RESULTS OF FEA ANALYSES AT NOZZLE/SHELL JUNCTIONS SUBJECTED TO EXTERNAL LOADS

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ABSTRACT

This paper presents the results of several nozzle and shell dimensional configuration analyses utilizing finite element (FE). The authors utilized typical shell and nozzle dimensions with typically allowed external nozzle loading . These FE results are compared to WRC 107 results to determine if the FE results may be used to establish the critical variables necessary to construct a standard allowable piping load basis.

INTRODUCTION

In the past external loadings on nozzles have been analyzed on a case by case basis utilizing WRC 107 (1965) procedures which are founded on older research results and conclusions. Previous papers (Porter and Martens et al, 1996, 1998, 1999) have presented methodology to calculate stresses and acceptance criteria for loads on nozzle to shell junctions on pressure vessels. This paper presents an extension of this work and begins to establish a basis for applying these methods to standard configurations and development of a defined "Standard Nozzle Loads" basis. The standard nozzle load basis would be utilized for preliminary pipe and vessel design and evaluation.

PROBLEM DEFINITION

Plant piping systems impose loads upon pressure vessels through the nozzle connections. The general duty clause in ASME Section VII Division 1 UG 22 (1998) requires the investigation of these loads during the design of the vessel. This requires the vessel and piping engineers to closely coordinate their design efforts to produce a safe and reasonable design. In order to minimize the engineering effort on these systems it is desirable to develop standard "maximum" loads for common nozzle/vessel configurations. It is the authors opinion that standard loads developed using FE analysis would be more accurate than those developed using WRC-107. The methods outlined in the referenced papers will be applied for the FE analysis. This paper will present a representative sample of the range of size and configurations that these methods may be applied to. It should be noted that all nozzles investigated were designed per ASME Section VIII, Division 1 mandatory reinforcing requirements.

FE ANALYSIS PROCEDURE

A programmed FE pre-processor (Martens, Porter and Hseih, 1996) is used in order to standardize the analysis approach and significantly speed up the input process. This can also be used to further refine individual geometry.

The post-processor (Martens, Porter and Hseih, 1996) provides a plot of stresses in the nozzle and shell utilizing the highest peak stress intensity indication to locate the line to plot. The post processor may also include the acceptance criteria plotted for reference in position to the indicated stresses. This will allow an immediate visual determination whether the loading and geometry is acceptable. As this procedure can be used for many geometry's and loading conditions, it can also be used to analyze many so-called "standard geometry's " in order to arrive at acceptable nozzle loading criteria for a range of conditions.

FINITE ELEMENT MODEL

A linear elastic FE model was constructed using quadrilateral thin shell elements with membrane and bending capabilities for relatively large radius and thin wall (r/t>10) configuration. A typical model, see Figure 1, consists of over 1000 nodes and 1000 elements such as is presented in Figure 1. External forces and moments were applied at the face of the flange utilizing a "spider web" which is a modeling technique that simplifies the transfer of forces and moments without affecting the accuracy of the results, as described by Martens, Porter and Hsieh (1996). Internal pressure was also included in the model. Note that the actual radial forces applied to the nozzle included an equivalent nodal force due to the pressure thrust on the nozzle. Stress intensity was evaluated at the junction of the nozzle and the shell, and at several distance points away from the juncture.

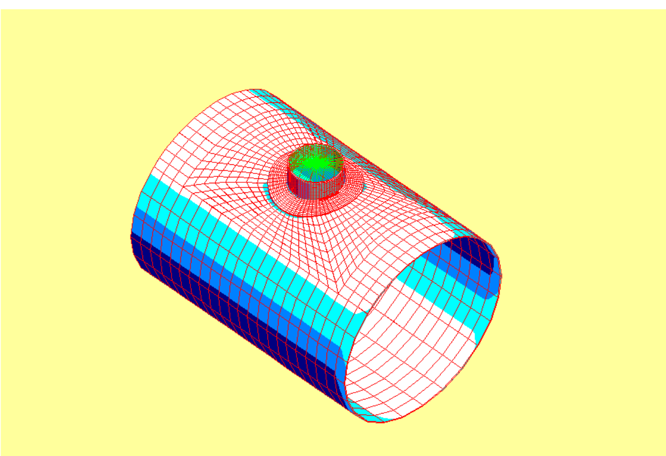

Figure 1 Typical Model

STRESS ANALYSIS DISCUSSION

The location at which to compare the FE indicated stresses to ASME Section VIII, Division 1, 1998 allowable stress utilizing Division 2 methodology is discussed by Porter et al (1996, 1998, 1999) and Heckmer et al (1997). The ability to develop a stress profile from the FE analysis results provides the engineer with much more stress detail then previous WRC type results. The shell hoop stress can be addressed by classic closed form calculation methodology as indicated in Division 1. The authors chose to concentrate on the combined primary and secondary loading condition as these nozzles are considered to be properly reinforced per the Division 1 criteria and this is the loading for which the WRC 107 methodology is utilized.

