Appendix D – Revised Conceptual Cradle Design Family 4

APPENDIX D.1 DRAWINGS

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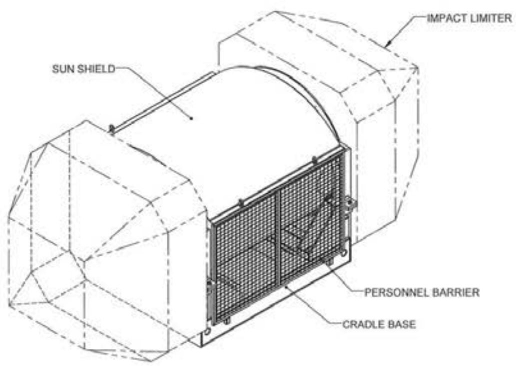
DWG NO 3015140 REV 1 SH 1

NOTES, UNLESS OTHERWISE SPECIFIED:

1. CONCEPTUAL DESIGN ASSUMES ALL WELDS ARE FULL PENETRATION UNLESS OTHERWISE NOTED. ALL WELDS WILL BE FURTHER SPECIFIED IN A FINAL DESIGN.
2. WELDING SHALL BE PERFORMED IN ACCORDANCE WITH AWS D1.1.
3. DIMENSIONS WITH TOLERANCES SPECIFIED ARE RAILCAR INTERFACE DIMENSIONS AND SHOULD BE CONSIDERED DURING FINAL CRADLE DESIGN.
4. ALL SURFACES OF THE CRADLE WELDMENT, EXCEPT FOR PIN HOLES, PINS AND THREADED HOLES, SHALL BE BLAST CLEANED PER SSP-SP-10 AND COATED WITH SELF-PRIMING ENAMEL, 2 COATS WITH A DRY FILM THICKNESS OF 4 TO 6 MILS PER COAT. THE NON-PAINTED CRADLE WELDMENT SURFACES SHALL BE LIGHTLY COATED WITH NUCLEAR GRADE "NEVER-SEEZ" GREASE.
5. ATTACHMENTS FOR PERSONNEL BARRIER TO THE CRADLE ARE TO BE DEFINED DURING THE FINAL DESIGN.
6. THE ADDITION OF ALIGNMENT MARKS BETWEEN THE CRADLE AND RAILCAR INTERFACE SHOULD BE CONSIDERED IN THE DETAILED DESIGN TO SUPPORT LOADING OPERATIONS.
7. ALTERNATE MATERIAL (PLATE, BAR, OR FORGING) HAVING THE SAME CHEMICAL COMPOSITION WITH MECHANICAL PROPERTIES EQUAL TO OR GREATER THAN THOSE SPECIFIED MAY BE USED WITH THE APPROVAL OF THE DESIGN AUTHORITY.
8. ALL FILLETS OR INTERNAL RADII AND OUTSIDE CORNERS SHALL BE NO GREATER THAN 0.12 IN. UNLESS OTHERWISE SPECIFIED.
9. A SET OF LIFTING LINKAGE SHALL BE USED FOR VERTICAL LIFTING AT THE FOUR LIFTING POINTS PROVIDED.

LIST OF MATERIALS

QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION
	A1		MP187 CRADLE ASSEMBLY	
44	1		PLATE, 1 THK	ASTM A572, GR 50 OR EQUIV
2	2		W18X119	ASTM A992
4	3		PLATE, 6.0 THK	ASTM A514
1	4		PLATE, 6.0 X 23.3 X 22.4	ASTM A514
4	5		PLATE, 3 1/2 THK	ASTM A572, GR 50
16	6		PLATE, 1 1/2 THK	ASTM A572, GR 50
4	7		PLATE, 2 THK	ASTM A572, GR 50
4	8		PLATE, 1/2 THK	ASTM A572, GR 50
2	9		RUBBER, 1 THK	80 DURO
4	10		SQ BAR, 6 X 6 X 8	ASTM A514
6	11		RUBBER, 1/2 THK	80 DURO
3	12		PLATE, 1/4 THK	ASTM A572, GR 50
4	13		SIDE SCREEN MESH, 50% OPEN AREA	STAINLESS STEEL
4	14	2994T69	HOIST RING, 3/4-10 UNC, 5000 WLL	McMASTER-CARR OR EQUIV
	15		DELETED	
4	16		BUILD-UP ANGLE, 6 X 8 X 1.5	ASTM A572, GR 50
6	17		PLATE, 1 THK	ASTM A514
12	18	98404A515	BALL LOCK PIN, Ø.50 X 3.5 LG	McMASTER-CARR OR EQUIV
4	19		BAR, Ø2.5 X 10.5 LG	ASTM A311, GR 1144 CLASS B
4	20	91268A958	HEX BOLT, 1 1/2-6 UNC X 5 LG	McMASTER-CARR OR EQUIV
4	21	94895A041	HEX NUT, 1 1/2-6 UNC	McMASTER-CARR OR EQUIV
AR	22		TUBE, 2 X 2 X .125 WALL	STAINLESS STEEL
4	23		BAR, Ø6.5	ASTM A276, TYPE 304
2	24		W16X57	ASTM A992
4	25		PLATE OR SQ BAR, 1 1/2 X 1 1/2 X 2 LG	ASTM A572, GR 50
4	26		PLATE OR SQ BAR, 2 X 2 X 3.8 LG	ASTM A572, GR 50
4	27		TUBE, 3 X 3 X 1/4 WALL	ASTM A500



ISOMETRIC VIEW

AREVA Federal Services
APR 13, 2017
Records Management

REV	DESCRIPTION	DRAWN	CHECKER	VERIFIED
1	SEE ECN NO. 3015140R0-E1	R. LE 4/04/17	4/12/17	4/12/17

REVISION HISTORY

	NAME/SIGNATURE	DATE
EM	D. H[illegible]	4/12/17
RE	D. WICK	4/6/2017
TECH CHK	S. KLEIN	4/6/2017
DFTG CHK	T. LE	4/6/2017
DRAWN	R. LE	4/04/17

NEXT ASSY: NA | FINAL ASSY: NA

THIRD ANGLE PROJECTION

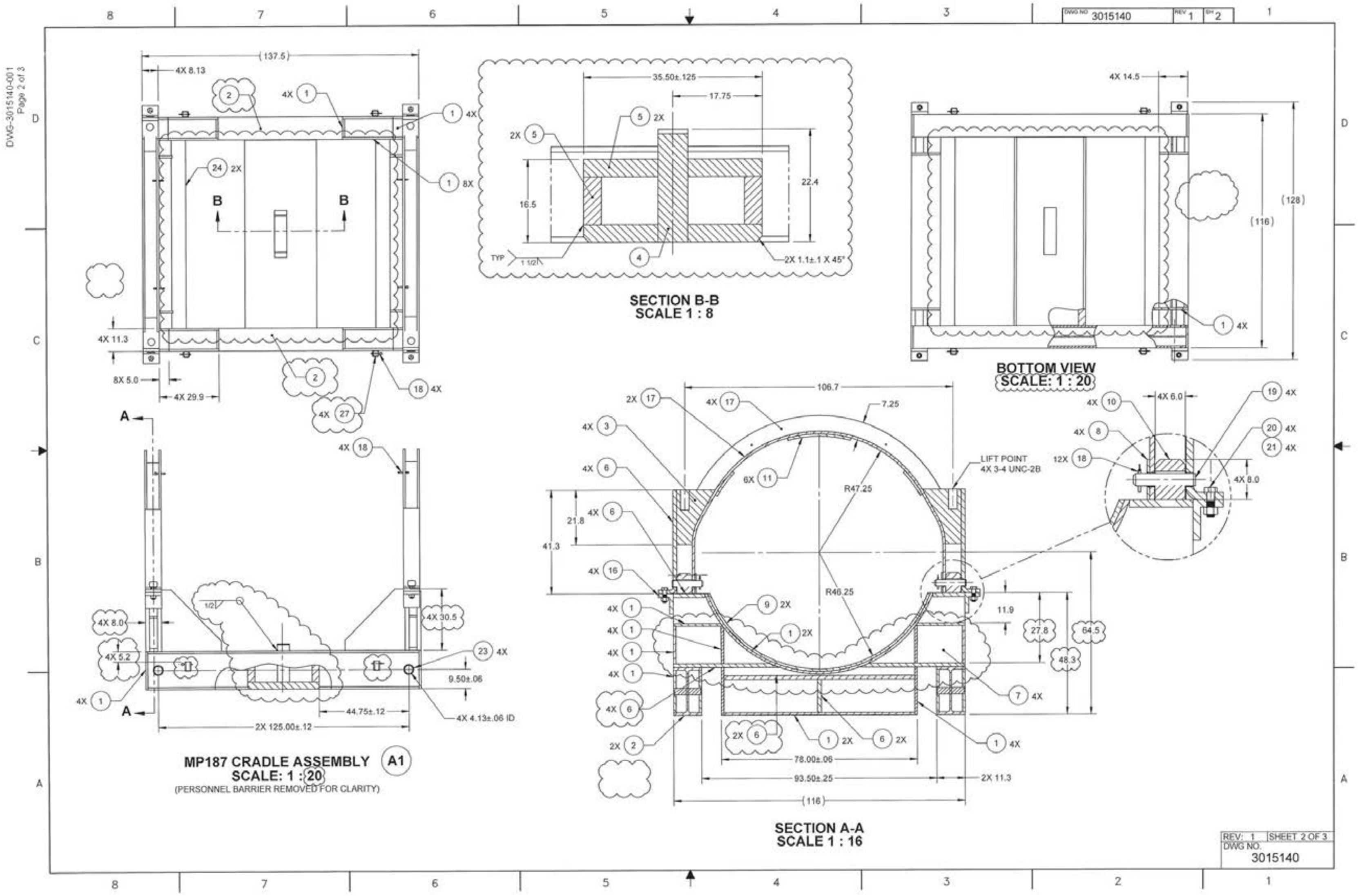
UNLESS OTHERWISE SPECIFIED:
INTERPRET DRAWINGS & TOLERANCES PER ASME Y14.5-2009 (REVISION OF ASME Y14.5M-1994)
INTERPRET WELD CALLOUTS PER ANSI/AWS A2.4
DIMENSIONS ARE IN INCHES

