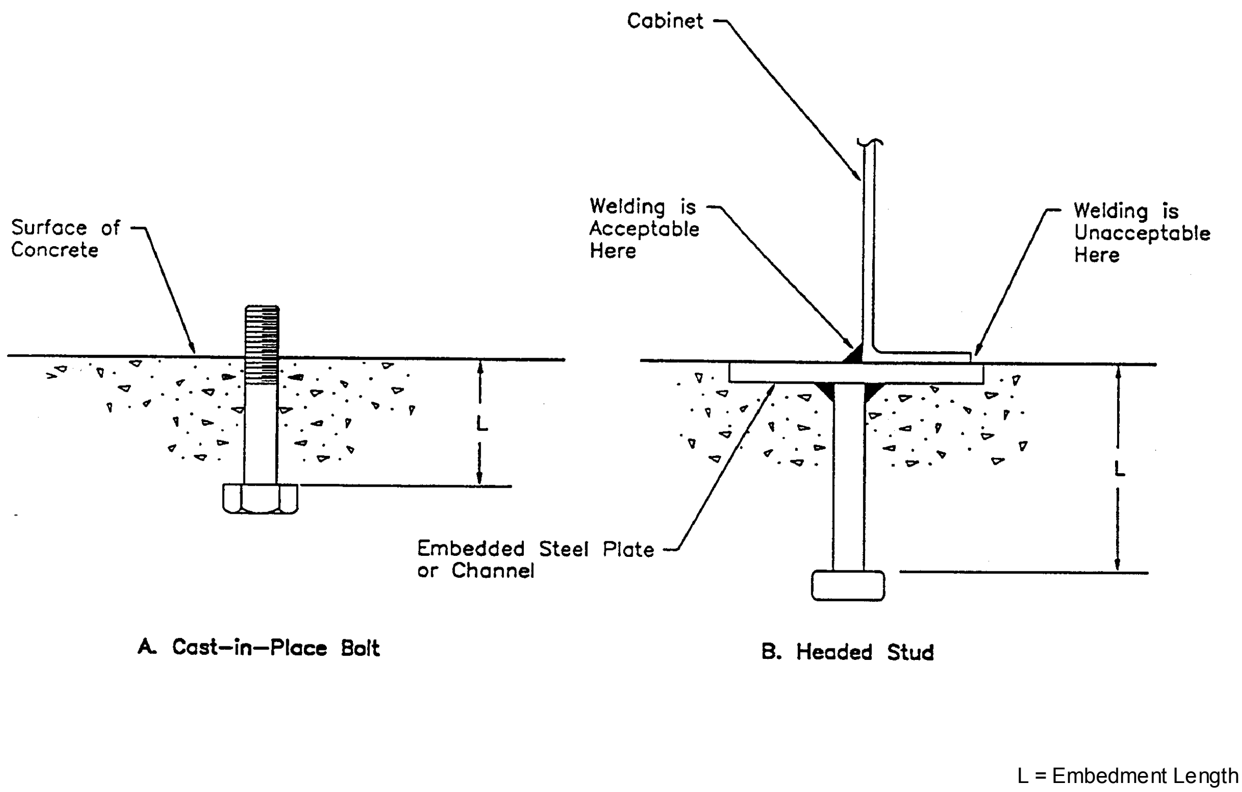


Figure C.3-1. Typical Installations of Cast-In-Place Bolt and Headed Stud

C.3.3 Spacing Check

If the spacing (S) between a cast-in-place anchor and another anchor is less than the minimum value (S_{min}) given in Table C.3-1, then a pullout capacity reduction factor (RS_p) and a shear capacity reduction factor (RS_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.3-1 to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows.

Note that a reduction factor should be applied for each nearby anchor, whether it is another cast-in-place anchor or a different type of anchor. For example, for 4 bolts in a line, the interior bolts would be subject to 2 reductions, while the exterior bolts would be subject to only 1 reduction.

