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Evaluation of the Stress Distribution on the Pressure Vessel Head and Nozzles according to Design by Analysis of ASME Code

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ABSTRACT

When additional pipes on the head of pressure vessels are required to enhance the safety of the NSSS, exact analysis according to Design by Analysis of ASME code is needed. In this paper, the stress analysis for the pressurizer of the Korean standard nuclear power plant is done in accordance with Design by Analysis of ASME code; then, the feasibility of 3 dimemsional FEM modelling using Design by Analysis is investigated. Also, the 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 are subject to various external loads. In particular, many nozzles or pipings are connected to the vessel head area for various system performances. Such pipes on the vessel head greatly affect the structural integrity of the pressure vessel head, namely stress concentration due to the discontinuity of the shape and crack possibilities at welded parts always exist at the openings of pressure vessels. Thus, the study of structural integrity at the openings of pressure vessel head has been proceeded constantly. When additional pipes on the head of pressure vessels are required to enhance the safety of the NSSS, exact analysis according to Design by Analysis of ASME code[1] is needed.

In this paper, the stress analysis for the pressurizer head and the PSV(Pressurizer Safety Valve) nozzles[2] of a KSNPP(Korean Standard Nuclear Power Plant) is done in accordance with Design by Analysis of ASME code, and then the feasibility of 3 dimemsional FEM(Finite Element Method) modelling using Design by Analysis is investigated. Also, factors which shall be considered for the opening and nozzle design are analyzed[3].

2. ANALYSIS

The head and nozzles of the pressurizer of the Korean standard nuclear power plant, which meet NB-3222.4(d) and NB-3331 of opening requirements and NB-3339 of alternative rules for nozzle design, are modelled using FEM code for Design by Analysis and are analyzed.

2.1 Analysis Model

The basic dimension of a pressurizer head[2] for FEM analysis is shown in Fig. 1, and that of a PSV in Fig. 2. The materials of the head and nozzles are SA 508 and SA 541 CL 3, respectively, and the mechanical properties are as follows:

Materials	SA 508, SA-541 CL3
Ultimate Tensile Strength (psi) at 700 °F	80000
Yield Strength (psi) at 700 °F	43100
Stress Intensity (psi) at 700 °F	26700
Modulus of Elasticity (psi)	27600000
Poisson's Ratio	0.3

The head part containing two nozzles, which takes up 3/8 of the total head for sufficient analysis space, was modelled for FEM analysis. For modelling the nozzle reinforcements of the pressurizer, the solid element was used and a three dimensional model with more than 20,000 solid elements, as shown in Fig. 3, has been built. IDEAS code[4] containing the FEM module was used for modelling and computer works were performed at workstation HP735.

2.2 Method of Analysis

2.2.1 Applied Loads

The applied loads contain dead weight, loads due to thermal expansion, mechanical loads under normal operating conditions, OBE and SSE earthquake loads, BLPB(Branch Line Pipe Break) loads, SDSVA(safety Depressurization System Valve Actuation) loads, SVA(Safety Valve Actuation) loads and 2500 psi of the design pressure[5][6] for a PWR pressurizer.

2.2.2 Loading Combinations

For PSV nozzle loads represented in reference 5, the results combined according to design loads and each operating condition are shown in Table 1. Level C loads include dead weight and thermal loads. In order to find the direction of the pipe which generates the severest stress on the head and nozzles, stress analyses for 8 cases, as in Table 2, were performed and then the direction of the pipe was found. The plus directions of each load are represented in Fig. 4.

Table 1. Load Combination for Operating Conditions

	Force(kips)		Moment(ft-kips)	
	F_x	F_y	M_x	M_y
Design Condition	13	16	5	27
Level A	6	4	9	13
Level B	16	19	13	38
Level C	20	10	18	48
Level D	31	61	27	144

Table 2. Direction of Nozzle loads

	F_x	F_y	M_x	M_y
Case 1	+	+	+	+
Case 2	+	+	-	+
Case 3	+	+	+	-
Case 4	+	+	-	-
Case 5	+	-	+	+
Case 6	+	-	-	+
Case 7	+	-	+	-
Case 8	+	-	-	-

2.2.3 Allowable Stress Intensity Criteria

The allowable stress intensity criteria for each operating condition is shown in Table 3. The stress intensity value (S_m) of SA 508 and SA 541 CL 3 is 26700 psi[5].

