RETURN TO ~~396-SS~~ P1-137

71-9183

Nuclear Assurance Corporation
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October 11, 1988
AHW/88/141/ETS

Mr. Charles E. MacDonald, Chief
Transportation Branch
NMSS:SGTB, Mail Stop WF4E4
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Dear Mr. MacDonald:

The USNRC has asked 11 questions regarding the cask supports and ISO container for the NAC-1 (NFS-4) cask amendment request, submitted by Nuclear Assurance Corporation (NAC) on May 25, 1988. The answers to these 11 questions are attached. These answers show that with several modifications to the cask support system (detailed in the attached answers to the USNRC questions), the supports can sustain a 2 g load factor. The g-load requirement for the cask support system is 2 g in the longitudinal, lateral, and vertical directions, applied simultaneously. The analyses performed by NAC, as explained in the attached answers, show that the supports meet this requirement. It has been noted that the 2 g load factor only applies to truck trailers with air ride suspensions; the Fontaine drop-frame trailers specified in the license drawings contain air ride suspensions and this fact has been verified by NAC.

The modifications to the cask support system essentially consist of additional bolts through the cask supports and base plate into the ISO container floor beams so that credit for the welds of the base plate to the container floor is unnecessary. The welds of the base plates to the container floor have been increased to 1/2-inch for the rotation trunnion support and 3/8-inch for the lift trunnion support for conservatism, but these welds are not used in the analyses because welds and bolts are not considered to function simultaneously. The bolt patterns used in the analyses are shown in the attached sketches and also in the license drawings. Additional bolts are shown on these sketches that are not used in the analyses but have been included in the hardware for conservatism.

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A further modification to the support system consists of the addition of 2.5-inch thick blocks to the trunnion strap lug to prevent the bending of the strap lug or attachment plate when load is applied.

Should you have any questions or require additional information, please contact me.

Sincerely,

NUCLEAR ASSURANCE CORPORATION

Alan H Wells

Alan H. Wells, PhD
Manager, Licensing and Analysis
Engineering and Transportation Systems

AHW/tko

Attachments

DOCKET NO. 71-9183

CONTROL NO. 24813

DATE OF DOC. October 11, 1988

DATE RCVD. October 12, 1988

FCUF ______ PDR ✓

FCAF ______ LPDR ______

I & E REF. ✓

SAFEGUARDS ______

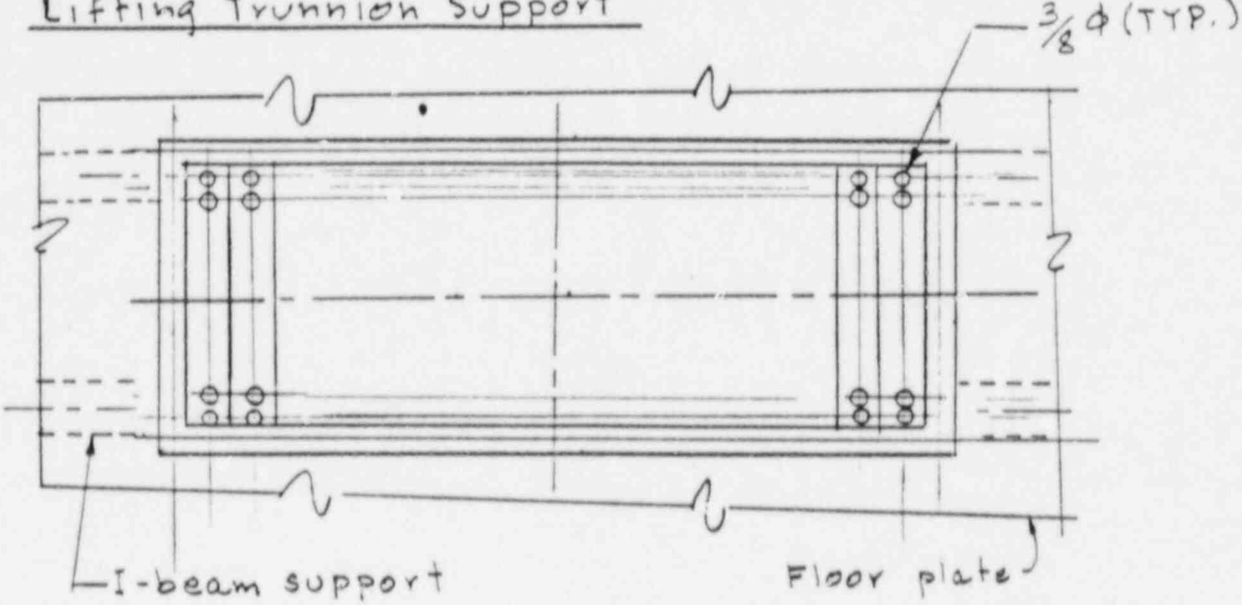
FCTC ✓ OTHER

DATE 10/12/88 [illegible]

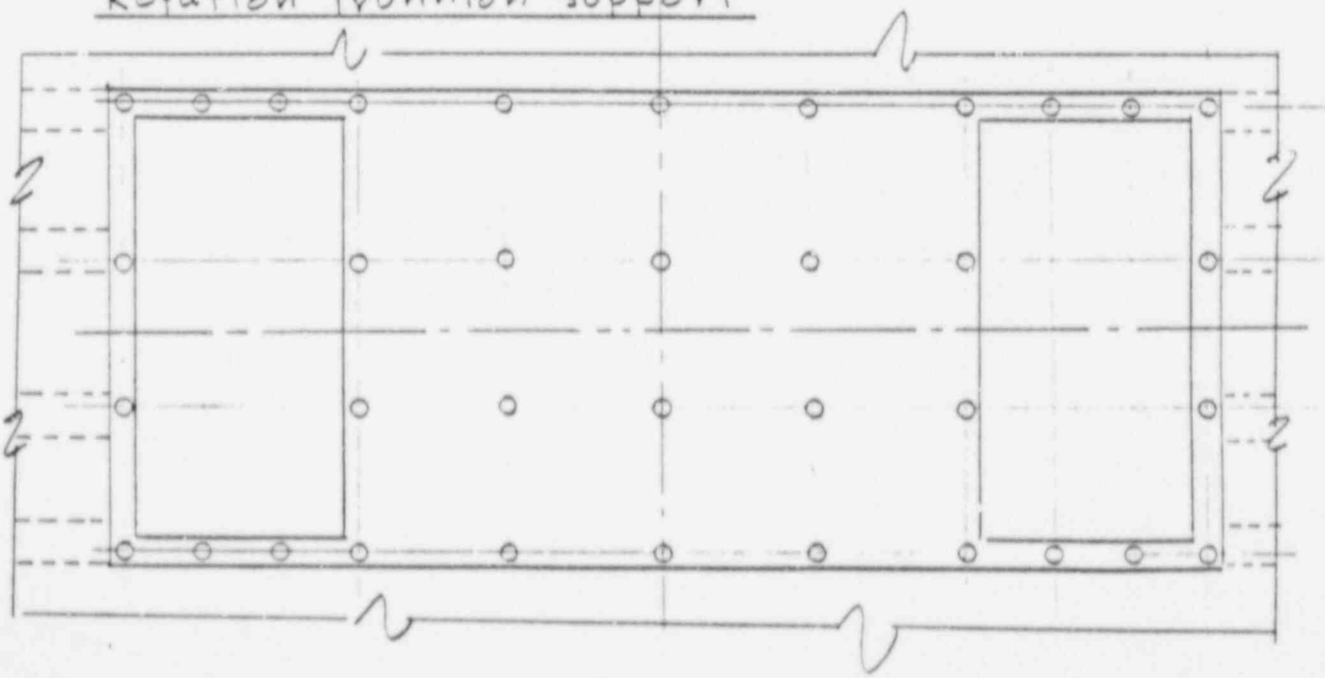
Fuel Movement Project
Cask Support - NAC-1

Adamson Container - Anchor bolt locations
SAE J429e, Gr. 8

Lifting Trunnion Support



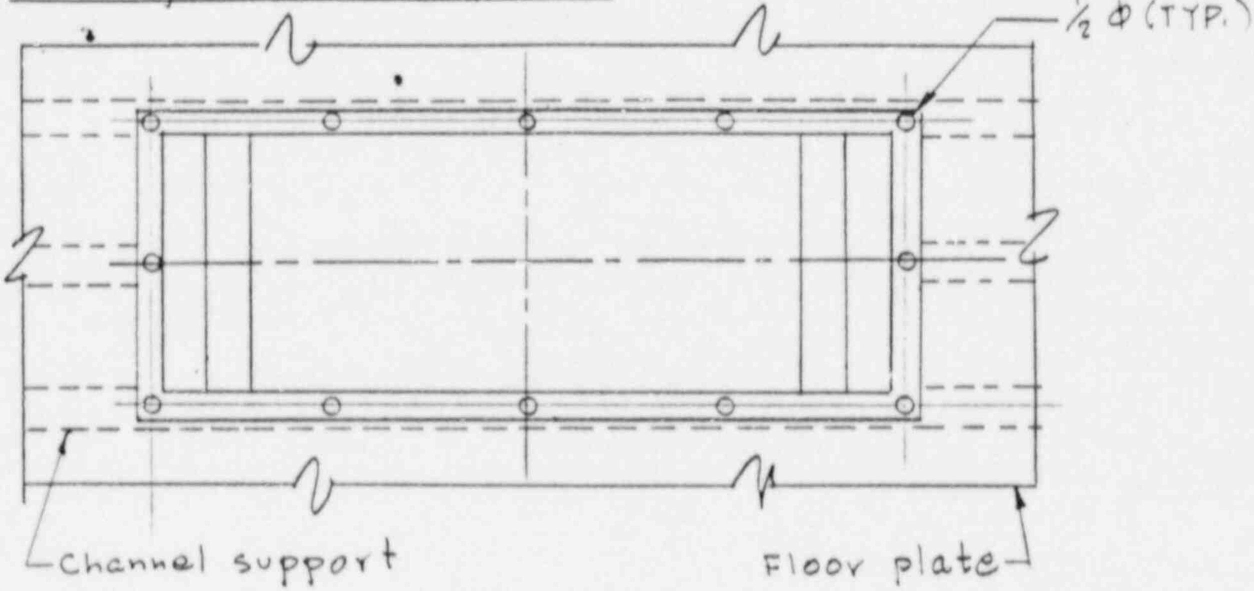
Rotation Trunnion Support



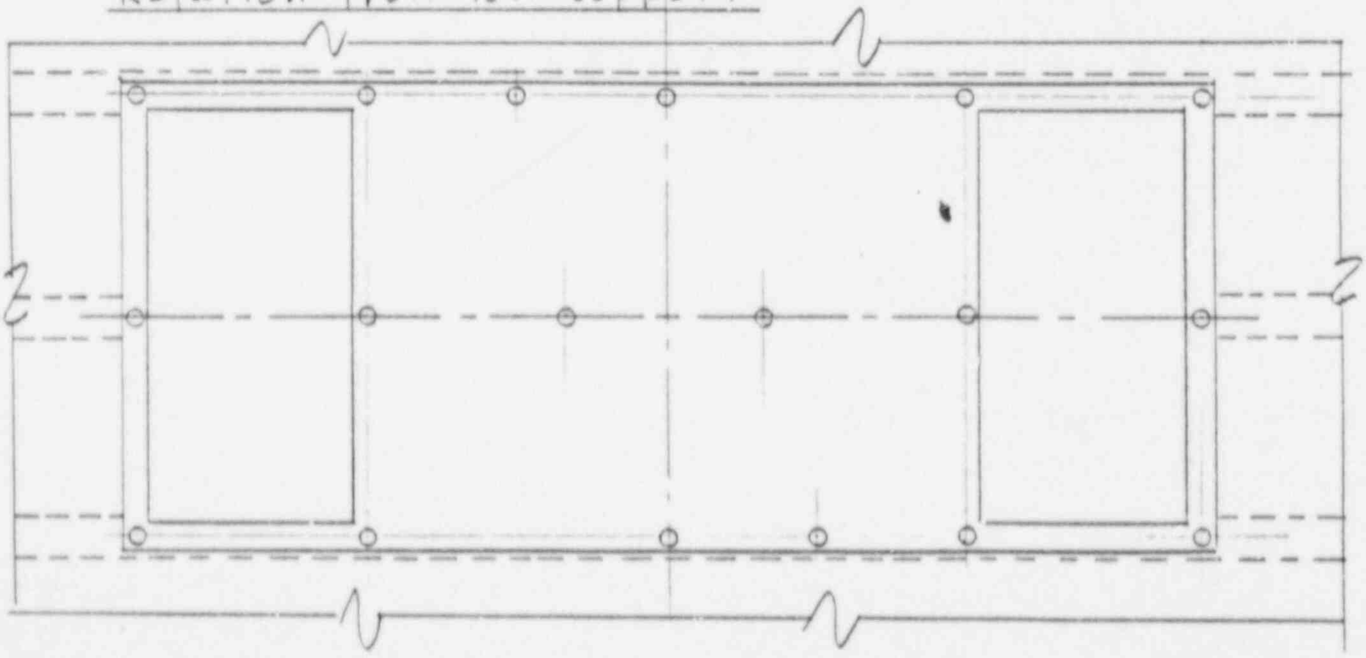
Fuel Movement Project
Cask Support - NAC-1

Evermaster Container - Anchor bolt locations
SAE J429 e, Gr. 8

Lifting Trunnion Support



Rotation Trunnion Support



NRC Comments - NAC-1 Cask Supports

Ref.: 1. Letter from Nuclear Assurance Corporation to U.S. Nuclear Regulatory Commission (A.H. Wells to C.E. MacDonald), AHW/88/55/ETS, May 25, 1988.

