NC-3400 PUMP DESIGN
NC-3410 GENERAL REQUIREMENTS FOR
CENTRIFUGAL PUMPS
NC-3411 Scope
NC-3411.1 Applicability. The rules of NC-3400 apply to (a) through (j) below:
(a) pump casings
(b) pump inlets and outlets
(c) pump covers
(d) clamping rings
(e) seal housings, seal glands, and packing glands
(f) related bolting
(g) pump internal heat exchanger piping
(h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections excluding the connecting weld
(i) piping identified with the pump and external to and forming part of the pressure-retaining boundary and supplied with the pump
(j) external and internal integral attachments to the pressure-retaining boundary
Hydrostatic test of seal glands and packing glands is not required.
NC-3411.2 Exemptions. The rules of NC-3400 do not apply to (a) through (c) below:
(a) pump shafts and impellers (shafts may be designed in accordance with Section III Appendices, Nonmandatory Appendix S)
(b) nonstructural internals
(c) seal packages
NC-3412 Acceptability
The requirements for the design of pumps are given in (a) and (b) below.
(a) The design shall be such that the requirements of NC-3100 are satisfied.
(b) The rules of this subarticle are met.
NC-3413 Design Specification
Design and Service Loadings (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). Loads from thermal expansion, deadweight, and applicable seismic forces from the connected piping shall be included in the Design Specification.
NC-3414 Design and Service Loadings
The general design considerations, including definitions, of NC-3100 plus the requirements of NC-3320, NC-3330, NC-3361, and NC-3362 are applicable to pumps. The pump shall conform to the requirements of NC-3400.
The stress limits listed in NC-3416 shall be used for the specified Design and Service Loadings. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, or any design equations, which have been demonstrated to be satisfactory, may be used.
NC-3415 Loads From Connected Piping
Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design.
NC-3416 Stress and Pressure Limits for Design and Service Loadings
Stress limits for maximum normal stress for Design and Service Loadings are specified in Table NC-3416-1. The symbols used in Table NC-3416-1 are defined as follows:
\[ S \] = allowable stress value, given in Section II, Part D, Subpart 1, Tables 1A and 1B. The allowable stress shall correspond to the highest metal temperature of the section under consideration during the condition under consideration.
\[ \sigma_b \] = bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
\[ \sigma_L \] = local membrane stress. This stress is the same as \[ \sigma_m \] except that it includes the effect of discontinuities.
\[ \sigma_m \] = general membrane stress. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.
NC-3417 Earthquake Loadings
(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.
(b) Where pumps are provided with driver or extended supporting structures and these structures are essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.
NC-3418 Corrosion
The requirements of NC-3121 apply.
NC-3419 Cladding
Cladding design dimensions used in the design of pumps shall be as required in NC-3122.

Notes to Editor:
1. This content is taken from the current NC-3400 in the 2019 Edition.
2. Replace all occurrences of "ND-" with "NCD-". This applies for the entire Subarticle, including all text, figures, and tables.
3. Cross check all references to Articles 1000, 2000, 3000, 4000, 5000, 6000, and 7000 to confirm that the paragraph number was not changed in another record.
NC-3400 PUMP DESIGN

NC-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

NC-3411 Scope

NC-3411.1 Applicability. The rules of NC-3400 apply to (a) through (j) below:
(a) pump casings
(b) pump inlets and outlets
(c) pump covers
(d) clamping rings
(e) seal housings, seal glands, and packing glands
(f) related bolting
(g) pump internal heat exchanger piping
(h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections excluding the connecting weld
(i) piping identified with the pump and external to and forming part of the pressure-retaining boundary and supplied with the pump
(j) external and internal integral attachments to the pressure-retaining boundary

Hydrostatic test of seal glands and packing glands is not required.

NC-3411.2 Exemptions. The rules of NC-3400 do not apply to (a) through (c) below:
(a) pump shafts and impellers (shafts may be designed in accordance with Section III Appendices, Nonmandatory Appendix S)
(b) nonstructural internals
(c) seal packages

NC-3412 Acceptability

The requirements for the design of pumps are given in (a) and (b) below.
(a) The design shall be such that the requirements of NC-3100 are satisfied.
(b) The rules of this subarticle are met.

NC-3413 Design Specification

Design and Service Loadings (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). Loads from thermal expansion, deadweight, and applicable seismic forces from the connected piping shall be included in the Design Specification.

NC-3414 Design and Service Loadings

The general design considerations, including definitions, of NC-3100 plus the requirements of NC-3320, NC-3330, NC-3361, and NC-3362 are applicable to pumps. The pump shall conform to the requirements of NC-3400. The stress limits listed in NC-3416 shall be used for the specified Design and Service Loadings. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, or any design equations, which have been demonstrated to be satisfactory, may be used.

NC-3415 Loads From Connected Piping

Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design.

NC-3416 Stress and Pressure Limits for Design and Service Loadings

Stress limits for maximum normal stress for Design and Service Loadings are specified in Table NC-3416-1. The symbols used in Table NC-3416-1 are defined as follows:

\[ S = \text{allowable stress value, given in Section II, Part D, Subpart 1, Tables 1A and 1B. The allowable stress shall correspond to the highest metal temperature of the section under consideration during the condition under consideration.} \]

\[ \sigma_b = \text{bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.} \]

\[ \sigma_L = \text{local membrane stress. This stress is the same as } \sigma_m \text{ except that it includes the effect of discontinuities.} \]

\[ \sigma_m = \text{general membrane stress. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.} \]

NC-3417 Earthquake Loadings

(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

(b) Where pumps are provided with drivers on extended supporting structures and these structures are essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.

NC-3418 Corrosion

The requirements of NC-3121 apply.

NC-3419 Cladding

Cladding design dimensions used in the design of pumps shall be as required in NC-3122.
**NC-3420  DEFINITIONS**

**NC-3421  Radially Split Casing**

A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

**NC-3422  Axially Split Casing**

An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

**NC-3423  Single and Double Volute Casings**

Figures NC-3423-1 and NC-3423-2 show typical single and double volute casings, respectively.

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**Table NC-3416-1  Stress and Pressure Limits for Design and Service Loadings**

<table>
<thead>
<tr>
<th>Service Limit</th>
<th>Stress Limits [Note (1)]</th>
<th>$P_{\text{max}}$ [Note (2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level A</td>
<td>$\sigma_m \leq S$</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$</td>
<td></td>
</tr>
<tr>
<td>Level B</td>
<td>$\sigma_m \leq 1.1S$</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$</td>
<td></td>
</tr>
<tr>
<td>Level C</td>
<td>$\sigma_m \leq 1.5S$</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$</td>
<td></td>
</tr>
<tr>
<td>Level D</td>
<td>$\sigma_m \leq 2.0S$</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>$(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**

(1) These requirements for acceptability of pump design are not intended to ensure the operability of the pump.

(2) The maximum pressure shall not exceed the tabulated factors listed under $P_{\text{max}}$ times the Design Pressure.

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**NC-3424  Seal Housing**

A seal housing is defined as that portion of the pump cover or casing assembly that contains the seal and forms a part of the primary pressure boundary.

**NC-3425  Typical Examples of Pump Types**

Figures NC-3441.1-1 through NC-3441.9-2 are intended to be typical examples to aid in the determination of a pump type and are not considered as limiting.

