Structural Analysis of Pressure Vessel for the ASME Nuclear Survey
(ASME 원자력 인증을 위한 압력용기의 구조해석)

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ABSTRACT

원자력공사에 관련된 장치와 부속 기기를 설계 및 제작 또는 설치하려면 ASME에서 인증하는 자격이 필요하고, 자격을 취득하거나 갱신하기 위하여 시설, 품질보증 프로그램, 설계 및 제작능력 등을 ASME 위원회의 실사를 받아야 한다. 이를 위한 일련의 과정 중에서 설계능력을 증명할 수 있는 설계해석 보고서를 제출하여야 하며 이를 위하여 현대중공업이 설계한 Chiller Surge Vessel의 설계조건 및 하중 및 하중조합에 대하여 Design Report를 작성하였으며, ASME Code의 요구조건을 모두 만족하는 것으로 평가되었다.

1. INTRODUCTION

In order to be qualified as a manufacturer to construct the equipment and component used in the nuclear power plant, the manufacturer needs to hold the ASME certificate of authorization. The ASME certificate is an authorization, received from the ASME, to construct component parts in accordance with the requirements of the ASME code. The ASME surveys the certificate holder's facilities and quality assurance program before granting this authorization. During the survey from the ASME survey team, the manufacturer needs to show the design capability through design documentation in accordance with the ASME code. Therefore, the documentation should include design report together with the supporting calculation and the computer program verification. The submitted design report should consist of the design calculation and stress analysis performed to show the adequacy of the design in accordance with Owner's Design Specification[1] and Section III, Division 1, Subsection NB of the 1995 Edition of the ASME Boiler and Pressure Vessel Code[2].

Hyundai Heavy Industries Co., Ltd.(HHI) has had the certificates of the ASME. In order to renew the certificate, the HHI has performed the complete set of design analyses for a specific pressure vessel called a chiller surge vessel.

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2. DESIGN CRITERIA

2.1 Codes and Standards

The specific industry codes and standards applied in the project are presented in the Design Specification. The pressure vessel with the support skirt and nozzles are classified into Class 1 Components. The rules of Subsection NB, Subarticle NB-3300, of Section III of the ASME Code are applied. The blind flange and welds connecting the blind flange to the nozzle are beyond the ASME Code boundary.

2.2 Material Parameters

Several material parameters are used throughout the Design. These are given in Table 1.

Table 1 Material Parameters

Material Parameter	Value
Design Stress Intensity, S_m	23.1 ksi
Tensile Strength	70.0 ksi
Yield Strength	34.6 ksi
Elastic Modules	28.8 x 10^3 ksi
Thermal Expansion Coefficients	5.746 $\times 10^{-6}$ in/in/°F
Poisson's Ratio for Steel	0.3
Weight Density of Steel	0.28356 lbs/in^3
Weight Density of Water	0.03611 lbs/in^3
Allowable Alternating Stress Intensity of SA 516 Gr. 70, S_a	357.0 ksi (N=25)
	69.3 ksi (N=1450)
	41.1 ksi (N=7000)

