

Appendix J – Atlas Ballast Load Conceptual Design

APPENDIX J-1 DRAWINGS

LIST OF MATERIALS									
S/D	QTY A4	QTY A3	QTY A2	QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION	
					A1		BALLAST LOAD ASSEMBLY		
					2		MAIN BALLAST LOAD WELDMENT		
					1		TOP BALLAST LOAD WELDMENT		
					4		TIE DOWN WELDMENT		
			1		1		PLATE, 2.5 THK X 85 X 48	ASTM A588	
		3	7		2		PLATE, 3.5 THK X 106 X 48	ASTM A588	
			2		3		PLATE, 2.5 THK X 64 X 15.5	ASTM A588	
			1		4		PLATE, 1.5 THK X 68 X 41.9	ASTM A588	
		1			5		PLATE, 1.5 THK X 68X 15.6	ASTM A588	
		1			6		PLATE, 2.5 THK X 106 X 48	ASTM A588	
		2			7		PLATE, 2.5 THK X 10 X 48	ASTM A588	
		1			8		PLATE, 2.5 THK X 15 X 48	ASTM A588	
	1				9		PLATE, 2.0 THK X 2 X 6	ASTM A588	
	2				10		PLATE, .5 THK X 1 X 3	ASTM A588	
				4	11	94975A488	18-8 STAINLESS STEEL QUICK RELEASE PIN & LANYARD, Ø5/16, 2.5 USABLE LENGTH	McMASTER-CARR	
				4	12	92185A240	SOCKET HEAD CAP SCR, 10-24 UNC-2A X .38	McMASTER-CARR	
				AR	13	1019659	SHACKLE, 1-3/4, 25T WLL	CROSBY	

NOTES, UNLESS OTHERWISE SPECIFIED:

- CONCEPTUAL DESIGN ASSUMES ALL WELDS ARE FULL PENETRATION WELDS UNLESS OTHERWISE SPECIFIED.
- WELDING SHALL BE PERFORMED IN ACCORDANCE WITH AWS D1.1.
- DIMENSIONS WITH TOLERANCES SPECIFIED ARE INTERFACE DIMENSIONS AND SHALL BE CONSIDERED DURING FINAL DESIGN.
- APPLY ITEM 3 HOLE LOCATIONS AFTER WELDING.
- ALTERNATE MATERIAL 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.
- GRIND WELDS AS REQUIRED TO ACHIEVE ASSEMBLY FIT-UP BETWEEN ITEM 4 OF MAIN BALLAST LOAD WELDMENTS.
- TWO SHACKLES (ITEM 13) ARE REQUIRED TO LIFT EACH A2 OR A3 WELDMENTS.
- REMOVE ITEMS A4 FROM ASSEMBLY PRIOR TO LIFTING A3 ASSEMBLY. DO NOT USE A4 TO LIFT A1 ASSEMBLY.

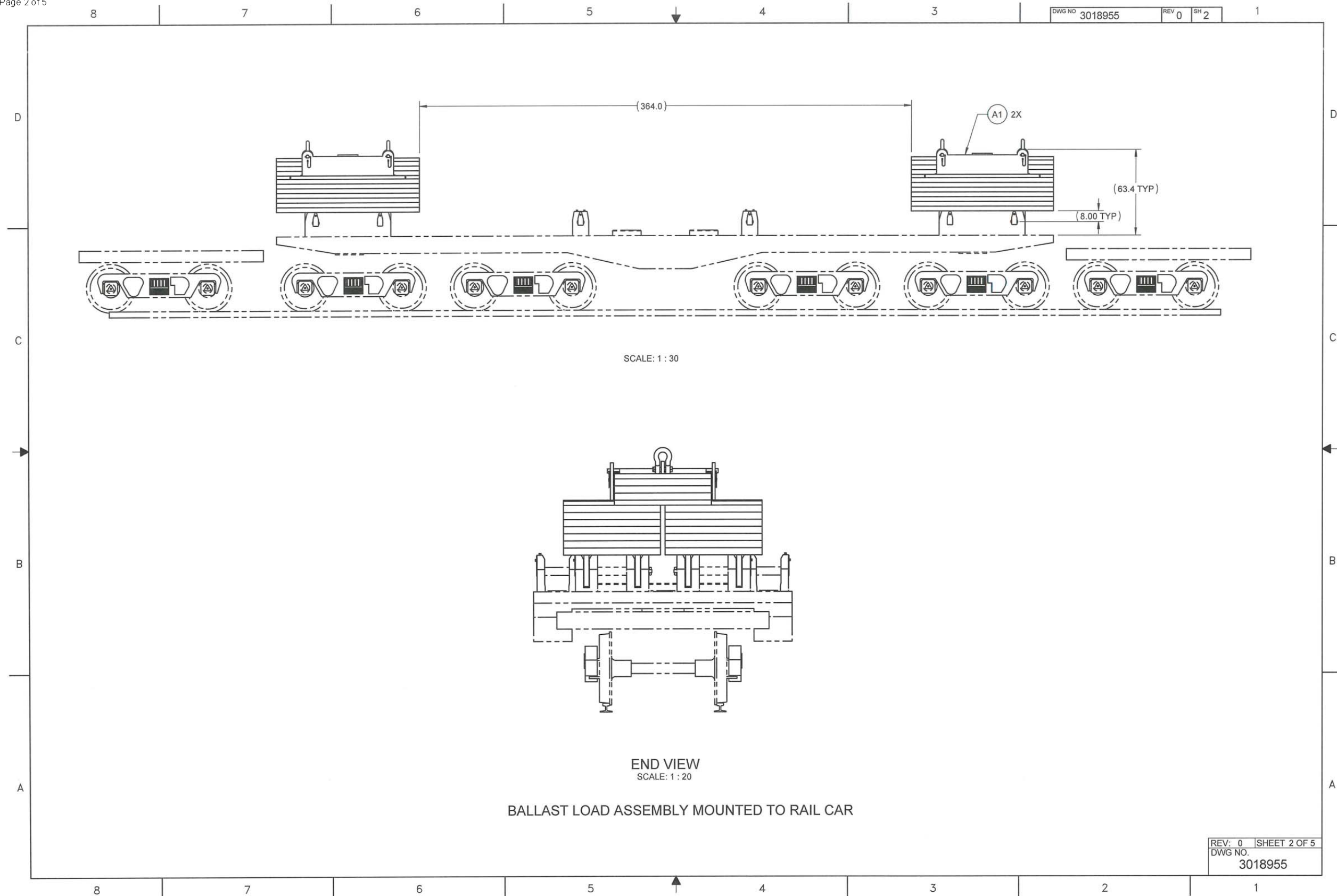
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ISOMETRIC VIEW

