FINITE ELEMENT ANALYSIS OF INCLINED NOZZLE-PLATE JUNCTIONS

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ABSTRACT

Estimation of stress concentration at nozzle to plate or shell junctions is a significant problem in the stress analysis of nuclear reactors. The topic is a subject matter of extensive investigations and earlier considerable success has been reported on analysis for the cases when the nozzle is perpendicular to the plate or is radial to the shell. Analytical methods for the estimation of stress concentrations for the practical situations when the intersecting nozzle is inclined to the plate or is non-radial to the shell is rather scanty. Specific complications arise in dealing with the junction region when the nozzle with circular cross-section meets the non-circular cut-out on the plate or shell. In this paper a finite element analysis is developed for inclined nozzles and results are presented for nozzle-plate junctions.

A method of analysis is developed with a view to achieving simultaneously accuracy of results and simplicity in the choice of elements and their connectivity. The circular nozzle is treated by axisymmetric conical shell elements. The nozzle portion in the region around the junction and the flat plate is dealt with by triangular flat shell elements. Special transition elements are developed for joining the flat shell elements with the axisymmetric elements under non-axisymmetric loading. A substructure method of analysis is adopted which achieves considerable economy in handling the structure and also conveniently combines the different types of elements in the structure.

The convergence of the stress concentration parameters and the stress distributions are studied by systematically increasing the number of elements in each region. Numerical studies show satisfactory convergence and indicate feasibility for applying the method to relatively large nozzles also.

1. Introduction

Estimation of stress concentrations at nozzle to plate or shell junctions is a significant problem in the stress analysis of nuclear reactors. A glimpse into the proceedings of the four SMiRT Conferences and into the Journal of Nuclear Engineering and Design shows that the topic is the subject of extensive investigation. Even with circular nozzles attached to flat plate or circular shells, the complexity in the junction configurations makes finite element analysis the most natural technique. Considerable success has been reported by earlier workers [1,2] with FEM analysis when the nozzle is normal to the plate or the shell. On the other hand situations when the nozzle is oblique to the plate or the shell require further investigation, because specific complications arise in dealing with such oblique connections. In this paper a finite element analysis is developed for inclined nozzles and results are presented for nozzle-plate junctions.

For a practical structural configuration such as a shell-nozzle junction, finite element analysis can be carried out with a variety of choices of elements and their connectivity, solution techniques, etc. With the availability of fast and large modern digital computers, one is tempted to use large computer memory with conventional elements. But such solutions need considerable effort and are often disappointing in their accuracy. On the other hand, the computer can be more efficiently used, if the analysis is harnessed to provide accuracy of results with simplicity in the modelling, and the elements. In this paper this is achieved by using axisymmetric conical shell elements for the circular nozzle, triangular flat shell elements in the junction regions of nozzle and the shell as also in the shell, and specially developed transition elements for joining the flat shell elements with the axisymmetric elements under non-axisymmetric loading. A substructure method of analysis achieves considerable economy in handling the structure when it is large or when more than one junction is involved, and also conveniently combines the different types of elements in the structure. Some typical results are presented.

The lone contribution in the SMiRT Conferences on inclined nozzle-cylindrical shell junctions was by Ando, et al. in 1971 [3]. Considering the well known shell theories, they developed the stiffness matrix for flat plate elements for the limiting case of infinite radius through Hellinger-Reissner formulation. They achieved a refined flat shell element. The present method is applicable for problems typified by this example and would be simpler.

2. Definition of the Problem

A typical flat plate-circular nozzle junction is shown in fig.1. A cylindrical nozzle is attached, oblique by an angle α to a square plate which is clamped along all its edges. The configuration is symmetric about the x-z plane and the nozzle is oblique by an angle α. At its ends A'B'C', the nozzle is subjected to axial load and moment distributions $p(\Theta)$ (axial), $m(\Theta)$

(moment), which may be described by

$$p(\theta) = p_o + \sum_{n=1}^{N} p_{n1} \cos n\theta + \sum_{n=1}^{N} p_{n2} \sin n\theta$$

$$m(\theta) = m_o + \sum_{n=1}^{N} m_{n1} \cos n\theta + \sum_{n=1}^{N} \sin n\theta \qquad (1)$$

Depending on the accuracy required, the Fourier series representing the arbitrary loading is truncated with finite number of harmonics N. The stage of truncation (N) will be significant to determine the degrees of freedom of the axi-symmetric elements under non-axisymmetric loading as will be described in the next section.