Note that if there are 5 or more cast-in-place anchors in a cluster which are spaced closer together than the minimum (S_{min}) as defined in Table C.3-1, then the pullout capacity reduction factor (RS_p) cannot be used; the anchors in that cluster should instead be identified as outliers.

$$P_{all} = P_{nom} \, RS_p$$

$$V_{all} = V_{nom} \, RS_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.3-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.3-1

RS_p = Pullout capacity reduction factors for closely spaced cast-in-place anchors

= 1.0 for $S \geq S_{min}$

= $\dfrac{A_{s,red}}{A_{s,nom}}$ $S < S_{min}$

= Outlier where there are 5 or more cast-in-place anchors in a cluster in which $S < S_{min}$

S = Spacing from the bolt being evaluated to an adjacent bolt measured center-to-center

S_{min} = Minimum spacing to develop full pullout strength from Table C.3-1

$A_{s,nom}$ = Nominal projected area of the nonoverlapping shear cone of a single bolt located at the minimum spacing distance (S_{min}) from Table C.3-2. The values of $A_{s,nom}$ given in Table C.3-2 are about 13 percent less than the full, geometric shear cone projected area.

$A_{s,red}$ = Reduced projected area of the nonoverlapping shear cone of a single bolt located less than the minimum spacing (S_{min}) from another bolt. The values of A_{red} are calculated from the following equation:

$$= \pi r^2 - \frac{1}{2}\left[r^2\,\theta - r\,S\,\sin\left(\frac{\theta}{2}\right)\right]$$

$$r = \frac{2L + D}{2}$$

$$\theta = 2\cos^{-1}\left[\frac{S}{2L + D}\right]$$

S = Spacing between bolt being evaluated and adjacent bolt measured center-to-center

L = Length of embedment of bolt being evaluated

D = Diameter of anchor bolt/stud

RS_s = Shear capacity reduction factor for closely spaced cast-in-place anchors

= 1.0 for $S \geq 2D$

= 0.5 for $S < 2D$

Table C.3-2
Nonoverlapping Projected Shear Cone Areas for Bolts Meeting Minimum Spacing Requirements

Bolt Diameter (D, in.)	Nonoverlapping Shear Cone Area ($A_{s,nom}$, in.^{2})
3/8	41.9
1/2	74.1
5/8	116.0
3/4	167.4
7/8	227.2
1	297.3
1-1/8	376.7
1-1/4	464.1
1-3/8	562.2

C.3.4 Edge Distance Check

If the distance (E) from a cast-in-place bolt or a headed stud to a free edge of concrete is less than the minimum value (E_{min}), given in Table C.3-1, then a pullout capacity reduction factor (RE_p) and a shear capacity reduction factor (RE_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}), given in Table C.3-1, to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows. A reduction factor should be applied for each nearby edge; e.g., if an anchor is near a corner, then two reduction factors apply.

$$P_{all} = P_{nom} RE_p$$
$$V_{all} = V_{nom} RE_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.3-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.3-1

RE_p = Pullout capacity reduction factor near edge cast-in-place bolts and headed studs

= 1.0 for $E \geq E_{min}$

= $\dfrac{A_{e,red}}{A_{e,nom}}$ for $E_{min} > E \geq 4D$

= Outlier for $E < 4D$

E = Edge distance from centerline of anchor to free edge

E_{min} = Minimum edge distance to develop full pullout capacity from Table C.3-1

D = Diameter of anchor bolt/stud

$A_{e,nom}$= Nominal projected shear cone area of a bolt which is located away from a free concrete edge at least the minimum edge distance (E_{min}) given in Table C.3-1.

= $0.96\ \dfrac{\pi}{4}\ (2L + D)^2$

L = Length of embedment of bolt being evaluated

$A_{e,red}$ = Reduced projected shear cone area of a bolt located at less than the minimum edge distance from a concrete edge

= $\pi r^2 - \dfrac{1}{2}\left[r^2\,\theta - 2r\ E\ \sin\left(\dfrac{\theta}{2}\right)\right]$

θ = $2\cos^{-1}\left[\dfrac{2E}{2L + D}\right]$

r = $\dfrac{2L + D}{2}$

RE_s = Shear capacity reduction factor for near edge cast-in-place bolts and headed studs

= 1.0 for $E \geq 8.75D$

= $0.0131\left[\dfrac{E}{D}\right]^2$ for $8.75D > E \geq 4D$

= Outlier for $E < 4D$

C.3.5 Concrete Strength Check

If the concrete compressive strength (f'_c) is less than 3500 psi, then a pullout capacity reduction factor (RF_p) and a shear capacity reduction factor (RF_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.3-1, to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) as follows:

$$P_{all} = P_{nom}\, RF_p$$

$$V_{all} = V_{nom}\, RF_s$$

Where:

