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Contributor: R. Masopust

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IAEA
Engineering Safety Section,
Division of Nuclear Installation Safety
Wagramer Strasse 5, P.O. box 100,
A-1400 Vienna, Austria

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Prepared by:

STEVENSON AND ASSOCIATES
Office in Czech Republic
Lábkova 8/34
318 06 Pilsen
Czech Republic

GUIDELINES FOR EVALUATION OF ANCHORAGE ADEQUACY FOR SAFETY-RELATED EQUIPMENT TYPICALLY USED ON VVER-TYPE NPPs

Prepared by: Rudolf Masopust

Checked by: Petr Zeman

Approved by: Rudolf Masopust

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1. INTRODUCTION

Regarding to the main document [1] this report gives the criteria which should be met when the capacity evaluation of anchorage of safety-related equipment is performed for the VVER-type NPPs. It should be noted that these criteria have been developed specifically for anchorage of VVER-type equipment components to the concrete and also to the steel building structures and they cover different types of anchor bolts and other anchorage details which are typical just for existing, constructed, or reconstructed VVER-type NPPs.

Lack of anchorage or inadequate anchorage has been a significant cause of equipment failing to function properly during and after past earthquakes. Real earthquakes have demonstrated that equipment components can slide, overturn, or move excessively when not properly anchored [2,3].

The screening approach for verifying of equipment anchorage presented in this report is based upon a combination of inspections, calculations, and engineering judgment. Inspections consist of measurements and visual evaluations of the equipment and its anchorage, supplemented by use of plant documentation and drawings. Calculations should be performed to compare the anchorage capacity to the corresponding loadings (demand) imposed upon the anchorage. Engineering judgment is also an important part in the evaluation of equipment anchorage.

There are various combinations of inspections, calculations, and engineering judgement which can be used to verify the adequacy of equipment anchorage. The responsible engineer should select the appropriate combination of elements for an each anchorage installation based on the information available. For example, a simple hand calculation may be sufficient for a pump which has only a few and very rugged anchor bolts in a symmetrical pattern. On the other hand, at times it may be advisable to use an equipment anchorage computer codes to determine the loads applied to multi-cabinet equipment particularly if its anchorage is not symmetrically located.

Generally, the four main steps of evaluation the adequacy of equipment anchorage include:

- anchorage installation inspection,
- anchorage capacity determination,
- anchorage demand determination,
- comparison of capacity to demand.

It is not necessary to perform the above steps in the order given. Trade-offs between different alternative approaches could affect the order in which these steps as performed.

The main types of anchorage typically used for VVER-type equipment are summarized in Table 1. This report is based on a number of already published and public available documents [3,4,5,6,7,8] and also on a number of test data and engineering experience.

Table 1 The Main Types of Anchorage Typically Used for VVER-Type Satety-Related Equipment

Anchorage Type	Description of Anchorage	Figure
Anchorage to Concrete Structures	Cast-in-Place J-Shaped Anchor Bolts	1
	Cast-in-Place Headed Anchor Bolts	2
	J-Shaped Anchor Bolts Grouted by Concrete in Beforehand Made Large Size Holes	3
	Anchor Bolts Grouted in Drilled-in-Place Small Size Holes	4
	Expansion Anchor Bolts	5
	Other Special Anchor Bolts	6,7
	Weld Connections to Steel Members with Studs Embedded into the Concrete Structure	8
Anchorage to Steel Structures	Weld and Bolt Connections to the Steel Structure	

Notes:

1) In-place testing of the pullout capacity of these anchor bolts is recommended when there are some doubts relating to the quality of their grouting.

2) Generally any expansion bolts are less suitable when loaded by intensive pulsating or alternating loads with a large number of repetitions. Therefore these bolts are recommended essentially for anchorage of such equipment which is subjected during normal operation conditions rather only to static or almost static loads.

3) Any fixation of equipment items to the liner is allowed only in those locations which are specified in the design including the allowable loadings.

4) Other types of anchorage can be also used under the condition that their capacity parameters (nominal capacities and reduction factors) are reliably documented. Such „non-standard“ types of anchorage are typically used for anchorage of light safety-related equipment items the mass of which is less than 100 kg.

2. ANCHORAGE INSTALLATION INSPECTION

The first main step in evaluating the seismic adequacy of anchorages is to check the anchorage installation and its connection to the base of the equipment. This inspection consists of visual checks and measurements along with a review of plant documentation and drawings where necessary and available.

All accessible anchorages should be visually inspected. Inaccessible anchorages not required for strength to secure the equipment item need not be inspected. Table 2 summarizes the checks which should be made for various types of anchorage. General guidelines for performing these checks are provided in the expert system GIP-VVER [9]. Engineering judgment is often used when performing these checks.

Table 2 Anchorage Installation Checks

Checked Attributes	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1. Equipment Characteristics [a]	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M
2. Type of Anchorage [b]	V,D	V,D	V,D	V,D	V,D	V,D	V,D	V,D
3. Size & Location of Anchorage	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M
4. Installation Adequacy [c]	V,M	V,M	V,M	V,M	V,M	V,M	V	V
5. Embedment Length [d]	D,M	D,M	D,M	D,M	D,M	D	-	-
6. Gap at Bolt Anchors [e]	V	V	V	V	V	V	-	-
7. Spacing Between Anchors [f]	D,M	D,M	D,M	D,M	D,M	D,M	-	-
8. Edge Distance [g]	D,M	D,M	D,M	D,M	D,M	D,M	-	-
9. Quality of Concrete [h]	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V	-
10. Cracks in Concrete [i]	V	V	V	V	V	V	V	-
11. Essential Relays in Cabinet [j]	-	-	-	-	D	-	-	-
12. Base Stiffness & Prying [k]	V	V	V	V	V	V	V	V
13. Base Strength & Load Path [l]	V	V	V	V	V	V	V	V
14. Embedment Steel and Pads [m]	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	V,D,M	-
15. Welds to Embedded/Exposed Steel [n]	-	-	-	-	-	-	-	V,D,M

Notes:

(1) Cast-in-Place J-Shaped Anchor Bolts
(2) Cast-in-Place Headed Anchor Bolts
(3) J-Shaped Anchor Bolts Grouted by Concrete in Beforehand Made Large Size Holes
(4) Anchor Bolts Grouted in Drilled-in-Place Small Size Holes
(5) Expansion Anchor Bolts
(6) Other Special Anchor Bolts
(7) Weld Connections to Steel Members Embedded in the Concrete Building Structures
(8) Weld and Bolt Connections to Steel Building Structures

V = visual
D = documentation and drawing review
M = measurement

(a) Typical equipment characteristics in relation to its anchorage are:

- mass,
- center of gravity,
- lowest natural frequency,
- equipment damping,
- equipment base overturning moment center of rotation.

(b) See Table 1.

(c) The checks should be made are:

- a visual check whether the bolt and nut is in place and uses a washer where necessary (lock washers are recommended where even low level vibration exists),
- a tightness check for expansion anchors to detect gross installation defects (see also Table 3),

(d) The embedment length of an anchor should be checked to confirm that it meets the minimum value as specified in the next section so that nominal allowable anchor capacities can be used. Capacity reduction factors can be applied to the nominal allowable capacities for certain types of anchors with less embedment.

It is not necessary to perform an embedment length check of expansion anchor bolts if the anchorage of the equipment is robus. The embedment length for anchot types other than expansion anchor bolts can be determined from installation drawings, by ultrasonic testing, or by other appropriate means.

(e) The size of the gap between the base of the equipment and the surface of the concrete should be less than 5 mm in the vicinity of the anchors. This limitation is necessary to prevent excessive bending moments on the concrete anchorage when shear loads are applied. Anchorages with gaps larger than 5mm should be classified as outliers and evaluated in more detail. There should be no gap at the anchor bolt locations for equipment containing essential relays.