2. Letter from U.S. Nuclear Regulatory Commission to Nuclear Assurance Corporation (C.E. MacDonald to A.H. Wells), September 15, 1988.

Nuclear Assurance Corporation requested an amendment to Certificate No. 71-9183 for the NAC-1 Cask (Ref. No. 1) to incorporate: (1) drawing Nos. NAC-347-586 F2 and NAC-347-586 F3 of the ISO Container Configuration; and (2) the use of the Fontaine Drop-Frame Trailer and the associated package center-of-gravity.

The U.S. Nuclear Regulatory Commission requested 11 points of additional information (Ref. No. 2) in connection with their review of the NAC request.

The NAC response to the requests for additional information is as follows:

1.0 U.S. NRC Comment:

Justify using design tiedown loads of 2.0 g for the cask supports in each of the three principal directions (i.e., longitudinal, lateral, and vertical) instead of the 10, 5, and 2 g loads specified in 10 CFR Part 71.

NAC Response:

The design load factors for the NAC-1 Cask Supports - ± 2.0 g in each of the three principal directions (longitudinal, lateral, and vertical) acting separately or in any combination - were selected as conservative values based on the requirements of 49 CFR 393.100c.4.e and 49 CFR 393.102b, which are Federal Highway Administration Transportation Regulations for Protection Against Shifting or Falling Cargo, General Rules, Special Rules for Miscellaneous Metal Articles, Special Rules for Intermodal Cargo Containers and for Securement Systems - Tiedown Assemblies, respectively.

The load factors specified by 49 CFR 393.100c.4.e are: 1.70 g downward, 0.50 g upward, 0.30 g lateral, and 1.80 g longitudinal. The load factor specified by 49 CFR 393.102b is: 1.50 g in any direction.

The structural analysis of the NAC-1 Cask Supports and Container Attachments uses the ± 2.0 g load factors in combination with a material yield strength allowable stress criteria.

The design tiedown loads specified in 10 CFR 71.45b.1 (10 g longitudinal, 5 g lateral, and 2 g vertical) are for a system of tiedown devices which is a structural part of the package; the NAC-1 Cask Supports are not a structural part of the package, since they are not welded or bolted to the package, but rather capture the trunnions via bolted straps. The cask supports have never been considered to be a part of the cask package in any of the drawings, Safety Analysis Reports, or Certificates of Compliance. Based on these considerations, the requirements of 10 CFR 71.45b.1 are not applicable to the NAC-1 Cask Supports.

2.0 **U.S. NRC Comment**:

Justify that the material strength of Aluminum 6061 T6 used in the analysis is higher than that shown in Table 1-8.4, Appendix I, Section III of the ASME code.

NAC Response:

The material yield strength of 6061-T6 aluminum alloy from the ASME Section III Appendices are used in the revised analyses of the NAC-1 Cask Supports and Attachments; S_y = 35 ksi minimum yield strength and S_u = 42 ksi minimum ultimate strength. The margins of safety remain positive for all of the analyses that were affected by this revised material yield strength. In conjunction with these analysis revisions, the analysis of the Forward Support Assembly (Rotation Trunnion) at a section 8.0 inches below the trunnion centerline was corrected to use the cross section dimensions of the final design configuration.

The original analysis used the typical yield strength of 6061-T6, S_y = 39.6 ksi at 100°F.

Based on the available test reports for the NAC-1 Cask Supports materials, the actual material yield strengths are 42 ksi minimum with one plate at 39.2 ksi. The support materials were produced to the ASME specifications.

4.0 U.S. NRC Comment:

Specify the materials used for the bolts in the package. Also, provide the sources for the material properties used in the analysis of the bolts.

NAC Response:

The bolts used in the NAC-1 Cask Supports and for their attachment to the ISO containers are as follows:

Forward Support Assy., Rotation Trunnion Clamp Bolt:
1-8 UNC SAE J429e, Grade 5

Aft Support Assy., Lifting Trunnion Strap Bolt:
1-8 UNC SAE J429e, Grade 8

Evermaster ISO Containers

Forward Support Base Plate to Cross-Channel Beams:
1/2-13 UNC SAE J429e, Grade 8

Aft Support Base Plate to Cross-Channel Beams:
1/2-13 UNC SAE J429e, Grade 8

Adamson ISO Containers

Forward Support Base Plate to I-Beam Cross-Members:
3/8-16 UNC SAE J429e, Grade 8

Aft Support Base Plate to I-Beam Cross-Members:
3/8-16 UNC SAE J429e, Grade 8

The mechanical properties of the bolts are:

SAE J429e, Grade 5 Medium Carbon Steel, Quenched and Tempered

S_u = 120,000 psi S_y = 92,000 psi

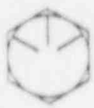
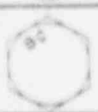
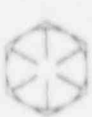
SAE J429e, Grade 8 Medium Carbon Steel, Quenched and Tempered

S_u = 150,000 psi S_y = 130,000 psi

NAC Response (cont):

The bolt material specification is:

> "SAE Standard J429e - Mechanical and Quality Requirements for Externally Threaded Fasteners," by the Society of Automot. . Engineers, Inc., New York, New York.

Identification Grade Mark	Specification	Fastener Description	Material	Nominal Size Range (in.)	Mechanical Properties		
					Proof Load (psi)	Yield Strength Min (psi)	Tensile Strength Min (psi)
	SAE J429 Grade 5	Bolts, Screws, Studs	Medium Carbon Steel, Quenched and Tempered	1/4 thru 1 Over 1 to 1-1/2	85,000 74,000	92,000 81,000	120,000 105,000
	ASTM A449			1/4 thru 1 Over 1 thru 1-1/2 Over 1-1/2 thru 3	85,000 74,000 55,000	92,000 81,000 58,000	120,000 105,000 90,000
	SAE J429 Grade 5.1	Sems	Low or Medium Carbon Steel, Quenched and Tempered	No. 6 thru 3/8	85,000	–	120,000
	SAE J429 Grade 5.2	Bolts, Screws, Studs	Low Carbon Martensitic Steel, Quenched and Tempered	1/4 thru 1	85,000	92,000	120,000
	ASTM A325 Type 1	High Strength Structural Bolts	Medium Carbon Steel, Quenched and Tempered	1/2 thru 1 1-1/8 thru 1-1/2	85,000 74,000	92,000 81,000	120,000 105,000
	ASTM A325 Type 2		Low Carbon Martensitic Steel, Quenched and Tempered	1/2 thru 1	85,000	92,000	120,000
	ASTM A325 Type 3		Atmospheric Corrosion Resisting Steel, Quenched and Tempered	1/2 thru 1 1-1/8 thru 1-1/2	85,000 74,000	92,000 81,000	120,000 105,000
	ASTM A354 Grade BB	Bolts, Studs	Alloy Steel, Quenched and Tempered	1/4 thru 2-1/2 2-3/4 thru 4	80,000 75,000	83,000 78,000	105,000 100,000
	ASTM A354 Grade BC				105,000 95,000	109,000 99,000	125,000 115,000
	SAE J429 Grade 7	Bolts, Screws	Medium Carbon Alloy Steel, Quenched and Tempered[4]	1/4 thru 1-1/2	105,000	115,000	133,000
	SAE J429 Grade 8	Bolts, Screws, Studs	Medium Carbon Alloy Steel, Quenched and Tempered	1/4 thru 1-1/2	120,000	130,000	150,000
	ASTM A354 Grade BD		Alloy Steel, Quenched and Tempered				

See footnotes on Page N–24

5.0 U.S. NRC Comment:

Show how the channel cross members are supported for both the Adamson and the Evermaster containers. Provide an analysis of the load carrying capability for both containers.

NAC Response:

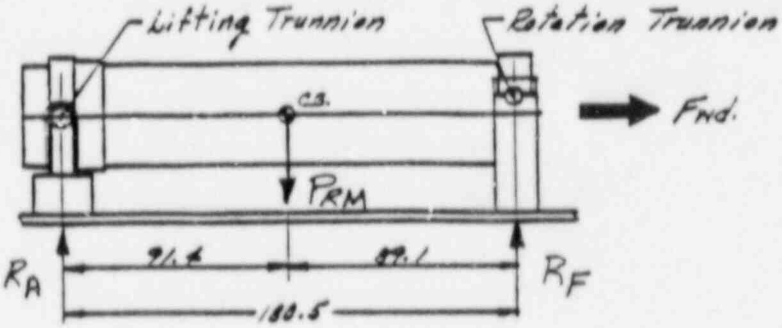
The floor cross-members are I-beams for the Adamson containers and channels for the Evermaster containers. An analysis of the load-carrying capability of the cross-members is provided by a beam analysis and by a bolt bearing and shear-tearout analysis. Additionally, the containers have each been load tested per the American Bureau of Ships (ABS) requirements, including a 2.0 g vertical floor load.

NAC-1 Cask
Evermaster ISO Container

Floor Beam-Load Capability

Rated Maximum Payload = P_{RM} = 23,950 kg = 52,690 lbs.

Since the cask C.G. is centered laterally and is located longitudinally as shown:



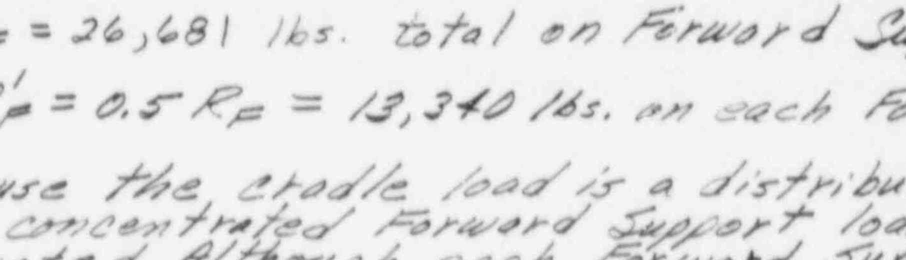
R_A = 26,009 lbs. on Cradle (Aft Support)

R_F = 26,681 lbs. total on Forward Supports

$R'_F = 0.5\, R_F$ = 13,340 lbs. on each Forward Support

Because the cradle load is a distributed load, only the concentrated Forward Support loading will be evaluated. Although each Forward Support has a 0.75-inch thick base plate which rests on the 12-millimeter thick container floor plate which rests on the channel-shaped cross-members, the support reactions are considered as concentrated loads on the floor beams. Three floor beams are considered to be effective in supporting the Forward Supports. Then, the floor beam load is:

$$P_{FB} = \frac{R'_F}{3} = 4450 \text{ lbs.}$$



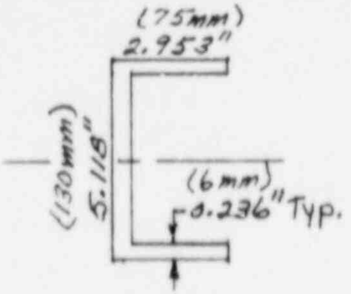
The maximum bending moment in a floor beam is:

$$M_{FB} = (19.95)\, P_{FB} = 88,778 \text{ in-lbs.}$$

NAC-1 Cask
Evermaster ISO Container

Floor Beam Load Capability (cont'd)

The floor beam properties are:



$A = 2.49 \text{ in.}^2$ $\quad$ $I/c = 4.02 \text{ in.}^3$

$I = 10.28 \text{ in.}^4$

$c = 2.559 \text{ in.}$

(Allowable Stress) JIS SM50 structural steel

$$S'_B = S_Y = 46{,}839 \text{ psi} \quad (33 \text{ Kg/mm}^2)$$

(Calculated Stress)

$$S_B = \frac{M_{FB}}{I/c} = 22{,}084 \text{ psi}$$

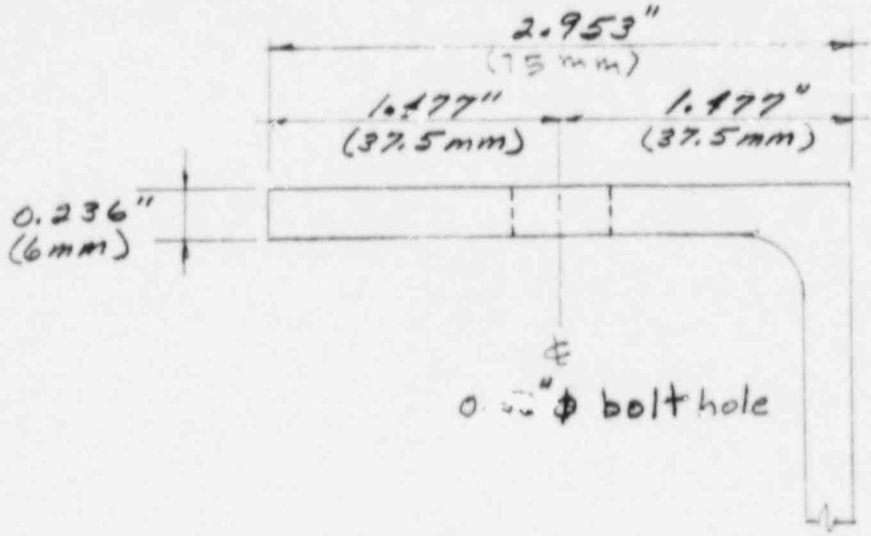
(Safety Factor)

$$S.F. = \frac{S'_B}{S_B} = 2.12$$

NAC-1 Cask
Evermaster ISO Container

Floor Beam - Bolt Bearing & Shear-Tearout

(Geometry) JIS SM50 structural Steel, $S_y = 46,839$ psi



(Load Capability)

Bearing

$A_{br} = (0.50)(0.236) = 0.118 \text{ in.}^2$

Bearing Factor, $F_{br} = 1.5$

$(P_{br})_{LC} = (0.118)(1.5)(46,839) = 8,300$ lbs.

