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Stress Indices for Non-radial Branch Connections for Piping

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Abstract

Procedure for determining the stress indices for non radial branch connections is discussed. A typical non radial branch connection, commonly used in the piping system of FRFCF is modeled and analyzed using CAST-3M for calculation various stress indices for the connection. B_2 Stress indices for the branch connection for in plane bending and out of plane bending is arrived at based on nonlinear finite element analysis and limit load approach. K_2 factor is determined using Peterson's curve, based on the curvature at the junction of run pipe and branch connection. Stress index C_2 and the stress intensification factor *i* are determined by employing the relations of these factors with other stress indices.

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Keywords: Stress index; twice elastic slope method; collapse load; limit load; non linear finite element analysis; branch connection

1. Introduction

The analysis of piping system based on design codes such as ASME or RCC-MR follows simplified procedures, in which the nominal stresses determined from the simplified analysis of the piping system will be multiplied by the stress indices or the stress intensification factors, to arrive at the actual stress or stress intensity of the piping component such as elbows, straight pipes or branch connections. These stress indices or stress intensification factors are estimated based on a series of experiments and outcome of the experiments are used derive formulas for calculating these factors. But these codes are silent on the stress indices or intensification factors for non radial branch connections. Non radial branch connections (Y-piece) are commonly used in piping systems of reprocessing plants. The stress indices for these Y-pieces are generated by finite element analysis, by applying the basic definitions of these factors as described in the codes. This paper describes the details of the methodology and analysis performed for determination of stress indices such as B_2, C_2, K_2 and *I* for typical Y-piece used in the Fast Reactor Fuel Cycle Facility (FRFCF).

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2. Definition and background of stress indices

Section-NB 3682 of ASME pressure vessel code [1] provides the following general definition of the stress indices,

$$B, C, or\ K = \frac{\sigma}{S} \tag{1}$$

Here for *B* indices σ represent the stress magnitude corresponding to the limit load *L,* and S is the nominal stress associated with limit load. For C or *K* indices, σ represents the maximum stress intensity corresponding to the limit load. For the stress intensification factor *i,* the value of σ represent the principal stress at a particular point, surface and direction due to the limit load *L.*

Methods for determining the B_2 index for the pipe bends are widely studied, which suggest either experimental approach or a detailed finite element analysis for the determination of the B_2 index. Avent *et al* [2] define the B_2 as

$$B_2 = \frac{\sigma_{mm}}{M_i / z} \tag{2}$$

where σ_{mm} is the maximum calculated membrane stress intensity in a model corresponds to the bending moment M_i. Since this is a linear approach, any moment below the proportional limit can be used for the determination of B_2. Mello and Grrifin [3] showed a relation between the collapse moment, M_{CL} and the stress index B_2 as

$$M_{CL} = \frac{Z(1.2S_y)}{B_2} \tag{3}$$

The authors have not used the above equation to calculate the B_2 index, but the collapse moment M_{CL} by calculating the value of the B_2 from equation given in the 1971 ASME boiler and pressure vessel code. Determination of B_2 from the experimentally determined collapse moment M_{CL} was demonstrated by Walis [4]. In this work, the limit load was defined as the load which results in a deflection twice that predicted based on elastic behavior. Once the limit load and limit moment was determined experimentally, the expression $M_{CL} = \frac{ZS_y}{B}$ is used to determine the primary stress index *B*. The author has used this procedure to determine the stress indices for the welded attachments, but the procedure suggested by him considered to be applicable more generally. Liu *et al.* [5] developed a procedure to determine the B_2 index by nonlinear finite element analysis that determines the collapse moment instead of the experiment. They have suggested an equation of the form

$$B_2 = \frac{S_{membrane,CL}}{\frac{M_{CL} D_0}{2I}} \tag{4}$$

Where $S_{membrane,CL}$ is the maximum membrane stress intensity in a pipe bend, corresponding to the collapse moment, determined from the elastic plastic finite element analysis due to in plane closing mode bending, in plane opening mode bending , out of plane bending or torsion. They have also used the linear analysis with membrane stress as conservative but more economical method to determine the B_2 index. The equation suggested by them for the linear analysis is

$$B_2 = \frac{S_{membrane}}{MD_0 / 2I} \tag{5}$$

where $S_{membrane}$ is the maximum membrane stress intensity for a moment that is below the collapse value. They found that the B_2 index determined from the limit analysis is about 40% lower than that obtained from the linear analysis. This is equations are also appears to be more general which can applied to any type of piping component.