AREVA

AREVA Federal Services LLC
Packaging Projects
Federal Way, WA 98003

DWG TITLE
ATLAS RAILCAR CRADLE FAMILY 4
CONCEPTUAL DRAWING

SCALE: SHOWN | WT. ~ LBS
REV: 1 | SHEET 1 OF 3
DWG SIZE: D | DWG NO. 3015140
CADFILE: 3015140-1.SLDDRW
DWG-3015140-001


DWG-3015140-001
Page 2 of 3
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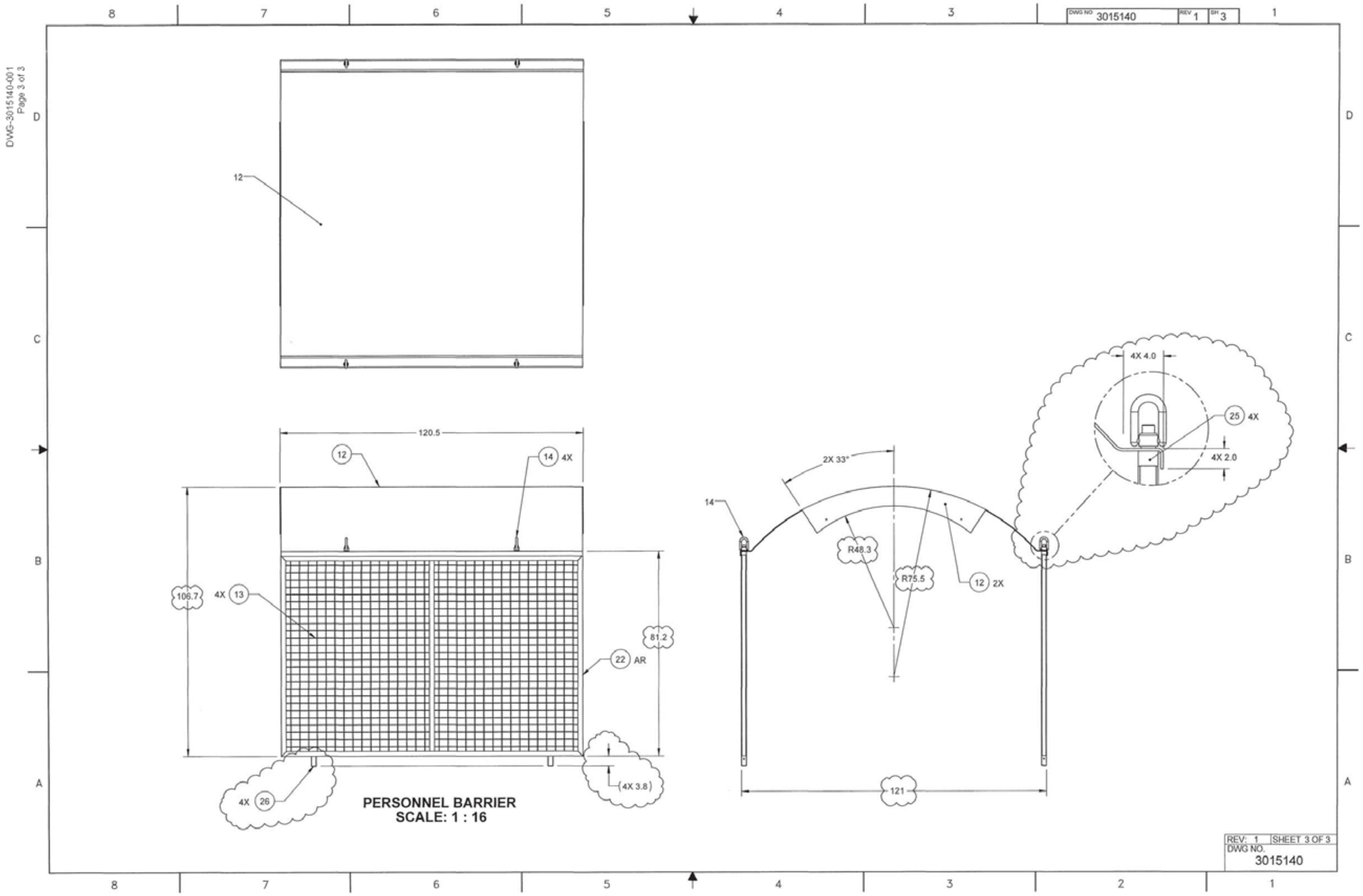
SCALE: 1 : 20
(PERSONNEL BARRIER REMOVED FOR CLARITY)
SECTION B-B
SCALE 1 : 8
BOTTOM VIEW
SCALE: 1 : 20
SECTION A-A
SCALE 1 : 16
LIFT POINT
4X 3-4 UNC-2B
REV: 1
SHEET 2 OF 3
DWG NO.
3015140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Page 3 of 3
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106.7
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14 4X
81.2
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4X 3.8
2X 33°
R48.3
R75.5
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4X 4.0
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121
PERSONNEL BARRIER
SCALE: 1 : 16
REV: 1 SHEET 3 OF 3
DWG NO.
3015140

APPENDIX D.2 CALCULATIONS

CALC-3015136-001
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AREVA	AREVA Federal Services LLC
	CALCULATION

Document No.:	CALC-3015136	Rev. No.	001	Page 1 of 32
Project No.:	00225.03.0050	Project Name:	DOE Atlas Railcar	
Title:	Atlas Railcar Family 4 Conceptual Cradle Structural Calculation			

Summary:

The Atlas Railcar Family 4 Cradle Assembly conceptual design has been evaluated in this document. As the result of this evaluation, it is found that the design is structurally sound and it can withstand all the loads in accordance with the DBRD [2]. This calculation is not safety related.

Contains Unverified Input / Assumptions: Yes: ☐ No: ☒

Software Utilized: MS Excel Software Active in AFS EASI: Yes: ☐ No: ☒ Error Reports & Associated Corrective Actions Reviewed: Yes: ☐ No: ☒	Version: 2010	Storage Media: Yes: ☒ No: ☐ Location: COLDstor

	Printed Name	Signature	Date
Preparer:	D. Wick	[signature]	4/3/2017
Checker:	A. Merlin	[signature]	4/3/2017
Approver:	D. Hillstrom	[signature]	4/12/17
Other:	S. Klein	[signature]	4/12/17

AFS-EN-FRM-002 Rev. 07 (Effective April 21, 2015)
Reference: AFS-EN-PRC-002

AREVA

AREVA Federal Services LLC

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-001

Project: 00225.03.0050 - DOE Atlas Railcar **Page 2 of 32**

Revision History

Rev.	Changes
000	Initial Release
001	Calculation updated for reduction in height modification of cradle. Appendix A updated for weight and CG calculation. Calculation updated to use SOW cask bounding weight of 271.3 kips. Minor reformatting for improving legibility.

AREVA Federal Services LLC

AREVA **Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-001

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1.0 PURPOSE

The Atlas Railcar Family 4 Cradle Assembly conceptual design (cradle), exclusively designed for the transport of Multi-Purpose cask 187 (MP187), is one of the four (4) family cradle designs. It is designed to serve under phase 1 (conceptual design phase) of the US Department of Energy (DOE) integrated nuclear waste management disposition system, called DOE Atlas Railcar Project [1]. The driving size limitations and design boundaries are delineated in the Design Basis Requirements Document (DBRD) [2]. The purpose of this document is to evaluate the structural integrity of the MP187 cradle under the loads specified in the following subsections, in accordance with the DBRD [2]. Additionally, the height and vertical CG from the bottom of the cradle and associated loads to the railcar at the pin locations will be determined and provided for the testing purpose of the railcar. The conceptual design is shown in Figure 1-1 and drawing 3015140 [3]. The 12-axle railcar shown in Figure 1-1is shown in drawing 3015278-002 [4].

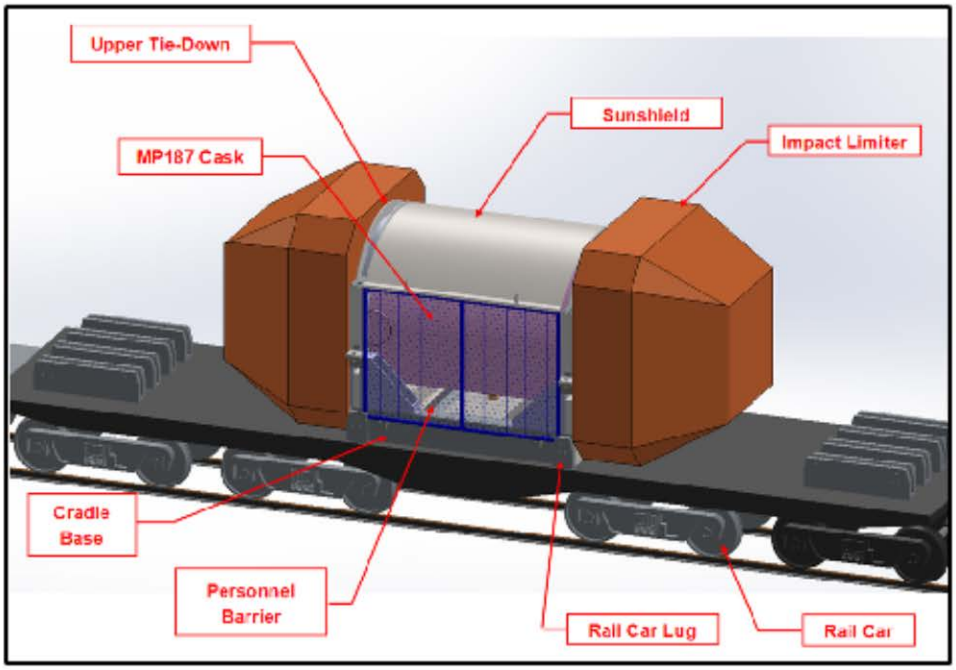

Figure 1-1: Family 4 Cradle Assembly Conceptual Design

The purpose of this revision is to reevaluate the cradle after a design change that reduces the centerline height of the cask from 69.50 inches to 65.00 inches. The weight and center of gravity of the cradle are recalculated in Appendix A. Loads have been updated to reflect the project MP187 design weight of 271.3 kips as presented in the Statement of Work (SOW) [1].

2.0 METHODOLOGY

Hand calculation will be used in this document to demonstrate that the cradle can support the applied loads. Allowable stresses are calculated using the given accelerations loads per the DBRD [2] against yield strength of the materials. Steel Construction Manual of AISC may be used as a guide also [5]. Because the design is merely conceptual, only the main or critical components and connections in the load path are evaluated in this document. The interfaces and loading conditions are as follows.

2.1 Interface Conditions

There are two (2) major interface conditions:

1. Loaded Cradle-to-Railcar interface: The total loaded cradle will be used in this case.
2. Cask-to-Cradle interface: Only the load from the cask will be applied to the affected members in this case.
3. The cradle does not support the loads from down-ending operations (transitioning from vertical orientation to horizontal orientation); a separate down-ending frame is used for this purpose (Chapter 7 of the SAR [6]).

2.2 Loading Conditions

There are three (3) loading conditions to be evaluated:

1. **Lifting Load**: The load will be distributed equally between all four (4) lifting points in accordance with DBRD [2]. ANSI N14.6 [7] will be used in this evaluation since the payload is higher than 10,000 lb.
2. **Tie-Down Loads**: The accelerations in the design input section of this document will apply individually per DBRD. The stresses resulting from the applied loads are then compared against the allowable yield stresses of the components in accordance with Section 2.2.2-13 of the DBRD. Analysis of the 2g vertical load bounds the 1g dead weight load.
3. **Fatigue Load**: Family 3 cradle conceptual design calculation [8] covers the fatigue evaluation for all other cradle designs, including this design.

2.3 Margin of Safety

The margin of safety (MS) in this calculation is defined as the allowable load divided by the applied load to be greater than 1 or:

$$MS = \frac{\text{Allowable Load}}{\text{Applied Load}} - 1 \geq 0$$

3.0 ASSUMPTIONS

3.1 Unverified Assumptions

All inputs are referenced against verifiable sources. There are no unverified inputs or assumptions used in this document.

3.2 Justified Assumptions

1. It is assumed that the loads are uniformly applied where shown in this document. This is considered as a standard practice.
2. It is assumed that the materials used in this design have no defects per the procurement standard practice; therefore their properties are accurate per the published codes and standards referenced in this document.
3. It is assumed that the materials are inherently homogeneous throughout; hence strengths of materials are uniform. This is justified based on the procurement standard practice.

4. It is assumed that the lift occurs through four (4) points and is equally balanced. This is a standard practice.
5. All welds are assumed to be either full or partial penetration with full strength as adjoining component. Where a full or partial penetration weld is not possible, it is assumed there will be adequate weld such that the strength of the weld is equal or greater than the full strength as adjoining component. Welds will be fully evaluated in the final design.
6. It is assumed that the lateral load from the MP187 to the upper tie-downs will be applied at the inner apex of the tie-down arch. This conservatively maximizes the moment used in the stress analysis of the pin connections.

