LEUPA

Type B(U) Package for Fissile Materials

ANALYSIS OF THE LEUPA PACKAGE RESTRAINT FOR TRANSPORT

Prepared by:
INVAP

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1 PURPOSE

1. Designing a restraint system and evaluating the structural integrity of the LEUPA package subject to acceleration while on transit.

2 SCOPE

1. This document evaluates the status of the load in the restraint elements of the LEUPA package in the event of lateral acceleration. The study is focused solely on accident conditions during transport.

3 APPLICABLE DOCUMENTS

1. APL1 - 0908-LE01-3AEIN-010 "Main Body Packaging".
2. APL2 - 0908-LE01-3BEIN-024 LEUPA - Criticality Analysis.
3. APL3 - 0908-LE01-3AEIN-005 "Container of Internal Containers".
4. APL4 - 0908-LE013AEIN-006 "Cadmium Chamber".

4 REFERENCE DOCUMENTS

1. REF1- Nuclear Regulatory Authority (ARN in Spanish). *Transport of Radioactive Materials.* Standard AR 10.16.1. Rev. 2. Argentina: ARN, 2011.
2. REF2 - ASME. *Power Piping.* ASME B 31.1 – 2007. United States: ASME 2007.
3. REF3 - ASME. *Boiler and Pressure Vessel Code.* ASME II, Part D, Appendix 1, Table 1-100 – 2007. United States: ASME 2007.
4. REF4 - IRAM. *Carbon Steel Plates, Hot Laminated, for* Structural applications. Standard IRAM-IAS U 500-42. Argentina: IRAM,2003.
5. REF5- IAEA. *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Materials.* Safety Guide No. TS-G-1.1 (ST-2). Austria: IAEA, 2008.
6. REF6- Van Beest B.V. Green Pin Catalogue, Sliedrecht: 2014.
7. REF7- Mediterranean Cables. Catalogue of Stainless Steel Cables, http://www.cablesmed.com/.

5 ABBREVIATIONS

Abbreviation	Description
CM	Center of mass
LEUPA	Package for the transport of low-enriched uranium
FM	Fissile Material.

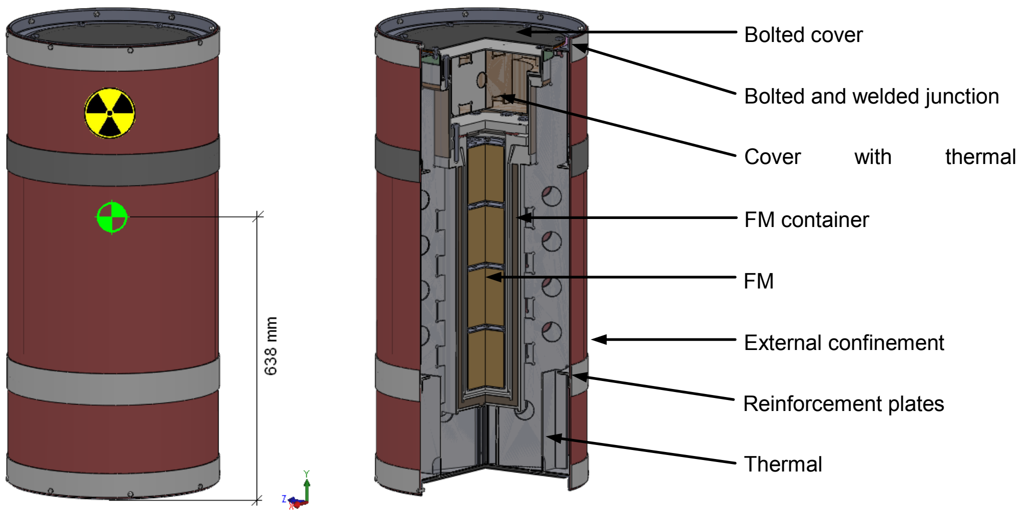
6 INTRODUCTION

6.1 Description of the Package

1. The package is designed for the transport of FM, and shall be equipped to protect the cargo from accidental impacts and high outdoor temperatures.

2. In summary, the package is composed of a double layer stainless steel interior container with cadmium between layers. That is the container with the FM, sealed with a bolted cover.
3. There is an external 3 mm thick stainless steel plate confinement. This confinement is reinforced with L profiles and there are also eight (8) sheets with radial configuration to center the internal container. Empty spaces are filled with thermal insulation material called "kaolite".
4. APL1 contains a list of the elements of the package.

Figura 1: Internal view of the package



6.2 Proposed Restraint

1. We propose a restraint system following the indications in REF5. The package is transported in vertical position with four tensors fixing the upper part of the package anchored to the transport floor, as presented in Figure 2.
2. In the lower part of the package there are four wedges restricting sliding of the base in the horizontal plane.
3. In the upper part of the package there is a restraint cover with four claws to fix the tensors.