3. Relation between stress indices and stress intensification factors

The stress indices described in the code are used for three purposes. *B*-indices are based on the limit load analysis, C indices represent the primary plus secondary stresses and *K*-Indices represents peak stresses which are involved in a fatigue evaluation. All three types of indices are used in the analysis for internal pressure loads, moment loads and thermal loads. The relationship between B_2 and C_2 indices in case of bends have been established from limited test data. From these experiments, a conservative estimate is that, the collapse moment is 4/3 of the moment to produce a local bending stress equal to the yield strength of the elbow material. This leads to a relation between B_2 and C_2 as $B_2 = (3/4)C_2$ .This relation remained the same in the ASME code from 1969 till 1981 [6]. The code revisions subsequent to 1981 has modified the relation between B_2 and C_2 as,

$$B_2 = \frac{2}{3} C_2 \tag{6}$$

which is remains unchanged in the ASME code till date in the case of bellows. There exist a relation between the stress intensification factor *i* and the stress indices C_2 and K_2 in the ASME code which is given as

$$i = \frac{c_2 k_2}{2} \tag{7}$$

The above relations help in determining the various stress indices when some of them are determined by analysis.

4. Determination of stress indices for non radial branch connection

The equations for determining the stress indices of the non radial branch connections are not provided in any of the design codes currently in practice for design and analysis of the piping systems. But various types of non radial branch connections are commonly used in the piping systems in the reprocessing plants. The design of these piping systems requires the knowledge of stress indices for the non radial branch connections. So the aim of the present study is to determine the stress indices for these connections. The methodology followed in analysis is as follows.

1. Calculate the B_2 index for non radial branch connections using equation (4) by using nonlinear finite element method.
2. Determination of the C_2 index using the relation given equation (6)
3. Determination of K_2 factor using Peterson's curve [7]
4. Determination of the *i* factor using the relation given in equation (7)

4.1. Determination of B_2 index by limit load analysis

A typical non radial branch connection in the Fast reactor fuel cycle facility (FRFCF) piping system is considered for the analysis. The main pipe is 20 NB, schedule 40 and the branch pipe is 8 NB, schedule 40. The angle between the main pipe and branch pipe is taken as 45^0. The material of the branch connection is taken as 304 L with an operating temperature of 200^0C. Considering the loading symmetry, for the in plane loading, an 180^0 sector solid model of the branch connection is made using CAST3M as shown in the Fig.1 with 8 node cubic element for determination of the stress index for the in plane loading. The length of the main pipe is taken sufficient enough to avoid the end effects. Symmetric boundary conditions are applied at the plane of symmetry and fixed boundary conditions are applied at both ends of the main piping as shown in figure.1. Vertically upward force is applied at the free end of the branch connection (in plane bending) as shown in the figure.1, in steps starting from zero with a step size of 1 N, The stress strain curve for 304 L corresponding to 200^0C given in appendix-A3 of RCC-MR is used for the analysis [8]. The load deflection curve for the location of the applied load is obtained as shown in fig.2, from which the collapse load is calculated using twice elastic slope method as described in appendix-II of ASME,2007 [9] as depicted in Fig.2. The collapse load is obtained as 1280 N. The deflection pattern and stress distribution of the component corresponding to the collapse load is shown in figures.3 and 4 respectively. The maximum membrane stress corresponding to the collapse load is obtained as 960 MPa near to the junction. The nominal stress corresponding to the collapse load is obtained as 448 MPa. From these two data we obtain the B_2 index as 1.81. The analysis repeated by applying the load vertically downward direction and found that the variation in B_2 index is negligible. Since the branch connection is locally thickened near the junction where the thickness of the branch pipe is around 4.5 mm instead of 2.24 m, the analysis is repeated with increasing the thickness of branch pipe from 2.24 mm to 4.5 mm by reducing the inner diameter. The load deflection curve for this case is shown in figure.5. By twice elastic slope method the collapse load is estimated as 1840 N. The maximum membrane stress corresponding to the collapse load is obtained as 790 MPa near to the junction. The nominal stress corresponding to the collapse load is 645 MPa. From these two data we obtain the B_2 index as 1.22. For determining the stress index for out of plane loading full model of the branch connection is made as shown in fig.5.Out of plane loading is applied at the free end of the branch connection. The loading sequence and determination of the collapse load is carried out similar to the previous case. The stress indices obtained for the two cases are listed in the table.1. The B_2stress indices obtained for case-1 and case-2 are 1.88 and 1.27 respectively. This indicates that the stress index for the out of plane loading is slightly higher than in plane loading case.

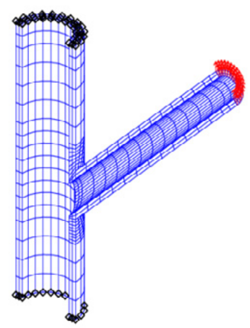

Fig. 1. Finite element modeling of non radial branch connections.

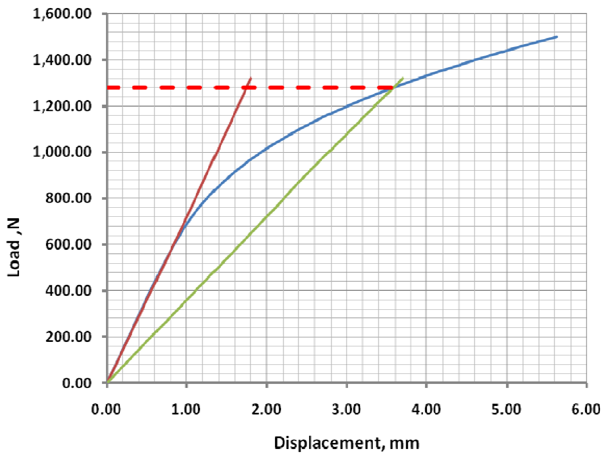

Fig. 2. Load deflection curve and collapse load determination.