3. Finite Element Formulation

The plate and the circular nozzle are discretized by using three types of finite elements, Fig.2, viz., (i) flat shell elements of triangular shape, (ii) axi-symmetric conical shell elements, (iii) a transition element in the region connecting flat shell elements with axi-symmetric ring elements. The highlights of these elements are described below.

(i) Flat shell element: This element is built up from a simple CST with two degrees of freedom per node and a triangular bending element with three degrees of freedom. For a general orientation of the shell element, six degrees of freedom (3 translations, 3 rotations) exist, due to the possibility of having non-zero components of displacements in all six directions. The behaviour of the plate in its own plane is described by the CST element and the bending is described by Razzaque's hybrid element [4]. This element enforces linear variation of the normal rotation along the element edges. Though it is a non-conformal element, the shape functions used satisfy the patch test and hence convergence is assured.

(ii) Axisymmetric element: The shape functions for the axisymmetric conical shell element are taken from [5]. The element has ring nodes. It is described by six degrees of freedom, three per node, under axisymmetric loading. When a superposed arbitrary loading is represented by a Fourier expansion upto the N^{th} harmonic, the element has a total of N x 6 x 2 degrees of freedom.

(iii) Transition element: The triangular flat shell element in the plate nozzle junction region and the axi-symmetric elements in the nozzle cannot be directly connected since they have different degrees of freedom. Hence a transition element is developed to connect the two regions. It has only one ring node on the side of axi-symmetric elements and on the other side as many nodes as in the adjoining ring of flat elements.

4. Numerical Results and Discussion

Numerical results are presented to bring out the effect of angle of inclination of the nozzle (Fig.3) and the ratio of nozzle diameter to plate width (Figs.4 and 5). The loading case considered is a uniform axial force P on the nozzle. The stress in the plate is presented in terms of the non-dimensional parameter $\sigma_x t^2/P \cos\alpha$ where t = thickness of the plate and the displacements are presented in terms of DW/PL^2.

The convergence of the stress and displacement distributions have been systematically studied by increasing the number of elements in each region. The trends of convergence are found to be excellent for the right angled nozzle and upto 45° of inclination. Convergence for angles in excess of 45 is under investigation.

Figure 3 shows that the stresses are maximum at the acute angle intersection of the plate and the nozzle and increase with increasing angle of inclination. Keeping the plate width constant, along the junction the stress parameter $\sigma_x t^2/P$ increases with decrease in hole diameter. Away from the junction the values decay rapidly and the trend is reversed, i.e., the parameter decreases with decreasing hole diameter. These effects are shown for right angle nozzle ($\alpha = 0°$) in Fig.4 and a 30° oblique angle in Fig.5.

For a comparison of the present transition element method with the conventional method of large number of shell elements, we choose a short right angled nozzle (height equal to diameter). The agreement in results is within 1% for the deflection parameter (Fig.6), but the degree of freedom are fewer by 20% by the present method. The advantages of the present technique in respect of both accuracy and ease increases rapidly with increasing length of nozzle.

5. Concluding Remarks

An efficient and economic procedure for analysing nozzle-plate and nozzle-shell junctions is presented. The use of special transition element that can join conventional triangular flat plate elements and axi-symmetric elements has made it possible to achieve a satisfactory FEM model with fewer degrees of freedom. The technique can be directly applied to nozzle junctions with cylindrical and spherical shells and also extended to include conical nozzles.