3. FEM Analysis Results

Through analysis results, the direction of nozzle loads which generated the severest stress on a head was CASE 7 in Table 2. Since Level B loads are the greatest among Design, Level A and Level B loads, Level B loads are applied to the FEM model. The analysis results of Level B, Level C and Level D loads are represented in Table 3. Calculated SI(Stress Intensity) values in Table 3 are the greatest stress intensity values calculated for each operating condition and are the values at element number 5697 in Fig. 5. FEM analysis results are represented as the colour contour and those of Level B, Level C and Level D operating conditions are shown in Fig. 6, Fig. 7 and Fig. 8, respectively.

Table 3. Analysis Results for Each Operating Conditions

Operating Conditions	Criteria	allowable stress criteria(psi)	Calculated S.I(psi)
Design, Level A, B	P_m	S_m = 26700	23985
	$P_m + P_b$	$1.5S_m$ = 40050	30540
Level C	P_m	$1.2S_m$ = 32040	23170
	$P_m + P_b$	$1.8S_m$ = 48060	29040
Level D	P_m	$\min(2.4S_m, 0.7S_u)$ = 56000	24925
	$P_m + P_b$	$1.5\min(2.4S_m, 0.7S_u)$= 84000	33740

4. REVIEW OF ANALYSES RESULTS

The internal pressure and piping loads were applied to the pressurizer head and PSV nozzles of a KSNPP(Korean Standard Nuclear Power Plant) and FEM analyses for each operating condition were performed. The review of the analysis results is as follows:

4.1 Direction of Piping Loads

The direction of piping(nozzle) loads which generated the severest stress around the openings was CASE 7 in Table 2, and the principal stress at this location was 31110 psi. The direction of piping loads which generated the lowest stress around openings was CASE 2, and the principal stress at this location was 27340 psi. This difference in the principal stress was 3770 psi and was not small. Therefore, the direction of piping loads must be considered when performing Design by Analysis. In each case, there is no great difference in the stress values at the middle part of the head between the two nozzles. Therefore, we find that the direction of piping loads greatly affects stress distribution around the nozzles.

4.2 Integrity of KSNPP Pressurizer and Nozzle

Since the pressurizer of the KSNPP meets the requirements of ASME NB-3224.4(d), the 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 loadings and meets ASME NB-3331 of the general requirements for openings. Also, PSV nozzles meet NB-3339 of the alternative rules for nozzle design.

On the other hand, the analysis results using FEM for a KSNPP pressurizer head and nozzle also meet the allowable stress intensity criteria specifed in ASME code. That is, all stress intensities calculated in Table 3, which are analysis results in accordance with each operating condition(Level A, B, C, D), are below the allowable stress intensity criteria specifed in ASME code. Therefore, the integrity of the KSNPP pressurizer head and nozzles is verified.

4.3 Effect of Piping Loads

In order to evaluate how piping loads affect the stress distributions of the head and nozzles, analysis results of two cases are compared: in the case that only internal pressure is applied to the head and nozzles; and in the case that internal pressure and the severest piping load are applied to the head and nozzles at the same time. In such cases, the stress difference between Level A and B is 1470 psi. In Level C, rather, the stress value is reduced due to piping loads. The stress difference in Level D is 4670 psi. Therefore, we find that piping loads affect the stress distributions of the pressurizer head.

4.4 Stress Distribution of Head and Nozzles within Normal Condition

The highest stress is represented near the boundary line intersecting the nozzles and the head. This stress value at the head is 30540 psi and at the nozzle is 18220 psi. The location of the highest stress changes according to the direction of piping loads but, the stress at the nozzle part is higher at the far side than at the close side of the pressurizer center line. The stress value at the far side is 18220 psi and at the close side is 9157 psi, respectively. With this, we can find that more reinforcements are needed at head part than at the nozzle part near the boundary line intersecting the nozzles and the head, and also more reinforcements are needed at the far side than at the close side of the pressurizer center line for the nozzle parts.

5. CONCLUSION

KSNPP pressurizer head and nozzles are modelled using IDEAS code which containing an FEM module, and Design by Analysis according to each operating condition is performed. FEM analysis results lead to the following conclusions:

(1) Since the analysis results according to Design by Analysis of ASME code for the KSNPP pressurizer head and nozzle meet the allowable stress intensity criteria specifed in ASME code, the integrity of that is verified. Also, since Design by Analysis of ASME code produces the quintative stress values at the head and nozzle parts, it is helpful in designing the pressurizer nozzle and openings.