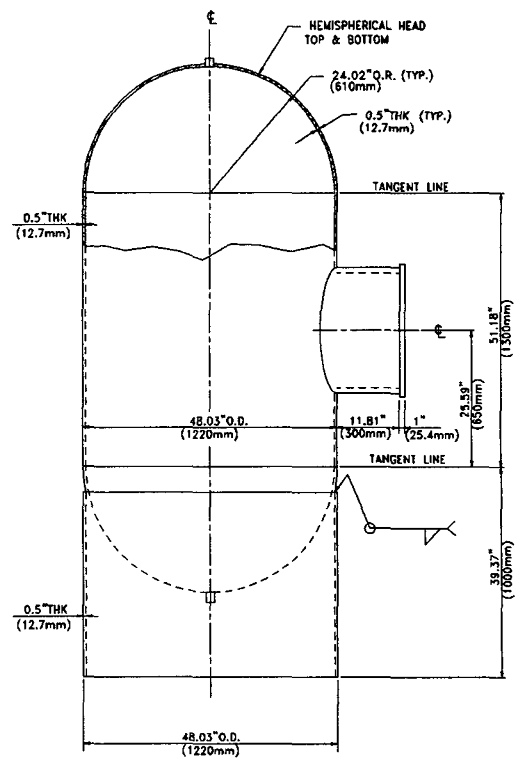


Fig. 1 Configuration of Pressure Vessel

2.3 Component Description

The chiller surge vessel is a vertically erected structure with a cylinder capped with a hemispherical head on each end. The vessel is supported by a cylindrical skirt welded to the lower head. The cylinder has an outside diameter of 48.03" and a straight shell length of 51.18". Bottom of the pressure vessel to lower tangent line length is 39.37". The nozzle with diameter of 23.62" is attached at mid-height of the vessel, and 1/2 inch nominal diameter couplings are attached to each head. The basic dimensions and configuration are established by the Design Specification as illustrated in Fig. 1.

3. LOADS AND LOAD COMBINATIONS

Basic loads and their combinations specified in the Design Specification. The loads can be classified into five basic categories. They are dead load, pressure and coincident temperature loads, nozzle loads, hydrostatic loads and seismic loads.

The load combination must comply with the requirements of the Design Specification. The combined loads formed from the loads above are mainly five cases. They are design load combination, level A load combination, level B load combination, level C load combination and test load combination. Table 2 shows the service limits and the load combinations.

Table 2 Service Limits and Load Combinations

Loads		Service Limits and Load Combinations				
		Design	Level A	Level B	Level C	Test
Pressure Loads, psi (KPa)		30.46 (210)	30.46 (210)	30.46 (210)	30.46 (210)	38.06 (262.5)
Metal Temperature, °F (℃)		200 (93)	160 (71)	160 (71)	160 (71)	68 min. (20)
Seismic Loads	OBE	0.12g	-	0.12g	-	0.12g
	SSE	-	-	-	0.24g	-
Dead Loads		O	O	O	O	O
Nozzle Loads		O	O	O	O	-
Hydrostatic Loads		O	O	O	O	O
Number of Cycles		1	7000 / 25	7000 / 25	1	1

4. DESIGN STRESS ANALYSIS

The geometry and thickness including the support skirt and attached nozzle as well as the main body of the vessel as shown in the Design Drawing are justified by performing stress analysis and by comparing the results with the applicable codes.

4.1 Finite Element Model

The NISA II Computer Program is used in the analysis and Fig. 2 presents the mathematical model consisting of the second order 3-D plate elements and 3-D concentrated (lumped) mass elements for the analysis of the pressure vessel. The lumped mass elements which lie at the corner nodes of element correspond to the horizontal mass of contained water. In order to properly analyze the welding part of fillet at the intersection of the skirt and shell, the elements corresponding to the fillet welding part have the same local nodal thickness as the thickness of the weld throat. All elements of the pressure vessel except the blind flange have corroded thickness, but for the conservative analysis the nominal thickness is used in calculating the dead weight of the pressure vessel. A fixed boundary condition at the bottom end of skirt support is assumed.