(f) The spacing from an each nearby anchor should be checked to confirm that it meets the minimum value as specified in the next section so that nominal allowable anchor capacities can be used. Capacity reduction factors can be used when the bolt-to-bolt spacings are less than the minimum specified values. These minimum spacings are for anchors with the minimum embedment. Greater spacings are necessary to develop the full pullout capacities of deeply embedded anchors if higher capacity values are used.

(g) The distance from an anchor to a free edge of concrete should be checked to confirm that it meets the minimum values as specified in the next section so that the nominal allowable anchor capacities can be used. Capacity reduction factors can be used for anchors which are closer to an edge than the minimum.

(h) The concrete compressive strength should be obtained from design documentation or field tests to confirm that it meets the specified minimum value as specified in the next section so that the nominal allowable anchor capacities can be used. Capacity reduction factors can be used for concrete which has lower strength than the minimum.

(i) The concrete should be checked to confirm that it is free of significant structural cracks in the vicinity of installed anchors as specified in the next section so that the nominal allowable pullout capacities of anchors can be used. Capacity reduction factors can be used for concrete which ha cracks larger than the acceptable maximum widths and are located in the vicinity of the anchor.

(j) Electrical cabinets and other equipment which are anchored by expansion anchor bolts should be checked to determine if they house essential relays. If essential relays are presented, a capacity reduction factor should be used for such equipment as specified in the next section.

(k) The base and anchorage load path of the equipment should be inspected to confirm that there is adequate stiffness and there is no significant prying action applied to anchors. One special case of base flexibility is a base isolation system.

Prying action can result from eccentric loads within the equipment itself and between the equipment and the anchors.

(l) The equipment base and structural load path should be checked to confirm that it has adequate strength to transmit the loads from the center of gravity of the equipment to the anchorage.

(m) If the equipment is welded to embedded steel or if it is mounted on a ground pad, the embedment steel and concrete pad should be checked. The location of welds should be such that large eccentric loads are not applied to the embedded steel. Equipment mounted on grout pads should be checked to confirm that the anchorages penetrate through the grout at into the structural concrete beneath. Anchorages installed only in the grout pad have failed in past earthquakes and do not have the capacity values assigned to anchors in structural concrete. If an item of equipment is anchored to a large concrete pedestal, the pedestal should have reinforcing steel and be of sound construction. The pedestal-floor interface should also be evaluated to determine whether it can transmit the loads.

(n) The strength of such an anchorage depends on the weld of the equipment to the steel and the pullout and shear resistance of the studs that anchor the steel into concrete. The following topics are important in such cases:

- allowable loads for typical welds,
- summary of equivalent weld sizes,
- weld check,
- tension-shear interaction for welds,
- embedded or exposed steel check.

Table 3 Recommended Checks of Anchorage by Measurement on Site

Purpose of Measurement on Site	Performance of Measurement	Recommended Period and Other Conditions
lowest natural frequency	using the vibration testing on site performed in horizontal and when necessary also in vertical direction	only if there is a reasonable suspicion that the lowest natural frequency of the equipment item cannot be correctly determined, and/or if the attachment of an equipment item to the building structure is not so rigid as assumed by the design,
embedment of anchor bolts	by the ultrasonic testing	only as an exception when other sources of information are not available,
tightness of anchor bolts	(a) the tightness of anchor bolts is checked usually by the moment wrench, (b) for expansion bolts the tight force is prescribed by their manufacturers, (c) for other anchor bolts the tight force should be about 60% of their pullout or tension capacity whichever governs	(a) for expansion bolts no checks necessary when the original tightness was made as maximum three years ago and if it is well documented, otherwise make the tightness check at least for three expansion bolts per each equipment item or per each support, (b) for other anchor bolts make this check only on the base of engineering judgment base, namely when there is a reasonable suspicious that the bolts are not properly tighted
concrete strength	using the Schmidt hammer or similar testing equipment	only if there is a reasonable suspicion that the quality of concrete cannot be correctly determined

3. ANCHORAGE CAPACITY DETERMINATION

3.1. General Considerations in Relation to Anchors (Bolts or Studs) Embedded into the Concrete Structure

The pullout (tension) capacity of the anchor (bolt or stud) should be determined as follows:

$$F_{a,all} = F_{a,nom}\ RL_F\ \{RS_F\}\ \{RE_F\} RB_F\ RC_F\ RR_F \quad (1)$$

where

$F_{a,nom}$ = nominal allowable pullout (tension) capacity of the anchor (bolt or stud),

RL_F = reduction factor for short embedment lengths,

RS_F = reduction factor for closely spaced anchors (bolts or studs),

RE_F = reduction factor for near concrete edge,

RB_F = reduction factor for low strength of concrete,

RC_F = reduction factor for cracked concrete,

RR_F = reduction factor for expansion anchors securing equipment with essential relays.

The shear capacity of the anchor bolt /stud should be determined as follows:

$$Q_{a,all} = Q_{a,nom}\ RL_Q\ \{RS_Q\}\ \{RE_Q\} RB_Q\ RC_Q\ RR_Q \quad (2)$$

where

$Q_{a,nom}$ = nominal allowable shear capacity of the anchor (bolt or stud),

RL_Q = reduction factor for short embedment lengths,

RS_Q = reduction factor for closely spaced anchors (bolts or studs),

RE_Q = reduction factor for near concrete edge,

RB_Q = reduction factor for low strength of concrete,

RR_Q = reduction factor for expansion anchors securing equipment with essential relays.

Brackets {} in equations (1) and (2) mean that the corresponding factor can be a product of several partial factors of the same type when the bolt / stud capacity is affected by more than one closely spaced bolts / studs or by more than one near concrete edge.

Note that the pullout (tension) and shear capacities are based on having adequate stiffness in the case of the equipment and on not applying significant prying action to the anchors, otherwise the nominal capacities of such anchors should be properly reduced.

3.2. Nominal Capacity Parameters and Reduction Factors of Cast-in-Place J-Shaped Anchor Bolts (Figure 1)

Table 4 Nominal Capacity Parameters of Cast-in-Place J-Shaped Anchor Bolts (Figure 1)

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kn.]	Nominal Shear Capacity [kn.]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
12	14.90	13.00	360	40	100
16	26.40	23.00	480	50	140
20	41.20	36.00	600	60	175
24	59.30	52.00	720	75	210
30	89.80	79.00	900	90	265

Note: Values in Table 4 have been determined for the following materials:

- steel of anchor bolts with the minimum yield limit $F_Y \geq 230$ MPa and with the tension strength $f_u \geq 350$ MPa [11],
- concrete with the characteristic cylindrical strength $f_{ck} \geq 20$ MPa [12].

Table 4 is valid for J-bolts with 180° hooks. It can be used also for J-bolts with only 90° hooks , but in these cases the minimum embedment lengths should be multiplied by a factor 1.3.

<u>Reduction Factors</u>:

- short embedment length

RL_F = 1.0 if $L \geq L_{min}$,

= L / L_{min} if $15D \leq L < L_{min}$,

= 0.0 if $L < 15D$,

RL_Q = 1.0 if $L \geq 15D$,

= $(L - 5D) / 10D$ if $5D \leq L < 15D$,

= 0.0 if $L < 15D$,

where

L	=	actual embedment length,
L_{min}	=	minimum embedment length (Table 4)
D	=	diameter of the anchor bolt,

- closely spaced bolts

RS_F	= 1.0	if	$S \geq S_{min}$,
	= 0.5	if	$S < S_{min}$,
RS_Q	= 1.0	if	$S \geq 2D$,
	= 0.5	if	$S < 2D$,

where

S	=	actual spacing,
S_{min}	=	minimum spacing (Table 4),
D	=	diameter of the anchor bolt,

- near concrete edge

$RE_F = RE_Q$	= 1.0	if	$E \geq E_{min}$,
	= $(E / E_{min})^2$	if	$4D \leq E < E_{min}$,
	= 0.0	if	$E < 4D$,

where

E	=	actual edge distance,
E_{min}	=	minimum edge distance,
D	=	diameter of the anchor bolt,

- low strength of concrete

$RB_F = RB_Q$	= 1.0	if	$f_{ck} \geq 20$ MPa,
	= $(f_{ck} / 20)^{1/2}$	if	12.5 MPa $\leq f_{ck} < 20$ MPa,
	= 0.0	if	$f < 12.5$ MPa,

where

f_{ck}	=	characteristic cylindrical strength of the concrete [12],

- cracked concrete

RC_F = 1.0 if $w < 0.30$ mm,

= 1.10 - 0.33 w if $0.30 \text{ mm} \leq w \leq 1.50$ mm,

= 0.0 if $w > 1.50$ mm,

where

w = width of the concrete cracks visually observed near to the anchor bolt during the walkdown.