(2) Since the direction of piping loads greatly affect the stress distributions at the head part around the nozzles, the direction of piping loads must be considered in performing Design by Analysis.

(3) The highest stress is represented near the boundary line intersecting the nozzles and the head. Also, the stresses at the nozzle part are higher at the far side than at the close side of the pressurizer center line. Therefore, more reinforcements are needed at parts at which stresses are highly represented.

ACKNOWLEDGEMENT

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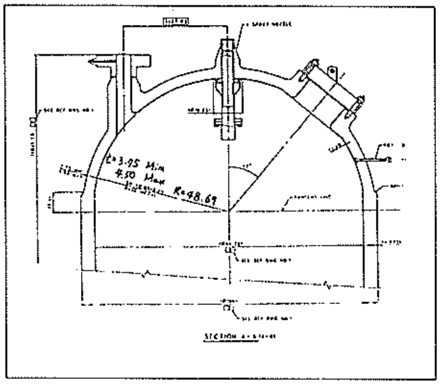

Fig. 1. Dimensions of Head

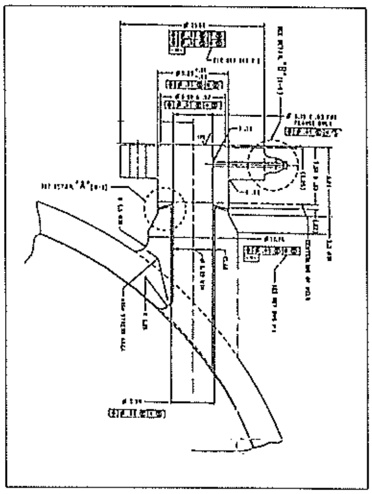

Fig. 2. Dimensions of Nozzle

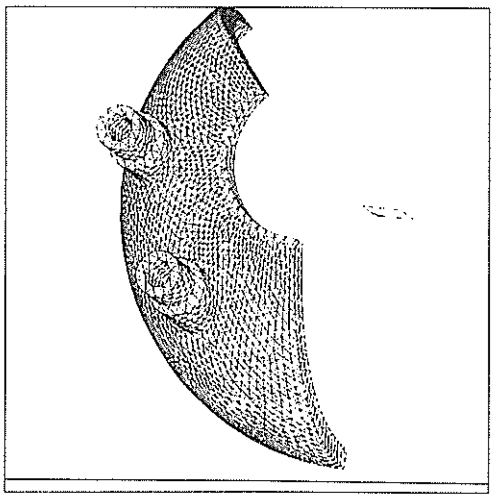

Fig. 3. Analysis Model

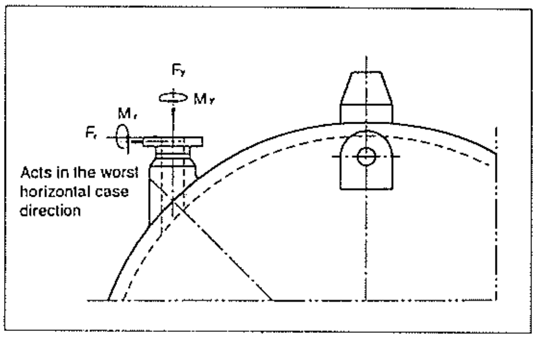

Fig. 4. Plus Directions of Nozzle Loads

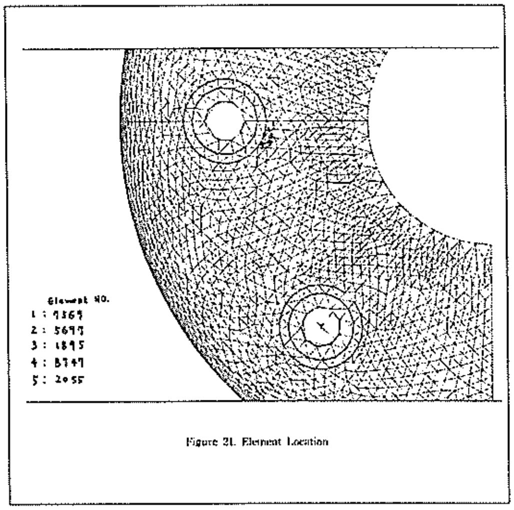

Fig. 5. Location of 5697 Element

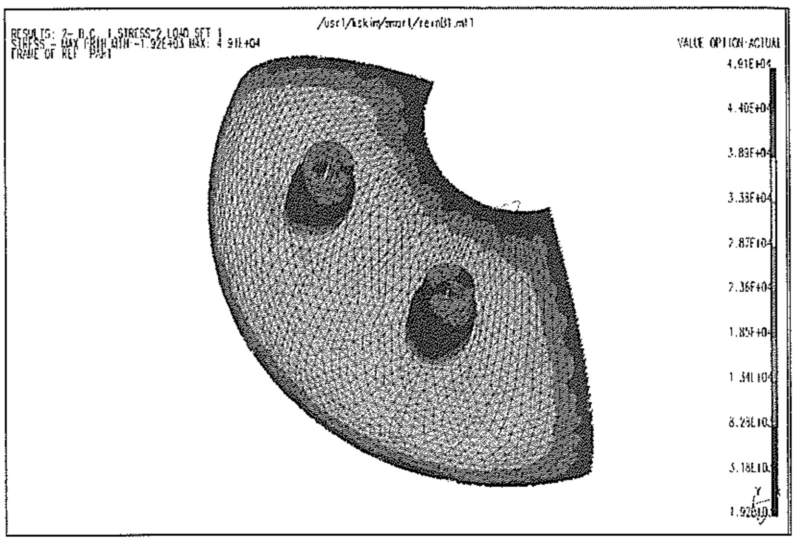

Fig. 6. Analysis Result of Level B

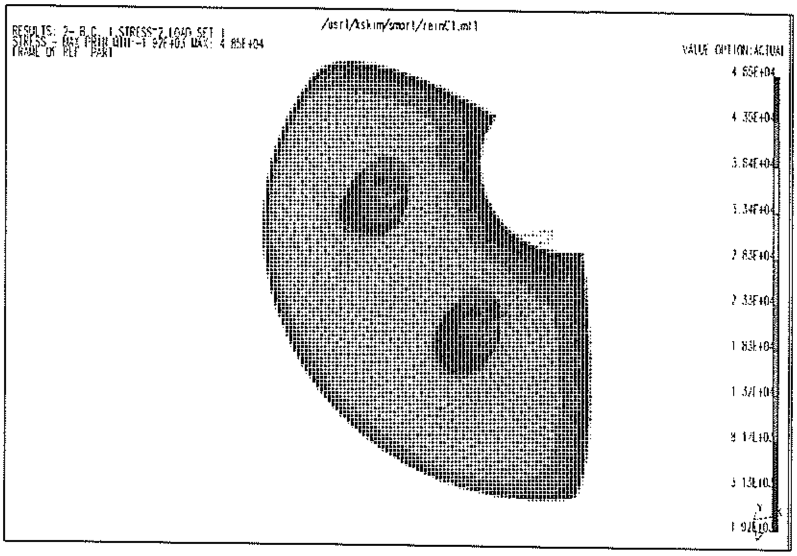

Fig. 7. Analysis Result of Level C

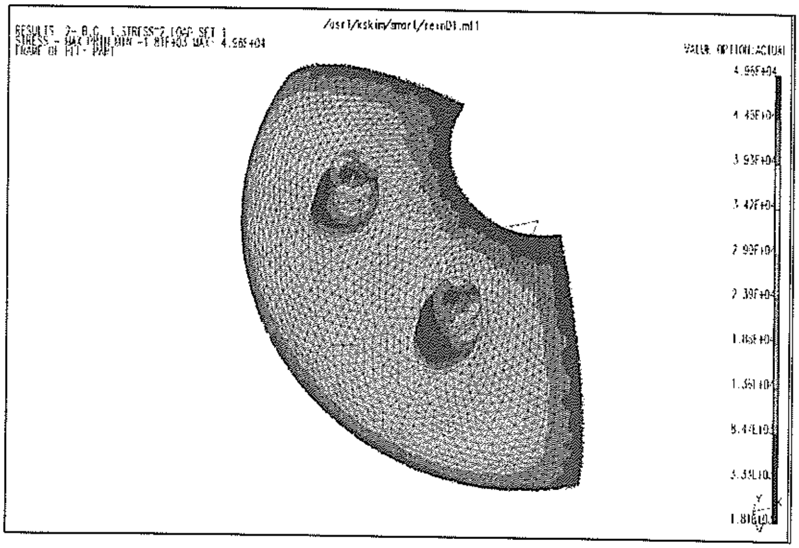

Fig. 8. Analysis Result of Level D