Appendix B – Revised Railcar-to-Cradle Attachment Interface

APPENDIX B-1 DRAWINGS

DWG-3015278-002
Page 1 of 8

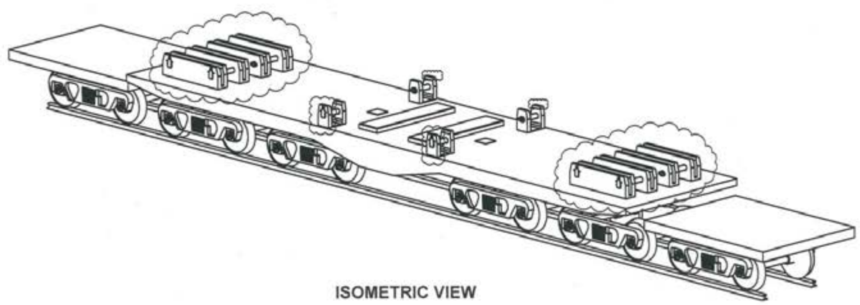
DWG NO 3015278 REV 2 SH 1

NOTES, UNLESS OTHERWISE SPECIFIED:

1. FABRICATE PER AWS D15.1.
2. ALL LUG AND SHEAR KEY WELDS ARE CRITICAL WELDS AS DEFINED BY AAR S-2043.
3. VISUALLY INSPECT (VT) ALL WELDS PER AWS D15.1, CLAUSE 17.2 AND USE CLASS 1 ACCEPTANCE CRITERIA. ALL INSPECTIONS MUST BE PERFORMED BY AN AWS CERTIFIED INSPECTOR.
4. MAGNETIC PARTICLE (MT) DYE PENETRANT OR ULTRASONIC INSPECTION SHALL BE PERFORMED ON ALL WELDS BETWEEN RAILCAR DECK AND CRADLE ATTACHMENT COMPONENTS (EXCEPT ITEM 5 AND 6) PER AWS D15.1 CLAUSE 17.66, 17.5 OR 17.4 RESPECTIVELY. USE CLASS A ACCEPTANCE CRITERIA. ALL INSPECTIONS MUST BE PERFORMED BY AN AWS CERTIFIED INSPECTOR.
5. THE WELD CONNECTION TO THE RAILCAR DECK TO BE SPECIFIED BY KASGRO RAIL. THE REQUIRED WELD FORCE FOR EACH CONNECTION IS SPECIFIED BY AFS CALCULATION CALC-3015276.
6. DELETED
7. APPLY ALL HOLES AND THREADED HOLE LOCATIONS AFTER WELDING.
8. APPLY A STAINLESS STEEL FACING TO THESE SURFACES. THE FACING MAY BE CLADDING OR WELD OVERLAY THAT IS AT LEAST .05 INCHES THICK AND NO GREATER THAN .13 INCHES THICK. THE DIMENSIONS OF OPENINGS AND LOCATIONS MUST BE MET AFTER THE FACING IS APPLIED. FOR PIN HOLES/SLOTS STAINLESS STEEL SHIM STOCK MAY BE USED AND TACKED IN PLACE.
9. MAY BE FABRICATED FROM THREE PIECES USING FULL PENETRATION WELDS. PERFORM VT AND MT PER GENERAL NOTES 3 AND 4.
10. CONCEPTUAL PIN LOADING COMPONENTS.
11. PIN AND INSIDE SURFACE OF PIN HOLES SHALL BE CLEANED AND COATED WITH PURE NICKEL NUCLEAR GRADE 'NEVER SEEZ' GREASE.

LIST OF MATERIALS

	S/D	QTY A2	QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION
			X	A1		CRADLE ATTACHMENT COMPONENTS	
		X	AR	A2		CONCEPTUAL PIN LOADING WELDMENT	
			1	1		ATLAS RAILCAR	
			12	2		BAR, .25 THK X 9.0 X 1.5	ASTM A276, TYPE 304
10		1	-	3		PLATE, .25 THK X 8 X 11.2	ASTM A240, TYPE 304
			12	4		PLATE, .25 THK X 4.0 X 10	ASTM A240, TYPE 304
			2	5		PLATE, .38 THK X 12. X 12	ASTM A240, TYPE 304
			4	6		PLATE, .50 THK X 9.0 X 12	ASTM A240, TYPE 304
			4	7		PLATE, 4.0 THK X 12 X 18	ASTM A572, GR 50
			4	8		PLATE, 4.0 THK X 12 X 18	ASTM A572, GR 50
			2	9		PLATE, 4.0 THK X 21 X 90	ASTM A572, GR 50
			-	10		DELETED	-
			-	11		DELETED	-
9			2	12		PLATE, LEFT 11 THK X 64 X 18	ASTM A572, GR 50
9			2	13		PLATE, RIGHT 11 THK X 64 X 18	ASTM A572, GR 50
9			4	14		PLATE CENTER 11 THK X 64 X 18	ASTM A572, GR 50
			4	15		ROUND, Ø4.0 X 20.7	ASTM A564, TYPE 630, CONDITION H1025
			8	16		ROUND, Ø4.0 X 37.2	ASTM A564, TYPE 630, CONDITION H1025
10		1	-	17		PIPE, 5.0 SCHEDULE 40 X 40.0	ASTM A312, TYPE 304
			AR	18		SHCS, 5/8-11 UNC X 1.25	SS



ISOMETRIC VIEW

AREVA Federal Services
APR 19, 2017
Records Management

REV	DESCRIPTION	DRAWN	CHECKER	VERIFIED
2	SEE ECN NO. 3015278R1-E1 & E2	Q. LE 4/11/17	S. Klein [signature] 4/13/17	D. WICK [signature] 4/13/17
1	SEE ECN NO. 3015278R0-E1	P.P. 8/31/16	M. KAMALIAN 8/31/16	S. KLEIN 8/31/16

REVISION HISTORY

			NAME/SIGNATURE	DATE
		EM	D. [signature]	4/17/17
		RE	S. KLEIN [signature]	4/13/17
		TECH CHK	D WICK [signature]	4/13/17
NA	NA	DFTG CHK	S. KLEIN [signature]	4/13/17
NEXT ASSY	FINAL ASSY	DRAWN	Q. LE	4/11/17

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

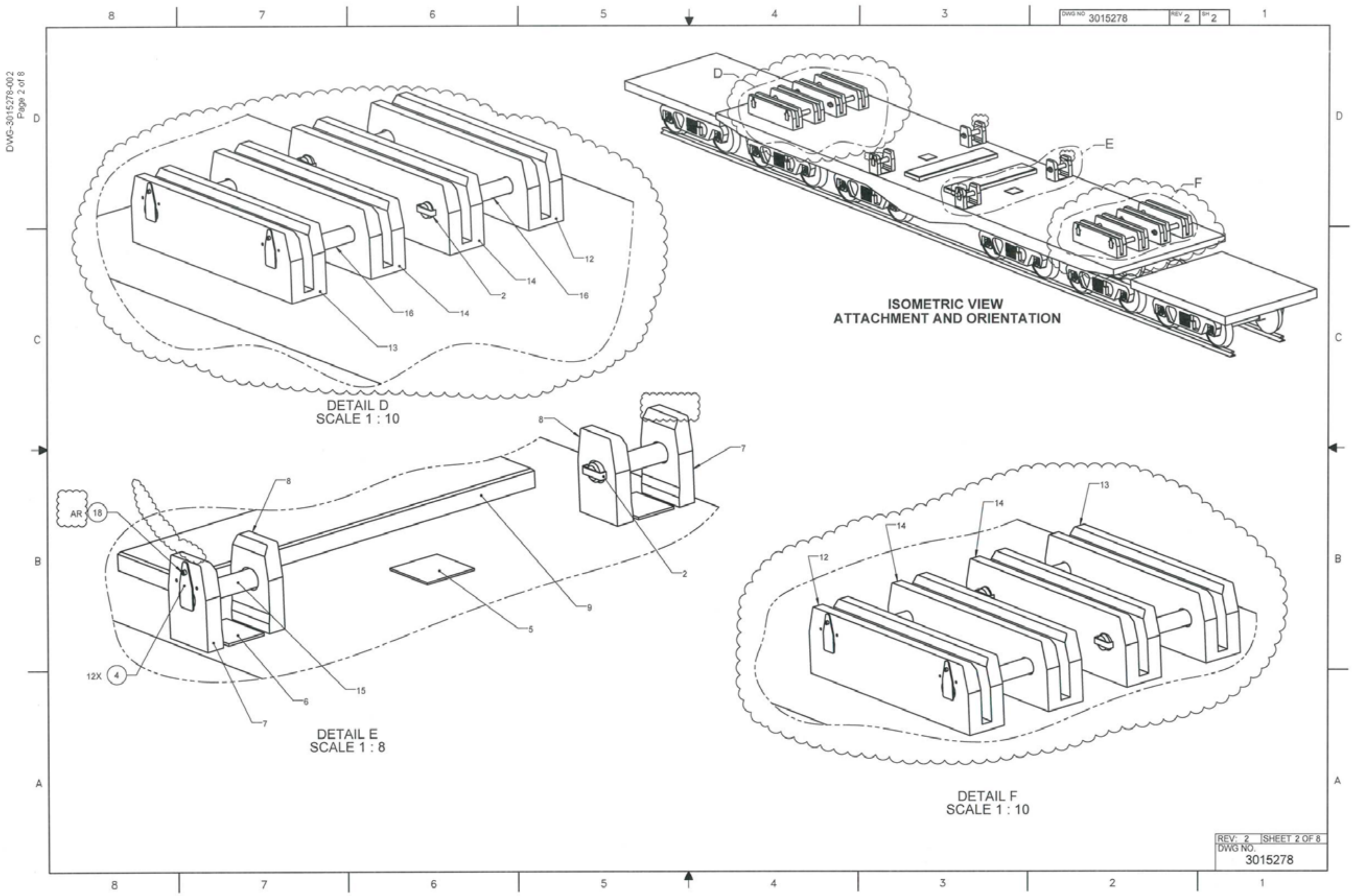
AREVA

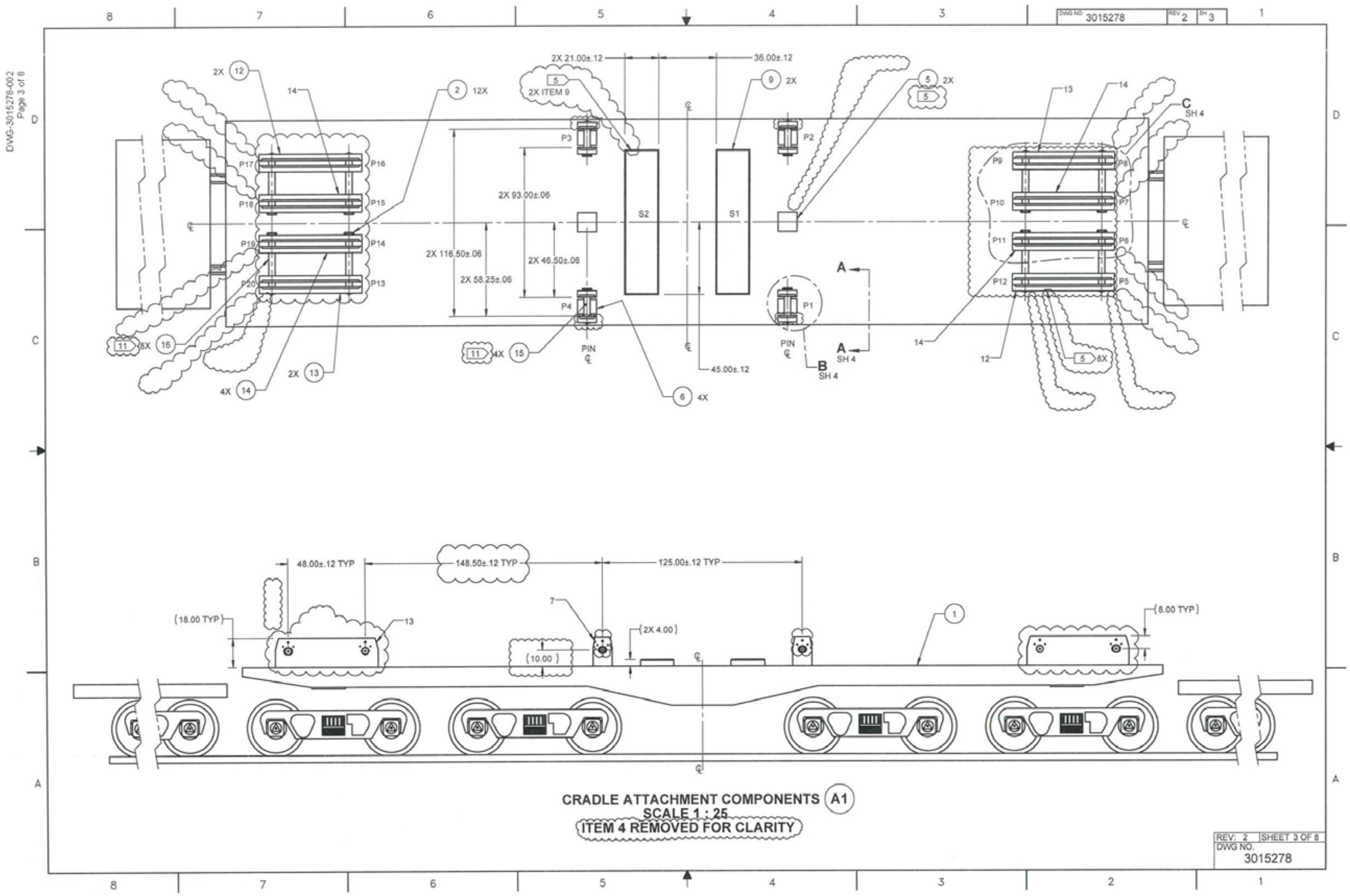
AREVA Federal Services LLC
Packaging Projects
Federal Way, WA 98003