**NC-3430  DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS**

(a) The design of welded construction shall be in accordance with NC-3450.
**NC-3432 Flanged Connections**

**(a)** Pumps with flanged connections that are cast integrally with the casing and meet all dimensional requirements (including tolerances) of flanged fittings (as shown in Table NCA-7100-1) with regard to the flange dimensions and required wall thicknesses, shall be considered to meet the pressure design requirements of this subarticle and are suitable for use within the pressure-temperature range shown in Section III Appendices, Mandatory Appendix I for the material utilized.

**(b)** Flanged connections not meeting the requirements of **(a)** shall be designed in accordance with Section III Appendices, Mandatory Appendix XI, Article XI-3000 or Section III Appendices, Nonmandatory Appendix L, Article L-3000.

**(c)** Pump flanges meeting all requirements of Table NCA-7100-1 and welded onto the integral inlets and outlets of the casing, shall be considered as meeting the pressure design requirements of this subarticle, provided that the inlet and outlet wall thicknesses comply with the standard flanged fitting. However, the nozzle-to-flange welds shall meet the requirements of **NC-1130**.

**NC-3432.2 External Loads.** When external nozzle loads interact with pumps, it is very likely that operability will dictate the maximum allowable loads. The major areas of concern are distortion of the casing and misalignment of driver and driven equipment. The casing shall be capable of withstanding the external loading plus the design pressure, provided in the Design Specification, without distortion that would impair the operation of the pump. In addition, the pump supports shall be capable of accommodating the external loads without sustaining any significant displacements that would cause unacceptable misalignment of rotating parts.

**(a)** Flanged connections meeting the requirements of **NC-3432.1** do not require further analysis when all requirements of **NC-3658.2** or **NC-3658.3** are met. All other flanged connections shall all meet the requirements of **(b)** below.

**(b)** Flanged connections shall meet the requirements of **NC-3658.1**.

**NC-3433 Reinforcement of Pump Casing Inlets and Outlets**

**NC-3433.1 Axially Oriented Inlets and Outlets.**

**(a)** An axially oriented pump casing inlet or outlet shall be considered similar to an opening in a vessel and shall be reinforced. It shall be treated as required in **NC-3330**.

**(b)** To avoid stress concentrations, the outside radius of Figures NC-3441.1(a)-1 and NC-3441.3-2 shall not be less than one-half the thickness of the inlet and outlets as reinforced.

**NC-3433.2 Radially Oriented Inlets and Outlets.** Reinforcement of radially oriented inlets and outlets is required. The applicable portions of **NC-3330** shall apply.

**NC-3433.3 Tangential Inlets and Outlets.** Except as modified in **NC-3433.4**, any design method that has been demonstrated to be satisfactory for the specified Design Loadings may be used.

**NC-3433.4 Minimum Tangential Inlet and Outlet Wall Thicknesses.** In Figure (c) of **NC-3433.4-1**, the value of \( l \), in. (mm), shall be determined from the relationship

\[
l = 0.5 \sqrt{r_i m}
\]

where

\[r_i = \text{maximum inlet or outlet inside radius, in. (mm)}
\]

\[d_i/2 = r_i + 0.5t_m, \text{ in. (mm)}
\]

\[t_m = \text{mean inlet or outlet wall thickness, in. (mm)}
\]

between section \( x-x \) and a parallel section \( y-y \) tangent to crotch radius.

The wall thicknesses of the inlet and outlet shall not be less than the minimum wall thickness of the casing for a distance \( l \) as shown in Figure **NC-3433.4-1**. The wall thickness beyond the distance \( l \) may be reduced to the minimum wall thickness of the connected piping. The change in wall thickness shall be gradual and have a maximum slope as indicated in Figure **NC-3450-1**.

**NC-3434 Bolting**

**NC-3434.1 Radially Split Configurations.** Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Section III Appendices, Mandatory Appendix XI.

**NC-3434.2 Axially Split Configurations.** Bolting in axially split configurations shall be designed in accordance with the procedure given in **NC-3441.7** for Type G pumps.

**NC-3435 Piping**

**NC-3435.1 Piping Under External Pressure.** Piping located within the pressure-retaining boundary of the pump shall be designed in accordance with **NC-3640**.
NC-3435.2 Piping Under Internal Pressure. Piping identified with the pump and external to or forming a part of the pressure-retaining boundary, such as auxiliary water connections, shall be designed in accordance with NC-3640.

NC-3436 Attachments

(a) External and internal attachments to pumps shall be designed so as not to cause excessive localized bending stresses or harmful thermal gradients in the pump. The effects of stress concentrations shall be considered.

(b) Attachments shall meet the requirements of NC-3135.

NC-3437 Pump Covers

Pump covers shall be designed in accordance with NC-3325 or NC-3326. Covers for which specific design rules are not given in NC-3325 or NC-3326 shall be designed by any method shown by analysis or experience to be satisfactory.

NC-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF, unless included under the rules of NC-3411.1(j).
**NC-3440 DESIGN OF SPECIFIC PUMP TYPES**

**NC-3441 Standard Pump Types**

**NC-3441.1 Design of Type A Pumps.** Type A pumps are those having single volutes and radially split casings with a single section as illustrated in Figures NC-3441.1-1 and NC-3441.1-2. Pumps with nozzle sizes NPS 4 (DN 100) discharge and smaller shall be constructed in accordance with (a) through (e). Larger pumps are permitted as stipulated in (f).

(a) **Casing Wall Thickness.** Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of \( t \), which is determined as follows:

\[
t = \frac{(P \cdot A)}{S}
\]

or 0.25 in. (6 mm), whichever is greater, where:

- \( A \) = scroll dimension, in. (mm), inside casing as shown in Figure NC-3441.1(a)-1. If the value of dimension \( A \) exceeds 20 in. (500 mm), the equation shall not be used and (f) below applies.
- \( P \) = Design Pressure, psig (MPa gage)
- \( S \) = allowable stress, including casting factor, psi (MPa) (NC-2571 and Section II, Part D, Subpart 1, Tables 1A and 1B)
- \( t \) = minimum allowable wall thickness, in. (mm)

(b) **Cutwater Tip.** The cutwater tip radius shall not be less than 0.05\( t \).

(c) **Cutwater Fillets.** All cutwater fillets, including the tips, where they meet the casing wall, shall have a minimum radius of 0.1\( t \) or 0.25 in. (6 mm), whichever is greater.

(d) **Crotch Radius** [Figure NC-3441.1(a)-1]. The crotch radius shall not be less than 0.3\( t \).

(e) **Bottom of Casing.** That section of the pump casing within the diameter defined by dimension \( A \) in Figure NC-3441.1(a)-1 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness the greater of \( t \) from (a) or \( t_b \). The value of \( t_b \) shall be determined by methods of NC-3320 or Section 1A.

---

1) For Class 2 pumps, the value of \( t_b \) shall be determined by the methods of NCD-3300 or Section III Appendices, Nonmandatory Appendix A using the appropriate equations for the casing shape or by methods permitted in Section III Appendices, Mandatory Appendix XIII.

2) For Class 3 pumps, the value of \( t_b \) shall be determined by the methods of NCD-3300 or Section III Appendices, Nonmandatory Appendix A using the appropriate equations for the casing shape.
Appendices, Mandatory Appendix I, Experimental Stress Analysis, or NCD-3414. If the design is qualified by analysis, the analysis shall be certified in accordance with NCA-3551.1.