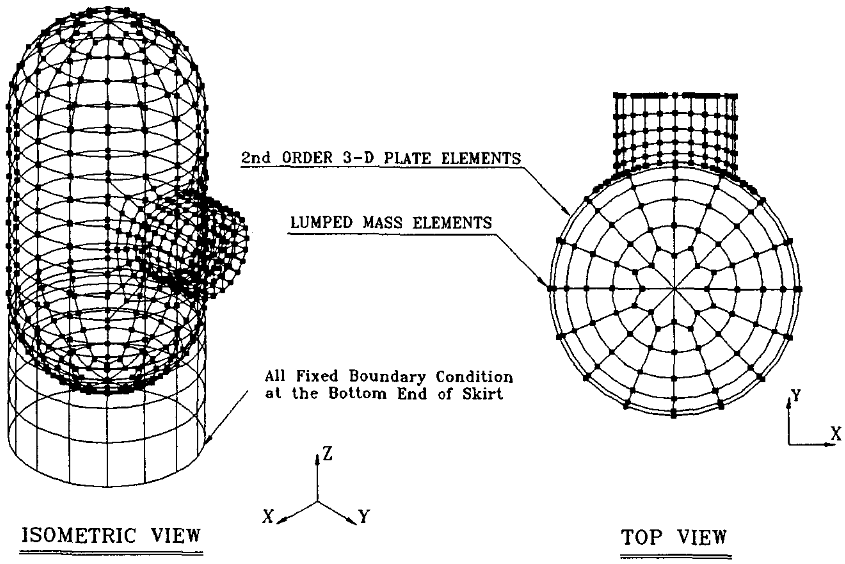


Fig. 2 Finite Element Model of Chiller Surge Vessel

4.2 Design Allowables

The allowable values of stresses are summarized in Table 3 according to the ASME Code.

Table 3 Allowable Stress Intensities for the SA-516 Gr. 70 [ksi (MPa)]

Load Combination	Stress Intensity S_m	Yield Strength S_y	Primary Membrane P_m	Local Membrane P_L	Membrane + Bending P_L+P_b	Primary + Secondary P_L+P_b+Q
Design	23.1 (159.3)	-	**1.0 S_m** 23.1 (159.3)			-
Level A	23.1[1] (159.3)	-	-	-	-	**3.0 S_m** 69.3 (477.8)
Level B	23.1[1] (159.3)	-	-	-	-	**3.0 S_m** 69.3 (477.8)
Level C	-	34.6[1] (238.6)	**1.0 S_y** 34.6 (238.6)	**1.5 S_y** 51.9 (357.9)	1.5 S_y 51.9 (357.9)	-
Test	-	34.6[1] (238.6)	**0.9 S_y** 31.1 (214.7)	-	1.07 S_y 37.0 (255.3)	-

Note : 1. The value used to calculate allowable stress intensity is obtained at the design temperature of 200 °F (90 °C) for the conservative design.

4.3 Analysis Results

An independent analysis is performed for each of six basic loads. The results from these analyses are summarized in Table 4 and the evaluation locations are shown in Fig. 3. In order to obtain the required combinations, the basic loads are combined appropriately by means of multiplying each analysis result by applicable factors. All of the load combinations are conducted using algebraic summation.

Table 4 presents the numerical results for the final load combinations along with the allowable stress intensities. These results are taken directly from the printed stress outputs. By comparing the computed stress intensities with the allowable stress intensities for each node, the design adequacy of the vessel is determined. Also, the contours of stress intensities for the Design Load Combination, and Level A and B Load Combinations are provided in Fig. 4 and Fig. 5, respectively. As shown in Table 4, the calculated membrane stress intensities are less than their respective primary membrane stress intensities. Thus, the ASME Code requirements for the Design Load Combination, Level C Load Combination and the Test Load Combination are met. The Level A Load Combination and the Level B Load Combination in Table 4 meet the requirement that the range of P_L+P_b+Q stress intensities be less than $3.0 \cdot S_m$. Therefore, the pressure vessel satisfies the design criteria and the design allowable stress intensity values.

