ASME B31J-2008

Standard Test Method for Determining Stress Intensification Factors (*i*-Factors) for Metallic Piping Components

ASME Code for Pressure Piping, B31

REAFFIRMED 2013

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The American Society of Mechanical Engineers

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Date of Issuance: May 30, 2008

This Standard will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to this edition.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Standard. Interpretations are published on the ASME Web site under the Committee Pages at http://cstools.asme.org as they are issued and will also be published within the next edition of this Standard.

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

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FOREWORD

In 1990, the B31 Code for Pressure Piping, Technical Committee on Mechanical Design (MDC), determined that there was a need to develop a standard test method to determine stress intensification factors (SIFs or *i*-factors) for piping components and joints. At the time, the B31 Code books provided SIFs for various standard piping components and joints, but did not provide guidance on how to establish SIFs for nonstandard piping components or joints.

This Standard is intended to provide a uniform approach to the development of SIFs for standard, nonstandard, and proprietary piping components and joints of all types. In its development, this Standard has been reviewed by individuals and committees of the Boiler and Pressure Vessel Code, B31, and B16. Comments resulting from the review have been considered and responded to, with revisions made to the Standard as appropriate.

Under direction of ASME Codes and Standards, both U.S. Customary and SI units are provided.

This Standard was approved by the American National Standards Institute on April 18, 2008.

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Code for Pressure Piping

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Secretary, B31 Standards Committee
The American Society of Mechanical Engineers
Three Park Avenue
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Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Interpretations. Upon request, the B31 Mechanical Design Technical Committee will render an interpretation of any requirement of the Standard. Interpretations can only be rendered in response to a written request sent to the Secretary of the B31 Standards Committee.

The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and the topic of inquiry.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Attending Committee Meetings. The B31 Standards Committee regularly holds meetings, which are open to the public. Persons wishing to attend any meeting should contact the Secretary of the B31 Standards Committee.

INTRODUCTION

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections and Standards, each an American National Standard, under the direction of the ASME Committee B31, Code for Pressure Piping.

Rules for each Standard provide standardized guidance for a specific task found in one or more B31 Section publications, as follows:

(a) B31G, Remaining Strength of Corroded Pipelines, provides a simplified procedure to determine the effect of wall loss due to corrosion or corrosion-like defects on pressure integrity in pipeline systems.

(b) B31J, Standard Test Method for Determining Stress Intensification Factors (*i*-Factors) for Metallic Piping Components, provides a standardized method to develop the stress intensification factors used in B31 piping analysis.

This is B31J, Standard Test Method for Determining Stress Intensification Factors (*i*-Factors) for Metallic Piping Components. Hereafter, in this Introduction and in the text of this B31 Standard, where the word "Standard" is used without specific identification, it means this B31 Standard. It is expected that this Standard will be incorporated by reference into the appropriate Sections of B31.

This Standard sets forth an engineering procedure deemed appropriate for the safe determination of the fatigue capacity of a piping component or joint in most services, relative to a standard butt-welded joint. However, the procedure cannot possibly foresee all geometries and services possible, and the use of competent engineering judgment may be necessary to extend the procedure to cover unusual geometries and service conditions or to ensure a safe testing environment.

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STANDARD TEST METHOD FOR DETERMINING STRESS INTENSIFICATION FACTORS (*i*-FACTORS) FOR METALLIC PIPING COMPONENTS

1 GENERAL

The ASME B31 Code for Pressure Piping and the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Components, Subsections NC and ND piping rules require the use of stress intensification factors (*i*-factors or SIFs) when checking the adequacy of components and joints (welded and nonwelded) in piping subject to loadings, including those cyclic loadings that may produce fatigue failures. As used herein, where the word "Code" is used without specific identification, it means the Code or Standard which incorporates or references this Standard. The piping Codes provide stress intensification factors for the most common piping components and joints. This Standard presents an experimental method to determine SIFs.

2 DEFINITIONS

piping components: mechanical elements suitable for joining or assembly into pressure-tight, fluid-containing piping systems. Components include pipe, tubing, fittings, flanges, gaskets, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, in-line portions of instruments, and separators.

stress intensification factor: a fatigue strength reduction factor that is the ratio of the elastically predicted stress producing fatigue failure in a given number of cycles in a butt weld on a straight pipe to that producing fatigue failure in the same number of cycles in the component or joint under consideration.