3.3. Nominal Capacity Parameters and Reduction Factors of Cast-in-Place Headed Anchor Bolts (Figure 2)

Table 5 Nominal Capacity Parameters of Cast-in-Place Headed Anchor Bolts

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
20	41.20	36.00	260	260	175
24	59.30	52.00	310	310	210
30	89.80	79.00	360	360	265
36	138.00	120.50	440	440	330
42	193.00	168.90	550	550	410
48	257.00	225.00	660	660	500

Note: Values in Table 5 have been determined for the following materials:

- steel of anchor bolts with the minimum yield limit $f_y \geq 230$ MPa and with the tension strength $f_u \geq 350$ MPa [11],
- concrete with the characteristic cylindrical strength $f_{ck} \geq 20$ MPa [12].

<u>Reduction Factors</u>:

- short embedment length

RL_F = RL_Q = 1.0 if $L \geq L_{min}$,

$$= \frac{(L + D)\,L}{(L_{min} + D)\,L_{min}} \quad \text{if } 5D \leq L < L_{min},$$

= 0.0 if $L < 5D$,

where

L	=	actual embedment length,
L_{min}	=	minimum embedment length (Table 5)
D	=	diameter of the anchor bolt,

- closely spaced bolts

RS_F	= 1.0		if $S \geq S_{min}$,
	= $(1 + S / S_{min}) / 2$		if $S < S_{min}$,
	= 0.0		for anchor bolts located from four and more closely spaced anchor bolts less than $0.7 \times S_{min}$,
RS_Q	= 1.0	if	$S \geq 3D$,
	= 0.5	if	$S < 3D$,

where

S	=	actual spacing,
S_{min}	=	minimum spacing (Table 5),
D	=	diameter of the anchor bolt,

- near concrete edge

RE_F = RE_Q	=	1.0	if	$E \geq E_{min}$,
	=	$(E / E_{min})^2$	if	$4D \leq E < E_{min}$,
	=	0.0	if	$E < 4D$,

where

E	=	actual edge distance,
E_{min}	=	minimum edge distance (Table 5),
D	=	diameter of the anchor bolt,

- low strength of concrete

RB_F = RB_Q	=	1.0	if	$f_{ck} \geq 20$ MPa,
	=	$(f_{ck} / 20)^{1/2}$	if	$12.5 \text{ MPa} \leq f_{ck} < 20$ MPa,
	=	0.0	if	$f < 12.5$ MPa,

where

f_{ck}	=	characteristic cylindrical strength of the concrete [12],

- cracked concrete

RC_F = 1.0 if w < 0.30 mm,
= 1.10 - 0.33 w if 0.30 mm ≤ w ≤ 1.50 mm,
= 0.0 if w > 1.50 mm,

where

w = width of the concrete cracks visually observed near to the anchor bolt during the walkdown.

3.4. Nominal Capacity Parameters and Reduction Factors of J-Shaped Anchor Bolts Grouted by Concrete in Beforehand Made Large Size Holes (Figure 3)

Table 6 Nominal Capacity Parameters of J-Shaped Anchor Bolts Grouted by Concrete in Beforehand Made Large Size Holes

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
12	7.50	13.00	500	150	100
16	13.20	23.00	670	200	140
20	20.60	36.00	850	250	175
24	29.70	52.00	1000	300	210
30	44.90	79.00	1260	375	265

Note: Values in Table 6 have been determined for the following materials:

- steel of anchor bolts with the minimum yield limit $f_y \geq 230$ MPa and with the tension strength $f_u \geq 350$ MPa [11],
- concrete with the characteristic cylindrical strength $f_{ck} \geq 20$ MPa [12].

The good quality of grouting by a usual concrete with strength f_{ck} at least 20 MPa and clean holes are assumed. The reduced pullout capacities given in Table 6 are based on the data given in the document [7] and also engineering experience. The higher pulout capacities can be used only on the basis of the properly performed tests of such anchor bolts. These tests should be performed also in cases of any doubts in relation to quality and/or performance of concrete grouting. Values in Table 6 are valid for J-shaped bolts without additional pins or weld connections to the concrete reinforcement and when they are grouted by usual concrete, not by special grouting mixtures. The pullout capacities of anchor bolts with additional pins or welded to the concrete reinforcement or when they are grouted by special grouting mixtures should be determined on the basis of properly performed tests or credible documentation.

Reduction Factors:

- short embedment length

$RL_F = RL_Q = 1.0$ if $L \geq L_{min}$,

$= L / L_{min}$ if $20D \leq L < L_{min}$,

$= 0.0$ if $L < 20D$,

where

L = actual embedment length,
L_{min} = minimum embedment length (Table 6)
D = diameter of the anchor bolt,

- closely spaced bolts

$RS_F = 1.0$ if $S \geq S_{min}$,

$= S / S_{min}$ if $S < S_{min}$,

$= 0.0$ for anchor bolts located from four and more closely spaced anchor bolts less than $0.7 \times S_{min}$,

$RS_Q = 1.0$ if $S \geq 2D$,
$= 0.5$ if $S < 2D$,

where

S = actual spacing,
S_{min} = minimum spacing (Table 6),
D = diameter of the anchor bolt,

- near concrete edge

$RE_F = RE_Q = 1.0$ if $E \geq E_{min}$,
$= (E / E_{min})^2$ if $4D \leq E < E_{min}$,
$= 0.0$ if $E < 4D$,

where

E = actual edge distance,
E_{min} = minimum edge distance (Table 6),
D = diameter of the anchor bolt,

- low strength of concrete

$$RB_F = RB_Q = 1.0 \quad \text{if} \quad f_{ck} \geq 20 \text{ MPa},$$
$$= (f_{ck}/20)^{1/2} \quad \text{if} \quad 12.5 \text{ MPa} \leq f_{ck} < 20 \text{ MPa},$$
$$= 0.0 \quad \text{if} \quad f < 12.5 \text{ MPa},$$

where

f_{ck} = characteristic cylindrical strength of the concrete [12],

- cracked concrete

$$RC_F = 1.0 \quad \text{if} \quad w < 0.30 \text{ mm},$$
$$= 1.10 - 0.33\,w \quad \text{if} \quad 0.30 \text{ mm} \leq w \leq 1.50 \text{ mm},$$
$$= 0.0 \quad \text{if} \quad w > 1.50 \text{ mm},$$

where

w = width of the concrete cracks visually observed near to the anchor bolt during the walkdown.