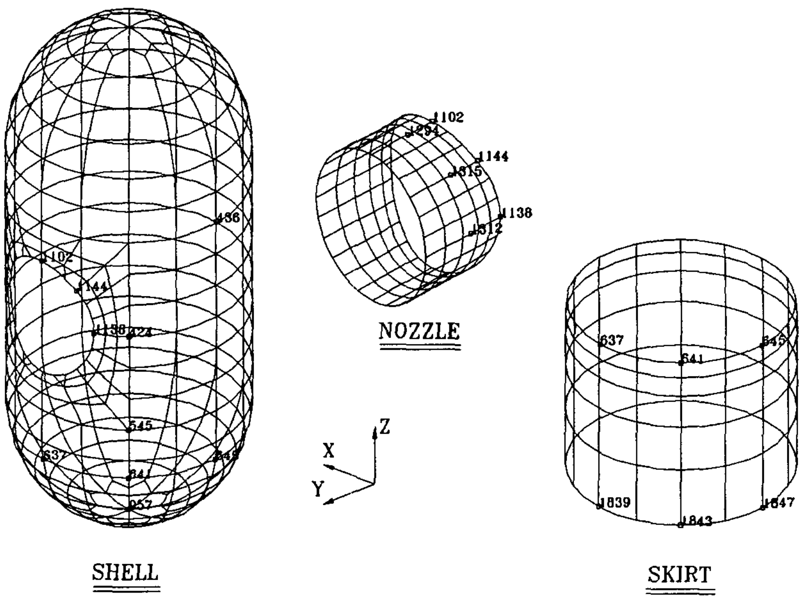
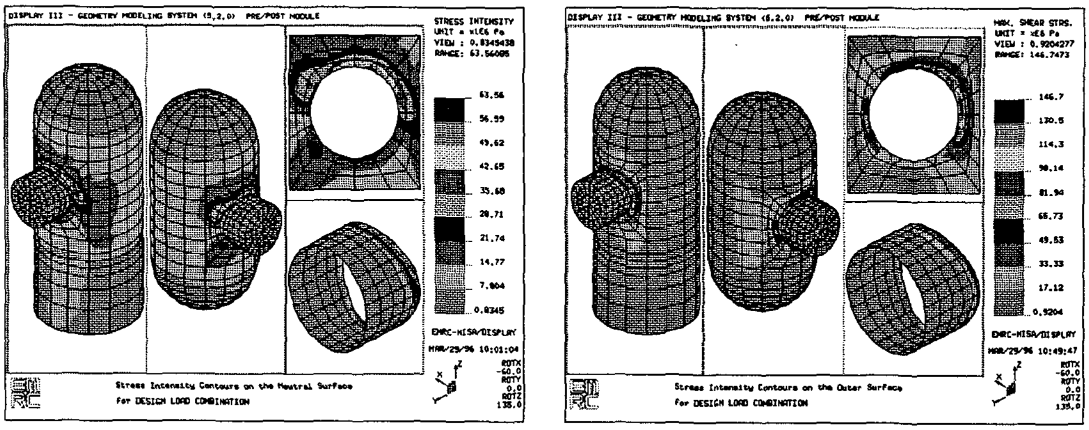


Fig. 3 Location of Nodes at Stress Evaluation Point

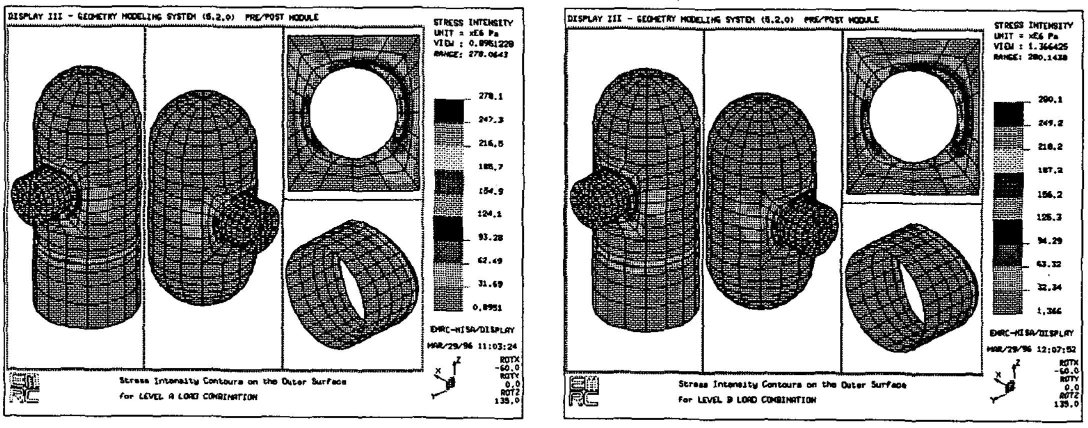
Table 4 Stress Intensities for All Load Combination [ksi ($x10^6$ Pa)]

