STRUCTURAL ANALYSIS FOR RESIN WASTE TRANSFER FLASK AND LIFTING YOKE

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ABSTRACT

CANDU™ is a Canadian nuclear power generation technology developed by Atomic Energy of Canada Limited (AECL). CANDU™ nuclear power plants use deuterium oxide (heavy water) as the moderator and coolant, and natural uranium as fuel. Natural uranium is simple to use and easy to fabricate as fuel. CANDU™ is one of the top performing nuclear products in the world today. AECL's CANDU™ nuclear power plants are operated around the world, and have consistently achieved outstanding performance track records.

The Spent Resin Waste Transfer Flask (SRWTF) and its lifting yoke are part of the waste handling equipment to transfer the waste within a CANDU™ Nuclear Power Plant. This paper discusses the Finite Element Analysis (FEA) of the various components of the flask. Experience gained during the design process and the optimisations of the designs are discussed.

INTRODUCTION

The Spent Resin Waste Transfer Flask (SRWTF) and its lifting yoke, as shown in Figure 1, are part of the waste handling equipment to transfer waste.

The SRWTF has been designed to hold the spent resin-waste containers. The SRWTF provides sufficient shielding for radiation protection to operating personnel during the transfer of the resin-waste from the loading location to the storage structure. The SRWTF allows for loading and unloading of the spent resin-waste containers and have top loading and bottom unloading capabilities. The SRWTF is designed to interface with the spent resin-waste processing equipment (i.e., appropriate piping connections, etc.) and the spent resin-waste container and the lifting and handling equipment.

The resins container is a stainless steel cylindrical container designed for approximately 3m^3 of resins. The SRWTF has a hoist unit installed on the top cover of its cylindrical body, which will allow an electrically-driven cable-and-pulleys system to lower or lift the spent resin container inside the flask during handling operations.

This paper discusses structural finite element analysis of some parts of the flask. It includes the bottom gate, frame, and the leg of the flask lifting yoke. During the process of analysis some potential ways of improving the design were found, e.g. linking the top and bottom plate of the bottom gate. These changes were recommended to optimise the design and are discussed in this paper.

DESCRIPTION OF STRUCTURE

The SRWTF is a cylindrical shell with a top cover and a bottom gate. All three components are made up of a sandwich of lead poured between two steel plates. The lifting yoke consists of a frame and two legs. The frame includes two triangular steel plates. The yoke leg is made of steel plate, which is attached to the cylindrical shell through a trunnion.

The outer diameter of the shell is approximately 78". The height of the cylindrical shell is about 74". The lifting yoke consists of a frame and two legs. The frame includes two thick triangular steel plates. The yoke leg is made of thick steel plate. The bottom gate of the flask consists of two circular steel plates and lead poured in between. The outer diameter of the gate is 69".

LOADS, MATERIALS AND IMPACT FACTOR

The loads include the weights of various components of the flask, such as the resin waste, the container inside the flask, grapple unit on top of the container, top cover of the flask, hoisting equipment on the flask top cover, cylinder of the flask, bottom gate of the flask and lifting yoke. The total lifting weight including the flask and the yoke is approximately 77 kips.

The flask is made of Carbon steel (CSA/CAN3-G40.21-Gr. 300W). Different load case scenarios were considered. The weight of resin and lead was the most severe in this case hence particular attention is given to these in this analysis. An impact factor of 1.25 due to the lifting and dropping of the flask is considered in the analysis.

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While pouring resin in the container a shift in the centre of gravity of the system might occur. The lifting yokes are analysed with particular attention to this aspect in order to be able to provide stability to the flask if such a situation arises.