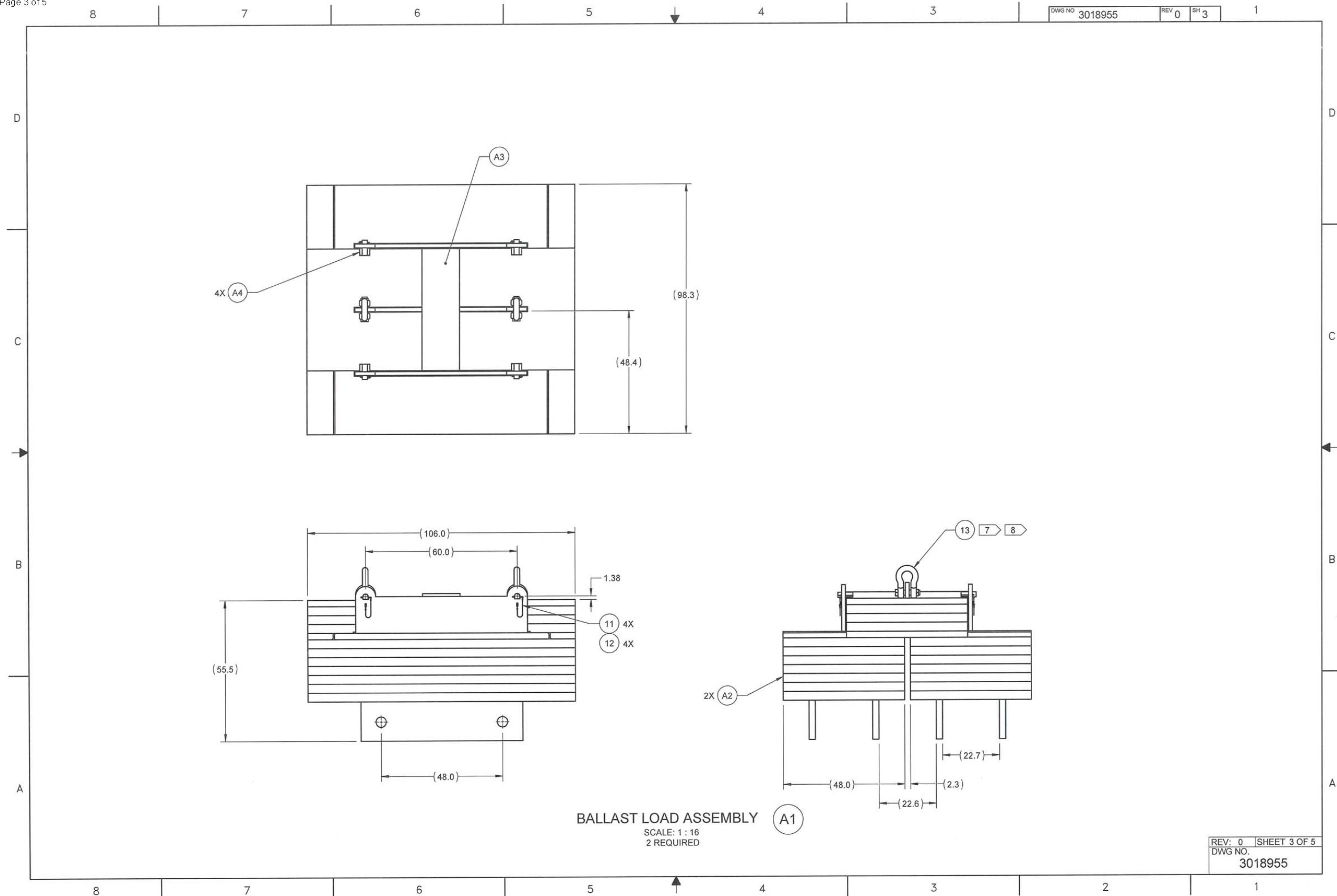
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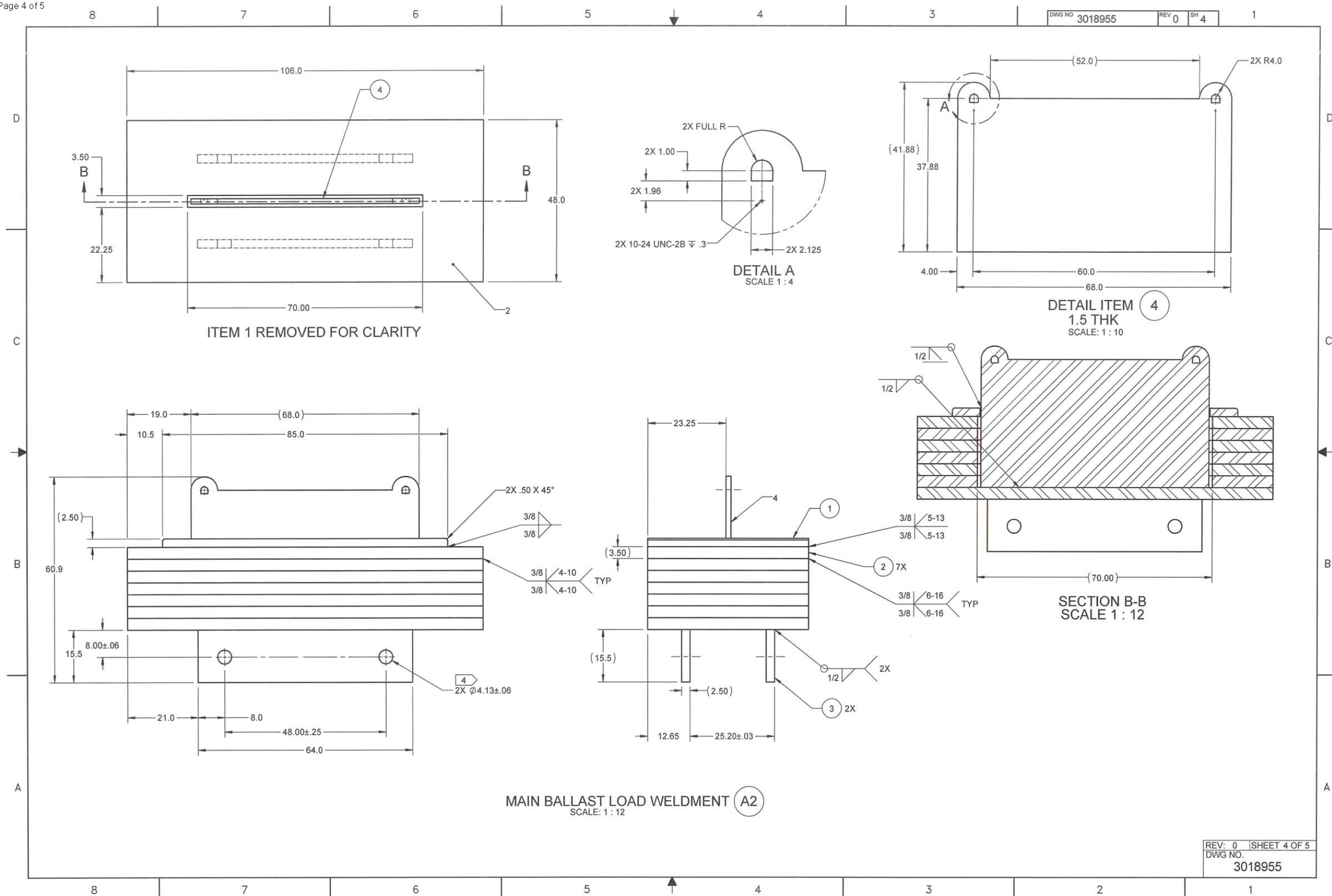
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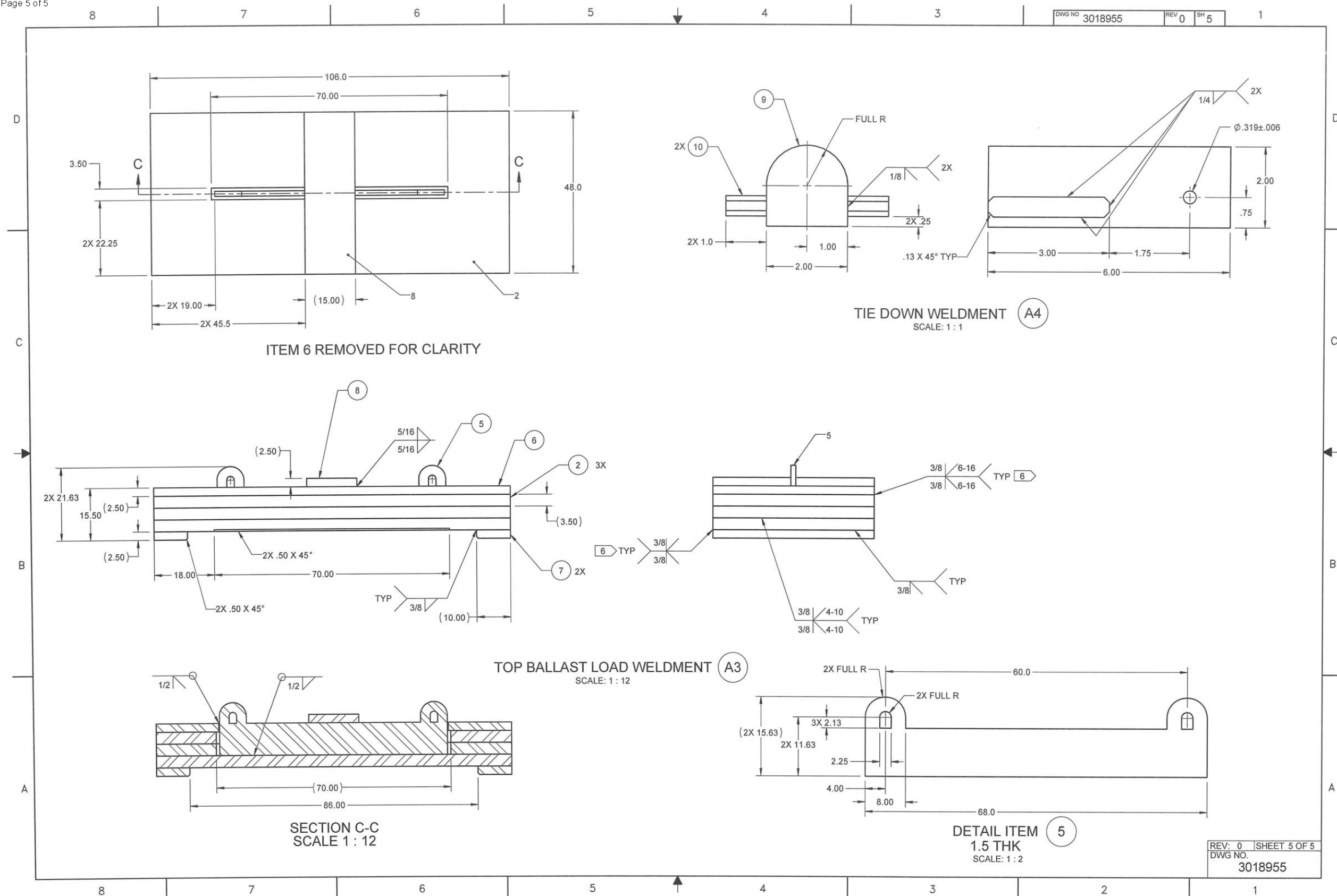
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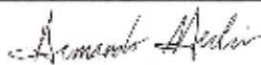


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APPENDIX J-2
CALCULATIONS

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	CALCULATION		
Document No.:	CAI C-3018954	Rev. No.	001 Page 1 of 29
Project No.:	00225.03.0050	Project Name:	DOE Atlas Railcar
Title: Atlas Railcar Conceptual Ballast Load Structural Calculation			
Summary: The purpose of this document is to evaluate the structural integrity of the conceptual ballast design to be used for the Atlas Railcar. The ballast load is required to attach to the Atlas Railcar when it is being transported in an empty condition (without a cradle or cask/cradle combination). This is needed to transport under Association of American Standards (AAS) S-2043 as specified in the Design Basis Requirements Document (DBRD), Section 2.2.1(15) [5]. This document is not safety related.			
Safety <input type="checkbox"/> Non-Safety <input checked="" type="checkbox"/>			
Contains Unverified Input / Assumptions: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>			
Software Utilized: None Software Active in AFS EASI: Yes: <input type="checkbox"/> NA*: <input checked="" type="checkbox"/> <small>*Not Applicable per Section 5.7 of AFS-EN-11RC-002</small>		Version: N/A	Storage Media: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>
Error Notices & Associated Corrective Actions Reviewed: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>		Location: N/A	
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Preparer:	Armando Merlin		03/02/2018
Checker:	Slade Klein		3/2/2018
Approver:	Donald Hillstrom		3/2/18
Other:	N/A		

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Revision History

Rev.	Changes
000	Initial Release
001	Revised for editorial changes.



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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 radioactive 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 to carry SNF and HLW packages.

As part of this project, DOE has contracted with AREVA Federal Services (AFS) to design a single standardized railcar tie-down interface, and transport package cradle concepts for the 17 HLW transport packages (herein referred to as "packages") listed in Attachment A of the Statement of Work [1].

1.2 Calculation Introduction

This calculation provides the preliminary structural evaluation for a ballast utilized with the Atlas Railcar as a proof-of-concept. These preliminary structural evaluations include the following:

- Railcar interface structural loads from the AAR Rule 88 A16c(3) per DBRD Section 2.2.2(13) [5] accelerations (see Section 5.1).
- Stresses in the primary structural members and associated welds in accordance with AAR Rule 88 A16c(3) accelerations (see Section 5.2).
- Lifting load – The load will be distributed equally between the two (2) lifting points in accordance with DBRD Section 2.2.3(8) [5]. The stresses resulting from the applied loads will then be compared to the allowable yield stresses of the components in accordance with ANSI N14.6 for a non-critical lift [4]. A dynamic load factor will be applied to all lift loads in accordance with Section 2.2.3(8) of the DBRD [5]. See Section 5.3 for lifting evaluation.
- Weight and center-of-gravity (cg) estimations (see Appendix A).