Figura 2: Proposed restraint

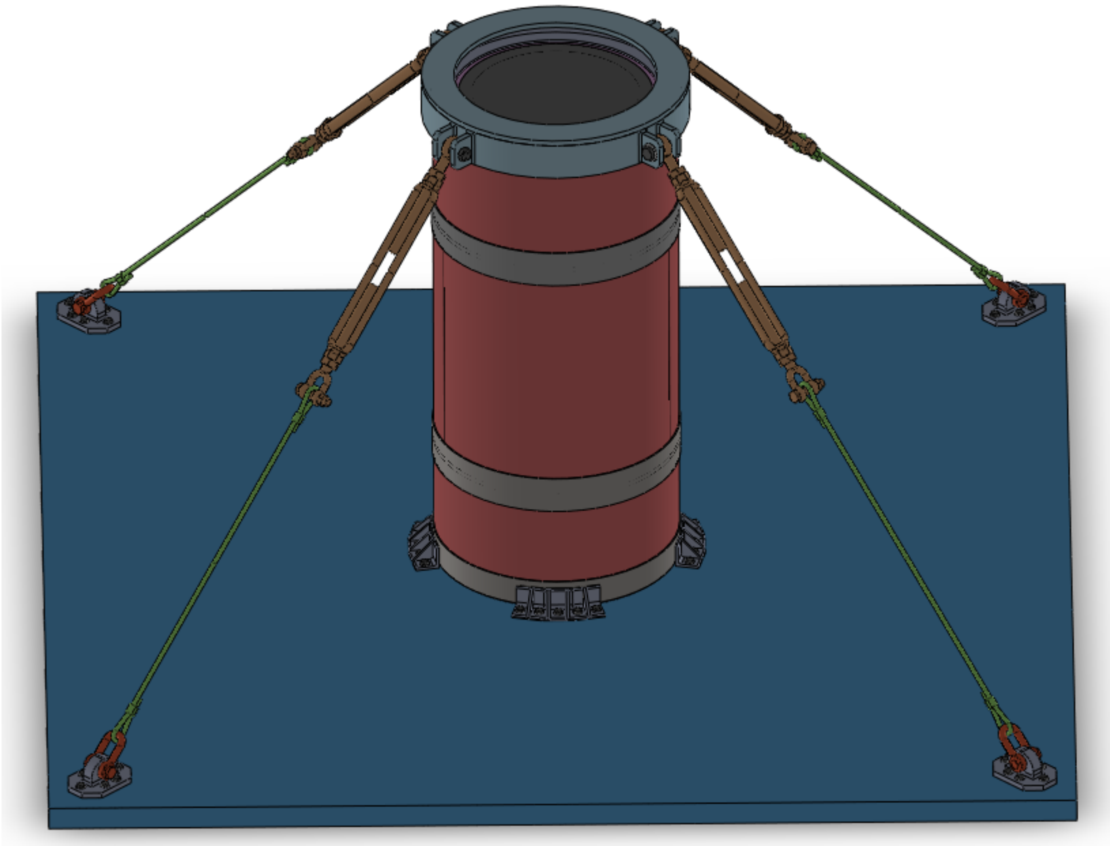
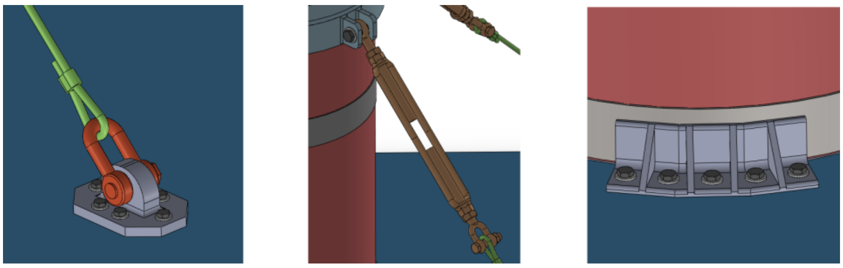