FINITE ELEMENT MODELS

It was found that the bottom gate, yoke frame and the yoke leg are the most critical parts of the whole structure. These parts were modelled and analysed for weaknesses. In this paper the finite element analysis for these parts are presented along with the recommendations on improvements. The main purpose of the finite element model was to find out the overall deformation pattern of each components and their stress distributions. Localized stress concentrations are not considered of interest because the bearing stresses were checked separately. The outcome of the bottom gate finite element analysis was also checked separately using the following classical formulas as in References [1] and [2]:

Plate Flexural Rigidity:
$$D := \frac{E \times t^3}{12 \times \left(1 - v^2\right)}$$

Maximum Bending Moment:
$$M_{max} := q \times r^2 \times \frac{(3 + v)}{16}$$

Maximum Stress:
$$\sigma_{max} := 6 \times \frac{M_{max}}{t^2}$$

Maximum Deflection:
$$\delta_{max} := \frac{(5 + v) \times q \times r^4}{64 \times (1 + v) \times D}$$

E	=	Young's Modulus
v	=	Poisson' s Ratio
q	=	Pressure
r	=	Radius
t	=	Thickness
σ	=	Stress
δ	=	Deflection

The above classical formulas are very useful for checking but they could lead to stresses and deflections that are one order of magnitude higher. Most of the time that occurs because many conservative assumptions are made to simplify the problem. Finite element optimisation analysis is one of the practical ways to arrive at cost effective design for such unique nuclear structures.

Different types of shell elements and beam elements were used in the FEA model. In this analysis isotropic material models were used.

Flask Bottom Gate:

Following is the simplified finite element model of the bottom gate.

The loads on the bottom gate of the flask include the weight of the inside container and the self-weight of the bottom gate. The bending moments at the centres of the sandwich steel plates are the main concern. The following assumptions are made:

1. The circular plates are simply supported at the edge.
2. The two steel plates take the loads separately, i.e., the top steel plate takes the weight of the inside container, the resin waste, the grapple unit on top of the container, and the plate self-weight; the bottom steel plate takes the weight of lead (0.41 lb/in³) and plate self-weight.
3. The loads are distributed uniformly.

It is worth mentioning that the assumption that the two plates take the loads separately is considered conservative. The two plates can share the loads through the lead in between. The stress and deflections will be significantly reduced if the top and bottom plates share loads together and if the ring that connects top and bottom plates is taken into consideration. To verify this, a finite element model is developed for the bottom gate using STARDYNE (Reference [3]). The finite element model is shown in Figures 2.

Both the top and bottom plates are modelled using quadrilateral and triangular plate elements with the same mesh, the same thickness of 0.5", and the same diameter of 69".

The top and bottom plates are connected through five 1" ϕ tie-rods, one at the centre, and the other four at the mid-radius. The tie-rods are modelled as beam elements with releases at both ends for rotations, i.e., only axial loads in the tie-rods are considered. There will be no shear or moment transferred through these tie rods. Hence the axial force is a direct result of differential out of plane deflection of two plates.

The ring is modelled as vertically supported around the perimeter. To avoid instability of the model, the centre of the top plate is restrained for rotation about Axis Z and is restrained in two horizontal directions.

A uniformly distributed load is applied to the top plate and bottom plate.

The finite element model of the bottom gate is analysed using the STARDYNE computer code (Reference [3]). The deformed shape is given in Figure 2 and the contour plots for Von Mises stress due to the given loads are presented in Figure 3 for the top plate, in Figure 4 for the bottom plate.

Yoke Frame:

The frame is modelled using both quadrilateral and triangular plate elements as seen in Figure 5. The centres of the three holes with pins are connected to the plate elements using rigid beams. The centre of the hole for the crane hook is modelled as simply supported, i.e., restrained in X, Y, and Z directions. A vertical point load of 19290 lbs, i.e., one fourth of the total weight, is applied to each centre of the two holes for the yoke leg.