The investigation matrix in Table 1 gives a range of nozzle and shells that are typical of those found in chemical and refinery vessel applications. Table 2 presents related nozzle thickness and piping imposed loading data. The stresses developed by FE and WRC 107 are presented in Table 3. The FE results are peak stress intensity due to primary and secondary loadings (pressure and imposed nozzle loadings) at approximately the location of the outside weld edge of the nozzle and shell junction. This is the general area that WRC analysis represents. Inspection of Figures 2 and 3 indicates that a significant stress increase occurs near the junction for the nozzle and shell.

WRC 107 presents results for inside and outside of the shell at "Quarter points"; 0, 90, 180, & 270 degree locations; on the nozzle cross section as noted in Sketch 1. WRC 107 presents stresses at points picked for ease of calculation and does not present the stress patterns available from FE analysis, including the stresses in the nozzle. The traditional method is to locate the highest combined stress intensity from these WRC locations and compare against Div. 2 Code allowables of 1.5Sm. This corresponds to the use of 1Sm criteria for primary loading at this critical area and allowing an additional 0.5Sm for the secondary loadings. Some engineers utilize a more complex analysis by combining the pressure membrane stress with the appropriate WRC 107 component stress and utilize a 3Sm criteria for combined primary and secondary loading stress. The weakness in this methodology is that it does not locate the true maximum stress point, unless Mc or Ml and Vc or Vl are zero. Yet this methodology has been in use for many years with success. It should be noted that most of the WRC 107 stress results in Table 3 meet the 1.5Sm criteria. The authors did not attempt to adjust the geometry or loadings to produce WRC maximum combined stress intensity results that meet the 1.5 Sm criteria or confirm general membrane stresses. Most of these nozzles would be considered acceptable using WRC calculation methodology.

FE analysis indicates that the stress intensity due to primary plus secondary loadings (pressure and piping imposed loading combined) in the area of the nozzle to shell junction are typically approximately twice the stress intensity produced by WRC 107 methodology. This in part is due to the FE analysis including the pressure induced membrane stress and bending stresses in its indicated maximum stress.

The location at which the FE analysis indicated stress intensity exceeds the material yield should be very limited as this area will receive permanent strain when the loading is applied. The stress intensity profile from a typical nozzle and shell analysis is presented in Figure 2 and 3.

The Finite Element methodology indicated stress intensity results presented here provide a more accurate picture of the stress patterns and will more closely define the maximum stresses and their locations. However, when these stresses are determined, they can be higher than the stresses calculated by WRC 107 and can be unacceptable considering the same acceptance stress criteria used previously.

The challenge then is to use this FE methodology in a way that will provide the same nozzle geometry and loading acceptability as the WRC 107 methodology, yet provide additional information to arrive at better solutions by developing appropriate acceptance criteria.

From here the engineer is left to his own judgement as to how to use the FE results. This includes acceptance criteria for indicated stress intensity and it's location.

The authors propose that the acceptance criteria of 3Sm is appropriate for the operating condition maximum stress intensity in this junction area. Inspection of Table 3 indicates that the 3Sm FE and 1.5SM WRC acceptance criteria appear to be reasonable. From inspection of Table 3 it is apparent that if the 1.5 Sm criteria utilized for WRC 107 results was applied to the FE results few of the nozzles would meet this criteria. The authors consider this to be an unacceptable conclusion as the use of WRC 107 has proven to provide reasonably safe designs. Therefor the authors propose that the FE results must be considered utilizing acceptance criteria other than 1.5Sm at the junction.

Further information in relation to acceptance criteria and applicable location is the subject of a technical paper by Porter et al (1999) to be presented at PVP 1999.

ADDITIONAL DISCUSSION

The authors chose to utilize WRC 107 for this comparison as this has been the industry standard for over 30 years. The use of WRC 297 methodology may provide additional insight but the authors consider the use of WRC 107 appropriate for this comparison.

The results of the FE analysis are difficult to compare to code criteria and results of WRC 107 analysis. The exact location of the maximum stress is seldom at the quarter point locations that are calculated per WRC as the nozzle loads are seldom only in one plane or axis corresponding to these quarter points. The FE analysis does provide stress intensity indication that is consistent with the multiple loadings that are usually applied to nozzles.

The engineer must determine the location appropriate to compare the FE stress results with the code allowable stresses. This location is not clearly defined by the code. The PVRC document by Heckmer and Hollinger (1996) and the Porter et al (1999) references give guidance in this area. The engineer must determine the suitability of the nozzle loadings and the stress analysis results.