Shear-Tearout

$A_s = (2)(0.236)(1.477-0.28) = 0.565 \text{ in.}^2$

$(P_{S-T})_{LC} = (0.565)(46,839)(0.577) = 15,270$ lbs.

Bolt Shear 1/2-13UNC SAE J429e Grade 8

$(P_{BS})_{LC} = \underbrace{(0.1419)(0.577)(130,000)}_{\text{Tensile Area} \times \text{Shear} \times S_y} = 10,644$ lbs.

Calculated Bolt Load (Forward Support - 18 bolts)

$(P_B)_C = (104,000^2 + 52,000^2)^{1/2}/18 = 6,460$ lbs/bolt (2g Loads)

Load Factor $L.F. = \dfrac{8,300}{(6460)(0.5)} = 2.57$

NAC-1 Cask
Adamson ISO Container

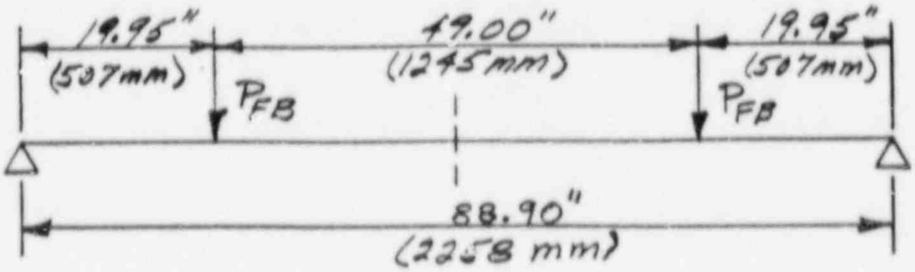
Floor Beam - Load Capability

From the Evermaster Container analysis:

$R'_F = 0.5 R_F = 13,340$ lbs. on each Forward Support.

In the Adamson Containers four floor beams are effective in supporting the Forward Supports. Then, the floor beam load is:

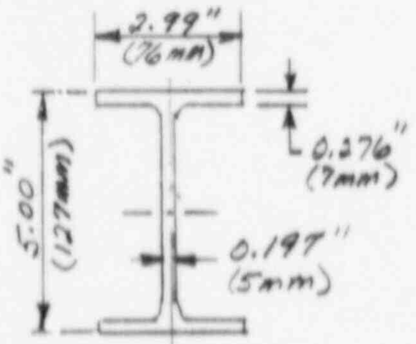
$$P_{FB} = \frac{R'_F}{4} = 3,335 \text{ lbs.}$$



The maximum bending moment in a floor beam is:

$$M_{FB} = (19.95)(P_{FB}) = 66,533 \text{ in-lbs.}$$

(Beam Properties)



$A = 2.53 \text{ in.}^2$

$I = 10.66 \text{ in.}^4$

$c = 2.50 \text{ in.}$

$I/c = 4.265 \text{ in.}^3$

(Allowable Stress) A36 structural steel

$S'_B = S_Y = 36,000$ psi

(Calculated Stress)

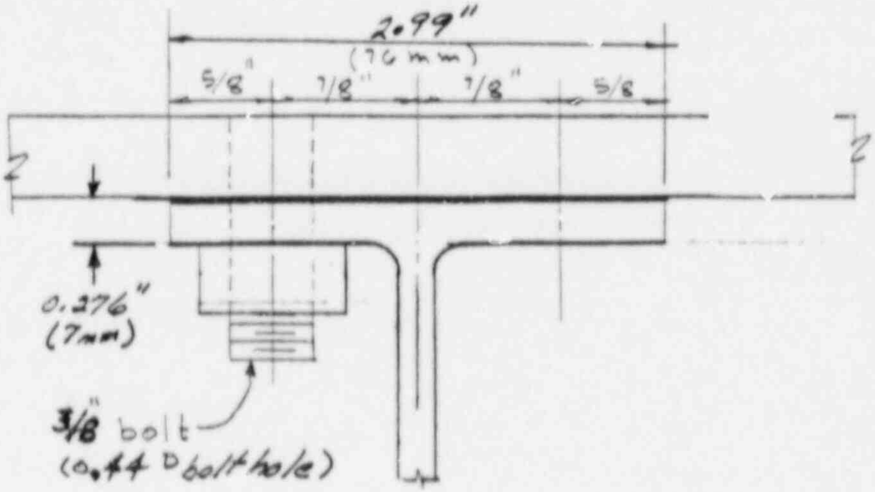
$$S_B = \frac{M_{FB}}{I/c} = 15,600 \text{ psi}$$

$$\text{Safety Factor} = S.F. = \frac{S'_B}{S_B} = 2.31$$

NAC-1 Cask
Adamson ISO Container

Floor Beam - Bolt Bearing & Shear-Tearout

(Geometry) A36 Structural Steel



(Load Capability)

Bearing

$A_{br} = (0.375)(0.276) = 0.1035 \text{ in.}^2$
Bearing Factor, $F_{br} = 1.5$

$(P_{br})_{LC} = (0.1035)(1.5)(36{,}000) = 5{,}590$ lbs.

Shear-Tearout

$A_S = (2)(0.276)(0.625 - 0.22) = 0.224 \text{ in.}^2$

$(P_{S\text{-}T})_{LC} = (0.224)(36000)(0.577) = 4{,}645$ lbs.

Bolt Shear 3/8-16UNC SAE J429e Grade 8

$(P_{BS})_{LC} = (0.0775)(0.577)(130{,}000) = 5{,}810$ lbs.
Tensile Area x Shear x S_y

(Calculated Bolt Load) (Forward Support - 36 Bolts)

$(P_B)_c = (\overset{116,276}{104{,}000}{}^2 + 52{,}000^2)^{1/2}/36 = 3{,}230$ lbs./bolt (2g Loads)

Load Factor $L.F. = \dfrac{4{,}645}{(3{,}230)(0.5)} = 2.87$

Lloyd's Register of Shipping

FREIGHT CONTAINER CERTIFICATE

Name of Manufacturer Adamson Containers Ltd. Certificate No. 501176

Location of Works Station Road, Reddish, Stockport, Cheshire. Office Manchester

Date 30.10.85.

This is to certify that the freight containers described below have been manufactured at these works and constructed and tested in accordance with the requirements of Lloyd's Register of Shipping for the Construction and Certification of Freight Containers and conform to the requirements of the International Convention for Safe Containers. The details of design, materials, construction and workmanship conform to the approved plans and to the prototype container identified as follows:

Manufacturer's Serial No. 938/001

Tare weight 2080 kg

Type Approval No. and C.S.C. Approval Reference GB-LR 6820-9/85

Manufacturer's model number CC-HH-1

Date of manufacture (year and month) 1985 September

Type of container 20'x8'x4'3" Open Top

Rating (Maximum operating gross weight) 27000 kg 59520 lb

Owner's name and code letters NACU

Nuclear Assurance Corporation

Lloyd's approved endorsements:

Stacking capability 160000 kg 352740 lb

Stacking test load 72000 kg per corner

Transverse racking test load 15240 kg 33600 lb

End wall strength N/A Side wall strength N/A

First examination due date 1990 August

Serial numbers	
Owner's	Manufacturer's
850001 to 850004	938/001 to 938/004
Number of containers covered by this certificate	FOUR

E. Cope

Authorised signatory on behalf of Manufacturer

The undersigned has carried out quality control surveillance at the above works during construction in accordance with the Freight Container Certification Scheme and has carried out examinations and supervised tests on sample production containers.

B. E. Baguley

Surveyor to Lloyd's Register of Shipping

B. E.Baguley.

Timber immunisation endorsement—see overleaf

Form 5202 (FC 12a) (11/78)

CARGO CONTAINER
PRODUCTION CERTIFICATE

Design Type Number: AB/ 785 / 86

Certificate No. 86-TA 0225

This Certificate is for 7 Containers

Date 27 September 1986

manufactured during September 1986

THIS IS TO CERTIFY that Seven (7) 20' x 8' x 8' Open Top Containers

built by Evermaster Industrial Corp.

for Nuclear Assurance Corp.

have been thoroughly inspected at each stage of manufacture by our inspection department under the quality control surveillance of the American Bureau of Shipping; and that the details of design, materials, construction and workmanship of the containers conform to the applicable specifications and to the American Bureau of Shipping Rules For Certification of Cargo Containers.

The container(s) are constructed in accordance with prints reviewed on 22 September 1986, reference T-3/TK-3765; under general arrangement drawing K03-20510000; the prototype of which has serial number E-8614400 & E-8614405; was tested on 27 September 1986, ~~[illegible]~~ and accepted with the issuing of prototype test certificate 86-TA 0220-X

Size 20' x 8' x 8'

Model E2051-01SA

Max. Gross Wt.	27,000 kg 59,522 lb	Tare Wt.	3,050 kg 6,724 lb	Payload	23,950 kg 52,798 lb		

Manufacturers serial numbers:	E-8614400	through	E-8614406
	-	through	-
	-	through	-
Operating numbers: (with alpha prefix)	NACU850005	through	NACU850011
	-	through	-
	-	through	-

Jeff H. K. Ni, Quality Control Superintendent

The undersigned has visited the plant of Evermaster Industrial Corporation

located at Chung-Li, Taiwan

and carried out quality control surveillance as indicated in the Rules For Certification of Cargo Containers.

F. T. Lee, Surveyor

American Bureau of Shipping

This certificate evidences compliance with the applicable Rules or other criteria of the American Bureau of Shipping and is issued solely for the use of the Bureau, its committees, its clients or other authorized entities. The certificate is a representation only that the containers have met the applicable Rules of the American Bureau of Shipping. The validity, applicability and interpretation of this certificate is governed by the Rules and standards of the American Bureau of Shipping who shall remain the sole judge thereof. Nothing contained in this certificate or in any report issued in contemplation of this certificate shall be deemed to relieve any designer, builder, owner, manufacturer, seller, supplier, repairer, operator or other entity of any warranty expressed or implied.

CTR AB 100 REV. 11/80

6.0 U.S. NRC Comment:

The combined strength of the welds and bolts were used in analyzing the cask support attachment. The welds and the bolts may not act simultaneously and may fail in sequence. Justify that the welds and the bolts will be acting simultaneously.

NAC Response:

Simultaneous load resistance of the bolts and the welds cannot be demonstrated using classical analysis and a no-yield criteria. Therefore, the analyses are revised to demonstrate that attachment bolts alone will resist any combination of the 2.0 g loads at the cask center of gravity in the longitudinal, lateral, and vertical directions. All of the attachment bolts are SAE J429e, Grade 8 material (S_u = 150 ksi; S_y = 130 ksi) and all attach the support base plates to the container cross-members through the container floor plates.

The additional load-carrying capabilities of the attachment welds, which are present, are conservatively not considered. Also, some additional SAE J429e, Grade 8 bolts have been added to the container floor plate in the surrounding area of the cask support base plates, but have not been considered in the analysis: Ten 1/2-inch bolts at the Evermaster Forward Support (Rotation Trunnions); eight 3/8-inch bolts at the Adamson Forward Support (Rotation Trunnions); and eight 3/8-inch bolts at the Adamson Aft Support (Lifting Trunnions).

The following analysis determines the maximum allowable loads at the Forward and Aft Supports for the Evermaster containers and for the Adamson containers. The allowable loads are compared to the applied 2.0 g loads and margins of safety are calculated for the longitudinal, lateral, and vertical directions. Finally, the bolts are analyzed for the maximum combined load case of vertical tension in combination with longitudinal shear and lateral shear.

Note: The tensile stress area of the bolts is conservatively used in the shear stress calculations.

NAC-1 Cask
Cask Supports

Attachment Bolts

Summary of Results

(Evermaster Container)

Forward Support (Rotation Trunnions) M.S. = +0.59

Aft Support (Lifting Trunnions) M.S. = +1.13

(Adamson Container)

Forward Support (Rotation Trunnions) M.S. = +0.74

Aft Support (Lifting Trunnions) M.S. = +0.55

NAC-1 Cask
Evermaster ISO Container
Load Capability

BOLTS - 1/2 -13UNC - TENSILE AREA = 0.1419 in^2 *

MATERIAL - SAE J429e, Grade 8 : S_u = 150 KSI.
S_y = 130 KSI.

ROTATION TRUNNION SUPPORT - 18 Bolts

HORIZONTAL Load Capacity (SHEAR LOADING)

ALLOWABLE shear stress

$S_s = 0.577(S_y)$
$= 0.577(130\text{ KSI})$
$S_s = 75\text{ KSI}$

Shear Load

$\left(18\text{ BOLTS} \times 0.1419 \frac{in^2}{BOLT}\right)\left(75\,000 \frac{lb}{in^2}\right) = \underline{\underline{191\,560\text{ lbs}}}$

2.554 in^2

VERTICAL Load Capacity (TENSILE LOADING)

ALLOWABLE tensile stress

$S_T = S_y$
$= 130\text{ KSI}$

Tensile Load

$\left(2.554 \frac{in^2}{SUPPORT}\right)\left(130\,000 \frac{lb}{in^2}\right) = \underline{\underline{332\,000\text{ lbs}}}$

* Tensile Stress Area also conservatively used for shear.

NAC-1 Cask

EVERMASTER CONTAINER

Load Capability (Cont'd.)

