1.0 OBJECTIVE

Perform a tie-down evaluation of the 8-120B cask (Reference 1) for the applied regulatory loading of 10CFR71.45 (Reference 2).

2.0 INTRODUCTION

Each 8-120 cask is transported on a dedicated trailer using appropriate tie-down arrangement that typically include a combination of flexible and rigid restraints. The cask is equipped with four tie-down arms that are used for the tie-down of the 8-120B cask during transportation (Figure 1). The transportation of the packages in the United States is controlled under the provisions of 49 CFR 393 (Reference 3). Loadings are specified by 49 CFR 393.102 for minimum performance criteria for cargo securement devices and systems. However, 10 CFR 71.45(b) (1) requires that:

"If there is a system of tie-down devices that is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times weight of the package with contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents."

Since the 10CFR71 loading on the tie-down system is much more severe than the 49CFR393 loading, it is used herein for the evaluation of the 8-120B cask for the transportation conditions.

The Evaluation of the 8-120B cask tie-down arm and outer shell is provided in this document to show that they meet the applicable requirements of 10CFR71.45 for the 74,000 lbs. gross weight (W) of the cask.

3.0 REFERENCES

(1) Energy*Solutions* Drawing No. C-110-E-0007, Rev.14, "8-120B Shipping Cask."

(2) Code of Federal Regulations, Title 49, Part 71.

(3) Code of Federal Regulations 49 CFR 393, Federal Motor Carrier Safety Regulations.

4.0 MATERIAL PROPERTIES

Cask Tie-Down Arm

Specification: ASTM A-514 or A-517.

Listing the minimum strength values from A-514 and A517 materials.

Minimum Yield Strength, S_y = 90,000 psi

Minimum Ultimate Strength, S_u = 105,000 psi

Cask Outer Shell

Specification: ASTM A-516 Gr. 70

Minimum Yield Strength, S_y = 38,000 psi

Minimum Ultimate Strength, S_u = 70,000 psi

5.0 ALLOWABLE STRESSES

Cask Tie-Down Arm

Allowable Normal Stress, = S_y

= 90,000 psi

Allowable Shear Stress, = $0.6 \times S_y$

= 54,000 psi

Cask Outer Shell

Allowable Normal Stress, = S_y

= 38,000 psi

Allowable Shear Stress, = $0.6 \times S_y$

= 22,800 psi

Weld

Base material allowable stresses are conservatively used for the welds.

6.0 STRUCTURAL EVALUATION

6.1 Applied Loading

As states earlier, the tie down system for transporting the package is designed in accordance with the loading conditions defined in 10 CFR 71, Paragraph 71.45(b)(1), and has to withstand the following loads applied together at center of gravity of the package:

Longitudinal Load:	10W	=	740,000 lbs.	= 740 kips
Lateral Load:	5W	=	370,000 lbs.	= 370 kips
Vertical Load:	2W	=	148,000 lbs.	= 148 kips

6.2 Description of the Tie-Down Device

The package has been provided with two 1-1/2” thick steel plates (tie-down arms) which are welded to the external shell of the cask body. The steel plates are used for tying the package down. They project outward from the cask in four directions so as to allow specially designed rigging components to be connected to the ends of the tie-down arms. Four shear blocks prevent movement of the base of the package.

The geometric configuration of the tie-down system was selected such that:

(1) The resultant tie-down arm tensile loads are tangent to the cask surface in order to minimize the effects of out-of-plane stresses in the cask shell. (See Figure 2 for determination of the tie-down geometry).
(2) The shear block loads are transferred to the cask surface via compression in the lower impact limiter.

6.3 Tie-Down Forces

The analytical model for determining the loads required preventing rotation and translation of the package due to the applied loads is shown in Figure 3. The shear block forces at the bottom of the package are represented by the orthogonal components of a single force vector, S, making an angle of θ with the global y-axis.

The six equations of equilibrium for the free body diagrams of Figure 3 yield the following for the six unknowns:

$$\sum F_x = 0$$

$$\frac{-59}{102.34}\times T_1 + \frac{59}{102.34}\times T_2 + \frac{59}{102.34}\times T_3 - S\times\sin\theta = 5(74) = 370$$

$$\sum F_y = 0$$

$$\frac{72.3}{102.34}\times T_1 + \frac{72.3}{102.34}\times T_2 - \frac{72.3}{102.34}\times T_3 + S\times\cos\theta = 10(74) = 740$$

$$\sum F_z = 0$$

$$\frac{42}{102.34}\times T_1 + \frac{42}{102.34}\times T_2 + \frac{42}{102.34}\times T_3 - V = 2(74) = 148$$

$$\sum M_x = 0$$

$$\left[\frac{42}{102.34}\times 23.73 + \frac{72.3}{102.34}\times 79\right]\times T_1 + \left[\frac{42}{102.34}\times 23.73 + \frac{72.3}{102.34}\times 79\right]\times T_2 - \left[\frac{42}{102.34}\times 23.73 + \frac{72.3}{102.34}\times 79\right]\times T_3 + 24\times S\times\cos\theta = 10\times 74\times 62.5 = 46{,}250$$