Figura 3: Restraint elements



Anchor **Tensor** **Wedge**

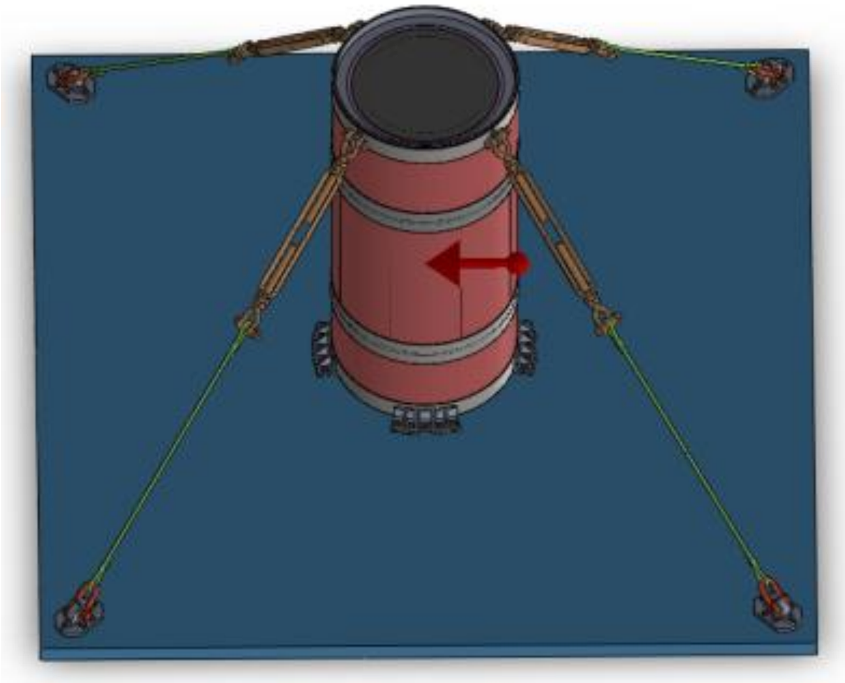
4. The cable, tensor and shackle elements of the restraint system are selected from catalogues. The fitting cover, the anchor and wedge are designed and evaluated specifically for this application.
5. A bolted junction was designed for the wedge and anchor.
6. Each anchor is connected to one of the four claws welded to the fitting cover in the upper part of the package. The claws were also analyzed to verify their stress state.
7. The angle between the tensors is $2\theta = 90°$, and the angle of each tensor with the floor is $\theta = 45°$. The height of the package (where tensors are restrained) is $h = 1150$ mm, and from the base to the center of gravity there is a distance of $q = 638$ mm.
8. The dimensions above shall be used in Appendix 11.1 to calculate the stresses in the tensors and wedge.

6.3 Simplifying hypothesis

6.3.1 Model

1. The evaluated status of the load is for the result of a sudden acceleration during transport. It was assumed that this acceleration acts in the horizontal plane in direction to the bisecting line between two tensors (see Figure 4). There is also the action of gravitational acceleration.

Figura 4: Lateral acceleration during transport



2. It was considered that due to the effect of acceleration, two of the four tensors act symmetrically, in addition to one of the four wedges in the floor.
3. The case was solved through an equivalent static state.
4. The status of the load of the base where the package rests and anchors are bolted is not verified because it is outside the scope of the study elements in this document.

7 MATERIALS

1. According to the APL2 the approximate total mass of the package is 430 kg, and can carry a payload of 50 kg of FM. The materials of the package are those stated in Table 1.

Tabla 1: Materials obtained from APL2.

Material	Approximate Mass [kg]	Density [g/cm^3]
Metallic Uranium	50	18.9
Polyethylene	0.4	0.9
Kaolite 1600	85	0,405
AISI 304L	244	7.9
Cadmium	58	8.65

2. The package is made of type 304L stainless steel, with the properties listed in Table 2, obtained from REF2 (ASME B31.1 Table A-3). The material of which the cover, anchors and wedges are made of is IRAM F36, obtained from REF4 (IRAM-IAS U 500-42:2003).

Tabla 2: Properties of 304L steel

Material	A312-TP304L
Modulus of elasticity (E)	192708 [MPa]
Yield Strength (Sy)	172.3 [MPa]
Tensile Strength (Sr)	482.6 [MPa]
Poisson (Linear Elasticity Period)	0.3

Tabla 3: Properties of IRAM F36 steel

Material	A312-TP304L
Modulus of elasticity (E)	210000 [MPa]
Yield Strength (Sy)	360 [MPa]
Tensile Strength (Sr)	500 [MPa]
Poisson (Linear Elasticity Period)	0.3

3. The calculation of admissible stress is determined according to the criteria in REF1. For the package material (304L), the calculation is as follows:

$$S_a = \min\left(\frac{S_u}{4};\frac{S_y}{1,5}\right) = 114\ [MPa]$$

4. For the material of the anchor plates and wedges (F36), the calculation is as follows:

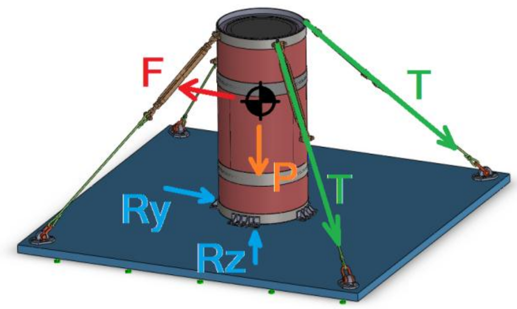
$$S_a = \min\left(\frac{S_u}{4};\frac{S_y}{1,5}\right) = 125\ [MPa]$$