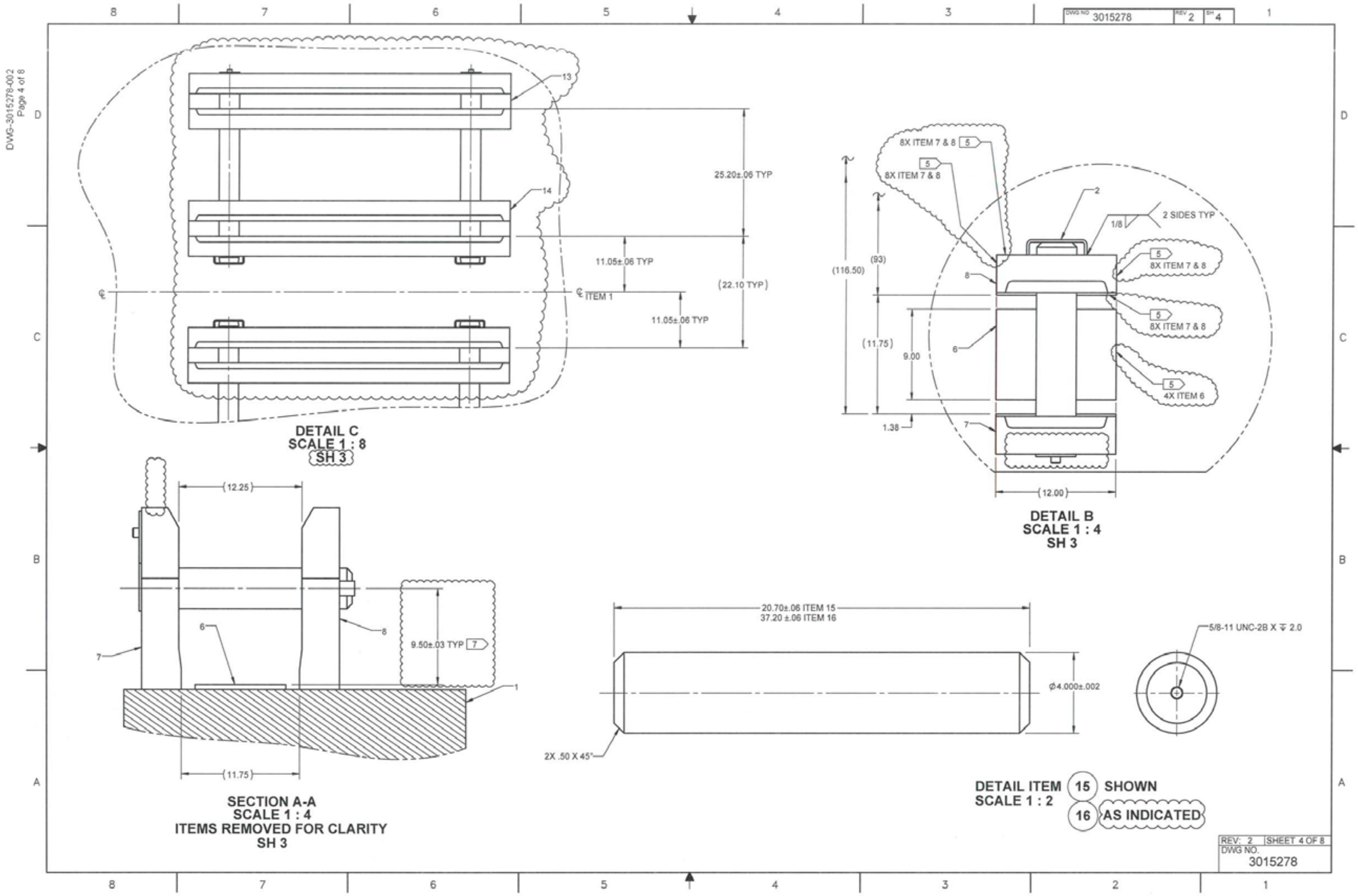
DWG TITLE: ATLAS RAILCAR
CRADLE ATTACHMENT COMPONENTS

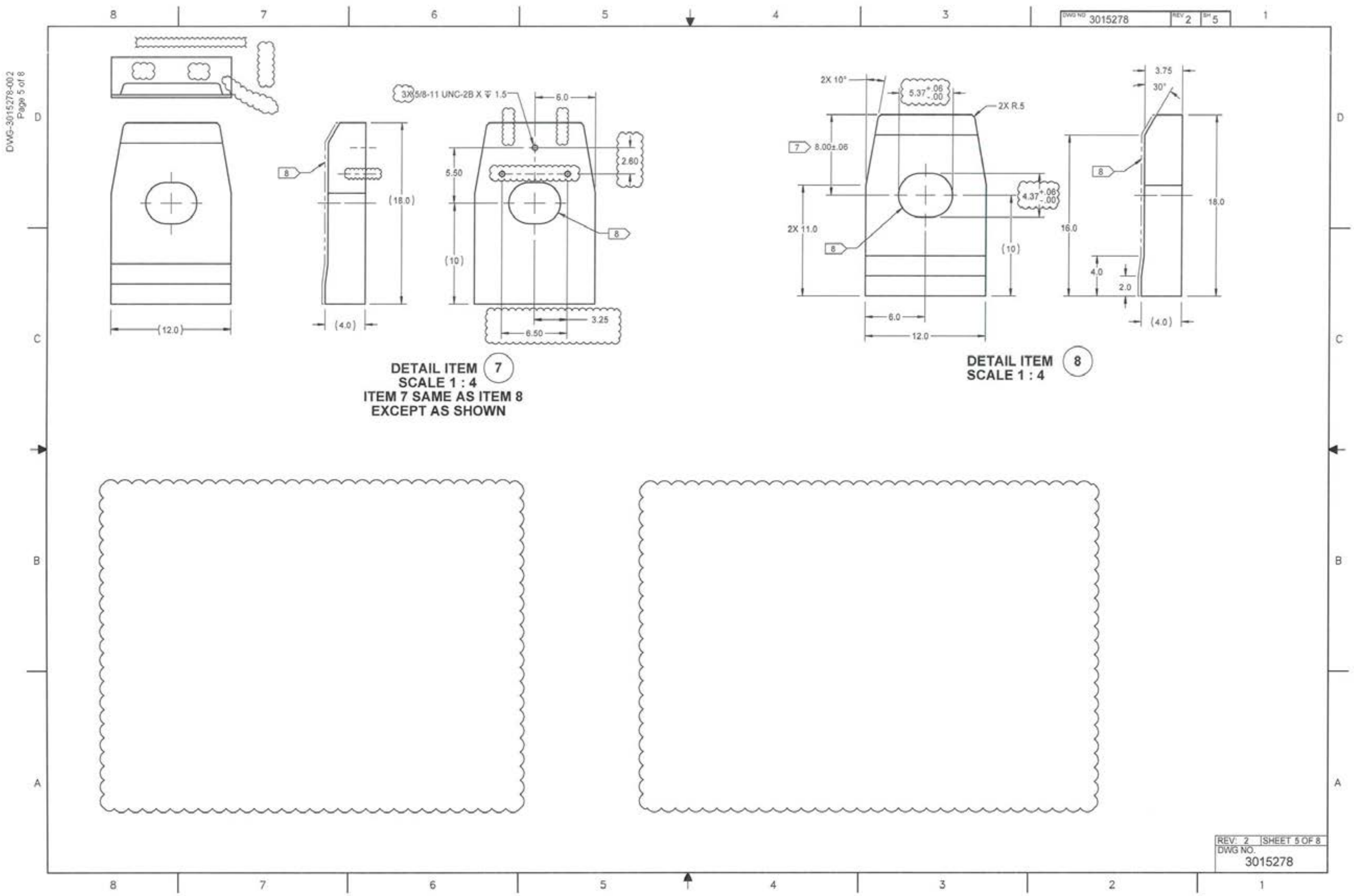
TOLERANCE BLOCK
FRACTIONS ± 1/8 2 PLACE DECIMALS ± .06
ANGLES ± 1° 1 PLACE DECIMALS ± .1

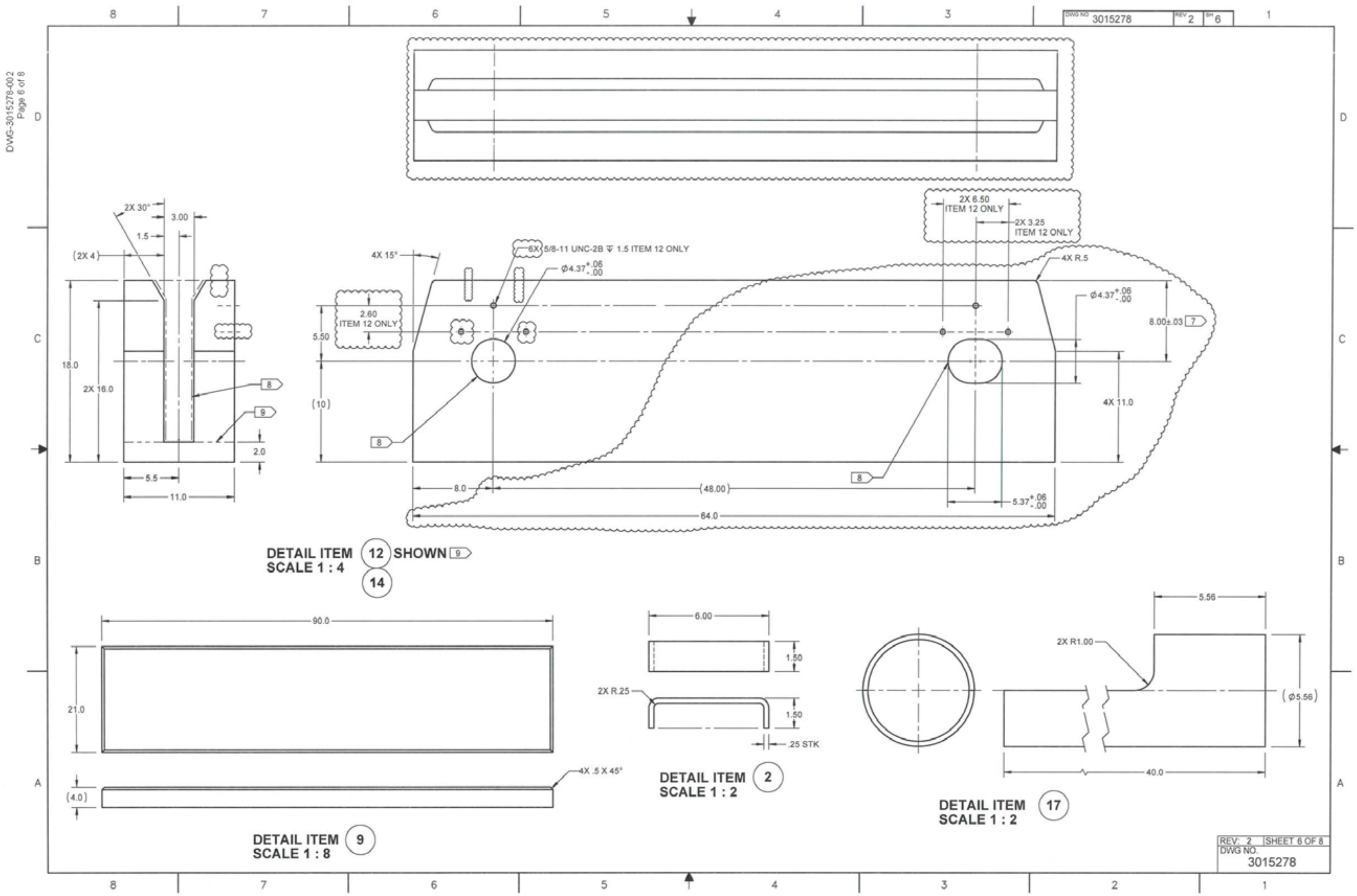
SCALE: SHOWN WT: -
REV: 2 SHEET 1 OF 8
DWG SIZE D DWG NO. 3015278
CADFILE: 3015278 SLDDRW
DWG-3015278-002

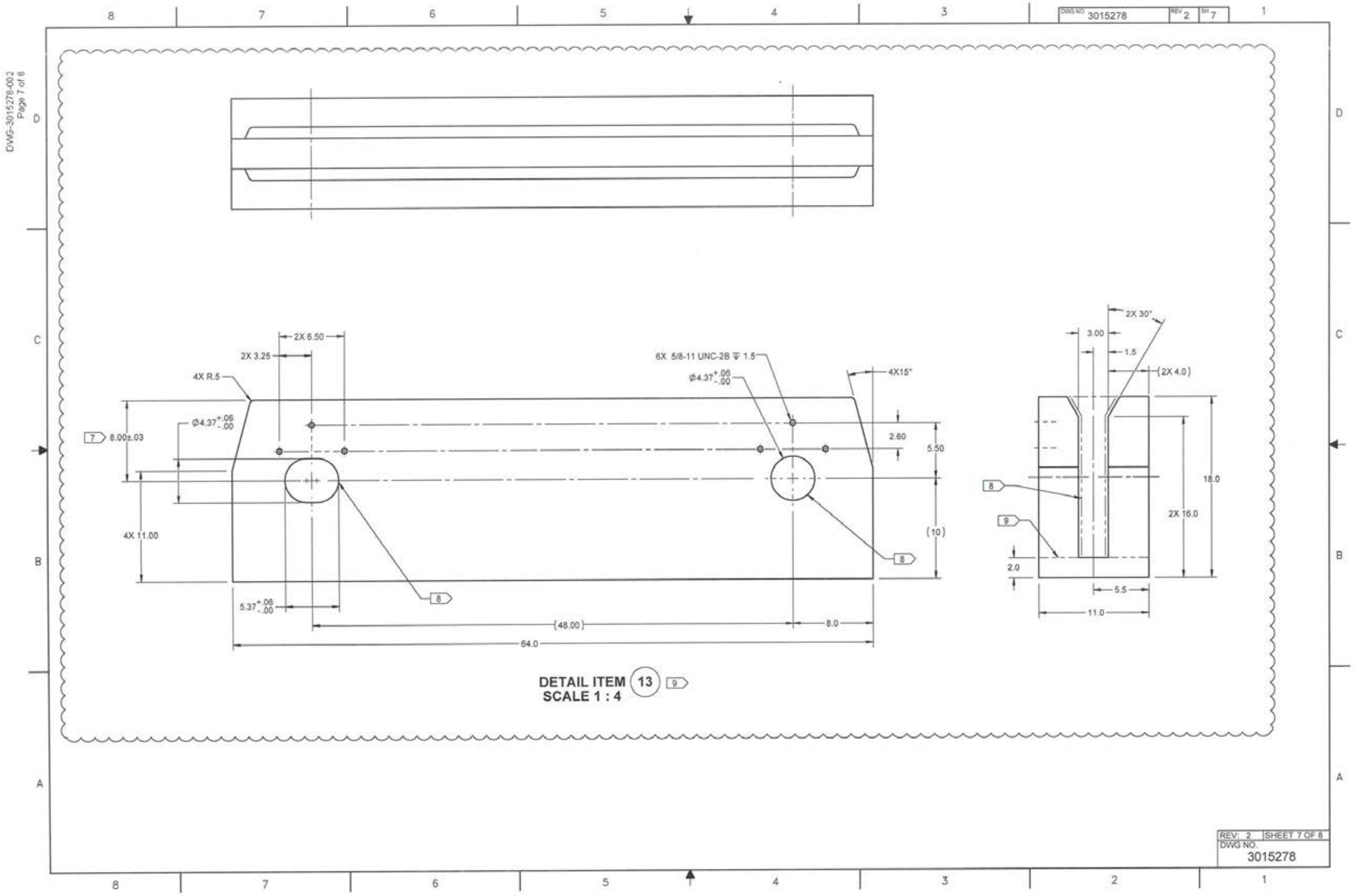

DWG-3015278-002
Page 2 of 8
DWG NO 3015278 REV 2 SH 2
ISOMETRIC VIEW
ATTACHMENT AND ORIENTATION
DETAIL D
SCALE 1 : 10
DETAIL E
SCALE 1 : 8
DETAIL F
SCALE 1 : 10
AR 18
12X 4
REV: 2 SHEET 2 OF 8
DWG NO.
3015278