Yoke Leg:

Eccentricity of the loads on flask can lead to out-of-plane bending on the yoke Leg. Although the assembly of the flask is generally symmetrical, there are three possible cases that could induce eccentricities. The hoisting equipment that sits on top of the flask can be off-centre. There is a clearance between the resin waste container inside the flask and the inside wall of the flaks, i.e., the entire container could be offset from the centreline of the flask by a distance equal to the clearance. If the container is full of resin waste, the waste is considered evenly distributed. Therefore, The eccentricity is equal to the clearance around the container. The yoke stud below the trunnion is intended to prevent the flask from excessive swinging. It is welded to both sides of the outer shell of the flask.

Since the eccentricity discussed above can occur in any direction, the in-plane bending of the yoke leg should also be considered. The in-plane bending of the yoke leg is shown in Figure 7.

RESULTS

The Von Mises stress contour for the bottom gate of the flask is shown in Figure 3. It is found that the maximum Von Mises stress in the bottom gate is 9.52 ksi, which is significantly lower than the allowable of 26.4 ksi. The maximum vertical deflection is 0.212" at the centre of the top plate (as seen in Figure 2). The maximum axial load in the tie rods is 96.45 lbs.

The bearing stresses in the outer and inner flask shells at the trunnion are checked and the results are well below the allowable limit.

The shear capacity of the welds around the two trunnions is of interest. Each trunnion is welded to both inner and outer cylindrical shells using ¼" fillet weld all around. It is found the total weld provided is adequate to resist any possible shear according to Reference [4].

A detailed stress analysis for the lifting yoke has also been performed. It is found that the bearing stresses are significantly less than the allowable stress of 26.4 ksi.

A finite element model of the yoke frame has also been developed. The stress contour for the yoke frame is shown in Figure 6. It is found that the maximum stress in the yoke frame is about 4.30 ksi. Multiplied by an impact factor of 1.25, the maximum stress is 5.38 ksi, which is significantly lower than the allowable of 26.4 ksi.

The stresses in the yoke leg due to out-of-plane bending and tension are combined with the stress due to in-plane bending. The stress contour for the yoke leg is shown in Figure 7. It is found that the maximum stress in the yoke leg is 17.1 ksi, which is lower than the allowable of 26.4 ksi.

The maximum stress results are summarized in the following table:

Table 1 – Maximum Stress Summary

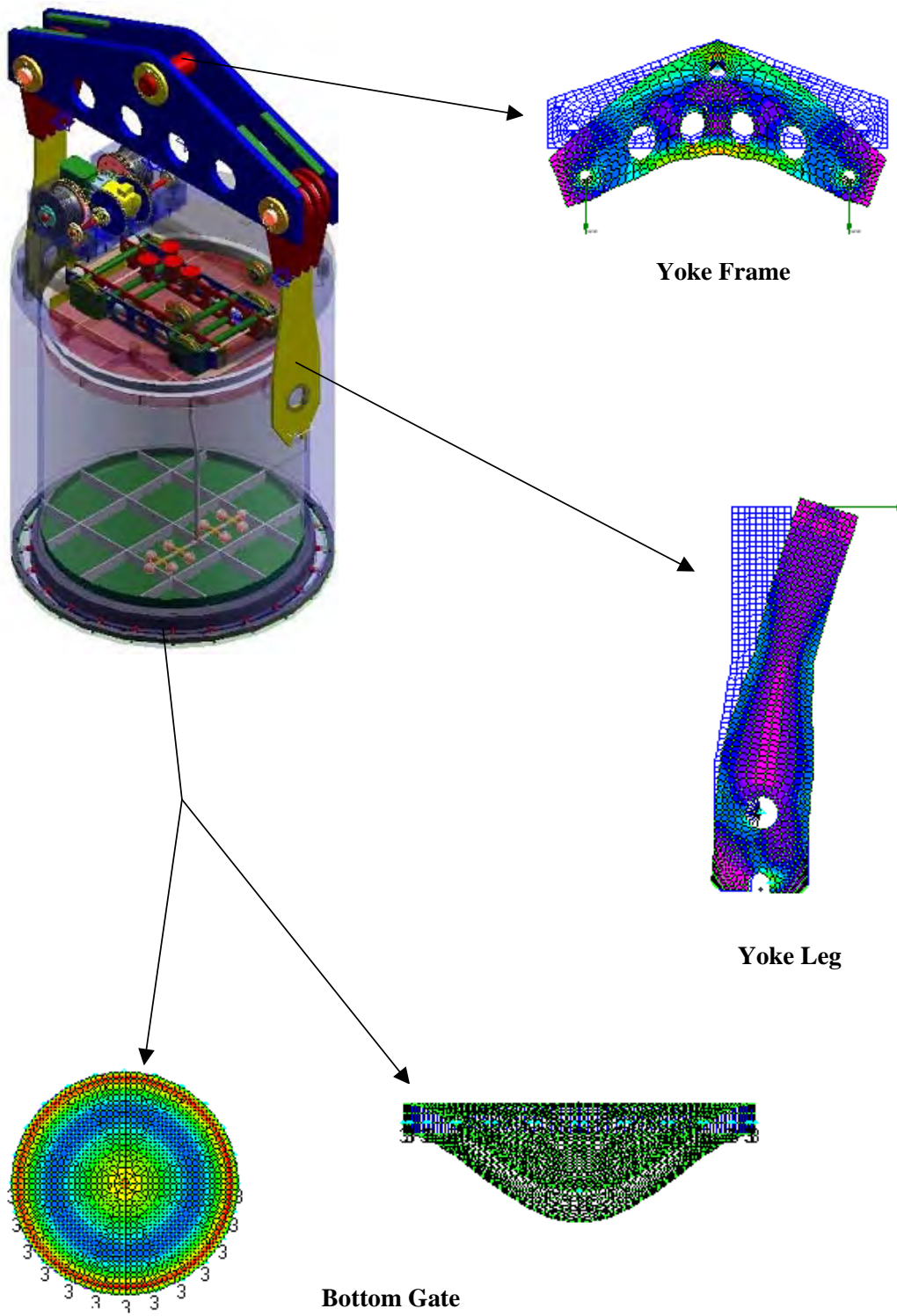|	**Calculated Stress (ksi)**	**Allowable Stress (ksi)**	**Safety Factor**
Bottom Gate	9.52	26.4	2.8
Yoke Frame	5.38	26.4	4.9
Yoke Leg	17.1	26.4	1.5