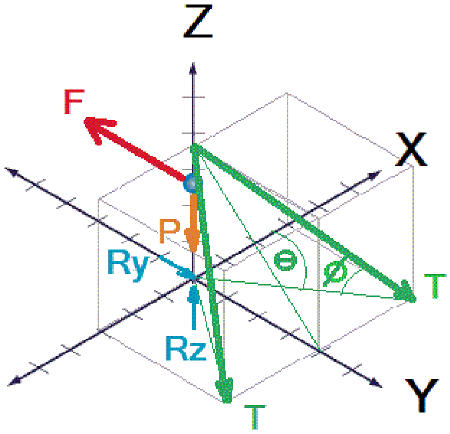
8 STATUS OF THE LOAD

8.1 Lateral Acceleration

1. According to REF. 5 the maximum lateral acceleration value is 10G. That acceleration applied to the package produces the "T" stresses in two of the tensors and the reaction the "Ry" active wedge. Gravitational acceleration produces the "P" force that is compensated by the "Rz" reaction of the floor.

Figura 5: Acting forces and phase diagram





8.2 Reaction in Tensors and Wedge

1. Breaking down the forces of the phase diagram and solving the equations system composed of the momentum balances and forces on each axis, the "T" force in tensors and reaction in "Ry" active wedge is obtained.
2. The equations system resulting from the forces equilibrium is as follows:

$$\Sigma Fx \Rightarrow 0 \; (by \; symmetry)$$
$$\Sigma Fy \Rightarrow \; 0 = -F + 2 \times T \times \cos\theta \times \cos\emptyset + Ry$$
$$\Sigma Fz \Rightarrow \; 0 = -2 \times T \times \cos\theta - P + Rz$$
$$\Sigma Mx \Rightarrow 0 = (2 \times T \times \cos\theta) \times r - Ry \times q$$

   Where:

   q Is the distance from the base to the center of gravity of the package.

   r Is the minimum distance of the center of gravity to the tensor $r = (h - q) \times \cos\emptyset$.

3. The equations system is solved in Appendix I and the results are summarized in the following table:

Tabla 4: Results of forces

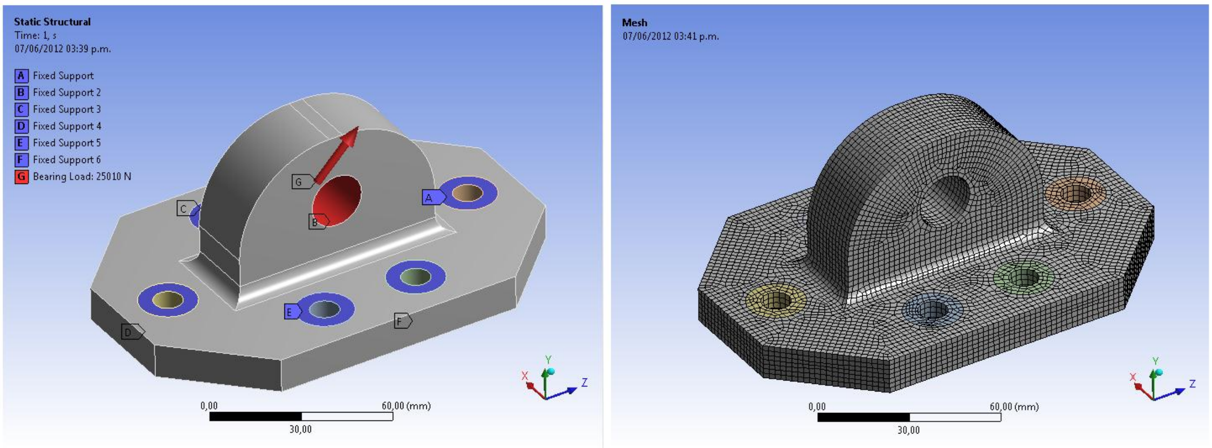
Force	Value [N]
T (force on each tensor)	25010
Ry (horizontal reaction on wedge)	20070
Rz (vertical reaction on the floor)	39877

