STP-PT-073

STRESS INTENSITY FACTOR AND K-FACTOR ALIGNMENT FOR METALLIC PIPES

ASME STANDARDS TECHNOLOGY, LLC

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FOREWORD

The purpose of this report is to align stress intensification and flexibility factors for metallic pipes used in ASME's Pressure Piping Codes (B31) and Boiler and Presure Vessel Code (B&PVC) Section III Class 2 and Class 3 Piping. The alignment recommendations are provided with examples along with major features of the aligned and updated equations. Validation is provided by comparison to existing Codes, alternate guidelines and test data in the supporting annexes.

Many people have graciously provided comments and recommendations during the course of this project, including: Ron Haupt, Bill Koves, John Cates WFI, Phil Ellenberger, John Minichiello, Don Edwards and Jim Montague (Conoco Phillips), Chris Hinnant, Peter Vu, Glynn Woods, Brian Holbrook, David Creates, Patrick Marcotte, and Ev Rodabaugh.

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ABSTRACT

This report's objective is to align stress intensification and flexibility factors for metallic pipe used in ASME's Pressure Piping Codes (B31) and Boiler and Presure Vessel Code (B&PVC) Section III Class 2 and Class 3 Piping, hereinafter the "Codes".

The alignment recommendations are given with examples in Annex A in this report. Validation is provided by comparison to existing Codes, alternate guidelines and test data in Annexes C through I in this report. References are included in Annex J in this report.

The steps that were taken to prepare the recommendations are:

- *(a)* Collect and compare test data and equations from different sources
- *(b)* Resolve differences
- *(c)* Develop consistent rules and translate to a single document
- *(d)* Perform verification
- *(e)* Produce examples

The major features of the aligned and updated equations are:

- *(a)* Flexibility factors were added for all branch connection types
  - *(1)* branch connection k-factors are adjusted when flanges are attached to one or both run ends
- *(b)* SIFs were updated to include:
  - *(1)* out-of-plane branch loading due to Schneider effect
  - *(2)* reduction of SIF for run loads where appropriate
  - *(3)* separation of branch and run SIF and flexibility factors
  - *(4)* weld-on fitting SIF correction
  - *(5)* individual development of in-plane, out-plane and torsional SIFs for both run and branch
  - *(6)* EPRI tests conducted after 1996
  - *(7)* clarification of locally thickened branch rules
  - *(8)* guidance for fabricated outer radius (r2) provided
  - *(9)* EPRI Rodabaugh/Wais results for concentric and eccentric reducers
  - *(10)* improved figures to identify branch connection types
  - *(11)* corrections when t/T < 1 for fabricated branch connections
  - *(12)* t/T effect for Sketch 2.2 and Sketch 2.3 iob when t/T < 0.85
- *(c)* Examples and Application notes were prepared.
- *(d)* Corrections and note changes recommended in WRC 329 were implemented.
- *(e)* Additional test requirements have been identified and a number are underway at PRG in Houston

ABBREVIATIONS AND ACRONYMS

D = mean diameter of matching pipe found from (D_o-T), in. (mm). For Sketches 2.1 through 2.6 in Table 1 of Annex A, the mean diameter of the matching run pipe

d = mean diameter of matching branch pipe found from (d_o-t), in. (mm)

E = modulus of elasticity, psi. (KPa)

I_b, I_r = matching branch and run pipe moment of inertia used in Table 2 of Annex A, in^4 (mm^4)

i = stress intensification factor (SIF)

k = flexibility factor with respect to the plane and component indicated

M = moment on branch or run legs shown in Fig. 2, in.-lb (N·mm)

P = gage pressure, psi (MPa)

r = mean radius of matching branch pipe found from (d_o-t)/2, in. (mm) for Sketches 2.1 through 2.6

r_2 = radii used with Fig. 5 and in Sketch 3.1, in.(mm). (See Annex A.)