Yoke Frame

Yoke Leg

Bottom Gate

Figure 1. Spent Resin Waste Transfer Flask and its Lifting Yoke
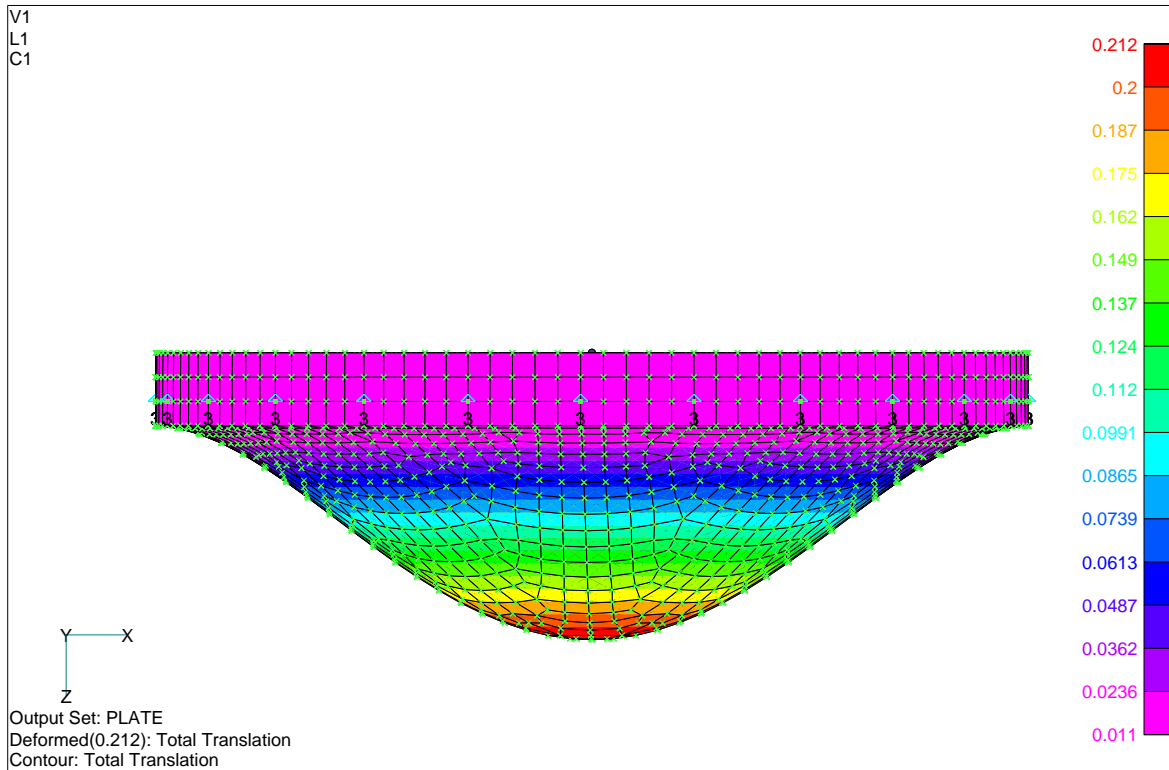
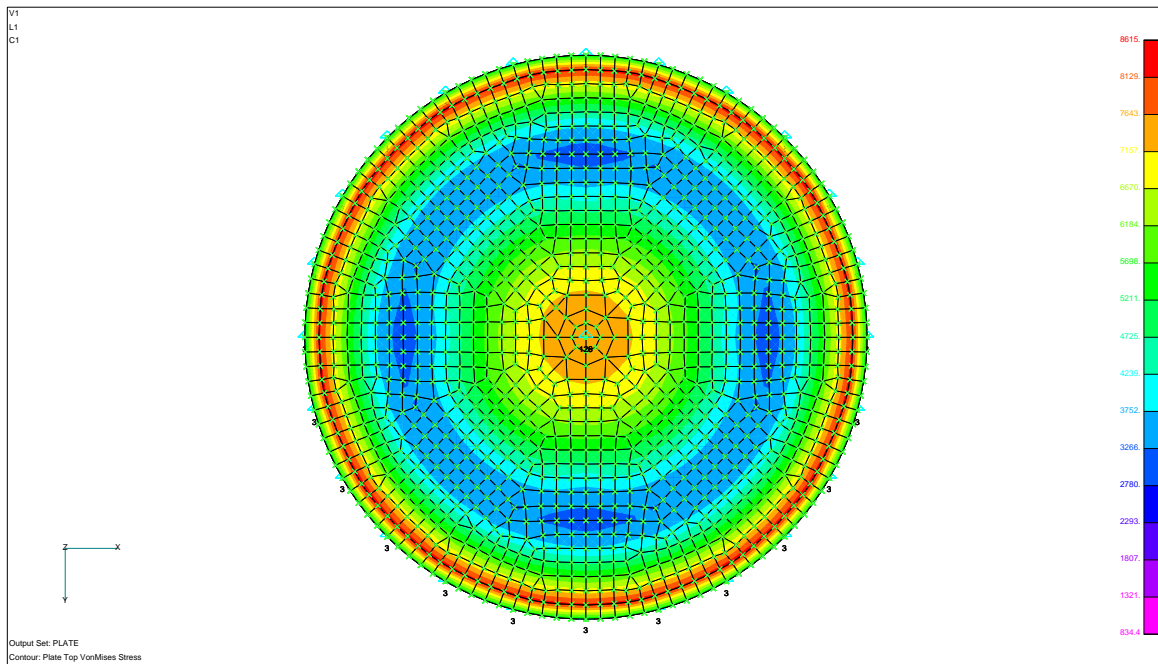**Figure 2. Bottom Gate Deflection Contour**
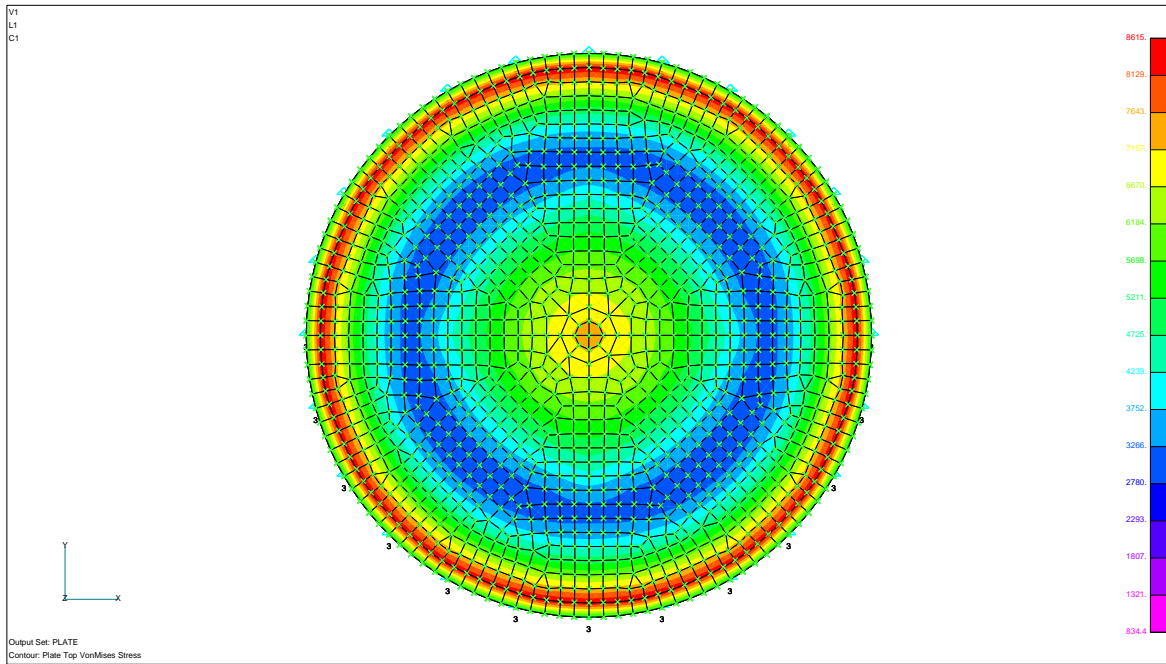