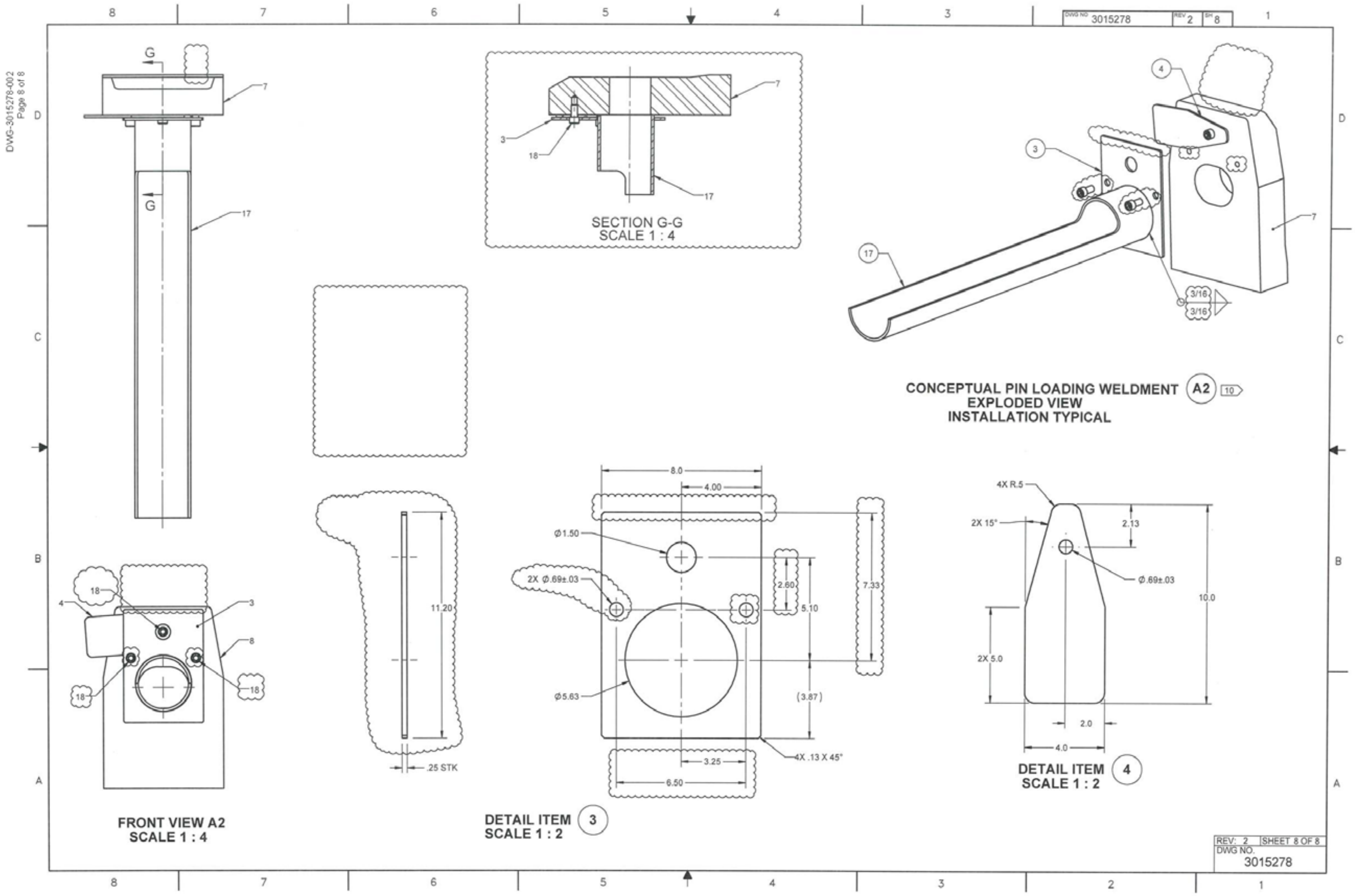

DWG NO 3015278 REV 2 SH 3
DWG-3015278-002
Page 3 of 8
2X 21.00±.12
36.00±.12
2X ITEM 9
2X 93.00±.06
2X 116.50±.06
2X 46.50±.06
2X 58.25±.06
45.00±.12
S2
S1
PIN
48.00±.12 TYP
148.50±.12 TYP
125.00±.12 TYP
(18.00 TYP)
(8.00 TYP)
(2X 4.00)
(10.00)
CRADLE ATTACHMENT COMPONENTS A1
SCALE 1 : 25
ITEM 4 REMOVED FOR CLARITY
REV: 2 SHEET 3 OF 8
DWG NO.
3015278


DWG NO 3015278 REV 2 SH 4
DWG-3015278-002 Page 4 of 8
DETAIL C
SCALE 1 : 8
SH 3
25.20±.06 TYP
11.05±.06 TYP
(22.10 TYP)
ITEM 1
11.05±.06 TYP
8X ITEM 7 & 8
2 SIDES TYP
(116.50)
(93)
(11.75)
9.00
1.38
4X ITEM 6
(12.00)
DETAIL B
SCALE 1 : 4
SH 3
(12.25)
9.50±.03 TYP
20.70±.06 ITEM 15
37.20 ±.06 ITEM 16
5/8-11 UNC-2B X ⌴ 2.0
Ø4.000±.002
2X .50 X 45°
(11.75)
SECTION A-A
SCALE 1 : 4
ITEMS REMOVED FOR CLARITY
SH 3
DETAIL ITEM 15 SHOWN
SCALE 1 : 2
16 AS INDICATED
REV: 2 SHEET 4 OF 8
DWG NO.
3015278


DWG NO 3015278
REV 2
SH 5
DWG-3015278-002
Page 5 of 8
3X 5/8-11 UNC-2B X ⊽ 1.5
DETAIL ITEM 7
SCALE 1 : 4
ITEM 7 SAME AS ITEM 8
EXCEPT AS SHOWN
DETAIL ITEM 8
SCALE 1 : 4
REV: 2
SHEET 5 OF 8
DWG NO.
3015278


DWG NO 3015278 REV 2 SH 6
DETAIL ITEM 12 SHOWN 9
SCALE 1 : 4
14
DETAIL ITEM 9
SCALE 1 : 8
DETAIL ITEM 2
SCALE 1 : 2
DETAIL ITEM 17
SCALE 1 : 2
REV: 2 SHEET 6 OF 8
DWG NO. 3015278


DWG NO 3015278 REV 2 SH 7
DWG-3015278-002 Page 7 of 8
2X 6.50
2X 3.25
4X R.5
6X 5/8-11 UNC-2B ⊽ 1.5
Ø4.37 +.06 -.00
4X15°
8.00±.03
2.60
5.50
4X 11.00
(10)
5.37 +.06 -.00
(48.00)
8.0
64.0
2X 30°
3.00
1.5
(2X 4.0)
18.0
2X 16.0
2.0
5.5
11.0
DETAIL ITEM 13
SCALE 1 : 4
REV: 2 SHEET 7 OF 8
DWG NO.
3015278


DWG-3015278-002
Page 8 of 8
3015278
REV 2
SH 8
SECTION G-G
SCALE 1 : 4
CONCEPTUAL PIN LOADING WELDMENT
EXPLODED VIEW
INSTALLATION TYPICAL
A2
3/16
3/16
Ø1.50
2X Ø.69±.03
Ø5.63
8.0
4.00
2.60
5.10
7.33
(3.87)
3.25
6.50
4X .13 X 45°
11.20
.25 STK
4X R.5
2X 15°
2.13
Ø.69±.03
10.0
2X 5.0
2.0
4.0
FRONT VIEW A2
SCALE 1 : 4
DETAIL ITEM 3
SCALE 1 : 2
DETAIL ITEM 4
SCALE 1 : 2
REV: 2 SHEET 8 OF 8
DWG NO.
3015278

APPENDIX B-2 CALCULATIONS

CALC-3015276-003
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AREVA

AREVA Federal Services LLC

CALCULATION

Document No.:	CALC-3015276	Rev. No.	003	Page 1 of 42
Project No.:	00225.03.0050	Project Name:	DOE Atlas Railcar	
Title:	Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation			

Summary:

This calculation contains the structural evaluation of the Atlas Railcar standardized attachment components. This calculation also calculates the combined center of gravity (cg) and weight for the railcar, cradles and packages.

This document is not safety related.

Safety ☐ Non-Safety ☒

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

Software Utilized: Software Active in AFS EASI: Yes: ☐ NA*: ☒ *Not Applicable per Section 5.7 of AFS-EN-PRC-002 Error Notices & Associated Corrective Actions Reviewed: Yes: ☐ No: ☒	Version: N/A	Storage Media: Yes: ☐ No: ☒ Location: N/A

	Printed Name	Signature	Date
Preparer:	S. Klein	[signature]	3/1/2018
Checker:	A. Ross	[signature]	1 MAR 18
Approver:	D. Hillstrom	Donald S Hillstrom	3/1/18
Other:	N/A		

AFS-EN-FRM-002 Rev. 09 (Effective January 31, 2018)
Reference: AFS-EN-PRC-002

Revision History

Rev.	Changes
000	Initial issue
001	Revised to update railcar to 12 axle design.
002	Revised to update for HI-STAR 190 casks/cradles and to add attachment components weight calculation. Revised for updated Atlas railcar deck heights and Family 1 and 4 cradle changes. Removed weld evaluation. Also, revised attachment component hole/slot size and added ballast load. Other editorial changes.
003	Revised project background for editorial changes. Revision bars left from revision 2 for clarity.

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1.0 PURPOSE

1.1 Project Background

The United States Department of Energy (DOE) is laying the groundwork for implementing an integrated nuclear waste management system. This includes preparing for future large-scale transport of spent nuclear fuel (SNF) and high-level waste (HLW); since transport will be a necessary component of any integrated nuclear waste management system. With this project the DOE will provide for the transportation of SNF and HLW by means of a specific railcar (named by the DOE as the Atlas railcar) to carry SNF and HLW casks.

As part of this project, DOE has contracted with AREVA Federal Services (AFS) to design the Atlas railcar including standardized attachment components (railcar tie-down interface), and transport package conceptual cradle designs for the 17 SNF transportation casks (herein referred to as "packages") listed in Attachment A of the Statement of Work (SOW) [1].

The DOE Atlas railcar (and by extension to subsystems, the package cradles) must be designed and built to satisfy the requirements of Association of American Railroads (AAR) Standard S-2043 [2] and the AFS Design Basis Requirements Document (DBRD) [3]. Application of this standard to the conceptual design analyses is described in Section 2.0. The standardized attachment components are part of the railcar and must also meet the AAR S-2043 requirements.

AFS has chosen to divide the 17 packages into 4 families based on the package tie-down methods. The packages contained in each of these four families are listed below:

Family 1 TN-32B, TN-40, TN-40HT, HI-STAR 60, HI-STAR 100, HI-STAR 100HB (also referred to as HI-STAR HB), HI-STAR 180, HI-STAR 190 SL and the HI-STAR 190 XL.

Family 2 MAGNATRAN®, NAC-STC™, NAC-UMS UTC™, and the TN-68.

Family 3 MP-197, MP-197HB, and the TS125.

Family 4 MP-187.

The empty Atlas railcar will require a ballast load to meet the requirements of AAR Standard S-2043. The ballast load conceptual design is a separate payload from the cask/cradles and must be considered in the attachment design.

1.2 Calculation Purpose

This calculation contains the structural evaluation of the Atlas Railcar standardized attachment components. This calculation also calculates the combined center of gravity (cg) and weight for the railcar, cradles and packages.

1.3 Atlas Railcar Standardized Attachment Components

The Atlas Railcar Standardized Attachment Components are depicted in AFS Drawing DWG-3015278 [4] and are shown in Figure 1-1 below. There are four center pin attachment blocks welded to the railcar that are used for cradle designs in families 1 through 4. The cradles are secured laterally and vertically using four attachment pins inserted through the center pin attachment blocks. Longitudinal restraint for cradle families 2 through 4 is provided by shear blocks welded to the railcar. Family 1 cradles are restrained longitudinally by end stop assemblies attached to the railcar using the outer eight attachment blocks, each of which has two pin locations. The end stop assemblies are pinned in place.

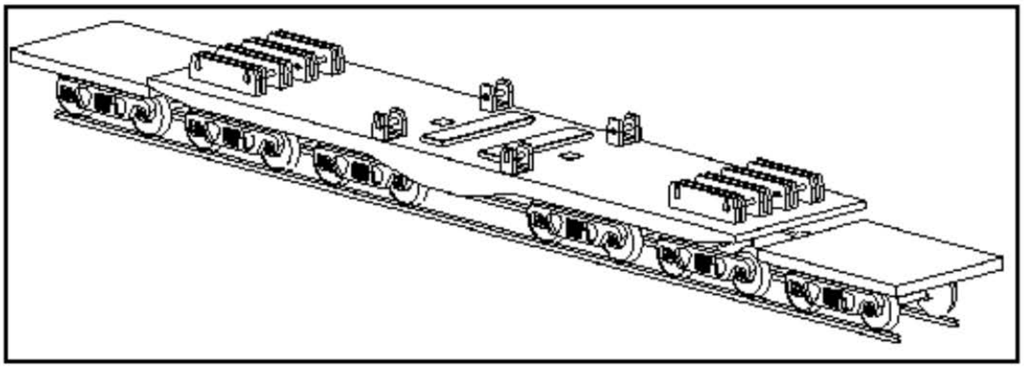


Figure 1-1: Atlas Railcar Standardized Attachment Components

2.0 METHODOLOGY

The conceptual design of each cradle and ballast load was evaluated to determine the tie-down loads applied to the railcar via the standardized attachment components. Each cradle or ballast load is required to support the 7.5g/2g/2g tie-down loads taken individually per Section 2.2.2.13 of the DBRD [3]. The bounding loads from the 17 package designs and associated conceptual cradle designs and the ballast load conceptual design are applied to the standardized attachment components and the bounding loads are shown in Section 4.0.

This calculation uses manual calculations to evaluate the standardized attachment components including the pin attachment blocks, the shear blocks and the attachment pins shown in AFS drawing DWG-3015278 [4]. Material properties are taken at 100 °F per the DBRD [3].

The combined cg and weight of the railcar and load is determined using the package weights and vertical cg locations, calculated weights and vertical cg locations of the conceptual cradle designs, calculated weight and vertical cg location of the conceptual ballast design and the railcar deck height and railcar vertical cg location provided by KASGRO [27].

The fatigue capability of the design will be explored to provide reasonable assurance that the attachment components will support the fatigue loads of Chapter 7 of M-1001 [28] for the design life of the railcar. The fatigue analysis of the railcar should cover the weld details between the attachment components and the railcar.

2.1 Acceptance Criteria

Stresses for the attachment components shall be compared to the allowable stresses. The allowable stress for the standardized attachment components is yield strength for tensile and compressive stresses per Section 2.2.2.13 of [3], and 0.6 of yield stress for shear stresses. Where necessary, stresses will be combined to determine the von Mises stress per equation 6-18 of [7] shown below and compared to the allowable tensile stress.

$$\sigma_v = \sqrt{\sigma_x^2 + 3\tau_{xy}^2}$$

Per Section 2.2.1.1 of [3], the cask car and buffer car must comply with the AAR's Manual of Standards and Recommended Practices which includes M-1001 [28]. Per Section 2.1.3 of M-1001, the combined cg of a fully loaded car must be less than 98 inches. The combined weight of the railcar, cradle and loaded cask or railcar and ballast load must be less than 65,750 pounds per axle (789,000 pound loaded car limit) per AFS-IN-16-0039 [6].

The attachment components must allow for impact limiter removal for all 17 of the packages listed in Attachment A of the SOW [1].

