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Effect of Opening Distance Patterns on the Stress Distribution of the Pressure Vessel Head

Kang Soo Kim, Suhn Choi, Tae Wan Kim, Gyu Mahn Lee and Keun Bae Park

Korea Atomic Energy Research Institute, Korea

ABSTRACT

The distance between openings introduced by non-radial nozzles on the surface of the hemi-spherical head governs the stress pattern around the openings and the head itself. ASME code NB-3338.2(d) defines the restricted opening distances to use the Stress Index Method. In this paper, when the distance between openings varies, the stress distributions around the openings of the head area are investigated using FEM models, and factors which shall be considered for the opening and nozzle design are analyzed.

1. INTRODUCTION

The Nuclear Steam Supply System(NSSS) in nuclear power plants includes many pressure vessels, such as a reactor vessel, steam generators and a pressurizer. These pressure vessels are under high pressure and high temperature during operation and many nozzles or pipings are connected to the head area for various system performances. Therefore, it is important to evaluate the stress distributions of the nozzle reinforcement and head parts around the openings of the pressure vessel. Particularly, the stress distributions shall be evaluated carefully when there is a need for additional openings to secure the structural integrity of the pressure vessel. For the design of head and nozzles, it is very helpful to understand the trends of stress distributions with regard to the distance between openings.

In this paper, the stress distributions around the nozzles of head area are investigated when the distance between the openings varies. The pressurizer of the Korean standard nuclear power plant[1] is used as a model for the analysis. Since this opening design meets the opening requirements of ASME code[2], Design by Formula was done and Design by analysis was not needed for the opening design. However, additional pipes could be connected to the head of the pressure vessel to enhance the safety of the NSSS. This means more pipes are connected to the constant space and opening distances become shorter. In such cases, the stress distribution around opening head and nozzles would be investigated and the necessity of Design by Analysis would be checked. The factors which have to be considered for the opening and nozzle design were analyzed. Also, since the t/r ratio(thickness/radius)of this pressurizer was around 1/10 and thus on the boundary value which was defined as a shell element, this pressurizer was modeled by the shell element and by the solid element using IDEAS code[3], and the two results were compared and discussed[4].

2. ASME REQUIREMENTS FOR OPENING DESIGN

NB-3222.4 of ASME code says analysis for cyclic operation. If the specified Service Loadings of the component meet all of the conditions of NB-3222.4(d), no analysis for cyclic service is required. NB-3331(a) states, for vessels or parts thereof which meet the requirements of NB-3222.4(d), analysis showing satisfaction of the requirements of NB-3221.1, NB-3221.2, NB-3221.3, and NB-3222.2 in the immediate vicinity of the openings is not required for pressure loading if the rules of NB-3330 are met. Also, openings are not limited as to size except to the extent provided in NB-3338.2(d), which defines the restricted opening distances for the use of the Stress Index Method. NB-3338.2(d) is specified as follows : the arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or along the longitudinal axis of a shell.

3. ANALYSIS

For openings not satisfying the requirements of NB-3338.2(d), a few models are built using IDEAS FEM code, and the stress distributions around the nozzles of head area are investigated when the distance between the openings varies.

3.1 Analysis Model

The basic dimension of the pressurizer for FEM analysis is shown in Fig. 1. The materials of the head and nozzle are SA 508 and SA 541 CL 3, respectively, and the mechanical properties are as follows[5]:

Materials	SA 508, SA-541 CL3
Yield Strength (psi) at 700 °F	43100
Modulus of Elasticity(psi)	27600000
Poisson's Ratio	0.3

The head containing two nozzles and a cylinder part, which has a length of 48 inches for sufficient analysis space, was modelled. Also, the t/r ratio(thickness/radius)of this pressurizer is around 1/10, and that is the boundary value for which the use of the shell element in the Finite Element Method(FEM) is suggested. Thus, this pressurizer was modelled both by the shell element as shown in Fig. 2 and the solid element as shown in Fig. 3. The two analysis results were compared and the compatibity for using the shell element in modelling this pressurizer was checked. A three dimensional model with more than 10,000 shell elements as shown in Fig. 4, has been built for the analyses. IDEAS code which contains the FEM module was used for modelling, and computer works were performed at workstation HP735.

3.2 Method of Analysis

3.2.1 Change of Stress Distribution according to Distance between Openings

The changes of stress distribution according to the distance between the openings is investigated for following three cases:

case (a) : the distance between adjacent nozzles is not less than three times the sum of the openings radii as shown in Fig. 4.

case (b) : the distance between adjacent nozzles is equal to three times the sum of the openings radii as shown in Fig. 7.

case (c) : the distance between adjacent nozzles is equal to two times the sum of the openings radii as shown in Fig. 8.

