ARTICLE II-2000
EXPERIMENTAL DETERMINATION OF STRESS INTENSIFICATION FACTORS

II-2100 INTRODUCTION

This Article presents a method to experimentally determine stress intensification factors (SIF) of piping components for use in the design of piping systems in accordance with Section III Division 1, NC-3600 or ND-3600, as applicable. Applicability to other Divisions shall be as specified in those Divisions.

II-2200 DEFINITIONS

Stress Intensification Factor. A fatigue strength reduction factor which is the ratio of the elastically predicted bending moment producing fatigue failure in a given number of cycles in a butt weld on a straight pipe of nominal dimensions, to that producing failure in the same number of cycles in the component under consideration.

II-2300 TEST PROCEDURE

II-2310 TEST EQUIPMENT

A schematic of a test arrangement is given in Figure II-2310-1.

(a) The machine framework must be sufficiently stiff to prevent anchor rotations.

(b) The pipe component shall be mounted close to the fixed end of the test assembly, but no closer than two pipe diameters.

(c) The free end shall be hinged in a slide capable of applying a fully reversible displacement.

(d) The test equipment shall be calibrated to read displacements with an accuracy of 1% of the imposed displacement amplitude.

II-2320 TEST SPECIMEN

The test specimen shall be SA-106 Grade B pipe and equivalent plates and forgings, otherwise the rules of II-2510 apply.
ARTICLE XIII-2000
STRESS ANALYSIS

XIII-2100 OVERVIEW

(a) A detailed stress analysis of all major structural components shall be prepared in sufficient detail to show that each of the stress limits of Articles XIII-3000 and XIII-4000 is satisfied when the component is subjected to the loadings defined in the Design Specification. As an aid to the evaluation of these stresses, equations and methods for the solution of certain recurring problems have been placed in Nonmandatory Appendix A. The stress index values provided in NB-3338 may also be used for openings designed in accordance with NC-3230, and NC-3259 or WC-3230, and NC-3259.

(b) The loadings to be considered are those defined in the Design Specification and include Design Loadings, Service Loadings, and Test Loadings. The Service Loadings may be the result of the service conditions defined in the Design Specification. The Design Specification designates a Service Limit for each service condition or loading. These Service Limits are identified as Level A, Level B, Level C, and Level D. Acceptance limits are defined in this Appendix for Design Loadings, each Service Level, and Test Loadings.

(c) The stress limits also differ depending on the stress classification (primary, secondary, etc.) from which the stress is derived. The six stress classifications are identified in XIII-2300, and are distinct and separate from each other, even though all may exist at the same point. Detailed stress analyses often produce results that are a combination of these classifications and it is necessary to separate each in order to properly compare to the applicable stress limits. Subarticle XIII-2600 provides guidance for selecting the appropriate stress classification. As an example, the stresses in classification Q are those parts of the total stress that are produced by thermal gradients, structural discontinuities, etc., and they do not include primary stresses that may also exist at the same point. A detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of $P_m + P_h + Q$, and not Q alone. Similarly, if the stress in classification F is produced by a stress concentration, the quantity $F$ is the additional stress produced by the notch over and above the nominal stress. However, $P_L$ is the total membrane stress that results from pressure and mechanical loads, including gross structural discontinuity effects, rather than a stress increment. Therefore, the $P_L$ value always includes the $P_m$ contribution.

(d) The combining of classified stresses for comparison to specified limits is illustrated in Figure XIII-2100-1. The solid lines illustrate the combination of the primary stresses due to the specified load combinations for comparison to the primary stress intensity limits defined for Design Loadings, and loadings for which Level A, Level B, Level C, or Level D Service Limits are specified. At each rectangular box, the applicable sets of the six stress components for each load combination are combined to calculate the maximum stress intensity (see XIII-2300), represented by the adjacent circle. The dashed lines identify the combinations of primary, secondary, and peak stress used to evaluate the combined effects of all the loadings for which Level A and B Service Limits are specified. In this case the rectangular boxes represent the sets of the six stress components to be evaluated to determine the maximum range of the stress differences over the life of the component (see XIII-2400) for comparison to the specified limits and to determine the cumulative fatigue life of the component.

XIII-2200 DESIGN STRESS VALUES AND MATERIAL PROPERTIES

The stress intensity limits are defined in terms of the design stress intensity and yield strength. The design stress intensity values $S_m$ are given in Section II, Part D, Subpart 1, Tables 2A and 2B for component materials and Table 4 for bolting materials. Values of yield strength, $S_Y$, are given in Section II, Part D, Subpart 1, Table Y-1. The design stress intensity and yield strength are tabulated at various temperatures. Values of the coefficient of thermal expansion and modulus of elasticity are in Section II, Part D, Subpart 2, Tables TE and TM. For all material properties, values at intermediate temperatures may be found by interpolation. The basis for establishing design stress intensity values is given in Mandatory Appendix III. The design fatigue curves used in conjunction with XIII-3500 are those in Mandatory Appendix I.

