Nozzle Stiffness and Stress Computation
Using a Parametrically Controlled Finite Element Modeling Approach

Dennis Martens
The Pritchard Corporation

Michael A. Porter
Dynamic Analysis

Charles S. Hsieh
The Pritchard Corporation

ABSTRACT

A method is presented which allows the vessel engineer to more accurately evaluate the flexibility and stresses in vessel nozzles within the time and expense parameters associated with the normal design process. In a critical process piping system design, the vessel design engineer first calculates nozzle stiffnesses for inclusion of the nozzle spring constants in the piping system analysis. The loads generated from piping analysis are then fed back to the vessel engineer for stress calculation. In an earlier paper "Improving the Accuracy of Piping programs When Analyzing Closely Coupled Equipment," the wide divergence in nozzle stiffnesses and stresses computed by the available formula approaches was illustrated. Additionally, it was shown that it is desirable to use the Finite Element approach to better assess both the stiffnesses and the stresses in vessel nozzles. To facilitate FE nozzle modeling, a parametric-driven program was developed to aid the vessel engineer in using the FE program COSMOS/M.

PROBLEM DEFINITION

The design of a closely coupled piping and vessel system for a Sulfur Recovery Unit (SRU) as illustrated in Figure 1 has been discussed by Porter et al. (1995). The diversity of nozzle stiffness and stress results using several different methods of calculation, such as WRC-107 (Wichman et. al., 1979),WRC-297 (Mershon et al., 1987), ASME Section III, Division 1, Mokhtarian and Endicott, (1986) and Finite Element Analysis (FEA) was discussed in the paper cited in the abstract. The analysis results indicated that FEA offered more reliable and realistic results than the other methods. However, FEA can increase the time and expense parameters associated with the normal design process. The Pritchard Corporation engineering group was charged with developing a simple cost-effective approach for utilization of FEA for routine nozzle investigations.

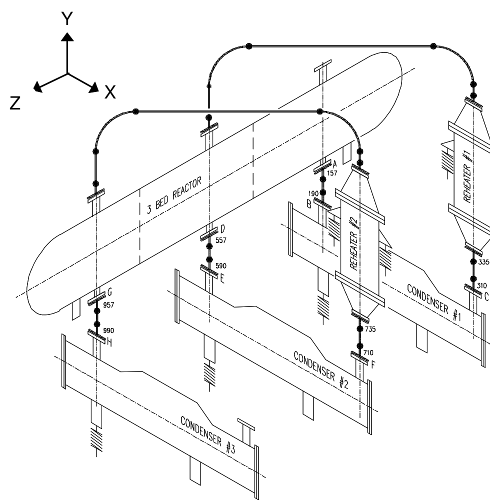

Figure 1

This paper presents a parametric driven technique to effectively use the COSMOS/M Finite element (FE) software to analyze the nozzle stresses in a system without adding a significant amount of time and/or cost to the design process.

CONVENTIONAL FE PROCEDURE

Conventional FE procedures require the engineer to construct a model, execute the FE calculation program and interpret the results. Depending on the experience of the analyst and the FE code involved, this process can take anywhere from a few hours to several days per nozzle to analyze. Most design projects will not support this level of effort for routine analysis activities.

PARAMETRIC PROCEDURE

Certain FE activities can be automated by use of a parametrically driven pre- and post-processor to reduce the engineering hours required for model construction and post-processing by a factor of 10 and more.

A parametric pre and post-processor program (PCFE) has been developed for this purpose. The program is written in the Microsoft FORTRAN language with an emphasis on creating a user-friendly environment in which uses the FE software automatic input file format. The program prompts the engineer for the input in the correct sequence necessary to ensure the integrity of data input.

The engineer begins by selecting from a chart which depicts typical configurations the geometry configuration that will be used in the model. Once the configuration is selected, the basic model parameters (required attenuation lengths, boundary conditions, etc.) are determined by the rules embedded in the program.