Figure 3. Von Mises Stress at Top Plate
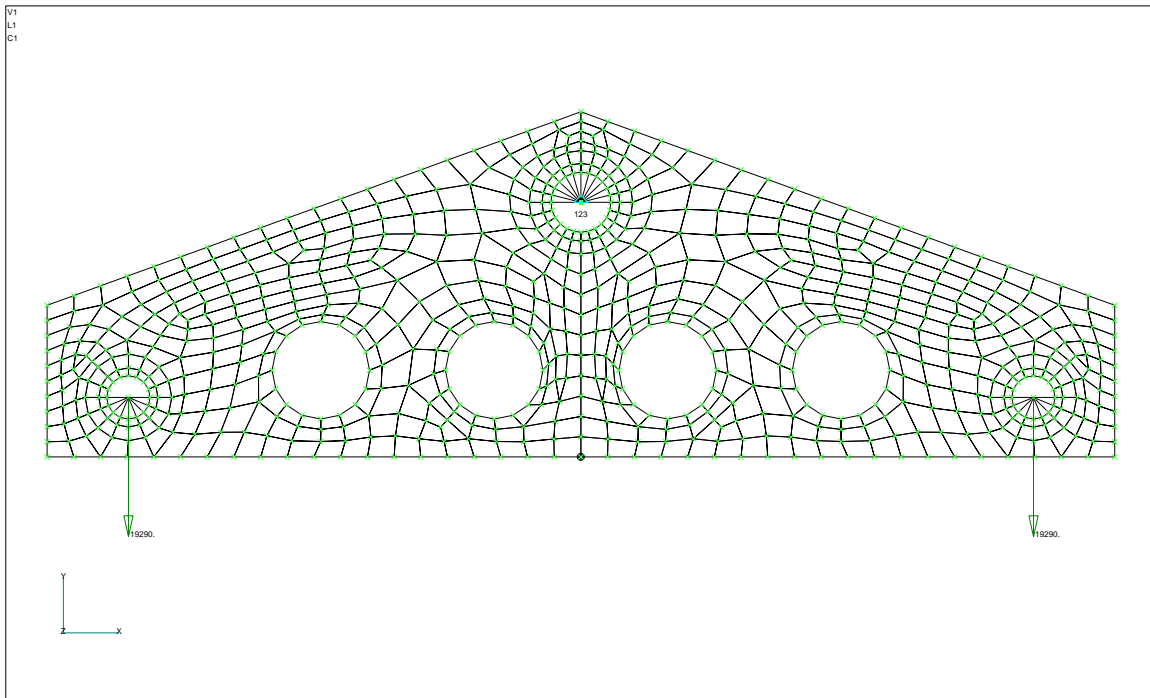
Figure 4. Von Mises Stress at Bottom Plate

