Stress indices for nonradial branch connections subjected to out-of-plane moment loadings

P.P.Raju
Sudbury, Mass., USA

1 ABSTRACT

The purpose of the subject paper is to disseminate the results and findings of the Pressure Vessel Research Committee(PVRC) Phase 2 program relative to the development of stress indices for 45 degree lateral connections under out-of-plane moment loading applied on the branch pipe.

The objective of the earlier Phase 1 program was to develop stress indices for lateral connections under three load cases namely, internal pressure, and in-plane moment loadings on the branch and the run pipe (or the vessel). A complete discussion of the results and conclusions of the Phase 1 program and the recommended indices for the design of lateral connections in vessels and piping can be found in WRC Bulletin 301 (Reference 1). The purpose of the Phase 2 program described herein is to ascertain the relative magnitudes of the in-plane and out-of-plane moment indices through selected parametric studies and recommend comprehensive C_2K_2 indices for use with equations in NB-3650, Section III of the ASME code and for the design of nozzles per NB-3338 Stress Index Method. The Phase 2 parametric studies performed on PVRC Models 2and 4 (d/D=0.5, D/T=10,40) indicate that the out-of-plane moment index could far exceed the in-plane index and the use of in-plane index to envelop the resultant moment in piping analysis could be unconservative.

2 INTRODUCTION

At the conclusion of the Phase 1 of the PVRC program on 45 degree lateral connections that resulted in the development of stress indices for internal pressure and in-plane moment loadings, the representatives of the fitting manufacturing industry felt that generating stress indices for out-of-plane loading on the lateral branch would be a worthwhile PVRC contribution to the technical literature and that piping designers could greatly benefit by these data.

A subsequent literature search revealed that data, both theoretical and experimental, on stress indices for out-of-plane moment on lateral (nonradial) branch connections were scarce and the limited data available were conflicting and inconclusive from the view point of the relative magnitude and the trend of the index in comparison with the in-plane moment index. As a result, the PVRC launched the Phase 2 parametric

study to develop and recommend stress indices for out-of-plane moment loading for incorporation into various ASME codes and comparison with in-plane moment indices so that the relative impact can be assessed in the structural integrity evaluation of branch connections.

For the Phase 2 study, it was decided to select two of the four models already analyzed for in-plane moment loading under the Phase 1 program. Models 2 and 4 with d/D=0.5 and D/T of 10 and 40 respectively were chosen for the reported study. The geometric parameters of these two models were found to nearly represent the configuration used in nuclear and petrochemical applications.

The purpose of the subject paper is to present and discuss the relative magnitude of the in-plane and out-of-plane moment indices based on the selected parametric studies and the proposed piping branch connection and vessel nozzle indices for use with the Stress Index Method permitted by Section III of the Boiler and Pressure Vessel Code.

A detailed discussion of (1) the technique and the procedure used to generate the 3-D finite element model, (2) the simulation of the out-of-plane moment through weighted nodal forces, and (3) antisymmetric boundary conditions is presented to promote similar parametric studies by the pressure vessel and piping industry.

The summary of results includes both in-plane and out-of-plane stress indices for critical regions in order that an accurate and comprehensive evaluation of nonradial branch connections could be made in the future.

3 MODEL CONFIGURATIONS

The geometry of Model 2, along with coordinate axes and the edge boundary conditions for the in-plane moment loading is shown in Figure 1. The comparable dimensions for Model 4 are as follows. The inside diameter D of the main vessel (or run pipe) is 30 inches (25.4mm/inch) and the wall thickness T is 0.75 inch. The lateral branch or nozzle intersects the main vessel or run pipe at an angle of 45 degrees. The inside diameter d of the nozzle or branch is 15 inches and the wall thickness t_n at the reinforced section of the nozzle is 2.60 inches. The wall thickness t of the branch pipe is 0.375 inch. The inside corner radius r_1 and the outside fillet radius r_2 are 0.375 and 0.75 inch respectively. The radius r_3 at the transition between the branch pipe and the reinforced section of the nozzle is 1.575 inches.

The intersection of the axes of the main vessel and the lateral nozzle is chosen as the global origin for both the models. The boundaries of Model 4 are extented to a length L_1 of 45 inches to the right of the global origin and a length L_2 of 15 inches to the left of the global origin. These lengths amount to a boundary layer of $4.0(RT)^{\frac{1}{2}}$ or greater from the acute and obtuse corner regions and are considered adequate to attenuate the edge effects. A length L_3 of 45 inches is considered along the lateral axis for Model 4. This provides ample length beyond Section A-A (Figure 1) to attenuate the edge effects toward the free end. All the parameters discussed above are shown in Figure 1 for Model 2.