The railcar tie-down interface (including attachment pins) is detailed in drawing [2] and is analyzed in calculation [3] for the maximum interface structural loads calculated.

1.3 Atlas Railcar Ballast Load Design Description

In accordance with the DBRD Section 2.2.1(15) [5] and preliminary dynamic modeling analysis, the Atlas Railcar will require additional mass to be able to be transported without a cask/cradle loading (minimum load condition). The required total additional mass or "Ballast Load" is estimated to be 200,000 lbs. +/- 10,000 lbs. per DBRD Section 2.2.3 (1a) [5].

The Ballast Load was designed to interface with the outer attachment pin blocks of the Atlas Railcar and constructed from modular sections or weldments weighing 40,000 lbs. +/- 2,000 lbs. each. This is to ensure legal weight transport by truck on public roadways per DBRD Section 2.2.3 (5) [5]. Therefore, the size and weight of the Ballast Load was designed to comply with the United States Laws and Federal Regulations for highway transportation [13]. The Ballast Load has to be modular and weigh an approximate maximum weight of 42,000 lbs. See Figure 1-1 and Figure 1-2 for Atlas Railcar Ballast Load assembly conceptual design and design features.



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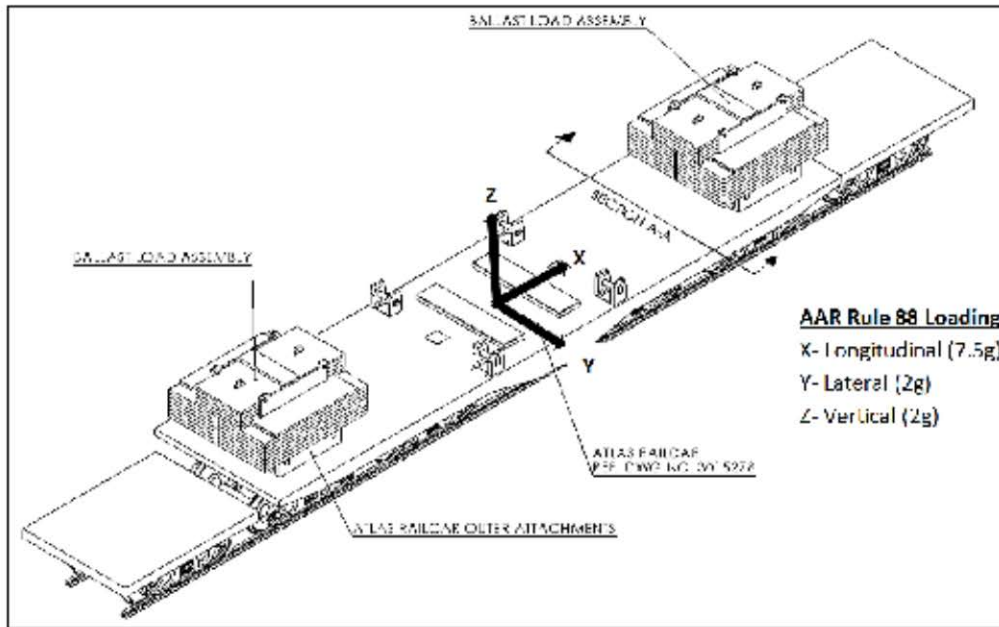


Figure 1-1: Atlas Railcar Ballast Load Concept Assembly

The Ballast Load concept has two (2) different weldment designs, a total of four (4) main weldment designs weighing approximately 40,000 lbs. each, and two (2) top weldments weighing approximately 20,000 lbs. each.

The Ballast Load is designed to be transported by truck (if necessary) in five or more loads. The ballast load weldments will require shoring, tie-down, and weight distribution during truck transportation. Suggestions for shoring and tie-down of the weldments during truck transportation are discussed in Section 5.4.



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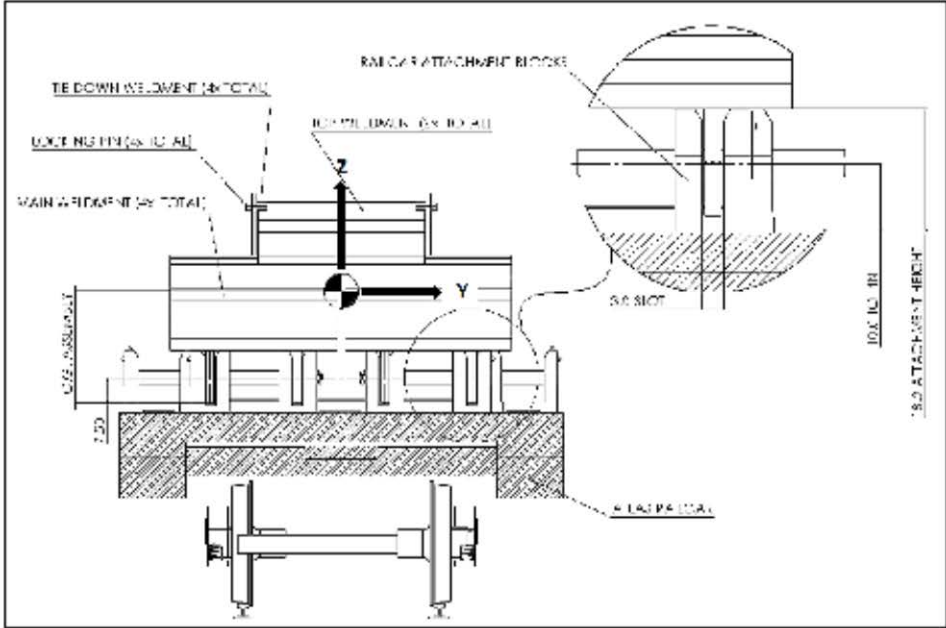


Figure 1-2: Atlas Railcar Ballast Load Assembly and Attachments (Section A-A from Fig. 1-1)

The Ballast Load assembly consists of the features and components described in Table 1-1, Table 1-2, and shown in Figure 1-3.

Table 1-1: Main Weldment Ballast Load Component Description and Features

Calculated Weight	Component	L (in.)	W (in.)	#	Description/ Purpose
~40.1 Kips per weldment (4 Total) (Ref. App. A)	3.5" Plates	106	48	7	Plates are used for weight.
	2.5" Plate	85	48	1	Plate used for weight.
	2.5" Plates	64	15.5	2	Railcar ballast load attachments.
	1.5" Plate	68	41.8	1	Lifting pad-eyes for main Weldment, lateral restraint for top weldment, and vertical restraint for top weldment.



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Table 1-2: Top Weldment Ballast Load Component Description and Features

Calculated Weight	Component	L (in.)	W (in.)	#	Description/ Purpose
~20.0 Kips per weldment (2 Total) (Ref. App. A)	3.5" Plates	106	48	3	Plates are used for weight.
	2.5" Plate	106	48	1	Plate used for weight.
	2.5" Plate	15	48	1	Top plate used for weight.
	2.5" Plates	10	48	2	Shear plates used as longitudinal restraint.
	1.5" Plates	8	15.6	2	Lifting pad-eyes for Top Weldment

The four (4) main weldments and the two (2) top weldments are constructed from ASTM A588 material [6]. All Ballast Load Assembly weldments need to be restrained for the loading requirements as stated in the DBRD Section 2.2.3(10) [5]. The main weldment attaches to the Atlas Railcar pin blocks which restrain the Ballast Load in all directions. The top weldment sits on top of the main weldments as shown in Figures 1-2 and 1-3. The top weldment shear plates restrain the top weldment from longitudinal movement (X). The lifting pad-eye lifting plates for the main weldments restrain the top weldment from movement on the lateral (Y) direction. In addition, the tie-down weldments (4 total) are used to restrain the top weldment from vertical (Z) movement during transportation. Lastly, locking pins (Ref. [8] Item No. 94975A488) on the tie-down weldments are used to restrain the tie-down weldments from movement in the lateral (Y) direction during transportation.

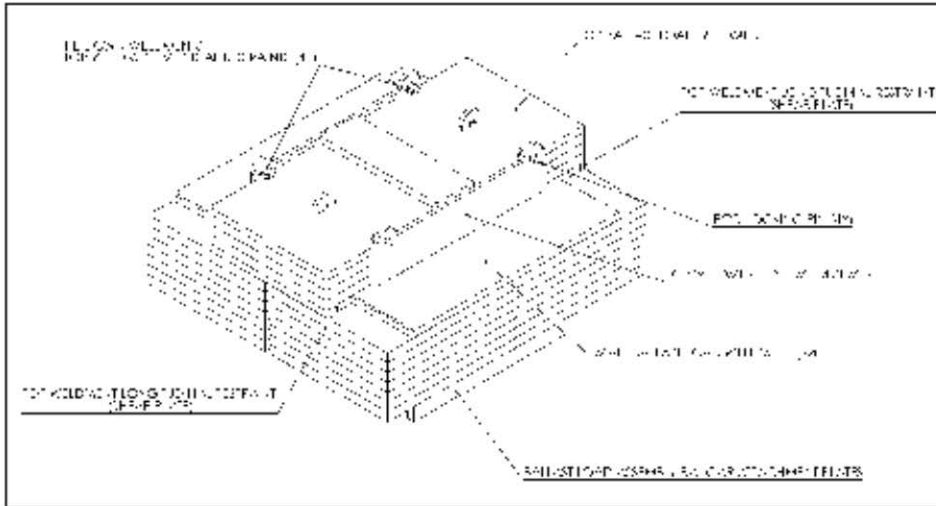


Figure 1-3: Ballast Load Assembly Components



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2.0 METHODOLOGY

This calculation uses first principle manual calculations to evaluate/size the *primary* structural members on the Atlas Railcar Ballast Load Assembly. The Ballast structural components and welds are sized such that the minimum margin of safety is +.20 to the material yield strength for the AAR loadings (see Section 4.2).

This calculation evaluates the conceptual design described in drawing [12]. Additional design detail is asserted in this calculation using figures since this is a structural *sizing* calculation for a conceptual design.