3.5. Nominal Capacity Parameters and Reduction Factors of Anchor Bolts Grouted in Drilled-in-Place Small Size Holes (Figure 4)

Table 7 Nominal Capacity Parameters of Anchor Bolts Grouted in Drilled-in-Place Small Size Holes by the Epoxy Resin

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
12	14.90	13.00	150	150	100
16	26.40	23.00	200	200	140
20	41.20	36.00	260	260	175
24	59.30	52.00	310	310	210
30	89.80	79.00	360	360	265
36	138.00	120.50	440	440	330
42	193.00	168.90	550	550	410
48	257.00	225.00	660	660	500

Note: Values in Table 7 have been determined for the following materials:

- steel of anchor bolts with the minimum yield limit $f_y \geq 230$ MPa and with the tension strength $f_u \geq 350$ MPa [11],
- concrete with the characteristic cylindrical strength $f_{ck} \geq 20$ MPa [12],
- shear strength of the epoxy resin at least 8 MPa [10],
- space between the bolt and the hole should be no more than 0.2 times D (D = diameter of anchor bolts).

It is also assumed that the type of grouting epoxy resin is selected in accordance with environmental conditions and temperature in particular.

Table 8 Nominal Capacity Parameters of Adhesive HILTI Anchor Bolts Grouted in Drilled-in-Place Small Size Holes by the Special Epoxy - Acrylate Resin (type HVA-HAS and HVA-HAS-R)

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
8	6.00	3.90	80	130	80
10	9.00	6.20	90	150	90
12	12.00	9.00	110	170	100
16	18.00	17.00	125	200	130
20	30.00	26.60	170	260	170
24	43.00	38.30	210	320	230

Note: Values in Table 8 have been extracted from the available HILTI documents [13]. The concrete should have the characteristic cylindrical strength $f_{ck} \geq 20$ MPa [12], anchor bolts should be installed according to the HILTI guidelines.

Table 9 Nominal Capacity Parameters of Adhesive HILTI Anchor Bolts Grouted in Drilled-in-Place Small Size Holes by the Special Epoxy - Acrylate Resin (type HVA-HIS and HVA-HIS-R)

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
8	7.50	4.00	80	130	110
10	10.50	7.00	90	150	130
12	15.50	10.00	110	170	150
16	14.50	18.50	125	200	170
20	40.00	29.00	170	260	230

Note: Values in Table 9 have been extracted from the available HILTI documents [13]. The concrete should have the characteristic cylindrical strength $f_{ck} \geq 20$ MPa [12], anchor bolts should be installed according to the HILTI guidelines.

Reduction Factors:

- short embedment length

$$RL_F = RL_Q = 1.0 \qquad \text{if} \quad L \geq L_{min},$$

$$= \frac{(L + D)\, L}{(L_{min} + D)\, L_{min}} \qquad \text{if} \quad 5D \leq L < L_{min},$$

$$= 0.0 \qquad \text{if} \quad L < 5D,$$

where

L	=	actual embedment length,
L_{min}	=	minimum embedment length (Table 7, 8, 9)
D	=	diameter of the anchor bolt,

- closely spaced bolts

RS_F	=	1.0	if $S \geq S_{min}$,
	=	$(1 + S / S_{min}) / 2$	if $S < S_{min}$,
	=	0.0	for anchor bolts located from four and more closely spaced anchor bolts less than $0.7 \times S_{min}$,

RS_Q	=	1.0	if $S \geq 3D$,
	=	0.5	if $S < 3D$,

where

S	=	actual spacing,
S_{min}	=	minimum spacing (Table 7, 8, 9),
D	=	diameter of the anchor bolt,

- near concrete edge

$RE_F = RE_Q$	=	1.0	if $E \geq E_{min}$,
	=	$(E / E_{min})^2$	if $4D \leq E < E_{min}$,
	=	0.0	if $E < 4D$,

where

E	=	actual edge distance,
E_{min}	=	minimum edge distance (Table 7, 8, 9),
D	=	diameter of the anchor bolt,

- low strength of concrete

$RB_F = RB_Q$	=	1.0	if $f_{ck} \geq 20$ MPa,
	=	$(f_{ck} / 20)^{1/2}$	if $12.5 \text{ MPa} \leq f_{ck} < 20$ MPa,
	=	0.0	if $f < 12.5$ MPa,

where

f_{ck}	=	characteristic cylindrical strength of the concrete [12],

- cracked concrete

RC_F	= 1.0	if	$w < 0.30$ mm,
	= 1.10 - 0.33 w	if	$0.30 \text{ mm} \leq w \leq 1.50$ mm,
	= 0.0	if	$w > 1.50$ mm,

where

w = width of the concrete cracks visually observed near to the anchor bolt during the walkdown.

3.6. Nominal Capacity Parameters and Reduction Factors of Expansion Anchor Bolts (Figure 5)

Table 10 Nominal Capacity Parameters of Expansion Anchor Bolts HILTI - Type HSL-TZ (HSL-G-TZ & HSL-B-TZ)

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
8	8.30	9.60	70	180	175
10	12.20	15.20	80	210	200
12	16.80	22.60	95	250	235
16	28.00	41.10	115	290	280
20	37.60	55.00	145	380	360
24	51.20	81.00	155	470	390

Note: Values in Table 10 have been extracted from the available HILTI documents [13]. The concrete should be sound and should have the characteristic cylindrical strength $f_{ck} \geq 30$ MPa [12]. Anchor bolts should be installed according to the HILTI guidelines. The nominal capacities given in Table 10 should be multiplied by the following additional reduction factors:

(a) 0.75 when, regardless to their tightness, anchor bolts are subjected to a dynamic loading with a repetition rate more than 50 cycles and with an amplitude of dynamic loading greater than 30% of its permanent static tension or shear loading, or when there is no check of the bolt tightness as recommended in Table 3,

(b) 0.60 when both facts described on (a) are occured together.

Table 11 Nominal Capacity Parameters of Expansion Anchor Bolts HILTI - Type HSA

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
6	3.20	2.40	45	105	105
8	4.70	4.50	55	120	120
10	5.80	6.80	60	130	130
12	9.50	10.80	80	180	180
16	14.00	14.50	95	210	210
20	21.00	20.50	115	260	260

Note: Values in Table 11 have been extracted from the available HILTI documents [13]. The concrete should be sound and should have the characteristic cylindrical strength $f_{ck} \geq 30$ MPa [12]. Anchor bolts should be installed according to the HILTI guidelines. The nominal capacities given in Table 11 should be multiplied by the following additional reduction factors:

(a) 0.75 when, regardless to their tightnees, anchor bolts are subjected to a dynamic loading with a repetition rate more than 50 cycles and with an amplitude of dynamic loading greater than 30% of its permanent static tension or shear loading, or when there is no check of the bolt tightness as recommended in Table 3,

(b) 0.60 when both facts described in (a) are occured together.

Table 12 Nominal Capacity Parameters of Expansion Anchor Bolts HILTI - Type HST and HST-R

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
8	5.00	4.20	55	120	120
10	7.70	6.60	70	150	150
12	10.60	9.60	80	180	180
16	15.20	15.70	95	220	220
20	22.40	24.50	115	275	275
24	29.50	35.30	145	320	320

Note: Values in Table 12 have been extracted from the available HILTI documents [13]. The concrete should be sound and should have the characteristic cylindrical strength $f_{ck} \geq 30$ MPa [12]. Anchor bolts should be installed according to the HILTI guidelines. The nominal capacities given in Table 12 should be multiplied by the following additional reduction factors:

(a) 0.75 when, regardless to their tightnees, anchor bolts are subjected to a dynamic loading with a repetition rate more than 50 cycles and with an amplitude of dynamic loading greater than 30% of its permanent static tension or shear loading, or when there is no check of the bolt tightness as recommended in Table 3,

(b) 0.60 when both facts described in (a) are occured together.

Table 13 Nominal Capacity Parameters of Expansion Anchor Bolts HILTI - Type HUC

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
12	34.30	40.00	125	350	250
16	54.40	65.90	170	450	350
20	80.10	80.00	220	550	440

Note: Values in Table 13 have been extracted from the available HILTI documents [13]. The concrete should be sound and should have the characteristic cylindrical strength $f_{ck} \geq 30$ MPa [12]. Anchor bolts should be installed according to the HILTI guidelines. The nominal capacities given in Table 13 should be multiplied by the following additional reduction factors:

(a) 0.75 when, regardless to their tightnees, anchor bolts are subjected to a dynamic loading with a repetition rate more than 50 cycles and with an amplitude of dynamic loading greater than 30% of its permanent static tension or shear loading, or when there is no check of the bolt tightness as recommended in Table 3,

(b) 0.60 when both facts described in (a) are occured together.