Figure 5. Finite Element Model of Yoke Frame
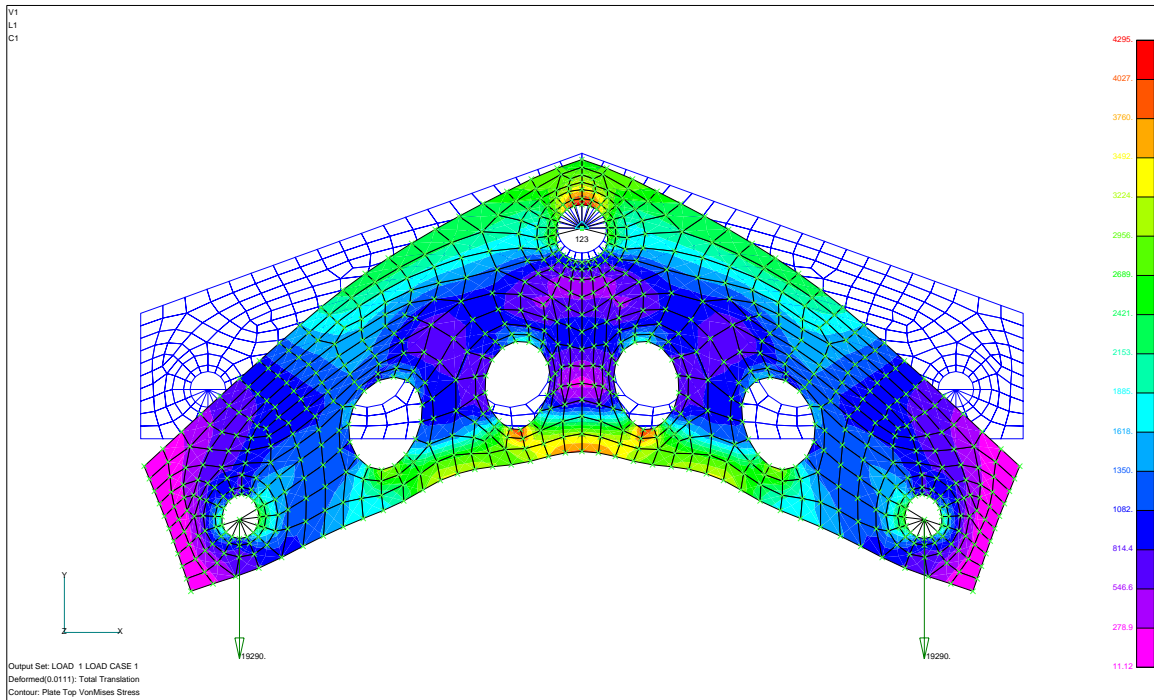
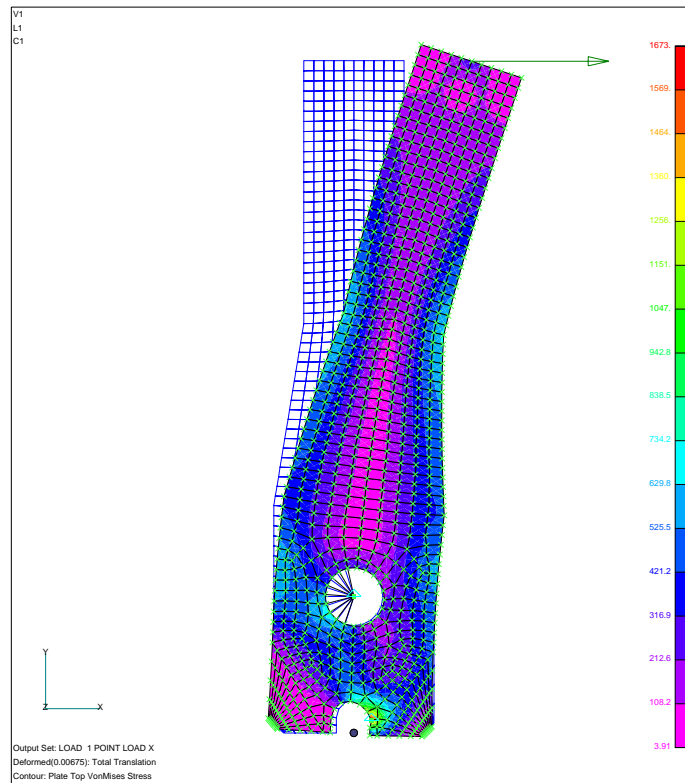**Figure 6. Deformation and Stress Contour of Yoke Frame**