The lifting criteria applied to the Ballast Load Assembly will conservatively be in accordance with ANSI N14.6 [4].

Stress allowables are defined where they are used, and the definition of “margin of safety” (MS) used herein is:

$$MS = \frac{\text{stress allowable}}{\text{calculated stress}} - 1$$

3.0 ASSUMPTIONS

3.1 Unverified Inputs and Assumptions

There are no unverified inputs or assumptions in this conceptual sizing calculation.

3.2 Justified Assumptions

1. Weld metal is conservatively assumed to have at least the strength of the adjoining base metal.
2. This calculation only considers nominal dimensions since this is only conceptual sizing.

4.0 DESIGN INPUTS

4.1 Conceptual Design Geometry

The conceptual ballast load design geometry is presented in figures located in Section 5.0 with the dimensions as required by the individual structural evaluation.

4.2 Design Loads

According to AAR Rule 88 A16c(3) the tie-down system for any payload carrying HLW on a railroad must not exceed the material yield strength when undergoing the following accelerations individually (see Section 2.2.2(13) and Section 2.5 of the Design Basis Requirements Document [5]):

- $a_x = \pm 7.5g$ longitudinal
- $a_z = \pm 2g$ vertical
- $a_y = \pm 2g$ lateral

All analyses herein shall only apply the inertial loads above and neglect the effects of gravity as described in the DBRD Section 2.5(4) [5].



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4.3 Material Properties

The following materials are conceptually used on the Atlas Ballast Load Assembly. The density of carbon steel used for all weight estimates herein is 0.284 lb/in³ per Table 17-12 of [9]. Weld metal is conservatively assumed to have at least the strength of the adjoining base metal. The material strength properties for the materials specified in drawing [12] are shown in Table 4-1.

Table 4-1: Material Properties

Material	Yield Strength (ksi)	Tensile Strength (ksi)
ASTM A588 [6]	50	70

Note(s): (1) Alternate material 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.

A temperature range of 0° F to 100° F is used for material properties for the proof-of-concept calculations herein as specified in Section 2.5.8 of the DBRD [5]. The material properties at 100° F are the same as the material properties at room temperature as specified in ASTM E8-04, Sect. 1.1 (Note 4) of [14] "room temperature shall be considered to be 50° F to 100° F unless otherwise specified." Other materials could be used that have similar properties in the final design as desired.

4.4 Atlas Ballast Load Weights and C.G.'s

The following table contains all of the calculated Ballast Load Assembly design inputs:

Table 4-2: Atlas Ballast Load Assembly Weights and C.G.

Assembly/Weldment Weights and C.G.	Calculated Value ^(Note 1)	Calculated Value - 10%	Calculated Value + 10%
Total Ballast Load ^(Note 3) Max. gross weight (W_{TB})	200.5 kips	180.5	220.60 kips
One Assembly ^(Note 2) Max. gross weight (W_B)	100.2 kips	90.2	110.2 kips
Main Weldment Max Gross Weight (W_{MAIN})	40.1 kips	36.1	44.1 kips
Top Weldment Max Gross Weight (W_{TOP})	20.0 kips	18	22.0 kips
Ballast Load Assembly C.G. from bottom of Ballast assembly (2 main weldments and 1 top weldment)	32.42 in.	N/A	N/A
Main Weldment C.G. from bottom of Ballast assembly	28.28 in.	N/A	N/A
Top Weldment C.G. from bottom of Ballast assembly	48.95 in	N/A	N/A

Note(s): **Note 1:** Reference Appendix A for component calculated weights and C.G.'s. Excel was only used as a comparison tool, all calculated weights were checked by a handheld calculator.
Note 2: One ballast assembly consists of two (2) main weldments and one (1) top weldment.
Note 3: Total ballast assembly consists of four (4) main weldments and two (2) top weldments.



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5.0 CALCULATIONS

5.1 Loads Applied to the Atlas Railcar Interface

This section calculates the loads on the Atlas railcar and the Ballast Load Assembly interface from the inertial loads described in Section 4.2. There are four pinned locations per Main Ballast weldment with a total of eight pinned locations per assembly. The C.G is dimensioned in reference to the pinned locations as show in Figure 5-1 using C.G. values from Table 4-2.

$$CG_{ASSEMBLY} = 32.42 \text{ in.} - 7.50 \text{ in.} = 24.92 \text{ in.}$$

$$CG_{MAIN} = 28.28 \text{ in.} - 7.50 \text{ in.} = 20.78 \text{ in.}$$

$$CG_{TOP} = 48.95 \text{ in.} - 7.50 \text{ in.} = 41.45 \text{ in.}$$

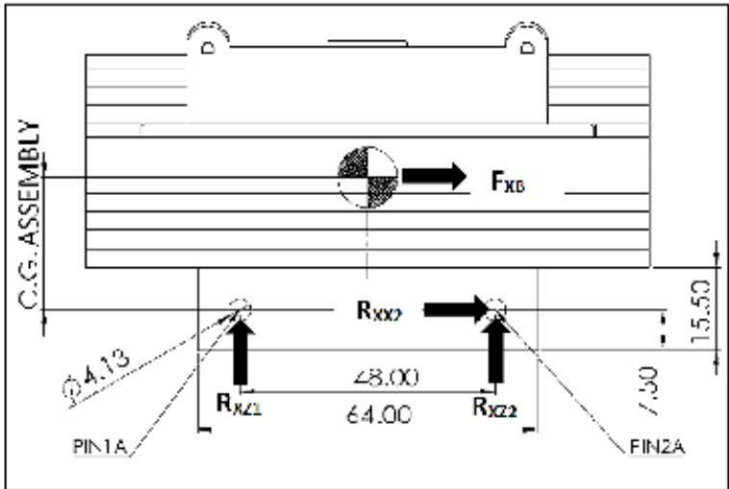


Figure 5-1: Longitudinal Loading (Side View)

The following equations are developed using basic principles. Four of the pinned locations are conservatively assumed to take the horizontal reaction, R_{XX2} . The moments from the loads and reactions are summed where the Ballast Load contacts on the PIN2A location (see drawing [12]).

$$\sum F_x = F_{xB} + (4 \text{ pins})(R_{XX2}) = 0$$

$$F_{xB} = W_B(a_x) = 110.2 \times (7.5) = 826.5 \text{ kips}$$

$$\sum M_{R_{XZ2}} = -F_{xB}(24.92) - (4 \text{ pins})(R_{XZ1})(48) = 0$$

$$\sum F_z = (4 \text{ pins})R_{XZ1} + (4 \text{ pins})R_{XZ2} = 0$$



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where, W_B is half the total Ballast Load weight on the Railcar from Table 4-2, a_x is the longitudinal load from Section 4.2, R_{XZ1} & R_{XZ2} are the vertical reaction loads at each pinned location, and R_{XX2} is the horizontal reaction load at PIN2A.

The weight and center of gravity (cg) inputs for the Ballast Load Assembly and Weldments are summarized in Table 4-2.

The reaction loads on the Atlas Railcar ballast pinned locations due to the +7.5g Longitudinal Loading are summarized in Table 5-1. Note: The direction of the reactions may be positive or negative depending on the direction of the loads applied.

Table 5-1: Railcar Interface Loading from +7.5g Longitudinal Load

Reactions	Values @ each pinned location
R_{XZ1} (kips)	-107
R_{XZ2} (kips)	107
R_{XX2} (kips)	207

The vertical loads are assumed to be uniformly distributed over four pinned locations instead of eight (conservative). This simplification is appropriate because the Ballast Load design is symmetrical in the (X) and (Y) direction. The combined C.G. is only offset from the center in the vertical (Z) direction (see Table 4-2). In addition, the loads will be calculated treating the assembly as a rigid body for simplification.

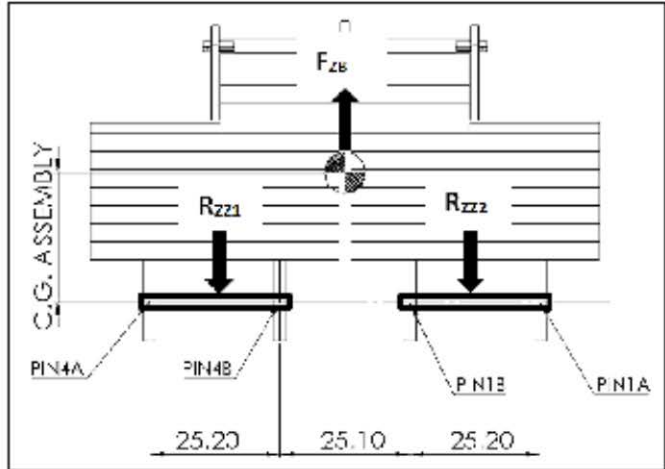


Figure 5-2: Vertical Loading (Front View)

The vertical reaction load at each pinned location (R_{ZZ1}) under this case is:



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$$F_{ZB} = W_B(a_x) = 110.2 \times (2) = 220.4 \text{ kips}$$

$$R_{ZZ1} = R_{ZZ2} = F_{ZB}/4 \text{ pins}$$

The vertical reaction loads using the weight values from Table 4-2 and the vertical accelerations from Section 4.2 are presented in Table 5-2. Note: The direction of the reactions may be positive or negative depending on the direction of the loads applied.

Table 5-2: Railcar Interface Loading from ±2g Vertical Load

Reactions	Values @ each pinned location
R_{ZZ1} (kips)	55
R_{ZZ2} (kips)	55

The lateral loads are reacted by the pin retainers blocks as shown in Figure 5-3. The tipping moment created by the vertical offset of the cg to the lateral reactions, R_{YZ1} & R_{YZ2} , is reacted by the two pinned locations furthest away from the pivot edge as shown in Figure 5-3.