Evaluation Point		Load Combination									
		Design			Level A	Level B	Level C			Test	
Item	Node	P_m	P_L	P_L+P_b	P_L+P_b+Q	P_L+P_b+Q	P_m	P_L	P_L+P_b	P_m	P_L+P_b
Vessel Shell	436	1.640 (11.31)	N/A	N/A	1.656 (11.42)	1.646 (11.35)	1.635 (11.27)	N/A	N/A	2.032 (14.01)	N/A
Weld of Nozzle	1144	N/A	8.097 (55.83)	13.484 (92.97)	22.307 (153.80)	22.536 (155.38)	N/A	8.170 (56.33)	13.597 (93.75)	N/A	5.929 (40.88)
Nozzle	1312	0.593 (4.09)	N/A	N/A	2.084 (14.37)	2.091 (14.42)	0.599 (4.13)	N/A	N/A	0.520 (3.58)	N/A
Weld of Skirt	641	N/A	0.908 (6.26)	1.878 (12.95)	4.476 (30.86)	4.563 (31.46)	N/A	0.963 (6.64)	1.906 (13.14)	N/A	1.074 (7.41)
Skirt	1843	N/A	0.744 (5.13)	0.823 (5.67)	1.450 (10.00)	1.496 (10.31)	N/A	0.770 (5.31)	0.847 (5.84)	N/A	0.193 (1.33)
Maximum of the Entire Model		N/A	9.219 (63.56)	21.284 (146.75)	40.329 (278.06)	40.631 (280.14)	N/A	9.277 (63.96)	21.437 (147.80)	N/A	8.563 (59.04)
Allowable Stress Intensity		23.1 (159.3)	34.6 (238.9)	34.6 (238.9)	69.3 (477.8)	69.3 (477.8)	34.6 (238.6)	51.9 (357.9)	51.9 (357.9)	31.1 (214.7)	37.0 (255.3)



(a) Membrane (b) Membrane+Bending

Fig. 4 Stress Intensity Contours for Design Load Combination



(a) Level A Load Combination (b) Level B Load Combination

Fig. 5 Primary+Secondary Stress Intensity Contours

4.4 Cyclic Analysis

Subsubparagraph NB-3222.4(d) of the ASME Code requires that the suitability of a vessel or a part for specified operating conditions involving cyclic application of loads and thermal conditions shall be determined by satisfying the conditions stated in the code. If the specified operation of the component meets all the conditions in the code, no further analysis for cyclic operation is required. The pressure vessel is examined for a maximum number of 7000 mechanical loads and 25 operating pressure cycles. If the requirements of NB-3222.4(d) are satisfied, further fatigue evaluation of the vessel or any part thereof is not required.

Six criteria stated in the ASME Code must be examined and they are as follows:

1. *Atmospheric to Service Pressure Cycle.*
2. *Normal Service Pressure Fluctuation.*
3. *Temperature Difference - Startup and shutdown.*

4. *Temperature Difference - Normal Service.*
5. *Temperature Difference - Dissimilar Materials.*
6. *Mechanical loads.*

In the comparison of six criteria of Subsubparagraph NB-3222.4(d) of the Code with the analysis results, it is found that the analysis results meet the ASME Code requirements for the fatigue.

5. SUMMARY OF RESULTS

The design analysis for the pressure vessel are performed for the loads and their combinations required by the Design Specifications in order to have a nuclear survey from the ASME Committee.

Three-dimensional finite element model was developed and used for the stress analysis of the pressure vessel for all required loads and load combinations in accordance with the Section III, Division 1, Subsection NB of the ASME Boiler and Pressure Vessel Code and Owner's Specifications. The finite element analysis for the chiller surge vessel including the skirt and nozzle, under required loads and load combinations, are performed, and the results of the analysis show that the design meets the requirement of the ASME Code.

REFERENCES

1. DESIGN SPECIFICATION, ASME Class 1 Chiller Surge Vessel, Specification Number EPC-9501, Revision 0, dated February, 02, 1996.
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3. NISA II User's Manual, Engineering Mechanics Research Corporation, Version 94.0, November, 1994.
4. Design Report of Chiller Surge Vessel for ASME Survey, DR-CSV-01, Oct. 1996, Hyundai Heavy Industries Co.
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6. Chiller Surge Vessel Analysis Supporting Calculations, CP-CSV-01, April 1 1996, Hyundai Heavy Industries Co.