LIFTING TRUNNION SUPPORT - 12 BOLTS

HORIZONTAL Load Capacity (SHEAR LOADING)

ALLOWABLE Shear stress

$S_S = 0.577 (S_y)$

$= 0.577 (130 \text{ KSI})$

$S_S = 75 \text{ KSI}$

Shear Load

$12 \frac{\text{Bolts}}{\text{Support}} \times 0.1419 \frac{\text{in}^2}{\text{Bolt}} \times 75000 \frac{\text{lb}}{\text{in}^2} = \underline{127700 \text{ lbs.}}$

Vertical Load Capacity (Tensile Loading)

Allowable Tensile Stress

$S_T = S_y$

$= 130 \text{ KSI}$

Tensile Load

$12 \frac{\text{Bolts}}{\text{Support}} \times 0.1419 \times 130\,000 \frac{\text{lbs}}{\text{in}^2} = \underline{221\,360 \text{ lbs}}$

ADAMSON CONTAINER

BOLT - 3/8" - 16UNC - TENSILE AREA = 0.0775 in² *

MATERIAL - SAE J429e, Grade 8: S_u = 150 KSI, S_y = 130 KSI

ROTATION TRUNNION SUPPORT - 36 BOLTS,

HORIZONTAL Load Capacity (SHEAR LOADING)

ALLOWABLE Shear Stress

$S_S = 0.577 (S_y)$

$= 0.577 (130 \text{ KSI})$

$S_S = 75 \text{ KSI}$

* Conservatively used for shear stress calcs.

NAC-1 Cask

ADAMSON CONTAINERS

Load Capability (cont'd.)

Shear Load

$36 \frac{\text{Bolts}}{\text{Support}} \times 0.0775 \frac{\text{in}^2}{\text{Bolt}} \times 75\,000 \frac{\text{lb}}{\text{in}^2} = \underline{209\,250 \text{ lbs}}$

Vertical Load Capacity (Tensile Loading)

Allowable Tensile Stress

$S_T = S_y$
$= 130 \text{ ksi}$

Tensile Load

$36 \frac{\text{Bolts}}{\text{Support}} \times 0.0775 \frac{\text{in}^2}{\text{Bolt}} \times 130\,000 \frac{\text{lb}}{\text{in}^2} = \underline{362\,700 \text{ lbs.}}$

LIFTING TRUNNION SUPPORT - 16 Bolts

HORIZONTAL Load Capacity (SHEAR LOADING)

ALLOWABLE Shear stress

$S_S = 0.577\ S_y$
$= 0.577\ (130 \text{ ksi})$
$S_S = 75 \text{ ksi}$

Shear Load

$16 \frac{\text{Bolts}}{\text{Support}} \times 0.0775 \frac{\text{in}^2}{\text{Bolt}} \times 75\,000 \frac{\text{lb}}{\text{in}^2} = \underline{93\,000 \text{ lbs}}$

VERTICAL Load Capacity (TENSILE LOADING)

ALLOWABLE Tensile stress

$S_T = S_y$
$= 130 \text{ ksi}$

Tensile Load

$16 \frac{\text{Bolts}}{\text{Support}} \times 0.0775 \frac{\text{in}^2}{\text{Bolt}} \times 130\,000 \frac{\text{lbs}}{\text{in}^2} = \underline{161\,200 \text{ lbs}}$

NAC-1 Cask
Load Capability

Separate Load Cases

EVERMASTER CONTAINER

ROTATION TRUNNION SUPPORT - FORWARD IN CONTAINER

ATTACHMENT - 18 - ½ - 13UNC BOLTS, GRADE 8, SAE J429e

S_u = 150 KSI , S_y = 130 KSI

LONGITUDINAL DIRECTION

ALLOWABLE LOAD - 191,560 lbs M.S. = $\frac{191}{104} - 1 = \underline{\underline{+0.84}}$

ACTUAL LOAD - 104,000 lbs

(ENTIRE CASK UNDER 2 g ACCELERATION ACTS ON THE FORWARD SUPPORT)

LATERAL DIRECTION

ALLOWABLE LOAD - 191 560 lbs M.S. = $\frac{191}{52} - 1 = \underline{\underline{+2.67}}$

ACTUAL LOAD - 52 000 lbs

(ONE HALF CASKS WEIGHT (EQUAL DISTRIBUTION BETWEEN FORE AND AFT SUPPORTS) UNDER 2g ACCELERATION ACTING ON THE FORWARD SUPPORT)

VERTICAL DIRECTION

ALLOWABLE LOAD - 332 000 lbs M.S. = $\frac{332}{52} - 1 = \underline{\underline{+5.38}}$

ACTUAL LOAD - 52 000 lbs

NAC-1 Cask
Load Capability - Separate Load Cases (cont'd.)

EVERMASTEC CONTAINER

LIFTING TRUNNION SUPPORT - AFT IN CONTAINER

ATTACHMENT - 12 - 1/2 - 13 UNC BOLTS, GRADE 8, SAE J429e

UTS = 150 ksi, Sy = 130 ksi

LONGITUDINAL DIRECTION

ALLOWABLE LOAD - 127 000 lbs — M.S. = + LARGE

ACTUAL LOAD - 0 lbs

(FORWARD SUPPORT WITHSTANDS ENTIRE LONG. LOAD)

LATERAL DIRECTION

ALLOWABLE LOAD - 127 700 lbs — $M.S. = \frac{127}{52} - 1 = +1.44$

ACTUAL LOAD - 52 000 lbs

VERTICAL DIRECTION

ALLOWABLE LOAD - 221 560 lbs — $M.S. = \frac{221}{52} - 1 = +3.25$

ACTUAL LOAD - 52 000 lbs

ADAMISON CONTAINER

ROTATION TRUNNION SUPPORT - FORWARD IN CONTAINER

ATTACHMENT - 36 - 3/8 - 16 UNC BOLTS, GRADE 8, SAE J429e

UTS = 150 ksi, Sy = 130 ksi

LONGITUDINAL DIRECTION

ALLOWABLE LOAD - 209 250 lbs — $M.S. = \frac{209}{104} - 1 = +1.01$

ACTUAL LOAD - 104 000 lbs.

LATERAL DIRECTION

ALLOWABLE LOAD - 209 250 lbs — $M.S. = \frac{209}{52} - 1 = +3.02$

ACTUAL LOAD - 52 000 lbs.

VERTICAL DIRECTION

ALLOWABLE LOAD - 362 700 lbs — $M.S. = \frac{362}{52} - 1 = +5.96$

ACTUAL LOAD - 52 000 lbs.

NAC-1 Cask

Load Capability - Separate Load Cases (Cont'd.)

ADAMSON CONTAINER

LIFTING TRUNNION SUPPORT - AFT IN CONTAINER

ATTACHMENT - 16 - 3/8 - 16 UNC BOLTS, GRADE 8, SAE J429e

UTS = 150 KSI, Sy = 130 KSI

LONGITUDINAL DIRECTION

ALLOWABLE LOAD - 93000 lbs.

ACTUAL LOAD - 0 lbs.

M.S. = + LARGE

LATERAL DIRECTION

ALLOWABLE LOAD - 93 000 lbs.

ACTUAL LOAD - 52 000 lbs.

$M.S. = \frac{93}{52} - 1 = +0.79$

VERTICAL DIRECTION

ALLOWABLE LOAD - 161 200 lbs

ACTUAL LOAD - 52000 lbs

$M.S. = \frac{161}{52} - 1 = +2.09$

NAC-1 Cask
Bolt Analysis - Combined Loads

EVERMASTER CONTAINER

ROTATION TRUNNION SUPPORT

ATTACHMENT - 18 - 1/2" -13 UNC, GRADE 8 BOLTS, SAE J429e

BOLT PROPERTIES - TENSILE STRESS AREA - 0.1419 in^2 *

MATERIAL PROPERTIES - S_u = 150 KSI
S_y = 130 KSI

LONGITUDINAL Shear Stress

APPLIED LOAD - 2g × 52 000 lbs = 104 000 lbs.

BOLT STRESS (SHEAR)

$$104\,000 \text{ lbs} \times \frac{1}{\underbrace{\left(18 \text{ BOLTS} \times 0.1419 \frac{in^2}{\text{BOLT}}\right)}_{2.554}} = 40\,710 \frac{lbs}{in^2}$$ ✓

LATERAL shear stress

APPLIED LOAD - 2g × 26 000 lbs = 52 000 lbs

BOLT STRESS (shear)

$$52\,000 \text{ lbs} \times \frac{1}{2.554\, in^2} = \longrightarrow 20\,360 \frac{lbs}{in^2}$$ ✓

VERTICAL Tensile stress

APPLIED LOAD = 2g × 26 000 lbs = 52000 lbs.

BOLT STRESS (Tension)

$$52\,000 \text{ lbs} \times \frac{1}{2.554\, in^2} = \longrightarrow 20\,360 \frac{lbs}{in^2}$$ ✓

Resultant Shear Stress

$$\tau = (40710^2 + 20360^2)^{1/2} = 45,517 \text{ psi}$$

* Conservatively used for shear stress Calcs.

NAC-1 Cask
Bolt Analysis - Combined Loads (Cont'd.)
EVERMASTER CONTAINER
Rotation Trunnion Support
Equivalent Stress

$$S_e = \sqrt{\sigma^2 + 3\tau^2}$$

$$= \sqrt{(20360)^2 \cdot 3(45,517)^2}$$

$$= 81,425 \text{ psi}$$

MARGIN OF SAFETY TO YIELD STRENGTH

$$M.S. = \frac{130\,000 \text{ lb/in}^2}{81,425 \text{ lb/in}^2} - 1$$

$$\boxed{M.S. = +0.59}$$

LIFTING TRUNNION SUPPORT
ATTACHMENT - 12 - ½" - 13UNC, GRADE 8 BOLTS

BOLT & MATERIAL PROPERTIES : See Rotation Trunnion

LONGITUDINAL Shear Stress
APPLIED LOAD - 2g × 0 lbs
FORWARD, (ROTATION TRUNNION) SUPPORT ASSUMED TO TAKE ENTIRE LONGITUDINAL LOAD.

BOLT STRESS (shear) $\longrightarrow$ 0 lb/in²

NAC-1 Cask
Bolt Analysis - Combined Loads (Cont'd.)
EVERMASTER CONTAINER
Lifting Trunnion Support
LATERAL Shear Stress

APPLIED LOAD - 2g × 26 000 lbs = 52 000 lbs

BOLT STRESS (Shear)

$$52\,000 \text{ lbs} \times \frac{1}{\left(12 \times 0.1419 \frac{in^2}{\text{Bolt}}\right)} = \longrightarrow 30\,530 \frac{lb}{in^2}$$ ✓

1.703 in² ✓

VERTICAL Tensile Stress

APPLIED LOAD - 2g × 26 000 lbs = 52 000 lbs

BOLT STRESS (Tension)

$$52\,000 \text{ lbs} \times \frac{1}{1.703 \, in^2} = \longrightarrow 30\,530 \frac{lb}{in^2}$$ ✓

Equivalent Stress

$$S_e = \sqrt{\sigma^2 + 3\tau^2}$$

$$= \sqrt{(30{,}530)^2 + 3(30{,}530)^2}$$

$$\simeq 61{,}060 \frac{lb}{in^2}$$ ✓

MARGIN OF SAFETY TO YIELD STRENGTH

$$M.S. = \frac{130\,000}{61\,060} - 1$$

$$\boxed{M.S. = +1.13}$$ ✓

NAC-1 Cask

Bolt Analysis - Combined Loads (Cont'd.)

ADAMSON CONTAINER

ROTATION TRUNNION SUPPORT

ATTACHMENT - 36 - 3/8" - 16 UNC, GRADE 8 BOLTS, SAE J429c

BOLT PROPERTIES - TENSILE AREA - 0.0775 in^2 *

MATERIAL PROPERTIES - S_u = 150 KSI,
S_y = 130 KSI

LONGITUDINAL Shear Stress

APPLIED LOAD - 2g × 52 000 lbs = 104 000 lbs.

BOLT STRESS (Shear)

$$104\,000 \text{ lbs} \times \left(\frac{1}{\underset{(2.790)}{36 \text{ Bolts} \times 0.0775 \frac{in^2}{\text{Bolt}}}}\right) = 37\,270 \frac{\text{lbs}}{in^2}$$ ✓

LATERAL Shear Stress

APPLIED LOAD - 2g × 26 000 lbs = 52 000 lbs

BOLT STRESS (Shear)

$$52\,000 \text{ lbs} \times \frac{1}{2.790 in^2} = \longrightarrow 18\,630 \frac{\text{lbs}}{in^2}$$ ✓

VERTICAL Tensile Stress

APPLIED LOAD - 2g × 26 000 lbs = 52,000 lbs.

BOLT STRESS (Tension)

$$52000 \text{ lbs} \times \frac{1}{2.790 in^2} = \longrightarrow 18\,630 \frac{\text{lbs}}{in^2}$$

Resultant Shear Stress

$$\tau = (37270^2 + 18630^2)^{1/2} = 41,667 \text{ psi}$$

* Conservatively used for shear stress Calcs.

NAC-1 Cask
Bolt Analysis - Combined Loads (Cont'd.)
ADAMSON CONTAINER
Rotation Trunnion Support
Equivalent Stress

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

$$= \sqrt{(18630)^2 + 3(41667)^2}$$

$$= 74{,}535 \text{ psi}$$

MARGIN OF SAFETY TO YIELD STRENGTH

$$M.S. = \frac{130{,}000}{74{,}535} - 1$$

$$\boxed{M.S. = +0.74}$$

LIFTING TRUNNION SUPPORT

ATTACHMENT - 16 - 3/8" - 16UNC. GRADE 8 BOLTS

BOLT PROPERTIES, MATERIAL PROPERTIES PER ROTATION TRUNNION SUPPORT

LONGITUDINAL Shear Stress

APPLIED LOAD - 0 lbs, FORWARD, ROTATION TRUNNION SUPPORT ASSUMED TO TAKE ENTIRE LONGITUDINAL LOAD.

BOLT STRESS (Shear) $\longrightarrow 0 \frac{lb}{in^2}$

NAC-1 Cask

Bolt Analysis - Combined Loads (Cont'd.)