3.2.2 Load Condition

2500 psi of design pressure for the PWR pressurizer[6] is applied as internal pressure. Since the moment and force generated by piping do not affect the stress distribution on head part under the normal operating condition, only the internal pressure is applied.

3.2.3 Boundary Conditions

For models represented by the shell element(Fig. 4, 7, 8), all nodes connected to the bottom of the cylindrical part are fixed in all directions. For models represented by the shell element and the solid element for the comparision(Fig. 2, 3), all nodes connected to the edges of the models are fixed in all directions.

4. RESULTS

4.1 Comparision of Stress Results by FEM Element Selection

Since the t/r ratio of this pressurizer is around 1/10, this pressurizer was modeled and analyzed by shell elements(Fig. 2) and solid elements(Fig. 3) at the same time. Comparing the two analysis results, there is little difference, and the stress distrbutions at corresponding locations on each model are nearly same. The principal stress near the nozzles of the model with the shell elements is 11700 psi, and that of the model with the solid elements is 11870 psi. The principal stress of the head parts between the adjacent nozzles of the model with the shell elements is 10590 psi and that of the model with the solid elements is 11590 psi. Generally, the analysis results by the solid elements are higher than those by the shell elements, but the difference between the values is not great. And thus the model using the shell element for this pressurizer is reasonable. For evaluating the stress distribution according to the distance between openings, all models were represented by shell elements.

4.2 In the case of Not Less than Three Times the Sum of Openings Radii

In the case that the distance between the adjacent nozzles is not less than three times the sum of the openings radii, the analytical model is shown in Fig. 4. The stress values of the head part in a circumferential direction between the adjacent nozzles is shown in Fig. 5, and the stress values of the head part in a radial direction between the adjacent nozzles is shown in Fig. 6. The principal stress of the head parts between the adjacent nozzles is 14200 psi, and the principal stress at a location far from the nozzle is 13340 psi. The stress of spherical shells without openings is found by the fomula $\sigma = \frac{pr}{2t}$ and is found to be 12340 psi.

Comparing these results, the difference in stress values is not great. Therefore, the models using the shell elements for this pressurizer are reasonable. The principal stress of the nozzle part at the far side of the pressurizer center line(the front side of nozzle: b location in Fig. 2) is 13340 psi, and that at the close side(the rear side of nozzle: a location in Fig. 2) is 14200 psi. The stress of the head part in a circumferential direction between the adjacent nozzles increases when approching the nozzle, as shown in Fig. 5, and the stress value at 20 inches from nozzle turns out to be constant. Also, as shown in Fig. 6, the principal stress of the head part in a radial direction between the adjacent nozzles decreases when the radius values of the head increase, and then the principal stress values increase until the radius of the head reaches its maximum, namely, the intersection location of the cylindrical part and the spherical head. By that, we find that installing nozzles at the far side of the intersection location of the cylindrical part and the spherical head has an advantage in view of the head strength. The highest stress is represented at the nozzle part near the boundary line intersecting the nozzles and the head. This stress value is 29090 psi. The stress at the nozzle part is higher at the far side than at the close side of the pressurizer center line and the stress of the nozzle is lower at the far side of the boundary line intersecting the nozzles and the head. By that, we find that at the time of the opening design, reinforcements are needed at the boundary line intersecting the nozzles and the head; also, more reinforcements are needed at the far side than at the close side of the pressurizer center line for the nozzle parts.

4.3 In the case of Three Times the Sum of Openings Radii

In the case that the distance between the adjacent nozzles is equal to three times the sum of the openings radii, the analytical model is shown in Fig. 7. The principal stress values of the head part between the adjacent nozzles is 22750 psi. The principal stress of the nozzle part at the far side of the pressurizer center line(the front side of nozzle) is 27740 psi and at the close side(the rear side of nozzle) is 14950 psi. The principal stress of the head part at the far side of the pressurizer center line is 24560 psi and at the close side is 25680 psi. The stress of case (b) is much higher than that of case (a), and the stresses at the front and rear side of the nozzle part are higher than those at the side direction of the nozzle part. Therefore, more reinforcements are needed at the front and rear side than at the side direction of the nozzle part, and more are needed at the front side than at the rear side of the nozzle part.

4.4 In the case of Two Times the Sum of Openings Radii

In the case that the distance between the adjacent nozzles is equal to two times the sum of the openings radii, the analytical model is shown in Fig. 8. The highest stress value occurs at the head part between the adjacent nozzles and is 32340 psi. The stress at the front side of the nozzle part is 27310 psi and that at the rear side of the nozzle part is 14090 psi. The stresses at the front and rear side of the nozzle part are higher than those at the side direction of the nozzle part. Therefore, more reinforcements are needed at the front and rear side than at the side direction of the nozzle part, and more are needed at the front side than at the rear side of the nozzle part.