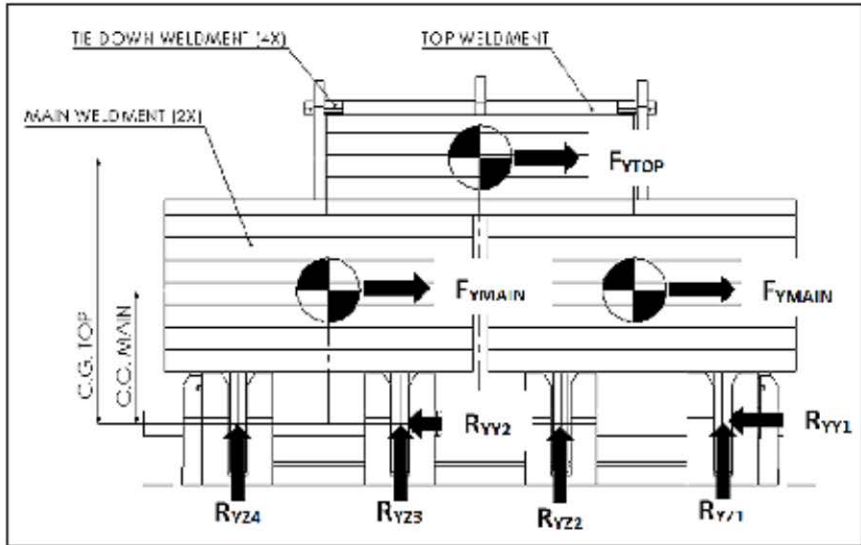


Figure 5-3: Lateral Load Free Body Diagram (Front View)

The pin retainer block reactions due to Lateral loading will be calculated by treating the 3 ballasts as separate masses. The top ballast will contribute to 1 of the main ballast pin reactions. The reactions R_{YZ2} , R_{YZ3} , and R_{YZ4} will not be calculated since the resulting reactions from one Main and Top weldments are bounding. The weldment weights and C.G.'s from Table 4-2 including the Lateral loading from Section 4.2 are as follows:



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$$W_{MAIN} = 44.1 \text{ kips}$$

$$W_{TOP} = 22.0 \text{ kips}$$

$$CG_{MAIN} = 28.28 \text{ in.} - 7.50 \text{ in.} = 20.78 \text{ in.}$$

$$CG_{TOP} = 48.95 \text{ in.} - 7.50 \text{ in.} = 41.45 \text{ in.}$$

The equations to solve for the lateral reaction loads, R_{YY1} , including the Lateral loading from Section 4.2 is as follows:

$$F_{YB} = (W_{MAIN} + W_{TOP}) \times (a_y) = 132.2 \text{ kips}$$

$$\sum F_Y = F_{YB} + (2 \text{ pinholes})R_{YY1} = 0$$

$$\sum M_{RYZ2} = (W_{MAIN} \times a_y)(20.78) + (W_{TOP} \times a_y)(41.45) + (2 \text{ pinholes})(R_{YZ2})(25).$$

The vertical pin reactions due to the lateral load, R_{YZ1} & R_{YZ2} , are calculated using the following equation:

$$\sum F_Z = R_{YZ1} + R_{YZ2} = 0$$

Using the values in Table 4-2 the results are summarized in Table 5-3. *Note: The direction of the reactions may be positive or negative depending on the direction of the loads applied.*

Table 5-3: Railcar Interface Loading from +2g Lateral Load

Reactions	Reactions @ each pinned location	Lateral Reaction @ 1 pin block
R_{YZ1} (kips)	73	N/A
R_{YZ2} (kips)	-73	N/A
R_{YY1} (kips)	66	$R_{yy1} \times 2 \text{ pins} = 132$

The maximum loads applied to the railcar interface are summarized in Section 6.1.

5.2 Structural Member and Weld Stress

The critical components that will be analyzed on the Ballast Load Assembly per drawing [12] are:

- Main Weldment (Item A2 of [12]) pin interface attachment plates (rails) for all interface design loads (see Section 5.2.1).
- Main Weldment lifting 1.5" thick plate for lateral (2g) loading from Top Weldment during transport (see Section 5.2.2).
- Main Weldments lifting pad eyes for vertical loading (2g) of Top Weldment restraint during transport including the tie-down weldment stresses (see Section 5.2.2).



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- Top Weldment (Item A3 of [12]) shear plates for Longitudinal (7.5g) loads during transport (see Section 5.2.3).

Other members/loadings are not considered to be relevant to the current proof-of-concept phase of the project.

5.2.1 Main Weldment - Attachment Rails Structural Evaluation

The Main Weldment rails restrain the Ballast Load Assembly in all directions and are the interface for attaching the Ballast Load Assembly to the Atlas Railcar pins (as described in Section 1.3 and shown in Fig. 1-2):

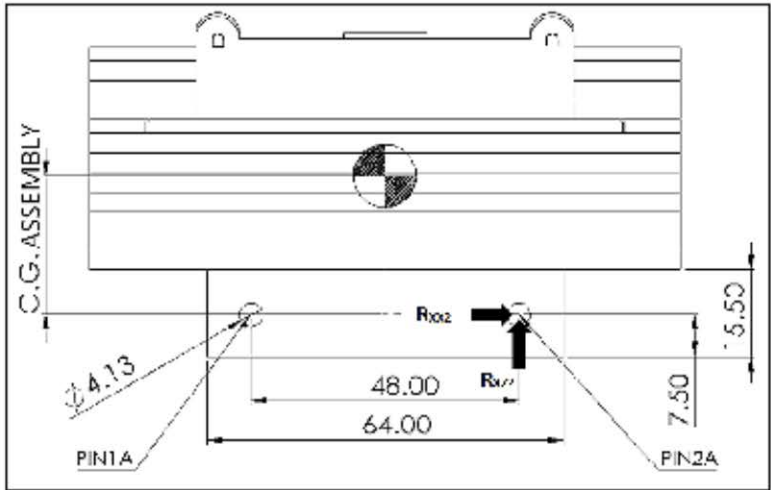


Figure 5-4: Main Weldment Attachment Plates (Rails)

Longitudinal and Vertical Loads on Ballast Load Attachment Plates

The maximum longitudinal load on each pin hole is R_{xx2} and vertical load is R_{xz2} from Section 5.1:

$$R_{xx2} = 207 \text{ kips}$$

$$R_{xz2} = 107 \text{ kips}$$

The areas for shear and bearing of the plate along the longitudinal direction (X) are calculated. The minimum shear area for the rail is from center of hole to edge of plate (8 inches) ref. Figure 5-4. The bearing stress is calculated using the pin diameter of 4 inches from DWG. [2] (Item 16) and the plate thickness of 2.5 inches:

$$A_{\text{Shear-rail-x}} = 2 \text{ planes} \times \left(8 - \left(\frac{4.13 \text{ in.}}{2} \right) \right) \times 2.5 \text{ in.} = 29.68 \text{ in.}^2$$

$$A_{\text{Bearing-rail-x}} = 4 \text{ in.} \times 2.5 \text{ in.} = 10 \text{ in.}^2$$



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The areas for shear and bearing of the plate along the vertical direction (Z) are calculated. The minimum shear area for the rail is from the center of hole to the bottom edge of plate (7.50 inches) ref. Figure 5-4:

$$A_{\text{Shear-rail-z}} = 2 \text{ planes} \times \left(7.50 - \left(\frac{4.13 \text{ in.}}{2} \right) \right) \times 2.5 \text{ in.} = 27.18 \text{ in.}^2$$

$$A_{\text{Bearing-rail-z}} = 4 \text{ in.} \times 2.5 \text{ in.} = 10 \text{ in.}^2$$

The bearing stress on the pin holes for both the longitudinal and vertical loads will be calculated due to the stress area being considerably less:

$$R_{\text{Bearing-rail-xz}} = \sqrt{R_{\text{xx2}}^2 + R_{\text{xz2}}^2} = 233 \text{ kips}$$

$$\sigma_{\text{Bearing-rail-xz}} = \frac{233 \text{ kips}}{10 \text{ in.}^2} = 23.3 \text{ ksi}$$

The minimum margin of safety using material properties for ASTM A588 for bearing stress on the pin holes is:

$$MS_{\text{bearing-rail-xz}} = \frac{50}{23.3} - 1 = +1.15$$

Lateral, Longitudinal, and Vertical Loads on the attachment plates 1/2" all around fillet Weld Evaluation

The maximum loads on each pin hole are R_{xx2} (Longitudinal), R_{xz2} (Vertical), and R_{yy1} (Lateral) from Section 5.1:

$$R_{\text{xx2}} = 207 \text{ kips}$$

$$R_{\text{xz2}} = 107 \text{ kips}$$

$$R_{\text{yy1}} = 66 \text{ kips}$$

The loads are applied individually on each of the three (XYZ) directions. The Vertical (Z) load is negligible compared to the Lateral (Y) and Longitudinal (X) loads on the weld.

The 1/2" fillet weld on the attachment plate geometry is as follows:

$$b = 64 \text{ in. (Weld length)}$$

$$d = 2.5 \text{ in. (Center distance of welds from 2.5" thick plate)}$$

$$h = 0.5 \text{ in. (Weld Size)}$$

The effective weld area for the all-around 1/2" fillet weld from Table 9-2, Case 6 of [10] is:

$$A_{\text{weld-rail}} = 1.414h(b + d) = 47.0 \text{ in.}^2$$

The moment on the weld due to railcar pin attachment Lateral (Y) reaction is:

$$M_{\text{Weld-rail-y}} = 66 \text{ kips} \times 2 \times 8 \text{ in} = 1056 \text{ kip-in}$$

The moment on the welds (4 weld groups) due to the Longitudinal (X) reaction from Section 5.1 and Figure 5-1 is:

$$F_{\text{XB}} = W_{\text{B}}(a_x) = 110.2 \times (7.5) = 826.5 \text{ kips}$$



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$$M_{weld-rail-x} = 826.5 \text{ kips} \times (24.92 \text{ in} - 8 \text{ in}) = 13,984 \text{ kip-in}$$