4.0 DESIGN INPUTS

4.1 Loads and Centers of Gravity (CG)

4.1.1 Cask and Cradle

As described in the MP187 SAR [6], the cask is nearly symmetrical, therefore the cg is very near the geometric center of the cask. In this calculation, this is interpreted as at the axial center of the cask; which corresponds to the 64.5-inch dimension found in Section A-A of the cradle drawing [3]. The maximum allowable transportation weight for the cask is found in Appendix A of the SOW [1]. The weight and CG for the cradle assembly come from the details in Appendix A.1. The combined cradle and cask weight and CG is computed below and the result is recorded in Table 4-1.

From Appendix A1: Weight of Cradle: $W_c = 32.5$ kip

CG of Cradle: $Z_{ccg} = 28.5$ in

From the MP187 SAR and [3], CG of Cask: $Z_{cask\,cg} = 64.5$ in

From the SOW: $W_{cask} = 271.3$ kip

Combined Weight: $W_t = W_c + W_{cask} = 303.8$ kip

Rounded up Combined CG: $Z_t = \frac{W_c Z_{ccg} + W_{cask} Z_{cask\,cg}}{W_t} = 60.6$ in

Table 4-1: Cask and Cradle Weight and CGs

Component	Weight (kip)	Vertical CG from Cradle bottom (in)	Ref.
MP187 (cask)	271.3	64.5	SOW[1], SAR[6], & [3]
Cradle Assembly	32.5	28.5	Appendix A
Cask + Cradle Assembly	303.8	60.6	Section 4.1.1

4.1.2 Tie-Down Loads

The following accelerations will be applied individually in the evaluations of the cradle components for the tie-down loading in accordance with the DBRD [2].

- ± 7.5g Longitudinal (axial)
- ± 2g Vertical
- ± 2g Lateral

4.1.3 Dynamic Factor

No dynamic factor is specified by the DBRD [2] for lifting load analysis. A dynamic load factor of 1.15 is used for lifting loads based on CMAA Specification No. 70-2004 [9].

4.2 Material Properties

The materials properties listed in Table 4-2 are from ASTM Standards [10].

Table 4-2: Materials Properties

ASTM Code	Yield (ksi)	N14.6 lifting based on yield (ksi)	Tensile (ksi)	N14.6 lifting based on ultimate (ksi)
A572, Gr 50	$S_y = 50$	50/3 = 16.67	$S_u = 65$	65/5 = 13
A514 up to 2.5" thick	$S_y = 100$	100/3 = 33.33	$S_u = 110$	110/5 = 22
A514 2.5" to 6" thick	$S_y = 90$	90/3 = 30	$S_u = 100$	100/5 = 20
A311, Gr. 1144, Class B	$S_y = 100$	100/3 = 33.33	$S_u = 115$	115/5 = 23

- The density of steel materials used in this document is 490 lb/ft^3 (0.284 lb/in^3) per Table 17-12 of [5].
- The unit weight of the wide flange W18x119 is 119 lb/ft (0.283 lb/in^3) from [5].
- The unit weight of the wide flange W16x57 is 57 lb/ft (0.283 lb/in^3) from [5].
- Allowable shear stress: 60% of materials yield or ultimate stress will be used, where applicable per [5].

5.0 CALCULATIONS

In addition to a general system description and analysis below, the following evaluations are presented to determine the loads to the railcar as well as to demonstrate that the critical members and connections of the cradle assembly are capable of supporting the MP187 under various loading conditions.

1. System General Descriptions (Section 5.1)
2. Loads to the Railcar Evaluations (Section 5.2)
3. Determine Bounding Load to Tie-Downs Connection (Section 5.3)
4. Stresses on the Tie-Down Connecting Members (Section 5.4)
5. Other Evaluations due to all Loads (Section 5.5)
    a. Critical Members affected by the Lifting Load (Section 5.5.1)
    b. Critical Members affected by 7.5g Longitudinal Load (Section 5.5.2)
    c. Critical Members affected by 2g Lateral Load (Section 5.5.3)
    d. Critical Members affected by 2g Vertical Load (Section 5.5.4)

5.1 System General Descriptions

The Atlas Family 4 cradle assembly conceptual design consists of the following main components (subassemblies) as shown in [3] and described below.

5.1.1 Cradle Base

The cradle base is shown in Figure 5-1. The cradle base provides the interface between the railcar and the cask. With the railcar, it is restrained at four (4) pin locations to react to the tie-down loads. It also interfaces with two (2) shear keys on the railcar to support the longitudinal shear loads. With the cask, the cradle base interfaces with a shear key at the center to resist the longitudinal load only. Laterally, the cradle upper and lower tie-downs will resist the cask's load and the railcar lugs will resist the load from loaded cradle.

All members are made of high strength low alloy steel. Two (2) main side beams are built from W18x119 built-up W-Section beams with one inch side plates reinforced with full or partial penetration welds. The main side beams are parallel and separated by 93 ½-inches. Connection between the two side beams is through the shear key support box and two W16x57 beams. The shear key support box transfers the 7.5g load directly from the shear key to the railcar shear bocks (not pictured). The shear key support box is fabricated with 3-1/2 inch thick wall plates and welded to the side plates of the W18x119 side beams. The shear key is similar in design to that shown in the MP187 SAR [6]. The concept of this subassembly is shown on sheet 2 of [3].

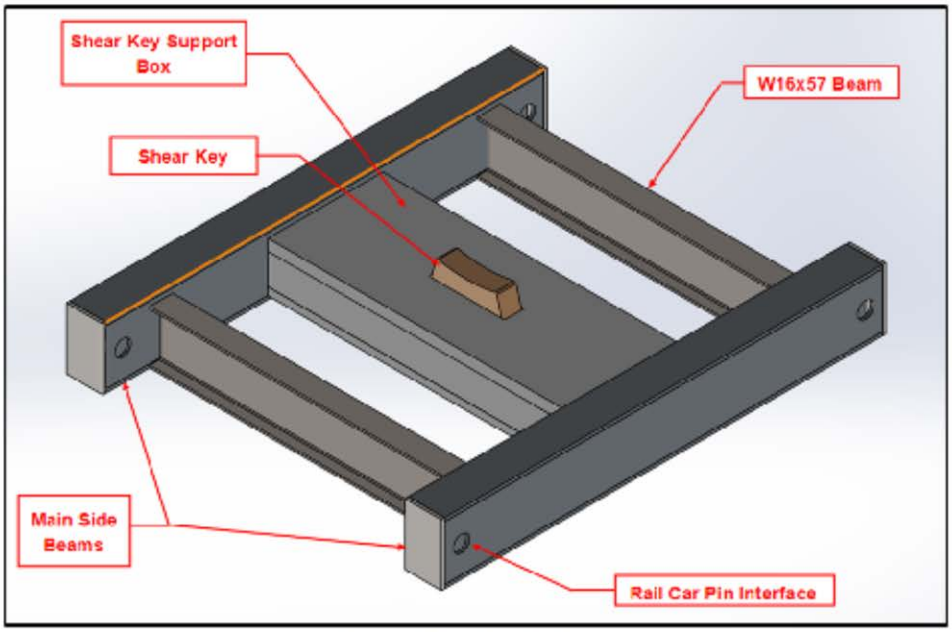

Figure 5-1: Cradle Base

5.1.2 Lower Tie-Down (saddle)

Two (2) saddles provide the nesting areas for the cask to rest on. Each saddle is approximately eight (8) inches wide and located at one end of the cradle base. Vertical loads from the cask are supported by two (2) 2 inch thick plates on the front and back of each saddle. Additional support for vertical and longitudinal loads is accommodated through two (2) gusset weldments; each connecting one side of the saddle to a corresponding main side beam. Each saddle includes two posts at the top to engage with the upper tie-downs. The upper tie-downs slip over the six (6) inch square posts and 2.5 inch pins will secure the tie-downs around the cask to the cradle base. The conceptual design is shown in Figure 5-2 with more detail on sheet 2 of the conceptual design drawing [3].

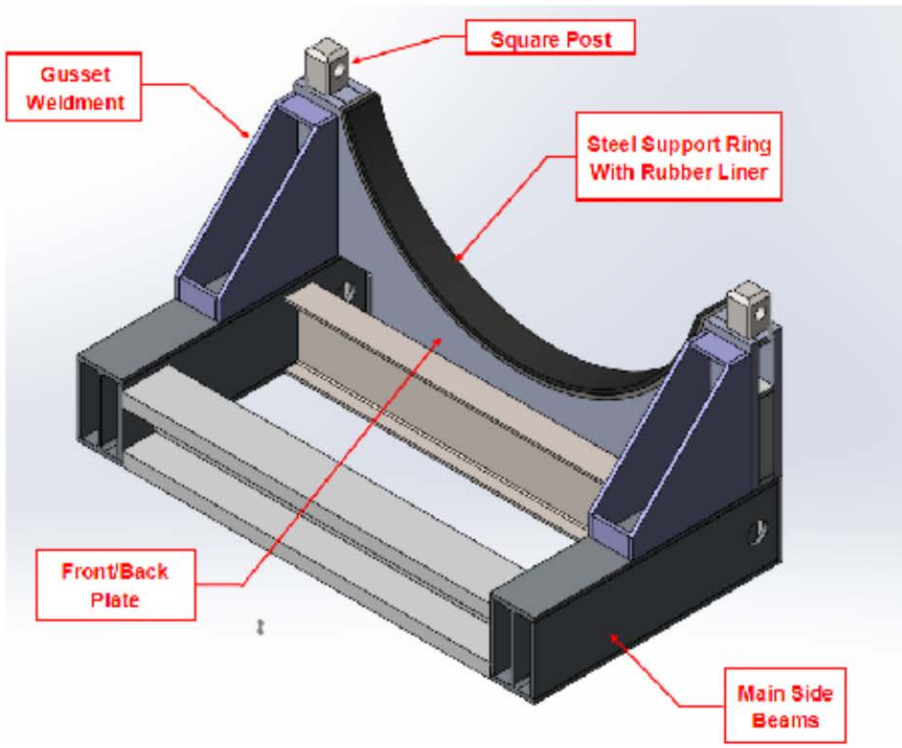

Figure 5-2: Lower Tie-Down (Saddle)

5.1.3 Upper Tie-down

The two upper tie-downs are designed, mainly, to minimize the cask movement vertically. Each upper tie-down is built to form a 7.25 x 8 C-shaped cross section (C-Channel) 1-inch thick, curved to nest around the upper portion of the cask, and will provide clearance for the cask's side trunnions. As mentioned above, the upper tie-downs will slip over the posts of the lower tie-downs and the 2.5 inch pins are sized to secure them in through 1.5 inch thick side plates. Additionally a 1 ½-inch bolt is used on each side of each tie-down. The rubber liner on the upper tie-down is designed to compress against the cask as the bolts are tightened sufficiently to allow the upper tie-down pin hole to align with the lower tie-down pin hole.

Each upper tie-down includes an outer 1.5 thick plate welded to the lower portion of the C-channel to add stiffness around the bent portion which is not in contact with the cask. This plate adds rigidity to the C-channel at the highest stress location due to the bounding load computed below. The plate is also welded to the lift lugs at the top to provide support for vertical lifting. At the bottom this plate is bent outwards to provide a surface to the 1.5 inch diameter bolt mentioned above.