2.2 Margin of Safety

A margin of safety is used to indicate the degree of confidence in the allowable loads and stresses. For acceptance the margin of safety must be greater or equal to zero. The margin of safety (MS) of component stresses is calculated as:

$$MS = \frac{\text{Allowable Stress}}{\text{Actual Stress}} - 1 \geq 0$$

Additional design confidence and increased conservatism is provided from 10% increase in load discussed in Section 4.1. All calculated margins of safety greater than or equal to zero include this additional factor.

3.0 ASSUMPTIONS

3.1 Unverified Inputs/Assumptions

None.

3.2 Justified Assumptions

None.

4.0 DESIGN INPUTS

4.1 Transportation Package Design Inputs

Design inputs for the tie-down loading are taken from the following calculations:

1. Atlas Railcar Family 1 Conceptual Cradle Structural Calculation [10]
2. Atlas Railcar Family 2 Conceptual Cradle Structural Calculation [11]
3. Atlas Railcar Family 3 Conceptual Cradle Structural Calculation [12]
4. Atlas Railcar Family 4 Conceptual Cradle Structural Calculation [13]
5. Atlas Railcar Conceptual Ballast Load Structural Calculation [17]

The tie-down loadings for each cask family were taken from the above calculations and compiled to list the maximum loading value at each attachment point as shown in Table 4-1. Pin locations are shown in Figure 4-1.

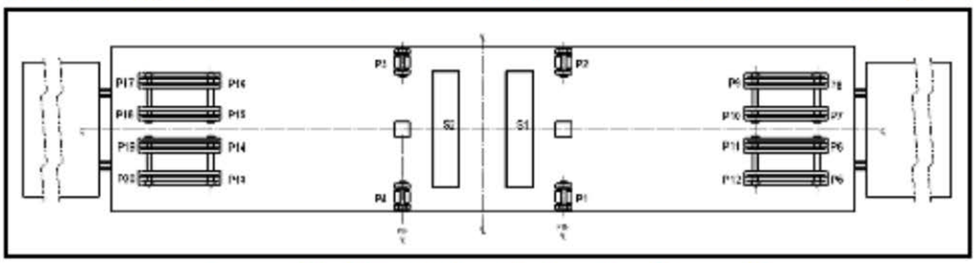


Figure 4-1: Atlas Railcar Pin Location Nomenclature

Table 4-1: Initial Tie-Down Loading Inputs (kips)

	Pin Location 1(1)	Pin Location2(1)	Pin Location 3(1)	Pin Location 4(1)
vertical (+z)	664	664	664	664
vertical (-z)	664	664	664	664
lateral (y)(3)	555	555	555	555
	Shear Block(1)			
axial (x)	2,655			
	Pin Location 5-8(2)	**Pin Location 9-12(2)**	**Pin Location 13-16(2)**	**Pin Location 17-20(2)**
Axial (+x)	0	858	207	0
Axial (-x)	0	207	858	0
vertical (+z)	107	979	979	107
vertical (-z)	979	107	107	979
lateral (y)	132	132	132	132

Notes:

1. The bounding vertical and axial (longitudinal) loads are from the MAGNATRAN package per Table 6-1 of [11]. The bounding lateral load is from Table 2.2 of HI-STAR 190 XL [10].

   The bounding vertical load is calculated based on the following assumptions: 1) the Family 1 casks are assumed to be restrained without motion by the end stop assemblies and impact limiter and shims (if required) are assumed to be rigid under the securement tie-down loads (7.5 g). 2) if crush of the impact limiter could occur under load, the cask vendor will need to add a shear key and address other features of the cradle that may be affected by the new load path. The vendor will also need to ensure that all SAR requirements are met. 3) shims (if required) are assumed to be rigid and captured.

2. The bounding loads for Pin locations 5-20 are taken from Table 2.2 of [10] or Table 6-1 of [17].

3. The maximum lateral load is from the HI-STAR 190 XL package per [10]. Conservatively, the lateral loading is assumed to result in a combined loading at one pin location. The maximum vertical load from any lateral load case is 283.6 kips from Table 2.2 of [10].

The standardized attachment components will be fabricated and attached to the Atlas railcar. These attachment points must accommodate both the conceptual and the final cradle designs for all 17 packages listed in the SOW. The conceptual cradle designs are not final and some small changes are anticipated in the final cradle design (to be performed at a later date). Therefore, an additional factor of 1.1 was added to the loadings to provide increased conservatism in the attachment component design. Final tie-down loading inputs are shown in Table 4-2.

Table 4-2: Final Tie-Down Loading Inputs (kips)

	Pin Location 1	Pin Location 2	Pin Location 3	Pin Location 4
vertical (+z)	730	730	730	730
vertical (-z)	730	730	730	730
lateral (y)[1]	611	611	611	611
	Shear Block			
axial (x)	2,921			
	Pin Location 5-8	**Pin Location 9-12**	**Pin Location 13-16**	**Pin Location 17-20**
Axial (+x)	0	944	228	0
Axial (-x)	0	228	944	0
vertical (+z)	118	1,077	1,077	118
vertical (-z)	1,077	118	118	1,077
lateral (y)	145	145	145	145

Notes: 1. The adjusted maximum vertical load to be combined with the lateral load in the lateral load case is 283.6(1.1) = 312 kips

To calculate the combined weight and center of gravity location, the maximum (loaded) cask weight, cask vertical cg location, minimum cradle weight, cradle vertical cg location as well as the railcar weight, deck height (when loaded) and railcar vertical cg location are required. The cask weights and cg locations are shown in Table 4-3. Cradle design inputs are shown in Table 4-4.

Table 4-3: Cask Design Inputs

Cask	Family	Maximum (Loaded) Cask Weight, lb	Minimum (Empty) Cask Weight, lb(1)	Cask Vertical cg from railcar deck, in(2)	Reference
NAC-STC	2	254,589	188,767	67.50+0.5 = 68.00	Table B-2 of [11]
NAC-UMS UTC	2	255,022	178,798	67.50+0.5 = 68.00	Table B-2 of [11]
MAGNATRAN	2	312,000	208,000	67.50+0.5 = 68.00	Table B-2 of [11]
HI-STAR 100	1	279,893	179,710	66.00+0.5 = 66.50	Table 4.1 of [10]
HI-STAR 100HB	1	187,200	-	66.00+.05 = 66.50	Table 4.1 of [10]
HI-STAR 180	1	308,647	<308,647	64.50+0.5 = 65.00	Table 4.1 of [10]
HI-STAR 60	1	164,000	<164,000	59.63+0.5 = 60.13	Table 4.1 of [10]
HI-STAR 190 SL	1	382,746	282,746	64.50+0.5 = 65.00	Table 4.1 of [10]
HI-STAR 190 XL	1	420,769(3)	304,369	64.50+0.5 = 65.00	Table 4.1 of [10]
MP187	4	271,300	190,200	64.5+0.5 = 65.00	Table 4.1 of [13]
MP197	3	265,100	176,710	62.00+0.5 = 62.50	Table 5.3-1 of [12]
MP197HB	3	303,600	179,000	64.00+0.5 = 64.50	Table 5.3-1 of [12]
TN-32B	1	263,000	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN-40	1	271,500	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN40HT	1	242,343	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN-68	2	272,000	<272,000	77.50+0.5 = 78.00	Table B-4 of [11]
TS125	3	285,000	196,118	72.80+0.5 = 73.30	Table 5.3-1 of [12]

Notes:

1. The empty cask weights are taken from the DOE SOW Attachment A [1].
2. The cg is increased by 0.5 inches due to the standardized attachment components shim plate.
3. The maximum weight for the HI-STAR 190 XL cask is from AFS-RFI-0015 [5].

Table 4-4: Cradle Design Inputs

Cask	Family	Nominal Cradle Weight, lb	Cradle Vertical cg from railcar deck, in[(1)]	Reference
NAC-STC	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
NAC-UMS UTC	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
MAGNATRAN	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
HI-STAR 100	1	67,091[(2)]	44.5+0.5 = 45.0	Table 6.1 of [10]
HI-STAR 100HB	1	73,182[(2)]	57.2+0.5 = 57.7	Table 6.1 of [10]
HI-STAR 180	1	58,273[(2)]	54.4+0.5 = 54.9	Table 6.1 of [10]
HI-STAR 60	1	83,727[(2)]	60.1+0.5 = 60.6	Table 6.1 of [10]
HI-STAR 190 SL	1	55,909[(2)]	52.0+0.5 = 52.5	Table 6.1 of [10]
HI-STAR 190 XL	1	53,636[(2)]	51.6+0.5 = 52.1	Table 6.1 of [10]
MP187	4	32,500	28.5+0.5 = 29.0	Table 4-1 of [13]
MP197	3	26,000	17 +0.5 = 17.5	Table 5.3-1 of [12]
MP197HB	3	26,000	17.5+0.5 = 18.0	Table 5.3-1 of [12]
TN-32B	1	74,000[(2)]	48.8+0.5 = 49.3	Table 6.1 of [10]
TN-40	1	75,091[(2)]	47.0+0.5 = 47.5	Table 6.1 of [10]
TN40HT	1	75,091[(2)]	47.0+0.5 = 47.5	Table 6.1 of [10]
TN-68	2	27,000	26 +0.5 = 26.5	Table B-3 of [11]
TS125	3	30,000	24.5 +0.5 = 25.0	Table 5.3-1 of [12]

Notes: 1. The cg is increased by 0.5 inches due to the standardized attachment components shim plate.

2. The central cradle weight is added to the end stop weight to calculate to total nominal cradle weight. Values are scaled from maximum.

4.2 Material Properties

The material properties listed in Table 4-5 are used in the design. The yield and ultimate strengths are the minimum values found in the ASTM standards [14] and [15]. Material density is from ASME B&PV Code Section II, Part D Table PRD [16]. The structure is primarily ASTM A572, Grade 50, high-strength low-alloy columbium-vanadium structural steel. Material properties at 100 °F are used. The attachment pins are constructed from ASTM A564, Type 630, Condition H1025, hot-rolled and cold-finished age-hardening stainless steel.

Table 4-5: Material Properties

Material	Yield Stress (ksi)	Ultimate Stress (ksi)
ASTM A572, Grade 50	50	65
ASTM A564, Type 630, Condition H1025	145	155

5.0 CALCULATIONS

5.1 Allowable Stresses

The allowable minimum yield strength and ultimate strength of ASTM A572, Grade 50 is 50 ksi and 65 ksi respectively [14]. The minimum yield and ultimate stress for ASTM A564, Type 630, Condition H1025 is 145 ksi and 155 ksi respectively [15].

The tie-down loading stresses for the 7.5/2/2g load cases are compared directly against yield strength. The pin attachment blocks and shear blocks are ASTM A572, Grade 50. The attachment pins are ASTM A564, Type 630, Condition H1025. The allowable stresses are:

Attachment Block/Shear Block allowable stress:	$S_{AT} = S_y = 50$ ksi
Attachment Block/Shear Block allowable shear stress:	$S_{AS} = 0.6S_y = 30$ ksi
Attachment Pin allowable stress:	$S_{A564} = S_y = 145$ ksi

5.2 Standardized Attachment Components

The following components are evaluated to determine the adequacy of the attachment component design:

- Center Pin Attachment Blocks
- Shear Blocks
- Outer Pin Attachment Blocks
- Attachment Pins

5.2.1 Center Pin Attachment Blocks

The center pin attachment blocks (Item 7 and 8 of [4]) are shown in Figure 5-1 and are used to secure the cradles to the railcar. The pin blocks are subjected to lateral and vertical tie-down loads. Using the bounding loads from Table 4-2 the tie-down loading is:

Center pin block (CPB) lateral tie-down load, $F_{CPB\_lat} = 611$ kip and the vertical load from lateral tie-down load, $F_{CPB\_vlat} = 312$ kip (load is shared by two blocks, Item 7 and 8 of [4]) is taken from Section 4.1 (Note 1 following Table 4-2).

Center pin block vertical tie-down load, $F_{CPB\_v} = 730$ kips (load is shared by two blocks, Item 7 and 8 of [4]).

As shown in Section 5.2.7, the load on the attachment pin which is applied to the center pin attachment blocks is not shared equally. The load can be offset in either direction. The maximum load distribution is 379.5/730 = .52.

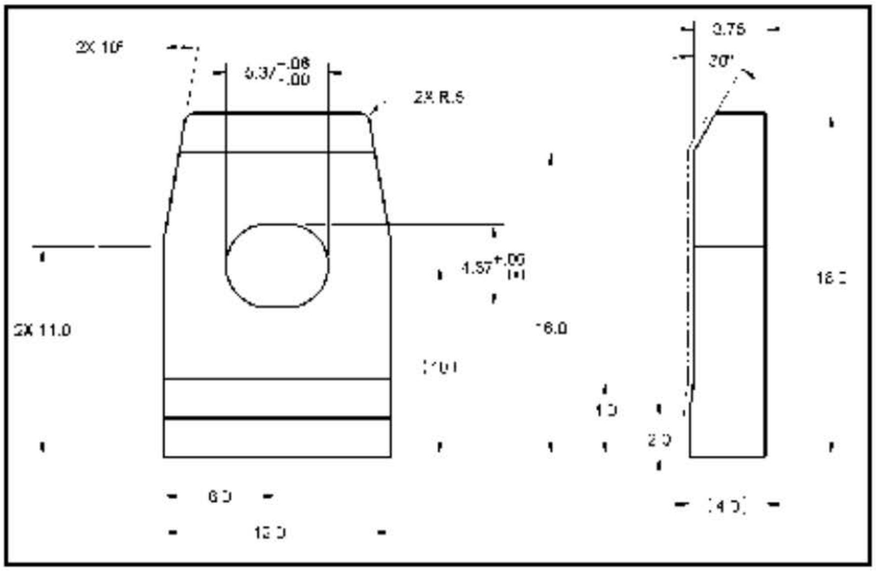


Figure 5-1: Center Pin Attachment Block

Center Pin Attachment Blocks - Vertical Load

The center pin attachment blocks are subjected to tension loading, shear tear-out, and bearing from the vertical tie-down load.

Tensile loading

The minimum tensile area is located at the hole center and is:

$$A = (12.00 - 5.37)(3.62) = 24.0\ in^2$$

where the block length is 12.00 inches, the slotted hole length is 5.37 inches and the block thickness is 3.75-0.13 = 3.62 inches (maximum stainless steel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected) at the hole per the drawing dimensions [4]. The tensile stress is:

$$\sigma = \frac{F_{CPB\_v}}{A} = \frac{730(.52)}{24.0} = 15.8\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AT} = 50 ksi. The margin of safety is:

$$MS = \frac{50}{15.8} - 1 = +2.16$$

Shear tear-out

The pin block is subjected to shear-tear out from vertical loading. The shear tear-out area is conservatively calculated using twice the straight line distance:

$$A = (2)\left(16.0 - 10.0 - \frac{4.37}{2}\right)(3.62) = 27.6\ in^2$$

where the height of the pin block chamfer is 16.0 inches, the height of the slotted hole is 10.0 inches, the slot diameter is 4.37 inches and the thickness of the block is 3.62 inches (see discussion above) per the drawing dimensions [4]. Conservatively, this neglects the material at less than the full 3.75 inch thickness. The shear tear-out stress is:

$$\tau = \frac{F_{CPB\_v}}{A} = \frac{730(.52)}{27.6} = 13.8\ ksi$$

From Section 5.1, the allowable shear stress, S_{AS} = 30 ksi. The margin of safety is:

$$MS = \frac{30}{13.8} - 1 = +1.17$$

Bearing stress

The pin attachment block features a slotted hole that interfaces with the round attachment pin. However, there is no normal loading condition that will exceed the weight of the cask and cradle to load the pin and attachment block. Therefore, bearing is not a concern for normal loading. The tie-down loading will load the pin; however bearing is not considered a failure and will not be evaluated here.