The central axis of the weld geometry due to bending in the Lateral (Y) and Longitudinal (X) directions is:

$$c_Y = \frac{2.5 \text{ in.}}{2} = 1.25 \text{ in.}$$

$$c_X = \frac{64 \text{ in.}}{2} = 32 \text{ in.}$$

The unit second moment of inertia I_{U-Y} and I_{U-X} and moment of inertia I_{rail-y} and I_{rail-x} for the weld from Table 9-2 and Section 9-4 of [10] are:

$$I_{U-Y} = \frac{2.5^2}{6} (3(64) + 2.5) = 202.6 \text{ in}^3$$

$$I_{rail-y} = 0.707hI_U = 72 \text{ in}^4$$

$$I_{U-X} = 4 \text{ plates} \times \left(\frac{64^2}{6} (3(2.5) + 64) \right) = 195,243 \text{ in}^3$$

$$I_{rail-x} = 0.707hI_U = 69,018 \text{ in}^4$$

The resulting shear bending stresses on the weld in the Lateral (Y) and Longitudinal (X) directions are:

$$\tau'_{weld-rail-Y} = \frac{1056 \text{ kip-in} \times 1.25 \text{ in}}{72 \text{ in}^4} = 18.33 \text{ ksi}$$

$$\tau'_{weld-rail-X} = \frac{13,984 \text{ kip-in} \times 32 \text{ in}}{69,018 \text{ in}^4} = 6.48 \text{ ksi}$$

The resulting shear stresses on the weld in the Lateral (Y) and Longitudinal (X) directions are:

$$\tau''_{weld-rail-Y} = \frac{66 \text{ kip} \times 2}{47 \text{ in}^2} = 2.81 \text{ ksi}$$

$$\tau''_{weld-rail-X} = \frac{207 \text{ kips}}{47 \text{ in}^2} = 4.40 \text{ ksi}$$

The combined shear stresses on the weld in the Lateral (Y) and Longitudinal (X) directions are:

$$R_{weld-rail-Y} = \sqrt{\tau'_{weld-rail-Y}{}^2 + \tau''_{weld-rail-Y}{}^2} = 18.54 \text{ ksi}$$

$$R_{weld-rail-X} = \sqrt{\tau'_{weld-rail-X}{}^2 + \tau''_{weld-rail-X}{}^2} = 7.83 \text{ ksi}$$

The minimum margin of safety will be on the Lateral (Y) direction:

$$MS_{weld-rail-X} = \frac{(0.6 \times 50)}{18.54} - 1 = +0.62$$



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5.2.2 Main Weldment Lifting Plate Evaluation

The lifting plate for the Main Weldment has three functions as described below:

- *Load Case 1*- The lifting pad-eyes are used for lifting and rigging of the Main Weldment.
- *Load Case 2*- The lifting plate pad-eyes are used as the vertical restraint for the Top Weldment during transportation.
- *Load Case 3*- The lifting plate is used as the lateral restraint of the Top Weldment during transportation.

Load Case 1 - Lifting Pad-eyes Evaluation (Lifting Condition)

This load case is evaluated in Section 5.3 Main and Top Weldments Lifting Evaluations.

Load Case 2 - Lifting Pad-eyes Vertical Restraint for Top Weldment Evaluation

During transportation the tie-down weldments will be secured within the Main Weldment pad-eyes as shown in Figure 5-5. The tie-down weldments are the vertical restraint for the Top Weldment. Four (4) tie-down weldments will be installed one at each main weldment lifting pad-eye.

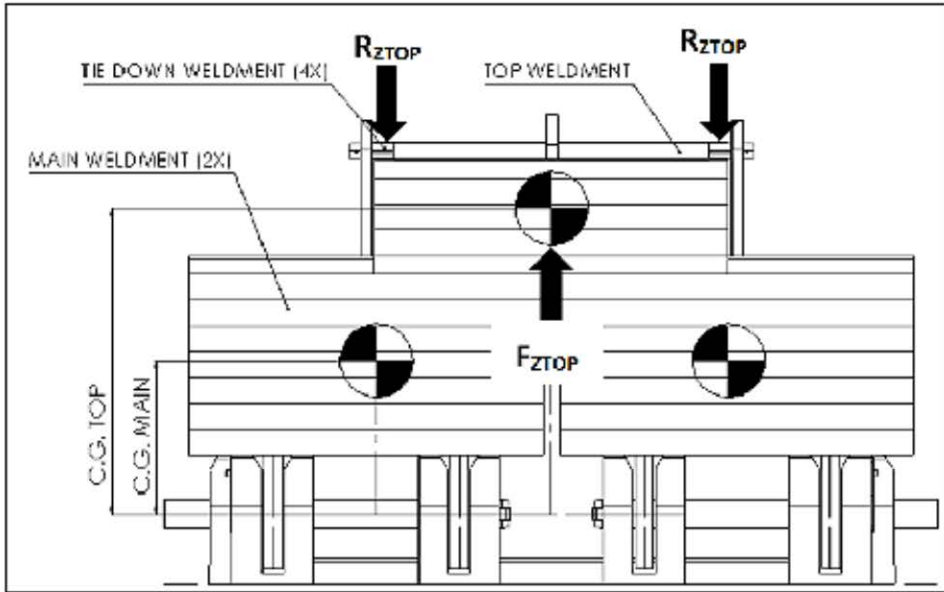


Figure 5-5: Top Weldment Vertical Load (2g)

The Vertical Load from the Top Weldment (See Table 4-2):

$$F_{ZTOP} = 22.0 \text{ kips} \times 2g = 44.0 \text{ kips}$$

The vertical load is distributed along all 4 tie-down weldments as shown in Figure 5-5.



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$$R_{ZTOP} = \frac{44.0 \text{ kips}}{4 \text{ padeyes}} = 11 \text{ kips}$$

R_{ZTOP} is less than the reaction R_{45} evaluated in Load Case 1 for the lifting condition from a single point at a 45 degree angle. The R_{45} load is bounding for the lifting pad-eye evaluation (see Section 5.3 for lifting condition evaluation). However, the tie-down weldments need to be evaluated for the R_{ZTOP} load.

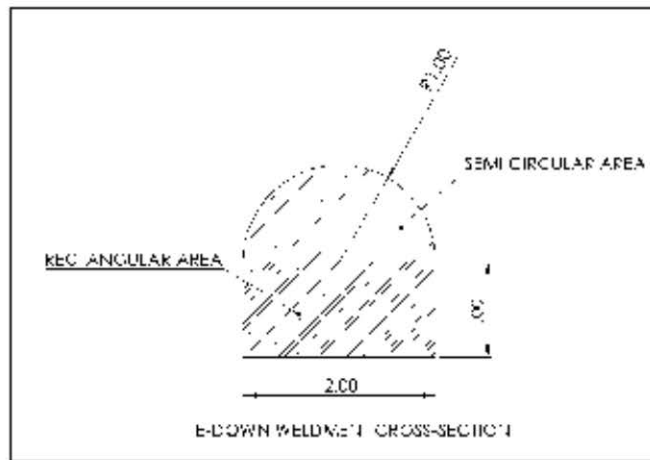


Figure 5-6: Tie-Down Weldment Cross-Section

The tie-down weldment section properties from Table 17-27 of [9] are as follows:

$$A_{\text{rectangle}} = 1 \text{ in.} \times 2 \text{ in.} = 2 \text{ in}^2$$

$$A_{\text{semi-circle}} = 1.570796R^2 = 1.57 \text{ in}^2$$

$$A_{\text{tie-down}} = A_{\text{rectangle}} + A_{\text{semi-circle}} = 3.57 \text{ in}^2$$

Centroid of composite cross section is:

$$c_{\text{rectangle}} = 0.5 \text{ in.}$$

$$c_{\text{semi-circle}} = 2 \text{ in.} - 0.575587R = 1.42 \text{ in.}$$

$$c_{\text{tie-down}} = \frac{(A_{\text{rectangle}} \times c_{\text{rectangle}}) + (A_{\text{semi-circle}} \times c_{\text{semi-circle}})}{A_{\text{tie-down}}} = 0.90 \text{ in.}$$

Moment of Inertia of composite cross section is:

$$I_{\text{rectangle}} = \frac{bh^3}{12} = 0.17 \text{ in}^4$$

$$I_{\text{semi-circle}} = 0.109757R^4 = 0.11 \text{ in}^4$$

$$I_{\text{tie-down}} = (I_{\text{rectangle}} + (A_{\text{rectangle}} \times (c_{\text{rectangle}} - c_{\text{tie-down}})^2)) + (I_{\text{semi-circle}} + (A_{\text{semi-circle}} \times (c_{\text{semi-circle}} - c_{\text{tie-down}})^2)) = 1.0 \text{ in}^4$$



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The bending moment on the tie-down weldment and bending stress is:

$$M_{tie-down} = 11 \text{ kips} \times 3 \text{ in.} = 33 \text{ kip-in}$$

$$\sigma_{bending-tie-down} = \frac{(33 \text{ kips-in}) \times (0.90 \text{ in.})}{1.0 \text{ in.}^4} = 29.7 \text{ ksi}$$

The shear stress on the tie-down weldment is:

$$\tau_{shear-tie-down} = \frac{11 \text{ kips}}{3.57 \text{ in.}^2} = 3.1 \text{ ksi}$$

The minimum margin of safety using material properties for A588 from Section 4.3:

$$MS_{shear-tie-down} = \frac{50(0.6)}{3.1} - 1 = +8.7$$

$$MS_{bending-tie-down} = \frac{50}{29.7} - 1 = +0.7$$

Load Case 3 – Main Weldment lifting plate evaluation from Top Weldment Lateral Load

The Main Weldment lifting plate (1.5" thick) restrains the Top Weldment lateral load during railcar transport. The 1.5" lifting plate will be evaluated for bending and shear since the lifting plate penetrates the entire body of the weldment assembly. By inspection, the lifting plate 1/2" fillet welds are not a concern.