(f) Pumps with an "A" dimension greater than 20 in. (500 mm) or nozzles larger than NPS 4 (DN 100) discharge are permitted. Design of these larger pumps must be performed in accordance with Section III Appendices, Mandatory Appendix XIII.

NC-3441.2 Design of Type B Pumps. Type B pumps are those having single volutes and radially split casings with double suction as illustrated in Figure NC-3441.2-1. Any design method that has been demonstrated to be satisfactory for the specified design conditions may be used.

NC-3441.3 Design of Type C Pumps. Type C pumps are those having double volutes and radially split casings with a single suction as illustrated in Figures NC-3441.3-1 and NC-3441.3-2. The splitter is considered a structural part of the casing. Casing design shall be in accordance with the requirements of this subarticle and with those given in (a) through (e) below.

(a) Casing Wall Thickness. Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of \( t \) determined as follows:

\[
t = \frac{0.5PA}{S}
\]

where

- \( A \) = scroll dimension inside casing as shown in Figure NC-3441.3-2, in. (mm)
- \( P \) = Design Pressure, psig (MPA gage)
\[ S = \text{allowable stress, including casting factor, psi (MPa) (NC-2571 and Section II, Part D, Subpart 1, Tables 1A and 1B)} \]
\[ t = \text{minimum allowable wall thickness, in. (mm)} \]

(b) Splitter Wall Thickness

(1) The splitter, which is considered a structural part of the casing, shall have a minimum wall thickness of \(0.7t\) as determined above for the casing wall and shall extend from point B in Figure NC-3441.3-2 sketch (a) through a minimum angle of 135 deg to point C. Beyond point C, the splitter wall may be reduced in thickness and tapered to blend with the cutwater tip radius.

(2) Cutwater tip and splitter tip radii shall not be less than 0.05\(t\).

(3) All cutwater and splitter fillets, including the tips, where they meet the casing wall, shall have a minimum radius of 0.1\(t\) or 0.25 in. (6 mm), whichever is greater.

(c) Crotch Radius (Figure NC-3441.3-2). The crotch radius shall not be less than 0.3\(t\).

(d) Bottom of Casing. That section of the pump casing within the diameter defined by dimension A in Figure NC-3441.3-2 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness no less than the value of \(t\) determined in (a) above.

(e) Alternative Rules for Casing Wall Thickness and Splitter Wall Thickness. As an alternative to (a) and (b) above, it is permissible to use a smaller casing wall thickness and a larger splitter wall thickness when requirements of (1) through (3) below are met.

(1) The casing wall thickness, as determined by (a) above, shall be maintained at a minimum \(t\) between the tangent point of the crotch radius to a point D radially opposite the splitter tip [Figure NC-3441.3-2 sketch (b)]. The casing wall shall be decreased uniformly to point E from which point a minimum thickness of \(0.7t\) shall be continued around the casing wall to a point on the discharge nozzle a distance \(l\) from the crotch, where \(l\) is defined in Figure NC-3433.4-1.

(2) The splitter wall thickness shall be as defined in (b) above, except that the splitter shall have a minimum thickness \(t\) instead of \(0.7t\).

(3) The requirements of (b)(2) and (b)(3) above shall apply.

NC-3441.4 Design of Type D Pumps.

(a) Type D pumps are those having double volutes and radially split casings with double suction as illustrated in Figure NC-3441.4(a)-1. Their design shall be in accordance with the applicable requirements of NC 3400.

(b) The requirements of NC 3441.3(a), NC 3441.3(b), and NC 3441.3(c), governing casing wall thickness, splitter wall thickness, and crotch radius, apply.

(c) In the casing portion between the cover and the casing wall, a wall thickness in excess of \(t\) may be required.

NC-3441.5 Design of Type E Pumps. Type E pumps are those having volute-type radially split casings and multivane diffusers which form a structural part of the casing as illustrated in Figure NC-3441.5-1. The design shall be in accordance with the applicable requirements of NC 3400.

NC-3441.6 Design of Type F Pumps.

(a) Type F pumps are those having radially split, axisymmetric casings with either tangential or radial outlets as illustrated in Figure NC-3441.6(a)-1. The basic configuration of a Type F pump casing is a shell with a dished head attached at one end and a bolting flange at the other. The outlet may be either tangent to the side or normal to the center line of the casing. Variations of these inlet and outlet locations are permitted.

(b) The design of Type F pumps shall be in accordance with the applicable requirements of NC 3400.
Figure NC-3441.3-2
Type C Pump

Cutwater tip radius
0.05t min.

Crotch radius
0.3t min.

Inlet
135 deg min.

Outlet

Point C

Point B

Outlet

Splitter tip radius

Uniform transition t to 0.7t wall thickness (min.)

See NC-3433.4

(a) Standard

Cutwater tip radius
0.05t min.

Crotch radius
0.3t min.

Outlet

Point B

Outlet

Point D

Cutwater tip radius
0.05t min.

Inlet

Bottom of casing t min.

0.7t min.

0.7t min.

0.7t min.

(b) Alternate

See NC-3433.4

0.7t min. wall thickness for this distance
An acceptable method for calculating the stress in the most highly stressed section of the pump case, such as the section with the greatest span, is given in (1) and (2) below. This method is not acceptable for those designs in which more than one bolt falls within a given section \[\text{Figure NC-3441.7(c)-1, Section B}\]. It is recognized that other acceptable procedures may exist that also constitute adequate design methods, and it is not the intention to rule out these alternative methods, provided they can be shown to have been satisfactory by actual service experience.

(1) The following assumptions are made:
   (-a) assign one bolt to Section \(X\); assign one half bolt to Section \(Y\), and one half bolt to Section \(Z\) (Section \(Z\) is identical to Section \(Y\));
   (-b) the flange and bolts act together in bending;
   (-c) the maximum moment occurs at the bolt;
   (-d) the total moment is distributed between the flange and case in proportion to their moments of inertia.

(2) Typical sections are shown in \(\text{Figures NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3}\). The procedure for the calculation is given in (-a) through (-o) below.

(-a) Establish the Design Pressure \(P\), psi (MPa).
(-b) Establish dimensions \(A, B, C, F, R, t_c, t_f, w,\) and \(b\) from \(\text{Figures NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3}\) and determine the following:

\[
A_b = \text{bolt root area, in.}^2 (\text{mm}^2)
\]
\[
A_G = \text{effective gasket area, in.}^2 (\text{mm}^2)
\]
\[
D = \text{diameter of bolt hole, in. (mm)}
\]
\[
d = \text{bolt root diameter, in. (mm)}
\]

\[
\text{DTF} = \text{Design Temperature, °F (°C)}
\]

\[
\text{Tangent Point} h
\]
\[
R
\]
**NC-3441.7 Design of Type G Pumps.**

(a) Type G pumps are those having axially split, single- or double-volute casings [Figures NC-3441.7(a)-1 and NC-3441.7(a)-2].

(b) Manufacturers proposing this design should thoroughly review nondestructive examination requirements for compatibility.
An acceptable method for calculating the stress in the most highly stressed section of the pump case, such as the section with the greatest span, is given in (1) and (2) below. This method is not acceptable for those designs in which more than one bolt falls within a given section [Figure NC-3441.7(c)-1, Section B-B]. It is recognized that other acceptable procedures may exist that also constitute adequate design methods, and it is not the intention to rule out these alternative methods, provided they can be shown to have been satisfactory by actual service experience.