ADAMSON CONTAINER

Lifting Trunnion Support

LATERAL Shear Stress

APPLIED LOAD - 2g × 26 000 lbs = 52 000 lbs.

BOLT STRESS (Shear)

$$52\,000\,\text{lbs} \times \frac{1}{\left(\frac{16 \times 0.0775\,\frac{\text{in}^2}{\text{Bolt}}}{1.240}\right)} = \longrightarrow 41\,930\ \frac{\text{lbs}}{\text{in}^2}$$

VERTICAL Tensile Stress

APPLIED LOAD - 2g × 26 000 lbs = 52 000 lbs.

BOLT STRESS (Tension)

$$52\,000\,\text{lbs} \times \frac{1}{1.240\,\text{in}^2} = \longrightarrow 41\,930\ \frac{\text{lbs}}{\text{in}^2}$$

Equivalent Stress

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

$$= \sqrt{(41\,930)^2 + 3(41{,}930)^2}$$

$$= \quad 83\,860\ \frac{\text{lbs}}{\text{in}^2}$$

MARGIN OF SAFETY TO YIELD STRENGTH

$$M.S. = \frac{130\,000}{83\,860} - 1$$

$$\boxed{M.S = +0.55}$$

7.0 **U.S. NRC Comment**:

Provide a sketch for the Adamson ISO container showing the arrangement of the thirty 1/4-inch Ø steel rivets and the added six 3/8-inch Ø grade 5 high strength bolts on the floor plate. Also, justify the assumption that S_y = 55 ksi for the rivets.

NAC Response:

The arrangement of the attachment bolts between the NAC-1 Cask Supports and the ISO container cross-members for the Adamson containers and for the Evermaster containers are shown on the licensing drawings, Nos. 347-586-F2 and 347-586-F3, respectively. These drawings are included in the NAC Response to the U.S. NRC Comment 3.

All of the attachment bolts are SAE J429e, Grade 8 material. The bolts in the Adamson containers are 3/8-inch diameter and those in the Evermaster containers are 1/2-inch diameter.

The 1/4-inch diameter steel rivets, which attach the floor plates, are conservatively not considered to provide any load reactions.

8.0 **U.S. NRC Comment**:

The equation used to calculate the stress of the aft support assembly lug plate is not applicable to the loading and support condition. Show that the combined stiffnesses of the lug and gusset plates are adequate to transfer the strap force (which is applied eccentrically on the lug plate to its center where the connection bolt is located).

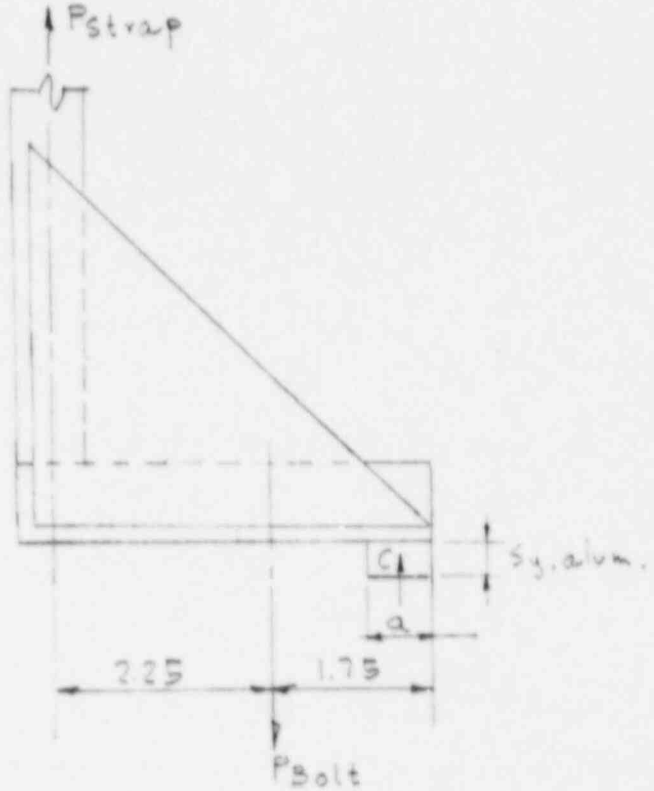
NAC Response:

The Aft Support assembly lug plate is redesigned to incorporate a 2.5-inch thick block of 6061-T6 aluminum alloy, which is welded to the strap and to the lug plate. A 6.0-inch long, 1.00-inch diameter, SAE J429e, Grade 8 bolt (S_u = 150 ksi, S_y = 130 ksi) is required. The detailed analysis is provided on the following pages.

Fuel Movement Project
Cask Supports - NAC-1 Cask

Bolts - Trunnion Attachment Lug

$P_{strap} = 25,808$ lb (page 13)



$S_{y,alum} = 0.98(35 \text{ ksi}) = 34.3$ ksi at $100°F$

Fuel Movement Project
Cask Supports - NAC-1 Cask

Calculate P_{Bolt}

$$C = 2.5'' \times a \times 34,300 \text{ psi} = 85,750\,a$$

$$P_{Bolt} = P_{strap} + C$$

$$P_{Bolt} = 25,808 + 85,750\,a \qquad (1)$$

$$2.25\,P_{Bolt} = C\left(4 - \frac{a}{2}\right)$$

$$2.25\,P_{Bolt} = 343,000\,a - 42,875\,a^2 \qquad (2)$$

$$a = 0.443, \quad P_{Bolt} = 63,795\ \#$$

Bolt properties (1 - 8 UNC) $A_t = 0.606$

$$f_t = \frac{P_{Bolt}}{A_{Bolt}} = \frac{63,795}{0.606} = 105,270 \text{ psi}$$

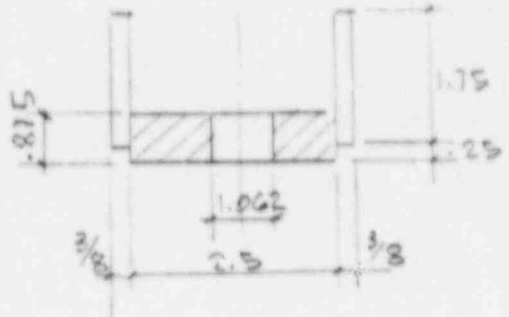
Allowable stress (SAE J429 e. Gr. carbon steel)

$$S_y = 130 \text{ KSI}$$

$$M.S. = \frac{S_y}{f_t} - 1 = \underline{+0.23}$$

Fuel Movement Project
Cask Supports - NAC-1

Bending of lug and gusset plates



$A_1 = (2.5-1.062).875 = 1.258 \times 0.4375 = 0.547$

$A_2 = 0.75 \times 1.75 \qquad = \underline{1.312} \times 1.125 \quad = \underline{1.476}$

$A = 2.570 \qquad A\bar{y} = 2.023$

$\bar{y} = 0.787$ in.

$I = \frac{.438 \times 0.875^3}{12} + 1.258 \times 0.3495^2 + \frac{0.75 \times 1.75^3}{12} + 1.312 \times 0.338^2$

$= 0.719 \text{ in}^4$

$M = 25.808 \times 2.25 = 58068$

$f_b = \frac{Mc}{I} = \frac{58068 \times (2 - .787)}{0.719} = 97,965$ psi

Fuel Movement Project
Cask Support - NAC-1

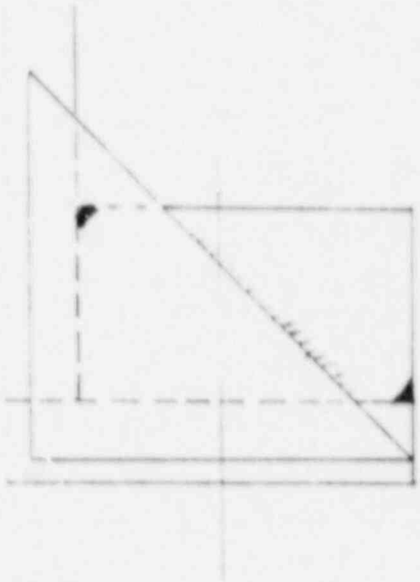
Alt. 1. Use thicker plate

$F_y = 34.3$ ksi at $100°F$

$$t = \left(\frac{6 \times M}{b F_y}\right)^{1/2} = \left(\frac{6 \times 58068}{1.438 \times 34{,}300}\right)^{1/2} = 2.66 \text{ in}$$

No. Use Alt. #2.

Alt. 2 Add reinforcement



Fuel Movement Project
Cask Support - NAC-1

For two beams that deflect same amount at end is proportional to I (t^3 if widths are same.

Try

$t_1 = 7/8$ in

$t_2 = 2$ in

$$P_1 = \frac{.875^3}{.875^3 + 2^3} 25{,}808 = 1994 \text{ lb}$$

$$P_2 = \frac{2^3}{.875^3 + 2^3} 25{,}808 = 23{,}814 \text{ lb}$$

$$M_2 = 23{,}814 (2.25) = 53{,}582$$

$$f_{b2} = \frac{6 \times M}{b t^2} = \frac{6 \times 53{,}582}{1.438 \times 2^2} = 55{,}892 \text{ psi}$$

$$M_1 = 1994 \times 2.25 = 4486$$

$$f_{b1} = \frac{6 \times 4486}{1.438 \times 0.875^2} = 24{,}450 \text{ psi}$$

<u>Try $t_1 = 7/8$ in , $t_2 = 2.5$ in</u>

$$M_2 = \frac{2.5^3}{0.875^3 + 2.5^3} \times 25{,}808 \times 2.25 = 55680 \text{ in-lb}$$

$$f_{b2} = \frac{6 \times 55680}{1.438 \times 2.5^2} = 37{,}172$$

Include the gusset plate thicknesses

$$f_{b2} = \frac{6 \times 55680}{(1.438 + 0.75) 2.5^2} = 24{,}430 \text{ psi}$$

$$M.S. = \frac{34{,}300}{24{,}430} - 1 = \underline{+0.40}$$

Fuel Movement Project
Cask Support - VAC-1
Aft Support Assy (Lifting Trunnion)
(7) Lug plate

$P_{Bolt} = 63,795$ lb

Plate stress (Ref 4, p. 225, Case 37)

$a = 3.50$ in
$b = 2.50$ in
$a/b = 1.4 \qquad \beta = 0.211$
$m = 1/\nu = 1/0.3 = 3.33$
$t = 2$ in

$$\text{Max } s = \frac{3W}{2\pi m t^2}\left[(m+1)\log\frac{2b}{\pi r_0} + 1 - \beta m\right]$$

$$= \frac{3 \times 63,795}{2\pi \times 3.33 \times 2^2}\left[(3.33+1)\log\frac{2\times 2.5}{\pi \times 0.5} + 1 - 0.211\times 3.33\right]$$

$$= 12,145 \text{ psi}$$

$$\text{M.S.} = \frac{34,300}{12145} - 1 = \underline{\underline{+1.82}}$$

9.0 U.S. NRC Comment:

Dimensions, which are not identifiable from the drawing, have been used in the analysis of the welds for the aft support assembly. Please provide design sketches showing the length and size of the welds for the various parts that were joined together to resist the applied load.

NAC Response:

A weld-map drawing of the Forward Support and of the Aft Support for the NAC-1 Cask in an ISO container have been prepared to clarify the details of the fabrication welds: Drawing Nos. 347-241-F36 and 347-241-F37.

10.0 **U.S. NRC Comment**:

The longitudinal tie-down force is acting alone on the forward support as discussed on page 1 of the Fuel Movement Project. Therefore, the longitudinal load on pages 27 and 28 should be doubled. Revise the analysis on pages 29, 30, 31 and 32 to account for the increased longitudinal force.

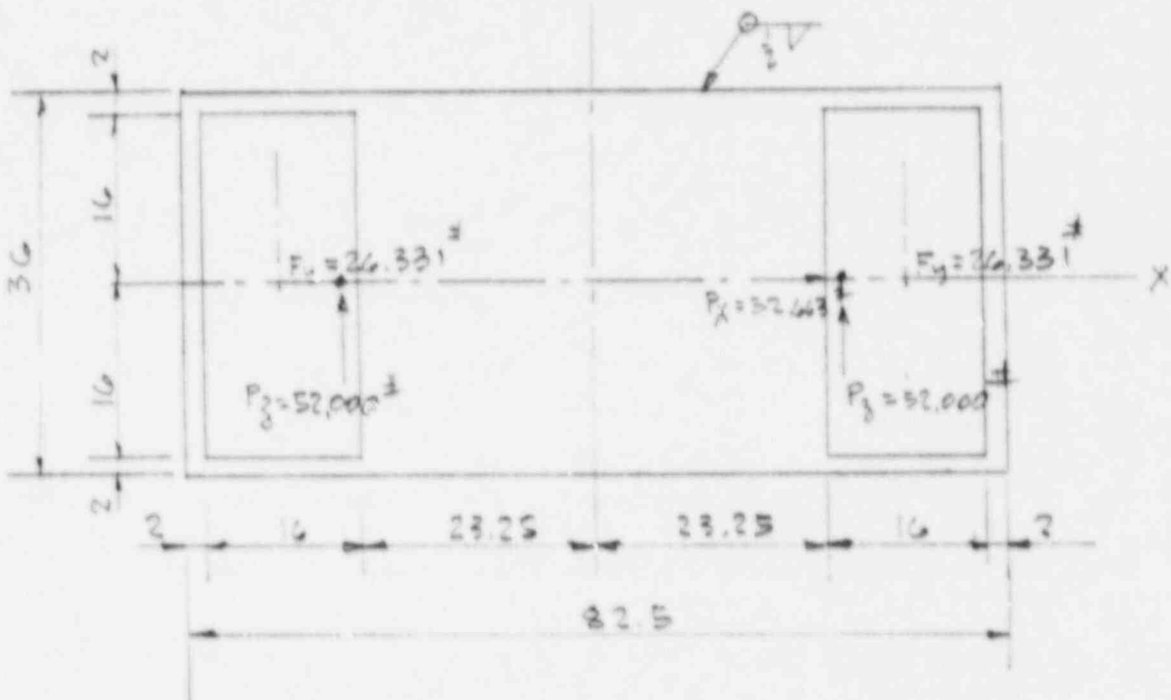
NAC Response:

The analyses on pages 27 through 31 are for one support, so that the longitudinal force used in the analyses is correct. The longitudinal force to be used for the analysis of the base plate weld on page 32 should be doubled to 104,000 pounds.