The input consists of all pertinent parameters, such as vessel/nozzle diameters, wall thickness, flange diameter, flange thickness, repad diameter, repad thickness, material properties, location of the nozzle, forces and moments on the nozzle, vessel internal pressure and so on.

The PCFE program constructs the element geometry, applies the boundary constraints, converts forces and moments to the appropriate nodal loads, and applies the internal pressure to the elements. To determining nozzle spring rate, the PCFE applies unit forces and moments at the center of the "spider web." This modeling technique simplifies the transfer of forces and moments without affecting the accuracy of the results. The "spider web" consists of rigid members, with proper end releases that transfer the applied forces and moments in the desired directions. The equivalent nodal forces (representing the force applied to the nozzle by internal pressure) are applied on the edge of the nozzle. This load is sometimes overlooked when analyzing nozzle loadings generated by piping system analysis.

The radius (r) to thickness (t) ratio of both vessel and nozzle are checked by the PCFE program. Using the commonly accepted threshold of r/t=10, the PCFE program selects either thin plate element and/or thick shell element as appropriate. Since input data validation is handled by the PCFE program, an engineer with limited FE experience is able to initiate the analysis. Once the data input is complete, the FE program creates the FE model by running a pre-processor command file that is generated by the PCFE program. No further manual input from the engineer is necessary. The FE will automatically check the model data base for errors, improper element shapes, etc.

Prior to the execution of the FE computational step, the engineer is afforded the opportunity to accept or reject the pre-processor created model. The engineer can visually check the overall geometry and mesh quality at the critical locations on the computer screen. At this point, the actual execution of the FE computation is started with a simple command. The FE calculation program will then form the element stiffness matrix, assemble global structural matrix, construct load vectors, and execute equation solvers to obtain analysis results.

INTERPRETATION OF RESULTS

The interpretation of the FE results is facilitated by the use of the PCFE post-processor that automatically extracts the results from the FE data base. PCFE combines load cases as appropriate, tabulates the nozzle spring rates in translational (radial) and rotational (circumferential and longitudinal) directions, and plots the deformed shapes and stress contours. The stress intensity plots (contours of top face, bottom face, membrane and bending stresses) are output to a hardcopy unit. These activities are all within the FE program environment and typical of the capabilities of most commercial FE codes. However, the interpretation of this information must be done by the engineer.

The PCFE post-processor program is currently being enhanced to find the maximum stress node, normally at the junction of the nozzle and the vessel. Using this point to define a reference section, PCFE will plot stress as a function of distance away from this point along both vessel and nozzle as discussed by Porter and Martens (1996). This procedure represents a simple and understandable guideline for the engineer to assess a nozzle design based on Appendix 4 of ASME Section VIII, Div. II methodology. With this type of stress plot, the engineer is able to determine if the nozzle is adequately designed by comparing the stress curve to the applicable material allowables.

CONCLUSIONS

Conventional FEA analysis requires an engineer with considerable FEA background to successfully accomplish the modeling tasks of defining the nodes, selecting the right type of element, generating the FE meshes, and applying the boundary constraints and loadings to the model. After execution of the FE program, additional time and expertise is required to extract and interpret the results of the analysis. The time required is excessive for normal design process conducted for everyday pressure vessel design.

As an example of the proceedure, Nozzle "A" of Fig. 1 has been analyzed. The spring constants of the nozzle were first calculated using PCFE and the FE program. Table 1 presents the stiffnesses that were computed.