(1) The following assumptions are made:

(-a) assign one bolt to Section $X$; assign one-half bolt to Section $Y$, and one-half bolt to Section $Z$ (Section $Z$ is identical to Section $Y$);

(-b) the flange and bolts act together in bending;

(-c) the maximum moment occurs at the bolt;

(-d) the total moment is distributed between the flange and case in proportion to their moments of inertia.

(2) Typical sections are shown in Figures NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3. The procedure for the calculation is given in (-a) through (-o) below.

(-a) Establish the Design Pressure $P$, psi (MPa). Establish dimensions $A$, $B$, $C$, $F$, $R$, $t_c$, $t_f$, $w$, and $b$ from Figures NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3 and determine the following:

$A_b = \text{bolt root area, in.}^2 (\text{mm}^2)$

$A_G = \text{effective gasket area, in.}^2 (\text{mm}^2)$

$D = \text{diameter of bolt hole, in.} (\text{mm})$

$d = \text{bolt root diameter, in.} (\text{mm})$

$\text{DTF} = \text{Design Temperature, } ^\circ F (^\circ C)$
$E$ = modulus of elasticity of bolt at service temperature, psi (MPa)  
$e$ = unit thermal elongation of bolt, in./in. (mm/mm)  
$G = B + 0.5t_c$, in. (mm)  
$m$ = gasket factor (Section III Appendices, Mandatory Appendix XI, Table XI-3221.1-1)  
$R = C - (B + t_c)$, in. (mm)  
$S_b = $ allowable stress, bolt, psi (MPa)  
$S_c = $ allowable stress, case, psi (MPa)  
$W = $ load used in calculating preliminary bolt stress, lb (N)  
\[ = W_X, W_Y, W_Z \]

$y$ = gasket design seating stress, psi (MPa) (Section III Appendices, Mandatory Appendix XI, Table XI-3221.1-1)  

(-b) Determine the effective gasket area $A_G$, in.$^2$ (mm$^2$), for Sections $X$ and $Y$:

\[
A_G = \left( A - f \right) w - \frac{\pi D^2}{4} \times K
\]

For the factor $K$, use 0.20 if case face is crowned for greatest contact pressure at inner edge and use 0.50 for flat surfaces.
(c) Determine bolt load, lb (N), and preliminary bolt stress $\sigma_{\text{PRE}}$, psi (MPa):

$$H = G \times w \times P$$

$$H_p = A_G \times m \times P$$

$$W_{m1} = H + H_p$$

$$W_{m2} = 0.5A_Gw$$

$$W = \max(W_{m1}, W_{m2})$$

$$\sigma_{\text{PRE}} = \frac{W}{A_b}$$

(d) Determine the total load $H_o$, lb (N):

$$H_D = B \times w \times P$$

$$H_G = H_p$$

$$H_T = H - H_D$$

$$H_o = H_D + H_G + H_T$$

(e) Determine the lever arms $h_D$, $h_G$, and $h_T$, in. (mm):

$$h_D = R + 0.5t_c$$

$$h_G = h_D$$

$$h_T = 0.5(R + t_c + h_G)$$

(f) Determine the total moment $M_o$, in.-lb (N-mm):

$$M_D = H_Dh_D$$

$$M_G = H_Gh_G$$

$$M_T = H_Th_T$$

$$M_o = M_D + M_G + M_T$$

(g) Determine the moments of inertia, in.\(^4\) (mm\(^4\)), $I_F$ (flange), $I_B$ (bolt), $I_C$ (case), and $I_T$ (total):

$$I_F = \left[ \frac{w(t_f)^3}{12} \right] - \left[ \frac{D(t_f)^3}{12} \right]$$

$$I_B = 0.049a^4$$

$$I_C = \frac{w(t_c)^3}{12}$$

$$I_T = I_F + I_B + I_C$$
(-h) Determine the moments, in.-lb (N·mm), carried \( M_F \) (flange), \( M_B \) (bolt), and \( M_C \) (case):

\[
M_F = M_0 F / l_T
\]
\[
M_B = M_0 B / l_T
\]
\[
M_C = M_0 C / l_T
\]

(-i) Determine the resultant bolt load \( F_R \), lb (N):

\[
F_R = \left[ H_B(b + h_B) + H_C(b + h_C) + H_f(b + h_f) - M_C - M_B \right] / b
\]

or

\[
F_R = H_0 + \left[ (M_0 - M_C - M_B) / b \right]
\]

(-j) Determine the resultant bolt stresses, psi (MPa)

\[
\sigma_{\text{load}} = F_R / A_b
\]
\[
\sigma_{\text{temp}} = eE
\]
\[
\sigma_{\text{tensile}} = \sigma_{\text{load}} + \sigma_{\text{temp}}
\]
\[
\sigma_{\text{bending}} = M_{bd} / 2l_b
\]

(-k) Determine the shear and bending flange stresses \( \sigma'_s \), psi (MPa), and \( \sigma'_B \), psi (MPa), respectively

\[
\sigma'_s = H_0 / w t_f
\]
\[
\sigma'_B = M_{C_F} / 2l_C
\]

(-l) Determine the tensile and bending case stresses \( \sigma''_s \), psi (MPa), and \( \sigma''_B \), psi (MPa), respectively

\[
\sigma''_s = H_B / w t_c
\]
\[
\sigma''_B = M_{Case} / 2l_C
\]

The combined stress \( S_{\text{COMB}} \) is as follows:

\[
S_{\text{COMB}} = \left( \frac{F_X}{S_X} + \frac{F_Y}{S_Y} \right) / \left[ \left( \frac{F_X}{S_X} \right)^2 + \left( \frac{F_Y}{S_Y} \right)^2 \right]^{1/2}
\]

(-m) Determine the maximum stresses using (-1) through (-4) below.

1. To determine the preliminary bolt stress, establish the load \( W \) and the stress \( \sigma_{\text{PRE}} \) for Section \( X \) and for Section \( (Y + Z) \)

\[
\sigma_{\text{PRE}} = \frac{W_X + W(Y + Z)}{W_X + W(Y + Z)}
\]

The allowable limit for this stress is \( S_b \).

2. To determine the resultant bolt stress, establish the load \( F_R \) and the stresses \( \sigma_t \) and \( \sigma_b \) for Section \( X \) and for Section \( (Y + Z) \)

\[
\sigma_t = \frac{F_{RX} + F_{RY}(Y + Z)}{F_{RX} + F_{RY}(Y + Z)}
\]
\[
\sigma_b = \frac{F_{RX} + F_{RY}(Y + Z)}{F_{RX} + F_{RY}(Y + Z)}
\]

The allowable limit for \( \sigma_{t,\text{COMB}} \) is \( 2S_b \).

3. To determine the flange stresses, establish the load \( H_o \), the shear stress \( \sigma'_s \), and the bending stress \( \sigma'_B \) for Section \( X \) and for Section \( (Y + Z) \)

\[
\sigma'_s = \frac{H_{OX} + H_{OY}(Y + Z)}{H_{OX} + H_{OY}(Y + Z)}
\]
\[
\sigma'_B = \frac{H_{OX} + H_{OY}(Y + Z)}{H_{OX} + H_{OY}(Y + Z)}
\]

The allowable limit for \( \sigma'_{s,\text{COMB}} + \sigma'_{b,\text{COMB}} \) is \( 3S_b \).

