Static and Dynamic Analysis of Water Pump by MSC.Patran

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Abstract

This paper is a report for the safety analysis aimed at assessing the reliability and integrity of pressure retaining boundary of essential service water pump with complicated geometry using finite element method in MSC.Patran. The static analysis is investigated under five service loadings including the loads from OBE (operation basis earthquake) and SSE (safety shutdowan earthquake) [1]. The natural frequencies and modal shapes of the pump are computed to check if the static equivalent load method can be used for the seismic analysis addressed in the future work. In addition, the stress analysis for the accessories of the pump, namely flanges and bolts, are also shown in the paper.

1. Introduction

The essential service water pump is classified as safety class 3 pump according to the regulations in the [2], [3] and [4]. It has the complicated structure of double volute-double suction as shown in Figure 4.1. Figure 4.2 is an illustration of the pump with pedestal and electric motor. There is a flexible connection between the pump and electric motor, and the pedestal is fixed by anchor bolts. To ensure the integrity of the pressure retaining boundary of the pump, the following parts of the pump need to be analyzed.

a. pump casing and pump covers;

b. pump inlets and outlets;

c. related bolting;

d. pump auxiliary nozzle connections up to the face of the first flange in welded connections, excluding the connecting weld;

e. external and internal integral attachments to the pressure retaining boundary. (For instance the partition plate at the outlet)

2. Static stress analysis of the pump, its bolting and flanges

2.1. Static stress analysis of the pump

According to the regulations in [3], to assure the structural integrity of the essential service water pump the corresponding stress limit values must be satisfied under various service loadings as illusrateed in Table 2.1.

The loads employed in structural integrity analysis are the ones corresponding to various service loadings designated in Table 2.1. The pressure limits under different service loadings are as the following:

1. design pressure limit: 1.0MPa;
2. operation pressure: 0.1MPa;

3. operation pressure limit: 1.0MPa for level A, 1.1MPa for level B, 1.2MPa for level C, and 1.5MPa for level D;
4. hydrostatic test:1.5MPa;

The loads applied on the inlet and outlet are listed in Table 2.2.

Table 2.1. Stress and pressure limits for design and service loadings. Here σ_m: general membrane stress, σ_b: bending stress, S: allowable stress, and S_y: yielding stress.

No.	Service limits	Load Combination	Stress limits
1	Design and Level A	Design pressure Steady state pipe load Other operating loads	$\sigma_m \leq 1.0S$ $\sigma_m + \sigma_b \leq 1.5S$
2	Level B(Abnormal)	Operating pressure of level B OBE load and OBE pipe load Other operating conditions	$\sigma_m \leq 1.1S$ $\sigma_m + \sigma_b \leq 1.65S$
3	Level C(Emergency)	Operating pressure of level C SSE load and SSE pipe load Other operating loads	$\sigma_m \leq 1.5S$ $\sigma_m + \sigma_b \leq 1.8S$
4	Level D(Accident)	Operating pressure of level D SSE load and SSE pipe load Other operating loads	$\sigma_m \leq 2.0S$ $\sigma_m + \sigma_b \leq 2.4S$
5	Hydrostatic test	1.5 times of the design pressure	$\sigma_m \leq 0.9S_y$ $\sigma_m + \sigma_b \leq 1.35S_y$

According to the stipulations in [3], the whole casting and forging parts connecting pressure retaining boundary which is $K = 2.0t$ (t is the thickness of the structure boundary) away from the pressure boundary should be included in the pressure retaining boundary analysis of the essential service water pump. Therefore the structural integrity analysis of the essential service water pump should include the pump shell, its pedestal and the outer part in axial direction of pump shaft .

MSC.Patran was used to accomplish the analysis with MSC.Nastran as analysis code. Even though the double volute-double suction water pump has the structural symmetry, the loads applied on the inlet and outlet of the pump are not symmetric. Therefore, in the static analysis under four cases Level A-D, the whole model of the pump has to be computed. The mesh of the whole pump as shown in Figure 4.3 consists of total 5105 nodes, 1783 plate elements and 5341 shell elements. In the case of hydrostatic test, the inlet and outlet of the pump are welded with flanges and there are not external loads applied on the inlet and outlet. Therefore the structural symmetry of the pump can be employed in the analysis and the mesh is shown in Figure 4.4.

The material of the pump and its flanges is: SA-216 WCC whose properties are ultimate stress $S_u = 483$Mpa, yielding stress $S_y = 200$Mpa, and allowable stress $S = min\{\frac{S_u}{4}, \frac{S_y}{3}\} = 121$Mpa.

Table 2.2. Forces and moments on the inlet and outlet of the pump (Unit: N, $N \cdot m$)

	F_x		F_y		F_z		M_x		M_y		M_z	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Thermal load	−1910	0	−3790	−2520	−3263	1598	−606	2201	564	0	−1458	0
Dead weight	29	0	1112	411	115	57	418	−187	37	0	59	0
OBE	940	124	1180	43	1476	128	151	19	769	80	594	20
SSE	1253	166	1574	57	1969	171	201	25	1025	108	793	26

Figure 4.5 ∼ Figure 4.14 are von Mises stress at the top and bottom layers of the shell elements (Z_1 and Z_2) under different service loadings. It can be observed from the stress distribution that higher stress always concentrates at the tip of partition plate and reenforcement ribs as illustrated in Figure 4.3 and 4.4, which conincides with the conclusions given in relevant regulations or handbooks. The maximum membrane stress was obtained by taking the average of the maximum von Mises stress from the top and bottom layers of the shell elements. This practice is conservative since the maximum stress from the top and bottom layers of the shell elements may not happen at the same element.

Table 2.3 lists results which are computed according to the requirements shown in Table 2.1. It can be concluded from the Table 2.3 that the pressure retaining boundary of the essential service water pump satisfies the requirements of strength and it can keep its structural integrity under different service loadings.

2.2. Stress analysis of flanges and bolting

The material of bolts is 2CrMo stainless steel which has ultimate stress $S_u = 1000$Mpa, yielding stress $S_y = 900$Mpa, allowable stress $S = min\{\frac{S_u}{4}, \frac{2S_y}{3}\} = 200$Mpa. The material of the flanges is the same as that of the pump shell.