Center Pin Attachment Blocks - Lateral Load

The center pin attachment blocks are subjected to shear and bending from the lateral load. There is also combined stress from the vertical load created from the lateral load moment. The pin attachment blocks support the lateral load at their base. The blocks have a 4.00 inch thick boss that extends 2 inches up the 18 inch high block. This boss face with the opposite pin block boss face create the 11.75 inch opening for cradle I-beam insertion. The lateral load results in a shear stress at the base of the block as well as a bending stress from the 2 inch high contact region. The moment is applied at the center of the contact or 1.25 inches (2.0 contact region and 0.5 inch high pad on railcar deck (2-0.5)/2+0.5 = 1.25 inches) from the railcar deck. Due to the moment and resisting load created by the lateral load being applied at the package cg, there is also a vertical load on the pin block. The tensile load is added to the bending stress and then combined with the shear stress to determine the combined stress. The combined tension and shear is also checked at the hole location.

The center pin block (CPB) lateral load, F_{CPB_lat} = 611 kip

The CPB vertical load from lateral tie-down load, F_{CPB_vlat} = 312 kip (load is shared by two blocks) is taken from Section 4.1.

At Block base

The pin block is subjected to shear, bending, and tension at the base. The base cross-section area is:

$$A = (12.00)(3.87) = 46.4\ in^2$$

where the width of the attachment block is 12.00 inches, and the thickness of the block at the base is 4.00-0.13 = 3.87 inches (maximum stainless streel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected) per [4]. The moment of inertia at the base is:

$$I = \frac{1}{12}(12.00)(3.87)^3 = 58.0\ in^3$$

The tensile stress is:

$$\sigma = \frac{F_{CPB_{vlat}}(.52)}{A} = \frac{312(.52)}{46.4} = 3.50\ ksi$$

The shear stress is:

$$\tau = \frac{F_{CPB\_lat}}{A} = \frac{611}{46.4} = 13.2\ ksi$$

The bending moment is:

$$M = (F_{CPB_{lat}})(1.25) = (611)(1.25) = 764\ in - kip$$

The bending stress is:

$$\sigma_b = \frac{My}{I} = \frac{764(\frac{4.00}{2})}{58.0} = 26.3\ ksi$$

where the overall thickness is conservatively used. The combined stress is:

$$\sigma_v = \sqrt{(\sigma + \sigma_b)^2 + 3\tau^2} = \sqrt{(3.50 + 26.3)^2 + 3(13.2)^2} = 37.6\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AT} = 50 ksi. The margin of safety is:

$$MS = \frac{50}{37.6} - 1 = +0.33$$

5.2.2 Center Pin Attachment Block Welds

The weld connection to the railcar deck will be specified by KASGRO Rail. The transportation loads applied to the center pin attachment blocks are listed below. The weld is loaded separately from the vertical and lateral tie-down loading with the lateral loading producing a combined load.

The vertical load shown below is applied separately at the pin hole:

Pin hole, center pin block (CPB) vertical load, F_{CPB_v} = 730 kips (load is shared by two blocks)

The vertical and lateral loads shown below are applied simultaneously at the pin hole:

Pin hole, center pin block lateral load, F_{CPB_lat} = 611 kip

Pin hole, vertical load from lateral tie-down load, F_{CPB_vlat} = 312 kip (load is shared by two blocks)

5.2.3 Shear Blocks

The shear blocks (Item 9 of [4]) are shown in Figure 5-2 and are used to react the axial tie-down loads from the cradles. The shear blocks are subjected to the longitudinal load only. Using the bounding loads from Table 4-2, the loading is:

Shear block (SB) longitudinal load, F_{SB_long} = 2,921 kip

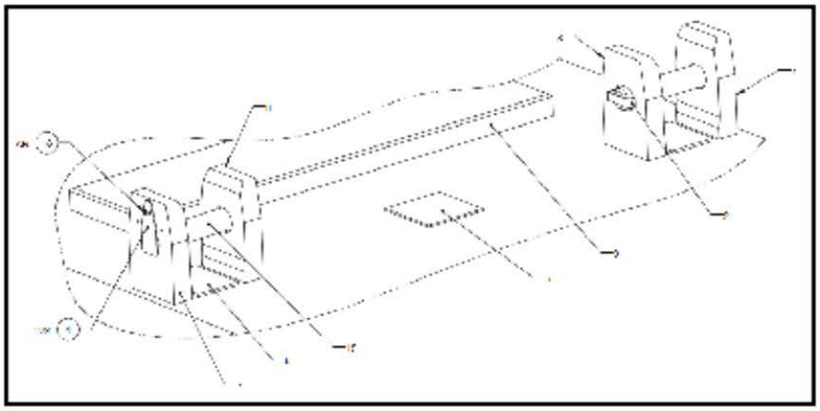


Figure 5-2: Shear Blocks

The shear blocks are subjected to shear from the longitudinal load. The shear area is:

$$A = (90.00)(21.00) = 1{,}890\ in^2$$

where the shear block width is 90.00 inches and the shear block length is 21.00 inches per the drawing dimensions [4]. The shear stress is:

$$\tau = \frac{F_{SB\_long}}{A} = \frac{2{,}921}{1{,}890} = 1.55\ ksi$$

From Section 5.1, the allowable shear stress, S_{AS} = 30 ksi. The margin of safety is:

$$MS = \frac{30}{1.55} - 1 = +18.4$$

5.2.4 Shear Blocks Weld

The weld connection to the railcar deck will be specified by KASGRO Rail. The transportation loads applied to the shear block are listed below.

The weld is loaded from the longitudinal tie-down loading

Shear block longitudinal load, F_{SB_long} = 2,921 kips

5.2.5 Outer Pin Attachment Blocks

The outer pin attachment blocks are used to secure the end stops to the railcar. The longitudinal tie-down load applies a combined longitudinal and vertical load (at P9-P12 and P13-P16) and a vertical load (at P5-P8 and P17-P20) to the outer pin blocks. See Figure 4-1 for pin locations and Figure 5-4 and Figure 5-5 for loading. The outer pin blocks are also loaded separately by the lateral and vertical tie-down loads. These loads are very small as the outer attachment blocks only restrain the end stop structure weight or ballast weight in these directions. The lateral and vertical tie-down loads are bounded by the loads applied at the center pin attachment blocks. The center pin attachment blocks are subjected to much higher loads and have a much shorter length.

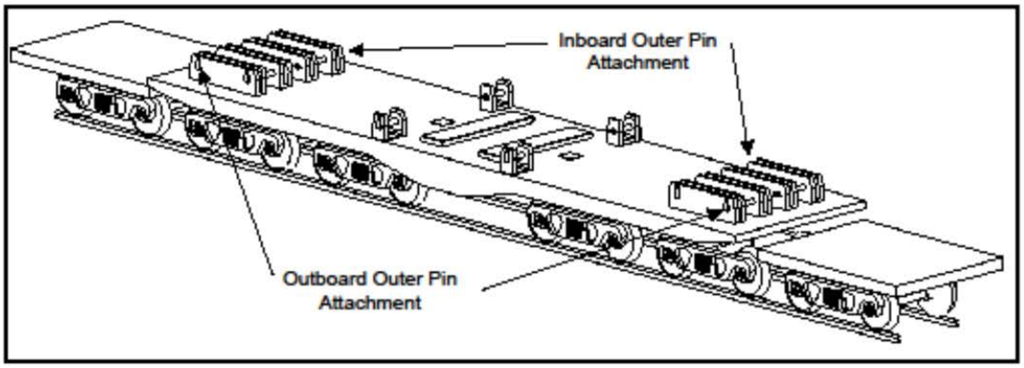


Figure 5-3: Outer Pin Attachment Block Nomenclature

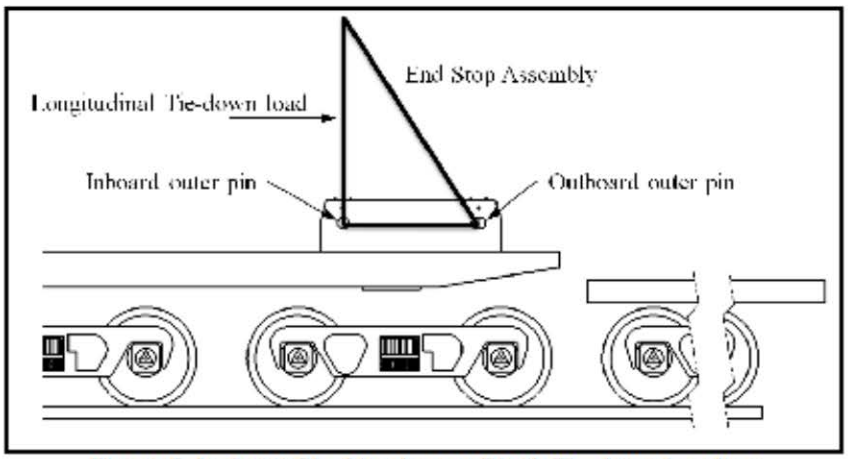


Figure 5-4: Outer Pin Attachment Block Tie-down Loading

Outer Pin Attachment Blocks –Loading

These loads are applied simultaneously. Using the bounding loads from Table 4-2, the loading is:

Inboard outer pin (IOPB) longitudinal load, F_{IOPB_long} = 944 kip

Inboard outer pin (IOPB) vertical (+) load, F_{IOPB_v} = 1,077 kip

Outboard outer pin (OOPB) vertical (-) load, F_{OOPB_v} = 1,077 kip

The combined load at the inboard pin location is:

$$F_{IOPB\_c} = \sqrt{944^2 + 1{,}077} = 1{,}432\ kip$$

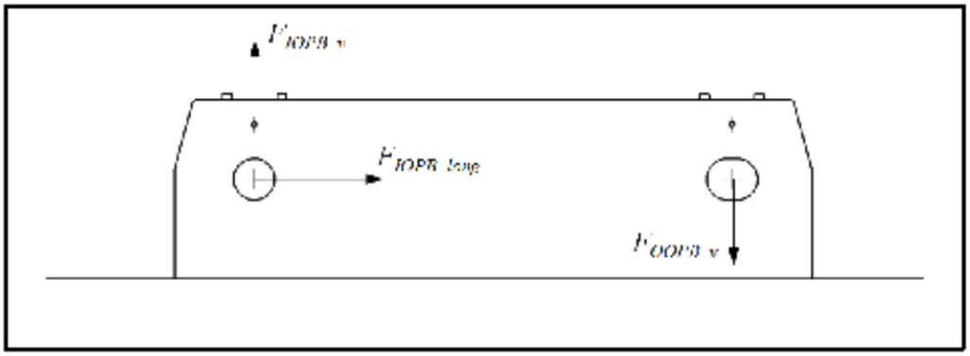


Figure 5-5: Outer Pin Attachment Block Loading

The outer pin attachment blocks (See Figure 5-9) are subjected to tension loading, shear tear-out, and bending from the combined longitudinal and vertical loads.

Tension Loading

The minimum tensile area is perpendicular to the line of action of the force as shown in Figure 5-6 below.

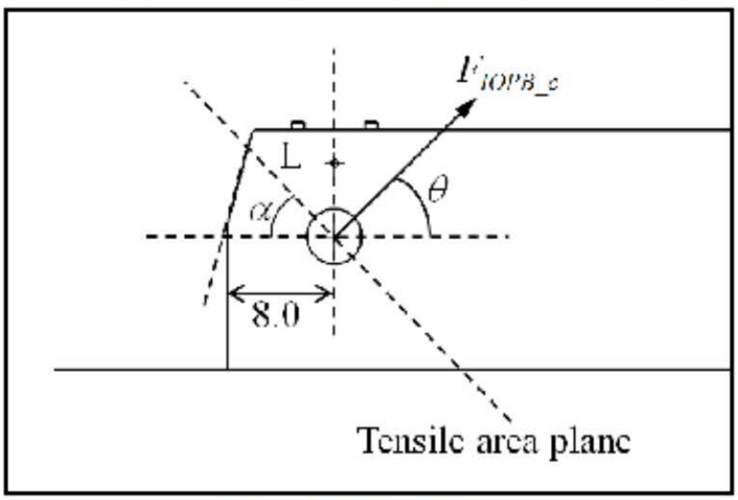


Figure 5-6: Tensile Area

Conservatively twice the distance from the pin hole to the chamfer edge will be used. The angles formed by the combined force are

$$\theta = \arctan(\frac{1{,}077}{944}) = 48.8°$$

$$\alpha = 90 - \theta = 41.2°$$

To calculate the edge distance, L, the chamfer line is extended down to the height of the pin hole to form the triangle shown in Figure 5-7 below.

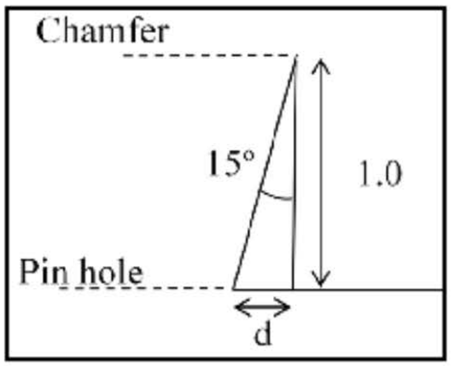


Figure 5-7: Chamfer Distance

The distance d is calculated as:

$$d = 1.0\tan(15) = .268\ in$$

The triangle formed by the intersection of the pin hole, extended chamfer line and distance L is shown in Figure 5-8 below.