4. To determine the tensile stress \( \sigma''_s \), and the bending stress \( \sigma''_B \) for Section \( X \) and for Section \( (Y + Z) \)

\[
\sigma''_s = \frac{H_{DX} + H_{DY}(Y + Z)}{H_{DX} + H_{DY}(Y + Z)}
\]
\[
\sigma''_B = \frac{H_{DX} + H_{DY}(Y + Z)}{H_{DX} + H_{DY}(Y + Z)}
\]

\[
\sigma'_{\text{max}} = \left[ \sigma'_{s,\text{COMB}}^2 + \left( \sigma'_{b,\text{COMB}} / 2 \right)^2 \right]^{1/2}
\]
\[
\sigma''_{\text{max}} = \sigma'_{\text{max}} + \sigma''_B / \text{COMB} / 2
\]

where \( \sigma''_{\text{max}} \) is the maximum normal stress. The allowable limit for \( \sigma''_{\text{max}} \) is \( S_c \) and the allowable limit for \( \sigma''_{\text{max}} \) is \( 1.5S_c \).
(4) To determine the case stresses, establish the load \( H_D \), the tensile stress \( \sigma''_t \), and the bending stress \( \sigma''_b \) for Section \( X \) and for Section \((Y + Z)\)

\[
\sigma''_{t\text{COMB}} = \frac{\frac{H_D}{\sigma''_t} + \frac{H_D}{\sigma''_t(Y + Z)}}{\sigma''_t(X) + \frac{\sigma''_t(Y + Z)}}
\]

\[
\sigma''_{b\text{COMB}} = \frac{\frac{H_D}{\sigma''_b} + \frac{H_D}{\sigma''_b(Y + Z)}}{\sigma''_b(X) + \frac{\sigma''_b(Y + Z)}}
\]

The allowable limit for \( \sigma''_{t\text{COMB}} \) is \( S_c \). The total stress is \( \sigma''_{t\text{COMB}} + \sigma''_{b\text{COMB}} \). The allowable limit for total stress is \( 1.5S_c \).

(\text{-o}) The above procedure will generally show some bolt stresses in excess of the indicated allowable values. Under these circumstances it is permissible to average bolt stresses between adjacent bolts. Such averaged stresses shall not exceed the specified allowables.
To determine the case stresses, establish the load \( H_D \), the tensile stress \( \sigma \), and the bending stress \( \sigma_b \) for Section \( X \) and for Section \( (Y + Z) \).

The allowable limit for \( \sigma \) is \( S_c \). The total stress is \( \sigma_t \). The allowable limit for total stress is 1.5 \( S_c \).

The above procedure will generally show some bolt stresses in excess of the indicated allowable values. Under these circumstances it is permissible to average bolt stresses between adjacent bolts. Such averaged stresses shall not exceed the specified allowables.

NC-3441.8 Design of Type H Pumps. Type H pumps are those having axially split, barrel-type casings (Figures NC-3441.8-1 and NC-3441.8-2) and radially split covers. The axially split casing shall be designed in accordance with the rules of NC-3441.7 for Type G pumps. The radially split cover shall be designed in accordance with the rules of NC-3437.

NC-3441.9 Design of Type K Pumps. Type K pumps are vertical pumps of one or more stages having a radially split casing as illustrated in Figures NC-3441.9-1 and NC-3441.9-2. The basic configuration is a casing consisting of a barrel and a head joined by bolted flanges. There is an inner assembly consisting of internal chambers of the head, one or more bowls, column sections, and a suction bell, all joined by flanges and arranged so that the external surfaces of these parts are subjected to inlet pressure. These pumps may be furnished with or without column(s) and with or without lateral restraints between the inner assembly and outer casing.

(a) Casing. The barrel and head of the casing shall be designed in accordance with the requirements of NC-3400 and with those given in (1) through (3) below.

(1) Barrel. The Design Pressure for the barrel shall be the pump inlet pressure or as otherwise stated in the Design Specification (NCA-3250), but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition. The static head shall be considered in the selection of the Design Pressure.

(2) Head. The external walls of the head, which form the pressure boundary, shall be designed for the pressures specified in (b) and (c) below. The Design Pressure for the internal chambers shall be as specified under the inner assembly rules.

(b) The Design Pressure for the portions of the head that form the pressure boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump outlet under any Service Condition.

(c) The Design Pressure for the portions of the head that form the pressure-containing boundary between the inlet pressure and the atmosphere shall be the inlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition.
Determine the shear and bending flange stresses, psi (MPa), and the tensile and bending case stresses, psi (MPa), respectively.

Use the following method for combining stresses in combined sections:

The combined stress $S_{COMB}$ is as follows:

Determine the maximum stresses using the following:

1. To determine the preliminary bolt stress, establish the load $W$ and stress $\sigma_{PRE}$ for Section X and for Section ($Y + Z$). The allowable limit for this stress is $S_b$.

2. To determine the resultant bolt stress, establish the load $F_R$ and the stresses $\sigma_t$ and $\sigma_b$ for Section X and for Section ($Y + Z$). The allowable limit for $\sigma_t$ is $2S_b$. The allowable limit for $\sigma_t + \sigma_b$ is $3S_b$.

3. To determine the flange stresses, establish the load $H_o$, the shear stress, and the bending stress for Section X and for Section ($Y + Z$), where $\sigma$ is the maximum normal stress. The allowable limit for $\sigma$ is $S_c$ and the allowable limit for $\sigma + \sigma_b$ is $1.5S_c$.

4. To determine the case stresses, establish the load $H_D$, the tensile stress, and the bending stress for Section X and for Section ($Y + Z$). The allowable limit for $\sigma$ is $S_c$. The total stress is $\sigma + \sigma_b$. The allowable limit for total stress is $1.5S_c$.

The above procedure will generally show some bolt stresses in excess of the indicated allowable values. Under these circumstances it is permissible to average bolt stresses between adjacent bolts. Such averaged stresses shall not exceed the specified allowables.

ND-3441.8 Design of Type H Pumps. Type H pumps are those having axially split, barrel-type casings (Figures ND-3441.8-1 and ND-3441.8-2) and radially split covers. The axially split casing shall be designed in accordance with the rules of ND-3441.7 for Type G pumps. The radially split cover shall be designed in accordance with the rules of ND-3437.

ND-3441.9 Design of Type K Pumps. Type K pumps are vertical pumps of one or more stages having a radially split casing, as illustrated in Figures ND-3441.9-1 and ND-3441.9-2. The basic configuration is a casing consisting of a barrel and a head joined by bolted flanges.
is an inner assembly consisting of internal chambers of the head, one or more bowls, column sections, and a suction bell, all joined by bolted flanges and arranged so that the external surfaces of these parts are subjected to inlet pressure. These pumps may be furnished with or without column(s) and with or without lateral restraints between the inner assembly and outer casing.

**Flanged Joints.** Except for flanged joints conforming to (5), flanged joints may be analyzed and the stresses evaluated by using methods given in Section III Appendices, Mandatory Appendix XI if of the "RF" type and in accordance with Section III Appendices, Nonmandatory Appendix L if of the "FF" type, as modified by (1) through (4) below or by (5) below.