Acknowledgements

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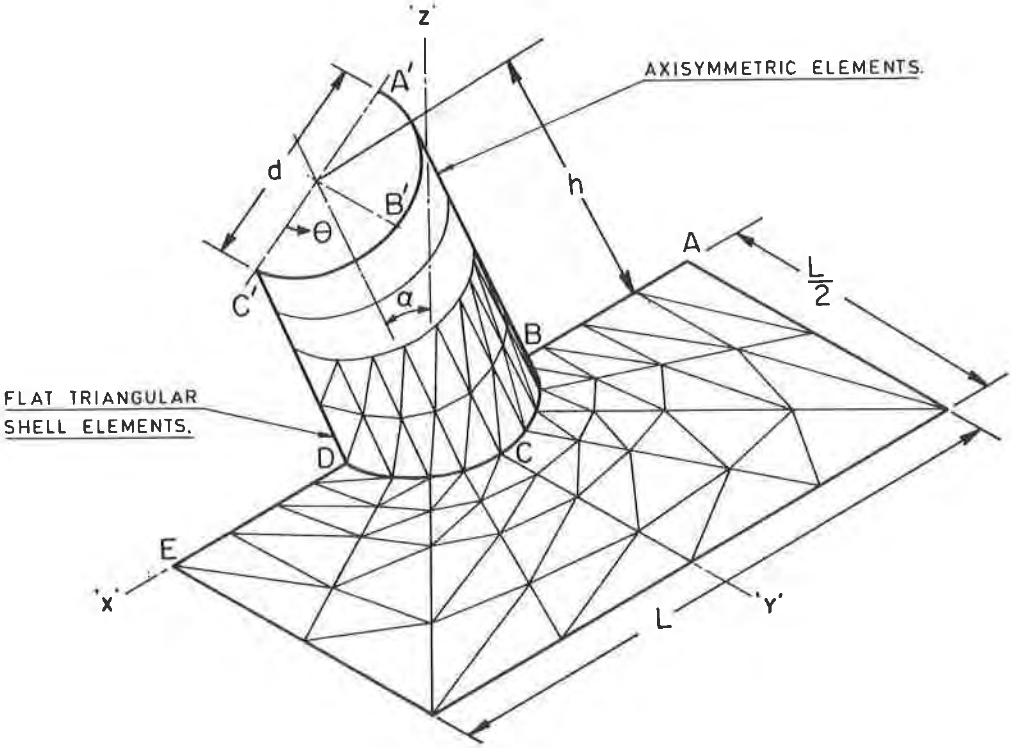

Fig.1 Flat plate-circular plate junction: Finite element idealisation.

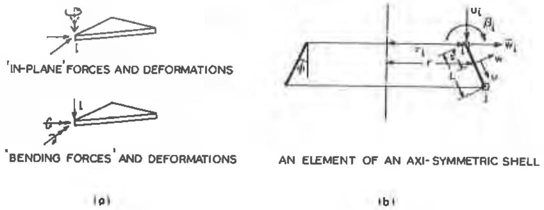

Fig.2 Types of elements used.

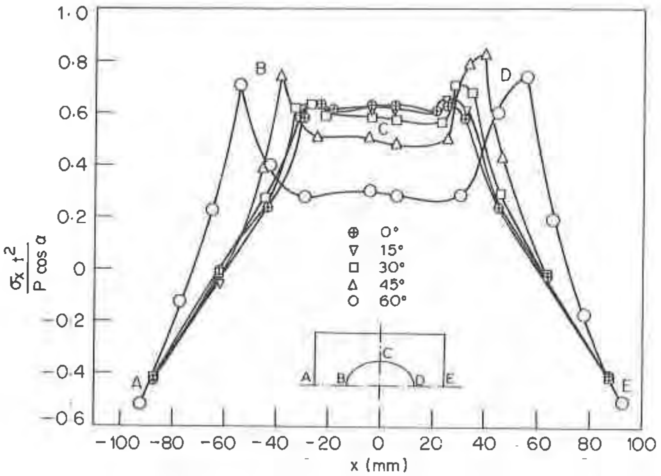

Fig.3 Stress distribution inplate along axis of symmetry and nozzle-plate junction: Effect of nozzle inclination for L/d = 5.0

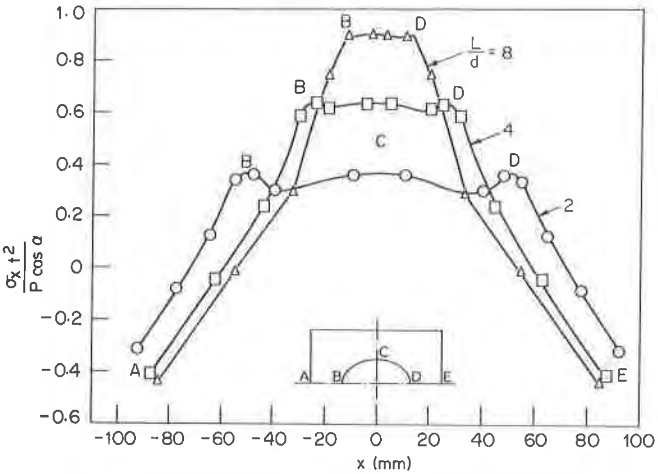

Fig.4 Stress distribution in plate along axis of symmetry and nozzle plate junction: Effect of nozzle diameter for $\alpha = 0°$