R = mean radius of matching pipe found from (D_o-T)/2, in. (mm)

R_1 = bend radius of welding elbow or pipe bend, in. (mm)

r_p = radius to outside edge of fitting for Sketches 2.3 and 2.6 measured in longitudinal plane, in. (mm)

r_x = external crotch radius of welding tee per ASME B16.9, extruded outlet and welded-in contour insert [Sketches 2.1, 2.4 and 2.5], measured in the plane containing the centerline axes of the run and branch, in.(mm)

s = miter spacing at centerline, in. (mm)

SIF = stress intensification factor

t = nominal wall thickness of matching branch pipe, in. (mm)

t_n = local branch pipe thickness used with Fig. 5(a) and (b), in. (mm)

T = nominal wall thickness of the fitting for elbows and miter bends (Sketches 1.1 through 1.3), and the nominal wall thickness of the matching pipe for tees (Sketches 2.1 through 2.6) and other components, in. (mm)

T_c = crotch thickness in Sketches 2.1, 2.4 and 2.5 in Table 1 in Annex A measured at the center of the crotch and in the plane shown, in. (mm)

t_p = reinforcement pad or saddle thickness, in. (mm)

Z = section modulus of pipe, in^3, (mm^3) (See Note 10.)

Z_b = section modulus of matching branch pipe, in^3, (mm^3) (See Note 10 to Table 1 in Annex A.)

α = reducer cone angle, degree

1 INTRODUCTION

In the Welding Research Council's (WRC) WRC Bulletin 329 (1987) E.C. Rodabaugh [1] outlined a number of recommendations for AMSE B31.1 Power Piping (B31.1), ASME B31.3 Process Piping (B31.3), BPVC Section III - Div. 1 - Subsection NC - Rules for Construction of Nuclear Facility Components - Class 2 Components (BPVC Section III NC) and BPVC Section III - Div. 1 - Subsection ND - Rules for Construction of Nuclear Facility Components - Class 3 Components (BPVC Section III ND). Specific recommendations were provided in WRC 329 Appendix A for BPVC Section III NC-3600 which were subsequently incorporated into the BPVC Section III Code.

The WRC 329 Section 5.0 Recommendations for B31.1 and B31.3 have not been incorporated into the B31.1 and B31.3 Codes as of the 2010 versions. The resolution of issues raised in WRC 329 is one objective of this report.

Rodabaugh [1][2][3][4][5][6][7] and Schneider [8] have long recognized the significant influence branch connection flexibility factors can have on piping flexibility results. In WRC 329 Rodabaugh states, "…present Code guidance for flexibility of branch connections can be very inaccurate. If the Code guidance is followed, there can be inaccuracies in the calculated moments, and [the stresses], that may be greater than that due to any of the inaccuracies in i-factors." Widera [9] and Wais [10] presented flexibility factors for unreinforced branch connections, and Wais [6] provided flexibility factors for pad reinforced branch connections. In 1987 Moore and others [4][11][12] conducted instrumented tests of welding tees. For this report PRG ran in excess of 30,000 brick and shell finite element analyses on unreinforced, reinforced, and contoured branch connections. PRG also conducted several tests of 4x4 unreinforced branch connections for in-plane and out-of-plane branch moments. Regressions were run on the collected data, and manual adjustments made to envelope k-factors observed in the test data. Certain k-factors are affected by contour dimensions not controlled by MSS, ASTM or ASME standards. In these cases the user is cautioned and the range of expected variation noted.

Since 1987 Rodabaugh, Woods, Scavuzzo, Wais, Widera, Hinnant and others [2][6][9][13][14][15][16][17][18][19][20][21][22] have released additional SIF test results and addressed various aspects of piping component behavior. Effort was made to incorporate these results into the recommendations in Annex A in this report.

Rodabaugh in WRC 329 [1] demonstrated the conservatism in the BPVC Section III NC and ND stress calculation approach in part due to the use of a single maximum valued stress intensification factor. Comparisons between this report's i-factors and the NC Code i-factors show that the approach developed by Rodabaugh in WRC 329 is reasonably conservative except in some cases when t/T is less than 1 for branch connections when r_2 is not provided.

The major stress intensification and flexibility factor issues addressed in this report are summarized below.

- *(a)* Provide flexibility factors for branch connections
- *(b)* Modify t/T exponent in i-factor equations where needed (ref WRC 329 para 4.2.1)
- *(c)* Thoroughly treat branch connections for d/D ratios less than 0.5.
- *(d)* Provide torsional i-factors for branch connection run and branch sides
- *(e)* Correct in-plane and out-of-plane relationship for run evaluation of branch connections
- *(f)* Add notes to address geometrically ill-defined branch connections
- *(g)* Address out-of-plane branch i-factor maximum that occurs between 0.5 < d/D < 1.
- *(h)* Address out-of-plane branch i-factor maximum that occurs for t/T < 1.
- *(i)* Address fabricated branch connection where a radius is provided (r2)
- *(j)* Update concentric and eccentric reducers to latest test and analysis recommendations
- *(k)* Correct k-factor for 90 degree bends and elbows