Table 1. Nozzle "A" Spring Constant

Radial	9.42E+05	lb/in
Circumferential	1.31E+08	in-lb/rad
Longitudinal	3.96E+08	in-lb/rad

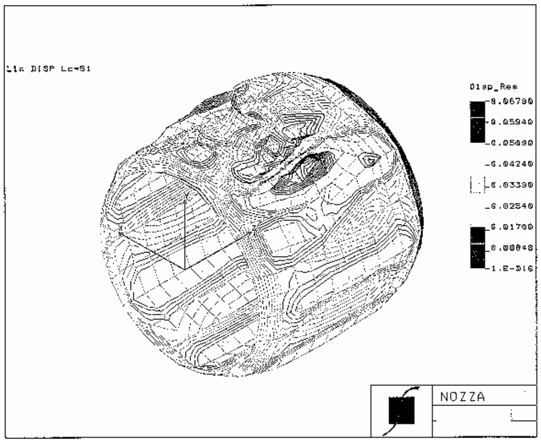

Figure 2

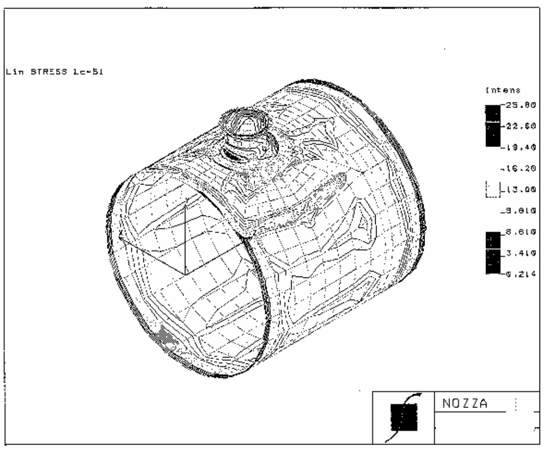

Figure 3

These stiffnesses were then incorporated into a the piping system analysis. The forces and moments from the output of the piping analysis at nozzle "A" were than input back to PCFE and FE programs for stress analysis. The results are listed in Figures 2 through 5. Using the criteria described by Porter and Martens (1996), the "P_L+P_b+Q" stress would occur within 1*t distance from the junction of the nozzle and shell and is compared against $3S_m$. The "P_L+P_b" stress is between 1*t and 5*t and the "P_m" stress is outside 10*t. All stress results are within the allowables, therefore Nozzle "A" is properly designed to accomodate the applied piping and pressure containment loadings.

This pre- and post-processor program has simplified the entire FEA process and provided an effective tool for the vessel engineer without an in-depth FE background to analyze a nozzle design. The example nozzle was input using PCFE in 10 minutes. FE model construction and analysis were accomplished without further engineer attention. The results were documented using PCFE in 10 minutes. Using this type of interface to a commercial FE code effectively reduces the engineer's time from 8 to 16 hours to 1/2 hour.