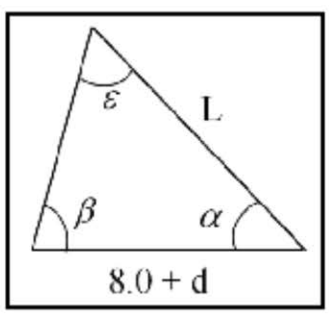


Figure 5-8: Tensile Area Geometry

The angles β and ε can be calculated as:

$$\beta = 90 - 15 = 75°$$

$$\varepsilon = 180 - 75 - 41.2 = 63.8°$$

The distance L can then be calculated using the law of sines

$$L = \frac{\sin(\beta)(8.0 + d)}{\sin(\epsilon)} = \frac{\sin(75)(8.0 + .268)}{\sin(63.8)} = 8.90\ in$$

The tensile area is

$$A = 2(2)\left(8.90 - \frac{4.37}{2}\right)(3.87) = 103.9\ in^2$$

where the block leg thickness is 4.0-.13 = 3.87 inches (maximum stainless steel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected), and there are two block legs per the drawing dimensions [4]. The tensile stress is:

$$\sigma = \frac{F_{IOPB\_c}}{A} = \frac{1{,}432}{103.9} = 13.8\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AT} = 50 ksi. The margin of safety is:

$$MS = \frac{50}{13.8} - 1 = +2.62$$

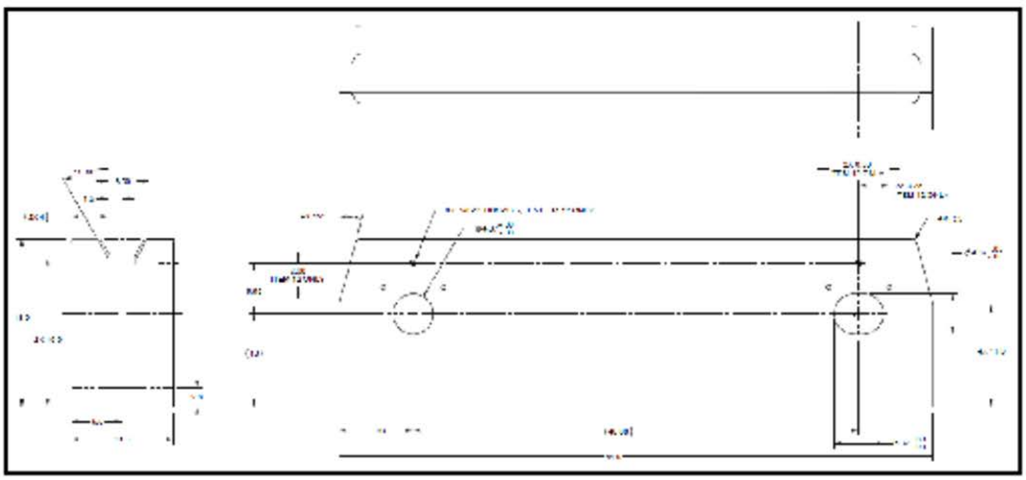


Figure 5-9: Outer Pin Attachment Block

<u>Shear tear-out</u>

The pin block is subjected to shear-tear out from combined loading at the inboard hole location. The shear tear-out area is conservatively calculated using twice the straight line vertical distance:

$$A = 2(2)\left(16.0 - 10.0 - \frac{4.37}{2}\right)(3.87) = 59.1\ in^2$$

where the height of the pin block chamfer is 16.0 inches, the center of the hole is 10.0 inches, the hole diameter is 4.37 inches and the thickness of the block leg is 3.87 inches (as discussed above), and there are two legs per [4]. Conservatively, this neglects the material at less than the full 4.0 inch thickness. Conservatively applying the combined load to the vertical tear-out area, the shear tear-out stress is:

$$\tau = \frac{F_{IOPB\_c}}{A} = \frac{1{,}432}{59.1} = 24.2\ ksi$$

From Section 5.1, the allowable tensile stress, S_{AS} = 30 ksi. The margin of safety is:

$$MS = \frac{30}{24.2} - 1 = +0.24$$

Bending

The outer pin blocks are not subjected to bending from bounding longitudinal tie-down load. The tensile and shear tear-out evaluations performed above are bounding.

5.2.6 Outer Pin Attachment Block Welds

The weld connection to the railcar deck will be specified by KASGRO Rail. The transportation loads applied to the outer pin attachment blocks are listed below.

The longitudinal and vertical loads shown below are applied simultaneously.

Applied at the pin hole, inboard outer pin block (IOPB) longitudinal load, F_{IOPB_long} = 944 kip

Applied at the pin hole, inboard outer pin block (IOPB) vertical (+) load, F_{IOPB_v+} = 1,077 kip

Applied at the pin hole, outboard outer pin block (OOPB) vertical (-) load, F_{OOPB_v-} = 1,077 kip

5.2.7 Attachment Pin

The attachment pins used by the center pin attachment blocks (Item 15 of [4]) are used to secure the cradles to the railcar. They are inserted through the center pin attachment blocks and the holes in the cradle main beams. The attachment pins used by the outer pin attachment blocks (Item 16 of [4]) to secure the end stop assemblies are double length and are used to secure both legs of the end stop. However the loading condition on each pin is similar for each location (double or single).

Pin at Center Pin Attachment Block

The maximum load on the attachment pin at the center pin attachment blocks is from the vertical tie-down load taken from Section 5.2.1:

$$F_{pin} = F_{CPB\_v} = 730\ kip$$

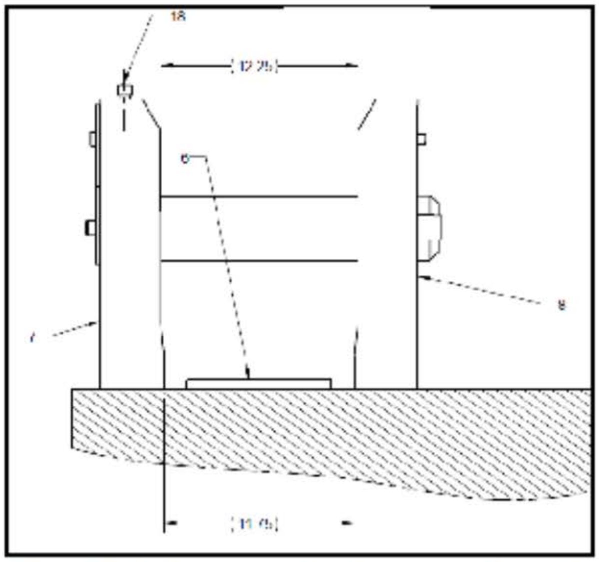


Figure 5-10: Attachment Pin Connection (Item 15)

The pin is subjected to shear and bending from the gap between the center pin attachment blocks and the cradle beams. The pin cross sectional area is:

$$A = \frac{\pi}{4}(4.00)^2 = 12.6\ in^2$$

where the pin diameter is 4.00 inches from [4]. The pin section modulus is:

$$S = \frac{\pi}{32}(4.00)^3 = 6.28\ in^3$$

Using Table 42, Case 5 of [19] and conservatively assuming the gap is maximized toward one end leaving only a 0.25 inch gap due to the boss at the block bottom, the load P is:

$$P = (F_{pin})/2 = 730/2 = 365\ kip$$

As shown on Figure 5-11, the reactions R1 and R2 are:

$$R_1 = \frac{P(L-a+c)}{L} = \frac{365(12.25 - 0.735 + 0.25)}{12.25} = 350.5\ kip$$

$$R_2 = \frac{P(L-c+a)}{L} = \frac{365(12.25 - 0.25 + 0.735)}{12.25} = 379.5\ kip$$

where the opening between the center pin attachment blocks is, L = (11.75+0.25+0.25) = 12.25 inches per [4], the connecting cradle I-beam is W18x119 per [20], [21], [22], [23] and [24], per [25], the width b = 11.265, the length a = 12.25-11.265-0.25 = 0.735 inches and the length c = 0.25 inches. The bending moments are:

$$M_1 = R_1 a = 350.5(0.735) = 257.6\ in-kip$$

$$M_2 = R_2 c = 379.5(0.25) = 94.9\ in-kip$$

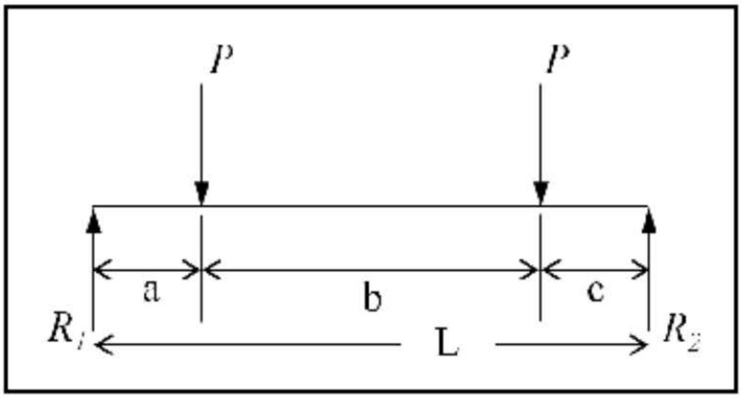


Figure 5-11: Attachment Pin Bending

The shear stress is:

$$\tau = \frac{MAX(R_1, R_2)}{A} = \frac{379.5}{12.6} = 30.1\ ksi$$

The bending stress is:

$$\sigma_b = \frac{MAX(M_1, M_2)}{S} = \frac{257.6}{6.28} = 41.0\ ksi$$

The von Mises stress is:

$$\sigma_v = \sqrt{{\sigma_b}^2 + 3(\tau^2)} = \sqrt{(41.0)^2 + 3(30.1)^2} = 66.3\ ksi$$

From Section 5.1, the allowable tensile stress, S_{A564} = 145 ksi. The margin of safety is:

$$MS = \frac{145}{66.3} - 1 = +1.19$$

Pin at Outer Pin Attachment Block

The maximum load on the attachment pin used at the outer pin attachment block is taken from Section 5.2.5 as:

$$F_{pin} = F_{IOPB\_c} = 1{,}432\ kip$$

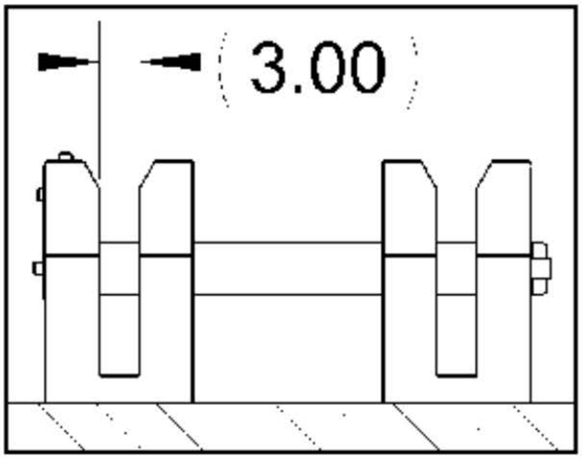


Figure 5-12: Attachment Pin Connection (Item 16)

The pin is subjected to shear and bending from the gap between the outer pin attachment blocks and the end stop plates. The pin cross sectional area is:

$$A = \frac{\pi}{4}(4.00)^2 = 12.6\ in^2$$

where the pin diameter is 4.00 inches from [4]. The pin section modulus is:

$$S = \frac{\pi}{32}(4.00)^3 = 6.28\ in^3$$

Again using Table 42, Case 5 of [19] the load P is:

$$P = (F_{pin})/2 = 1{,}432/2 = 716\ kip$$

As shown on Figure 5-11, the reactions R1 and R2 are:

$$R_1 = \frac{P(L - a + c)}{L} = \frac{716(3.00 - 0 + 0.50)}{3.00} = 835.3\ kip$$

$$R_2 = \frac{P(L - c + a)}{L} = \frac{716(3.00 - 0.50 + 0)}{3} = 596.7\ kip$$

where the opening between the outer pin attachment blocks is, L = 3.00 inches per [4], the connecting end stop plates are 2.00 +.25 +.25 inches (Items 4(2x) and 5 of [20]) wide, b = 2.50 inches, the length a = 3.00-2.50-0.50 = 0 inches and the length c = 0.50 inches. The bending moments are:

$$M_1 = R_1 a = 835.3(0) = 0\ in - kip$$

$$M_2 = R_2 c = 596.7(0.50) = 298.4\ in - kip$$

The shear stress is:

$$\tau = \frac{MAX(R_1, R_2)}{A} = \frac{835.3}{12.6} = 66.3\ ksi$$

The bending stress is:

$$\sigma_b = \frac{MAX(M_1, M_2)}{S} = \frac{298.4}{6.28} = 47.5\ ksi$$

The von Mises stress is:

$$\sigma_v = \sqrt{\sigma_b{}^2 + 3(\tau^2)} = \sqrt{(47.5)^2 + 3(66.3)^2} = 124.3\ ksi$$

From Section 5.1, the allowable tensile stress, S_{A564} = 145 ksi. The margin of safety is:

$$MS = \frac{145}{124.3} - 1 = +0.17$$

5.3 Cradle Weight

Weights for the conceptual cradle designs are listed in Table 4-4. To bound the dynamic response of the railcar and any changes in the future final cradle designs, a range of ±10% is added to the cradle weight. The nominal, maximum, and minimum cradle weights are shown in Table 5-1 below:

Table 5-1: Adjusted Cradle Weights

Cask	Family	Nominal Cradle Weight, lb	Maximum Cradle Weight, lb	Minimum Cradle Weight, lb
NAC-STC	2	42,000	46,200	37,800
NAC-UMS UTC	2	42,000	46,200	37,800
MAGNATRAN	2	42,000	46,200	37,800
HI-STAR 100	1	67,091	73,800	60,382
HI-STAR 100HB	1	73,182	80,500	65,864
HI-STAR 180	1	58,273	64,100	52,446
HI-STAR 60	1	83,727	92,100	75,354
HI-STAR 190 SL	1	55,909	61,500	50,318
HI-STAR 190 XL	1	53,636	59,000	48,272
MP187	4	32,500	35,750	29,250
MP197	3	26,000	28,600	23,400
MP197HB	3	26,000	28,600	23,400
TN-32B	1	74,000	81,400	66,600
TN-40	1	75,091	82,600	67,582
TN40HT	1	75,091	82,600	67,582
TN-68	2	27,000	29,700	24,300
TS125	3	30,000	33,000	27,000

5.4 Combined cg and Railcar Weight

In order to meet the combined cg requirement of 98 inches, as required by Rule 89 of the AAR Field Manual of the AAR Interchange Rules [8], the railcar weight must be considered. The required railcar weight is determined using the package weights and vertical cg locations, the conceptual cradle designs calculated weights and vertical cg locations, the attachment components (AC) calculated weights and vertical cg locations (Appendix A), the ballast load weight and vertical cg location and the railcar deck height and railcar vertical cg location provided by KASGRO [27].

The total cg of the cask, cradle and railcar is shown in the following table. The unloaded railcar deck height was provided by KASGRO to be 59.25 inches [27]. This value is lower when under load. Per KASGRO, the loaded deck height from the rails is 55.375 inches [27]. Conservatively, the unloaded deck height of 59.25 inches will be used. This value was used to adjust the cask and cradle cg's provided in Table 4-3 and Table 4-4. The railcar cg (unloaded condition) is 35.3 inches from the rails [27]. To calculate the worst case cg for each cask and cradle combination, the maximum cask weight is used from Table 4-3 and the minimum cradle weight is used from Table 5-1. The minimum attachment components weight is used from Appendix A. The total cg is calculated as follows:

$$total\ cg = \frac{Railcar\ W \times Railcar\ cg + AC\ W \times AC\ cg + Cradle\ W \times Cradle\ cg + Cask\ W \times Cask\ cg}{Total\ Weight}$$

The combined total cg's are calculated and shown in Table 5-2, Table 5-3 and Table 5-4 below. Three railcar weights are considered, 195,000 lb., 200,000 lb. and 205,000 lb.. These weights were selected based on the range provided by KASGRO. The minimum railcar weight of 195,000 lb. was selected to provide the minimum required railcar weight needed to meet the cg limit with an acceptable margin. The allowable cg is 98 inches per Section 2.1. The cg margins for each of the casks are calculated in Table 5-5. The bounding cask is the HI-STAR 190 XL which has a margin of 98-96.08 = 1.92 inches for a 195,000 lb. railcar.