The information presented in Table 3 provides an insight into the suitability of applying the 3Sm criteria to FE results at the general location at which the 1.5Sm criteria for WRC 107 results, for nozzles reinforced per Division 1 criteria.

THE CONCLUSIONS

The authors intended to establish a general methodology that could be utilized for establishing standard allowable nozzle imposed piping loads to reduce calculation efforts. It is apparent, from the variety of configurations investigated, that the complexity of the loadings combined with the multiple nozzle and shell configurations makes this task very difficult.

It is the authors conclusion that it is possible to provide standard nozzle loading criteria based on FE analysis results for a specific configuration. The current computer and software tools can be utilized to analyze a wide range of nozzles and loading configurations thus allowing validation of standard nozzle loadings. It is apparent that generalized nozzle loading acceptance criteria is best based on analysis of specific configurations that can be consider typical and not extrapolated from a few analyzed configurations. From this conclusion it is apparent that a considerable number of nozzle and loading configurations must be analyzed to provide the basis for standard nozzle loadings that may be used for preliminary design. It is the authors intention to expand the configurations investigated by the FE methodology in an effort to establish reasonable maximum loads that may be applied to these configurations for preliminary design work.

The authors have concluded that;

1. The application of nozzle design criteria, including reinforcement, contained in ASME Section VIII Division 1 will provide a reasonable amount of piping imposed loading ability.
2. The general industry practice of utilizing WRC 107 methodology for loadings imposed on nozzles has successfully provided safe applications. Therefor a FE

analysis indicated stress intensity result of the same nozzle should not invalidate a nozzle that WRC 017 has validated and that has preformed successfully in practice

3. The investigation of the nozzle to shell junction stresses due to operating loads can be accomplished with FE with greater accuracy than using WRC 107. FE also allows a greater range of nozzle to shell sizes to be investigated than WRC 107 and WRC 297. With this advantage the engineer can enhance the safety of a nozzle application while achieving the most economical design.
4. An engineering community consensus for nozzle to shell junction FE indicated stress intensity acceptance criteria, and its' location, remains to be defined. Until a consensus definition is achieved the engineer must exercise good judgement when reviewing the results of nozzle to shell junctions investigated by FE methodology.

CAUTIONS

The authors suggest caution in the evaluation of FE analysis stress results in the junction of the nozzle and shell area. The FE analysis will provide considerably more stress data than closed form calculations such as WRC type procedures. The engineer should evaluate the stress profile in this junction area to assure a smooth transition from the general membrane stress area away from the junction to the junction is achieved. The authors suggest referring to reference publications listed below for a more complete understanding of this complex subject.

The authors have addressed the operating load stress investigation in this paper as this is the classic methodology when utilizing SRC 107 procedures. The use of FE for analysis of a nozzle to shell junction should include confirmation that the design load stress is also acceptable as indicated in Porter et al (1999).

The authors recommend that the engineer carefully consider nozzle to shell junction indicated stress intensities where 3Sm would result in continued creep relaxation strain. The use of carbon steels and chrome moly steels where the code allowable stresses are based on creep failure values are examples where this caution is applicable. It is noted that considerable nozzle to shell junction area strain may occur with out significant relaxation of piping imposed nozzle loadings resulting in a creep type failure.

References:

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3. Hechmer, J.L. and Hollinger, G.L., 1997, "3D Stress Criteria: Guidelines for Application", PVRC Grant 91-14 Final Report, ASME, New York, New York.
4. Martens, D.H., Porter, M.H. and Hsieh, C.S. 1996 "Nozzle Stiffness and Stress Computation Using A Parametrically Controlled Finite Element Modeling Approach", <u>PVP Vol. 336</u>, ASME, New York, NY
5. Porter, M.A. and Martens, D.H., 1996, "A Comparison of the Stress Results from Several Commercial Finite Element Codes with ASME Section VIII, Division 2 Requirements, <u>PVP Vol. 336</u>, ASME, New York, NY, pp. 341-346
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7. Porter, M.A. Martens, D.H., and Hsieh, C.S., 1998, "Stress evaluation of a Typical Vessel Nozzle using PVRC 3D Stress Criteria: Guidelines for Application", <u>PVP Vol. 368</u>, ASME, New York, NY, pp. 297-301.
8. Porter, M.A. Martens, D.H., and Caldwell, S.M., "A Suggested Evaluation Procedure for Plate Element Finite Element Models" to be presented at 1999 ASME PVP Conference.