9 RESULTS

9.1 Verification of Anchors

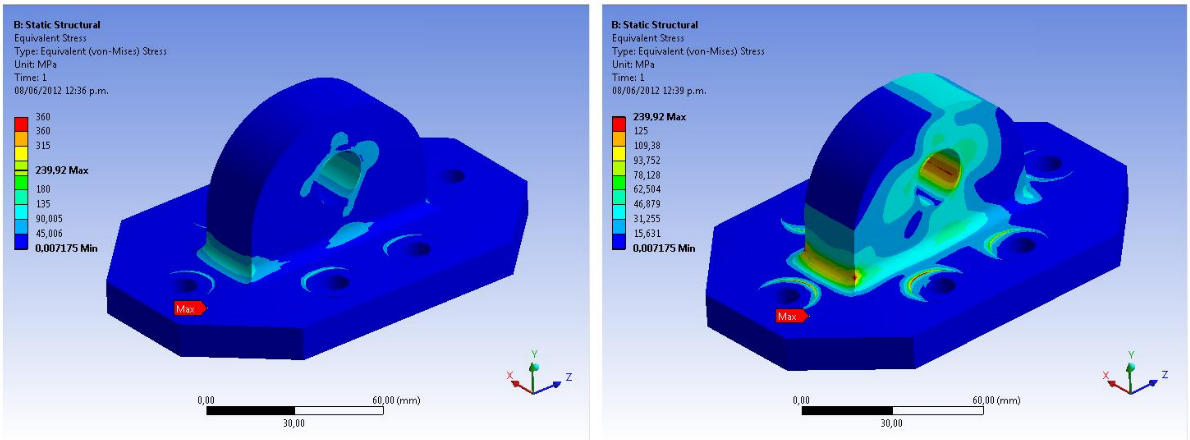
1. The stress state of one of the two active anchors was studied, subject to a "T" tension in the cable of 25 [kN].

Figura 6: Status of the load and meshing of the anchor



2. The results obtained are presented in Figure 7. The colored map indicating the stress state that has the yield strength of material F36 as limit scale in the first image, and the admissible strength in the second image.

Figura 7: Stresses in the anchorage system



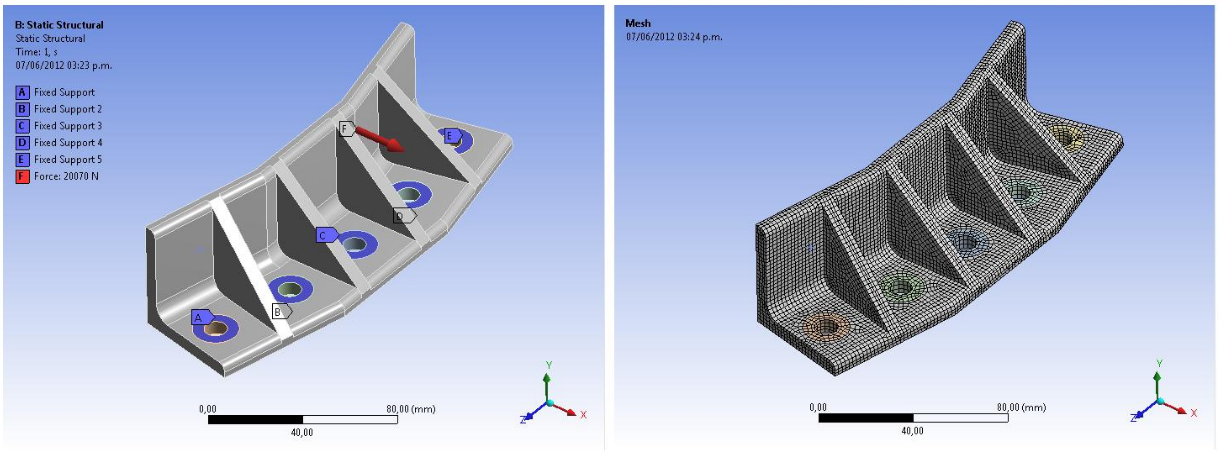
Limite de escala: Tension de fluencia (360 MPa)

Limite de escala: Tension de admisible (125 MPa)