Reduction Factors:

- short embedment length

$RL_F = RL_Q = 1.0$ if $L \geq L_{min}$,

$= 0.0$ if $L < L_{min}$,

where

L = actual embedment length,
L_{min} = minimum embedment length (Tables 10, 11, 12, 13)
D = diameter of the anchor bolt,

- closely spaced bolts

$RS_F = 1.0$ if $S \geq S_{min}$,

$= S / S_{min}$ if $3D \leq S < S_{min}$,

$= 0.0$ if $S < 3D$,

$RS_Q = 1.0$ if $S \geq 3D$,
$= 0.5$ if $S < 3D$,

where

S	=	actual spacing,
S_{min}	=	minimum spacing (Table 10, 11, 12, 13),
D	=	diameter of the anchor bolt,

- near concrete edge

RE_F	= RE_Q	=	1.0	if	$E \geq E_{min}$,
		=	$(E / E_{min})^2$	if	$4D \leq E < E_{min}$,
		=	0.0	if	$E < 4D$,

where

E	=	actual edge distance,
E_{min}	=	minimum edge distance (Table 10, 11, 12, 13),
D	=	diameter of the anchor bolt,

- low strength of concrete

RB_F	= RB_Q	=	1.0	if	$f_{ck} \geq 30$ MPa,
		=	$f_{ck} / 30$	if	15 MPa $\leq f_{ck} <$ 30 MPa,
		=	0.0	if	$f <$ 15 MPa,

where

f_{ck}	=	characteristic cylindrical strength of the concrete [12],

- cracked concrete

RC_F	=	1.0	if	there are no visually observed cracks,
	=	0.70	if	$w \leq 0.30$ mm,
	=	0.0	if	$w > 0.30$ mm,

where

w	=	width of the concrete cracks visually observed near to the anchor bolt during the walkdown,

- essential relays in equipment components secured by expansion anchor bolts

RR_F	= RR_Q	=	0.75	essential relays are located in equipment components secured by expansion anchor bolts,
		=	0.0	in all other cases.

Note: This factor is applicable only with expansion anchors.

3.7. Capacity Determination of Fillet Welds to Steel Structural Members or Steel Anchor Plates Embedded into Concrete (Figure 8)

Fillet welds are often used in anchorage of equipment. Their allowable capacity should be determined as follows:

$$F_{w,all} = 0.67\, \sigma_{all}\, a_w\, l_w \qquad (3)$$

where

σ_{all} = allowable stress for steel elements to be connected by the weld, (usually $\sigma_y / 1.2$, where σ_y = minimum yield stress)

a_w = effective thickness of the fillet weld ($a_w = 0.707 \times t_w$, where t_w = thickness of the weld leg),

l_w = effective length of the fillet weld ($l_w = L_w - 2a_w$, where L_w = actual measured length of the weld).

It is assumed that the fillet welds are provided manually by the properly selected electrodes.

The minimum effective length of the fillet weld should not be less than six times the effective thickness of the weld, or else the effective thickness of the weld should be considered not to exceed 1/6 of its effective length.

The effective thickness of the fillet weld should be at least 4, 6, or 8 mm for the thickness of steel elements to be connected by the weld up to 10 mm, from 11 to 30 mm and more than 30 respectively.

Plug welds are not recommended in anchorage of equipment. Nevertheless, if they are used, their shear and tensile capacities can be estimated as follows:

- shear capacity = $0.15\, \sigma_{all}\, A_w$

where

σ_{all} = allowable stress for steel elements to be connected by the weld, (usually $\sigma_y / 1.2$, where σ_y = minimum yield stress),

A_w = cross section area of the plug weld.

The tensile capacity of such plug welds can be taken as 0.25 times the shear capacity of the weld.

3.8. Capacity Determination of Steel Plates with Anchors Embedded into Concrete

3.8.1. General

The possible failure modes of such anchorage plates are:

- failure of anchors (studs) welded to the steel anchorage plate,
- failure of the steel anchorage plate itself.

The governing failure mode is usually failure of anchors (studs) which are welded to the steel anchorage plate. Failure of the steel anchorage plate itself is less probable and can be reliably excluded from the consideration when simple practical rules relating to the thickness of the plate and distribution of its anchors as described in references [6,8] are met.

3.8.2. Nominal Capacity Parameters and Reduction Factors of Anchors Made of Concrete Reinforcement Bars (Figure 9)

The nominal capacities of anchors made of concrete reinforcement bars, which are welded to the anchor plate are:

$$F_{a,nom} = A_s \sigma_s \tag{4}$$

$$Q_{a,nom} = 0.7\, F_{a,nom} \tag{5}$$

where

σ_s = allowable stress for reinforcement bars to be welded to the anchor plate, (usually σ_y / 1.2, where σ_y = minimum yield stress)

A_s = cross section area of the anchor.

It is assumed that the governing failure mode of these anchors is their plastic stretching, not failure of welds by means of which these reinforcement bars are connected to the anchor plate. Otherwise their nominal capacities should be adequately reduced.

The minimum embedment length and the end arrangement of anchors are determined depending on the type of reinforcement bars and for concrete strength f_{ck} = 20 MPa using the design rules for concrete structures [12] (L_{min} = usually from 25 to 35D).

The following relationships are recommended to determine the minimum spacing and minimum edge distance when these anchor are used:

$$S = 3D \tag{6}$$

$$E = 9D \tag{7}$$

where

D = diameter of the anchor.

Reduction Factors:

- short embedment length

RL_F	$= 1.0$	if	$L \geq L_{min}$,
	$= L/L_{min}$	if	$15D \leq L < L_{min}$,
	$= 0.0$	if	$L < 15D$,
RL_Q	$= 1.0$	if	$L \geq 15D$,
	$= (L - 5D)/10D$	if	$5D \leq L < 15D$,
	$= 0.0$	if	$L < 15D$,

where

L = actual embedment length,
L_{min} = minimum embedment length (see [12]),
D = diameter of the anchor bolt,

- closely spaced bolts

RS_F	$= 1.0$	if	$S \geq S_{min}$,
	$= 0.5$	if	$S < S_{min}$,
RS_Q	$= 1.0$	if	$S \geq 2D$,
	$= 0.5$	if	$S < 2D$,

where

S = actual spacing,
S_{min} = minimum spacing (see (6)),
D = diameter of the anchor bolt,

- near concrete edge

$RE_F = RE_Q$	$= 1.0$	if	$E \geq E_{min}$,
	$= (E / E_{min})^2$	if	$4D \leq E < E_{min}$,
	$= 0.0$	if	$E < 4D$,

where

E = actual edge distance,
E_{min} = minimum edge distance (see (7)),
D = diameter of the anchor bolt,

- low strength of concrete

$RB_F = RB_Q$	$= 1.0$	if $f_{ck} \geq 20$ MPa,
	$= (f_{ck}/20)^{1/2}$	if $12.5 \text{ MPa} \leq f_{ck} < 20$ MPa,
	$= 0.0$	if $f < 12.5$ MPa,

where

f_{ck} = characteristic cylindrical strength of the concrete [12],

- cracked concrete

RC_F	$= 1.0$	if $w < 0.30$ mm,
	$= 1.10 - 0.33\,w$	if $0.30 \text{ mm} \leq w \leq 1.50$ mm,
	$= 0.0$	if $w > 1.50$ mm,

where

w = width of the concrete cracks visually observed near to the anchor bolt during the walkdown.