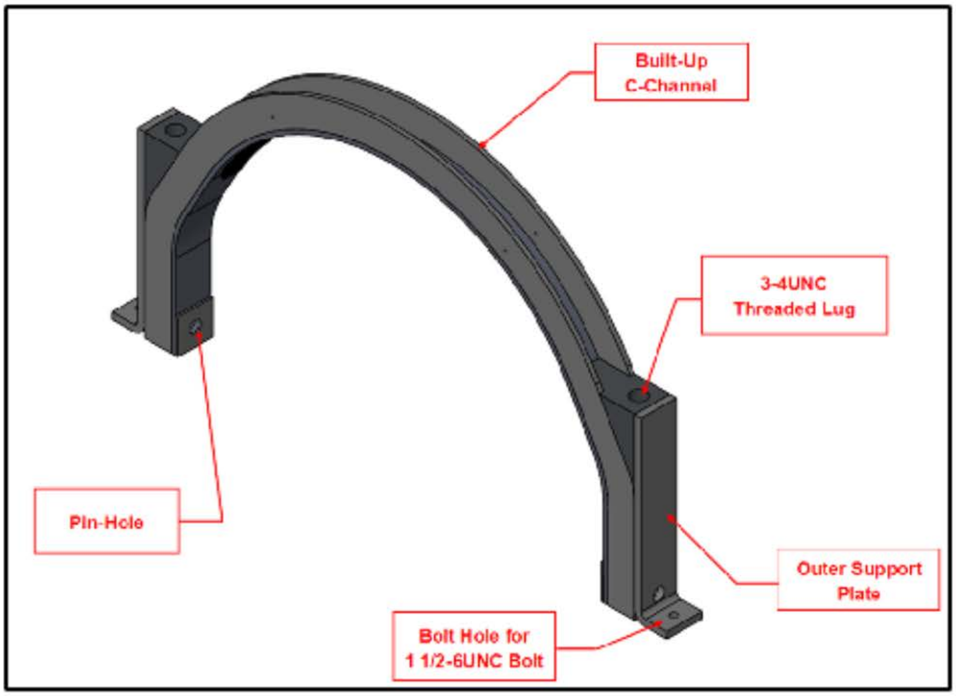

Figure 5-3: Upper Tie-Down

5.1.4 Sun Shield and Personnel Barrier

The personnel barrier assembly consists of a curved 1/4 inch thick plate as a shade provider and two (2) side metal screens as personnel barriers. The personnel barrier is made from two (2) inch stainless steel tubing framed around a 50% open area screen. The entire assembly, which has an estimated weight of less than 2,000 lb (Appendix A), is lifted by the four (4) hoist rings rated for 5,000 lbs. each. The personnel barrier is secured onto the cradle assembly via ball lock pins.

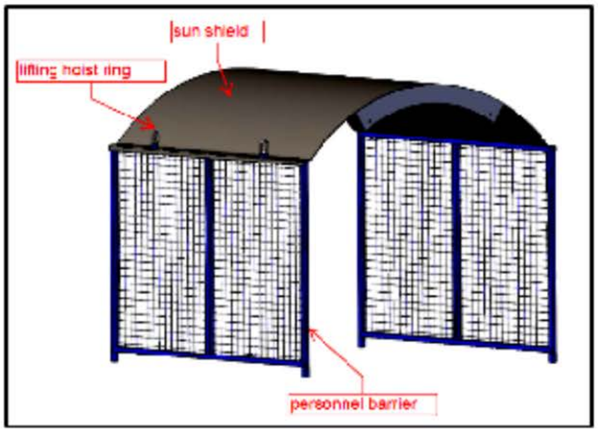

Figure 5-4: Sun Shield and Personnel Barrier

5.2 Determine Bounding Tie-Down Loads to the Railcar

The tie-down loads directions and pin locations are shown in Figure 5-5.

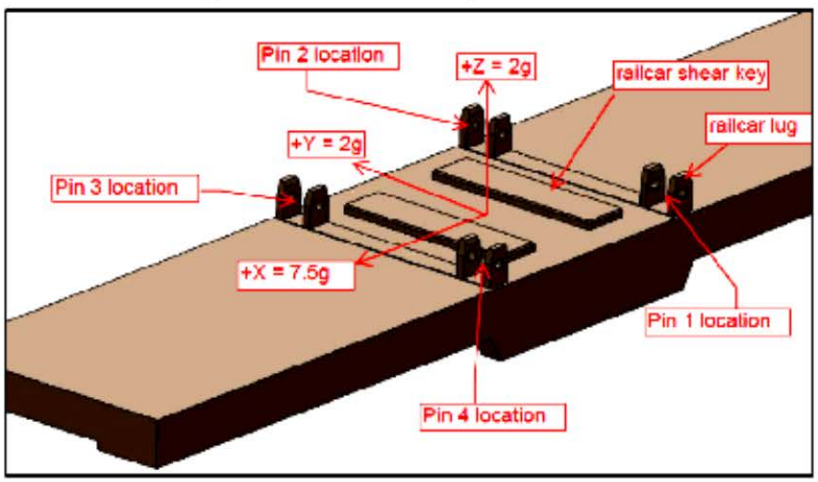

Figure 5-5: Pin Locations and Acceleration Directions

5.2.1 Longitudinal Load

The 7.5 longitudinal acceleration results in a shear force that is resisted by the railcar shear key and a moment on each pin. The free body diagram is shown in Figure 5-6.

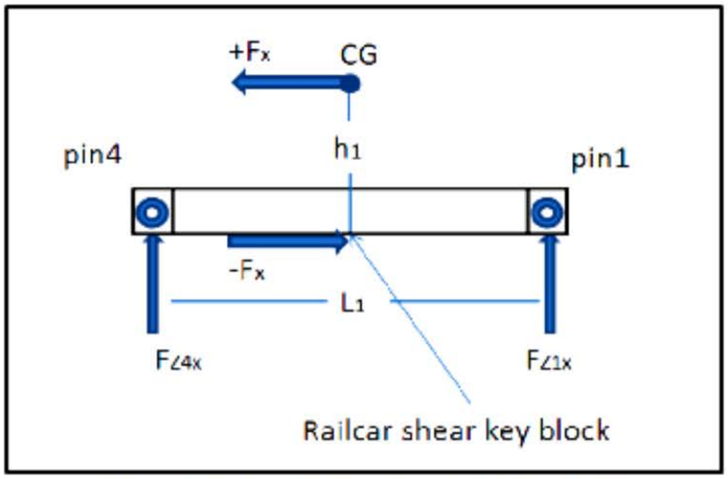

Figure 5-6: Longitudinal Load to Railcar FBD

The load:	$F_x = \frac{1}{2}(7.5g)(303.8\ \text{kip}) = 1{,}139\ \text{kip}$
Vertical moment arm:	$h_1 = Z_t = 60.6\ \text{in}$
Distance between Pins:	$L_1 = 125.0\ \text{in}$
$\Sigma M_{pin} = 0$:	$F_{z1x} = \frac{F_x(h_1)}{L_1} = 552\ \text{kip}$

5.2.2 Lateral Load

Similarly, the 2g lateral load will be resisted by the two lugs on the railcar. The reaction will occur at the base of the cradle.

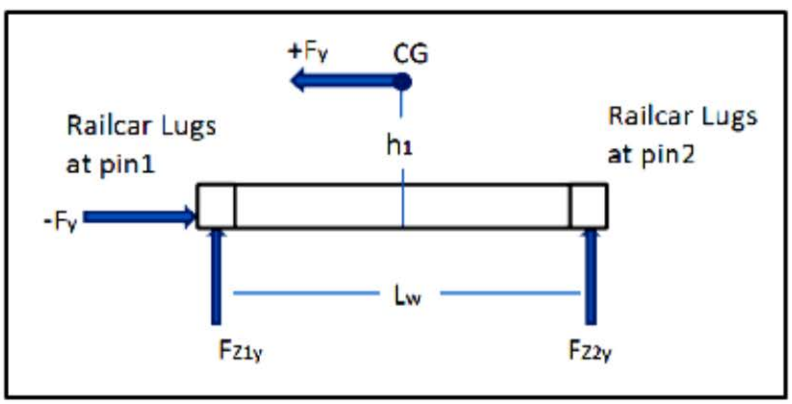

Figure 5-7: Lateral Load to Railcar FBD

The lateral load: $F_y = \frac{1}{2}(2g)(303.8\ kip) = 303.8\ kip$

Vertical moment arm: $h_1 = 60.6\ in$

Distance between the pins: $L_w = 116\ in - 11.3\ in = 104.7\ in$

$\Sigma M_{pin2} = 0$: $F_{z1y} = \frac{F_y(h_1)}{L_w} = 176\ kip$

5.2.3 Vertical Load

The result of the 2g vertical force as follows:

The Load: $F_z = \frac{1}{4}(2g)(303.8\ kip) = 152\ kip$

5.2.4 Summary of the Tie-Down Loads to the Railcar

The summary of the tie-down loads to the railcar is listed in Table 5-1.

Table 5-1: summary of Tie-Down Loads to the Railcar

Acceleration	Load to the Railcar (kip)
7.5g Longitudinal double shear on any pin location	$\pm F_z = 552$
7.5g Longitudinal on railcar shear key	$\pm F_x = 1{,}139$
2g Lateral on any railcar lug	$\pm F_y = 303.8$

5.3 Determine Bounding Load to Tie-Downs Connection

In this evaluation, the lifting load and the loads from the tie-downs in each direction are compared and the bounding load will be used to determine the stresses on the upper and lower tie-down members.

5.3.1 Longitudinal Load

The longitudinal load of 7.5g is resisted by the cask's shear key and a load is applied to the pin connection between the upper and lower tie-downs. In this section, the load on the pin connection will be determined. Summing the moment of the loads applied to the cask:

$$\Sigma M = 7.5g(271.3\ kip)(46.25\ in) - F_{z1}(129.4\ in) = 0$$

Load to saddle: $F_{z1} = 727\ kip$

There is one pin on each side of the saddle; each Pin takes on-half of this load.

Load to pin: $F_{pin} = \frac{1}{2}F_{z1} = 364\ kip$

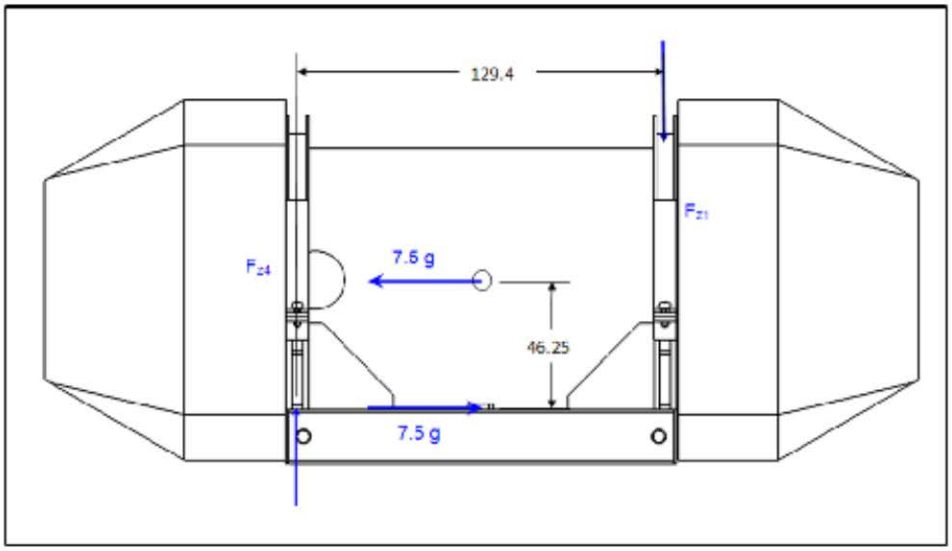

Figure 5-8: Longitudinal Loads to Cask

5.3.2 Lateral Load

The lateral load includes a 2g tie-down load that is resisted in part by the upper tie-down and partly by the lower tie-down. The load on the lower tie-down is applied over one-half of the saddle segment with a load conservatively focused one-third of the way down from the top edge of the saddle (the load point). The load on the upper tie-down is conservatively applied where it contacts the top of the cask. The load on the tie-downs is computed by summing the forces and moments applied to the cask as a rigid body.