Figure 7. Deformation and Stress Contour of Yoke Leg

SUMMARY AND CONCLUSIONS

A structural analysis for the key components of the Spent Resin Waste Transfer Flask and its lifting yoke is presented. The results of finite element methods were partially verified by using standard classical formulas.

A recommendation was made to connect the top and the bottom plate of the bottom gate by tie rods, so that the top and bottom plates can share the loads by means of restricting each other from out of plane movement. Linking these top and bottom plates also reduces the deflection and stresses. By linking the top and bottom plates using tie rods the bottom gate can be strengthened in a very cost effective manner.

A summary of various stresses calculated is given in Table 1. It is observed that a minimum factor of safety is 1.5 for yoke leg. It is noted that the calculated stresses are very conservative. Therefore, the structural design of the lifting yoke and the flask bottom gate is adequate.

REFERENCES

[1]   S. Timoshenko, "Theory of Plates and Shells", McGraw-Hill Book Company, Inc., 1940.

[2]   Warren C.Young, "Roark's Formulas for Stress & Strain", Sixth Edition, McGraw Hill, 1989.

[3]   STARDYNE Computer Program, Version 5.11 – "User Information Manual". Research Engineers Inc., 1996.

[4]   Canadian Standards Association, CAN/CSA 16-01, "Limit States Design of Steel Structures", December 2001.

NOMENCLATURE

E = Young's Modulus

ν = Poisson' s Ratio

q = Pressure

r = Radius

t = Thickness

σ = Stress

δ = Deflection

SRWTF = Spent Resin Waste Transfer Flask

AECL = Atomic Energy of Canada Limited