3 TEST PROCEDURE

3.1 Test Equipment

A schematic of a test arrangement is given in Fig. 3.1.

(a) The machine framework must be sufficiently stiff to prevent significant rotation at the fixed end of the assembly. A significant rotation is one readily visible to the observer.

(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 test rig shall be capable of applying a fully reversed displacement at the free end without binding in the two orthogonal directions. That is, the free end shall not bind the assembly in a direction out of the plane of testing.

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

(e) The piping attached directly to the tested component should be a similar schedule to the tested component.

3.2 Test Specimen

The test specimen may be lower strength carbon steel, such as ASTM A 106 Grade B pipe or ASTM A 234 Grade WPB fittings, and equivalent plates and forgings, corresponding to the "UTS < 80 ksi" curve in Fig. 5-110.1 of Appendix 5 of Section VIII, Division 2 of the ASME Boiler and Pressure Vessel Code. For other materials, the material constant, C, shall be modified as described in para. 5.1.

The fabrication, welding, and examinations of the tested components shall be the same as will be followed in fabrication of the component and installation for service. Weld contours should be representative of those intended to be used in fabrication and installation.

3.3 Applied Displacement Calibration

(a) The test specimen shall be placed in the test assembly and displacements shall be applied in positive steps to obtain a load-displacement plot analogous to that shown in Fig. 3.3. At least five points shall be recorded in the linear region of the plot.

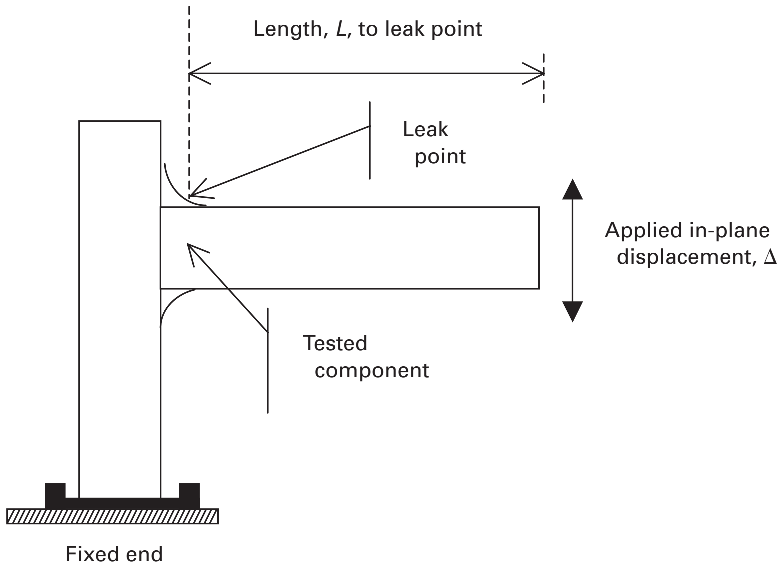
(b) The initial loading sequence shall be stopped when it is clear from the load-displacement plot that the recorded load displacement is no longer linear, i.e., the loading sequence will require one or two steps into the nonlinear range.

(c) The specimen must then be unloaded, following the same recording sequence as during loading.

(d) Steps (a) through (c) are repeated in the negative direction to approximately the same negative displacement as the loading sequence reached in (b).

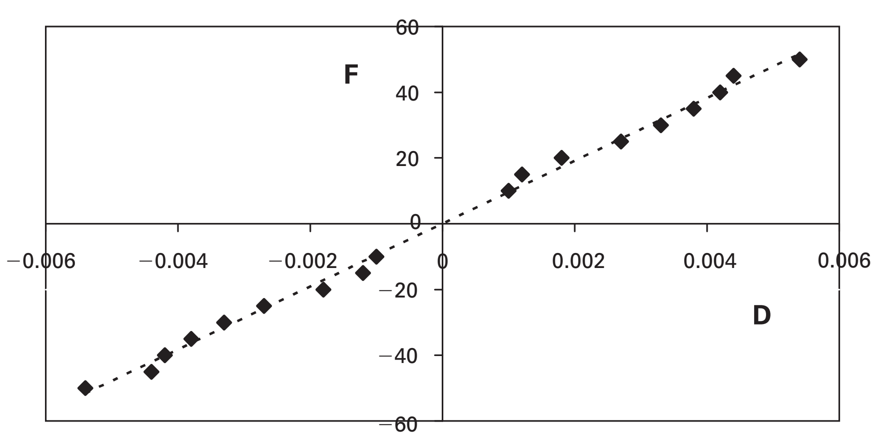
(e) The linear region of the load-displacement curve and its straight-line extension will be used in determining the force, F_e, in para. 4.1.