Load applied to restraint:	$P = (2g)\frac{1}{2}W_{cask} = 271.3 \text{ kip}$
Lateral forces summation:	$\Sigma F_x = F_{ltd} - P + F_{utd} = 0$
Cask radius:	$R = 46.25 \text{ in}$
CG to load point vertical distance:	$y = \frac{1}{3}(R - 16.2 \text{ in}) + 16.2 \text{ in} = 26.2 \text{ in}$
Summation of moments:	$\Sigma M = (R + y)F_{ltd} + (R)P = 0$
Lower restraint load:	$F_{ltd} = \frac{R}{R+y}P = 173.2 \text{ kip}$

Upper restraint load: $F_{utd} = P - F_{ltd} = 98.1 \text{ kip}$

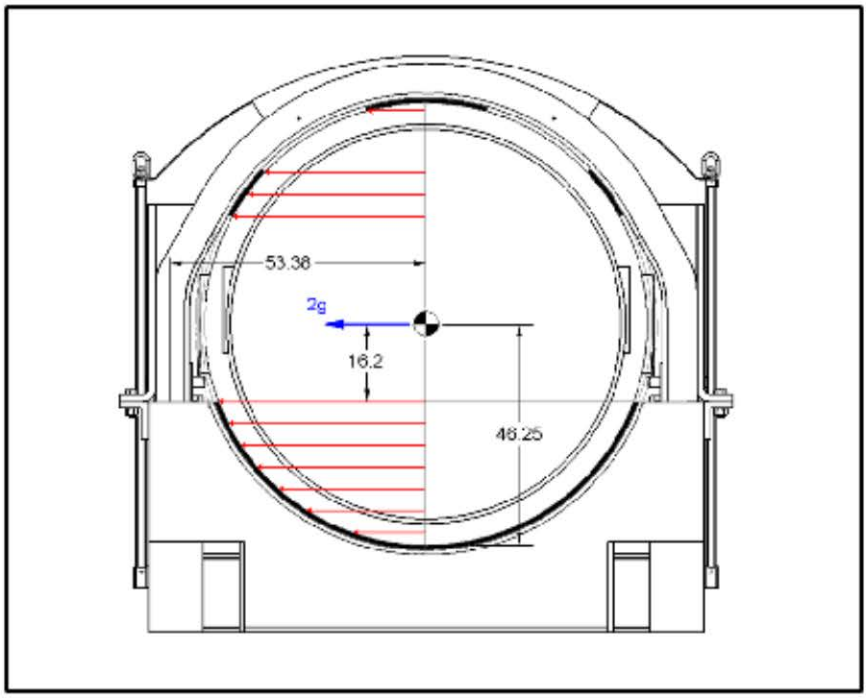

Figure 5-9: Lateral Load Distribution on the Tie-Downs

For the upper tie-downs, as shown in Figure 5-10, conservatively it is assumed a maximum moment arm which is at the highest point of contact between the cask and the upper tie-down to the pin location.

Moment arm: $d_1 = 46.25\ \text{in} + 12.2\ \text{in} = 58.45\ \text{in}$

$d_2 = 2 \times 53.38\ \text{in} = 106.8\ \text{in}$

For the upper portion of the load:

Moment: $\Sigma M_{pin2} = d_1 \times F_{utd} - d_2 \times F_{z1l} = 0$

$F_{z1l} = 53.7\ \text{kip}$

Lateral shear reaction: $F_{y1l} = \frac{1}{2}P = 135.7\ \text{kip}$

The resultant: $F_{z1y} = \sqrt{F_{z1l}^2 + F_{y1l}^2} = 145.9\ \text{kip}$

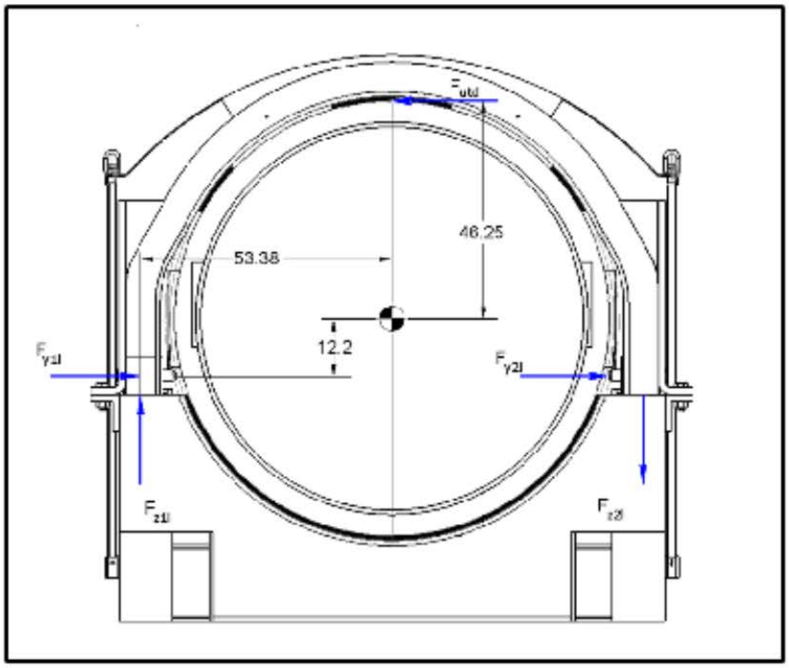

Figure 5-10: Lateral Load on Upper Tie-Downs

5.3.3 Vertical Load

There are two (2) vertical loads to consider, the tie-down 2g vertical load and the lifting load, hence:

5.3.3.1 2g Vertical Load

The 2g vertical acceleration results in reactions forces as follows:

$$F_{z1z} = (2g)\frac{1}{4}(271.3\ \text{kip}) = 136\ \text{kip}$$

5.3.3.2 Vertical Lifting Load

For lifting, the lifting lugs are designed directly above the tie-down connections so that there is no eccentricity. Based on Table 4-2, the ultimate stress allowable for all materials is bounding. In order to compare the bounding load in the system, five (5) times the loaded cradle is considered to account for the allowable based on the bounding tensile stress against the ultimate stress of the materials in accordance with the lifting requirements of ANSI N14.6 [7]. Conservatively, the full weight of the cradle will be considered. Additionally, a load factor of 1.15 will be added, hence:

$$F_{liftu} = \frac{5}{4}(1.15)(303.8\ \text{kip}) = 437\ \text{kip}$$

5.4 Stresses on the Tie-Down Connection Members

Between all the loads in Sections 5.3.1, 5.3.2, and 5.3.3, the vertical lifting load is the highest load and therefore will be used for the evaluations of the members associated in connection between the upper and the lower tie-downs per Figure 5-11.

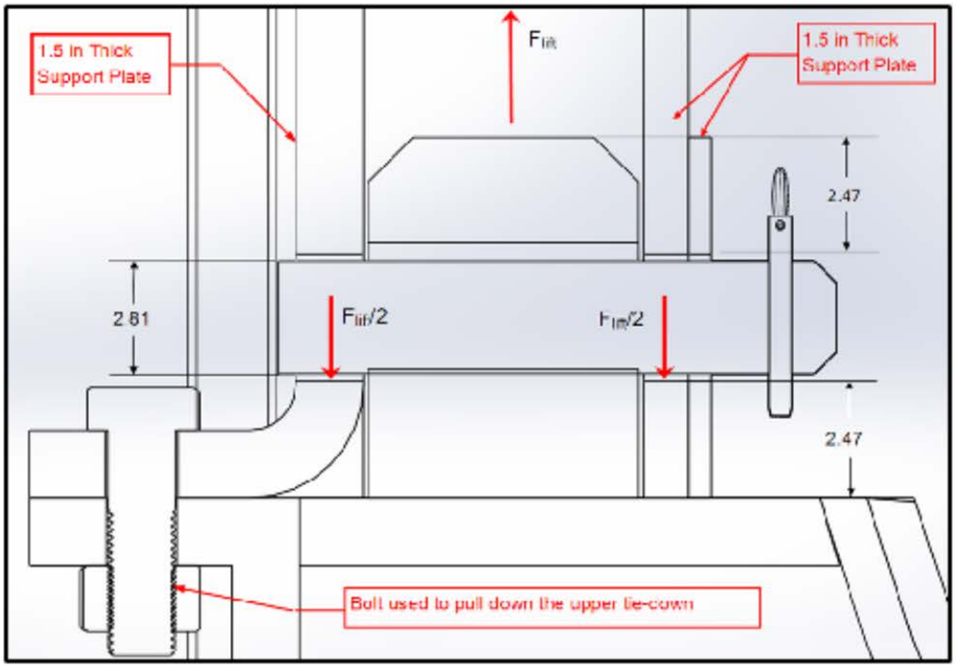

Figure 5-11: Tie-Down Loads

5.4.1 Stress on the Tie-Downs Retainer Pin

The applied load from Section 5.3.3.2: $F_{pin} = F_{liftu} = 437$ kip

The pin is in double shear and made of A311, Gr. 1144, Class B with $S_u = 115$ ksi.

The pin is sized for 2.5 in. dia. with an area of: $A_{pin} = \frac{\pi}{4}(2.5\text{ in})^2 = 4.9\text{ in}^2$

The applied double shear stress on the pin: $F_{app} = \frac{F_{pin}}{2A_{pin}} = 44.6$ ksi

Allowable shear force on the pin: $S_{pin} = 0.6S_u = 69$ ksi

The Margin of Safety: $MS_{pin} = \frac{S_{pin}}{F_{app}} - 1 = 0.55$ OK

5.4.2 Stress on the Upper Tie-Down Side Supporting Plates

Each side of the pin is supported with a 1.5 inch thick plate by 8.13 inches wide, made from ASTM A514 and ASTM A572 Grade 50 with a minimum ultimate strength S_u = 65 ksi. The tear out area of these plates bounds all other areas under this load, hence.

The applied load:	$F_{plate} = \frac{1}{2}F_{liftu} = 219\ kip$	
Plate tear-out area with edge distance of 2.47 in.:	$A_{plate} = (1.5\ in)(2.47\ in) = 3.71\ in^2$	
The applied shear stress:	$F_{app} = \frac{F_{plate}}{2A_{plate}} = 30.0\ ksi$	
Allowable shear force:	$S_{plate} = 0.6 \times S_u = 39\ ksi$	
The Margin of safety:	$MS_{plate} = \frac{S_{plate}}{F_{app}} - 1 = 0.30$	OK

5.4.3 Stress on the Lower Tie-Down Post

The lower tie-down post is 6 x 6 x 8 tall, made from ASTM A514 with S_u = 100 ksi.