There are two flange connections which are called inlet flange and outlet flange respectively, and both belong to the integral type flange. The stress of the flanges and bolts can be evaluated according to the following formulae and readers can refer to [5] for the explanation of each item in the equations:

Longitudinal hub stress: $S_H = \frac{fM_0}{L} g_1^2 B$

Radial flange stress: $S_R = \frac{(1.33te+1)M_0}{L} t^2 B$

Tangential flange stress: $S_T = \frac{YM_0}{t^2} B - ZS_R$

Bolt stress: $\sigma = \frac{W_{m_1}}{nA_{m_1}}$

The stress results for the inlet and outlet flanges and bolts are listed in Table 2.4. It can be observed that the flange stresses and bolt stress calculated by the equations do not exceed the corresponding allowable stresses.

Table 2.3. Results from stress analysis and stress limits check corresponding to the criteria shwon in Table 2.1

Service limits	Load combination	σ_m(Mpa)	$\sigma_m+\sigma_b$(Mpa)	Stress limits
Design and Level A	Design internal pressure Thermal load Dead weight Loads under OBE	91.7	106.0	$\sigma_m < S = 121.00$ $\sigma_m+\sigma_b < 1.5S = 181.00$
Level B	Pressure under level B Thermal load Dead weight Loads under OBE	101.8	118.0	$\sigma_m < 1.1S = 133.00$ $\sigma_m+\sigma_b < 1.65S = 200.00$
Level C	Pressure under level C Thermal load Dead weight Loads under SSE	110.7	128.0	$\sigma_m < 1.5S = 181.00$ $\sigma_m+\sigma_b < 2.05S = 242.00$
Level D	Pressure under level D Thermal load Dead weight Loads under SSE	138.5	160.0	$\sigma_m < 2.0S = 242.00$ $\sigma_m+\sigma_b < 2.4S = 290.00$
Hydrostatic test	Pressure under hydrostatic test	144.0	167.0	$\sigma_m < 0.9S_y = 180.00$ $\sigma_m+\sigma_b < 1.35S_y = 270.00$

In the stress analysis of the pedestal, the employed FEM model is shown in Figure 4.15. To make sure that the analysis is conservative, the loads from level D was used in the computation. It can be seen from Figure 4.16 that the maximum stress happens on the part of the pedestal which is right below the inlet of the pump with $\sigma_{max} = 177$Mpa. It is the same location where the anchor bolt was used to fasten the pedestal. The material of the pedestal is Q235 channel steel with allowable stress $[\sigma] = 405$Mpa. It is obvious that the pedestal satisfies the safety requirement by the fact $\sigma_{max} < [\sigma]$.

3. Dynamic analysis of the pump

The dynamic analysis of the essential service water pump classified as Class 3 has two purposes: 1) To obtain the natural frequencies and modes for the model of interest; 2) To carry out the response spectrum analysis of the pressure retaining boundary of the pump which will be addressed in the future work. There are two models: Model I and Model II in the current dynamic analysis and for each of them only the first six modes are computed:

1. Model I as shown in Figure 4.3 with 23699 degrees of freedom;
2. Model II consists of pump, electric motor and their pedestal with 30300 degrees of freedom (Figure 4.15).

Table 2.4. Results of flange and bolt stresses

Flanges	Load case	Stress (Mpa)	Allowable stress (Mpa)	Conclusion
Inlet flange	Design conditions	$\sigma = 24.3$ $S_H = 44.9$ $S_R = 55.7$ $S_T = 56.0$ $0.5(S_H + S_R) = 50.3$ $0.5(S_H + S_T) = 50.4$	$S_b = 200$ $1.5S = 181$ $S = 121$ $S_b = 200.0$ $S = 121$ $S = 121$	$\sigma < S_b$ $S_H < 1.5S$ $S_R < S$ $S_T < S_b$ $0.5(S_H + S_R) < S$ $0.5(S_H + S_T) < S$
	Gasket seated	$\sigma = 22.5$ $S_H = 30.3$ $S_R = 30.7$ $S_T = 63.3$ $0.5(S_H + S_R) = 34.0$ $0.5(S_H + S_T) = 46.8$	$S_b = 200$ $1.5S = 181$ $S = 121$ $S_b = 200$ $S = 121$ $S = 121$	$\sigma < S_b$ $S_H < 1.5S$ $S_R < S$ $S_T < S_b$ $0.5(S_H + S_R) < S$ $0.5(S_H + S_T) < S$
Outlet flange	Design conditions	$\sigma = 21.6$ $S_H = 47.4$ $S_R = 90.4$ $S_T = 109.0$ $0.5(S_H + S_R) = 68.9$ $0.5(S_H + S_T) = 78.2$	$S_b = 200$ $1.5S = 181$ $S = 121$ $S_b = 200.0$ $S = 121$ $S = 121$	$\sigma < S_b$ $S_H < 1.5S$ $S_R < S$ $S_T < S_b$ $0.5(S_H + S_R) < S$ $0.5(S_H + S_T) < S$
	Gasket seated	$\sigma = 20.0$ $S_H = 26.6$ $S_R = 50.0$ $S_T = 62.3$ $0.5(S_H + S_R) = 38.3$ $0.5(S_H + S_T) = 44.5$	$S_b = 200$ $1.5S = 181$ $S = 121$ $S_b = 200$ $S = 121$ $S = 121$	$\sigma < S_b$ $S_H < 1.5S$ $S_R < S$ $S_T < S_b$ $0.5(S_H + S_R) < S$ $0.5(S_H + S_T) < S$

The first six order natural frequencies of the Model I and Model II are listed in Table 3.1 and 3.2 respectively. The first order natural frequency of Model II is reduced by 30 Hz in comparison with that of Model I, and other frequencies of Model II also decreased dramatically, which is caused by the low toughness of the pedestal. According to [3], the equivalent static load method can be employed to perform seismic response analysis for the pressure retaining boundary since the minimum natural frequency is over 33 Hertz. This part of work will be addressed later. Figure 4.17 and 4.18 illustrate the first two modes for Model I, and Figure 4.19 and 4.20 are the first two modes corresponding to Model II. It needs to point out that the red lines denotes the modal shapes.

4. Conclusion

According to the above-mentioned analysis, the pressure retaining boundary of the essential service water pump including its support, flanges and bolts can keep structural integrity under different service loadings. The natural frequencies of the pump with/without the electric motor are all above 33 Hz. Therefore the equivalent static load method can be used in the future work of seismic response analysis.