Fig. 3.1 Representative Test Arrangement



GENERAL NOTES:
(a) The force, F_e, is determined from the best-fit straight line (Fig. 3.3) based on Δ.
(b) The moment, M_e, at the leak point is equal to F_eL.

Fig. 3.3 Displacement, *D*, and Force, *F*, Recorded During Loading and Unloading of a Test Specimen, in Both Positive and Negative Directions, With Linear Displacement



GENERAL NOTE: The slope of the best-fit straight line is used in the subsequent tests to determine the stress intensification factor.

3.4 Cycles to Leakage

(a) The test specimen shall be placed in the test configuration and pressurized with water. The pressure should be sufficient to detect leakage. A head pressure of 12 in. (300 mm) of water at the expected failure location (leak point) is usually sufficient. Equivalent methods of through-wall crack detection are permissible.

(b) The specimen shall be subjected to displacement limited fully reversed cyclic displacements until a through-wall crack is detected in the component or its weld to the pipe.

(c) The fully reversed displacement shall be applied at a frequency not to exceed 120 cycles per minute. Higher frequencies are permitted, provided it is shown that there are no deleterious effects on temperature.

(d) The number of cycles, N, at which the through-wall crack occurs shall be recorded. The cyclic displacements shall be selected such that failure occurs in a minimum of $N = 500$ cycles of reversed displacements. The full range of nominal bending stress at the leak point [see para. 4.1 and eq. (2)] may exceed twice the actual material yield stress.

(e) If the displacement level is changed during the test, the number of equivalent cycles shall be determined as described in para. 4.6.

4 STRESS INTENSIFICATION FACTOR

4.1 Calculated Stress

The applied moment at the leak point, M_e, is

$$M_e = F_e L \tag{1}$$

where

F_e = force corresponding to the applied displacement amplitude, read on the straight line of Fig. 3.3, lb (N)

L = distance between the point of applied displacement and the leak point, in the direction perpendicular to the imposed displacement, in. (mm)

M_e = applied elastic moment amplitude at the time leakage occurs, in.-lb (N·mm)

The elastically calculated stress amplitude corresponding to the elastic moment at the leak point is

$$S = \frac{M_e}{Z} \tag{2}$$

where

S = stress amplitude at leak point, psi (MPa)

Z = section modulus as defined in para. 4.2, in.^{3} (mm^3)

4.2 Section Modulus

The value of the section modulus, Z, used in calculating the stress amplitude at the leak point in para. 4.1 shall be that of the pipe intended to be used with the component. If the stress at the leak point is computed using Z other than that of the matching pipe, the manner in which Z is computed must be explicitly specified in the definition of the stress intensification factor, and the value of Z at the same location shall be used in design.

Table 4.4 Stress Intensification Increase Factor

Number of Test Specimens	Testing Factor, R_i
1	1.2
2	1.1
3	1.05
≥4	1.0

4.3 Stress Intensification Factor

The stress intensification factor is established as

$$i = \frac{C}{S(N)^b} \tag{3}$$

where

b = material exponent, 0.2 for metals

C = material constant, 245,000 psi (1 690 MPa) for a carbon steel test specimen

i = stress intensification factor

N = number of cycles to failure

S = nominal stress amplitude at the leak point, psi (MPa)

4.4 Number of Test Specimens

(a) The value of the stress intensification factor, i, shall be the average value from several, preferably a minimum of four, cyclic displacement tests.

(b) Where fewer than four tests are conducted, the average stress intensification factor, i, shall be increased by a factor R_i given in Table 4.4.

(c) The stress intensification factor to be used with Code analyses shall not be less than 1.0.

4.5 Directional Stress Intensification Factors

(a) For nonaxisymmetric components, a directional stress intensification factor shall be established independently for each direction of bending.

(b) Where the design Code requires the use of a single stress intensification factor, the largest value from the directional stress intensification factors shall be used.