Table 1: Geometry Matrix

The following geometrical combinations were analyzed to gain comparison information:

Vessel/Nozzle Geometry Combinations

Vessel / Nozzle	48" ID 7/16" wall thk.	60" ID ½" wall thk.	72" ID 5/8" wall thk.	96" ID ¾" wall thk.	144" ID ¾" wall thk.
2" Std. Wall Pipe	285 Psi 50 Psi				
8" Std. Wall Pipe		285 Psi 50 Psi	50 Psi		
16" XS Pipe	285 Psi 50 Psi				
24" XS Pipe				270 Psi 50 Psi	180 Psi 50 Psi

Table 2: Nozzle Loading Data

Vessel Dia. inch	Design Press psi	Nozzle Size/Thk inch	Endload* Radial lb	Shear Circ lb	Shear Long lb	Moment Circ inlb	Moment Long inlb	Moment Tors inlb
48	50	2 / 0.154	441	330	441	1740	2256	2604
48	285	2 / 0.0915	441	330	441	1740	2256	2604
48	50	16 / 0.500	3528	2642	3528	111000	144400	166600
48	285	16 / 0.312	3528	2642	3528	111000	144400	166600
60	50	8 / 0.322	4234	3170	3170	66620	86500	99910
60	285	8 / 0.322	1764	1321	1321	27760	36070	41630
72	50	8 / 0.322	4234	3170	3170	66620	86500	99910
96	50	24 / 0.500	6480	4853	6476	305900	397600	458800
96	270	24 / 0.500	6480	4853	6476	305900	397600	458800
144	50	24 / 0.500	6480	4855	6476	305900	397600	458800
144	180	24 / 0.500	6480	4855	6476	305900	397600	458800

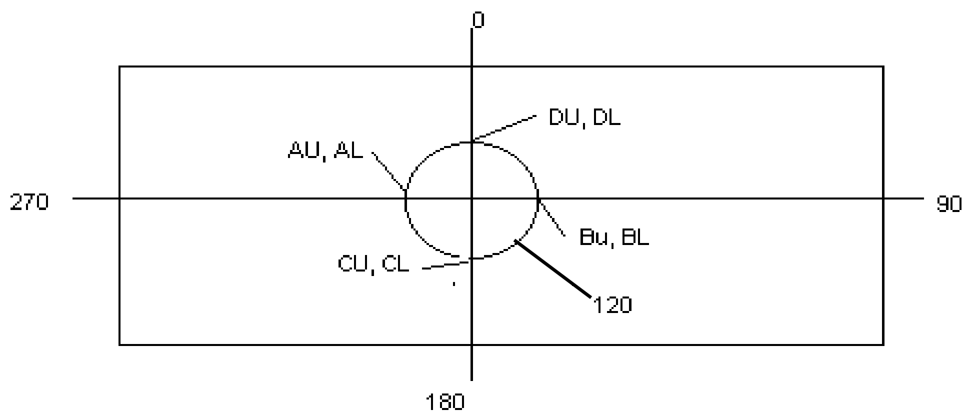
* This loading does not include end load from internal pressure, this must be added to this value

All design temperatures = 500 degrees F

Thicknesses used are in corroded condition

Materials of construction : SA-516-70 for shell and reinforcing pads

SA-106-B for nozzles



Sketch 1: WRC 107 Location Nomenclature

Table 3: Stress Analysis Results

Vessel Dia inch	Design Press psi	Nozzle Size inch	WRC107 Max Stress Intensity Inside psi	WRC107 Max Stress Intensity Outside psi	FEA * Max Stress Intensity Inside psi	FEA * Max Stress Intensity Outside psi
48	50	2	13291@CL	7249@DU	10500 @ 120	16100 @ 120
48	285	2	39053@CL	32989@DU	23800 @ 120	41400 @ 120
48	50	16	10947 @ CL	10345 @ DU	20400 @ 120	25200 @ 120
48	285	16	23834 @ CL	23194 @ DU	45800 @ 120	54500 @ 120
60	50	8	19621 @ CL	13999 @ AU	30300 @ 120	45500 @ 120
60	285	8	21297 @ CL	18270 @ DU	37500 @ 120	44200 @ 120
72	50	8	17400 @ AL	17600 @ BU	23000 @ 120	32600 @ 120
96	50	24	9672 @ CL	8521 @ DU	22300 @ 120	31800 @ 120
96	270	24	23747 @ CL	22567 @ DU	54500 @ 120	64000 @ 120
144	50	24	11781 @ CL	9958 @ DU	27400 @ 120	38500 @ 120
144	180	24	24257 @ CL	22412 @ DU	52500 @ 120	64900 @ 120

* Stress location taken at the junction of the outside diameter of the nozzle and the shell, similar to the locations for WRC 107. The location angle for the indicated stress is an approximation.

NOTE: per ASME Section VIII Division 1, SA-516-70 type materials at 500 F is Sa= 17,500 psi
This stress becomes Sa= 20,000 psi if Code Case 2278 is applied.