9.2 Verification of Wedge

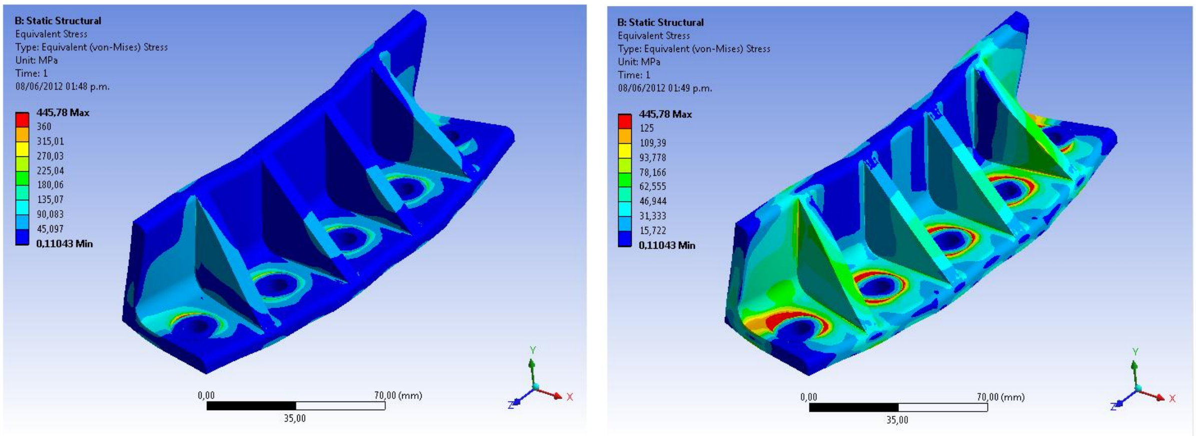
1. The stress state of the active wedge, subject to a horizontal "F" force of 20 [kN] was studied.

Figura 8: Status of the load and meshing of the wedge



2. The results obtained are presented in Figure 9. The colored map indicating the stress state that has the yield strength of material F36 as limit scale in the first image, and the admissible strength in the second image.

Figura 9: Stresses in the wedge



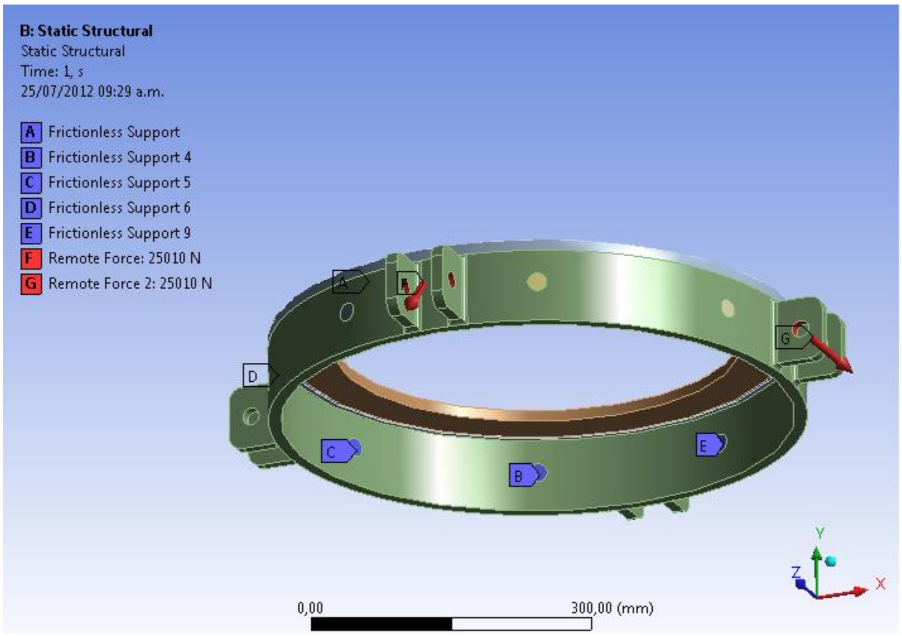
Limite de escala: Tension de fluencia (360 MPa)

Limite de escala: Tension de admisible (125 MPa)

9.3 Verification of the Package's Restraint Cover

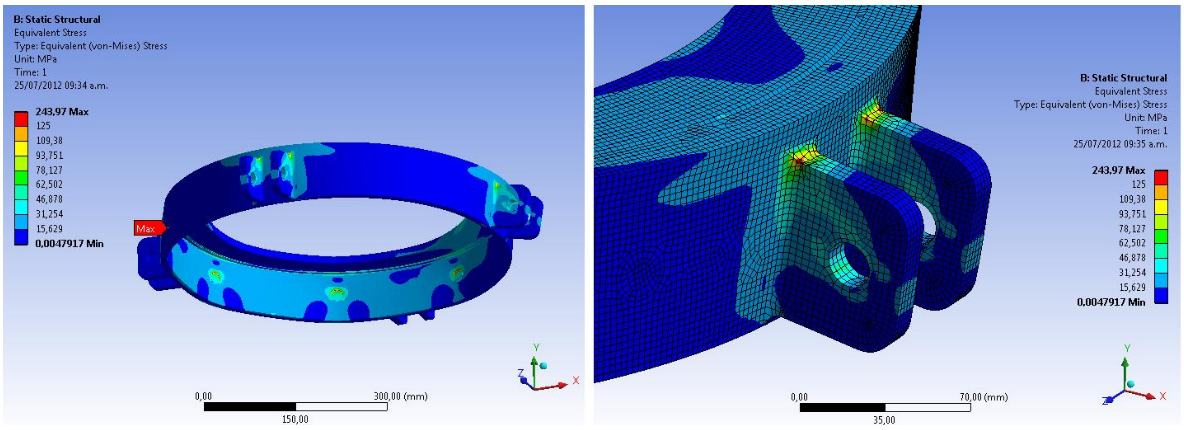
1. The stress state of one of the two active claws was studied, subject to a "T" tension in the cable of 25 [kN].
2. The contact of the fitting cover with the package is through the upper edge of the L profile. The heads of the bolts in the upper part of the package also make contact with the interior cylindrical face of the fitting cover. The contacts above were identified in the model as support without friction.
3. In the event of an accident here the forces indicated in Table 4 on the package, only two of the four claws act. Also, the fitting cover rests on the package and on the heads of four of the eight circumferential bolts of the container. See Figure 10.