4.6 Variable Amplitude Test

If the applied displacement amplitude is changed during a cyclic test, the number of cycles to leakage shall be determined by

$$N = N_j + \sum (r_i)^{1/b} \times N_i \text{ for } i = 1, 2, \ldots n \tag{4}$$

where

b = material exponent, 0.2 for metals

j = the number of the test case chosen as the base case

N = equivalent number of cycles to leakage, at maximum amplitude X_j

N_i, N_j = number of cycles at amplitudes X_i, X_j, where all $X_i < X_j$

r_i = X_i/X_j; $r_i < 1$

X_i, X_j = amplitudes of displacement applied during cycles N_i, N_j, in. (mm)

5 VARIATIONS IN MATERIALS AND GEOMETRY

5.1 Material Constant and Material Exponent

When using a test specimen made of Code-listed materials other than lower strength carbon steel, a new material constant, C, shall be established as follows:

(U.S. Customary Units)

$$C \text{ (other material)} = \frac{245{,}000 \times E \text{ (other material)}}{27{,}800{,}000 \text{ psi}} \quad (5a)$$

(SI Units)

$$C \text{ (other material)} = \frac{1\,690 \times E \text{ (other material)}}{192\,000 \text{ MPa}} \quad (5b)$$

where

C = material constant, for use in eq. (3), psi (MPa)

E = modulus of elasticity, psi (MPa)

5.2 Geometric Similarity

(a) The stress intensification factor derived from the tests is applicable to components that are geometrically similar within 20% of the dimensions (or the dimensionless ratios, if applicable) of the test specimens for those dimensions that affect the stress intensification factor.

(b) Dimensional extrapolations other than in para. 5.2(a) shall be identified in the test report, along with their technical justification. For example, a complex fitting may have multiple tests run on different diameters and thicknesses to establish a relationship between SIF and dimensional parameters. Alternatively, if the geometry is simple enough so that a closed form evaluation can be done, then the technical justification can be based on a single-size fitting with the closed form evaluation showing how the SIF is extrapolated to other sizes.

6 TEST REPORT

A test report shall be prepared and certified to meet the requirements of this Standard by a Registered Professional Engineer, or person of equivalent expertise, as defined by national practice[1], competent in the design and analysis of pressure piping systems. The test report shall be complete and written to facilitate an independent review. The report shall contain

(a) description of the tested specimens.

(b) nominal pipe and piping component size and dimensions and actual cross-sectional dimensions of importance in interpreting the test results.

(c) description and photograph(s) or sketch(es) of the test equipment, including positioning of the test specimens in the machine.

(d) calibration of the test equipment. This information may be provided by reference.

(e) certified material test reports for the tested component, including mill-test value of yield and ultimate strength.

(f) component and component-to-pipe weld examinations where they are required by the construction Code, with certification of Code compliance of the welds. A copy of the Welding Procedure Specification (WPS) and the Welding Operator Performance Qualification (WPQ) of the welding operator who welded the components, along with a narrative of the visual examination of the welds used in the test pieces, shall also be included. If possible, good quality photographs of all or a portion of the weldments should be included in the report.

(g) assembly procedure used for joints.

(h) loading and unloading load-displacement points and line, in accordance with para. 3.3.

(i) values of material constant, C, section modulus, Z, number of cycles to leakage, N, length to leak point, L, and imposed displacement for each test.

(j) derivation of the force, F_e, moment, M_e, and the stress intensification factor, i, for each test.

(k) description and photograph(s) or sketch(es) of the leak location.

(l) justification for geometric similarity, if any, in accordance with para. 5.2.

[1] "Registered Professional Engineer or person of equivalent expertise" is defined as follows: An individual licensed to provide engineering services by a state, province, or other government body.

NONMANDATORY APPENDIX A COMMENTARY ON B31J[1]

A-1 GENERAL

The Codes for Pressure Piping (for example, ASME B31.1 and B31.3; ASME BPVC, Section III, Class 2/3) use stress intensification factors (*i*-factors) for various piping components and joints as a measure of their fatigue performance relative to girth butt welds. Occasionally, a need arises to establish *i*-factors for components not included in the Codes, such as a branch connection in an elbow or some proprietary piping component. This Standard provides a set of requirements that will ensure that newly developed *i*-factors will be consistent with the existing *i*-factors.