Table 3.1. Natural frequencies of Model I

Mode No.	Circular frequency (rad/sec)	Frequecy (Hertz)	Period (sec)
1	5.1824E+2	8.2482E+01	1.2123E-2
2	9.7024E+2	1.5442E+02	6.4758E-3
3	1.3199E+3	2.1008E+02	4.7600E-3
4	1.8923E+3	3.0118E+02	3.3202E-3
5	2.6853E+3	4.2738E+02	2.3398E-3
6	2.7985E+3	4.4541E+02	2.2451E-3

Table 3.2. Natural frequencies of Model II

Mode No.	Circular frequency (rad/sec)	Frequecy (Hertz)	Period (sec)
1	4.3635E+2	6.9448E+1	1.4399E-2
2	4.6963E+2	7.4744E+1	1.3379E-2
3	6.3504E+2	1.0107E+2	9.8941E-3
4	6.7977E+2	1.0819E+2	9.2429E-3
5	7.0164E+2	1.1167E+2	8.9549E-3
6	1.1316E+3	1.8010E+2	5.5524E-3

References

[1] ASME, ASME Boiler and Pressure Vessel Code, Section III, Division 1, Appendices, Article N-1000: Dynamic Analysis Methods, American Society of Mechanical Engineers, New York, 2001.

[2] ASME, ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NCA, Article NCA-2000: Classification of Components and Supports, American Society of Mechanical Engineers, New York, 2001.

[3] ASME, ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection ND-3400: Pump Design, American Society of Mechanical Engineers, New York, 2001.

[4] USNRC, 1996, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants Report No. NUREG-0800, Section 3.9.3 (Rev.3) -ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures, US Nuclear Regulatory Commission, Washington, D.C

[5] ASME, ASME Boiler and Pressure Vessel Code, Section III, Division 1, Appendices, Article XI-3000: Design Requirements, American Society of Mechanical Engineers, New York, 2001.