Figura 10: Studied status of the load of the fitting cover



1. The results obtained are presented in Figure 11. The colored map indicating the stress state that has the yield strength of material F36 as limit scale.
2. The highest stresses are in the surface of the cover where the bolt heads rest, and the upper part of the welding of the claws.
3. The highest stress value recorded is approximately 240 [MPa] in the support surfaces of the heads of the bolts of the container.

Figura 11: Stresses in the claw

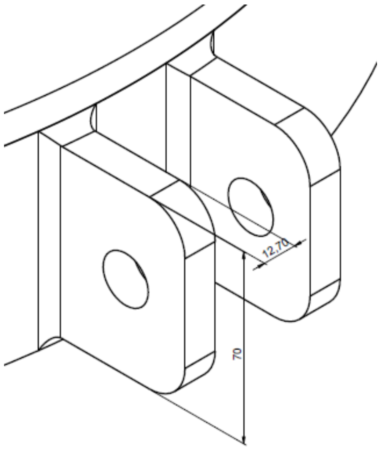


9.4 Verification of Weldings

1. The status of the claws welded to the cover, where tensors are fitted, was verified. The admissibility criteria assumed for the stresses in the welding is that indicated in REF1, based on the properties of the base metal obtained as:

$$S_{asol} = \min\left(\frac{0,85}{3,5} \times Su;\ \frac{2}{3} \times 0,85 \times Sy\right)$$

2. It was assumed that the welding of the fillet of claws is full penetration weld.



$$T = 25\ [kN]$$
$$A = 2 \times (70 \times 12{,}7) = 1778\ [mm]$$

$$S = \frac{T}{A} = 14\ [MPa]$$
$$S_{asol}(304L) = 97{,}63\ [MPa]$$

$$\boldsymbol{FS = \frac{S}{S_{adm_{sol}}} \times 100 = 14}\ [\%]$$

3. The service factor for the area of wildings is approximately 14%.

9.5 Verification of Bolts

1. It was verified that the status of bolts upon cutting and crushing both for those of the active wedge as that of the anchors. Bolts selected for these applications are M10-type, 8.8 quality.
2. Said bolts have a shear resistance of 3478 [kg/cm^2], and crushing resistance of 2239 [kg/cm^2].

Tabla 5: Applied loads and characteristics of the bolts

Junction	Plate [cm]	Loads		Bolts			
		Applied Force [N]	Applied Force [kgf]	Diameter (D) [cm]	Area (A) [cm^2]	Amount Bolts (CB)	Cross Sections (PC)
Wedge	0.95	20070	2048	1.00	0,785	5	1
Anchor	0.95	25010	2552	1.00	0,785	6	1

Tabla 6: Verification of bolts

Verif. of Shear resistance			Verif. of Crushing		
Shear Strength (TC=FA/CB*PC*A) [kgf/cm^2]	τ adm [kgf/cm^2]	Service Factor (FS=TC/ τ adm)	σ apl (σ apl=FA/CB*D*esp) [kgf/cm^2]	$\sigma\ apl_{adm}$ [kgf/cm^2]	Service Factor (FS= σ apl/ $\sigma\ apl_{adm}$)
522	3478	0.15	431	2239	0.19
542	3478	0.16	448	2239	0.20

9.6 Selection of Sling Components

1. The general selection criteria of the sling elements was the resistance of each one specified by the manufacturer. We searched for components available in the market, which are presented in the following sections.

9.6.1 Shackle

1. The selected shackle is highlighted and supports a maximum work load of 3250 [kg] (31.8 [kN]). That resistant capacity provides the shackle a 78% service factor when subject to the maximum stress.

Fiaura 12: Selection of shackle (imaae extracted from REF6)

Security-Related Information Figure Withheld Under 10 CFR 2.390.

9.6.1 Tensor

1. The selected tensor is highlighted and supports a maximum work load of 3270 [kg] (32.0 [kN]). That resistant capacity provides the tensor a 78% service factor when subject to the maximum stress.