The applied load:	$F_{post} = F_{liftu} = 437\ kip$	
Post tear-out edge distance with 2.81 in dia. Hole:	$e = \frac{6-2.81}{2} = 1.6in$	
The tear out area:	$A_{post} = 2(6e) = 19.2\ in^2$	
The applied shear stress:	$F_{app} = \frac{F_{post}}{A_{post}} = 22.8\ ksi$	
Allowable shear force:	$S_{plate} = 0.6 \times S_u = 60\ ksi$	
The Margin of safety:	$MS_{post} = \frac{S_{post}}{F_{app}} - 1 = 1.63$	OK

5.5 Other Evaluations

5.5.1 Critical Members Affected by the Lifting Load

Each upper tie-down includes two (2) lifting lugs, shown in Figure 5-12. The lengths of the welds in the figure are estimated based on the geometry of the lifting lug and the full-penetration callout note (Note 1) of the drawing. Each lug includes a 3-4 UNC, 2B with a minimum thread engagement length 4 inches. A lifting attachment such as a swivel hoist ring with minimum safety margin of 5 to 1 against working load limit based on the lift point load shall be used. Each lug will carry 1/4 of the total load of 437 kip.

The welds are full penetration or equivalent in area where full penetration is not possible. Due to large perimeter length of the welds the stress on this weld group is bounded by the stress on the internal threads. This analysis will be limited to the internal thread of the lift lug. The applied load of 437 kip includes a five-times multiplier, as discussed in Section 5.3.3.2, to allow for the ANSI N14.6 load case for a non-critical lift case in addition to a dynamic load factor 1.15.

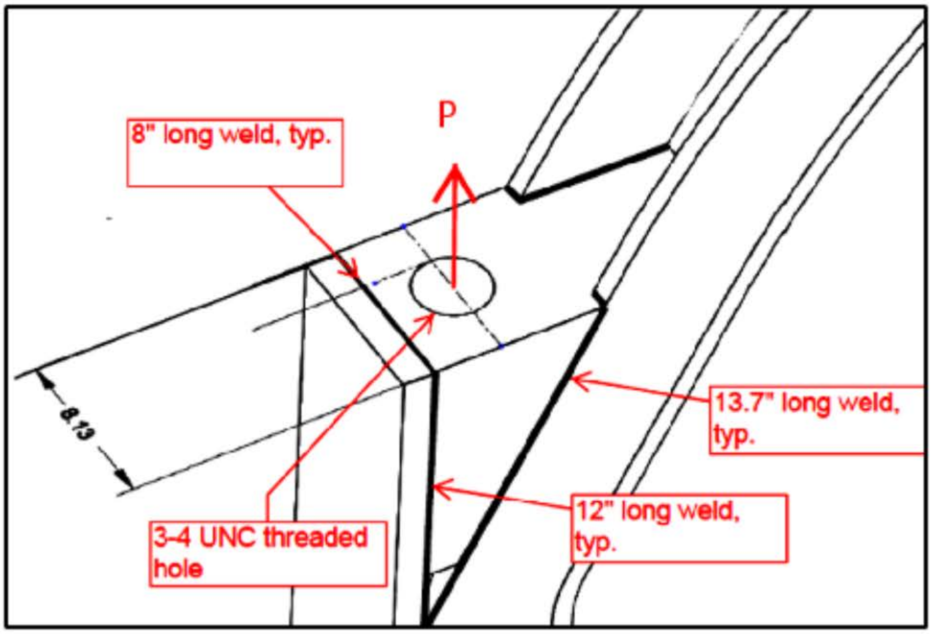

Figure 5-12: Lifting Lug

The material is a six-inch thick plate of ASTM A514 with minimum yield stress of 90 ksi and a minimum ultimate stress of 100 ksi. The allowable shear on the threads is based on yield. The internal thread shear area is calculated using formulas for stress areas and lengths of engagement of screw threads found in the Machinery's Handbook [11] for the given thread engagement of 4 inches.

The lifting lug load:	$P = F_{liftu} = 437$ kip
Threads per inch:	$n = 4$
Length of thread engagement:	$L\_e = 4.0$ in
Minimum major diameter of external thread:	$D_{smin} = 2.9730$ in
Maximum pitch diameter of internal thread:	$E_{nmax} = 2.8515$ in
Internal thread area:	$A_n = 3.1416 n L_e D_{smin}\left[\frac{1}{2n} + 0.57735(D_{smin} - E_{nmax})\right] = 29.2\ \text{in}^2$
Thread shear stress:	$\tau = \frac{P}{A_n} = 15.0$ ksi
The allowable Stress:	$S_A = 0.6x\ 90\ \text{ksi} = 54\ \text{ksi}$
Margin of Safety:	$MS_t = \frac{S_A}{\tau} - 1 = 2.6$ OK

5.5.2 Critical Members Affected by 7.5g Longitudinal Load

5.5.2.1 Loaded Cradle to the Railcar

The 7.5g tie-down load causes a shear load to the railcar that is resisted by the railcar cask shear keys on the deck of the railcar and a moment on the four (4) inch pins at the connection points between the railcar and the cradle.

The shear force from the railcar shear key is reacted at the bottom by a 3-1/2 inch thick x 93.5 inches long plate at the bottom of a built-up I-beam. The moment, however, results in a vertical shear force on each pin which is evaluated in [12] based on the bounding load from all Atlas cradle family conceptual designs.

5.5.2.2 Cask to Cradle

The 7.5g tie-down load (applied in either longitudinal direction) will be applied to the top of the shear key and transferred to the box section supporting the shear key. This force is balanced by an equally large force from the railcar attachments at the base of the box section. This creates a moment in the welds that attach the box section to the main side beams of the cradle. Additionally, the shear key is subjected to bending and shear loads from applied load and the box section support loads. A free body diagram (FBD) of the cask shear key is shown in Figure 5-13 and another FBD of the box section is shown is shown in Figure 5-14.

The shear key is a six (6) inches thick by 22.4 inches long by 23.3 wide with a taper on top to reduce the width no less than 20 inches. The shear key bears the entire cask load of 271.3 kips. The contact point on the shear key from the cask is conservatively taken at the top end of the shear key.

MP187 max weight:	$W_{cask} = 271.3\ \text{kip}$
Shear key load:	$F_{SK} = 7.5W_{cask} = 2{,}035\ \text{kip}$
Shear key elevation:	$h_k = 22.4\ \text{in}$
Box section height:	$d_k = 16.5\ \text{in}$
Shear key width:	$y_k = 23.3\ \text{in}$
Shear key thickness:	$x_k = 6.0\ \text{in}$
Sum of Moments:	$\Sigma M_2 = h_k F_{SK} - d_k R_1 = 0$
Top plate reaction force:	$R_1 = \frac{h_k}{d_k} F_{SK} = 2{,}763\ \text{kip}$
Sum of forces:	$\Sigma F = F_{SK} + R_2 - R_1 = 0$
Bottom plate reaction force:	$R_2 = R_1 - F_{SK} = 728\ \text{kip}$
Maximum shear force:	$V = R_1 = 2{,}763\ \text{kip}$
Maximum moment:	$M = (h_k - d_k)F_{SK} = 12.0 \times 10^3\ \text{in} - \text{kip}$
Maximum stress distance:	$c_k = \frac{1}{2} x_k = 3.0\ \text{in}$
Section area:	$A_k = y_k x_k = 140\ \text{in}^2$
Section moment of inertia:	$I_k = \frac{1}{12} y_k x_k^3 = 419\ \text{in}^4$
Shear stress:	$\tau_k = \frac{V}{A_k} = 19.7\ \text{ksi}$
Allowable stress:	$S_A = 0.6S_{yA514} = 54\ \text{ksi}$

Margin of safety:	$MS = \frac{S_A}{F_{key}} - 1 = 1.74$
Bending stress:	$\sigma = \frac{Mc_k}{I_k} = 86.0\ \text{ksi}$
Allowable stress:	$S_A = S_{yA514} = 90\ \text{ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma} - 1 = 0.05$

The margin of safety is positive showing that the section can support the applied loads.

The shear key support box is intended to be in contact with the railcar shear support block over its full length. This results in a couple between the applied load and the reaction force. The stresses in the shear key support box are due to the torsional loading from the load applied from the package to the cradle weldment.

Shear key load:	$F_{SK} = 2{,}035\ \text{kip}$
Shear key elevation:	$h_k = 22.4\ \text{in}$
Shear key restraint height:	$d_k = 16.5\ \text{in}$
Shear key restraint beam width:	$b_k = 35.5\ \text{in}$
Shear key restraint beam wall thickness:	$t_k = 3.5\ \text{in}$
Shear key load arm length:	$l_k = h_k = 22.4\ \text{in}$
Applied torsion:	$T = \frac{1}{2} l_k F_{SK} = 22.79 \times 10^3 \text{in} \cdot \text{kip}$
Shear load:	$V = F_{SK} = 2{,}035\ \text{kip}$
Vertical chord distance:	$c_z = \frac{1}{2} d_k = 8.25\ \text{in}$
Horizontal chord distance:	$c_x = \frac{1}{2} b_k = 17.75\ \text{in}$
Cross sectional area:	$A = d_k b_k - (d_k - 2t_k)(b_k - 2t_k) = 315.0\ \text{in}^2$
Moment of inertia x-x:	$I_{xx} = \frac{1}{12}\left[b_k d_k^3 - (b_k - 2t_k)(d_k - 2t_k)^3\right]$
	$I_{xx} = 11.25 \times 10^3 \text{in}^4$
Moment of inertia z-z:	$I_{zz} = \frac{1}{12}\left[d_k b_k^3 - (d_k - 2t_k)(b_k - 2t_k)^3\right]$
	$I_{zz} = 43.19 \times 10^3 \text{in}^4$
Polar Moment of inertia:	$J = I_{xx} + I_{zz} = 54.44 \times 10^3 \text{in}^4$
Horizontal torsional stress component:	$\tau_x' = \frac{Tc_z}{J} = 3.45\ \text{ksi}$
Shear Stress:	$\tau_x'' = \frac{V}{A} = 6.46\ \text{ksi}$
Vertical torsional stress component:	$\tau_z' = \frac{Tc_x}{J} = 7.43\ \text{ksi}$
Combines shear stress:	$\tau = \sqrt{(\tau_x' + \tau_x'')^2 + {\tau_z'}^2} = 12.4\ \text{ksi}$
Allowable shear stress:	$S_A = 0.6 S_{yA572} = 30\ \text{ksi}$

Margin of safety: $MS = \frac{S_A}{\tau} - 1 = 1.42$

The margin of safety is positive showing that the section can support the applied load. The minimum weld size connecting the shear key restraint should have an effective throat of 1 1/2-inches. Since the load path is from the shear key directly through the shear key support box to the railcar structure these loads will only be seen if the railcar support is unconnected. The calculation below demonstrates that this size of weld will support the loads.