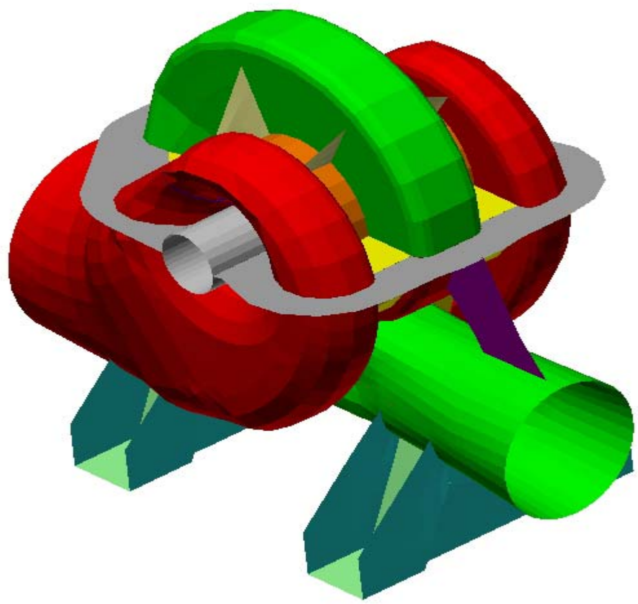

Figure 4.1. Geometry of essential service water pump

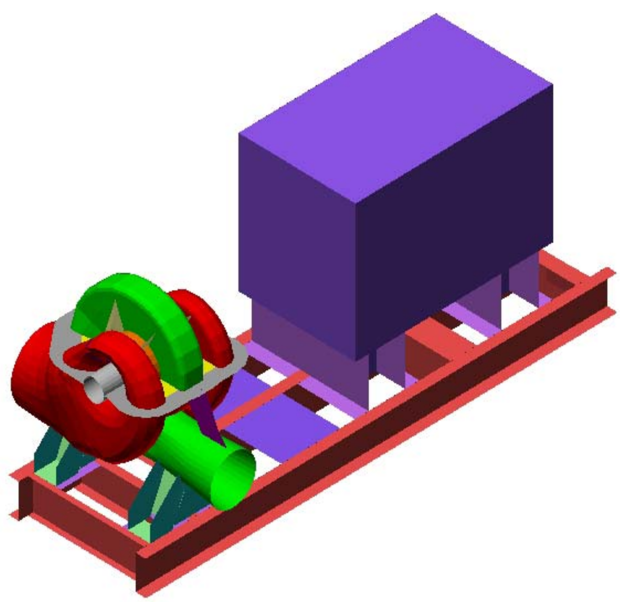

Figure 4.2. Essential service water pump, its pedestal and electric motor

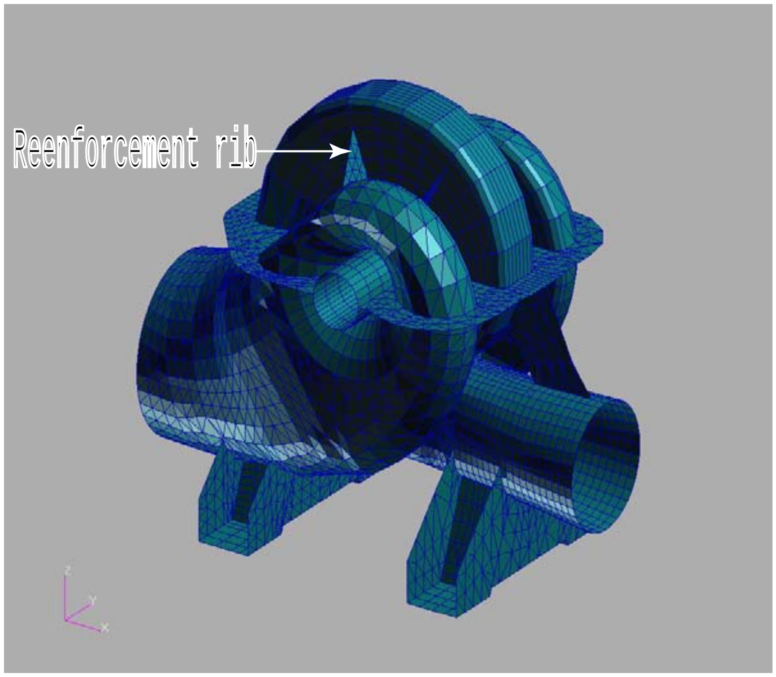

Figure 4.3. FEM mesh of the pump under Level A $\sim$ Level D

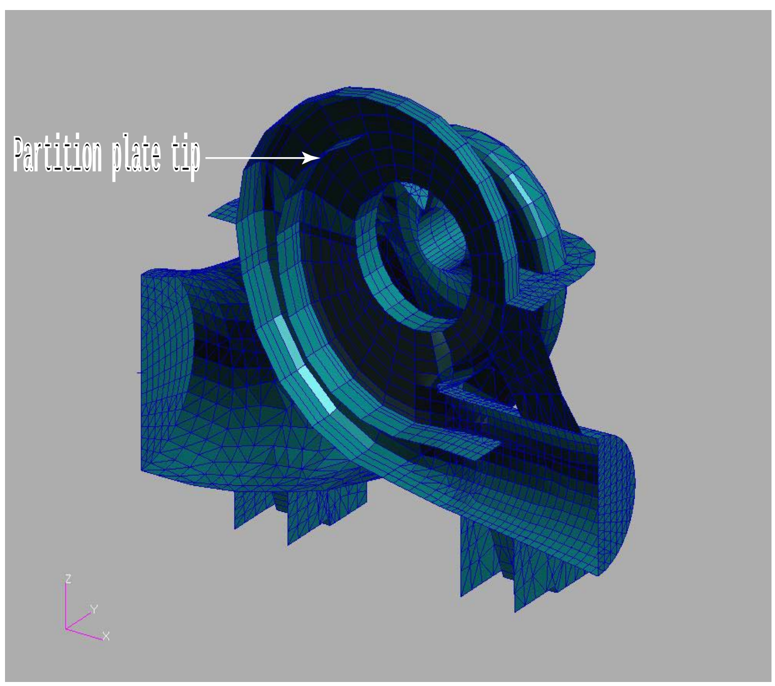

Figure 4.4. FEM mesh of the pump under hydrostatic test

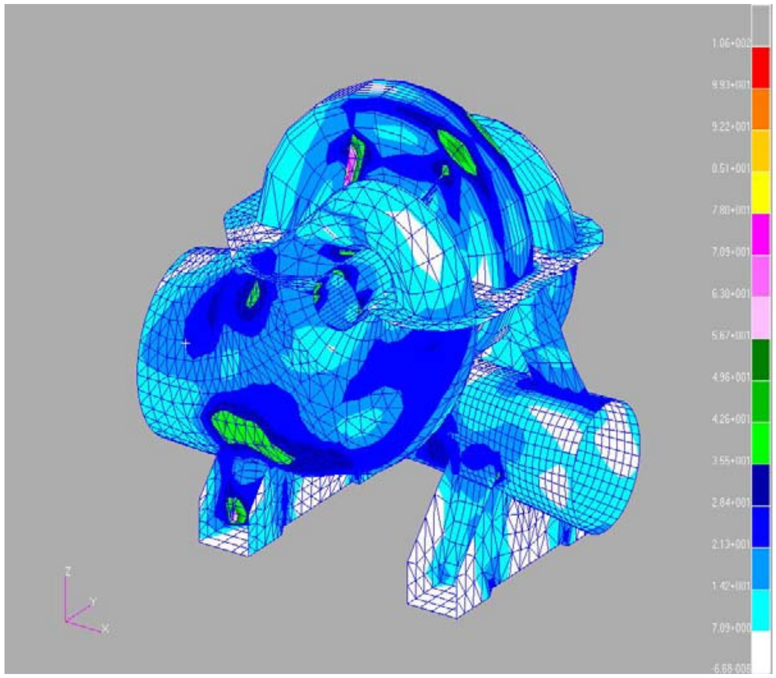

Figure 4.5. Von Mises stress at the top layer - Z_1 under service loading of level A

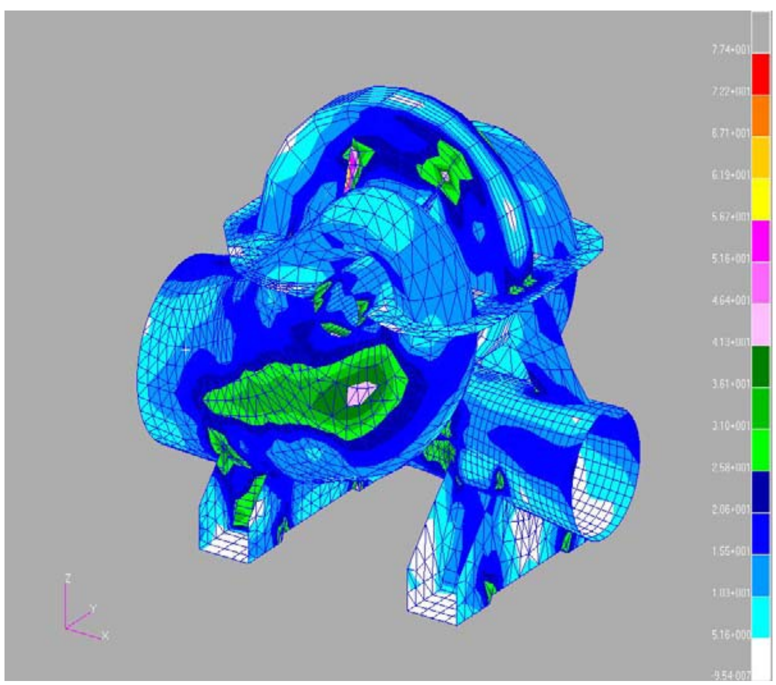

Figure 4.6. Von Mises stress at the bottom layer - Z_2 under service loading of level A