Figura 13: Selection of tensor (image extracted from REF6)

Security-Related Information Figure Withheld Under 10 CFR 2.390.

9.6.1 Cable

1. The selected cable is highlighted and supports a maximum work load of 5670 [kg] (55.5 [kN]). That resistant capacity provides the cable a 45% service factor when subject to the maximum stress.

Figura 14: Selection of cable (image extracted from REF6)

STAINLESS STEEL WIRE AISI 316
MINIMUM BREAKING LOAD

NOMINAL DIAMETER	1x19+0 standard	7x19+0 standard	7x7+0 standard	Dyform 1x19+0
mm	kgf	kgf	kgf	kgf
2	320	226	242	----
2,5	500	355	----	690 (1)
3	720	510	545	1.000 (1)
4	1.280	907	968	1.780 (1)
5	2.000	1.420	1.510	2.440
6	2.880	2.040	2.180	3.550
7	3.550	2.780	2.970	4.910
8	4.640	3.630	3.870	6.150
10	7.250	5.670	6.050	9.770
11	8.770	----	----	12.100
12	10.400	8.160	8.710	14.400
14	14.180	11.100	11.900	19.300 (2)
16	18.560	13.600	----	25.600 (2)
19	21.620	----	----	32.000 (3)
22	29.070			
26	40.600			

2. Within the alternatives for cables in figure 14 the one with the most (and thinner) wires was selected due to its higher flexibility for manipulation.

9.7 Comments on the Results

1. Of the verified elements, the most compromised are the wedge and claws. In the case of the wedge, Figure 9; it is evaluated if the stress state using the stress state as the scale limit it can be observed that this value is practically not exceeded.
2. Given that the analyzed status of the load results from an accidental case, even though admissible stresses are exceeded to a certain extent, the element will not collapse or suffer relevant plastic deformations.
3. The 10G acceleration introduced to the studied model will cause damages to the transport vehicle but not the package or the sling elements.
4. Likewise, if we analyze the stress result of one of the claws we observe that there will be a small plastic deformation but no release or tearing.
5. Given the that this element is more compromised, the stress state of the welding was proved in section 9.4, and it was observed that half the admissible stress of the base material is not reached.

10 CONCLUSIONS

1. Under the stated conditions, the geometric characteristics and properties of the stated materials, the conclusions are as follows:
   a. Based on the results obtained, the selected sling elements verify the status of the load.
   b. For the analyzed status of the load, the sling elements designed verify the status of the load and are those described in section 11.2.

11 APPENDIXES

11.1 Calculation of Forces

1. Below is the calculation of stresses and forces of the phase diagram in Figure 5

▪ **Equilibrio de fuerzas en sujecion de contenedor LEUPA**

```
In[1]:= Clear["Global`*"]

In[2]:= (*DATOS DE ENTRADA*)
        m = 460;      (*masa contenedor [kg]*)
        g = 9.8;      (*aceleracion gravitatoria [m/s^2]*)
        a = 10×g;     (*aceleracion maxima [m/s^2]*)
        ϕ = 45×π/180; (* angulo de tensor con plano plataforma[-]*)
        θ = 45×π/180; (* angulo de tensor con plano de fza[-]*)
        h = 1.150;  (*altura del contenedor [m]*)
        q = 0.638;  (*distancia base-CG [m]*)
        p = h - q;  (*distancia tapa-CG [m]*)
        r = p×Cos[ϕ];   (*minima distancia linea de tensor-CG [m]*)

In[10]:= (*FUERZAS POR ACELERACIONES*)
         F = m×a      (*Fueza por aceleración [N]*)
         P = m×g      (*Peso [N]*)

Out[10]= 45080.

Out[11]= 4508.

In[12]:= (*RESOLUCION DE EQUILIBRIO DE FUERZAS*)
         Solve[{0 == -F + 2×T×Cos[ϕ]×Cos[θ] + Ry,     (*Sumatoria de fuerzas en Y*)
           0 == -2×T×Cos[θ] - P + Rz,      (*Sumatoria de fuerzas en Z*)
           0 == (2×T×Cos[θ])×r - Ry×q}, {T, Rz, Ry}]     (*Sumatoria de momentos en plano Y-Z*)

Out[12]= {{T → 25009.6, Rz → 39876.9, Ry → 20070.4}}
```

11.2 Main Measurements of Sling Pieces Designed

11.2.1 Anchor

Security-Related Information Figure Withheld Under 10 CFR 2.390.

11.2.2 Wedge

Security-Related Information Figure Withheld Under 10 CFR 2.390.

11.2.3 Fitting Cover

Security-Related Information Figure Withheld Under 10 CFR 2.390.