P_{all}	=	Allowable pullout capacity of anchor	
P_{nom}	=	Nominal pullout capacity of anchor from Table C.3-1	
V_{all}	=	Allowable shear capacity of anchor	
V_{nom}	=	Nominal shear capacity of anchor from Table C.3-1	
$RF_p = RF_s$	=	Pullout (p) and shear (s) capacity reduction factors for cast-in-place bolts and headed studs in low strength concrete	
	=	1.0	for $f'_c \geq 3500$ psi
	=	$\sqrt{\dfrac{f'_c}{3500}}$	for 3500 psi $> f'_c \geq 2500$ psi
	=	Outlier	for $f'_c < 2500$ psi
f'_c	=	Concrete compressive strength (psi)	

C.3.6 Check for Concrete Cracks

If there are significant structural cracks in the concrete where the cast-in-place bolts and headed studs are installed, then a pullout capacity reduction factor (RC_p) should be multiplied by the nominal pullout capacity (P_{nom}) given in Table C.3-1 to obtain the allowable pullout capacity (P_{all}) as follows. The shear capacity of the cast-in-place bolts and headed stud anchors is not significantly affected by cracks in the concrete.

The pullout capacity reduction factor applies only to significant structural cracks which penetrate the concrete mass and pass through the vicinity of the anchor installation. Concrete with surface (craze) cracks or shrinkage cracks which only affect the surface of the concrete should be considered uncracked. It may be necessary to exercise judgment to establish whether cracks in the vicinity of an anchor actually pass through the installation. Inspections for crack width should be visual (i.e., detailed measurement of crack widths is not necessary).

$$P_{all} = P_{nom} RC_p$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.3-1

RC_p = Pullout capacity reduction factor for cast-in-place anchors in cracked concrete

= 1.0 for no cracks and for $CS < 0.01$ in.

= $1.08 - 8\ CS$ for $0.01 \text{ in.} \leq CS \leq 0.06$ in.

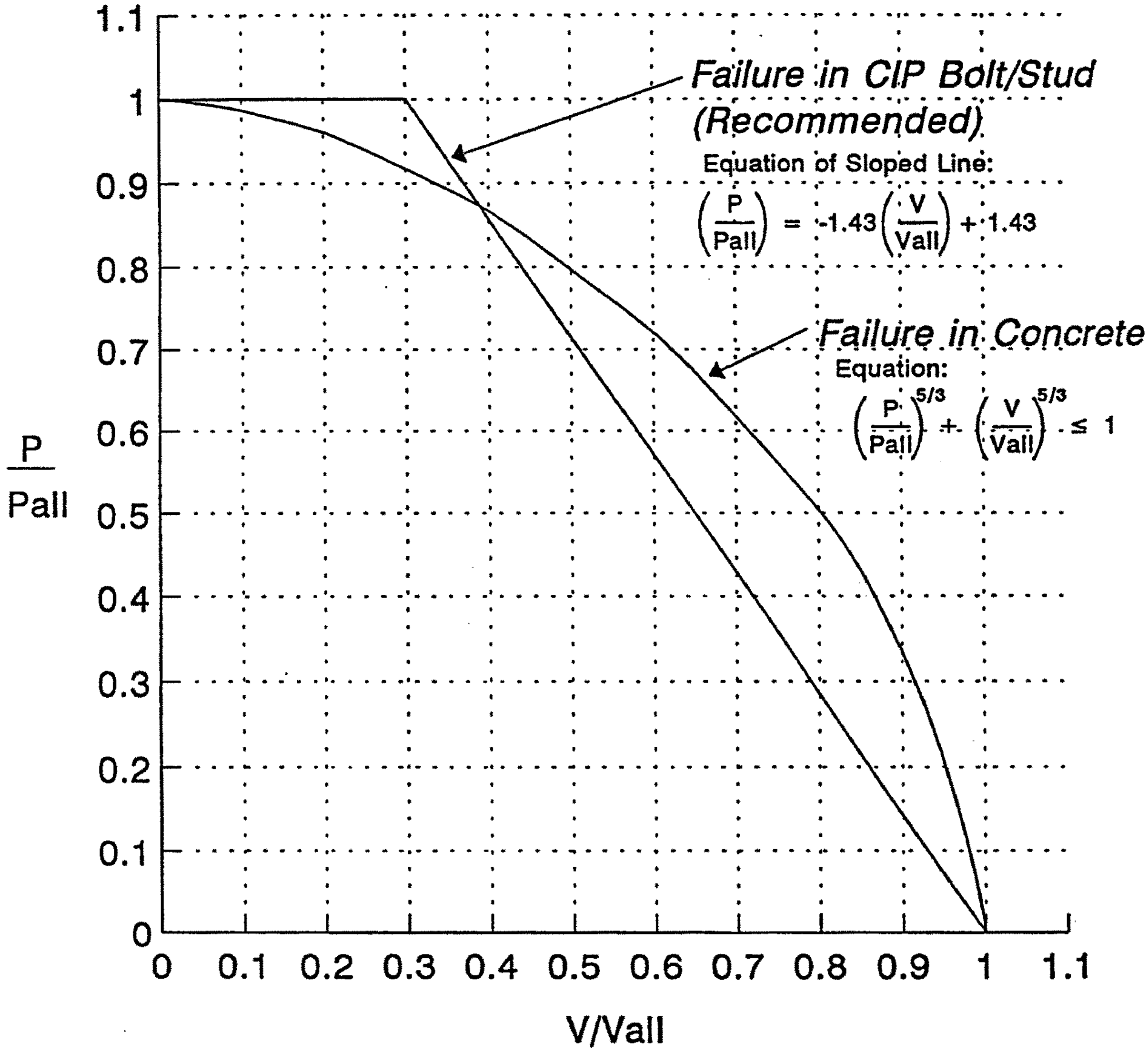
= Outlier for $CS > 0.06$ in.