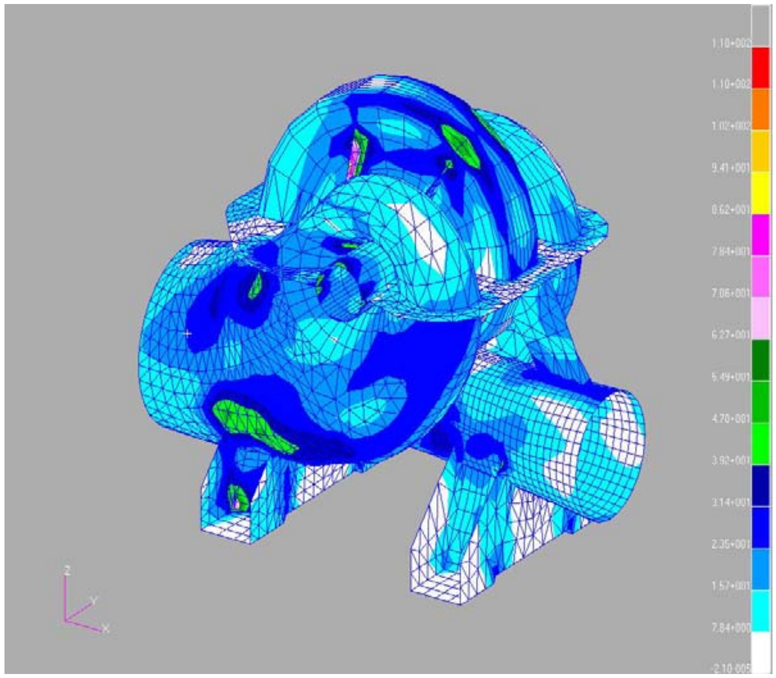

Figure 4.7. Von Mises stress at the top layer - Z_1 under service loading of level B

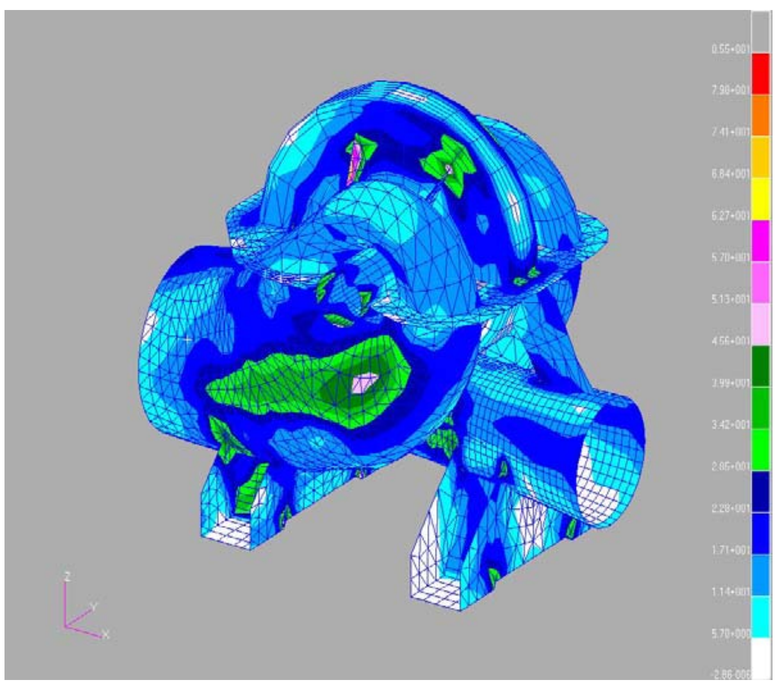

Figure 4.8. Von Mises stress at the bottom layer - Z_2 under service loading of level B

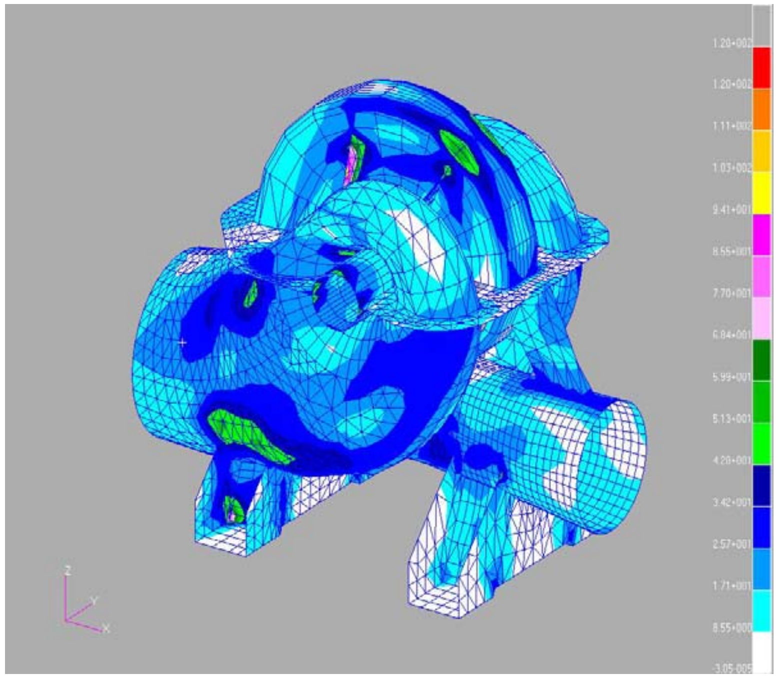

Figure 4.9. Von Mises stress at the top layer - Z_1 under service loading of level C

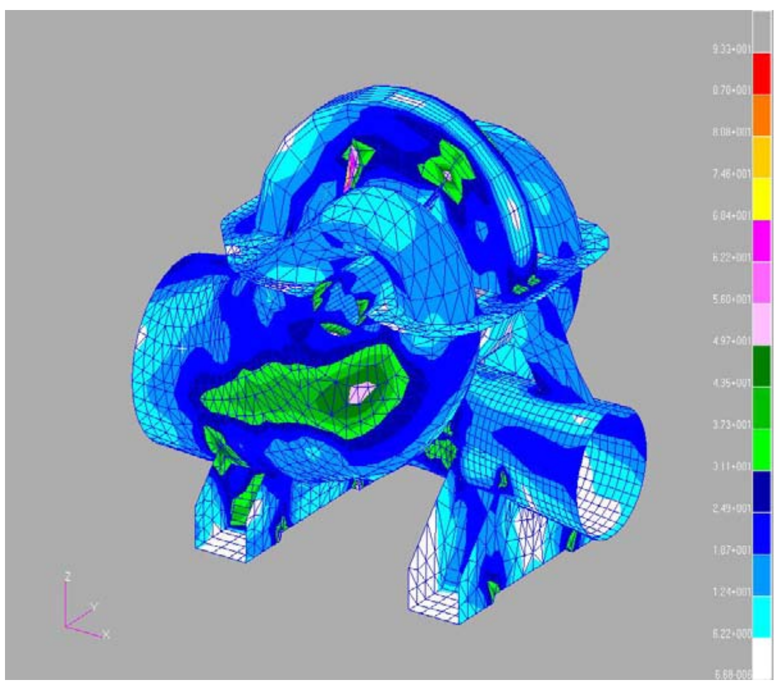

Figure 4.10. Von Mises stress at the bottom layer - Z_2 under service loading of level C