(a) Papers by Markl [2], Markl and George [3], and Markl [4] provided the basis for most of the *i*-factors in the Codes. Key aspects of the testing and interpretation of test results are as follows:

(1) a preliminary load-deflection plot was developed (see Fig. 3.3)

(2) cyclic bending tests were run with controlled displacements

(3) failure was defined as a through-wall crack

(4) the *i*-factor was calculated by eq. (3)

(b) Markl [5] discusses "Allowable Stress Range" and, in Appendices 1 and 2 of his paper, describes rules that were eventually incorporated in ANSI B31.1-1955. These rules are essentially unchanged. This paper discusses the following three concepts that are fundamental to the use and interpretation of *i*-factors as a control of fatigue failure:

(1) the *i*-factors are dependent upon dimensions and are independent of the material

(2) as a consequence of (1), *i*-factors developed by Markl using ASTM A 106 Grade B material are presumed to be applicable to components made of any of the metallic materials listed in the Piping Codes

(3) the Code stress limits [e.g., $f(1.25S_c + 0.25S_h)$] are proportional to the fatigue strength of materials used in the components

(c) Materials and Material Extrapolations. Markl ran tests on specimens made of ASTM A 106 Grade B material. Paragraph 3.2 prescribes analogous Grade B materials. It is recognized that some components may not be made from Grade B materials, e.g., a copper tubing fitting. If tests were run, for example, on a copper elbow, then a different C constant would be needed so that the concept that *i*-factors are independent of the material would be preserved. Section 3 is written to allow this, with rules provided in section 5.

(d) Dimensions and Dimensional Extrapolations. Markl's tests were run on NPS 4 test specimens. Markl's broad extrapolations to other dimensions were based on elbow theory. For elbows, his in-plane tests led to

$$i = 0.90/h^{2/3}$$

where

$h = tR/r^2$
R = bend radius
r = mean radius of elbow cross section
t = wall thickness

Paragraph 5.2 permits dimensional extrapolations, provided the technical justification for such extrapolations is included in the test report. An example of such justification is the elastic-stress theory for elbows used by Markl. More generally, an acceptable justification for extrapolations would consist of a valid elastic-stress theory applicable to the type of component, e.g., a branch connection. Care would be needed to ensure that the elastic-stress theory is indeed applicable over the range of dimensional extrapolations given in the test report.

Appropriate dimensional extrapolations for branch connections have been a major problem. The subject of branch connections, their theory, testing, and the effect of weld profile on *i*-factors are exhaustively treated in references [6] and [7]. The need for ensuring the weld geometry used in the testing is also that used in the field is clearly shown in reference [6], in which a subtle change in profile produced a change in i value by a factor of 2. Thus, paras. 4.2, 6(b), and 6(f) require the weld contour to be representative of the installation.

(e) Basis for Requirements. The paragraphs from the Standard that are considered self-explanatory do not have a corresponding commentary.

(1) Section 3

(a) Paragraph 3.1. Markl's test was a cantilever test with the specimen oriented as shown in Fig. 3.1. The intent of the two diameters is to prevent end effects (stiffening) from affecting the SIF results. Calibration of instrumentation is necessary to ensure repeatability by independent organizations. Preventing binding in the

[1] ASME B31J is based on the work by E. C. Rodabaugh in WRC Bulletin 392 [1]. The commentary above first provides a synopsis of Mr. Rodabaugh's discussion in [1]. Readers wishing more detail are urged to refer to references [1] through [5]. After the synopsis, a basis for each requirement in ASME B31J is provided.

two orthogonal directions ensures that there will be no unintentional loading on the specimen.

(b) Paragraph 3.2. Markl's tests specimens were ASTM A 106 Grade B material, or equivalent in the case of forgings, castings, and plate. Use of different materials requires a new C constant to be developed, since materials such as copper, aluminum, or very high-strength steels exhibit different fatigue life from plain carbon steel. The intent of the test is to develop an SIF that is geometry dependent, not material dependent.

Identifying nominal dimensions and wall thicknesses is important, particularly in the case of branch connections, to ensure extrapolation of results to other sizes is done correctly. The importance of the weld profile is clearly shown in reference [6].