CS = Crack size (approximate size based on visual observation)

C.3.7 Shear-Tension Interaction

For existing cast-in-place bolts subjected to simultaneous shear and tension, the shear-tension interaction depends on the anticipated failure mode. Figure C.3-2 presents the interaction curves for cast-in-place bolts for failure in the bolt steel or failure in the concrete. Since the anchorage criteria in this procedure (and Reference 7) for cast-in-place bolts, and headed studs ensure that failure does not occur in the concrete, it is recommended that the interaction formulation for steel failure be used, i.e., the bi-linear shear-tension curve shown in Figure C.3-2.

S/T CIP (GIP-3)



V/Vall	0.0	0.1	0.3	0.5	0.7	0.9	1.0
P/Pall - CIP Bolt/Stud	1.0	1.0	1.0	.71	.43	.14	0.0
P/Pall - Concrete	1.0	.99	.92	.80	.62	.33	0.0

Figure C.3-2. Shear-Tension Interaction Limitations for Cast-In-Place Bolts and Headed Studs (Source: Reference 7)

C.4 CAST-IN-PLACE J-BOLTS

The term J-Bolt refers to a plain steel bar with a hook formed at the embedded end, and threaded at the other end. A typical J-bolt is shown in Figure C.4-1. The following topics are covered in this section of the appendix. The [2]subsection number of each of these topics is also given.