In summary, in the case that the distance between the adjacent nozzles is not less than three times the sum of the openings radii, the principal stress value of the head part between the adjacent nozzles is 14200 psi; in the case of three times the sum of the openings radii, the stress value is 22750 psi; and in the case of two times the sum of the openings radii, it is 32340 psi. By this, we find that the stress values of head parts between the adjacent nozzles increase considerably according to the reduction of the distance between the adjacent nozzles. And also, we can find that the principal stresses at the front side of nozzle part are higher than those at the rear side of nozzle part and the stresses at the front and rear side of nozzle part are higher than those at the side direction of nozzle part. Therefore, more reinforcements are needed at the front and rear side than at the side direction of nozzle part, and more are needed at the front side than at the rear side of the nozzle parts. In the case that the distance between the adjacent nozzles is less than three times the sum of their inside radii for the openings in a head, Design by Analysis applied to piping loads according to each operating condition is needed and reinforcements for nozzles according to the analysis results are needed.

5. CONCLUSION

The stress distributions around the head area and nozzles are analyzed using FEM models when the distance between the openings varies. Analysis results lead to the following conclusions:

(1) In the case that the distance between the adjacent nozzles is less than three times the sum of their inside radii for the openings in a head, the stress values of the head part between the adjacent nozzles increase considerably according to the reduction of the distance between the adjacent nozzles. Therefore, Design by Analysis applied to piping loads according to each operating condition is needed and reinforcements for nozzles according to the analysis results are needed.

(2) The stress at the front side of nozzle part is higher than that at the rear side of nozzle part and the stress at the front and rear side of nozzle part is higher than that at the side direction of nozzle part. Therefore, more reinforcements are needed at the front side and rear side than at the side direction of the nozzle part, and more are needed at the front side than at rear side of the nozzle part.

(3) At the time of nozzle installation, to install it at the far side of the intersection location of the cylindrical part and the spherical head has an advantage in view of head strength.

ACKNOWLEDGEMENT

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5. NO291-ME-DR270-00, Rev.3, "Design Requirements for the Pressurizer for UCN 3&4", 1995.
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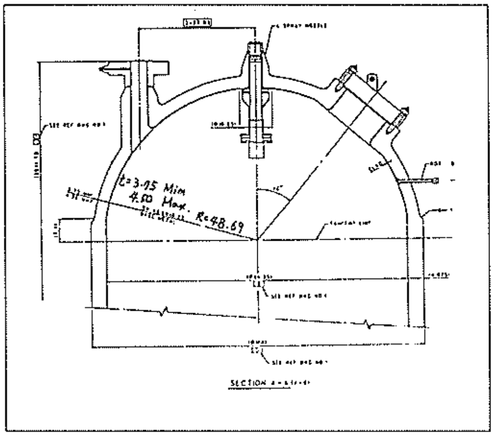