The maximum railcar weight of 205,000 lb. was selected to meet the maximum allowed combined weight. The maximum combined weight of the railcar, cradle and loaded cask must be less than 65,750 pounds per axle (789,000 pound loaded car limit) per AFS-IN-16-0039 [6]. The maximum combined weight is calculated using the maximum cask weight from Table 4-3, the maximum cradle weight from Table 5-1, the maximum attachment components weight calculated in Appendix A, and the railcar weight. Maximum weights are shown in Table 5-6 below. The minimum margin is 73,066 pounds for the HI-STAR 190 XL loaded on a 205,000 pound railcar.

The maximum ballast load weight and cg are taken from Table 4.2 of [17] as 220,600 lb. and 32.42 inches (from the bottom of the ballast load assembly). The ballast cg from the rails can be calculated as 32.42 -7.5 + 10 +59.25 = 94.17 inches [4][18]. The maximum combined ballast and railcar cg is:

$$total\ cg = \frac{Railcar\ W \times Railcar\ cg + AC\ W \times AC\ cg + Ballast\ W \times Ballast\ cg}{Total\ Weight}$$

$$total\ cg = \frac{195{,}000 \times 35.3 + 31{,}165 \times 67.24 + 220{,}600 \times 94.17}{195{,}000 + 31{,}165 + 220{,}600}$$

$$total\ cg = 66.60\ inches$$

where the maximum attachments components weight (31,165 lb.) and cg height (67.24 inches) is used from Appendix A. The ballast load cg is very low compared to the conceptual cradle and cask payload and will not be bounding for the maximum cg case.

Table 5-2: Combined CG Height, 195,000 lb. Railcar

Cask	Family	Cask cg(1), in	Max Cask Weight, lb	Cradle cg(1), in	Min Cradle Weight, lb	Total Weight(2), lb	Total cg(1), in
NAC-STC	2	127.25	254,589	86.75	37,800	512,887	86.32
NAC-UMS UTC	2	127.25	255,022	86.75	37,800	513,320	86.36
MAGNATRAN	2	127.25	312,000	86.75	37,800	570,298	90.44
HI-STAR 100	1	125.75	279,893	104.25	60,382	560,773	89.32
HI-STAR 100HB	1	125.75	187,200	116.95	65,864	473,562	84.13
HI-STAR 180	1	124.25	308,647	114.15	52,446	581,590	91.02
HI-STAR 60	1	119.38	164,000	119.85	75,354	459,853	80.91
HI-STAR 190 SL	1	124.25	382,746	111.75	50,318	653,562	94.52
HI-STAR 190 XL	1	124.25	420,769	111.35	48,272	689,540	96.08
MP187	4	124.25	271,300	88.25	29,250	521,048	86.15
MP197	3	121.75	265,100	76.75	23,400	508,998	83.83
MP197HB	3	123.75	303,600	77.25	23,400	547,498	87.63
TN-32B	1	132.25	263,000	108.55	66,600	550,098	92.00
TN-40	1	132.25	271,500	106.75	67,582	559,580	92.42
TN40HT	1	132.25	242,343	106.75	67,582	530,423	90.23
TN-68	2	137.25	272,000	85.75	24,300	516,798	92.91
TS125	3	132.55	285,000	84.25	27,000	532,498	91.36

Notes:

1. A value of 59.25 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight and the minimum attachment components weight (25,498 lb.) and cg 7.99+ 59.25 = 67.24 inches from the rail.

Table 5-3: Combined CG Height, 200,000 lb. Railcar

Cask	Family	Cask cg(1), in	Max Cask Weight, lb	Cradle cg(1), in	Min Cradle Weight, lb	Total Weight(2), lb	Total cg(1), in
NAC-STC	2	127.25	254,589	86.75	37,800	517,887	85.83
NAC-UMS UTC	2	127.25	255,022	86.75	37,800	518,320	85.86
MAGNATRAN	2	127.25	312,000	86.75	37,800	575,298	89.96
HI-STAR 100	1	125.75	279,893	104.25	60,382	565,773	88.84
HI-STAR 100HB	1	125.75	187,200	116.95	65,864	478,562	83.62
HI-STAR 180	1	124.25	308,647	114.15	52,445	586,590	90.54
HI-STAR 60	1	119.38	164,000	119.85	75,355	464,853	80.42
HI-STAR 190 SL	1	124.25	382,746	111.75	50,318	658,562	94.07
HI-STAR 190 XL	1	124.25	420,769	111.35	48,273	694,540	95.65
MP187	4	124.25	271,300	88.25	29,250	526,048	85.67
MP197	3	121.75	265,100	76.75	23,400	513,998	83.36
MP197HB	3	123.75	303,600	77.25	23,400	552,498	87.15
TN-32B	1	132.25	263,000	108.55	66,600	555,098	91.49
TN-40	1	132.25	271,500	106.75	67,582	564,580	91.92
TN40HT	1	132.25	242,343	106.75	67,582	535,423	89.72
TN-68	2	137.25	272,000	85.75	24,300	521,798	92.35
TS125	3	132.55	285,000	84.25	27,000	537,498	90.84

Notes:

1. A value of 59.25 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight and the minimum attachment components weight (25,498 lb.) and cg 7.99+ 59.25 = 67.24 inches from the rail.

Table 5-4: Combined CG Height, 205,000 lb. Railcar

Cask	Family	Cask cg[1], in	Max Cask Weight, lb	Cradle cg[1], in	Min Cradle Weight, lb	Total Weight[2], lb	Total cg[1], in
NAC-STC	2	127.25	254,589	86.75	37,800	522,887	85.35
NAC-UMS UTC	2	127.25	255,022	86.75	37,800	523,320	85.38
MAGNATRAN	2	127.25	312,000	86.75	37,800	580,298	89.49
HI-STAR 100	1	125.75	279,893	104.25	60,382	570,773	88.38
HI-STAR 100HB	1	125.75	187,200	116.95	65,864	483,562	83.12
HI-STAR 180	1	124.25	308,647	114.15	52,445	591,590	90.07
HI-STAR 60	1	119.38	164,000	119.85	75,355	469,853	79.94
HI-STAR 190 SL	1	124.25	382,746	111.75	50,318	663,562	93.63
HI-STAR 190 XL	1	124.25	420,769	111.35	48,273	699,540	95.22
MP187	4	124.25	271,300	88.25	29,250	531,048	85.19
MP197	3	121.75	265,100	76.75	23,400	518,998	82.90
MP197HB	3	123.75	303,600	77.25	23,400	557,498	86.69
TN-32B	1	132.25	263,000	108.55	66,600	560,098	90.99
TN-40	1	132.25	271,500	106.75	67,582	569,580	91.42
TN40HT	1	132.25	242,343	106.75	67,582	540,423	89.22
TN-68	2	137.25	272,000	85.75	24,300	526,798	91.81
TS125	3	132.55	285,000	84.25	27,000	542,498	90.33

Notes:

1. A value of 59.25 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight and the minimum attachment components weight (25,498 lb.) and cg 7.99+ 59.25 = 67.24 inches from the rail.

Table 5-5: Total cg's and Margin to 98 inches

Cask	Family	195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
		total cg, in	margin, in	total cg, in	margin, in	total cg, in	margin, in
NAC-STC	2	86.32	11.68	85.83	12.17	85.35	12.65
NAC-UMS UTC	2	86.36	11.64	85.86	12.14	85.38	12.62
MAGNATRAN	2	90.44	7.56	89.96	8.04	89.49	8.51
HI-STAR 100	1	89.32	8.68	88.84	9.16	88.38	9.62
HI-STAR 100HB	1	84.13	13.87	83.62	14.38	83.12	14.88
HI-STAR 180	1	91.02	6.98	90.54	7.46	90.07	7.93
HI-STAR 60	1	80.91	17.09	80.42	17.58	79.94	18.06
HI-STAR 190 SL	1	94.52	3.48	94.07	3.93	93.63	4.37
HI-STAR 190 XL	1	96.08	1.92	95.65	2.35	95.22	2.78
MP187	4	86.15	11.85	85.67	12.33	85.19	12.81
MP197	3	83.83	14.17	83.36	14.64	82.90	15.10
MP197HB	3	87.63	10.37	87.15	10.85	86.69	11.31
TN-32B	1	92.00	6.00	91.49	6.51	90.99	7.01
TN-40	1	92.42	5.58	91.92	6.08	91.42	6.58
TN40HT	1	90.23	7.77	89.72	8.28	89.22	8.78
TN-68	2	92.91	5.09	92.35	5.65	91.81	6.19
TS125	3	91.36	6.64	90.84	7.16	90.33	7.67

Table 5-6: Total Weight and Margin to 789,000 pounds

Cask	Family	195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
		Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.
NAC-STC	2	526,954	262,046	531,954	257,046	536,954	252,046
NAC-UMS UTC	2	527,387	261,613	532,387	256,613	537,387	251,613
MAGNATRAN	2	584,365	204,635	589,365	199,635	594,365	194,635
HI-STAR 100	1	579,858	209,142	584,858	204,142	589,858	199,142
HI-STAR 100HB	1	493,865	295,135	498,865	290,135	503,865	285,135
HI-STAR 180	1	598,912	190,088	603,912	185,088	608,912	180,088
HI-STAR 60	1	482,265	306,735	487,265	301,735	492,265	296,735
HI-STAR 190 SL	1	670,411	118,589	675,411	113,589	680,411	108,589
HI-STAR 190 XL	1	705,934	83,066	710,934	78,066	715,934	73,066
MP187	4	533,215	255,785	538,215	250,785	543,215	245,785
MP197	3	519,865	269,135	524,865	264,135	529,865	259,135
MP197HB	3	558,365	230,635	563,365	225,635	568,365	220,635
TN-32B	1	570,565	218,435	575,565	213,435	580,565	208,435
TN-40	1	580,265	208,735	585,265	203,735	590,265	198,735
TN40HT	1	551,108	237,892	556,108	232,892	561,108	227,892
TN-68	2	527,865	261,135	532,865	256,135	537,865	251,135
TS125	3	544,165	244,835	549,165	239,835	554,165	234,835

Notes:

1. The weight limit of 789,000 pounds is based on a selected limit of 65,750 lb/axle for a 12 axle railcar.
2. The maximum combined weight is the summation of the maximum cradle weight from Table 5-1, the maximum cask weight from Table 4-3, the maximum attachment components weight from Appendix A, and the provided railcar weight.

5.5 Attachment Components Cask Interface

Some of the packages must have their impact limiters installed on the railcar deck. Table 5-7 shows the distance required for impact limiter removal/insertion for the two packages (MP187, HI-STAR 190 XL) that are bounding. It can be seen from [4] that the distance between the attachment components is:

$$125 + 2(148.50) - 2(8) = 406\ inches$$

The minimum required clearance for impact limiter removal of the MP187 is 372 inches from [26]. In this case there is 34 additional inches of clearance. However, the clearance was calculated assuming the impact limiter has a flat bottom end. In reality all of the cask impact limiters have some taper which provides additional clearance.

The minimum required clearance for impact limiter removal of the HI-STAR 190 XL is 406 inches. The package is 362 inches long and 18 inches is required on each end for impact limiter removal. The package vendor requested that an additional 4 inches of clearance be added to each side for a total of 406 inches [9]. In this case the design meets the requirement.

Table 5-7: Bounding Required Impact Limiter Clearance

Family	Cask	Total length (to facilitate removal of impact limiters)
4	MP187	Package Length: 308 inches (see SOW Appendix A [1]) Impact Limiter Overlap: 32 inches (SAR DWG NUH-05-4000NP R9 & DWG NUH-05-4001NP R13 [26]) =308+ 2(32) = **372 inches**
1	HI-STAR 190 XL	Package Length: 362 inches (see SOW Appendix A [1]) Impact Limiter Overlap: 18 inches (Information from vendor [9]) Additional Clearance: 4 inches (Requested by vendor) = 362 + 2(18) + 2(4) = 406 inches.

5.6 Fatigue

The railcar is expected to perform service for up to 50 years and are not expected to travel more than the maximum value of 3,000,000 miles per Section 7.1.2.1 of M-1001 [28]. While this period of performance is not expected to be maintenance free, it is reasonable to assume that the structure would perform its support function without major component failure. To this end, this analysis presents a cursory examination of the fatigue loading over this lifespan. The detailed fatigue analysis will be included with the evaluation of the railcar.

An example of the accepted method for calculating fatigue life is shown in Chapter 7 of the M-1001. From the example case Figure 7-3, it can be seen that 97 percent of the vertical fatigue loading is due to stress ranges under 0.3g. As this is from an example, case it is assumed to be normal in comparison to other railcar response curves. Since a majority of the fatigue loading is within this range, the fatigue life of the cradle is assumed to be defined by these loads.

The attachment component structural analysis demonstrates that a bounding acceleration load of 2g in the vertical direction can be supported when compared against yield strength. This is equivalent to using an allowable stress of ½ yield stress under normal gravity loading. All of the attachment component analyses demonstrate that this yield criterion is met.

If we assume that the stress variation due to cyclic loading is no more than +/- 0.2g (or a range of 0.4g), and that the allowable stress is just met at one gravity, the minimum and maximum stress that will be found in any component with a yield stress of 50 ksi due to cyclic loading will be due to the variable stress. This stress is:

Mean Stress:	$S = \frac{1}{2}\ 50\ \text{ksi} = 25\ \text{ksi}$
Variable Stress:	$S_v = 0.2S = 5\ \text{ksi}$
Maximum Stress:	$S_{mx} = 30\ \text{ksi}$
Minimum Stress:	$S_{mn} = 20\ \text{ksi}$

Stress Ratio: $R = \frac{S_{mn}}{S_{mx}} = \frac{2}{3}$

The stress that produces failure in steel at 2,000,000 cycles can be computed from cases in Table 7.55 of Chapter 7 of M-1001. This table presents values for determining the fatigue properties of the Modified Goodman Diagram (MGD) for a particular member. As an example, the allowable stress is 50 ksi for an A992 beam. From Table 7.55, Flg. No. 7.4.1.8 the following information is available:

Y intercept of MGD:	$b = 26$ ksi
MGD Slope:	$m = 0.9$
S-N Curve Slope:	$k = 0.16$
Cycles at Fatigue Stress S_e:	$N_e = 2 \times 10^6$ cycles

The stress at which the beam is expected to fail at two million cycles is:

Fatigue Stress (at Ne): $S_e = \frac{b}{1-mR} = 65$ ksi

Since the Fatigue Limit is greater than the maximum load, the S-N curve slope is half the value above.

Cycles to failure: $N = \frac{N_e}{\left(\frac{S_{mx}}{S_e}\right)^{\frac{2}{k}}} = 31.5 \times 10^9$ cycles

For a 50 year life, the railcar is expected to cover 3,000,000 miles. Assuming a cyclic rate of β= 300 cycles per mile (based on the example of Section 7.2.4.1.1.2 of M-1001), the expected life will be:

$$\text{Life} = \frac{N}{\beta} = (31.5 \times 10^9 \text{ cycles})/(300 \text{ cycles/mile}) = 105 \times 10^6 \text{ miles}$$

The life prediction for this component is much larger than the required lifespan for the component; therefore, it is reasonable to say that it will support fatigue loading without any modification. Similar analysis performed on an axially loaded flat plate for material with a 50 ksi yield stress limit demonstrates improved fatigue life in comparison to the beam section.

6.0 COMPUTER SOFTWARE USAGE (IF SOFTWARE IS USED)

No computer software is used in this calculation.