$$\sum M_y = 0$$

$$\left[\frac{42}{102.34}\times 29.04-\frac{59}{102.34}\times 79\right]\times T_1+\left[\frac{59}{102.34}\times 79-\frac{42}{102.34}\times 29.04\right]\times T_2$$

$$+\left[\frac{59}{102.34}\times 79-\frac{42}{102.34}\times 29.04\right]\times T_3-24\times S\times\sin\theta = 5\times 74\times 62.5) \quad = \quad 23{,}125$$

$$\sum M_z \quad = \quad 0$$

$$\left[\frac{(59^2+72.3^2)^{0.5}}{102.34}\times 37.5\right]\times T_1-\left[\frac{(59^2+72.3^2)^{0.5}}{102.34}\times 37.5\right]\times T_2$$

$$+\left[\frac{(59^2+72.3^2)^{0.5}}{102.34}\times 37.5\right]\times T_3 \quad = \quad 0$$

In matrix notation the equations appear as:

$$\begin{bmatrix} -0.577 & 0.577 & 0.577 & -1 & 0 & 0 \\ 0.706 & 0.706 & -0.706 & 0 & 1 & 0 \\ 0.410 & 0.410 & 0.410 & 0 & 0 & -1 \\ 65.550 & 65.550 & -65.550 & 0 & 24 & 0 \\ -33.626 & 33.626 & 33.626 & -24 & 0 & 0 \\ 34.194 & -34.194 & 34.194 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ S\sin\theta \\ S\cos\theta \\ V \end{bmatrix} = \begin{bmatrix} 370 \\ 740 \\ 148 \\ 46{,}250 \\ 23{,}125 \\ 0 \end{bmatrix}$$

Simultaneous solution of the six equations yields the following:

T_1 = 293 kips
T_2 = 653 kips
T_3 = 360 kips
$S\sin\theta$ = 46 kips
$S\cos\theta$ = 326 kips
V = 388 kips

6.4 Tie-Down Arm

The tie-down arm is detailed as shown in Figure 4. The maximum tie-down arm load of 653 kips = 653,000 lbs. was determined in Section 6.3 above.

Stresses for the tie-down arm and its connection to the exterior cask shell are determined as follows:

Tension on Net Section at Hole

$$A_{net} = (6.5 - 2.875) \times 2.75 = 9.97 \text{ in}^2$$

$$\sigma_t = \frac{653{,}000}{9.97} = 65{,}497 psi$$

$$\sigma_{allow} = \sigma_y = 90{,}000 psi$$

Therefore:

$$F.S. = \frac{\sigma_{allow}}{\sigma_t} = \frac{90{,}000}{65{,}497} = 1.37$$

Contact Bearing at Lifting Hole

$$A_{brg} = 2.75 \times 2.75 = 7.56 \ in^2$$

$$\sigma = \frac{653{,}000}{7.56} = 86{,}376 \ psi$$

$$\sigma_{allow} = 1.35 \times 90{,}000 = 121{,}500 \ psi \text{ (Reference4)}$$

Therefore:

$$F.S. = \frac{\sigma_{allow}}{\sigma} = \frac{121{,}500}{86{,}376} = 1.41$$

Arm Tension

$$A_{arm} = 1.5 \times 6.5 = 9.75 \ in^2$$

$$\sigma_t = \frac{653{,}000}{9.75} = 66{,}974 \ psi$$

$$\sigma_{allow} = \sigma_y = 90{,}000 psi$$

Therefore:

$$F.S. = \frac{\sigma_{allow}}{\sigma} = \frac{90{,}000}{66{,}974} = 1.34$$

Edge Tear out

$$A = (3.25 + 0.75 - 0.5 \times 2.875) \times 2.75 \times 2 = 14.09 in^2$$

$$\tau = \frac{653{,}000}{14.09} = 46{,}345\ psi$$

$$\tau_{allow} = 54{,}000\ psi$$

Therefore:

$$F.S. = \frac{\tau_{allow}}{\tau} = \frac{54{,}000}{46{,}345} = 1.17$$

Weld Stresses

Welds connecting each tie-down arm to the cask outside shell are evaluated in Section 6.5.

6.5 Cask Outer Shell

To evaluate the cask outer shell, conservatively assuming the maximum tensile load of 653,000 lbs. is applied at each tie-down arm (symmetrical loading) and therefore a one-quarter finite element model of the 8-120B cask can be utilized. The model of the outer shell and one tie-down arm is made of all solid elements. The cask outside shell is made of 20-node solid element (ANSYS SOLID186) and that of the tie-down arm is made of 10-node solid element (ANSYS SOLID187). Each tie-down arm is welded onto the cask outer shell with groove and fillet welds, as shown in Reference 1. The groove welds are included in the FEM and the fillet welds are conservatively ignored. Since the objective of the modeling is to obtain stresses at the tie-down arm and the cask outer-shell interface, the doubler-plates near the tie-down arm holes have been neglected. The stresses in the vicinity of the hole have been evaluated in Section 6.3.