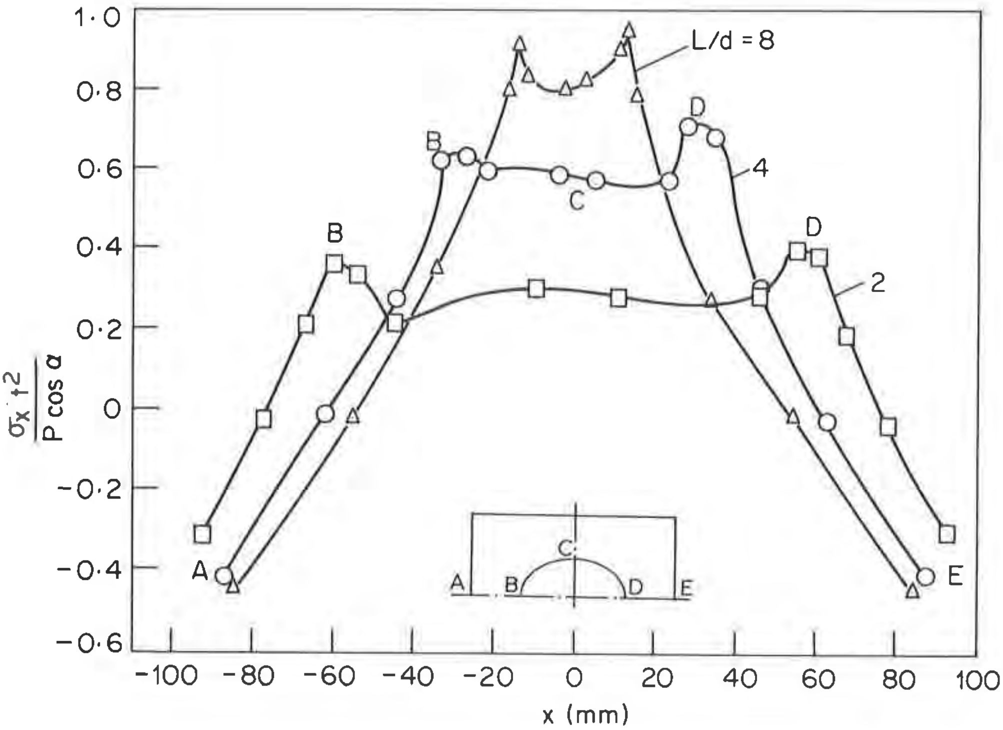

Fig.5 Stress distribution in plate along axis of symmetry and nozzle-plate junction: Effect of nozzle diameter for $\alpha = 30°$

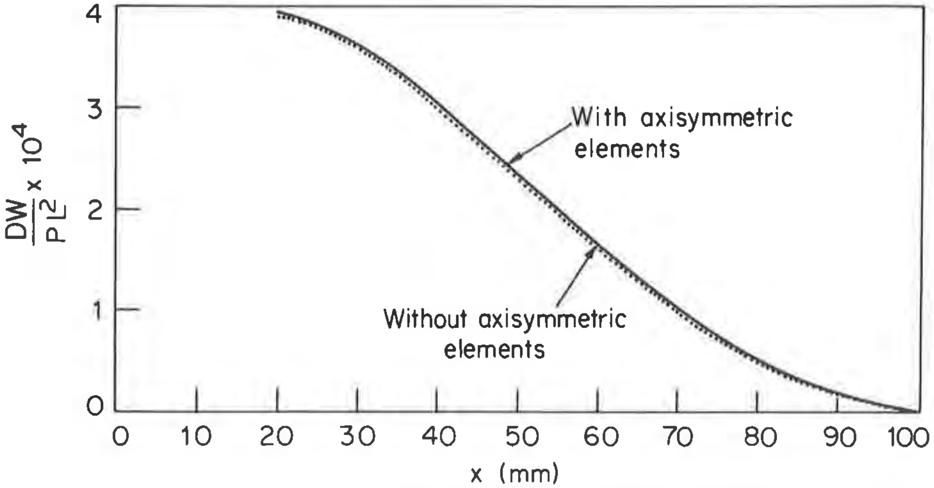

Fig.6 Comparison of deflection parameter at nozzle-plate junction from solutions with and without axisymmetric elements.