1. The Design Pressure to be used for the calculation of $H$ in Section III Appendices, Mandatory Appendix XI or Section III Appendices, Nonmandatory Appendix L shall be replaced by the flange design pressure $P_{FD} = P + P_{eq}$ (1)

where

- $P$ = design or Service Condition Pressure as defined in NCA-2140 psi (MPa)
- $P_{eq}$ = equivalent pressure to account for the axial force and moments applied to the flange joint, psi (MPa)

The equivalent pressure, $P_{eq}$, shall be determined from the seismic and external loads acting on the flanged joint using the equation

$$P_{eq} = \frac{KM_f}{\pi G^2} + \frac{4F}{\pi G^2}$$

where

- $F$ = the axial load at the flange, lbf (N)
- $G$ = the diameter at the location of the gasket load reaction, in. (mm)
- $K$ = If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.

2. The allowable stress limits $S_H$, $S_R$, and $S_T$ shall not be greater than 1.5 $S_0$. (4)

3. If the flanged joint conforms to one of the standards listed in Table NCA-7100-1 and if each $P_{FD}$ as calculated by eq. (1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied. (5)

**Casing.** The barrel and head of the casing shall be designed in accordance with the requirements of NCD-3400 and with those given in (1) and (2) below.

1. Barrel. The Design Pressure for the barrel shall be the pump inlet pressure or as otherwise stated in the Design Specification (NCA-3250), but in no case shall it be
Figure ND-3441.9-1
Type K Pump

- Seal housing extension
- Head
- Outlet
- Inlet
- Internal chamber of head
- Column
- Bowl
- Barrel
- Lateral restraint (optional)
- Bowl
- Suction bell
- Lateral restraint (optional)
Figure ND3441.9-2
Type K Pump

- Head
- Internal chamber of head
- Inlet
- Outlet
- Column
- Bowl
- Barrel
- Lateral restraint (optional)
- Suction bell
- Lateral restraint (optional)
The minimum thickness of the head waterway shall be determined by the equation

\[
t_m = \frac{P D_o}{2(SE + Py)} + A
\]

where

- \( A \) = corrosion or erosion allowance as specified by the Design Specification, in. (mm). If both surfaces are wetted, the corrosion allowance must be applied to both surfaces.
- \( D_o \) = the outside diameter of the head waterway, in. (mm)
- \( d \) = inside diameter of the head waterway, in. (mm)
- \( E \) = the joint efficiency for the type of longitudinal joint used, as given in Table 1A or Table 1B, or casting quality factor as given in the notes to Section II, Part D, Subpart 1, Tables 1A and 1B.
- \( S \) = the allowable stress for the material at the design temperature (Section II, Part D, Subpart 1, Tables 1A and 1B), psi (MPa)
- \( t_m \) = minimum required wall thickness of the head waterway in its finished form, in. (mm)
- \( y = 0.4 \) for \( D_o/t_m \) greater or equal to 6.0
- \( = \) \( d + D_o \) for \( D_o \) / \( t_m \) less than 6.0

The above head waterway minimum thickness is in its finished form. If curved segments of pipe are used as the waterway, the minimum wall thickness after bending shall be not less than the required value.

The discharge nozzle loads shall include the Design Pressure and piping moments. The equivalent pressure shall be determined using eq. \((a)(1)(1)\) with \( F = 0 \) in eq. \((a)(1)(2)\) as applied to the head geometry.

(c) The Design Pressure for the portions of the head that form the pressure-containing boundary between the inlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump outlet under any Service Condition.

This portion of the head shall be designed in accordance with ND 3320 for pressure vessels.

(b) The Design Pressure for the portions of the head that form the pressure boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump outlet under any Service Condition.

The inlet nozzle loads shall include the Design Pressure and piping moments. The equivalent pressure shall be determined using eq. \((a)(1)(1)\) with \( F = 0 \) in eq. \((a)(1)(2)\) as applied to the head geometry.

The discharge nozzle loads shall include the Design Pressure and piping moments. The equivalent pressure shall be determined using eq. \((a)(1)(1)\) with \( F = 0 \) in eq. \((a)(1)(2)\) as applied to the head geometry.

The pump and those which do not form part of the pressure boundary to the atmosphere.
differential pressure that can be developed across the wall of that column under any Service Condition. Unpacked flange joints are permitted.

(3) Bowls. The Design Pressure for the bowl(s), \( P_b \), shall include the piping moments. The equivalent pressure shall be determined using eq. (a)(1)(1) with \( F = 0 \) in eq. (a)(1)(2), as applied to the bowl geometry and shall be determined as the maximum differential pressure to which the bowl may be subjected under any Service Condition.

The design of the bowls shall be completed in accordance with (a) through (c) below for unribbed bowl geometries. For those bowl geometries which use external ribs to increase bowl and flange stiffness the design shall be completed using methods which have been proven in actual service. Unless special provisions are made to ensure that interchangeability between bowls is prevented all bowls shall be designed to the same requirements.

(a) Bowl Minimum Thickness. The minimum thickness of the bowl shell, remote from discontinuities, shall be not less than that determined by

\[
t_m = \frac{P_b D_0}{2(SE + P_{b,0}')} + A
\]

where the terms are as defined in (b)(2)(b) but as applied to the bowl geometry and material and the bowl minimum thickness is applicable only to a location within the bowl which is remote from discontinuities and may have to be increased in order to satisfy the local evaluations of (b) and (c) below.

(b) Vane/Shell Interaction. Consideration shall be given to the restraining effect of the diffuser vanes on the radial expansion of the shell due to internal pressure. An acceptable method of accounting for this effect is presented below

\[
F_D = \frac{2 (2 - \mu) P_b A_D^2}{16 l_D t_D} + \frac{P_b \pi A_D}{n_v t_D^3}
\]

where

- \( A_D \) = the mean diameter of the vane portion of the bowl as defined in Figure ND-3441.10-2, in. (mm)
- \( F_D \) = vane load/unit length, lb/in. (N/m)
- \( l_D \) = the radial mean vane length as defined in Figure ND-3441.10-2, in. (mm)
- \( n_v \) = the number of vanes in the bowl waterway
- \( P_b \) = the maximum internal bowl differential pressure, psi (MPa)
- \( t_D \) = the shell thickness at the vane-shell intersection as defined in Figure ND-3441.10-2, in. (mm)
- \( t_v \) = the mean vane thickness, in. (mm)
- \( \mu \) = Poisson’s ratio

The local shell bending stress, \( \sigma_B \), shall be less than \( 1.5SE \). Its value is determined by the equation

\[
\sigma_B = \frac{3 F_D \pi A_D}{n_v A_D^2} \quad (8)
\]

The vane membrane stress, \( \sigma_v \), shall be less than \( SE \) as determined by the equation

\[
\sigma_v = \frac{F_D}{t_v} \quad (9)
\]

(c) Bowl Flanges. The flange joint between the individual bowl discharge flange and the next stage bowl inlet flange is usually such that the outlet flange rotational restraint is insufficient to restrict outlet flange rotation. Therefore, the prying action between flat faced flanges can be ignored and the outlet flange shall be analyzed in accordance with Section III Appendices, Mandatory Appendix XI. This may not be true for ribbed flanges or the last stage bowl that attaches to the column assembly. If any of these joints have sufficient rigidity to support the prying action it shall be analyzed as an Section III Appendices, Nonmandatory Appendix I, flange. The analysis shall be in accordance with (a) using eq. (a)(1)(1) with \( F = 0 \) in eq. (a)(1)(2). The definition of the outlet flange geometry for the analysis is shown in Figure ND-3441.10-2.