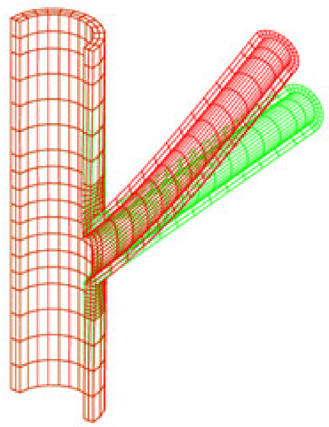

Fig. 3. Deformation of branch corresponding to the collapse load.

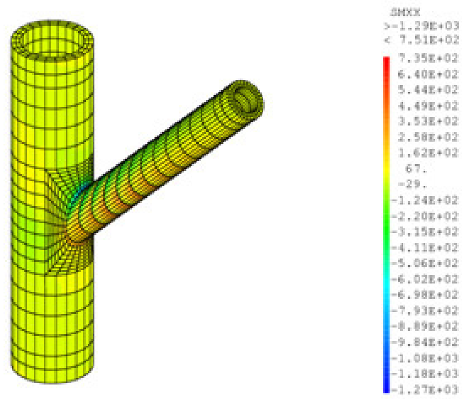

Fig. 4. Stress distribution corresponding to the collapse load.

Table 1. Stress indices for non radial branch connections.

Stress index/factor	Case-1 with 2.24 mm thickness of branch pipe		Case-2 with 4.5 mm thickness of branch pipe	
	In plan loading	Out of plane loading	In plan loading	Out of plane loading
B_2	1.81	1.88	1.22	1.27
C_2	2.71	2.82	1.8	1.905
K_2	5	5	5	5
i	6.78	7.05	4.5	4.76

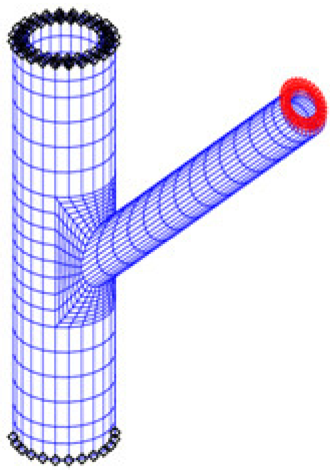

Fig. 5. Model for out of plane loading.

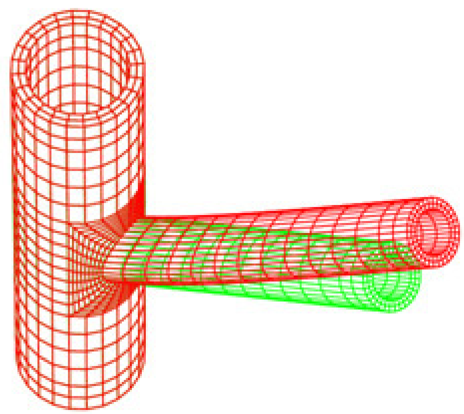

Fig. 6. Out of plane bending.

4.2. Determination of C_2 index

The C_2 index for the given component is derived the B_2 index calculated by limit load analysis by employing the equation (6) and the value for the C_2 index for in plane is obtained as 2.71 and 1.8 respectively for the two cases mentioned in paragraph 4.1. Similarly $C_2$for out of plane bending is obtained as 2.82 and 1.9 respectively for two cases.

4.3. Determination of K *index*

K-Indices represent peak stresses which are involved in a fatigue evaluation. So this factor can be evaluated from the Peterson's curve corresponding to the fillet radius at the junction between the main pipe and branch pipe. Since the junction in this case is very sharp, the K factor will have a value of 5.0. This value can be reduced drastically by providing a small fillet radius at the junction.

4.4. Determination stress intensification factor i

The value of the stress intensification factor *i* is derived by employing the relation given in equation (7). Accordingly the value of *i* is obtained for in plane bending as 6.78 and 4.5 respectively for two cases considered in the analysis. The values for out of plane bending for the two cases are 7.05 and 4.76 respectively. The values of various stress indices are summarized in table.1 for the two typical cases analyzed.

5. Conclusions

Procedure for determining the stress indices for non radial branch connections is discussed. A typical non radial branch connection commonly used in the piping system of FRFCF is modeled and analyzed using CAST3M for calculation various stress indices. B_2 Stress indices for the branch connection is arrived for in plane and out of plane loading based on nonlinear finite element analysis and limit load approach. K_2 Factor is determined using Peterson's curve based on the curvature at the junction of run pipe and branch connection. Stress index C_2 and the stress intensification factor *i* are determined by employing the relation of these factors with other stress indices.

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