3.8.3. Nominal Capacity Parameters and Reduction Factors of Anchors Made of Headed Studs (Figure 10)

Table 14 Nominal Capacity Parameters of Cast-in-Place Headed Anchor Bolts

Diameter of Anchor Bolt [mm]	Nominal Pullout Capacity [kN]	Nominal Shear Capacity [kN]	Minimum Embedment Length [mm]	Minimum Spacing [mm]	Minimum Edge Distance [mm]
8	10.40	5.80	105	105	70
10	16.25	9.00	130	130	90
12	23.40	13.00	155	155	110
14	32.00	17.60	180	180	125
16	41.60	23.00	200	200	140
20	65.00	36.00	260	260	175

Note: Values in Table 14 have been determined for the following materials:

- steel of anchor bolts with the minimum yield limit $f_y \geq 230$ MPa and with the tension strength $f_u \geq 350$ MPa [11],
- concrete with the characteristic cylindrical strength $f_{ck} \geq 20$ MPa [12].

It is assumed that stud plastic stretching is governing failure mode rather than any failure of the weld by means of which the stud is connected to the anchorage steel plate.

<u>Reduction Factors:</u>

- short embedment length

$RL_F = RL_Q = 1.0$ if $L \geq L_{min}$,

$= \dfrac{(L + D)\,L}{(L_{min} + D)\,L_{min}}$ if $5D \leq L < L_{min}$,

$= 0.0$ if $L < 5D$,

where

L	=	actual embedment length,
L_{min}	=	minimum embedment length (Table 13)
D	=	diameter of the anchor bolt,

- closely spaced bolts

$RS_F = 1.0$ if $S \geq S_{min}$,

$= (1 + S / S_{min}) / 2$ if $S < S_{min}$,

$= 0.0$ for anchor bolts located from four and more closely spaced anchor bolts less than $0.7 \times S_{min}$,

$RS_Q = 1.0$ if $S \geq 3D$,
$= 0.5$ if $S < 3D$,

where

S	=	actual spacing,
S_{min}	=	minimum spacing (Table 13),
D	=	diameter of the anchor bolt,

- near concrete edge

$RE_F = RE_Q = 1.0$ if $E \geq E_{min}$,
$= (E / E_{min})^2$ if $4D \leq E < E_{min}$,
$= 0.0$ if $E < 4D$,

where

E	=	actual edge distance,
E_{min}	=	minimum edge distance (Table 13),
D	=	diameter of the anchor bolt,

- low strength of concrete

$RB_F = RB_Q = 1.0$ if $f_{ck} \geq 20$ MPa,
$= (f_{ck} / 20)^{1/2}$ if $12.5 \text{ MPa} \leq f_{ck} < 20$ MPa,
$= 0.0$ if $f < 12.5$ MPa,

where

f_{ck} = characteristic cylindrical strength of the concrete [12],

- cracked concrete

$RC_F = 1.0$ if $w < 0.30$ mm,
$= 1.10 - 0.33\,w$ if $0.30 \text{ mm} \leq w \leq 1.50$ mm,
$= 0.0$ if $w > 1.50$ mm,

where

w = width of the concrete cracks visually observed near to the anchor bolt during the walkdown.

4. ANCHORAGE DEMAND DETERMINATION

4.1. General Information

The third main step in evaluation the adequacy of equipment anchorages is to determine the loads applied to the anchorage. The well-known methods of structural mechanics and dynamics should be used for these purposes. There are two possibilities:

(a) The stress and strain analysis of the equipment item is explicitly performed, then the forces and moments acting on its anchorage and corresponding to an each considered loading case can be obtained as a product of such analysis.

(b) When the stress and strain analysis of the equipment item is not explicitly performed, however the proper anchorage is required to assure, for instance, its seismic resistance, the following simplified approach is recommended to determine the loads applied to the equipment anchorage:

- determine the appropriate input seismic accelerations for the item of equipment for an each of the three directions of spatial seismic motion,
- determine the seismic inertial equipment loads for an each of the three directions of seismic motion using the equivalent static load method,
- determine the seismic internal anchor loads by calculating the various load components for an each direction of seismic motion,
- calculate the combined seismic loads on an each anchor of the three directions of seismic motion and, then, combine the load components from these three directions using the SRSS rule or another appropriate rule [14,15],
- calculate the total anchor loads on an each anchor by adding the combined seismic loads to the deadweight loads and any other non-seismic loads on the equipment as required by the prescribed acceptance criteria.

Figure 11 demonstrates how the insufficient base stiffness can cause prying action applied to the anchors. Figure 12 present several examples of stiff and excessively flexible anchorage connections with possible prying actions in anchors.

4.2. Important Assumptions in Relation to Anchorage Demand Determination

There are several important assumptions when the anchorage demand of the equipment item is calculated:

(a) The anchor loads caused by the equipment overturning moment can be based on the assumption that plane sections remain plane during loading and that the material of the equipment base and anchors behave in a linear-elastic manner. This results in a linear distribution of anchor loads for a set of anchors which are equal in stiffness and size. The same assumption can be used also to the distribution of stresses and forces under the steel plates with anchors embedded in concrete.

(b) The recommended location for the overturning axis is at the equipment centerline for equipment with flexible bases. For rigid base equipment, the overturning axis can be taken at the edge of the equipment.

(c) It is also assumed that the shear loads acting in the equipment base are usually transmitted into the concrete only by anchors themselves. The friction between the equipment base and its grouting pad can be used only when there is a safe and durable pretension of anchor bolts.

5. COMPARISON OF CAPACITY TO DEMAND

The final main step in evaluating the adequacy of equipment anchorages is to compare the anchorage capacity to demand. This comparison can be done using the interaction formulations as presented herein.

Based on references [3,4] and also engineering experience the following three „pullout-shear“ interaction formulas are recommended for anchors (bolts or studs):

- linear formula (conservative)

$$F_a / F_{a,all} + Q_a / Q_{a,all} \leq 1.0 \qquad (8)$$

- quadratic formula (unconservative)

$$(F_a / F_{a,all})^2 + (Q_a / Q_{a,all})^2 \leq 1.0 \qquad (9)$$

- bilinear (realistic)

$$F_a / F_{a,all} \leq 1.0 \qquad \text{for } Q_a / Q_{a,all} \leq 0.3 \qquad (10)$$

$$0.7\, F_a / F_{a,all} + Q_a / Q_{a,all} \leq 1.0 \qquad \text{for } 0.3 \leq Q_a / Q_{a,all} \leq 1.0 \qquad (11)$$

where

F_a = pullout (tension) force applied to the anchor (bolt or stud),

Q_a = shear force applied to the anchor (bolt or stud),

$F_{a,all}$ = allowable pullout (tension) capacity of the anchor (bolt or stud),

$Q_{a,all}$ = allowable shear capacity of the anchor (bolt or stud).

The first linear formula (8) is conservative and can be used for the first estimation and for any failure modes of anchors or concrete. The quadratic formula (9) can be recommended when failure of concrete governs (the pullout of a concrete body). The last formulas (10) and (11) are recommended when the failure of anchor material governs.

When fillet welds are subjected to loads which are perpendicular and parallel to the weld, the allowable loads can be compared to these applied loads using the following interaction formula:

$$(F_w / F_{w,all}) + (Q_w / F_{w,all}) \leq 1.0 \qquad (12)$$

where

F_w = applied force parallel to the fillet weld,

Q_w = applied force perpendicular to the fillet weld

$F_{w,all}$ = allowable capacity of the fillet weld.