XIII-2300 DERIVATION OF STRESS INTENSITIES

This subarticle outlines the procedure for the calculation of the stress intensities that are subject to the specified limits. The steps in the procedure are stipulated below. Membrane stress is derived from the stress
ARTICLE A-4000
DESIGN CRITERIA AND EQUATIONS FOR TORISPHERICAL AND ELLIPSOIDAL HEADS

A-4100 INTRODUCTION

A-4110 SCOPE

The equations defining the curves in Figure NC-3224.6-1 are summarized in this Article. The analysis is for pressure on the concave portion of the head and does not include effects of thermal gradients and loadings other than pressure.

A-4120 NOMENCLATURE

The nomenclature adopted in this Article is defined as follows:

\( D = \) inside diameter of a head skirt, or inside length of the major axis of an ellipsoidal head

\( L = \) inside crown radius of torispherical head

\( P = \) internal design pressure

\( r = \) inside knuckle radius of torispherical head

\( S = \) membrane stress intensity limit from Section II, Part D, Subpart 1, Tables 2A and 2B multiplied by the stress intensity factors in Table NC-3217-1, psi (kPa)

\( t = \) minimum required thickness of head

A-4130 METHOD USED TO DETERMINE DESIGN PRESSURE

The maximum internal pressure capacity or required thickness of a torispherical and ellipsoidal pressure vessel head is determined from the controlling criterion of primary membrane stress, elastic–plastic collapse load, buckling collapse, and fatigue. For thick heads, where \( P/S > 0.08 \) (approximately \( t/L = 0.04 \) to 0.05), primary membrane stress dominates. For thin heads, where \( t/L < 0.002 \), buckling collapse is the limiting condition. For the intermediate thickness heads, \( 0.05 > t/L > 0.002 \), where \( P/S < 0.08 \), elastic–plastic collapse pressure and fatigue due to pressurization cycles are the determining conditions. At the present time, only design of the intermediate thickness heads is considered in this Division.

A-4140 MATHEMATICAL EXPRESSIONS FOR CURVES IN FIGURE NC-3224.6-1

The equation for computing \( A \) for given set of parameters \( r/D \) and \( P/S \) is as follows:

\[
A = a_1 + a_2 x + a_3 x^2 + \left( b_1 + b_2 x + b_3 x^2 \right) y + \left( c_1 + c_2 x + c_3 x^2 \right) y^2
\]

\((1)\)

where

\[
x = r/D \quad (2)
\]

\[
y = \log \left( P/S \right) \quad (3)
\]

Constants \( a_1 \) through \( c_3 \) are given in A-4141 for natural logarithms and in A-4142 for common base logarithms.

A-4141 Natural Logarithms

\[
y = \ln \left( P/S \right) \quad (4)
\]

\[
t/L = e^A \quad (5)
\]

and

\[
a_1 = -1.2617702
\]

\[
b_1 = 0.66298796
\]

\[
c_1 = 0.26078909 \times 10^{-4}
\]

\[
a_2 = -4.5524592
\]

\[
b_2 = -2.2470836
\]

\[
c_2 = -0.42262179
\]

\[
a_3 = 28.933179
\]

\[
b_3 = 15.682985
\]

\[
c_3 = 1.8878333
\]

A-4142 Common Base Logarithms

\[
y = \log_{10} \left( P/S \right) \quad (6)
\]

\[
t/L = 10^A \quad (7)
\]

and
A-4150 SAMPLE PROBLEM

Consider a torispherical head having the parameters $L = 84$ in.; $D = 90$ in.; $r = 5.5$ in.; $P = 200$ psi; and for material SA-515 Grade 70, $S = 23,300$ psi. With these data and using eq. A-4140(1) and the common logarithms and constants of A-4142:

\[
\begin{align*}
  a_1 &= -0.5479782 \\
  b_1 &= 0.66298796 \\
  c_1 &= 0.61890975 \times 10^{-4} \\
  a_2 &= -1.9771079 \\
  b_2 &= -2.2470836 \\
  c_2 &= -0.97312263 \\
  a_3 &= 12.565520 \\
  b_3 &= 15.682985 \\
  c_3 &= 4.3468967 \\
\end{align*}
\]

\[
\begin{align*}
  y^2 &= 4.269702828 \\
  A &= -2.013430932 \\
\end{align*}
\]

Solving eq. A-4140(1):

\[
\begin{align*}
  t/L &= 10^A = 0.009695474 \\
  t &= 0.814 \text{ in.} \\
  &\text{Direct reading of Figure NC-3224.6-1 gives the following:} \\
  t/L &= 0.0097 \\
  t &= 0.814 \text{ in.}
\end{align*}
\]