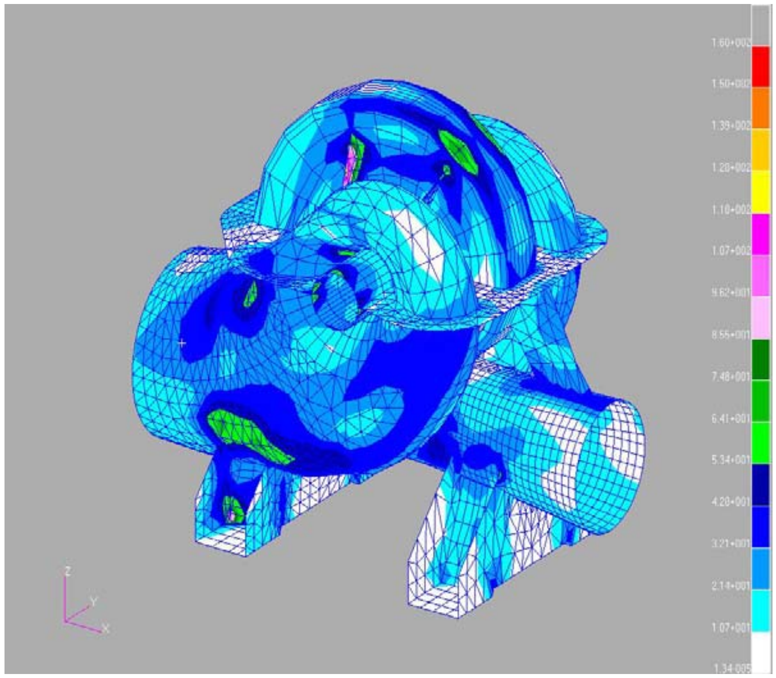

Figure 4.11. Von Mises stress at the top layer - Z_1 under service loading of level D

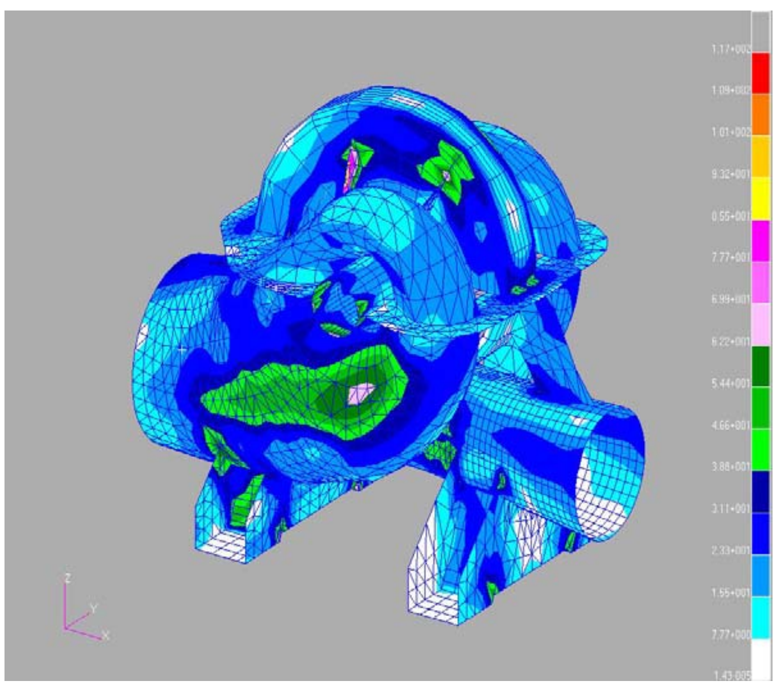

Figure 4.12. Von Mises stress at the bottom layer - Z_2 under service loading of level D