USED ABBREVIATIONS

ASCE	American Society of Civil Engineers
GIP	Generic Implementation Procedure
NPP	Nuclear Power Plant

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APPENDIX - FIGURES

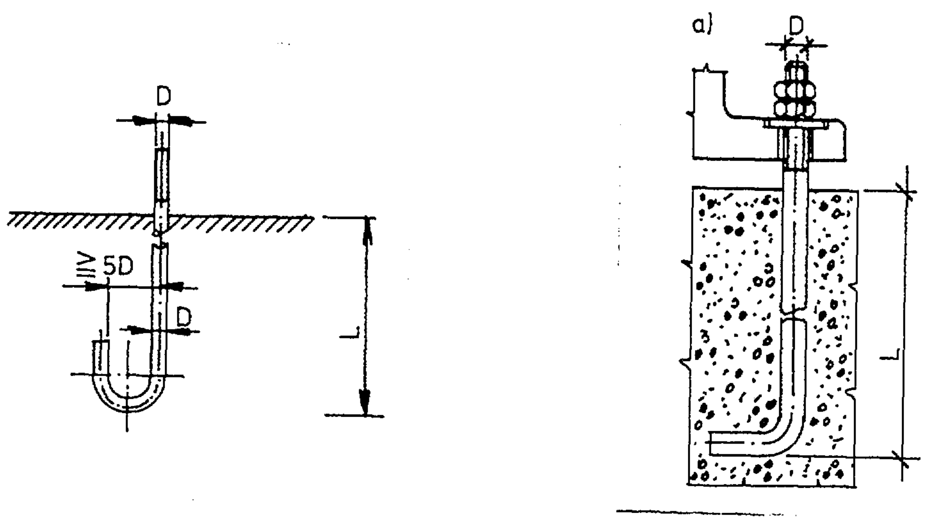


Figure 1 Cast-in-Place J-Shaped Anchor Bolts

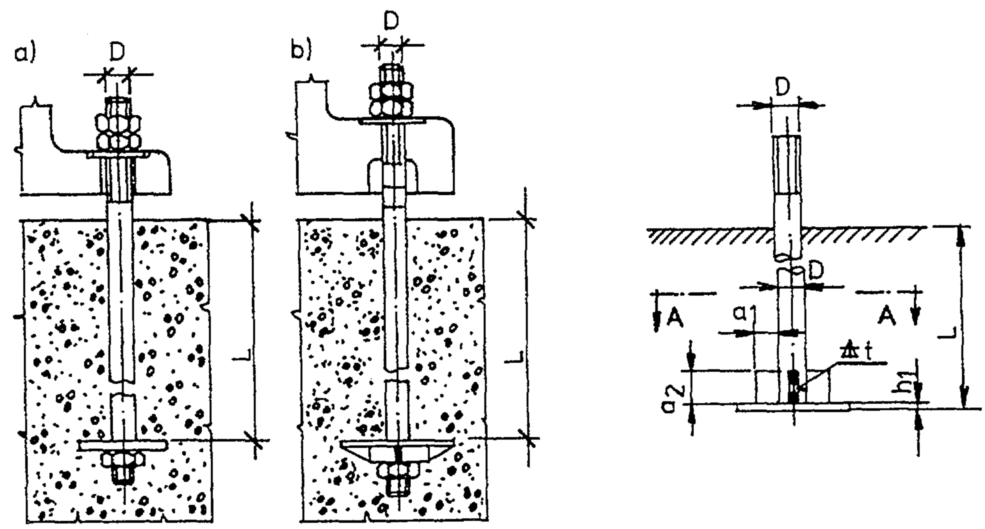


Figure 2 Cast-in-Place Headed Anchor Bolts

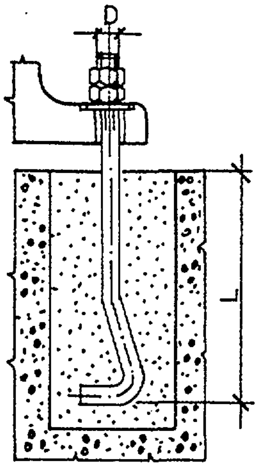


Figure 3 J-Shaped Anchor Bolts Grouted by Concrete in Beforehand Made Large Size Holes

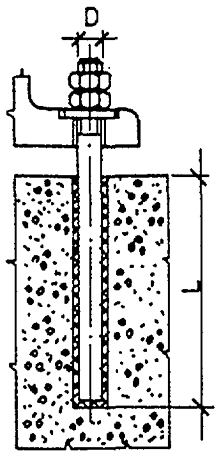


Figure 4 Anchor Bolts Grouted in Drilled-in-Place Small Size Holes

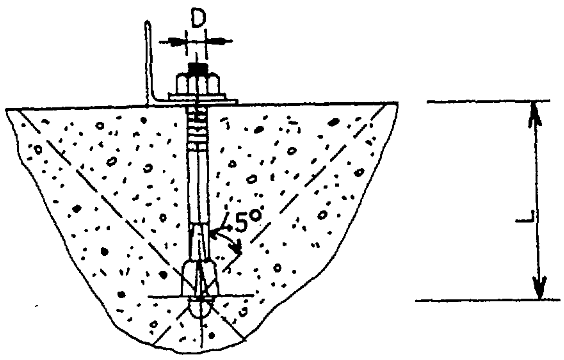


Figure 5 Expansion Anchor Bolts

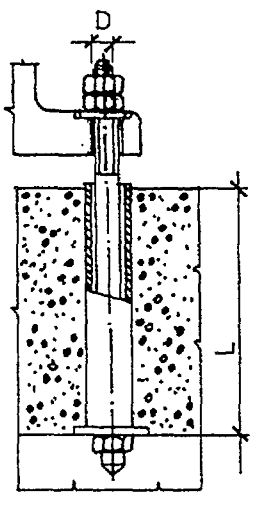


Figure 6 Anchor Bolts Through the Concrete Floor

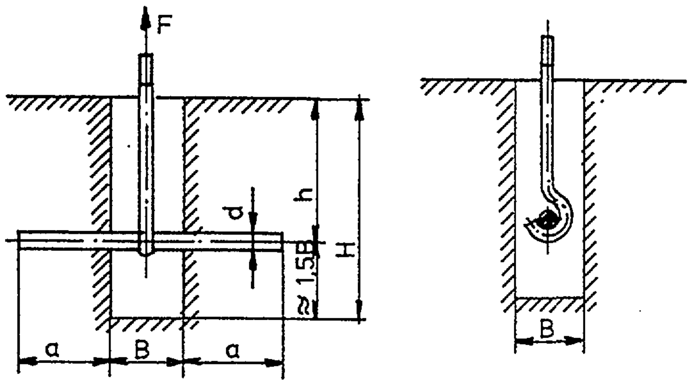


Figure 7 J-Shaped Anchor Bolts with Pins

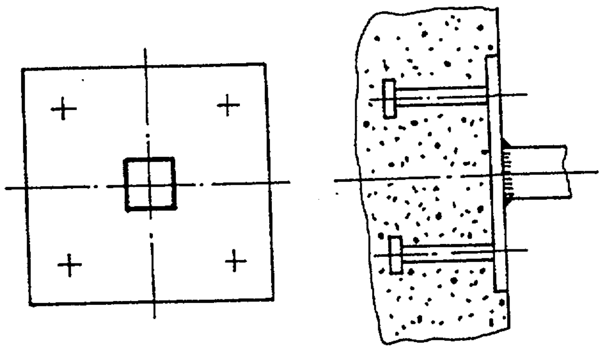


Figure 8 Weld Connections to Steel Members with Studs Embedded into the Concrete Structure