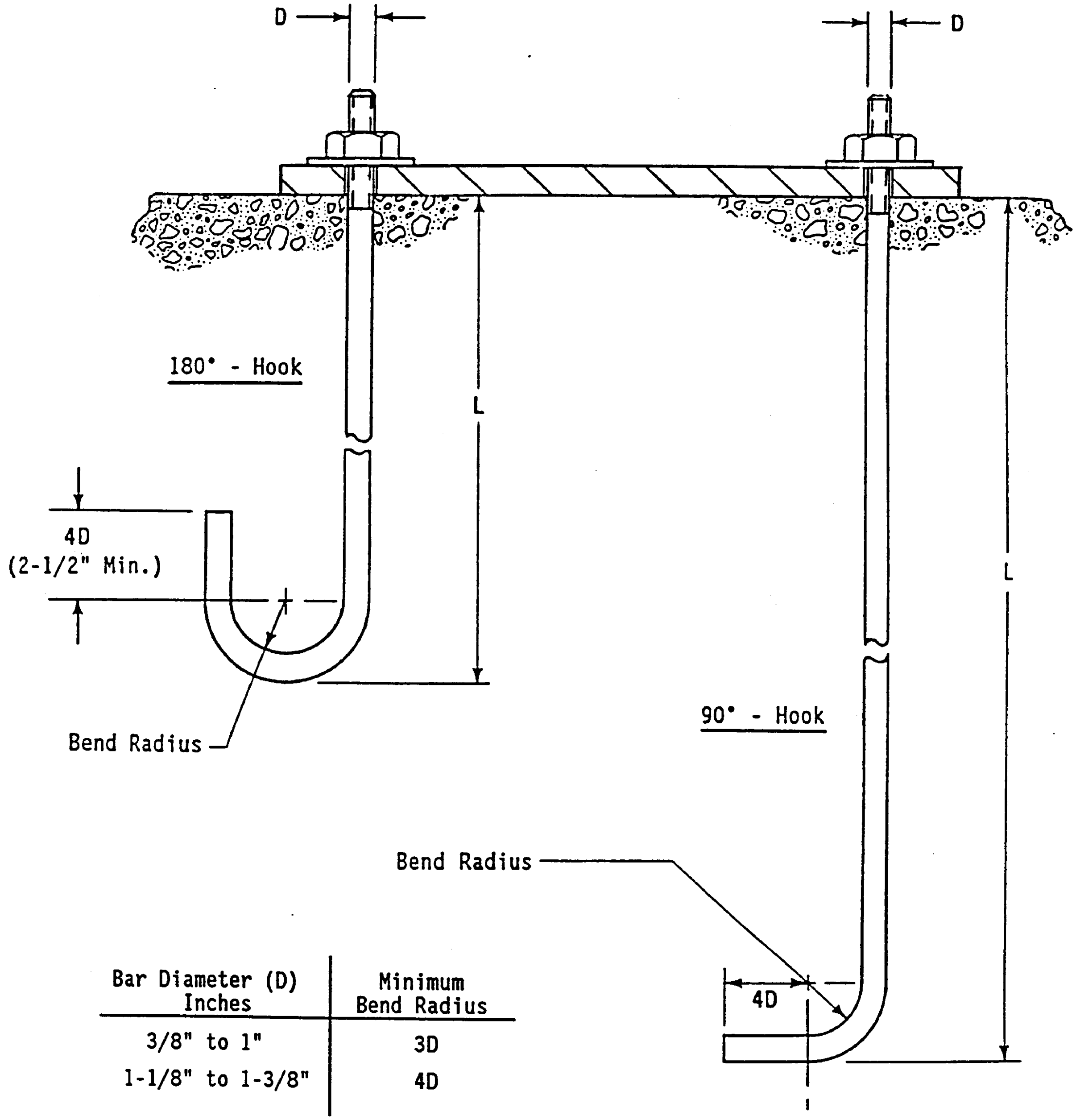
C.4.1	Nominal Allowable Capacities
C.4.2	Embedment Check
C.4.3	Spacing Check
C.4.4	Edge Distance Check
C.4.5	Concrete Strength Check
C.4.6	Check for Concrete Cracks

The specific checks described in this section should be performed in conjunction with the generic anchorage installation inspection checks described in Section 4.4.1. (See Table 4-2 for the checks which are applicable for this anchor type.)

The nominal allowable capacities and capacity reduction factors provided in this section should be used in the anchorage capacity equations given in Section 4.4.2.

C.4.1 Nominal Allowable Capacities

The nominal allowable load capacities which can be used for cast-in-place J-bolts are listed in Table C.4-1, below. An embedded bar can be considered as a J-bolt only if it has a hook on the embedded end meeting the minimum dimensions shown in Figure C.4-1.



Bar Diameter (D) Inches	Minimum Bend Radius
3/8" to 1"	3D
1-1/8" to 1-3/8"	4D

Figure C.4-1. Typical J-Bolt Installations
(Source: Reference 7)

Table C.4-1
Nominal Allowable Capacities for J-Bolts Cast-In-Place
($f'_c \geq 3500$ psi)[1]

Bar Diameter (D, in.)	Pullout Capacity (P_{nom}, kip)	Shear Capacity (V_{nom}, kip)	Minimum Embedment[2] (L_{min}, in.) 180° Hook	90° Hook	Minimum Spacing[3] (S_{min}, in.)	Min. Edge Distance[3] (E_{min}, in.)
3/8	3.74	1.87	16	20-1/2	1-1/8	3-3/8
1/2	6.66	3.33	21-1/4	27-1/4	1-1/2	4-3/8
5/8	10.44	5.22	26-5/8	34-1/8	1-7/8	5-1/2
3/4	15.03	7.51	31-7/8	40-7/8	2-1/4	6-5/8
7/8	20.44	10.22	37-1/4	47-3/4	2-5/8	7-3/4
1	26.69	13.35	42-1/2	54-1/2	3	8-3/4
1-1/8	33.80	16.90	47-7/8	61-3/8	3-3/8	9-7/8
1-1/4	41.72	20.86	53-1/8	68-1/3	3-3/4	11
1-3/8	50.40	25.25	58-1/2	75	4-1/8	12-1/8

Notes:

1. The pullout and shear capacities shown here are from J-Bolts installed in sound, uncracked concrete with a compressive strength (f'_c) of al least 3500 psi.
2. Embedment length is defined in Figure C.4-1.
3. Spacing and edge distance are measured from the center of the bolt(s).