Effective throat: $t_w = 1.5 \text{ in}$

Cross sectional area: $A = d_k b_k - (d_k - 2t_w)(b_k - 2t_w) = 147 \text{ in}^2$

Moment of inertia x-x: $I_{xx} = \frac{1}{12}\left[b_k d_k^3 - (b_k - 2t_w)(d_k - 2t_w)^3\right]$

$I_{xx} = 6.626 \times 10^3 \text{in}^4$

Moment of inertia z-z: $I_{zz} = \frac{1}{12}\left[d_k b_k^3 - (d_k - 2t_w)(b_k - 2t_w)^3\right]$

$I_{zz} = 22.90 \times 10^3 \text{in}^4$

Polar moment of inertia: $J = I_{xx} + I_{yy} = 29.53 \times 10^3 \text{in}^4$

Distance to maximum stress point: $r = \sqrt{c_x^2 + c_z^2} = 19.57 \text{ in}$

Torsional shear stress: $\tau = \frac{Tr}{J} = 15.11 \text{ ksi}$

Allowable shear stress: $S_A = 0.6 S_{y572} = 30 \text{ ksi}$

Margin of safety: $MS = \frac{S_A}{\tau} - 1 = 0.99$

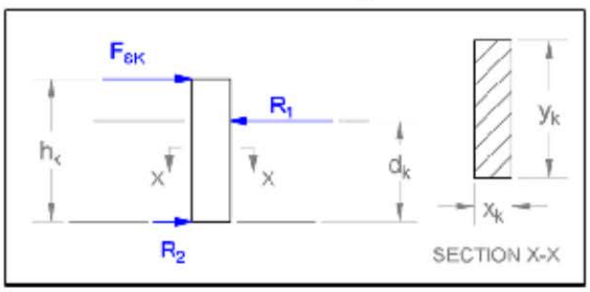

Figure 5-13: Cask and Cradle Shear Key

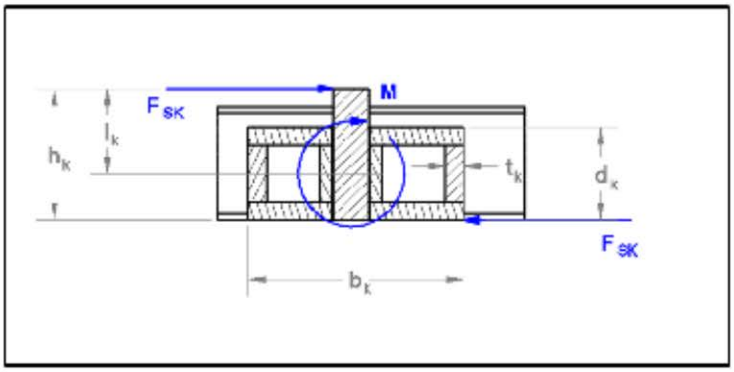

Figure 5-14: Longitudinal Load on Cask Shear Key

5.5.3 Critical Members Affected by 2g Lateral Tie-Down Load

5.5.3.1 Loaded Cradle to the Railcar

The lateral load to railcar is resisted by the railcar lugs evaluated in [12].

5.5.3.2 Cask to Cradle

The 2g tie-down load in either lateral direction is not resisted by the center shear key rather it is resisted by tie-downs. However, the stresses on the pin connection members between the upper and the lower tie-downs are bounded by those determined in Section 5.3.

5.5.4 Critical Members Affected by 2g Vertical Tie-Down Load

5.5.4.1 Loaded Cradle to the Railcar

The vertical load to railcar is resisted by the railcar pins evaluated in [12].

5.5.4.2 Cask to Cradle

The 2g tie-down vertical load is resisted by the pin at interface between the upper and the lower tie-downs. The upper tie-down structure prevents the package from rising vertically from the cradle. This cannot occur during lifting. Bending stresses in the upper tie-down only occur when they are resisting the upward loads. The 364 kip from Section 5.3.1 seen at the pin connection due to the 7.5g longitudinal load case is the bounding load.

There is one primary area of concern for high stresses. It is where the tie-down transitions from the solid cross-section to the lower boxed section A-A shown in Figure 5-15. Since the support at the tie-down due to the cask separates at approximately 37° up from the center of the cask the load can be applied to the section from here. This section may be seen as a cantilever beam. Figure 5-16 shows the cross Section A-A.

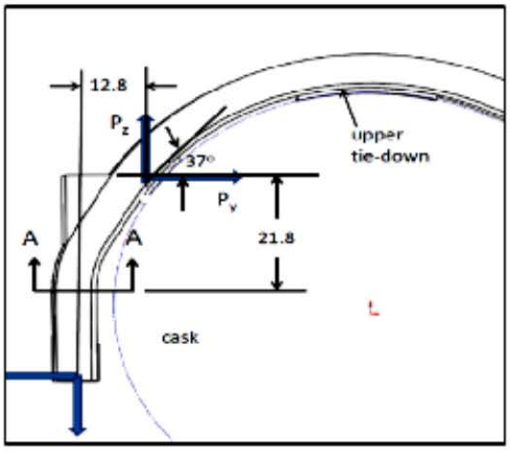

Figure 5-15: Bounding Load on Upper Tie-Down

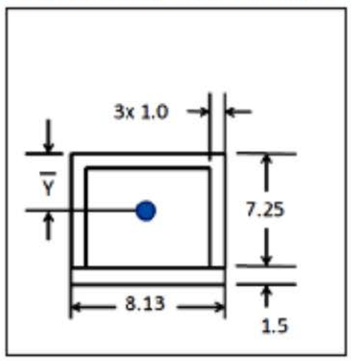

Figure 5-16: Load on the Box Section A-A

Vertical load: $P_z = 364\ \text{kip}$

Lateral load: $P_y = (P_z)\tan(37°) = 274\ \text{kip}$

Moment: $M = P_y\,(21.8\ \text{in}) - P_z\,(12.8\ \text{in}) = 1314\ \text{in}\cdot\text{kip}$

Outer area: $A_1 = (7.25\ \text{in} + 1.5\ \text{in})(8.13\ \text{in}) = 71.14\ \text{in}^2$

Inner void area: $A_2 = -(6.00\ \text{in})(6.13\ \text{in}) = -38.31\ \text{in}^2$

Height of section: $h = 1.5\ \text{in} + 7.25\ \text{in} = 8.75\ \text{in}$

Centroid of outer area: $Y_1 = \frac{1}{2}h = 4.38\ \text{in}$

Centroid of void: $Y_2 = \frac{1}{2}(6.00\ \text{in}) + 1.5\ \text{in} = 4.63\ \text{in}$

Centroid of section: $\overline{Y} = \frac{\Sigma A_{\neg i}(\overline{Y_i})}{\Sigma A_i} = 4.09 \text{ in}$

Stress point: $c = \max(\overline{Y}, h - \overline{Y}) = 4.66 \text{ in}$

Section MOI: $I = \frac{1}{12}(8.13 \text{ in})(8.75 \text{ in})^3 + (71.14 \text{ in}^2)(4.38 \text{ in} - 4.09 \text{ in})^2 -$

$\frac{1}{12}(6.13 \text{ in})(6.25 \text{ in})^3 + (-38.31 \text{ in}^2)(4.63 \text{ in} - 4.09 \text{ in})^2 = 323.97 \text{ in}^4$

Bending stress: $S_b = \frac{Mc}{I} = 18.9 \text{ ksi}$

Allowable stress $S_a = 50 \text{ ksi}$

Margin of Safety: $MS = \frac{S_a}{S_b} - 1 = 1.65$ OK

6.0 RESULTS/CONCLUSIONS

The Atlas Railcar Family 4 Cradle conceptual design has been structurally evaluated in this document. As the result of this evaluation, it is found that the design is structurally sound and it can withstand all the applied loads.

In this document, only the weakest failure modes in the load paths were identified and analyzed. A more detailed structural evaluation will be required for a comprehensive calculation package should fabrication of this cradle assembly be necessary. According to the above evaluations, the least margin of safety found is +0.05 from Section 5.5.2.2. The methods used for the allowable stresses are from ANSI N14.6 [7] for lifting and to yield stress of the materials for all others. Note that a four (4) point vertical lift must be used when lifting the entire loaded cradle.

The weight and CG for the package and cradle can be found in Table 4 1. The railcar reaction forces are found in Table 5-1.

6.1 Results of Applicable Literature Searches and Other Applicable Background Data

None.

7.0 COMPUTER SOFTWARE USAGE

7.1 Non-Engineering Application Software

Computer software was limited to use of Microsoft Excel. The computation was run using Microsoft Excel version 14.0.7165.5000 (32-bit) on a Lenovo Think Station Model S30, labeled DWICK1.adom.ad.corp, running Windows 7 Enterprise with service pack 1 installed. The one file was generated for this calculation to calculate the cradle weights and the vertical location of the center of gravity is listed in Table 7-1.

Table 7-1: Computer File Listing

Filename	Description	Date and Time	Size
CALC-3015136-001A.xlsx	Weight and CG Spreadsheet	2/28/2016 8:45 PM	87 kB

8.0 REFERENCES

1. Department of Energy: Contract DE-NE0008390, Part 1, Section C, *Statement of Work*
2. EIR-3014611-007, *Design Basis Requirement Document (DBRD) for the DOE ATLAS Railcar Project*, AREVA Federal Services LLC
3. DWG-3015140-001: *Atlas Railcar Cradle Family 4 Conceptual Drawing*, AREVA Federal Services LLC
4. DWG-3015278-002, *Atlas Railcar Cradle Attachment Components*, AREVA Federal Services LLC
5. American Institute of Steel Construction Inc., *(AISC): Steel Construction Manual*, 13th edition
6. *NUHOMS® -MP187 Multi-Purpose Cask: Safety Analysis Report*, Rev. 17, Docket 71-9255
7. American National Standard Institute (ANSI N14.6-1993), *Special Lifting Devices for Shipping Containers weighing 10 000 Pounds (4500 kg) or More*
8. AFS Document Number CALC-3015135, *Atlas Railcar Family 3 Conceptual Cradle Structural Calculation*
9. CMAA Specification No. 70-2004, *Specifications for Top Running Bridge & Gantry Type Multiple Girder Electric Overhead Traveling Cranes*, Crane Manufacturers Association of America, Inc., Charlotte , NC
10. ASTM International Standards: *Annual Book of ASTM Standards*, 2012
11. Oberg, Erik et al, Machinery's Handbook, 26th Edition, Industrial Press Inc., New York NY, 2008
12. AFS Document Number CALC-3015276: Atlas Railcar Cradle Attachment Structural and Combined Center of Gravity Calculation