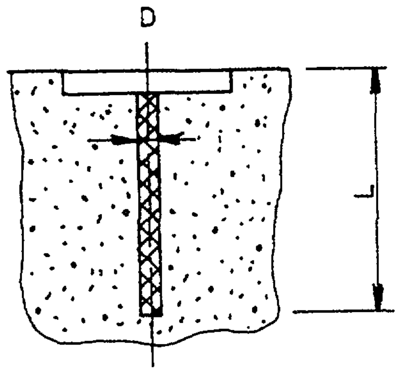


Figure 9 Anchors Made of Concrete Reinforcement Bars

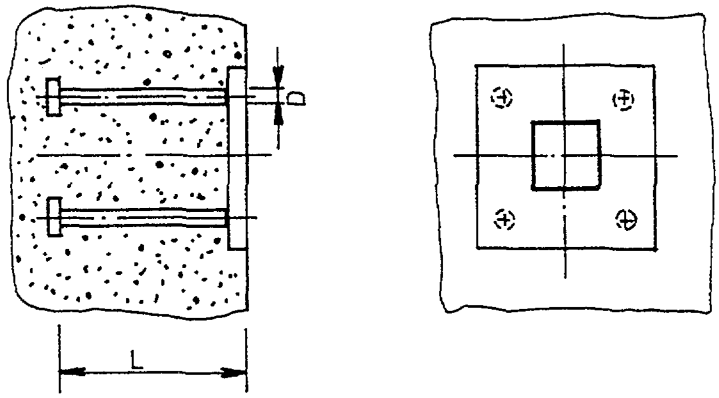


Figure 10 Anchors Made of Headed Studs

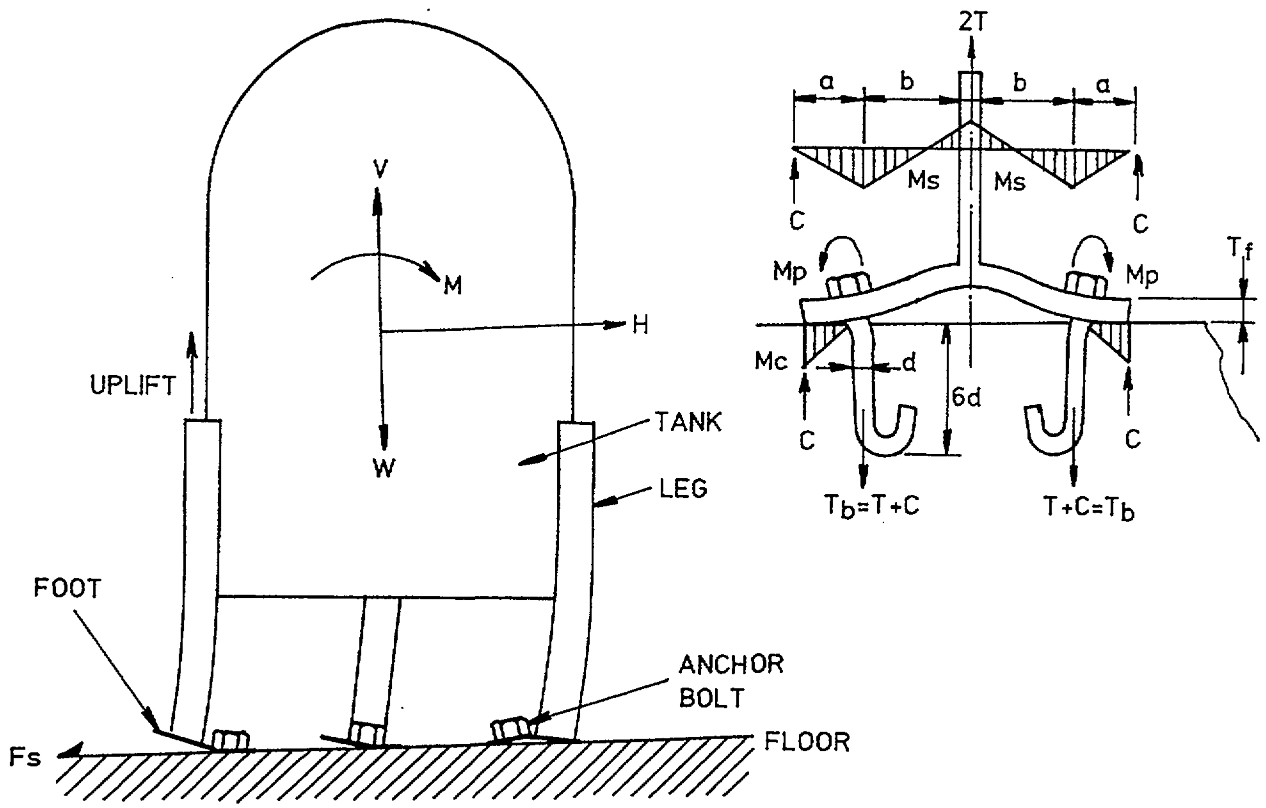
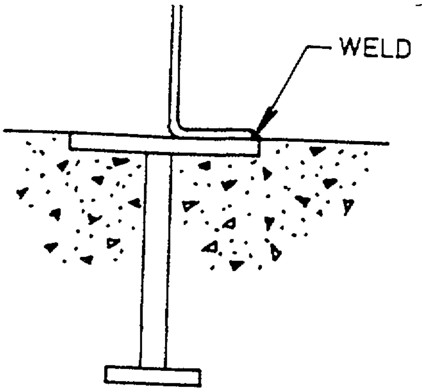
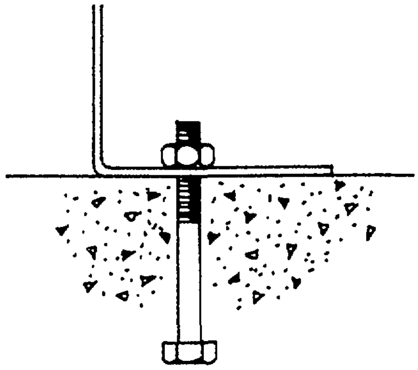


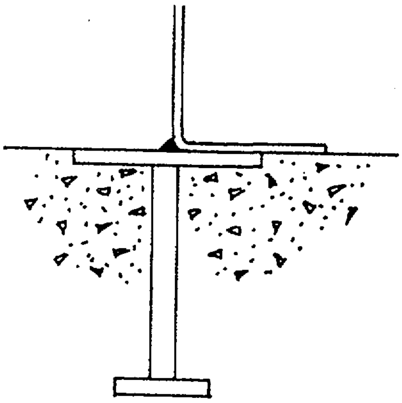
Figure 11 Influence of Base Stiffness on Prying Action Applied to Anchors



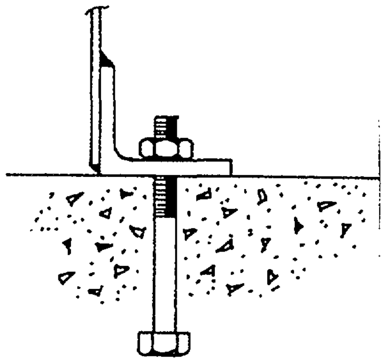
(a) undesirable flexible welded anchorage, weld only from external side, uplift causes sheet metal frame to bend



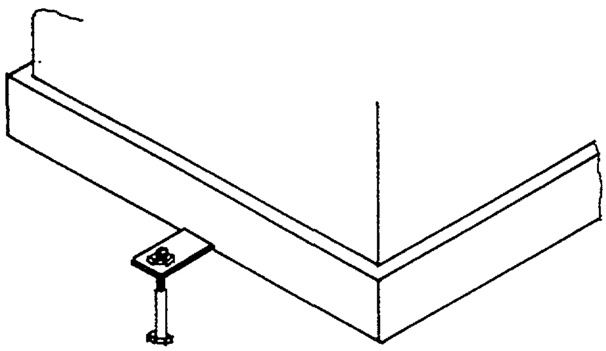
(b) undesirable flexible bolted anchorage, uplift causes sheet metal to bend



(c) desirable stiff welded anchorage, loads pass through sheet metal wall



(d) desirable stiff bolted anchorage, structural angle base provided adequate stiffness



(e) undesirable flexible base anchorage, plate can bend from uplift loads and base frame might bend from shear loads

Figure 12 Examples of Stiff and Excessively Flexible Anchorage Connections