The interface between the unwelded portion of the tie-down arm and the outer shell of the cask has been modeled by pairs of 3-dimensional 8-node contact (CONTA 174) and 3-dimensional target segments (TARGE 170) elements. The tie-down arm load is applied at the hole-surface as a distributed load.

Figure 5 shows the finite element model of the outer shell and the tie-down arm. Figure 6 gives the maximum principal stress (tensile) for the outer shell. The maximum principal stress (tensile) of 36,653 psi obtained from the analysis is less than the yield stress of the material (38,000 psi) and is considered acceptable.

Figure 7 provide the maximum stress intensities in the entire finite element model. It shows that under the applied loading of 653,000 lbs, the maximum stresses are developed in the tie-down arm near the hole and in the welds. These stresses are much higher than those in the cask outer shell. Therefore, it is concluded that the failure of the tie-down arm under excessive loading will not impair the cask from meeting other requirements of the regulations.

The electronic data used for the above analyses are included in Appendix 1.

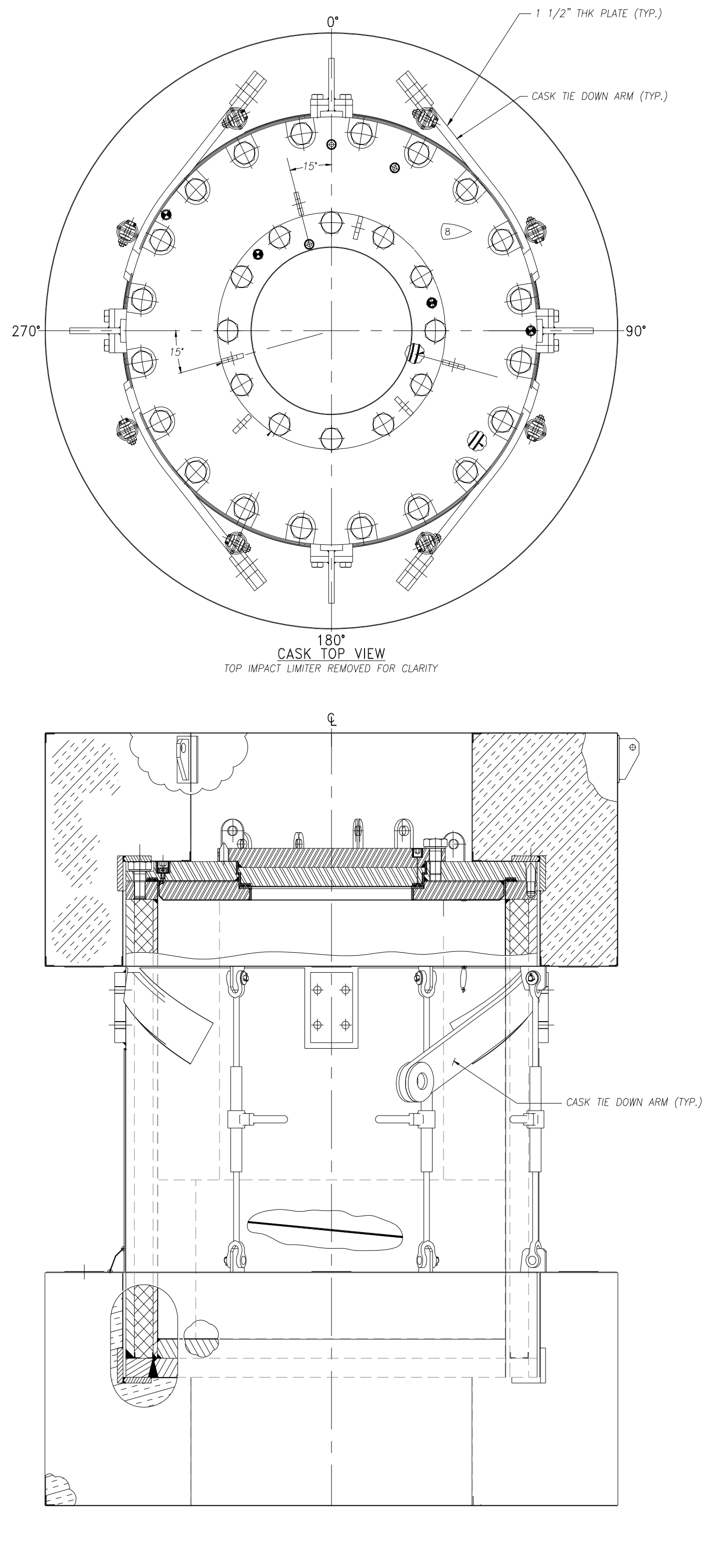
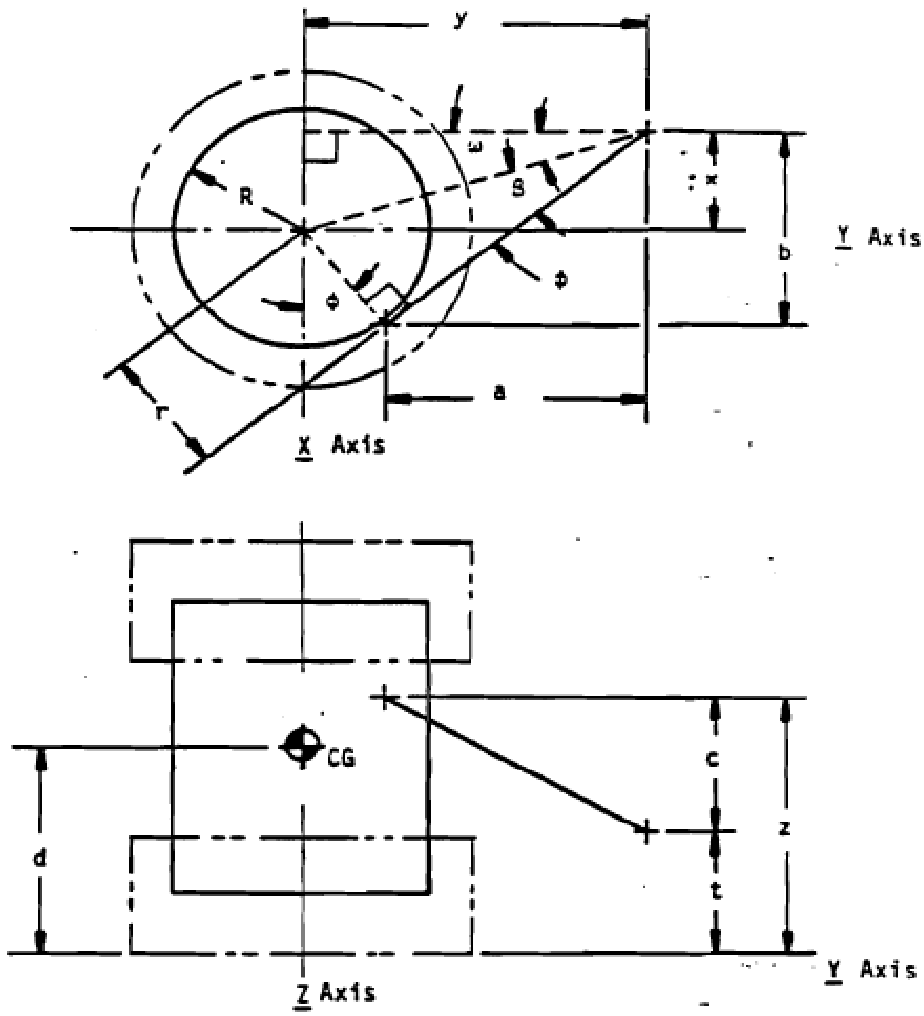