7.0 RESULTS/CONCLUSIONS

7.1 Standardized Attachment Components

The results of the analyses in this calculation demonstrated that the standardized attachment components are adequate to perform required function. The margins of safety for the evaluated components are shown in Table 7-1.

Table 7-1: Margins of Safety

Component	Loading	Margin of Safety
Center Pin Attachment Blocks (Section 5.2.1)	Tensile stress from vertical load	+2.16
	Shear tear-out from vertical load	+1.17
	Combined stress from lateral load at base	+0.33
Shear Blocks (Section 5.2.3)	Combined stress from longitudinal load	+18.4
Outer Pin Attachment Blocks (Section 5.2.5)	Tension Stress from combined load	+2.62
	Shear tear-out from combined load	+0.24
Attachment Pin (Section 5.2.7)	Combined stress (minimum)	+0.17

All margins of safety are positive and the components are adequate to support the applied loading.

7.2 Standardized Attachment Components Welds

The forces applied to the welds between the attachment components and the railcar deck are taken from Section 5.2.2, Section 5.2.4, and Section 5.2.6 and are shown in Table 7-2.

Table 7-2: Required Weld Strength

Weld	Forces Applied to Weld
Center Pin Attachment Block Weld (Section 5.2.2), (Item 7-8 of [4])	730 kip (vertical) at pin slot
	611 kip (lateral) at bracket and 312 kip (vertical) at pin slot
Shear Blocks Weld (Section 5.2.4), (Item 9 of [4])	2,921 kips (longitudinal)
Outer Pin Attachment Block Welds (Section 5.2.6) (Item 12-14 of [4])	944 kip (longitudinal) and 1,077 kip (vertical +) at inboard pin hole and 1,077 (vertical -) at outboard pin slot

7.3 Combined cg and Railcar Weight

The bounding combined cg and maximum weight are taken from Table 5-5 and Table 5-6 are shown in Table 7-3.

Table 7-3: Total cg's and Weight

Bounding Combined cg and Minimum Margin to 98 Inches							
		195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
Cask	Family	total cg, in	margin, in	total cg, in	margin, in	total cg, in	margin, in
Maximum Margin = HI-STAR 60	1	80.91	17.09	80.42	17.58	79.94	18.06
Minimum Margin = HI-STAR 190 XL	1	**96.08**	**1.92**	95.65	2.35	95.22	2.78
Bounding Total Weight and Minimum Margin to 789,000 pounds							
Cask	Family	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.
Maximum Margin = HI-STAR 60	1	482,265	306,735	487,265	301,735	492,265	296,735
Minimum Margin = HI-STAR 190 XL	1	705,934	83,066	710,934	78,066	715,934	**73,066**

7.4 Literature Search and other Background Data

A formal literature search was not applicable to this scope of work. All required background information is given under Section 1.1, *Project Background*.

8.0 REFERENCES

The following references were used in this analysis:

1. Department of Energy Contract DE-NE0008390, Part 1, Section C, *Statement of Work*.
2. Association of American Railroads, *Manual of Standards and Recommended Practices, Section C – Car Construction Fundamentals and Details*, Standard S-2043, *Performance Specification for Trains Used to Carry High-Level Radioactive Material*, 2009
3. AREVA Federal Services Engineering Information Record, EIR-3014611, *Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar*, Rev. 8.
4. AREVA Federal Services Drawing, DWG-3015278, *Atlas Railcar Cradle Attachment Conceptual Drawing*, Rev. 2.
5. AREVA Federal Services LLC, Request for Information, AFS-RFI-0015-00, November 2016.
6. AREVA Federal Services, LLC Incoming Document AFS-IN-16-0039, Submitted and Requested Information to AFS for Cask Car, August 9, 2016.
7. Joseph Shigley, Charles Mischke, Mechanical Engineering Design, 5th Edition, McGraw-Hill, 2002.
8. Association of American Railroads, *Field Manual of the AAR Interchange Rules*.
9. Phone communication with Steve Agace, Holtec International (October 27, 2016).

10. AREVA Federal Services Calculation, CALC-3015133, *Atlas Railcar Family 1 Conceptual Cradle Structural Calculation*, Rev. 2

11. AREVA Federal Services Calculation, CALC-3015134, *Atlas Railcar Family 2 Conceptual Cradle Structural Calculation*, Rev. 0

12. AREVA Federal Services Calculation, CALC-3015135, *Atlas Railcar Family 3 Conceptual Cradle Structural Calculation*, Rev. 0

13. AREVA Federal Services Calculation, CALC-3015136, *Atlas Railcar Family 4 Conceptual Cradle Structural Calculation*, Rev. 1

14. American Society for Testing and Materials, ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*, 2007.

15. American Society for Testing and Materials, ASTM A564/A564M, *Standard Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes*, 2010.

16. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section II, Part D, "Properties (Customary)," 2015.

17. AREVA Federal Services Calculation, CALC-3018954, *Atlas Railcar Conceptual Ballast Load Structural Calculation*, Rev 0.

18. AREVA Federal Services Drawing, DWG-3018955, *Atlas Railcar Ballast Load Assembly Conceptual Drawing*, Rev. 0.

19. The Aluminum Association, Aluminum Construction Manual, Section 3, Engineering Data for Aluminum Structures, Fifth Edition, December 1986.

20. AREVA Federal Services Drawing, DWG-3015137, *Atlas Railcar, Cradle Family 1, Conceptual Drawing*, Rev. 1

21. AREVA Federal Services Drawing, DWG-3015138, *Atlas Railcar, Cradle Family 2 (NAC), Conceptual Drawing*, Rev. 1

22. AREVA Federal Services Drawing, DWG-3015277, *Atlas Railcar, Cradle Family 2 (TN-68), Conceptual Drawing*, Rev. 0.

23. AREVA Federal Services Drawing, DWG-3015139, *Atlas Railcar, Cradle Family 3, Conceptual Drawing*, Rev. 0

24. AREVA Federal Services Drawing, DWG-3015140, *Atlas Railcar, Cradle Family 4, Conceptual Drawing*, Rev. 1

25. AISC MO16, Manual of Steel Construction, Allowable Stress Design, 9th Edition

26. Docket 71-9255, *Safety Analysis Report for the NUHOMS®-MP187 Multi-Purpose Cask*, Non-Proprietary Version, Rev 17, July 2003

27. AREVA Federal Services, LLC Incoming Document AFS-IN-17-0008, Needed Center of Gravity and Deck Height Data for Atlas Project, March 15, 2017.

28. Association of American Railroads, *Manual of Standards and Recommended Practices*, Section C, Part II *Design, Fabrication, and Construction of Freight Cars*, M-1001, 2011

9.0 APPENDIX A – ATTACHMENT COMPONENTS WEIGHT CALCUALTION

The weight and center of gravity of the attachment components from the railcar deck is calculated below. The Attachment component geometry is taken from DWG-3015278 [4]. The weight of each component is calculated using hand calculations. The density of stainless steel is taken as 0.290 lb/in^3 and the density of carbon steel is taken as .280 lb/in^3 [16]. For the ease of some calculations, geometry is simplified, resulting in a small conservative increase in weight. Only the weight of the items present for transport is calculated.

Pin Stop Bar (Item 2)

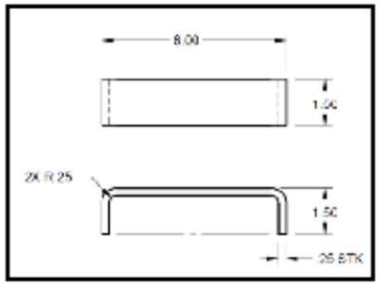
Length: 6.00 + 1.5 + 1.5 = 9 in.

Width: 1.5 in.

Thickness: .25 in.

Weight: .290(9)(1.5)(.25) = .98 lb.

cg from railcar deck: 10 in.



Pin Tray Keeper (Item 3)

The pin tray keeper is part of the pin loading weldment assembly, which is not attached during transport.

Pin Keeper Plate (Item 4)

Width: 4.0 in.

Height: 10.0 in

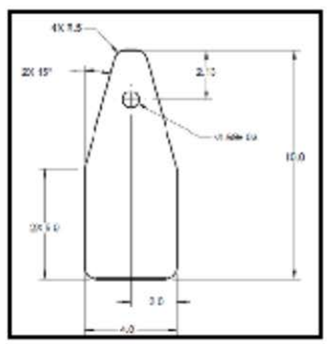
Thickness: .25 in.

Weight: .290(4.0)(10.0)(.25) = 2.90 lb.

(Assuming the shape to be a rectangle and neglecting the hole)

cg from railcar deck: 18 in.

(conservatively assumed to be top of pin attachment block)



Deck Spacer Plate (Item 5)

Length: 12.0 in.

Width: 12.0 in.

Thickness: .38 in

Weight: .290(12.0)(12.0)(.38) = 15.9 lb.

cg from deck: .38/2 = .19 in.

Deck Spacer Plate (Item 6)

Length: 12.0 in.

Width: 9.0 in.

Thickness: .50 in

Weight: .290(12.0)(9.0)(.50) = 15.7 lb.

cg from deck: .50/2 = .25 in.

Center Pin Attachment Block (Item 7- 8)

Height: 18.0 in.

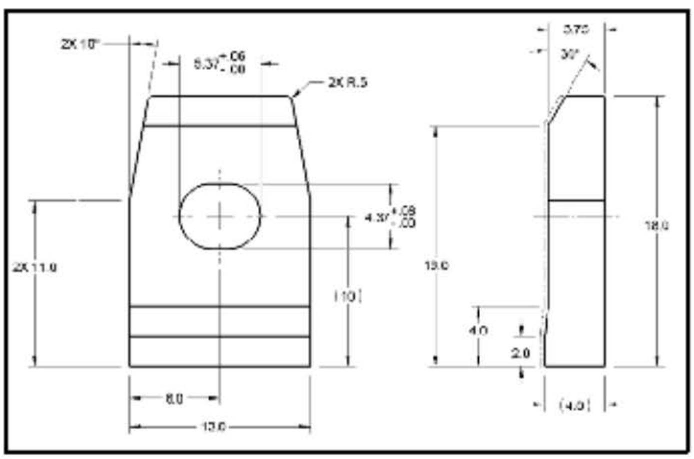
Width: 12.0 in.

Thickness (bottom): 4.0 in

Thickness (top): 3.75

Weight: $.280((12.0)(4.0)(4.0) + (3.75)[12(18.0 - 4.0) - \pi/4(4.37)^2 - 4.37(1)]) = 209.8$ lb.

cg from deck: 18/2 = 9 in.



Shear Block (Item 9)

Height: 4.0 in.

Width: 90.0 in.

Length: 21.0 in.

Weight: .280(4.0)(90.0)(21.0) = 2116.8 lb.

cg from deck: 4.0/2 = 2 in.

Outer Pin Attachment Block (Item 12-14)

Height: 18.0 in.

Width: 11.0 in.

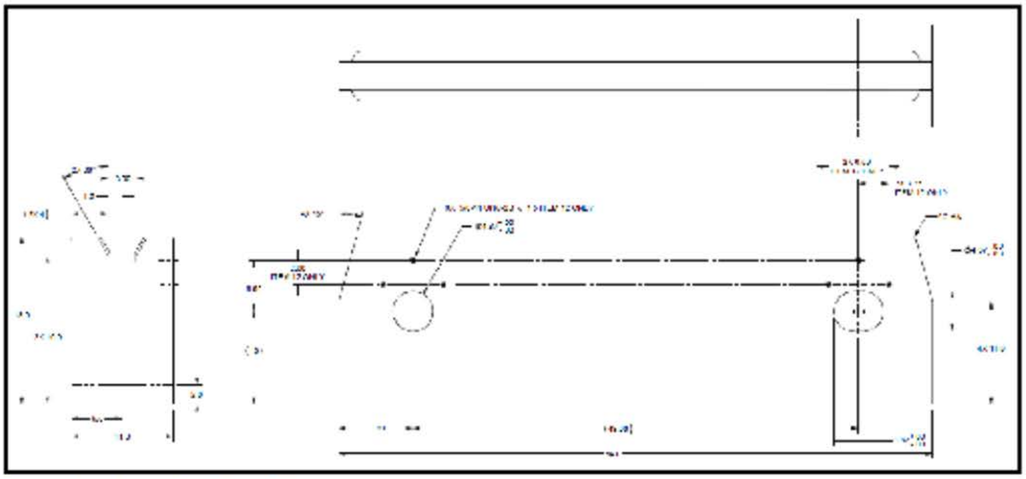
Length: 64.0 in.

Thickness (base): 2.0 in

Thickness (legs): 4 in.

Weight: $.280[(2.0)(11.0)(64.0) + 2(4)\{(64.0)(18.0\text{-}2.0) - \pi/4(4.37)^2 - \pi/4(4.37)^2 \text{-}1(4.37)\}] = 2611.0$ lb.

cg from deck: $18/2 = 9$ in.



Center Attachment Pin (Item 15)

Diameter: 4.000 in.

Length: 20.70 in.

Weight: $.290(\pi/4(4.000)^2(20.70)) = 75.4$ lb.

cg from deck: 10 in.

Outer Attachment Pin (Item 16)

Diameter: 4.000 in.

Length: 37.20 in.

Weight: $.290(\pi/4(4.000)^2(37.20)) = 135.6$ lb.

cg from deck: 10 in.

Pin Attachment Tray (Item 17)

The pin attachment tray is part of the pin loading weldment assembly, which is not attached during transport.

Fasteners (Item 18)

Diameter: 5/8 (0.625) in.

Length: 1.25 in.

Weight: $.289(\pi/4(.625)^2(1.25)) = .11$ lb.

cg from deck: 18 in.

(conservatively assumed to be top of the pin attachment block)

Table 9-1: Attachment Components Weight Summary

Component	Item	Qty.	Weight each (lb.)	cg each (in)	Total Weight (lb.)	W x (cg)
Pin Stop Bar	2	12	0.98	10	11.8	118
Pin Tray Keeper						
Pin keeper Plate	4	12	2.9	18	34.8	626.4
Deck Spacer Plate	5	2	15.9	0.19	31.8	6
Deck Spacer Plate	6	4	15.7	0.25	62.8	15.7
Center Pin Attach Block (outer)	7	4	209.8	9	839.2	7552.8
Center Pin Attach Block (inner)	8	4	209.8	9	839.2	7552.8
Shear Block	9	2	2116.8	2	4233.6	8467.2
DELETED	10					
DELETED	11					
Outer Pin Attachment Block (left)	12	2	2611	9	5222	46998
Outer Pin Attachment Block (right)	13	2	2611	9	5222	46998
Outer Pin Attachment Block (center)	14	4	2611	9	10444	93996
Center Attachment Pin	15	4	75.4	10	301.6	3016
Outer Attachment Pin	16	8	135.6	10	1084.8	10848
Pin Attachment Tray	17					
Fasteners	18	36	0.11	18	4	72
				Total:	28,331.6	226,266.9

The Attachment Components weigh 28,331.6 pounds and have a vertical cg, measured from the railcar deck, of 226,266.9/28,331.6 = 7.99 inches. The vertical cg measured from the rails, is 7.99 + 59.25 = 67.24 inches.

To bound the dynamic response of the railcar and any changes in the future final attachment component design, a range of ±10% is added to the weight. The nominal, maximum, and minimum attachment components weights are: 28,331.6 lb. (nominal), 31,165 lb. (maximum), 25,498 lb. (minimum)