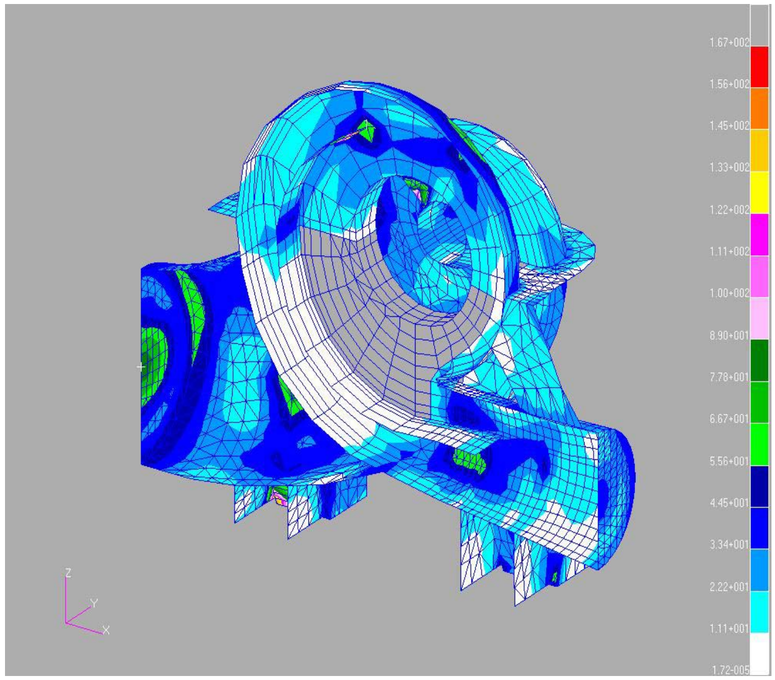

Figure 4.13. Von Mises stress at the top layer - Z_1 under hydrostatic test

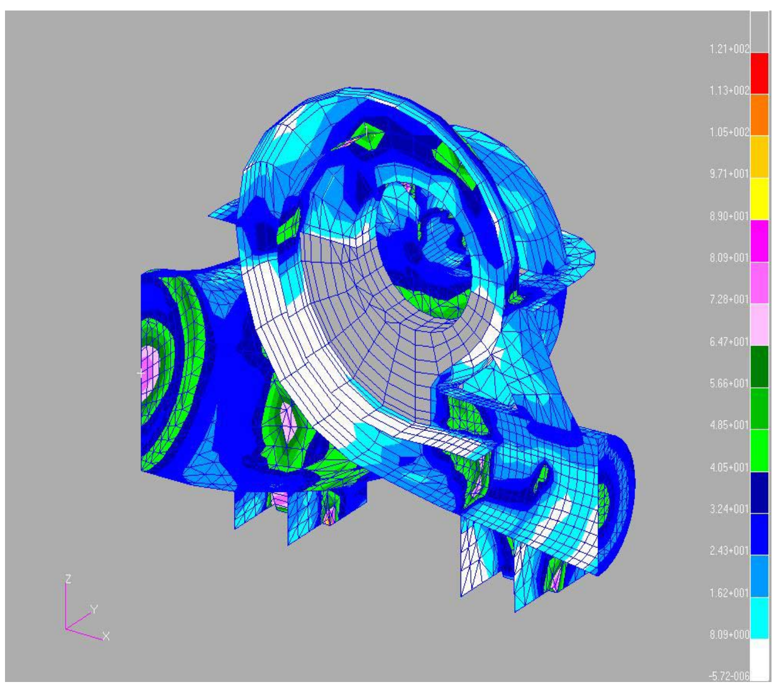

Figure 4.14. Von Mises stress at the bottom layer - Z_2 under hydrostatic test

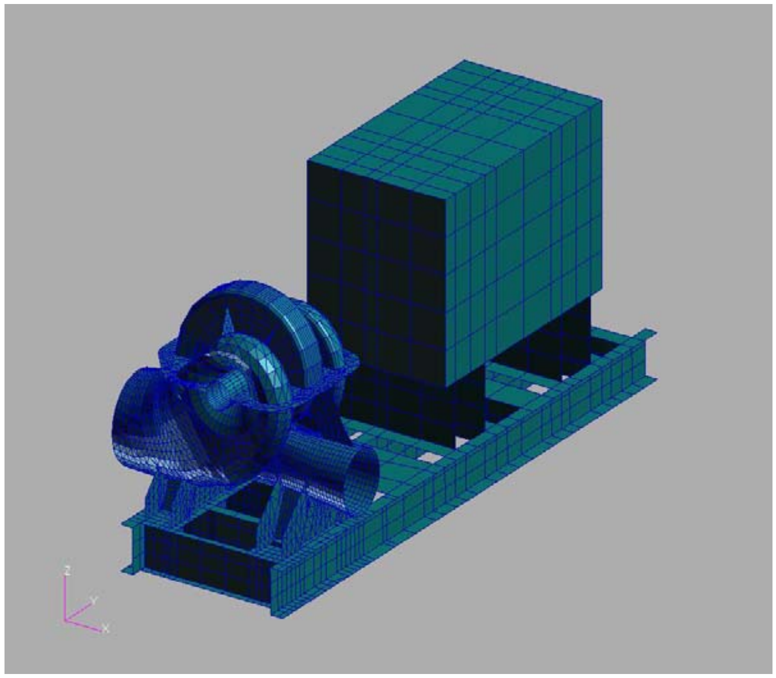

Figure 4.15. FEM mesh of the Model II

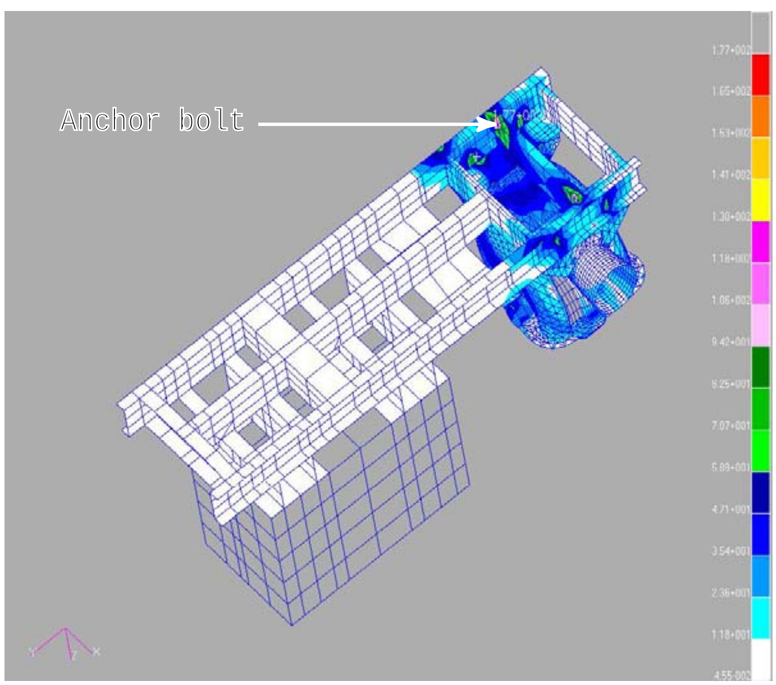