Fig. 1. Dimensions of Model

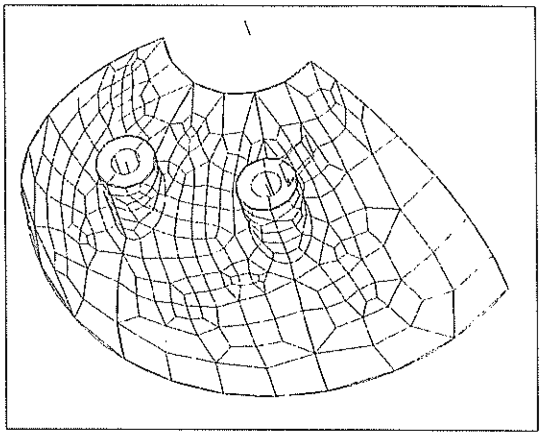

Fig. 2. Analysis Model by Shell Element

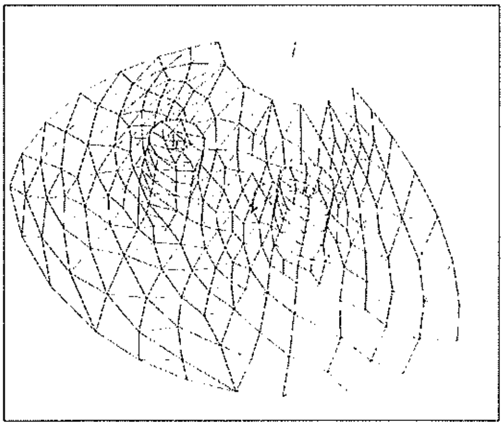

Fig. 3. Analysis Model by Solid Element

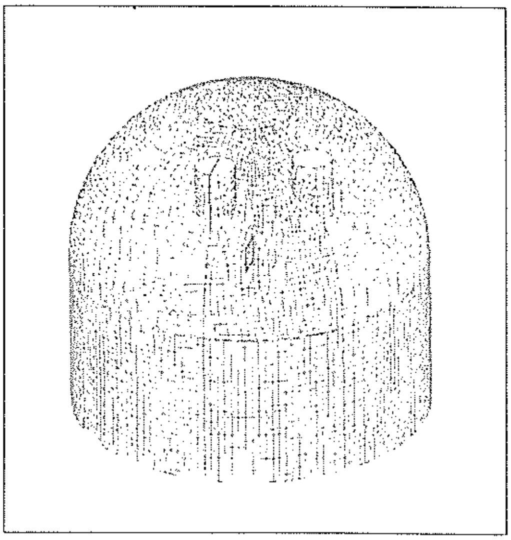

Fig. 4. Analysis Model of Case (a)

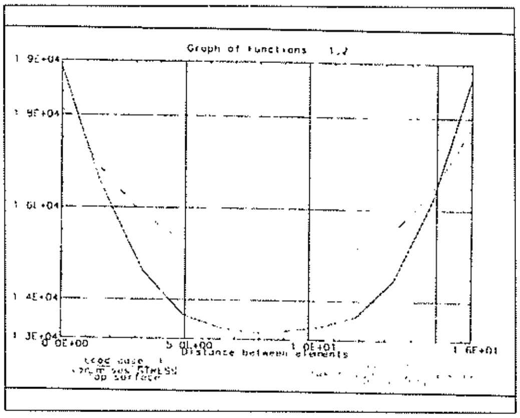

Fig. 5. Stresses in Circumferential Direction

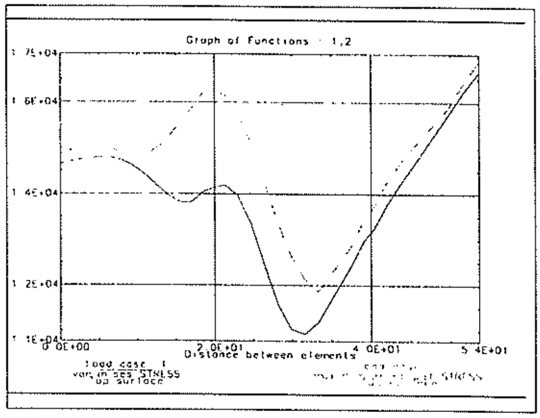

Fig. 6. Stresses in Radial Direction

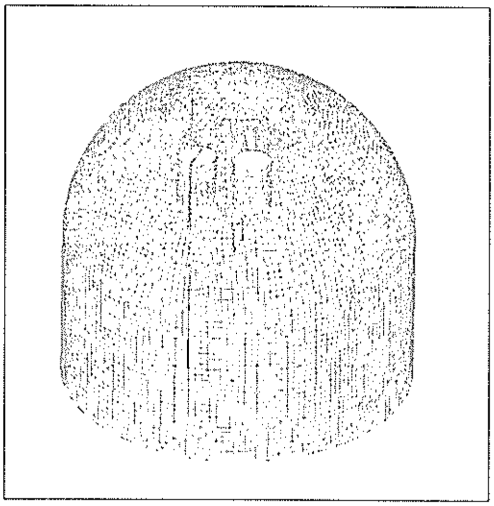

Fig. 7. Analysis Model of Case (b)

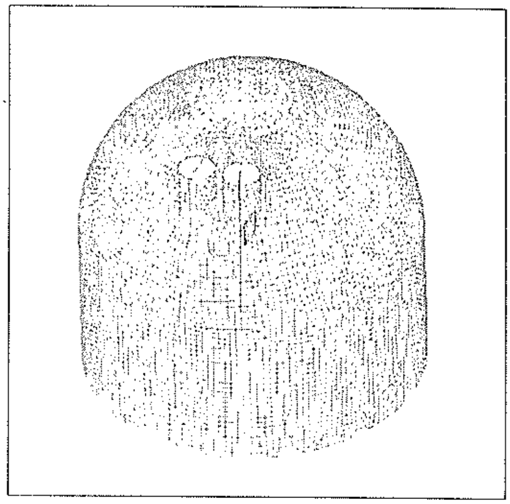

Fig. 8. Analysis Model of Case (c)