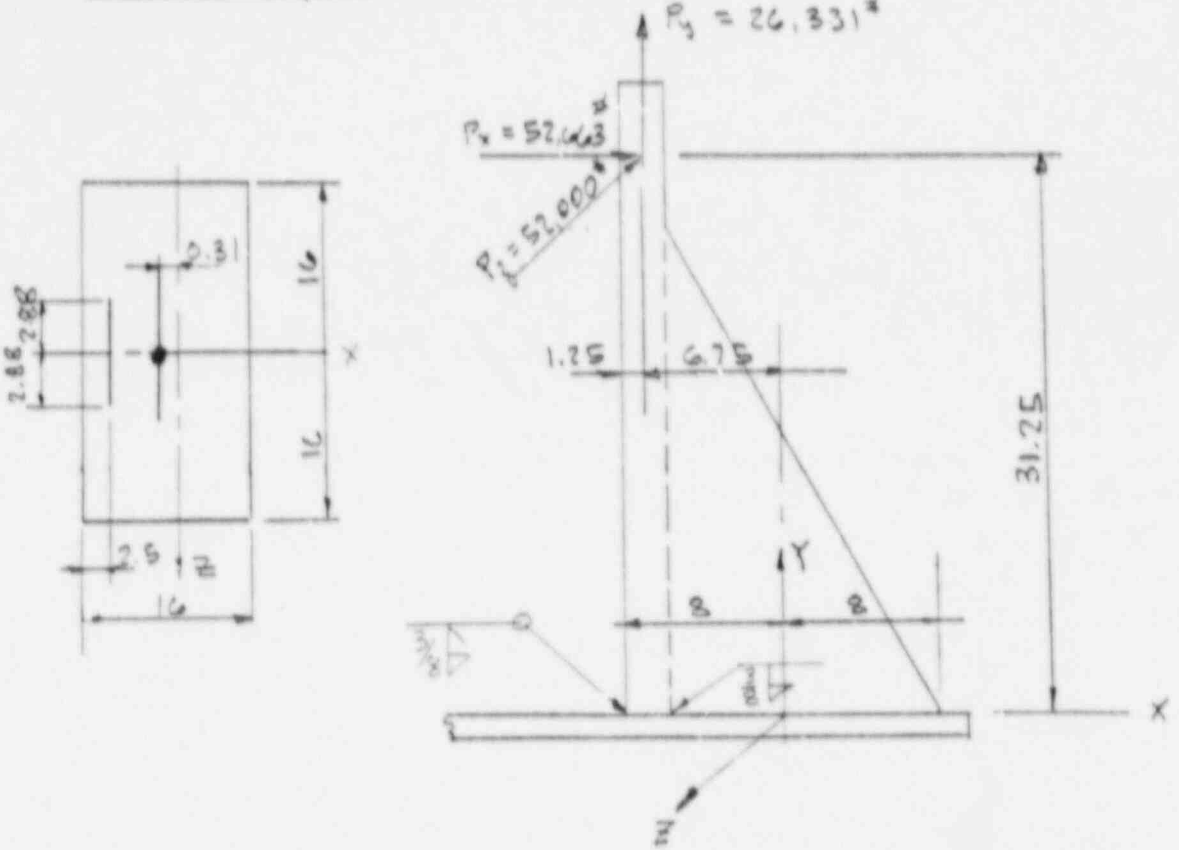
The actual base plate weld is a 0.5-inch fillet completely around, based on the fabrication drawings and visual verification on-site. The attached analysis verifies the adequacy of this base plate weld. However, since the attachment of the container floor plate to the cross-members (1/4 Ø bolts) cannot be defined because the 1/4 Ø bolt material is unknown, bolts through the supports and floor plate(s) to the cross-members are used to carry the entire load.

Fuel Movement Project
Cask Supports - NAC-1 Cask
Forward Support Assy (Rotation Trunnion)

Loads
$(P_V)_{RT}$ = 26,331 lbs, each of rotation trunnions
$(P_L)_{RT}$ = 52,000 lbs, " " "
$(P_{Lat})_{RT}$ = 32,663 lbs, one rotation trunnion only



Fuel Movement Project
Cask Support - NAC-1
Weld - support to base plate



Weld properties

$$\bar{x} = \frac{(8-2.5)5.76}{2(16+32)+5.76} = 0.31 \text{ in}$$

$$I_x = \frac{32^3}{6} + \frac{5.76^3}{12} + 2\times16\times16^2 = 13,669 \text{ in}^3$$

$$I_z = \frac{16^3}{6} + 32\times0.31^2 + 32(7.69^2+8.31^2) + 5.76(5.5-.31)^2 = 4943 \text{ in}^3$$

$$I_y = I_x + I_z = 18,612$$

$L_x = 2\times16 = 32$ in

$L_z = 2\times32 + 5.76 = 69.76$ in

$L_y = 101.76$ in

Fuel Movement Project
Cask Support - NAC-1

Loads

$P_x = 52,663$ #

$P_z = 52,000$ #

$P_y = 26,331$ #

$M_x = 52,000(31.25) = 1,625,000$ in-lb

$M_z = 52,663(31.25) + 26,331(6.75-0.31) = 1,815,000$ in-lb

$M_y = 52,000(6.75-0.31) = 335,000$ in-lb

Weld stresses

$$f_x = \frac{52,663}{32} + \frac{335,000 \times 16}{18,612} = 1934$$

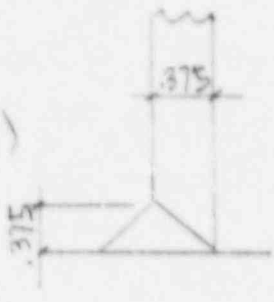
$$f_z = \frac{52,000}{39.76} + \frac{335,000 \times 8.31}{8612} = 295$$

$$f_y = \frac{26,331}{39.76} + \frac{1,625,000 \times 16}{18,612} + \frac{1,815,000 \times 8.31}{4443} = 5212$$

$f_r = 5631$ #/in

Weld allowable

5356 filler metal ($S_y = 12.0$ ksi)



$F_v = 0.375 \times \sqrt{2}\,(12,000) = 6364$ #/in

$$M.S. = \frac{6364}{5631} - 1 = \underline{+0.13}$$

Fuel Movement Project
Cask Support - NAC-1

Forward support assy
Weld - base plate to floor plate ($\frac{1}{2}$" fillet)
Weld properties

$L = 2(82.5 + 36) = 237$ in

$S_x = \frac{36^2}{3} + 82.5 \times 36 = 3402 \text{ in}^2$

$S_y = \frac{82.5^2}{3} + 82.5 \times 36 = 5239 \text{ in}^2$

Loads

$P_x = 52{,}663$ #
$P_z = 2(52{,}000) = 104{,}000$ #
$P_y = 2(26{,}331) = 52{,}662$ #
$M_x = 104{,}000(32) = 3{,}328{,}000$ in-lb
$M_z = 52{,}663(32) = 1{,}685{,}000$ in-lb

Weld stresses

$f_x = \frac{52{,}663}{237} = 222$ #/in

$f_z = \frac{104{,}000}{237} = 439$ #/in

$f_y = \frac{52{,}662}{237} + \frac{3{,}328{,}000}{3402} + \frac{1{,}685{,}000}{5239} = 1522$ #/in

$f_r = 1600$ #/in

Weld allowable

$F_r = \frac{1}{2} \times 0.707 \times 12{,}000 = 4{,}242$ #/in

M.S. $\frac{4242}{1600} - 1 = \underline{\underline{+1.65}}$

Because the attachment of the floor plate to the container cross-members (1/4 Ø bolts) cannot be defined, bolts thru the supports to the cross-members are used to carry the entire load.

J

Thermacote Welco

Manufacturers of Thermo and Welco Alloy Products

THERMACOTE WELCO COMPANY

HIGHWAY 161 YORK ROAD • P.O. BOX 697 • KINGS MOUNTAIN NORTH CAROLINA 28086 • (704) 739-6421

FILLER METAL CERTIFICATION   Date 8-27-85

To: A-L Welding
Augusta, Ga.

Welco Product 5356 3/32 x 36

Heat Number 402817

The above material complies with the following specifications and requirements as noted:

A.W.S. Spec. A 5.10 A.W.S. Class ER 5356 A.S.T.M. ____

Military ____ Federal ____

Other ____

Chemical Analysis: Filler Metal (X) Typical
( ) Mill Report

Carbon		Phosphorus			
Chromium	.05-.20%	Sulphur		Physical Properties	
Copper	.10%	Molybdenum		Tensile	
Manganese	.05-.20%	Columbium			
Nickel		Aluminum	Remainder	Elongation in 2"	
Silicon	.25%	Magnesium	4.5-5.5%		
Iron	.40%	Titanium	.06-.20%	Yield	
Zinc	.10%	Beryllium	.0008%		
Lead		Nitrogen		Reduction in Area	
Tin		Others	.15% Total		
Cobalt					

(Single values shown represent maximum percentages unless otherwise specified.)

The undersigned hereby certifies that the above information is correct to the best of his knowledge and belief.

William H. Roland Jr.

William H. Roland, Jr.
President

HEADQUARTERS OFFICES KINGS MOUNTAIN, N.C.
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Welco

Manufacturers of Thermo and Welco Alloy Products

THERMACOTE WELCO COMPANY

FILLER METAL CERTIFICATION Date 8/21/85

To: National Welders Supply
Columbia, S.C.

Welco Product 5356 .035 x 15#

Heat Number 700-1

The above material complies with the following specifications and requirements as noted:

A.W.S. Spec. A 5.10 A.W.S. Class ER 5356 A.S.T.M. ______

Military ______ Federal ______

Other ______

Chemical Analysis: Filler Metal (X) Typical
( ) Mill Report

Carbon ______	Phosphorus ______	
Chromium .05-.20%	Sulphur ______	Physical Properties
Copper .10%	Molybdenum ______	Tensile ______
Manganese .05-.20%	Columbium ______	
Nickel ______	Aluminum Remainder	Elongation in 2" ______
Silicon .25%	Magnesium 4.5-5.5%	
Iron .40%	Titanium .06-.20%	Yield ______
Zinc .10%	Beryllium .0008%	
Lead ______	Nitrogen ______	Reduction in Area ______
Tin ______	Others .15% Total	
Cobalt ______	______	

(Single values shown represent maximum percentages unless otherwise specified.)

The undersigned hereby certifies that the above information is correct to the best of his knowledge and belief.

William H. Roland Jr.

William H. Roland, Jr.
President

RITEWAY
Rec and approved by
QC
PO A1041
IT 1 UNIT 5.35
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DISP 35 DATE

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PLANTS KINGS MOUNTAIN, NC • PASADENA, CA

Metals Handbook Ninth Edition

Volume 2 Properties and Selection: Nonferrous Alloys and Pure Metals

Prepared under the direction of
the ASM Handbook Committee

William H. Cubberly, Director of Reference Publications
Hugh Baker, Managing Editor
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Paul M. Unterweiser, Manager, Publications Development
Craig W. Kirkpatrick, Chief Copy Editor
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Kathy Nieman, Editorial Assistant

AMERICAN SOCIETY FOR METALS
METALS PARK, OHIO 44073

Table 5 Minimum expected properties at room temperature for butt welded aluminum alloys(a)(b)