Figure 4.16. Stress analysis of bolting in the pedestal

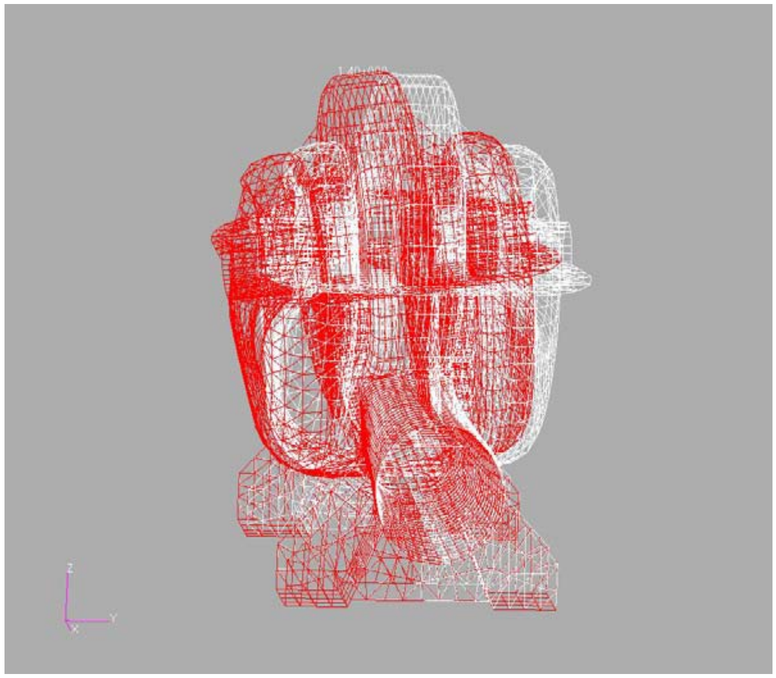

Figure 4.17. The first mode of Model I

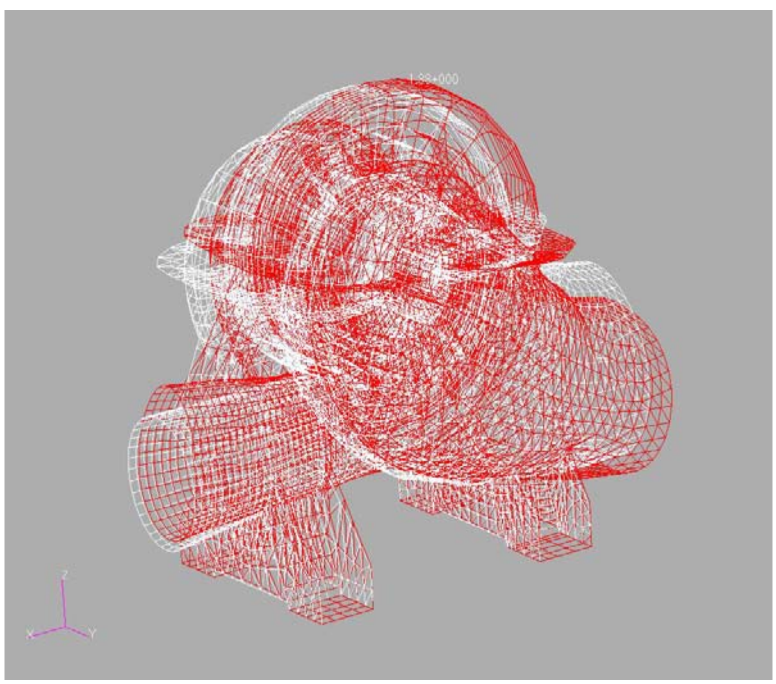

Figure 4.18. The second mode of Model I

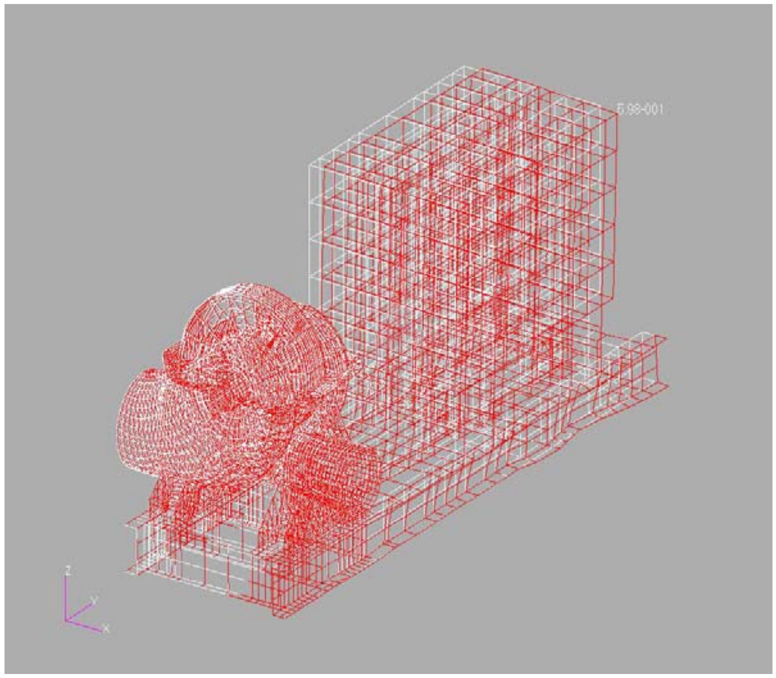

Figure 4.19. The first mode of Model II

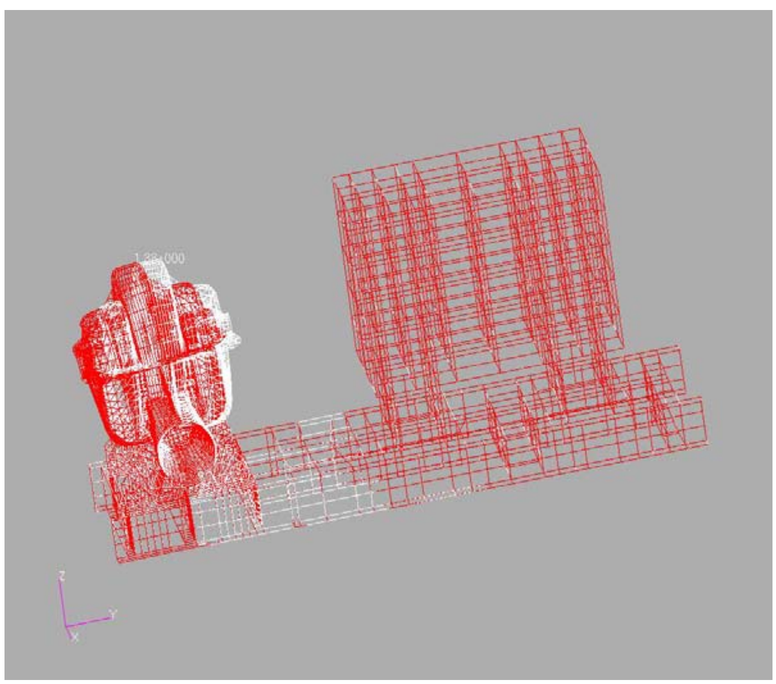

Figure 4.20. The second mode of Model II