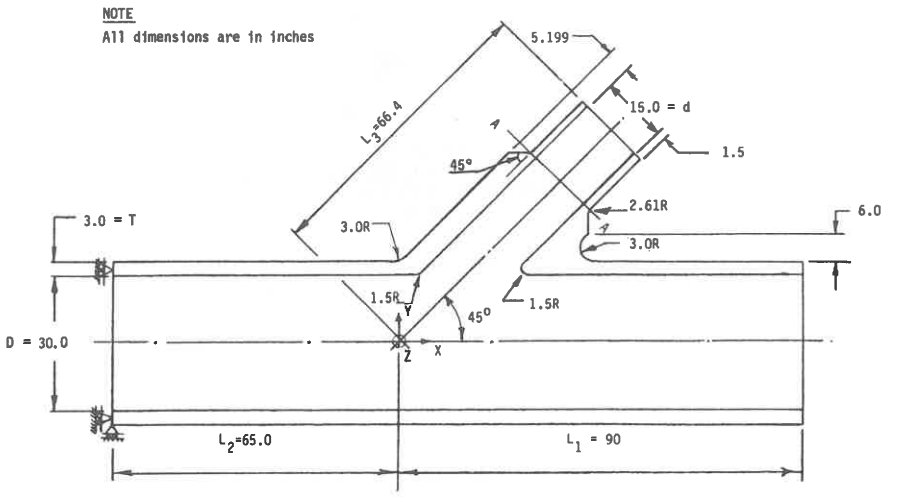

Figure 1 PVRC Model 2. Geometry

4 3-D FINITE ELEMENT MODEL

A detailed discussion of the technique and procedure used to generate the 3-D finite element model is presented in Reference 1. A brief description is, however, presented herein to make this paper a stand alone document.

The finite element model was developed using the 3-D isoparametric solid element (STIF 45) of the general purpose ANSYS computer program (Reference 2). This element is defined by eight nodal points having three degrees of freedom at each node. Since the model is symmetric about the longitudinal X-Y plane (Refer to Fig.1), a half symmetric finite element model is generated to reduce the number of elements to be used in the computation. The ANSYS node and element generator (PREP7) is used in generating the models. This generator is an extended capability version of the node and element generation capability in the ANSYS program. PREP7 calculates points along the intersection of surfaces. Selective plots and printouts may be produced as the model is generated. Model editing features are also availabe in PREP7.

The finite element models are generated in several segments and merged at the end. In all, the half symmetry finite element mesh of Models 2 and 4 consists of 2600 and 2208 isoparametric solid elements respectively. As a minimum, three elements through the thickness are used in all regions except the lateral branch pipe where two elements through the thickness are considered sufficient. In the circumferential direction of the branch, the model consists of one element every 10 degrees and the main vessel is modeled with one element every 10 degrees upto 90 degrees and one element every 15 degrees between 90 and 180 degrees. In the critical acute crotch region, a row of seven elements is used to obtain a smooth stress profile. For the innermost elements around the crotch region (from 0 to 180 degrees) a twenty seven integration points

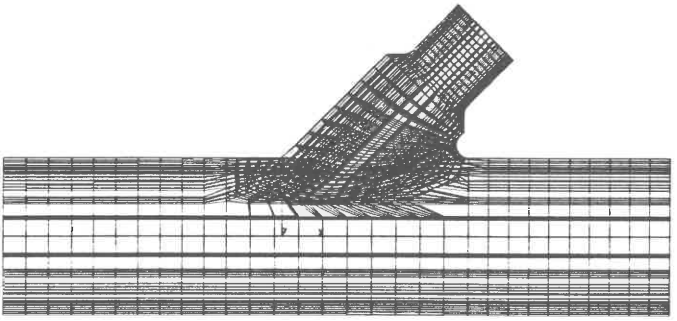

Fig.2 PVRC Model 2. Front View

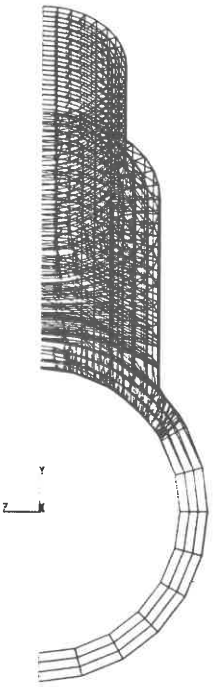

Figure 3 PVRC Model 2 Side View

printout option is selected. A discussion on the basic concepts and formulation of isoparametric elements is included in Reference 3.

Since the wave front size is dependent upon the order in which the elements are input, the elements generated are reordered to decrease the wave front size. Two finite element plots of Model 2 are presented in Figures 2and 3. Different viewing vectors are used in generating these plots. Detailed sectional plots can be found in WRC Bulletin 301.