Alloy and temper	Product forms	Thickness range mm	Thickness range in.	Tensile strength Ultimate(b) MPa	ksi	Tensile strength Yield(c) MPa	ksi	Compressive yield strength(c) MPa	ksi	Shear strength Ultimate MPa	ksi	Shear strength Yield MPa	ksi	Bearing strength Ultimate MPa	ksi	Bearing strength Yield MPa	ksi
1100-H12, H14	All	All	All	76	11	31	4.5	31	4.5	55	8	17	2.5	160	23	55	8
3003-H12, H14, H16, H18	All	All	All	97	14	48	7	48	7	69	10	28	4	205	30	83	12
Alclad 3003-H12, H14, H16, H18	All	All	All	90	13	41	6	41	6	69	10	24	3.5	205	30	76	11
3004-H32, H34, H36, H38	All	All	All	150	22	76	11	76	11	97	14	45	6.5	315	46	140	20
Alclad 3004-H32, H34, H36 H38, H14, H16	All	All	All	145	21	76	11	76	11	90	13	45	6.5	305	44	130	19
3003-H25	Sheet	All	All	115	17	62	9	62	9	83	12	34	5	250	36	105	15
5005-H12, H14, H32, H34	All	All	All	97	14	48	7	48	7	62	9	28	4	195	28	69	10
5050-H32, H34	All	All	All	125	18	55	8	55	8	83	12	30	4.5	250	36	83	12
5052-H32, H34	All	All	All	170	25	90	13	90	13	110	16	52	7.5	345	50	130	19
5083-H111	Extrusions	All	All	270	39	145	21	140	20	160	23	83	12	540	78	220	32
H321	Sheet and plate	4.7-38.1	0.188-1.5	275	40	165	24	165	24	165	24	97	14	550	83	250	36
H321	Plate	38.1-76.2	1.501-3.0	270	39	160	23	160	23	165	24	90	13	540	78	235	34
H323, H343	Sheet	All	All	275	40	165	24	165	24	165	24	97	14	550	80	250	36
5086-H111	Extrusions	All	All	240	35	125	18	115	17	145	21	69	10	485	70	195	28
H112	Plate	6.4-12.7	0.25-0.499	240	35	115	17	115	17	145	21	60	9.5	485	70	195	28
H112	Plate	12.7-25.4	0.50-1.0	240	35	110	16	110	16	145	21	62	9	485	70	195	28
H112	Plate	25.4-50.8	1.001-	240	35	97	14	97	14	145	21	55	8	485	70	195	28
H32, H34	Sheet and plate	All	2.0	240	35	130	19	130	19	145	21	76	11	485	70	195	28
5154-H38	Sheet	All	All	205	30	105	15	105	15	130	19	59	8.5	415	60	160	23
5454-H111	Extrusions	All	All	215	31	110	16	105	15	130	19	66	9.5	425	62	165	24
H112	Extrusions	All	All	215	31	83	12	83	12	130	19	49	7	425	62	165	24
H32, H34	Sheet and plate	All	All	215	31	110	16	110	16	130	19	66	9.5	425	62	165	24
5456-H111	Extrusions	All	All	285	41	165	24	150	22	165	24	97	14	565	82	260	38
H112	Extrusions	All	All	285	41	130	19	130	19	165	24	76	11	565	82	260	38
H321	Sheet and plate	4.7-38.1	0.188-1.5	290	42	180	26	165	24	170	25	105	15	580	84	260	38
H321	Plate	38.1-76.2	1.501-3.0	285	41	165	24	160	23	170	25	97	14	565	82	260	38
H323, H343	Sheet	All	All	290	42	180	26	180	26	170	25	105	15	580	84	260	38
6061-T6, T651, T6510, T6511(d)	All	Over 9.5	Over 0.375	165	24	140	20	140	20	105	15	83	12	345	50	205	30
T6, T651, T6510, T6511(e)	All	Over 9.5	Over 0.375	165	24	105	15	105	15	105	15	62	9	345	50	205	30
6063-T5, T6	All	All	All	115	17	76	11	76	11	76	11	45	6.5	235	34	150	22
6351-T5(d)	Extrusions	Over 9.5	Over 0.375	165	24	140	20	140	20	105	15	83	12	345	50	205	30
T5(e)	Extrusions	Over 9.5	Over 0.375	165	24	105	15	105	15	105	15	62	9	345	50	205	30

(a) Gas tungsten-arc or gas metal-arc welding with no postweld heat treatment. (b) Filler wires used are those recommended in Table 3. Ultimate tensile values are ASME weld-qualification-test values. (c) 0.2% offset in 250-mm (10-in.) gage length across a butt weld. (d) Values are for welding with 5183, 5356 or 5556 filler wire, regardless of thickness. Values also apply to thicknesses less than 9.5 mm (0.375 in.) when welding is done with 4043, 5554 or 5654 filler wire. (e) Values are for welding with 4043, 5554 or 5654 filler wire.

thickness to 6 mm (¼ in.) thick, or butt joints in aluminum wire and rod from 0.6 to 10 mm (0.025 to ⅜ in.) in diameter, and for joining aluminum to other metals.

Explosive welding is accomplished by the energy released from detonation of high explosives. This is a lap welding process that allows aluminum to be joined to itself or to other metals without loss of strength, and is used to produce transition joints between aluminum and dissimilar metals. Explosive welding has been useful in joining aluminum pipes and bus bars in the field.

Friction (inertia) welding is a butt welding process in which a spinning part is pushed against a stationary part and the frictional heat and force generated produce a solid-state bond at the interface. Aluminum alloys can be joined by friction welding to similar or dissimilar aluminum alloys and to other metals. When alloy 6061-T6 is fusion welded to 304 stainless steel, a brittle intermetallic compound is formed, but when 6061-T6 is friction welded to 304 it forms a satisfactory joint for cryogenic and heat-transfer applications.

Ultrasonic welding resembles resistance welding in the general configuration of equipment used. Overlapping parts to be joined are clamped between tips to weld them at a spot, or between rolls to weld a seam. No heat energy, as such, is supplied. The weld is made without fusion in the ordinary sense of the term. An intense, localized, mechanical wiping does occur where the parts are pressed together. This action scrubs away oxides or other impurities, rearranges the metallic structural configuration at both surfaces, and merges them to form a sound metallurgical bond.

Ultrasonic welding is well suited for handling material having thicknesses in the lower part of resistance welding's range—for aluminum, the range is from foil thicknesses (less than 0.005 mm, or 0.0002 in.) up to about 2.4 mm (³⁄₃₂ in.). Furthermore, with ultrasonic welding very thin aluminum foil can be joined to very thick aluminum, and aluminum can be joined to many dissimilar metals.

Although it is not formed by general fusion of metal, the bond achieved by ultrasonic welding is an intimate metallurgical union. Strength is proportional to weld size. When tested to destruction, ultrasonic welds in hard alloys usually fail in shear. Those in softer alloys usually pull out a button. Weld strength data for electric-resistance spot welds may be used for design. Testing done so far indicates this would be conservative. Some test results are published in ASME paper No. 60-WA-332 in the table entitled "Comparison of Ultrasonic Strength with Resistance Welds on Aluminum Alloy Applications for Ultrasonic Welding of Aluminum."

Indentation caused by clamping force seldom exceeds 5% of metal thickness. It is greater with the softer aluminum alloys than with the harder materials.

Adjacent or overlapping welds can be made, and proximity to an already completed weld spot does not downgrade the quality or strength of the next one. When lap seams are made to join foil, the joints can be trimmed simply by tearing off the excess lap adjacent to the weld seam.

Resistance of aluminum alloys to corrosion is not adversely affected by ultrasonic welding, but the usual precautions should be taken whenever dissimilar metals are joined.

Electron beam welding applies heat by means of a concentrated beam of high-velocity electrons. Magnetic fields focus and accelerate electrons from an incandescent filament. The beam and the work are usually under high vacuum—in the order of one micron. While the size of the work is limited by the available vacuum chamber, this environment is ideal for preventing weld contamination. Equipment for welding in low vacuum and in air also has been developed.

Well-fitted joint preparation is essential, and high concentration of energy in a focused beam makes very narrow, single-pass welds possible. Welding has little or no effect on the heat-treated or cold-worked structure of the base metal, and weld contamination is nil.

Because equipment cost is high, this method is useful only where sound, high-strength joints are more important than low welding cost. Apparatus is available to handle parts 9 m (30 ft) or more in diameter, and aluminum alloy thicknesses up to 100 mm (4 in.) have been welded.

Laser Beam Welding. The word "laser" means light amplification by stimulated emission of radiation. Laser welding has developed into a high-volume production process for joining and cutting metals. The high-intensity light beam from a fused laser is highly collimated and has good wavelength purity. Because of the resultant high power density, material in a local area of a workpiece can be melted and/or vaporized with little or no effect on the adjacent material. One of the disadvan-

Table 6 Minimum expected tensile strengths at various temperatures for butt welded aluminum alloys

Alloy and temper	Filler-metal alloy	Tensile strength in MPa (ksi) at: −185 °C (−300 °F)	−129 °C (−200 °F)	73 °C (−100 °F)	38 °C (100 °F)	150 °C (300 °F)(a)	260 °C (500 °F)(a)
2219-T37(b)	2319	334 (48.5)	275 (40)	250 (36)	240 (35)	215 (31)	130 (19)
2219(c)	2319	445 (64.5)	410 (59.5)	380 (55)	345 (50)	260 (38)	150 (22)
3003	1100	190 (27.5)	148 (21.5)	121 (17.5)	97 (14)	66 (9.5)	34 (5)
5052	5356	260 (38)	215 (31)	183 (26.5)	170 (25)	145 (21)	72 (10.5)
5083	5183	375 (54.5)	315 (46)	280 (40.5)	275 (40)	...	...
5086	5356	330 (48)	280 (40.5)	245 (35.5)	240 (35)	...	...
5454	5554	305 (44)	255 (37)	220 (32)	215 (31)	180 (26)	105 (15)
5456	5556	385 (56)	328 (47.5)	293 (42.5)	290 (42)	...	...
6061-T6(b)	4043	238 (34.5)	205 (30)	183 (26.5)	165 (24)	150 (20)	41 (6)
6061(c)	4043	380 (55)	341 (49.5)	315 (46)	290 (42)	217 (31.5)	48 (7)

(a) Alloys not listed at 150 °C (300 °F) and 260 °C (500 °F) are not recommended for use at sustained operating temperatures of over 65 °C (150 °F). (b) As welded. (c) Heat treated and aged after welding

Table 7 Minimum expected shear strengths of fillet welds in aluminum alloys

Filler-metal alloy	Shear strength MPa	ksi
1100	52	7.5
2319(a)(b)	110	16
2319(c)	150	22
4043(a)	79	11.5
5052	52	7.5
5154	83	12
5554	115	17
5556	140	20
5654	83	12

(a) Naturally aged (two to three months). (b) Artificially aged after welding. (c) Heat-treated and aged after welding.

Fig. 4 Range of typical shear strengths for single spot welds in three high-strength aluminum alloys

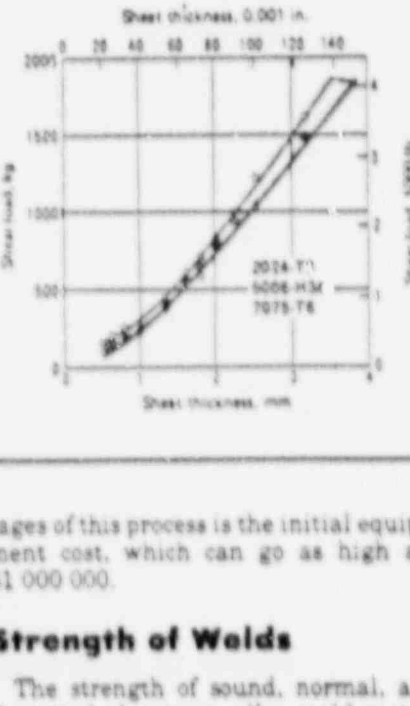
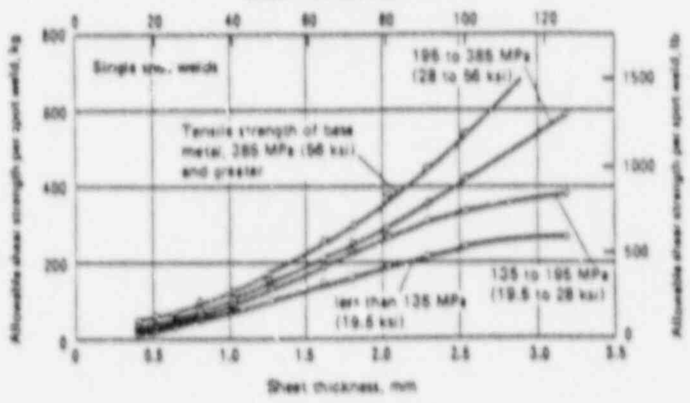


Fig. 5 Allowable shear strengths for single spot welds in aluminum alloys of different tensile strengths



In welding two sheets of unequal thickness, allowable shear strength is based on the thickness of the thinner sheet.

tages of this process is the initial equipment cost, which can go as high as $1 000 000.

Strength of Welds

The strength of sound, normal, as-deposited aluminum alloy weld metal is approximately 80 to 280 MPa (12 to 40 ksi). Joints in non-heat-treatable alloys can be made so that they will fail in the base metal, rather than in the weld metal, by proper selection of the filler alloy. For hard-rolled tempers, the base metal in the heat-affected zone on either side of the joint is softened by the heat of welding, precluding the possibility of obtaining high joint efficiency. With heat treatable alloys of the 6xxx series, 100% efficiency can be obtained when the welded structure can be solution and precipitation heat treated after welding. Nearly 100% efficiency can be obtained when welding in the T4 temper by using one of the high-speed welding techniques, such as inert-gas-shielded metal-arc welding or electron beam welding, in which the amount of heat flowing into the base metal of the joint is limited, and by precipitation heat treating after welding. In the 2xxx and 7xxx series, such practice produces less improvement in joint efficiency. Alloy 2014 and especially alloy 2219 are widely welded for spacecraft boosters, where machined or chemically milled lands are provided to achieve adequate strength across the welded joints. Summaries of minimum expected butt-welded properties of commonly welded aluminum alloys are given in Tables 5 and 6. The minimum expected shear strength of fillet welded aluminum is given in Table 7.

The fatigue life of welded joints at high loads varies with the alloy. As the load is decreased, differences disappear until, at about one to ten million cycles of axial loading ($R = 0$), the fatigue strength of an arc-welded joint is approximately the same regardless of alloy and is 50 to 70% that of the unwelded alloy. Typical data are given in Fig. 3 for alloys 3003-O, 5154-H34 and 6061-T6.

Design criteria for resistance spot welded aluminum usually are based on the minimum reproducible shear strength (of single-spot specimens) obtainable under the established manufacturing conditions. Figure 4 presents such test data for three high-strength alloys. Figure 5 shows design-allowable shear strength in relation to the tensile strength and thickness of the alloy being welded.

Design allowables developed in single-spot shear specimens are applicable to multispot patterns, provided the distance between adjacent welds is not less than two nugget diameters. Closer distances will result in shunting current losses, which will reduce current density in the spot weld and reduce the size of the weld and its shear strength. Such losses, which increase with the thickness of the material, must be taken into account in design.

Brazing Processes

Brazing is a type of joining process in which coalescence is obtained by heating the base metal to a temperature below its solidus temperature and adding a filler alloy, using flux. The flux promotes wetting of the joint surface by the filler alloy, which is selected to have a liquidus temperature slightly below the solidus of the base metal. Although the base metal is not melted, there is definite diffusion between the base and filler metals.