C.4.2 Embedment Check

The nominal pullout capacities (P_{nom}) given in Table C.4-1 are based on the assumption that the embedded length is at least as long as the minimum embedment lengths (L_{min}) given in Table C.4-1.

If the embedment length (L) is less than the minimum value (L_{min}), then a pullout capacity reduction factor (RL_p) should be multiplied by the nominal pullout capacity (P_{nom}) to obtain the allowable pullout capacity (P_{all}). A capacity reduction factor for shear is not needed since J-bolts develop their full shear strength even when the embedment is so small that the J-bolt becomes an outlier due to insufficient embedment for pullout (at L = 16D).

$$P_{all} = P_{nom}\, RL_p$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.4-1

RL_p = Pullout capacity reduction factor for cast-in-place J-bolts

$= 1.0$ for $L \geq L_{min}$

$= \dfrac{L + 20D}{62.5D}$ for 180° hook when $L_{min} > L \geq 16D$

$= \dfrac{L + 8D}{62.5D}$ for 90° hook when $L_{min} > L \geq 16D$

= Outlier for $L < 16D$

L = Length of J-Bolt embedment per Figure C.4-1 (in.)

L_{min} = Minimum length of J-Bolt embedment from Table C.4-1

D = Rod diameter (in.)

C.4.3 Spacing Check

The nominal shear capacities (V_{nom}) for J-bolts given in Table C.4-1 are based on a minimum spacing of 3D, where D is the diameter of the J-bolt.

For spacings less than 3D, the J-bolt is an outlier.

C.4.4 Edge Distance Check

The minimum edge distances given in Table C.4-1 for J-bolts are the same as those for cast-in-place bolts and headed studs. Likewise the capacity reduction factors for J-bolts installed near an edge are also the same as discussed in Section C.3.4 for cast-in-place bolts and headed studs.

C.4.5 Concrete Strength Check

If the concrete compressive strength (f'_c) is less than 3500 psi, then a pullout capacity reduction factor (RF_p) and a shear capacity reduction factor (RF_s) should be multiplied by the nominal pullout and shear capacities (P_{nom}, V_{nom}) given in Table C.4-1, to obtain the allowable pullout and shear capacities (P_{all}, V_{all}) for J-bolts.

$$P_{all} = P_{nom}\, RF_p$$

$$V_{all} = V_{nom}\, RF_s$$

Where:

P_{all} = Allowable pullout capacity of anchor

P_{nom} = Nominal pullout capacity of anchor from Table C.4-1

V_{all} = Allowable shear capacity of anchor

V_{nom} = Nominal shear capacity of anchor from Table C.4-1

$RF_p = RF_s$ = Pullout (p) and shear (s) capacity reduction factors for J-bolts in low strength concrete

= 1.0 for $f'_c \geq 3500$ psi

= $\sqrt{\frac{f'_c}{3500}}$ for $2500 \text{ psi} \leq f'_c < 3500$ psi

= Outlier for $f'_c < 2500$ psi

f'_c = Concrete compressive strength (psi)

C.4.6 Check for Concrete Cracks

The areas adjacent to J-bolt installations should be inspected for significant structural cracks which penetrate the concrete mass. Concrete with surface (craze) cracks or shrinkage cracks which only affect the surface of the concrete should be considered uncracked. Inspections for crack width should be visual (i.e., detailed measurement of crack widths is not necessary). J-bolts should be classified as outliers when either of the following two crack sizes are exceeded:

- When cracks are larger than about 0.02 inch wide and traverse through the J-bolt installation, or
- When cracks are larger than about 0.05 inches wide and exist near the J-bolt installation.

C.4.7 Shear-Tension Interaction

It is left to the user to select an appropriate shear-tension interaction formulation for use with J-bolts when both tension and shear loads are significant.

C.5 GROUTED-IN-PLACE BOLTS

The topics covered in this section of the appendix for grouted-in-place bolts are as follows. The [2]subsection number of each of these topics is also given.

The specific checks described in this section should be performed in conjunction with the generic anchorage installation inspection checks described in Section 4.4.1. (See Table 4-2 for the checks which are applicable for this anchor type.)

The nominal allowable capacities and capacity reduction factors provided in this section should be used in the anchorage capacity equations given in Section 4.4.2.