Figure 1: Tie-Down Arms for the 8-120B Cask



R = 36.75 = CASK RADIUS
r = 37.5 = R+ TANGENT OFFSET
d = 62.5 = CASK C.G. ELEV.
t = 37.0 = TRAILER EAR ELEV.
x = 30.0 = Y AXIS OFFSET
y = 96.0 = X AXIS OFFSET
z = 79.0 = CASK TANGENT ELEV.
ω = 17.35° = ATN (x/y)
β = 21.89° = ASN [r/(y/cosω)]
ϕ = 39.25° = ω + β
a = 72.27 = y - rsin ϕ
b = 59.04 = x + rcos ϕ
c = 42.0 = z - t
L = 102.34 = $(a^2 + b^2 + c^2)^{1/2}$

Figure 2: Tie-Down Arms Geometry

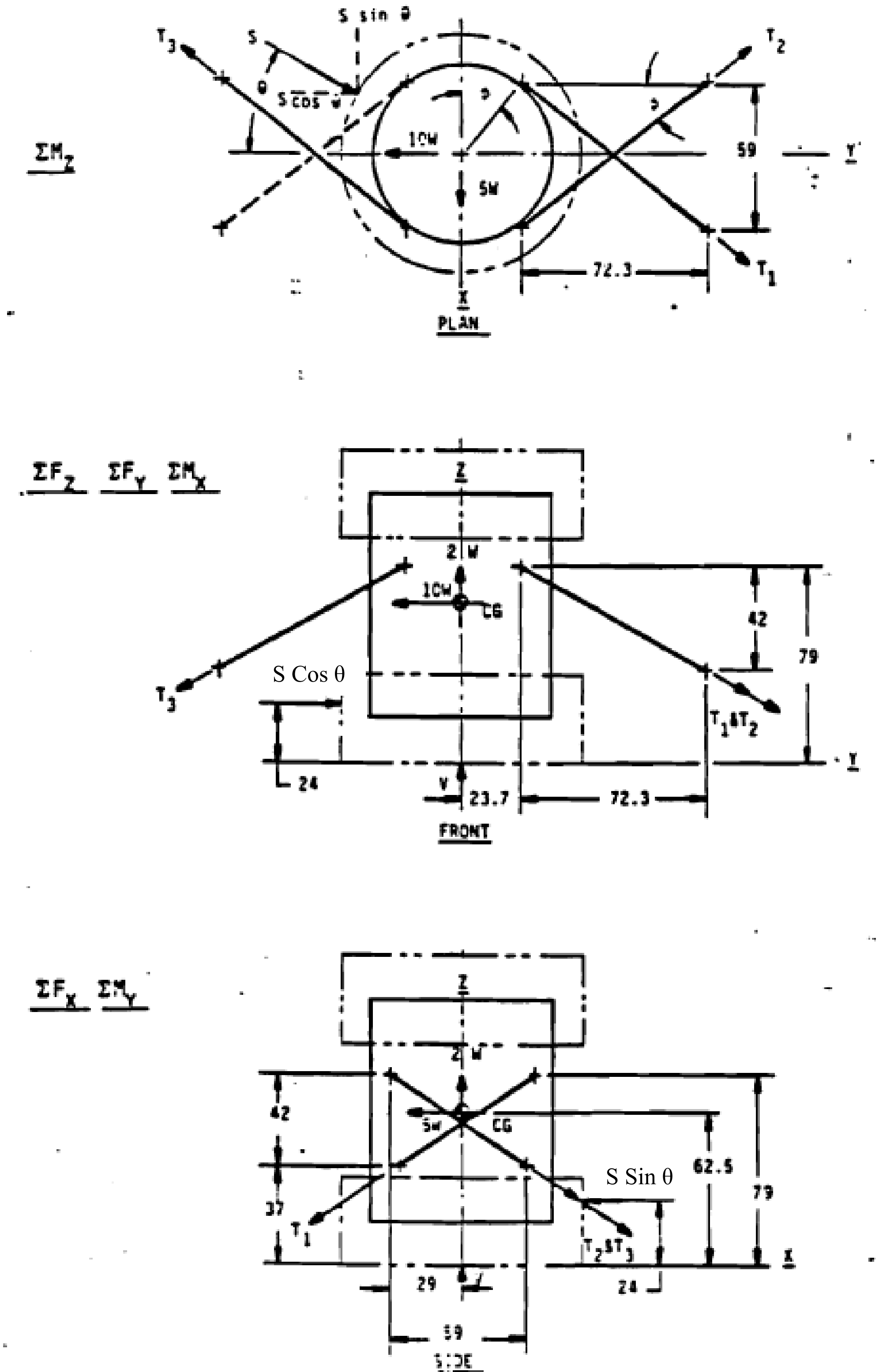


Figure 3: Tie-Down Free body Diagram

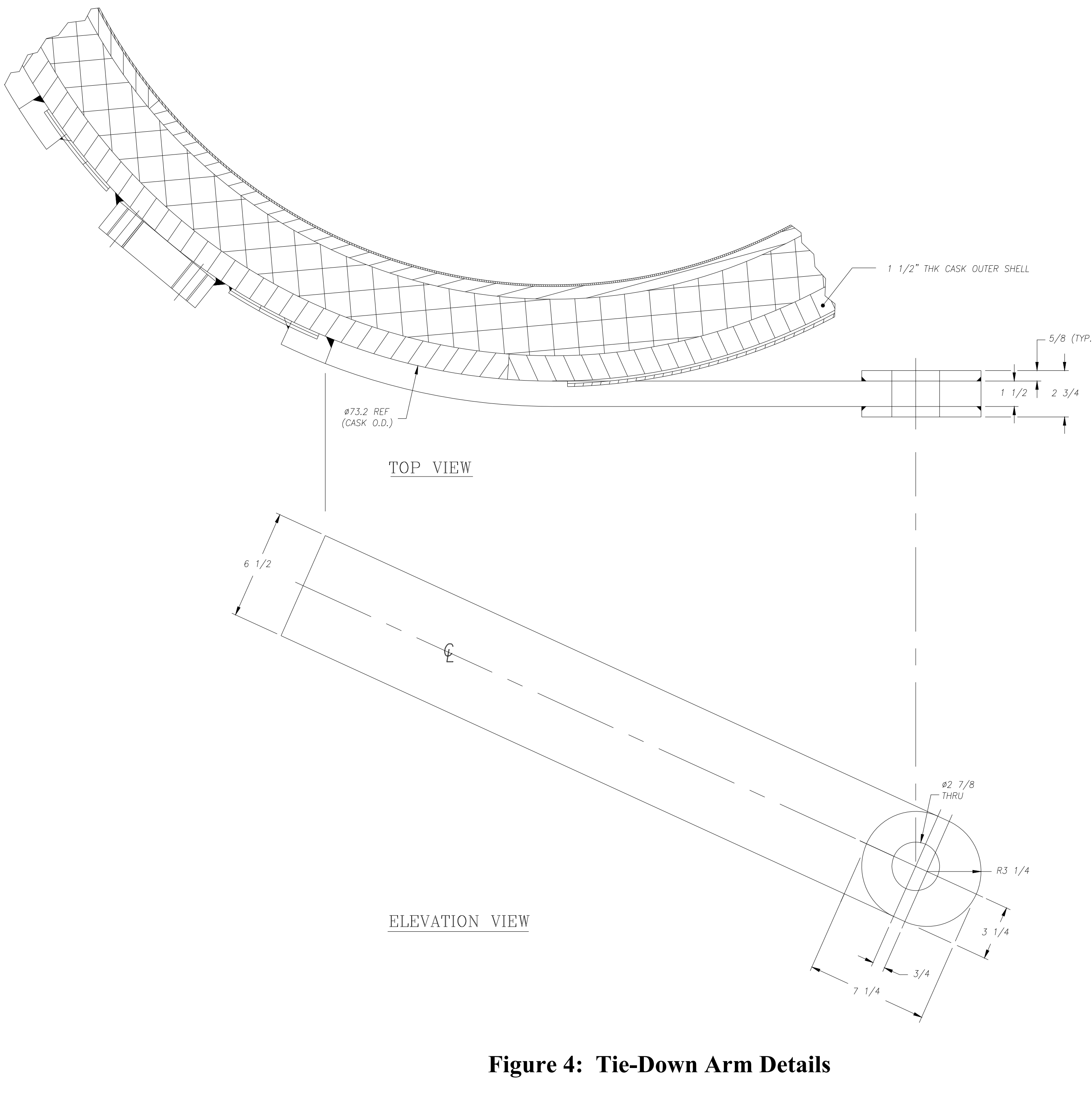


Figure 4: Tie-Down Arm Details

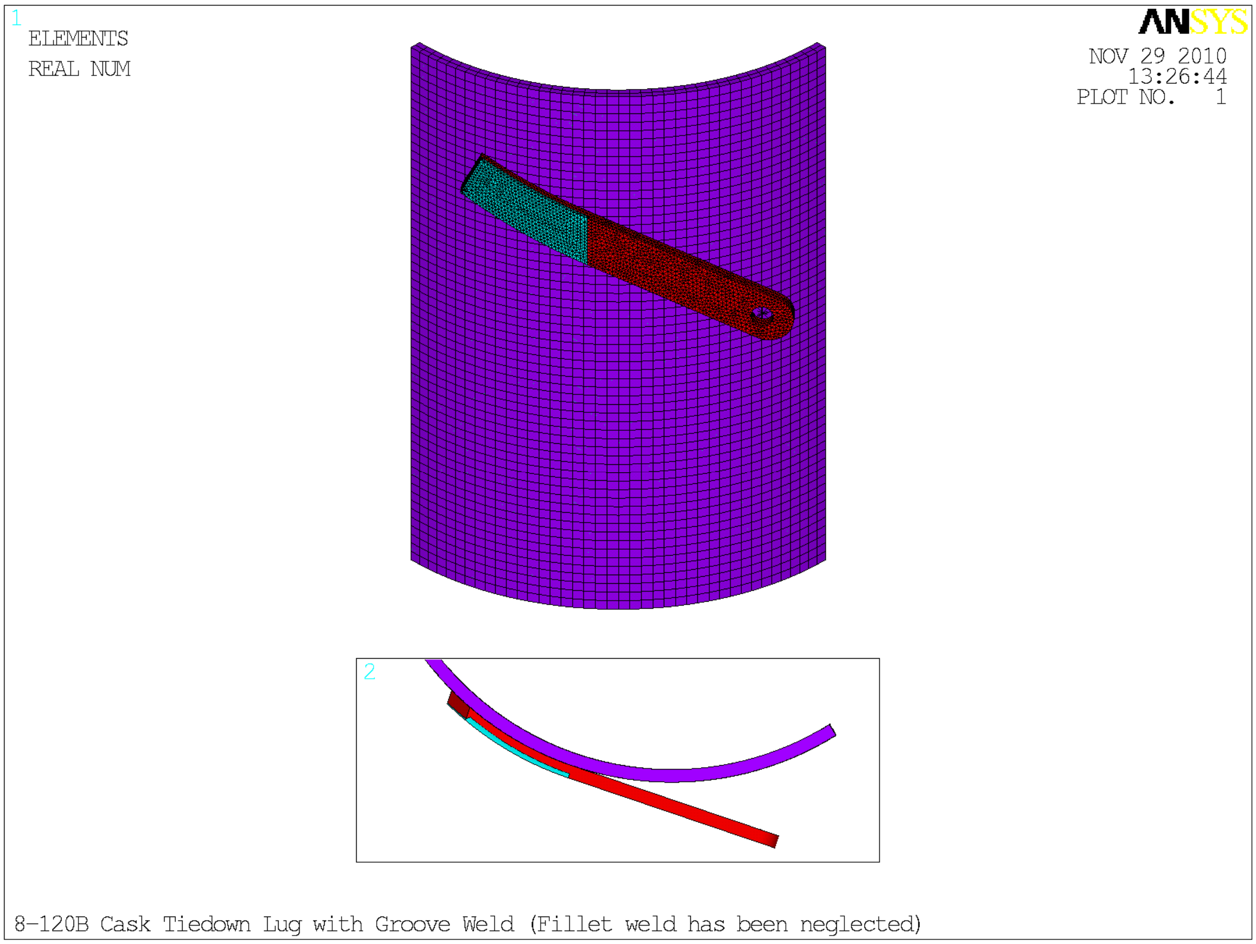


Figure 5: FEM of 8-120B Cask Outer Shell & Tie-Down Arm

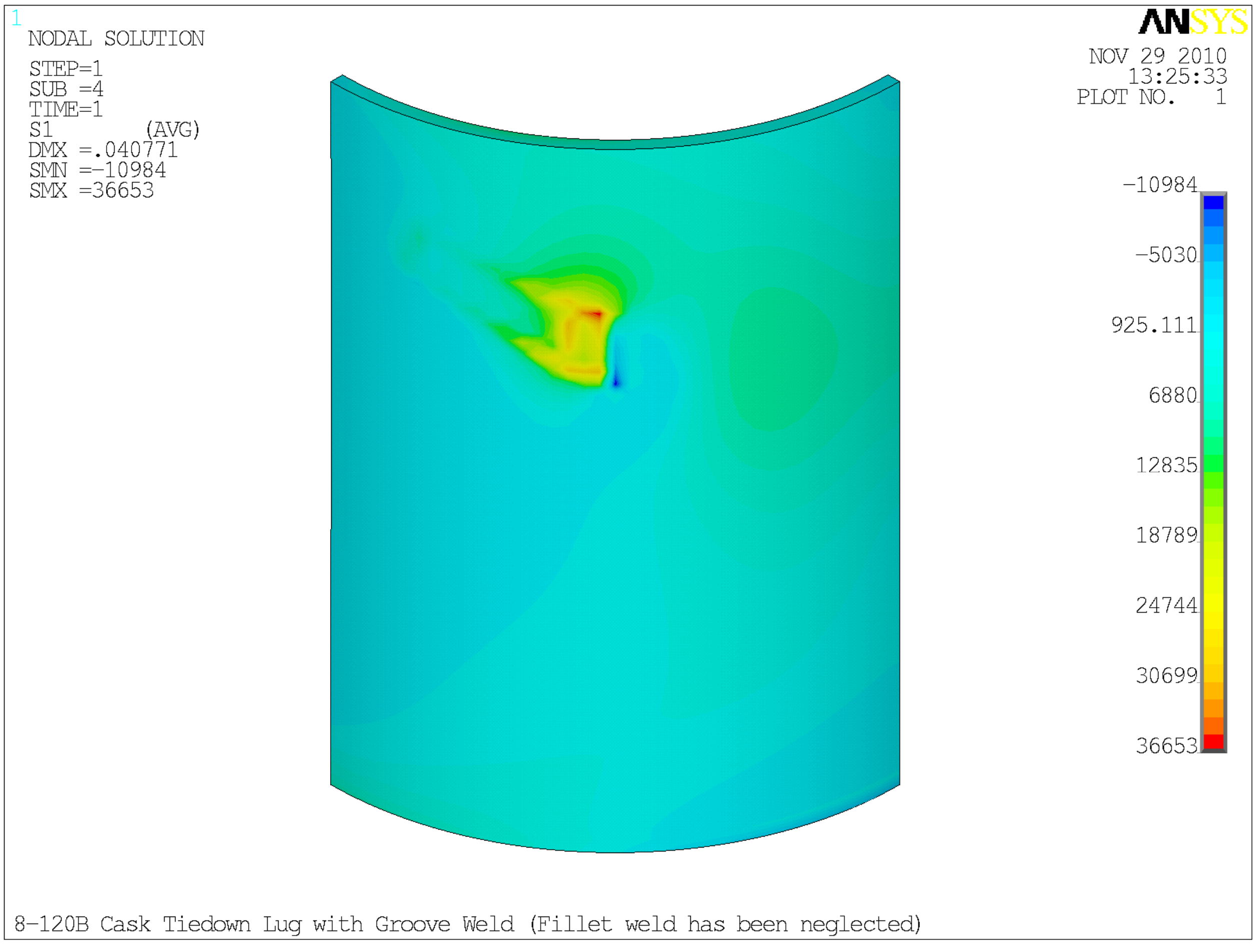


Figure 6: 8-120B Cask Outer Shell Maximum Principal Stress