The minimum radial distance between the bolt circle and the outside of the bowl or the inside rabbit fit shall be equal to or greater than one bolt diameter.

(4) Suction Bell. The Design Pressure for the suction bell, \( P_{sb} \), shall be determined as the sum of the differential pressure developed at the first stage of the pump under any service condition plus an equivalent pressure to account for moments on the suction bell. The equivalent pressure shall be calculated using eq. (a)(1)(1) with \( F = 0 \) in eq. (a)(1)(2). The suction bell pressure, \( P_{sb} \), is applied only to the suction bell flange. Below the suction bell flange (the section above line A-A in Figure ND-3441.9-1 and ND-3441.9-2), the remaining portions of the bell are not considered subject to a differential pressure.

(5) Each bowl and suction bell shall be manufactured of material meeting the rules of NCD-2190 and designed using the casting quality factor as given in the notes to Section II, Part D, Subpart 1, Tables 1A and 1B.
Notes to Editor:

1. This content is taken from the current ND-3400 in the 2019 Edition.

2. Replace all occurrences of "ND: -" with "NCD: -". This applies for the entire Subarticle, including all text, figures, and tables.

3. Cross check all references to Articles 1000, 2000, 3000, 4000, 5000, 6000, and 7000 to confirm that the paragraph number was not changed in another record.
atmospheric pressure plus submerged head pressures. Because of the installation and operation, pumped fluids within the bowl and column assemblies may transfer through the flanged connections back to the fluid source. This fluid transfer does not affect the integrity of the overall pressure boundary.

Type L pumps shall be designed in accordance with the requirements of ND 3400 and with those given in (a) through (e) below. Alternatively, the configuration may be designed in accordance with Section III Appendices, Mandatory Appendix II, Design by Experimental Stress Analysis, or Section III Appendices, Mandatory Appendix XIII, Design Based on Stress Analysis.

(a) Flanged Joints. Except for flanged joints conforming to (5) below, flanged joints may be analyzed and the stresses evaluated by using methods given in Section III Appendices, Mandatory Appendix XI if of the "RF" type and in accordance with Section III Appendices, Nonmandatory Appendix L if of the "FF" type, as modified by (1) through (4) below.

(1) The Design Pressure to be used for the calculation of \( H \) in Section III Appendices, Mandatory Appendix XI or Section III Appendices, Nonmandatory Appendix L shall be replaced by the flange design pressure

\[
P_{FD} = P + P_{eq}
\]

where

\( P \) = Design or Service Condition Pressure as defined in ND 3441.9(a)(1)(1) \( \text{psi (MPa)} \)

\( P_{eq} \) = equivalent pressure to account for the moments applied to the flange joint, \( \text{psi (MPa)} \)

(2) The equivalent pressure \( P_{eq} \) shall be determined from the seismic and external loads acting on the flanged joint using the equation

\[
P_{eq} = \frac{K M_f}{\pi G^{3/2}} + \frac{P B}{4 F}
\]

where

\( F \) = the axial load at the flange, lb (N)

\( G \) = the diameter at the location of the gasket load reaction, in. (mm)

\( K \) = If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.

\( M_f \) = the resultant bending moment on the flange joint, in.-lb (N-mm)

(3) Section III Appendices, Mandatory Appendix XI, XI-3240, eq. (6) for longitudinal hub stress shall be revised to include primary axial membrane stress as follows:

\[
S_H = \frac{f M_g}{L G^{3/2} B} + \frac{P B}{4 G O}
\]

where \( P \) is the Design or Service Pressure as defined in ND 3441.9(a)(1)(1) \( \text{psi (MPa)} \). Other terms are defined in Section III Appendices, Mandatory Appendix XI, XI-3130.

(4) The allowable stress limits \( S_H, S_R, \) and \( S_T \) shall not be greater than 1.55.

(5) If the flanged joint conforms to one of the standards listed in Table ND-3350 and if each \( P_{FD} \) as calculated by eq. ND-3441.9(a)(1)(1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied.

(b) Head Waterway. The Design Pressure for portions of the head which form the pressure boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification. In no case shall it be less than the maximum pressure at the pump outlet under any Service Condition. The minimum thickness of the head waterway required for Design Pressure and for temperatures not exceeding those for various materials in Section II, Part D, Subpart 1, Tables 1A and 1B shall be not less than that determined by the equation

\[
A = \frac{4 F}{\pi G^2} + \frac{P D_o}{2 (S E + P y)} + A
\]

where

\( A \) = corrosion or erosion allowance as specified by the Design Specification, in. (mm). If both surfaces are wetted, the corrosion allowance must be applied to both surfaces.

\( D_o \) = the outside diameter of the head waterway, in. (mm)

\( d \) = inside diameter of the head waterway, in. (mm)

\( E \) = the joint efficiency for the type of longitudinal joint used, as given in ND 3350 or casting quality factor as given in the notes to Section II, Part D, Subpart 1, Tables 1A and 1B

\( S \) = the allowable stress for the material at the design temperature (Section II, Part D, Subpart 1, Tables 1A and 1B), psi (MPa)

\( t_m \) = minimum required wall thickness of the head waterway in its finished form, in. (mm)

\[
y = 0.4 \quad \text{for} \quad D_o/t_m \geq 6.0
\]

\[
y = \frac{d}{d + D_o} \quad \text{for} \quad D_o/t_m < 6.0
\]
The above head waterway minimum thickness is in its finished form. If curved segments of pipe are used as the waterway, the minimum wall thickness after bending shall be not less than the required value.

(c) Column. The Design Pressure for the column $P_c$ shall include the effects of the piping moments and axial loads. It shall be not less than the maximum differential pressure that can be developed across the wall of that column under any Service Condition. The weight of the pump bowls and impeller thrust shall be taken into consideration. $P_c$ shall be determined using eqs. (a)(1)(1) and (a)(1)(2) but with “G” equal to the average column shell diameter.

(1) Column Thickness. The minimum thickness of the column shall be not less than that determined by the equation

$$t_m = \frac{P_c D_o}{2(SE + P_v)} + A$$  \hspace{1cm} (5)

where the terms are as defined in (b) above, except as applied to the column geometry and material.

(2) Column Flanges. Flanged joints in the column shall be designed in accordance with (a) except that the design pressure shall be $P_c$. The equivalent pressure shall be determined using eq. (a)(1)(1) as applied to the column geometry and shall be not less than the maximum differential pressure which can be developed across the wall of that column under any Service Condition. Unpacked flange joints are permitted.

(4) Bowls. The Design Pressure for the bowl(s) $P_b$ shall be determined as the maximum differential pressure to which the bowl may be subjected under any service condition.

The design of the bowls shall be completed in accordance with (1) through (3) below for unribbed bowl geometries. For those bowl geometries that use external ribs to increase bowl and flange stiffness, the design shall be completed using methods that have been proven in actual service. In both cases, the pump bowl experiencing the largest load shall be used in the design. Unless special provisions are made to ensure that interchangeability between bowls is prevented, all bowls shall be designed to the same requirements.