C.5.1 Nominal Allowable Capacities

The nominal allowable pullout and shear capacities which can be used for grouted-in-place bolts are listed in Table C.5-1, below. Note that the values in this table are identical to those in Table C.3-1 for cast-in-place bolts and headed studs except that the pullout capacities (P_{nom}) are reduced by a factor of 10. This was done since the pullout capacity of grouted-in-place bolts is significantly affected by the method of installation. Since documentation of the method used to install grouted-in-place bolts often is not available, the pullout capacities given in the table below are reduced significantly.

However, if the bolts were installed using effective installation procedures similar to those in Reference 28, then the pullout capacities of this grouted-in-place bolts may be taken to be the same as for cast-in-place bolts (i.e., use the capacities given in Table C.3-1). Some of the installation techniques used in Reference 28 include such things as thorough cleansing of the concrete hole, acid etching of the concrete hole to roughen the surfaces, and use of grout which expands while it is curing.

Table C.5-1
Nominal Allowable Capacities for Grouted-In-Place Bolts
($f'_c \geq 3500$ psi)[1]

Bolt/Stud Diameter (D, in.)	Pullout Capacity[2] (P_{nom}, kip)	Shear Capacity (V_{nom}, kip)	Minimum Embedment[3] (L_{min}, in.)	Minimum Spacing[4] (S_{min}, in.)	Min. Edge Distance[4] (E_{min}, in.)
3/8	0.37	1.87	3-3/4	4-3/4	3-3/8
1/2	0.67	3.33	5	6-1/4	4-3/8
5/8	1.04	5.22	6-1/4	7-7/8	5-1/2
3/4	1.50	7.51	7-1/2	9-1/2	6-5/8
7/8	2.04	10.22	8-3/4	11	7-3/4
1	2.67	13.35	10	12-5/8	8-3/4
1-1/8	3.38	16.90	11-1/4	14-1/4	9-7/8
1-1/4	4.17	20.86	12-1/2	15-3/4	11
1-3/8	5.04	25.25	13-3/4	17-3/8	12-1/8

Notes:

1. The pullout and shear capacities shown here are for ASTM A-307 or equivalent strength bolts installed in sound, uncracked concrete (i.e., no cracks passing through the anchor bolt installation) with a compressive strength of 3500 psi or greater. For bolt capacities in lower strength concrete see Section C.3.5. For bolt capacities in cracked concrete see Section C.3.6.
2. The pullout capacities (P_{nom}) are based on not having used special installation practices (or not knowing whether such practices were used). However, if installation procedures similar to those in Reference 28 were used, then the pullout capacities for cast-in-place bolts (Table C.3-1) can be used in place of the values in this table.
3. See Figure C.3-1 for definition of embedment length (L). Smaller embedments than the minimum given here can be used with the reduction factor given in Section C.3.2.
4. Minimum spacings and edge distances are measured from bolt center to bolt center or concrete edge. Spacings and edge distances less than the minimums given here can be used with the reduction factors given in Sections C.3.3 and C.3.4.

C.5.2 Embedment, Spacing, and Edge Distance Checks

For grouted-in-place bolts having embedments, spacings, and/or edge distances which are less than the minimum values given in Table C.5-1, the capacity reduction factors given in Sections C.3.2, C.3.3, and C.3.4 for cast-in-place bolts may be used to reduce the nominal pullout and shear capacities given in Table C.5-1.

C.5.3 Checks for Concrete Strength and Cracks in Concrete

When grouted-in-place bolts are installed in concrete which has a compressive strength of $f'_c \leq 3500$ psi, the capacity reduction factors given in Section C.3.5 for cast-in-place bolts may be used to reduce the nominal pullout and shear capacities given in Table C.5-1.

If there are significant structural cracks in the concrete where the grouted-in-place bolts are installed, then the pullout capacity reduction factors given in Section C.3.6 for cast-in-place bolts may be used to reduce the nominal pullout capacities given in Table C.5-1.

C.5.4 Shear-Tension Interaction

For grouted-in-place bolts subjected to simultaneous shear and tension, the guidelines given in Section C.3.7 for cast-in-place bolts may be used to compare the allowable loads to the applied loads.

C.6 WELDS TO EMBEDDED OR EXPOSED STEEL

Equipment at nuclear plants [2]is often anchored by welds to steel plates or channels which are embedded in concrete (see Figure C.3-l.b). The strength of such an anchorage depends on the weld of the equipment to the steel and the shear and pullout resistance of the headed stud that anchors the steel into the concrete. The following topics are covered in this section of the appendix. The [2]subsection number of each of these topics is also given.