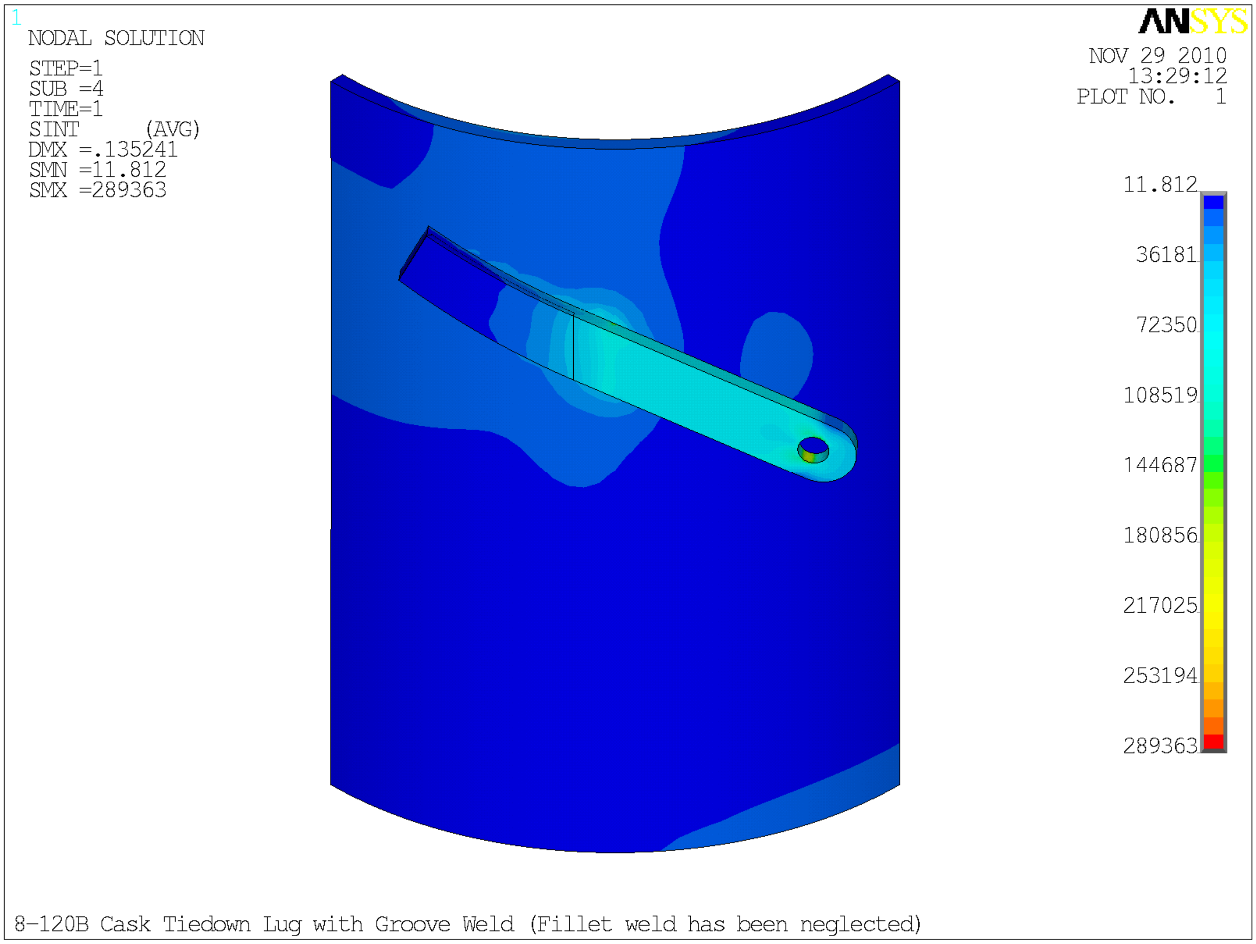


Figure 7: 8-120B Cask Tie-Down Arm Maximum Stress Intensity

Note: The tie-down arm stresses shown in this figure include the local stresses at the point of load application and at the weld termination. The tie-down arms have been analyzed in details in Section 6.4.

Appendix 1

Electronic Data and CD Directory

```
Volume in drive F is My Disc
Volume Serial Number is 3E4F-5D1E

 Directory of F:\

11/15/2010  10:17 AM       112,001,024 file.db
11/15/2010  10:05 AM       284,033,024 file.rst
11/29/2010  01:25 PM           141,455 file013.png
11/29/2010  01:26 PM           139,681 file014.png
11/29/2010  01:29 PM           120,807 file015.png
11/29/2010  01:29 PM        11,269,113 model.out
               6 File(s)    407,705,104 bytes
               0 Dir(s)               0 bytes free
```