AREVA Federal Services LLC

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-001

Project: 00225.03.0050 - DOE Atlas Railcar **Page 31 of 32**

APPENDIX A: WEIGHT AND CG CALCULATIONS

A.1 Cradle Assembly Weight and CG Calc

Component	QTY/ assy	x length (in)	y length (in)	z length (in)	var1 (in)	var2 (in)	area (in^2)	volume (in^3)	density (lb/in^3)	mass (lb)	mass (ton)	dy (in)	y' cg (in)	y cg (in)	M (in*lb)	NOTES
Cradle	1									32474.4	16.3			28.5	925909	
1 Base Skid (Cradle Base)	**1**									**15407.8**				**8.9**	**136651**	
A. W18x119 Beam Weldment (Main Side Beams)	2									5529.6				9.5	52531	
1 Skid Base I-Beam (item 2)	2	11.3	19.0	135.5			35.1	9512.1	0.283	2687.4		0.0	9.5	9.5	25530	AISC Steel Const. Manual [3] for x , y lengths and area
2 Skid I-Beam Closed Plate (item 1)	4	1.0	16.9	135.5				9149.0	0.284	2598.3		1.06	8.4	9.5	24684	dy = W18x119 flange thickness
3 End Cap (item 1)	4	11.3	19.0	1.0				858.8	0.284	243.9		0.0	9.5	9.5	2317	
B. Shear Key and Support Weldment (Box Weldment)	1									8975.8				8.5	76674	
1 Shear Key (Item 4)	1	23.3	22.4	6.0				3131.5	0.284	889.3		0.0	11.2	11.2	9960	simplified geometry
2 Top Plate (Item 5)	1									3160.3				14.8	46614	
a. Body	*1*	*93.5*	*3.50*	*35.5*				*11617.4*	*0.284*	*3299.3*		*13.0*	*1.8*	*14.8*	*48665*	
b. Slot	*-1*	*23.30*	*3.5*	*6.0*				*-489.3*	*0.284*	*-139.0*		*13.0*	*1.8*	*14.8*	*-2050*	
3 Side Plate (Item 5)	2	93.5	9.5	3.5				6217.8	0.284	1765.9		3.5	4.8	8.3	14569	
4 Bottom Plate (Item 5)	1									3160.3				1.8	5531	
a. Body	*1*	*93.5*	*3.50*	*35.5*				*11617.4*	*0.284*	*3299.3*		*0.0*	*1.8*	*1.8*	*5774*	
b. Slot	*-1*	*23.30*	*3.5*	*6.0*				*-489.3*	*0.284*	*-139.0*		*0.0*	*1.8*	*1.8*	*-243*	
C. W16x57 Beam (Item 24)	2	7.12	16.4	93.5			16.8	3141.6	0.283	888.3		0.0	8.2	8.2	7284	AISC Steel Const. Manual [3] for x , y lengths and area
D. Personnel Barrier Attachment Bracket	4	3.0	4.5	3.0	0.25		2.8	49.5	0.284	14.1		13.8	-2.3	11.6	162	var1 = wall thickness
2 Saddle Support Gusset Weldment (Lower	**4**									**1460.3**				**35.3**	**51508**	
A. Gusset Plate (Item 1)	**8**									**1354.7**				35.3	47810	
1 Body	8	1.0	30.0	30.5				7320.0	0.284	2078.9		19.0	15.25	34.25	71202	
2 Champher	-8	1.0	25.0	25.5				-2550.0	0.284	-724.2		24.0	16.7	32.3	-23392	
B. End Plate (Item 1)	**4**	**9.3**	**5.0**	**1.0**				**186.0**	**0.284**	**52.8**		**19.0**	**2.5**	**21.5**	**1136**	
C. Top Plate (Item 1)	**4**	**9.3**	**1.0**	**5.0**				**186.0**	**0.284**	**52.8**		**49.0**	**-0.5**	**48.5**	**2562**	
3 Saddle Weldment (Lower Tie-Down)	**2**									**8994.7**				**20.3**	**182913**	
A. Support Plate (Item 7)	**4**									**6211.3**				**20.5**	127154	
1 Boundary Plate	4	116.0	47.3	2.0			5486.8	43894.4	0.284	12466.0		1.0	23.7	24.7	307287	See Detail calc aside
2 Saddle Cutout	-4			2.0			2033.0	-16263.7	0.284	-4618.9		1.0	34.5	35.5	-163775	See Detail calc aside
3 Rail Cutout	-4	20.0	18.0	2.0			720.0	-5760.0	0.284	-1635.8		1.0	9.0	10.0	-16358	See Detail calc aside
B. Radial Plate (Item 1)	**2**	**118.5**	**1.0**	**8.00**	**70.4**			**1896.6**	**0.284**	**538.6**		**17.3**	**11.4**	**28.7**	**15432**	**var1 = arclength of plate in radians**
C. Bottom Horizontal Plate (Item 1)	**2**	**76.0**	**1.0**	**14.50**				**2204.0**	**0.284**	**625.9**		**0.0**	**0.50**	**0.5**	**313**	
D. Second Up Horizontal Plates (Item 6)	**2**	**76.0**	**1.5**	**4.0**				**912.0**	**0.284**	**259.0**		**14.8**	**0.75**	**15.5**	**4015**	**Conservatively allow for 0 gap between this plate and radial pl**
E. Third Up Horizontal Plates (Item 6)	**4**	**41.9**	**1.5**	**4.0**				**1006.6**	**0.284**	**285.9**		**19.0**	**0.8**	**19.8**	**5646**	
F. Fourth Up Horizontal Plates (Item 1)	**4**	**19.0**	**1.0**	**4.0**				**304.0**	**0.284**	**86.3**		**35.4**	**0.50**	**35.9**	**3099**	**Length is conservatively longer, but insignificantly so**
G. Top Horizontal Plate (Item 6)	**4**	**12.6**	**1.5**	**4.0**				**301.2**	**0.284**	**85.5**		**46.8**	**0.8**	**47.6**	**4068**	
H. Bottom Vertical Plate (Item 6)	**2**	**1.5**	**13.8**	**4.0**				**165.0**	**0.284**	**46.9**		**1.0**	**6.9**	**7.9**	**369**	
I. Bottom Outer vertical Plate (Item 1)	**4**	**1.0**	**19.0**	**20.2**				**1531.4**	**0.284**	**434.9**		**0.0**	**9.5**	**9.5**	**4132**	
J. Inner Vertical Plates (Item 1)	**4**	**1.0**	**14.9**	**4.0**				**238.4**	**0.284**	**67.7**		**20.5**	**7.5**	**28.0**	**1892**	
K. Outer Vertical Plates (Item 1)	**4**	**1.0**	**14.9**	**4.0**				**238.4**	**0.284**	**67.7**		**20.5**	**7.5**	**28.0**	**1892**	
L. Square Post (Item 10)	**4**									**284.9**				**52.3**	**14900**	
1 Body	4	6.0	8.0	6.0				1152.0	0.284	327.2		48.3	4.0	52.3	17111	
2 Hole	-4	6.0	2.81	2.81				-148.8	0.284	-42.3		48.3	4.0	52.3	-2211	

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Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

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Component	QTY/ assy	x length (in)	y length (in)	z length (in)	var1 (in)	var2 (in)	area (in^2)	volume (in^3)	density (lb/in^3)	mass (lb)	mass (ton)	dy (in)	y' cg (in)	y cg (in)	M (in*lb)	NOTES
M. Radial Pad (Item 9)	2									0.0					0	Negligible Weight (assigned to zero)
4 Built-up Angle (Item 16)	**4**									**173.2**				**45.5**	**7874**	
A. Long Leg	4	1.5	8.0	8.13				390.2	0.284	110.8		48.3	-4.0	44.3	4910	
B. Short Leg	4	4.5	1.5	8.13				219.5	0.284	62.3		48.3	-0.8	47.6	2964	
5 Saddle Tie-Down Assembly (Upper Tie-	**2**									**4504.6**				**78.1**	**351712**	
A. Saddle Tie-Down	**2**									**3790.8**				**80.5**	**305050**	
1 Radius Plate (Item 17)	2									856.2				88.0	75312	
a. Main Plate	*2*	*48.25*	*1.0*	*8.13*	*58.65*	*1.024*	*97.8*	*1589.6*	*0.284*	*451.5*		*64.5*	*39.8*	*104.3*	*47104*	*var1 = angle theta, var2 = angle theta (radians)*
b. Transition Plate	*4*	*9.1*	*15.2*	*8.13*	*17.73*	*1.0*	*17.7*	*576.6*	*0.284*	*163.7*		*89.6*	*-7.6*	*82.0*	*13426*	*var 1 = length, var2 = thickness*
c. End Plate	*4*	*1.0*	*26.1*	*8.13*			*26.1*	*848.4*	*0.284*	*241.0*		*48.3*	*13.0*	*61.3*	*14782*	
2 Circular Segment Face Plates (Item	4									1050.7				90.3	94855	
a. Main Plate	*4*	*54.50*	*6.25*	*1.00*	*58.65*	*1.024*	*657.4*	*2629.6*	*0.284*	*746.8*		*64.5*	*37.7*	*102.2*	*76329*	*var1 = angle theta, var2 = angle theta (radians)*
b. End Sector Dog Ears (approx.)	*8*	*7.3*	*3.3*	*1.00*	*31.35*	*0.5*	*11.9*	*95.2*	*0.284*	*27.0*		*89.6*	*1.1*	*90.7*	*2451*	*var1 = angle theta, var2 = angle theta (radians)*
c. Bottom Face Plate	*8*	*6.3*	*19.5*	*1.00*			*121.9*	*975.0*	*0.284*	*276.9*		*48.3*	*9.8*	*58.1*	*16074*	
3 Lifting Point Block	4									1847.0				72.0	132951	
a. Main Plate	*4*	*15.1*	*15.2*	*8.13*	*6.0*		*160.5*	*5217.6*	*0.284*	*1481.8*		*89.6*	*-17.4*	*72.2*	*106989*	*var1 =*
b. End Plate	*4*	*6.0*	*6.6*	*8.13*			*39.5*	*1285.8*	*0.284*	*365.2*		*67.8*	*3.3*	*71.1*	*25962*	
4 Rectangular Segment Face Plates	4	8.13	8.0	0.5			65.0	130.1	0.284	36.9		48.3	4.0	52.3	1932	
B. Neoprene	**2**									**0.0**		**0.0**	**0.0**	**0.0**	**0**	**Negligible Weight (assigned to zero)**
C. Outer Support Plate (Item 16)	**4**									**655.3**				**66.4**	**43527**	
1 Long Leg	4	1.5	41.3	8.13				2014.6	0.284	572.2		48.3	20.7	69.0	39450	
2 Short Leg	4	6.0	1.5	8.13				292.7	0.284	83.1		48.3	0.8	49.1	4077	
D. Pins (Item 19)	4	10.5	2.5	2.5				206.2	0.284	58.6		52.3	1.3	53.6	3135	
6 Personnel Barrier	**1**									**1933.8**				**101.0**	**195251**	
A. Side Panels	**2**									**461.5**				**56.5**	**26055**	
1 Tube, Vertical, Ends (Item 22)	4	2.0	79.2	2.0	0.125		0.938	297.0	0.284	84.3		13.8	39.6	53.4	4504	var1 = wall thickness
2 Tube, Vertical, Center (Item 22)	2	2.0	75.2	2.0	0.125		0.938	141.0	0.284	40.0		15.8	37.6	53.4	2138	var1 = wall thickness
3 tube, Bottom (Item 22)	2	2.0	2.0	116.5	0.125		0.938	218.4	0.284	62.0		13.8	1.0	14.8	918	var1 = wall thickness
4 Tube, Top (Item 22)	2	2.0	2.0	116.5	0.125		0.938	218.4	0.284	62.0		91	1.0	92	5707	var1 = wall thickness
5 Boss, Pin	4	2.0	3.8	2.0				60.8	0.284	17.3		13.8	-1.9	11.9	205	
6 Boss, Swivel Hoist Ring	4	2.0	2.0	2.0				32.0	0.284	9.1		93.25	1.00	94.25	857	
7 Swivel Hoist Rings	4									40.0		95.25	2.0	97.25	3890	assume 10 lb each
8 Side Screen Mesh, 50% open	4	57.25	75.2	0.06			4305.2	516.6	0.284	146.7		15.8	37.6	53.4	7835	assum 0.6-inch thick
B. Sun Shade	**1**									**1472.3**				**114.9**	**169196**	
1 Main Panel	1	127.9	0.25	120.5	1.694			3852.8	0.284	1094.2		45	71.4	116.4	127358	var 1 = arclength of panel in radians
2 End Panel	2		7.7	0.25	75.5	48.3	1939.5	969.7	0.284	275.4		112.8	3.9	116.7	32126	var1 = outer radius, var2= inner radius (centered on cask axis), use cg at ave vertical radius position of plate.
3 Side Panel	2									102.7				94.6	9712	
a. Top	*2*	*4.00*	*0.25*	*120.5*				*241.0*	*0.284*	*68.4*		*95*	*-0.1*	*94.9*	*6495*	
b. Side	*2*	*0.25*	*2.00*	*120.5*				*120.5*	*0.284*	*34.2*		*95*	*-1.0*	*94.0*	*3217*	

- Details of the weight calculation can be found in the Excel worksheet "CALC-301536-001A.xlsx" that accompanies this calculation.
- Dimensions, material properties, and quantities of cradle components are based on the conceptual design drawing [3].