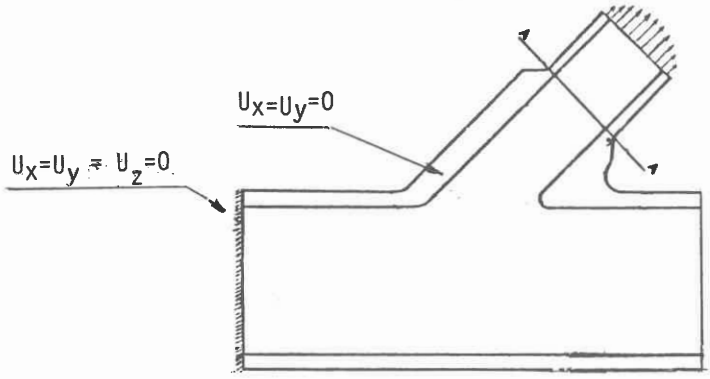

Figure 4 Schematics. Applied Load & B.C's

The nodal forces based on the expression above can be calculated in the same manner as demonstrated above.

A similar procedure is adopted to calculate the nodal forces for Model 2. The applied nominal stress at the loaded branch end is maintained at 1000 psi for this model also.

7 BOUNDARY CONDITIONS

In order to induce an out-of-plane moment loading on lateral half symmtry model, anti-symmetry boundary conditions are imposed on the symmetry plane.

Symmetry plane costraints

$U_X=0$, $U_Y=0$

U_Z= Unconstrained

The left end of the model is completely constrained by restraining all three degrees of freedom ; i.e; $U_X = U_Y = U_Z = 0$. This edge condition is different from the in-plane moment loading case for obvious reasons. The schematics of the nodal forces, constrained degrees of freedoms and the boundary conditions are presented in Figure 4.

8 ANALYSIS PROCEDURE

Revised input files were prepared from the data stored on magnetic tapes saved from the Phase 1 program to reflect the changes in the boundary and constraint conditions and the nodal forces from the earlier in-plane moment load evaluation.

A data check run was made to verify the input. Upon complete verification of the input data, a solution run was made and the results of the analysis were saved on tape for post-processing. The computed results were checked for consistency and accuracy in the key regions.Several stress and displacement plots were also obtained for selected planes and cross sections to detect any anomalies. However, only integration point stresses extrapolated to the surface are used in computing the maximum stress index which for the out-of- plane moment occurs at the transverse plane, 90 degrees from the symmetry plane.

9 SUMMARY OF RESULTS

The stress indices based on the extrapolated Gaussian point values on the inside and outside surfaces of the selected locations are presented below in Table 1 and compared with the in-plane momentloading.

Table 1 Summary of stress indices

Location	Surface	Model	Branch Moment	
			In-Plane	Out-of-Plane
Acute Crotch	Inside	2	0.10	0.05
		4	0.13	0.07
Obtuse Crotch	Inside	2	0.02	0.01
		4	0.11	0.07
SectionA-A Acute	Outside	2	1.40	0.31
		4	1.33	0.28
SectionA-A Obtuse	Outside	2	1.40	0.30
		4	1.32	0.24
Entire Model	---	2	1.40	2.70
		4	1.32	2.50

10 PROPOSED ASME STRESS INDICES

For the design of nonradial nozzles in pressure vessels per NB-3338 of Section III of the ASME B&PV Code, a stress index value of 2.70 is recommended for out-of-plane moment loading applied on the branch end. This index is applicable only if the axis of the nozzle makes an angle less than or equal to 45 degrees with the normal to the vessel wall and if $d/D \leq 0.50$. The indices for internal pressure and in-plane moment loading are available from WRC-Bulletin 301. The dimensional limitations specified in the above bulletin shall apply here also.

For the design of lateral branch connections in piping per NB-3680 of the Code, the recommended C_2K_2 for the out-of-plane moment applied on the branch pipe is 2.70. This value is comparable to the minimum recommended value for the branch moment index in a radial branch connection. Obviously, a reduced value could be justified for radial branch connection based on the similar value calculated here for lateral branch connections. Indices for other loading conditions are available from WRC-Bulletin 301.

11 CONCLUSION

The results and recommendations presented here and in WRC-Bulletin 301

represent a significant contribution from the Pressure Vessel Research Committee in promoting a safe and economical design of pressure vessel and piping components. The proposed stress indices fill a major void left in the Code since its inception. It is, however, recommended that the industry follow the lead established by PVRC through these benchmark studies and expand the database to develop comprehensive design guidelines for nonradial branch connections. The details of what the expanded database should include are clearly spelled out in Section 17.0 of WRC Bulletin 301.

12 ACKNOWLEDGMENT

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13 REFERENCES

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