(1) Bowl Minimum Thickness. The minimum thickness of the bowl shell, remote from discontinuities, shall be not less than that determined by

$$t_m = \frac{P_b D_o}{2(SE + P_v)} + A$$  \hspace{1cm} (6)

where

$D_o$ = the largest outside diameter of the bowl, taken at the suction end of the individual bowl assembly (Figure ND 3441.10-2), in. (mm)

The above minimum bowl thickness is applicable only to a location within the bowl that is remote from discontinuities and may have to be increased in order to satisfy the local evaluations of (2) and (3) below.

(2) Vane/Shell Interaction. Consideration shall be given to the restraining effect of the diffuser vanes on the radial expansion of the shell due to internal pressure. An acceptable method of accounting for this effect is presented below.

$$F_D = \frac{2(2 - \mu) P_b A_D^2}{16 \lambda f D_o} + \frac{t_D \pi D_o}{2}$$  \hspace{1cm} (7)

where

$A_D$ = the mean diameter of the vaned portion of the bowl as defined in Figure ND 3441.10-2, in. (mm). The section shall be taken at a portion of the bowl where the hub can be considered essentially solid.

$F_D$ = vane load/unit length, lbf/in. (N·mm)

$t_D$ = the radial mean vane length as defined in Figure ND 3441.10-2, in. (mm)

$n_v$ = the number of vanes in the bowl waterway

$P_b$ = the maximum internal bowl differential pressure, psi (MPa)

$\mu$ = Poisson’s ratio

The local shell bending stress $\sigma_v$ shall be less than 1.5SE. Its value is determined by the equation

$$\sigma_v = \frac{F_D}{t_D}$$  \hspace{1cm} (8)

(3) Bowl Flanges. Flanged joints in the bowls shall be designed in accordance with (a) except that the design pressure shall be $P_b$. The equivalent pressure shall be determined using eq. (a)(1)(1), as applied to the bowl geometry and shall be not less than the maximum differential pressure that can be developed across the wall of that bowl under any Service Condition. Unpacked flange joints are permitted. The flange joint between the individual bowl discharge flange and the next stage bowl inlet flange is usually such that the outlet flange rotational restraint is insufficient to restrict outlet flange rotation. Therefore, the prying action between flat faced flanges can be ignored and the outlet flange shall be analyzed in accordance with Section III Appendices, Mandatory Appendix XI. This may not be true for ribbed flanges or the last stage bowl that attaches to the column assembly. The definition of the outlet flange geometry for the analysis is shown in Figure ND 3441.10-2.
Figure ND-3441.10-2
Type L Pump Bowl
The minimum radial distance between the bolt circle and the outside of the bowl or the inside rabbet fit shall be equal to or greater than one bolt nominal diameter.

(e) Suction Bell. The Design Pressure for the suction bell \( P_{sb} \) shall be determined as the sum of the differential pressure developed at the first stage of the pump under any service condition plus an equivalent pressure to account for moments on the suction bell. The equivalent pressure shall be calculated using eq. (a)(1)(1), with \( F = 0 \) in eq. (a)(1)(2), except using the geometry of the suction bell. The suction bell pressure, \( P_{sb} \), is applied only to the suction bell flange. Below the suction bell flange (Section A-A of Figure ND-3441.10-1), the remaining portion of the bell and any strainer basket that may be attached thereto are not considered subject to a differential pressure load.
Notes to Editor:
1. This content is taken from the current NC-3400 in the 2019 Edition.
2. Replace all occurrences of "NC-" with "NCD-". This applies for the entire Subarticle, including all text, figures, and tables.
3. Cross check all references to Articles 1000, 2000, 3000, 4000, 5000, 6000, and 7000 to confirm that the paragraph number was not changed in another record.

Change NC-3441.10 to NCD-3441.11

**NC-3441.10 Type N Pumps**

*(a)* Type N pumps have radially split, multistage barrel type casings with single nozzles each for suction and discharge, radially disposed with respect to the shaft axis [Figure NC-3441.10-1, sketch (a)].

The design shall be in accordance with the applicable requirements of NC-3400.

*(b)* Minimum transition radii at critical sections of the barrel shall be limited to 0.2 in.

*(c)* The circumferential pitch between drilled and tapped holes shall be a minimum of 2d where d is the nominal diameter of the bolt or stud [Figure NC-3441.10-1, sketch (b)].
Figure NC-3441.10-1
Type N Pump

Suction nozzle
Barrel casing
Suction cover
Seal gland
Discharge nozzle
Discharge cover
Seal gland

(a)

(b)

(c)

Change NC-3441.10-1 to NCD-3441.11-1
(d) The minimum distance, $X$, between the bottom of the hole and the nozzle opening shall be greater than or equal to the greater of the minimum, nozzle, wall thickness or 50% of the hole diameter as shown [Figure NC-3441.10-1, sketch (c)].
NC-3442 Special Pump Types

NC-3442.1 Design of Type J Pumps (Centrifugal).

(a) Type J pumps are those that cannot logically be classified with any of the preceding types of centrifugal pumps.

(b) It is not planned to establish rules for Type J pumps. Any design method that has been demonstrated to be satisfactory for the specified Design Conditions may be used.

NC-3442.2 Design of Reciprocating Pumps. See NC-3450.

NC-3450 DESIGN OF CLASS 2 RECIPROCATING PUMPS

NC-3451 Scope

(a) These rules cover the strength and pressure integrity of the structural parts of the liquid end [Figure NC-3451(a)-1], whose failure would violate the pressure boundary. Such parts include

(1) liquid cylinder and valve chambers
(2) valve covers
(3) liquid cylinder heads
(4) stuffing boxes
(5) packing glands
(6) manifolds
(7) piping and nozzles normally identified with the pump and furnished by the pump supplier
(8) related bolting
(9) external and internal integral attachments to the pressure-retaining boundary

(b) These rules do not apply to the plunger or piston, nonstructural internals, including valves, valve seats, gaskets, packing, and cylinder mounting bolting. Hydrostatic testing of packing glands is not required.

NC-3452 Acceptability

The pressure boundary parts shall be capable of withstanding the specified Design Pressures, and the design shall be such that the requirements of NC-3100 are satisfied in addition to these rules.

NC-3453 Material and Stresses

Material and allowable stresses shall conform to the requirements of Article NC-2000.

NC-3454 Design Requirements

NC-3454.1 Design of Welded Construction.

(a) Design of welded construction shall be in accordance with NC-3350.

(b) Partial penetration welds, as shown in Figure NC-4244(e)-1 sketch (c-3) and Figure NC-4266(d)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed NPS 2 (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

NC-3454.2 Piping. Piping located within the pressure-retaining boundary of the pump, and identified with the pump, shall be designed in accordance with NC-3600.

NC-3454.3 Liquid End. Any design method that has been demonstrated to be satisfactory for the specified design may be used.

NC-3454.4 Fatigue. The liquid cylinder and pressure-retaining bolting are exposed to significant fatigue loadings that shall be considered in the design. Any design method that has been demonstrated to be satisfactory for the specified design may be used.

NC-3454.5 Earthquake Loadings. The effects of earthquake shall be considered in the design of pumps. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

NC-3454.6 Corrosion. In designs where corrosion of material is a factor, allowances shall be made.

NC-3454.7 Bolting. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Section III Appendices, Mandatory Appendix XI.
Figure NC-3451(a)-1
Horizontal Single-Acting Power Pump Liquid Ends

(a)

(b)