The specific checks described in this section should be performed in conjunction with the generic anchorage installation inspection checks described in Section 4.4.1. (See Table 4-2 for the checks which are applicable for welds.)

C.6.1 Allowable Loads for Typical Welds

The allowable loads for typical welds made with E60 electrodes are listed in Table C.6-1, below. These allowable loads are based on a weld stress allowable of 30,600 psi.

Table C.6-1
Allowable Capacities for Typical Welds
(E60 Electrodes)

Weld Sizes t (in.)	L (in.)	Throat Area (A = .707 t L) ($in.^2$)	Allowable F_w (kips)
1/8	1/2	0.0442	1.35
1/8	3/4	0.0663	2.03
1/8	1	0.0884	2.70
3/16	1/4	0.0331	1.01
3/16	1/2	0.0663	2.03
3/16	3/4	0.0994	3.04
3/16	1	0.1326	4.06
1/4	1/4	0.0442	1.35
1/4	1/2	0.0884	2.70
1/4	3/4	0.1326	4.06
1/4	1	0.1768	5.41

Where: t = Thickness of the weld leg
L = Length of the weld
A = Cross-sectional area through the throat of the weld
= 0.707 t L
F_w = Allowable load capacity of weld

C.6.2 Summary of Equivalent Weld Sizes

A summary of equivalent weld sizes which have the same capacity as other types of fasteners is shown in Table C.6-2, below.

Table C.6-2
Summary of Equivalent Weld Sizes

Welds		Equivalent Bolt Diameter (D, in.)	
Typical Size (L x t, in.)	**Throat Area ($in.^2$)**	**Expansion Anchor Bolts**	**Cast-in-Place Anchor Bolts**
1/2 x 1/8	0.0442	3/8	---
1 x 1/8	0.0884	1/2	---
1 x 3/16	0.1326	3/4	3/8
1 x 1/4	0.1768	3/4	3/8
2 x 3/16	0.2651	7/8	1/2
2 x 1/4	0.3535	1	5/8
2 x 3/8	0.5305	---	3/4

C.6.3 Weld Check

The welds used for anchoring equipment to embedded or exposed steel should be inspected in the following areas:

- Determine the overall length (L) and thickness (t) of the welds. The weld thickness should be limited to the thinnest part of either the weld itself or the connecting part.
- Check for weld burn-through on cabinets made of thin material.
- Check for weld quality, particularly in puddle welds which carry high tension loads.
- The minimum effective length of fillet welds should not be less than 4 times the nominal size of the weld, or else the size of the weld should be considered not to exceed l/4 of its effective length.

C.6.4 Shear-Tension Interaction for Welds

When welds are subjected to simultaneous shear and tension, the allowable loads can be compared to the applied loads using the following shear- tension interaction formulation:

$$\left(\frac{P}{F_w}\right)^2 + \left(\frac{V}{F_w}\right)^2 \leq 1$$

Where:

P	=	Pullout (tensile) load applied to weld [kip]
V	=	Shear load applied to weld [kip]
F_w	=	Allowable load for weld from Table C.6-1 [kip]

C.6.5 Embedded or Exposed Steel Check

The embedded steel or the exposed steel to which the equipment is anchored by the weld should be evaluated to determine whether it has the capacity to carry the loads applied to it.

The allowable stresses from Part 2 of the AISC code (Reference 29) may be used for evaluating the adequacy of exposed steel and the structural members of an embedded steel assembly. The guidelines given in Section C.3 of this appendix can be used for evaluating the cast-in-place bolts and headed studs which are a part of the embedded steel assembly.

REASONS FOR CHANGES TO GIP, PART II, APPENDIX C

Listed below are the specific reasons for making the changes marked with a vertical line in the margin of this appendix to create GIP-3A from GIP-3, Updated 5/16/97. The endnote numbers listed below correspond to the bracketed numbers (e.g., [1]) located in the text of this appendix where the changes are made.

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[1] SSER No. 2, Sec. II.4.4.7 – The Staff concurred with the GIP statement in Part I, Section 2.3.4 that the factor of safety currently recommended for new nuclear plants should be used for new installations and newly designed anchorages in modifications or replacements instead of those contained in the GIP for resolution of USI A-46. However, the Staff provided alternative language to describe this requirement.

The GIP has been edited in Part I, Section 2.3.4 to incorporate the alternative Staff language. Part II, Section 4.4.2 and Appendix C have also been amended to include a paragraph reminding the licensee of this requirement.

[2] Typographical error corrected.