The Top Weldment lateral load on the Main Weldment 1.5" thick lifting plate is:

$$F_{YTOP} = 22.0 \text{ kips} \times 2g = 44.0 \text{ kips}$$

The lateral load on the Main Weldment lifting plate is $D_{TOP} = 6.43$ inches high from the top surface of Main Weldment assembly (see Figure 5-7). The moment on the plate due to the Top Weldment Lateral load is:

$$M_{weld-liftplate-y} = 44.0 \text{ kips} \times 6.43 \text{ in.} = 282.9 \text{ kip-in}$$

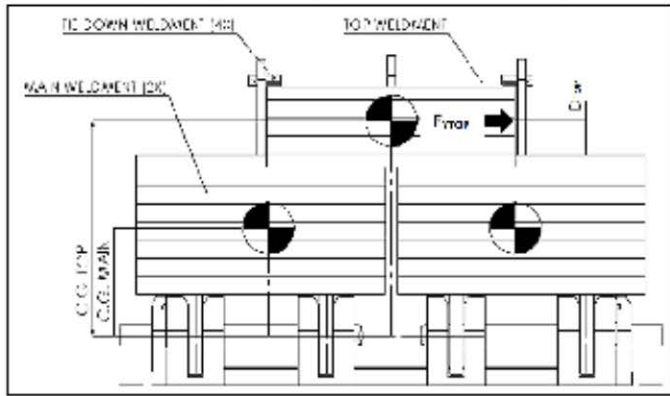


Figure 5-7: Lateral Load (2g) Top Weldment



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The 1.5" thick plate cross-section properties are as follows:

$$b = 68 \text{ in. (Plate length)}$$

$$d = 1.5 \text{ in. (1.5" thick plate)}$$

The plate cross-sectional area is:

$$A_{\text{liftplate-y}} = 1.5(68) = 102 \text{ in.}^2$$

The plate central axis of bending is:

$$c_{\text{liftplate-y}} = \frac{1.5 \text{ in.}}{2} = 0.75 \text{ in.}$$

The moment of inertia for the plate:

$$I_{\text{liftplate}} = \frac{bd^3}{12} = 19.13 \text{ in.}^4$$

The bending stress on the plate due to the lateral reaction:

$$\sigma_{\text{liftplate-y}} = \frac{282.9 \text{ kip-in} \times 0.75 \text{ in}}{19.13 \text{ in.}^4} = 11.1 \text{ ksi}$$

The shear stress on the plate due to the lateral reaction:

$$\tau_{\text{liftplate-y}} = \frac{44 \text{ kips}}{102 \text{ in.}^2} = 0.43 \text{ ksi}$$

The combined stress on plate is:

$$R_{\text{liftplate-y}} = \sqrt{\sigma_{\text{liftplate-y}}^2 + \tau_{\text{liftplate-y}}^2} = 11.1 \text{ ksi}$$

The minimum margin of safety due to the combined stress is:

$$MS_{\text{liftplate-y}} = \frac{50}{11.1} - 1 = +3.5$$

5.2.3 Top Weldment Longitudinal Load Evaluation

The vertical and lateral restraints for the Top Weldment have been evaluated in the previous Section 5.2.2. The Top Weldment longitudinal restraints (X) during transport are the 48" L x 10" W x 2.5" thick shear plates (Item No. 7 of [12]). The shear plates are welded to the Top Weldment assembly by a 48" long 3/8" fillet weld on one (1) side and a 68" long 3/8" bevel weld on the remaining three (3) sides of the plate.



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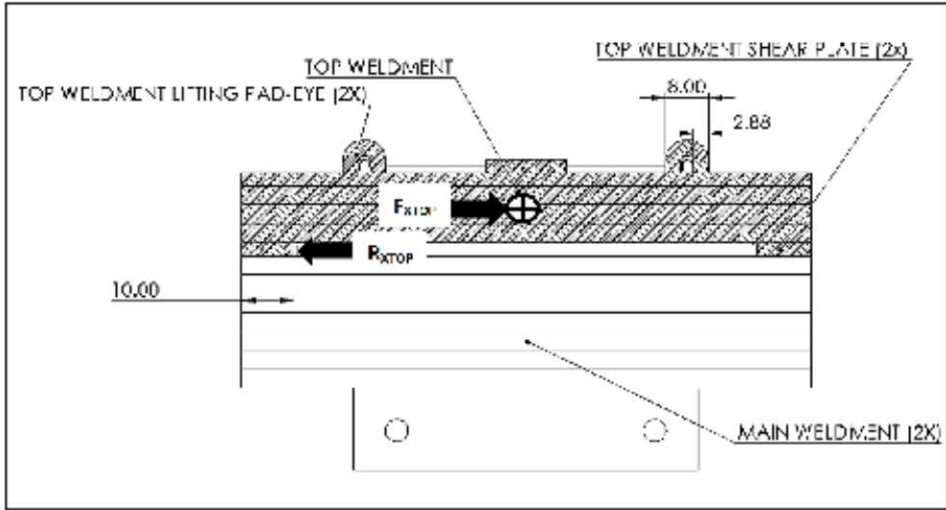


Figure 5-8: Top Weldment Longitudinal Load (7.5g)

The Top Weldment longitudinal load from one shear plate is:

$$F_{XTOP} = 22.0kips \times 7.5 = 165.0 kips$$

In accordance with AWS-D1.1, Figure 3.3 of [15] the weld size for a single groove weld could be 1/8" smaller than specified depending on the welding process used. Therefore, the effective weld area for the 3/8" fillet weld (1 side) and the 3/8" bevel weld (3 sides) will be assumed to be a 1/4" single groove weld all around for conservatism using Table 9-2, Case 6 of [10] is:

$$b = 48 \text{ in. (Weld length)}$$

$$d = 10 \text{ in. (Width spacing of welds)}$$

$$h = 0.25 \text{ in. (Size of weld conservatively assuming a 1/4" fillet weld instead of 3/8")}$$

$$A_{weld-shearplate} = 1.414h(b + d) = 20.50 \text{ in.}^2$$

The shear stress on the shear plate weld from the Top Weldment longitudinal load:

$$\tau_{weld-shearplate} = \frac{165 \text{ kips}}{20.50 \text{ in.}^2} = 8.05 \text{ ksi}$$

The margin of safety for the shear plate weld along the longitudinal (X) direction is:

$$MS_{weld-liftplate} = \frac{50(0.6)}{8.05} - 1 = +2.73$$



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5.3 Main and Top Weldments Lifting Evaluation

Main Weldment Lifting Pad-eyes Evaluation

The lifting load for the Main Weldment from Section 4.4 is:

$$F_{Main} = 44.1 \text{ kips}$$

The Main Weldment has two lifting points as shown in Figure 5-9. It is assumed that the Main Weldment will be lifted from a single point at a 45-degree angle for conservatism. A spreader beam/frame is recommended for lifting during field operations to apply a vertical load only on the lifting pad-eyes.

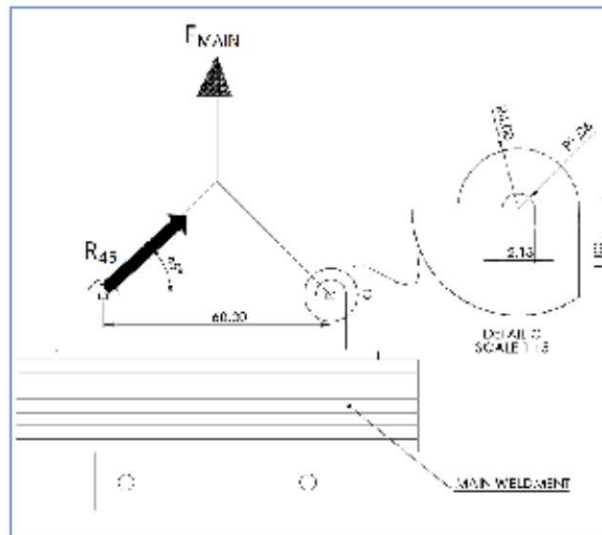


Figure 5-9: Main Weldment Lifting Pad-eyes

The resulting load on the pad-eyes from lifting from a single point at a 45-degree lift angle is:

$$R_{45MAIN} = \frac{(44.1/2)}{\sin(45)} = 31.2 \text{ kips}$$

The minimum plate thickness is 1.50 inches. The recommended shackle for lifting and rigging is a Crosby G-2130 Part No. 1019659 [7] with a pin diameter of 2.04 inches and a working load limit of 25 tonnes. The areas for shear, bearing, and tension of the plate are:

$$A_{Shear-lift} = 2 \text{ planes} \times \left(4 - \left(\frac{2.13 \text{ in.}}{2} \right) \right) \times 1.5 \text{ in.} = 8.81 \text{ in.}^2$$

$$A_{Bearing-lift} = 1.5 \text{ in.} \times 2.04 \text{ in.} = 3.06 \text{ in.}^2$$

$$A_{Tension-lift} = (8 \text{ in.} - 2.13 \text{ in.}) \times 1.5 \text{ in.} = 8.81 \text{ in.}^2$$



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A dynamic load factor of 1.15 is applied per the specification for overhead traveling cranes published by the Crane Manufacturers Association of America [11]. The bearing stress on the pad-eyes and shear stress are calculated below:

$$\sigma_{\text{Bearing-lift}} = \frac{(31.2 \text{ kips}) \times (1.15)}{3.06 \text{ in.}^2} = 11.7 \text{ ksi}$$

$$\tau_{\text{shear-lift}} = \frac{(31.2 \text{ kips}) \times (1.15)}{8.81 \text{ in.}^2} = 4.07 \text{ ksi}$$

The margin of safety is calculated using the lesser of 1/3 yield and 1/5 ultimate in accordance with [4]. The material of the lug is the 50 ksi yield strength material from Table 4-1.

$$MS_{\text{Bearing-lift}} = \frac{\min(\frac{50}{3}, \frac{70}{5})}{11.7} - 1 = +0.20$$

$$MS_{\text{shear-lift}} = \frac{.6 \times \min(\frac{50}{3}, \frac{70}{5})}{4.07} - 1 = +1.06$$

Top Weldment Lifting Pad-eyes Evaluation

The Top Weldment is designed to be lifted similar to the Main Weldment design. The lifting load for the Top Weldment from Section 4.4 is:

$$F_{\text{TOP}} = 22.0 \text{ kips}$$

The resulting loads on the pad-eyes from lifting from a single point at a 45-degree lift angle are:

$$R_{45\text{TOP}} = \frac{(22/2)}{\sin(45)} = 15.6 \text{ kips}$$

$$R_{45\text{shear}} = R_{45\text{TOP}} \times \cos(45) = 11 \text{ kips}$$

The shear, tension, and bearing stress on the pad-eyes for the Top Weldment is not a concern since the same design has been evaluated for the Main Weldment at 31.2 Kips.

Main and Top Weldments stacked plates weld evaluation (Lifting)

The Main Weldment design consists of a top 85" x 48" x 2.5" thick plate and seven (7) stacked 106" x 48" x 3.5" thick plates. The 1.5" thick lifting plate is welded to the bottom (3.5") and top (2.5") plates of the weldment assembly by two 68" long x 1.5" wide ½" size welds and the lifting plate penetrates the entire body of the Main Weldment assembly connecting all the stacked plates from the center (see Figure 5-10). By inspection the resulting stresses on the stacked plates is not a concern. All critical components on the 1.5" lift plates and Main Weldment has been evaluated in the previous sections.