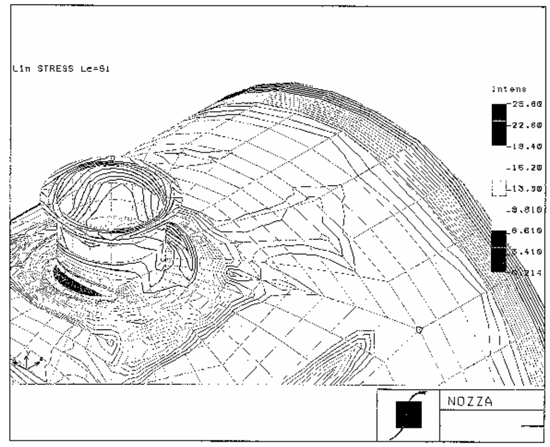

Figure 4

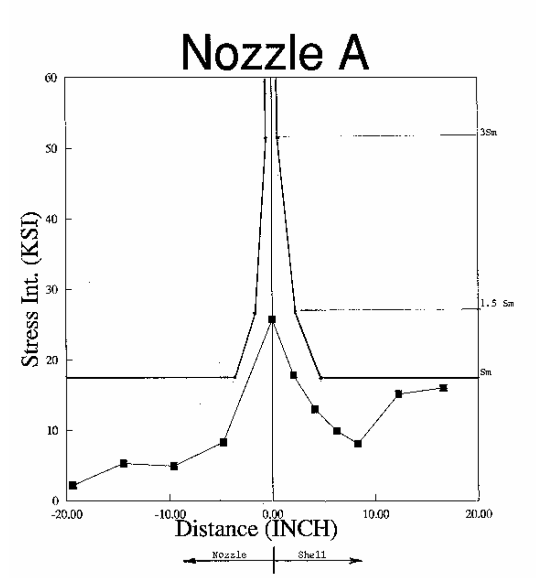

Figure 5

The software has been used by the vessel engineers at The Pritchard Corporation on numerous projects with proven effectiveness and results. While a review of the output by an engineer that is familiar with the FE process is still necessary, much of the basic drudgery has been removed. The typical vessel engineer should be able to effectively use this FEA process.

RECOMMENDATIONS

It is the authors' recommendation that the pressure containment industry consider the adoption of simplified FEA procedures as common practice for analyzing spring rates and external load and moment-induced stresses on nozzles. The goal to "continue producing safe pressure vessels while reducing costs" requires the most effective use of the design process. The automation of design engineering activities is needed to achieve this goal. Vessel designers should consider developing specialzed FE interfaces similar to that described in this paper to effectively use automation for routine and repetitive investigations.

The authors remain concerned that over-automation will effectively reduce the design engineer's participation which could result in the occurance of serious errors. This PCFE approach is focused on the elimination of the repetitive design work while maintaining the "hands on" engineering effect. It is the authors' opinion that the "hands on" approach is a necessary step to encourage engineers to be "intuitive" in the design. The PCFE approach of simplifying the input and gathering results provides the engineer with a friendly interface to allow this intuitive activity to occur.

REFERENCES:

ASME Boiler and Pressure Vessel Code, Sec. III, Nuclear Power Plant Components, Div.1, 1992, American Society of Mechanical Engineers, New York.

ASME Boiler and Pressure Vessel Code, Section VIII, Divisions 1 and 2, 1992, American Society of Mechanical Engineers, New York, NY.

Chen, H. and Chao, Y.J., 1993, "Contact Between Vessel Shell and Welded Pad in Nozzle Reinforcement," *Transactions of the ASME*, Volume 115, November, 1993, The American Society of Mechanical Engineers, New York, pp 364-372.

COSMOS/M User Reference Manual, Structural Research & Analysis Corp., 1995, Santa Monica, CA.

Hechmer, J.L., and Hollinger, G.L., 1995, "3D Stress Criteria: Guidelines for Application", PVRC Grants 92-09 & 91-14, Final Report, August, 1995 - Draft, August 1995.

Mershon, J.L., Mokhtarian, K., Ranjan, G.V., and Rodabaugh, E.C., 1987, "Local Stresses in Cylindrical Shells Due to External Loadings on Nozzles - Supplement to WRC Bulletin No. 107 - (Revision I)," *Welding Research Council Bulletin 297*, September, 1987.

Microsoft FORTRAN Compiler Language Reference Manual, Microsoft Corp., 1992, Redmond, WA.

Mokhtarian, K., and Endicott, J.S., 1986, "Sensitivity Analysis of Flexibility at Cylinder-Cylinder Junctions," in *Design and Analysis of Plates and Shells*, G.E.O. Widera, H. Chung, D. Hui, Eds, ASME Special Publication PVP-Vol. 105, ASME, New York, pp 65-69.

Porter, M.A., Martens, D.H., Korba, A., 1995, "Improving the Accuracy of Piping Programs When Analyzing Closely Coupled Equipment," *Fitness-for-Service and Decisions for Petroleum and Chemical Equipment*, PVP-Vol. 315, pp 335-339.

Porter, M.A., and Martens, D.H., 1996, "A Comparison of Stress Interpretation Results from Several Commercial Finite Element Codes," *ASME Pressure Vessel and Piping Conference*, July, 1996.

Wichman, K.R., Hopper, A.G., and Mershon, J.L., 1979, "Local Stresses in Spherical and Cylindrical Shells Due to External Loadings", *Welding Research Council Bulletin No. 107*, August, 1965, revised March, 1979.