(c) Paragraph 3.3. Markl's tests were based on linear elastic equivalent moments, i.e., a constant displacement or rotation was applied and the moment at the failure location was based on extrapolation of the M-θ (or F-δ) elastic curve. This allows agreement with the way linear elastic thermal expansion analyses are used, even though predicted stresses may be above yield.

(d) Paragraph 3.4. The use of a nominal pressure is to ensure a ready means of detecting a through-wall crack. The use of 500 cycles as a minimum is to ensure correlation with the lower bounds of Markl's work. From reference [4], it can be seen that the preponderance of tests lie above 1,000 cycles. The few that fall below show a fair amount of scatter off the proposed straight line. Until more work is done in the very low cycle range, the lower limit of 500 will remain.

(2) Section 4

(a) Paragraph 4.1. If forces are being applied, it is important to measure the distance from the point of application to the point of failure in order to determine the appropriate equivalent moment.

(b) Paragraph 4.2. The section modulus is used in piping analysis to convert the calculated moments to stresses. Thus, it is important that the section modulus used to calculate the stress in the test agrees with that to be used in the analysis (and described in the Code).

(c) Paragraph 4.3. The equation in para. 4.3 is taken directly from the work by Markl [e.g., reference [4], eq. (4)]. Since Markl's tests formed the basis of the current *i*-factors and Code rules, use of Markl's equation is appropriate for correlation.

(d) Paragraph 4.4. The factor for the number of tests is to provide for uncertainty. The basis for the factors is engineering judgment. The basis is a reasonable estimate when compared to ASME BPVC, Section III, Appendix II, II-1520(f) for the statistical variation in test results

$$K_{SS} = 1.47 - 0.044 \times \text{number of replicate tests}$$

$$K_{SS} \geq 1.0$$

While K_{SS} would produce slightly higher factors, those provided in para. 4.4 are deemed acceptable based on the scatter in Markl's original testing.

(e) Paragraph 4.6. The equation for variable amplitude tests is the same basic equation as was incorporated in ANSI B31.1-1955 and is still used by the piping Codes to convert different operating condition stress ranges, typically thermal stress ranges, to a single base stress range.

(3) Section 5

(a) Paragraph 5.1. Based on the work in "Thermal Fatigue and Thermal Stress" by Manson, the material exponent, n, for metals stays fairly constant at 0.2, and has been set to that value in the Standard. Based on work done by W. Koves, the material constant, C, can be found from a ratio of the moduli of elasticity, i.e.,

$$C\text{ (other material)} = 245{,}000\ E\text{(other material)}/E\text{(carbon steel} = 27.8\text{E6 psi)}$$

(b) Paragraph 5.2. Dimensional extrapolations need to be justified based on either elastic-stress theory or tests of additional sizes. Elastic theory was the basis of Markl's extrapolation work in elbows and straight pipe. It is important that extrapolation be justified.

(4) Section 6. The reason for the test report is to assure owners that the testing was carried out in compliance with B31J. Since the test report must also describe any weld profiles, the owner can also ensure that such profiles/procedures are incorporated into the welding program for the installation. The basis for the *i*-factor must be able to be reviewed by the owner or his agent.

A-2 REFERENCES

[1] WRC Bulletin 392, "Standardized Method for Developing Stress Intensification Factors for Piping Components," E. C. Rodabaugh, June 1994.

[2] Markl, A. R. C., "Fatigue Tests of Welding Elbows and Comparable Double-Mitre Bends," Trans. ASME, Volume 69, 869–879 (1947).

[3] Markl, A. R. C. and George, H. H., "Fatigue Tests on Flanged Assemblies," Trans. ASME, Volume 72, 77–87 (1950).

[4] Markl, A. R. C., "Fatigue Test of Piping Components," Trans. ASME, Volume 74, 287–303 (1952).

[5] Markl, A. R. C., "Piping-Flexibility Analysis," Trans. ASME, Volume 77, 127–149 (1955).

[6] WRC Bulletin 392, "Effects of Weld Metal Profile on the Fatigue Life on Integrally Reinforced Weld-On Fittings," G. E. Woods and E. C. Rodabaugh, June 1994.

[7] WRC Bulletin 329, "Accuracy of Stress Intensification Factors for Branch Connections," E. C. Rodabaugh, December 1987.

ASME CODE FOR PRESSURE PIPING, B31

NOTE:
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