The Top Weldment design consists of a top 106" x 48" x 2.5" thick plate and three (3) stacked 106" x 48" x 3.5" thick plates. See Figure 5-11 for Top Weldment stacked plate design. Similarly to the Main Weldment design, the 1.5" lifting plate for the Top Weldment penetrates through the entire body of the assembly and welded to the bottom plate (3.5") and top (2.5") plates by two 68" long x 1.5" wide ½"



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size fillet and groove welds. All critical components on the lift plates have been evaluated in the previous sections.

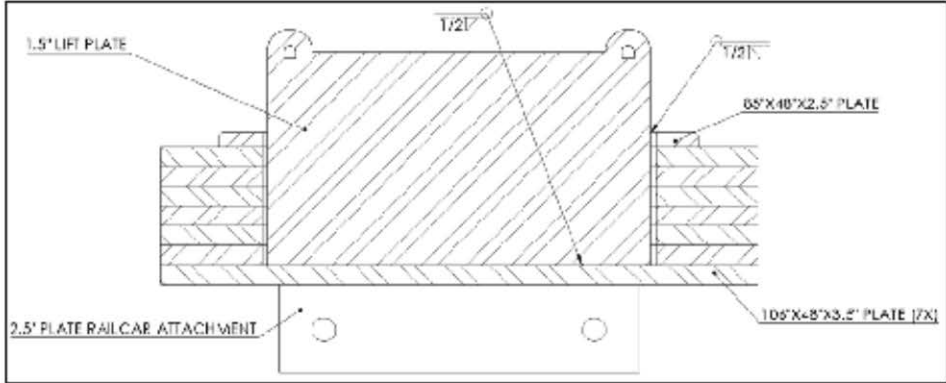


Figure 5-10: Main Weldment Stacked Plates (Lifting)

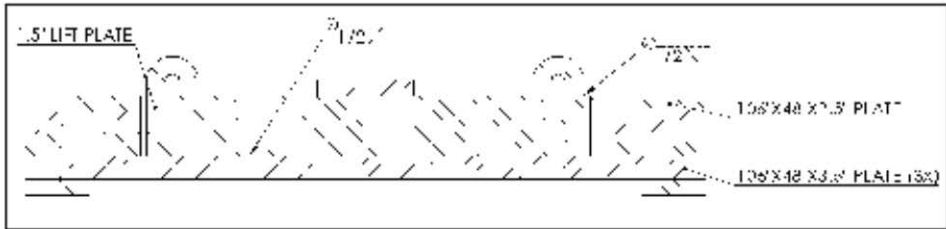


Figure 5-11: Top Weldment Stacked Plates (Lifting)

5.4 Truck Transportation Recommendations

The ballast load weldments will require shoring, tie-down, and weight distribution during truck transportation. Recommendations for truck transportation include using W16 x 50 beams for weight distribution on the truck deck. A conceptual design for the shoring is provided in Figure 5-12. The shoring will alleviate the weight of the Main Weldment (44.1 kip) from the rails (2.5" thick plate) and will distribute the load on the truck deck.

The two holes on the 1.5" thick lifting plate or the 4.13" holes (4 total) on the Main Weldment assembly can be used (as required) to tie-down the assembly during truck transport. A more detailed design and analyses for the shoring/cribbing will be performed at a later date.



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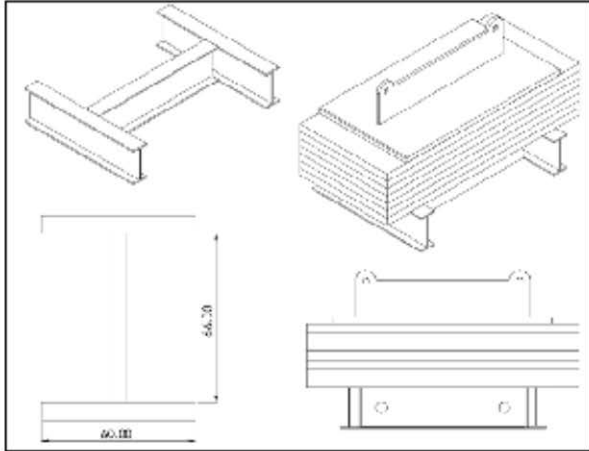


Figure 5-12: Conceptual Ballast Load Shoring for Truck Transport

6.0 RESULTS AND CONCLUSIONS

6.1 Railcar Interface Loading Summary

Table 6-1 is a summary of the bounding loads applied to the Atlas railcar interface from Section 5.1.
 NOTE: The summarized loads in Table 6-1 are for a Ballast Load Assembly consisting of two (2) Main Weldments and one (1) Top Weldment weighing a total of 110.3 kips.

Table 6-1: Railcar Tie-down Loads

Section 4.2 Loading	Direction	Reaction per pinned location	Calculated Reaction, kips	Max Loading, kips
Longitudinal (7.5g)	Vertical (Z)	R_{XZ1}	-107	$R_{XX2} = 207$
Longitudinal (7.5g)	Vertical (Z)	R_{XZ2}	107	
Longitudinal (7.5g)	Longitudinal (X)	R_{XX2}	207	
Vertical (2g)	Vertical (Z)	R_{ZZ1}	55	$R_{XZ2} = 107$ Vertical reaction is bounded by Longitudinal 7.5g reaction.
Vertical (2g)	Vertical (Z)	R_{ZZ2}	55	
Lateral (2g)	Vertical (Z)	R_{YZ1}	73	$R_{YY2} = 66$ Reaction on pin block is twice $R_{YY1} = 132$
Lateral (2g)	Vertical (Z)	R_{YZ2}	-73	
Lateral (2g)	Lateral (Y)	R_{YY2}	66	



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6.2 Concept Design Summary

The conceptual design for the Ballast Load Assembly was evaluated for the AAR tie-down loads and lifting. As shown in Section 5.0 all the margins of safety were at least +0.20. This is deemed adequate to assure the Ballast Load Assembly concept is viable in support the Atlas Railcar design.

6.3 Literature Search and other Background Data

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

7.0 REFERENCES

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11. CMAA Specification #70, *Specification for Top Running Bridge & Gantry Type Multiple Girder Electric Overhead Traveling Cranes*, Crane Manufacturers Association of America, Inc. 1994.
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13. Federal Highway Administration, DOT, 23CFR Ch. I (4-1-13 Edition), *“Part 658.17 Weight”*
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APPENDIX A: CALCULATION ATTACHMENTS



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A.1 Ballast Load Assembly Calculated Weights and C.G.

Assembly	Component	Latitude Y (in.)	Vertical Z (in.)	Longitudinal X (in.)	Area (in ²)	Volume (in ³)	Density (lb/in ³)	Quantity	Weight (lb)	dy (in)	Component C.G. (in)	Y.C.G.	M (in ⁴ lb)	NOTES
Total Ballast Load on Railcar									202500.47					
Ballast Load Assembly									101250.24			27.42	2709855.00	Solidworks C.G. 15.92115 50.82 46
Main Sclast Weldment (2X)									50250.30			28.28	226869.51	
Main Ballast Weldment (1X)									40150.05					
	Railcar Attachment Plate	2.5	15.5	64	2480.00	0.204	4	2017.28	0.00	3.75	3.75	21833.52	6 plates total	
	Railcar Attach. bolts	2.5	4.13	N/A	12.47	0.284	8	75.52	0.00	3.50	3.50	870.66	8 bolts total (4)* (2)* (2)*	
	3.5" plates (1x per 455W)	48	3.5	136	17928.00	0.284	14	7694.8	18.34	13.25	27.28	6544677.89	Center location of all 3.5 plates	
	2.5" plates (1x per 455W)	48	2.5	85	10200.00	0.284	2	2752.00	40.00	3.25	42.25	238890.09	Center location of all 2.5 plates	
(See Note 2)	Lifting plates (1x per 455W)	1.5	14.88	88	486.08	0.284	2	853.12	42.30	5.10	49.90	41997.72	Rectangular Section	
	Lifting plates (1x per 455W)	1.5	4	N/A	22.13	0.284	4	42.88	00.38	-2.00	18.27	2308.44	Semi-Circular Section AWS pg 17-19	
	Lifting plates (1x per 455W)	1.5	2.13	N/A	3.95	0.284	4	8.04	42.30	14.38	16.38	344.73	Lifting plates (4)* (1)* (2)* (1)*	
Top Ballast Weldment (1X)									2000.24			48.06	973462.51	
	3.5" plates (1x per 455W)	48	3.5	136	17928.00	0.284	8	5172.48	42.30	8.25	47.28	274487.88	Center location of all 3.5 plates	
	2.5" plates	48	2.5	136	12720.00	0.284	2	3024.48	13.34	3.25	14.25	194877.04		
	2.5" top plate (short)	48	2.5	15	1620.00	0.284	2	512.00	25.00	3.25	16.75	28010.00		
	2.5"x10" plate	48	2.5	10	720.00	0.284	2	681.60	40.00	3.25	41.25	287784.0		
(See Note 2)	Lifting plate	1.5	2.13	9	25.92	0.284	2	44.52	25.00	3.07	16.57	521.22	Resting on the surface of ballast	
	Lifting plate	1.5	4	N/A	22.13	0.284	2	21.41	00.00	-2.00	18.20	1246.19	Semi-Circular Section AWS pg 17-19	
	Lifting plate	1.5	2.25	N/A	3.96	0.284	2	7.09	00.00	0.00	16.90	1301.60	Lifting plates (4)* (1)* (2)* (1)*	
Tie Down Weldment (1X)									10.62			16.90	1201.97	
	2x2x6 plate	2	6	2	24.00	0.284	4	27.36	0.00	0.00	16.90	1540.49		
	0.5x1.0x1.0 plate	3	0.5	1	1.50	0.284	2	3.41	0.00	0.00	16.90	182.50		

NOTES:
 1 The vertical datum (y=0 and Z=0) is located at the base of the ballast load assembly
 2 Lifting plate dimensions that penetrate the ballast assembly are not accounted for since they are accounted for within the plate volume calculations.