Brazing can be used successfully on very thin material and on assemblies

11.0 U.S. NRC Comment:

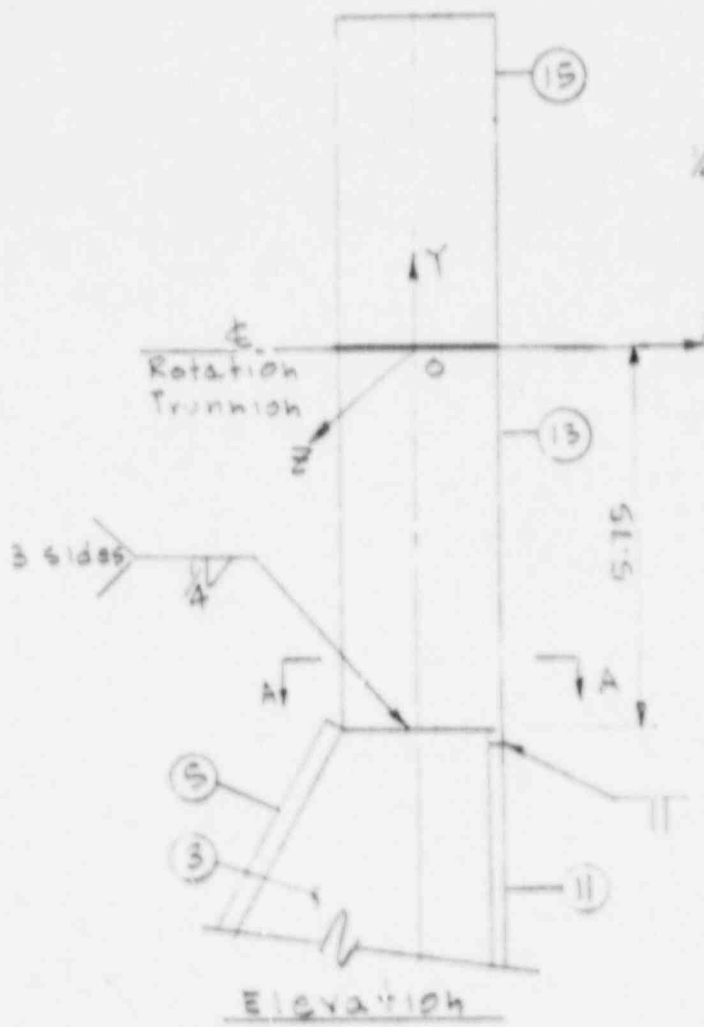
It appears that the same weld may have been used to resist upward, longitudinal, and lateral loads in separate calculations (pages 27, 28). Provide a design sketch to show all the welds and calculate the stress based on combined loads.

NAC Response:

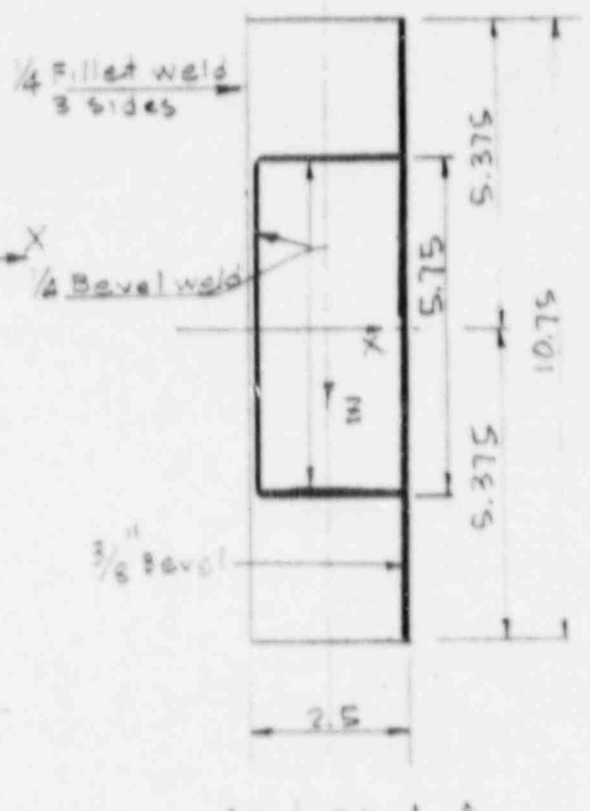
The subject welds previously analyzed on pages 27 and 28 are reanalyzed for the combined loadings in the vertical, lateral, and longitudinal directions. A sketch defining the weld locations, lengths, and sizes is provided. The weld filler-metal is ER5356 with ultimate and yield shear stress allowables of $S_{su} = 15$ ksi and $S_{sy} = 12$ ksi.

Fuel Movement Project
Cask Support - NAC-1

Weld - 13 cable to support plates -3, -5 & -11
and stiffners -7, & -9



Elevation



Section A-A

Loads @ ℄ point "O"

P_x = 52,663 # (Lat.)

P_z = 52,000 # (Long.)

P_y = 26,331 # (Vert.)

Fuel Movement Project
Cask Support - NAC-1

Due to proximity of the longitudinal and lateral loads to the weld, bending stresses are not developed.

Section properties

$$A_w = 0.707(0.25)(10.75 + 2 \times 2.5) +$$

$$0.25(5.75 + 2 \times 2.5) + 0.375(10.75) = 9.50 \text{ in}^2$$

Weld stresses

$$f_x = \frac{52{,}663}{9.50} = 5543 \text{ psi}$$

$$f_z = \frac{52{,}000}{9.5} = 5474 \text{ psi}$$

$$f_y = \frac{26{,}331}{9.5} = 2772 \text{ psi}$$

$$f_r = (f_x^2 + f_z^2 + f_y^2)^{\frac{1}{2}} = 8269 \text{ psi}$$

Weld allowable stress

Weld filler metal - ER5356

$^{**}S_{su} = 15$ ksi, $^{**}S_{sy} = 12$ ksi

$$M.S. = \frac{12{,}000}{8269} - 1 = +0.45$$

* Conservatively use allowable shear stress; f_y is actually a tensile load on the bevel welds.
** Ref. Metals Handbook, Vol. 2, page 197.

J Thermacote Welco 3

Manufacturers of Thermo and Welco Alloy Products

THERMACOTE WELCO COMPANY

HIGHWAY 161 YORK ROAD • P.O. BOX 851 • KINGS MOUNTAIN, NORTH CAROLINA 28086 • (704) 739-6421

FILLER METAL CERTIFICATION Date 8-27-85

To: A-L Welding
Augusta, Ga.

Welco Product 5356 3/32 x 36

Heat Number 402817

The above material complies with the following specifications and requirements as noted:

A.W.S. Spec. A 5.10 A.W.S. Class ER 5356 A.S.T.M. ______

Military ______ Federal ______

Other ______

Chemical Analysis: Filler Metal (x) Typical
( ) Mill Report

Carbon		Phosphorus			
Chromium	.05-.20%	Sulphur		Physical Properties	
Copper	.10%	Molybdenum		Tensile	
Manganese	.05-.20%	Columbium			
Nickel		Aluminum	Remainder	Elongation in 2"	
Silicon	.25%	Magnesium	4.5-5.5%		
Iron	.40%	Titanium	.06-.20%	Yield	
Zinc	.10%	Beryllium	.0008%		
Lead		Nitrogen		Reduction in Area	
Tin		Others	.15% Total		
Cobalt					

(Single values shown represent maximum percentages unless otherwise specified.)

The undersigned hereby certifies that the above information is correct to the best of his knowledge and belief.

William H. Roland Jr.

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President

HEADQUARTERS OFFICES: KINGS MOUNTAIN, N.C.
TWO PLANTS: KINGS MOUNTAIN, N.C. • PASADENA, CA
[illegible] • KINGS MOUNTAIN, N.C. • PORTLAND, ORE. • HOUSTON, TEX.

Welco

Manufacturers of Thermo and Welco Alloy Products

4

THERMACOTE WELCO COMPANY

FILLER METAL CERTIFICATION   Date 8/21/85

To: National Welders Supply
Columbia, S.C.

Welco Product 5356 .035 x 15#

Heat Number 700-I

The above material complies with the following specifications and requirements as noted:

A.W.S. Spec. A 5.10 A.W.S. Class ER 5356 A.S.T.M. ______

Military ______ Federal ______

Other ______

Chemical Analysis: Filler metal (X) Typical
( ) Mill Report

Carbon		Phosphorus			
Chromium	.05-.20%	Sulphur		Physical Properties	
Copper	.10%	Molybdenum		Tensile	
Manganese	.05-.20%	Columbium			
Nickel		Aluminum	Remainder	Elongation in 2"	
Silicon	.25%	Magnesium	4.5-5.5%		
Iron	.40%	Titanium	.06-.20%	Yield	
Zinc	.10%	Beryllium	.0008%		
Lead		Nitrogen		Reduction in Area	
Tin		Others	.15% Total		
Cobalt					

(Single values shown represent maximum percentages unless otherwise specified.)

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RITEWAY
Rec and Approved By
QC
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ACCT
INSP DATE

William H. Roland Jr.

William H. Roland, Jr.
President

HEADQUARTERS OFFICES KINGS MOUNTAIN, N.C.
PLANTS KINGS MOUNTAIN, N.C. • PASADENA, CA

5

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AMERICAN SOCIETY FOR METALS
METALS PARK, OHIO 44073

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1100-H12, H14	All	All	All	.. 76	11	31	4.5	31		55	8	17	2.5	160	23	55	8
3003-H12, H14, H16, H18	All	All	All	.. 97	14	48	7	48		69	10	28	4	205	30	83	12
Alclad 3003-H12, H14, H16, H18	All	All	All	.. 90	13	41	6	41	6	69	10	24	3.5	205	30	76	11
3004-H32, H34, H36, H38	All	All	All	.. 150	22	76	11	76	11	97	14	45	6.5	315	46	140	20
Alclad 3004-H32, H34, H36 H38, H14, H16	All	All	All	.. 145	21	76	11	76	11	90	13	45	6.5	305	44	130	19
3003-H25	Sheet	All	All	.. 115	17	62	9	62	9	83	12	34	5	250	36	105	15
5005-H12, H14, H32, H34	All	All	All	.. 97	14	48	7	48	7	62	9	28	4	195	28	69	10
5050-H32, H34	All	All	All	.. 125	18	55	8	55	8	83	12	30	4.5	250	36	83	12
5052-H32, H34	All	All	All	.. 170	25	90	13	90	13	110	16	52	7.5	345	50	130	19
5083-H111	Extrusions	All	All	.. 270	39	145	21	140	20	160	23	83	12	540	78	22[illegible]	32
H321	Sheet and plate	4.7-38.1	0.188-1.5	.. 275	40	165	24	165	24	165	24	97	14	550	80	250	36
H321	Plate	38.1-76.2	1.501-3.0	.. 270	39	160	23	160	23	165	24	90	13	540	78	235	34
H323, H343	Sheet	All	All	.. 275	40	165	24	165	24	165	24	97	14	550	80	250	36
5086-H111	Extrusions	All	All	.. 240	35	125	18	115	17	145	21	69	10	485	70	195	28
H112	Plate	6.4-12.7	0.25-0.499	.. 240	35	115	17	115	17	145	21	66	9.5	485	70	195	28
H112	Plate	12.7-25.4	0.50-1.0	.. 240	35	110	16	110	16	145	21	62	9	485	70	195	28
H112	Plate	25.4-50.8	1.001-2.0	.. 240	35	97	14	97	14	145	21	55	8	485	70	195	28
H32, H34	Sheet and plate	All		.. 240	35	130	19	130	19	145	21	76	11	485	70	195	28
5154-H38	Sheet	All	All	.. 205	30	105	15	105	15	130	19	59	8.5	415	60	160	23
5454-H111	Extrusions	All	All	.. 215	31	110	16	105	15	130	19	66	9.5	425	62	165	24
H112	Extrusions	All	All	.. 215	31	83	12	83	12	130	19	49	7	425	62	165	24
H32, H34	Sheet and plate	All	All	.. 215	31	110	16	110	16	130	19	66	9.5	425	62	165	24
5456-H111	Extrusions	All	All	.. 285	41	165	24	150	22	165	24	97	14	565	82	260	38
H112	Extrusions	All	All	.. 285	41	130	19	130	19	165	24	76	11	565	82	260	38
H321	Sheet and plate	4.7-38.1	0.188-1.5	.. 290	42	1[illegible]0	26	165	24	170	25	10[illegible]	15	580	84	260	38
H321	Plate	38.1-76.2	1.501-3.0	.. 285	41	165	24	160	23	170	25	9[illegible]	14	565	82	260	38
H323, H343	Sheet	All	All	.. 290	42	180	26	180	[illegible]6	170	25	1[illegible]	5	580	84	260	38
6061-T6, T651, T6510, T6511(d)	All	Over 9.5	Over 0.375	.. 165	24	140	20	140	20	105	15	83	[illegible]2	345	50	205	30
T6, T651, T6510, T6511(e)	All	Over 9.5	Over 0.375	.. 165	24	105	15	105	15	105	15	62	9	345	50	205	30
6063-T5, T6	All	All	All	.. 115	17	76	11	76	11	76	11	45	6.5	235	34	150	22
6351-T5(d)	Extrusions	Over 9.5	Over 0.375	.. 165	24	140	20	140	20	105	15	83	12	345	50	205	30
T5(e)	Extrusions	Over 9.5	Over 0.375	.. 165	24	105	15	105	15	105	15	62	9	345	50	205	30

(a) Gas tungsten-arc or gas metal-arc welding with no postweld heat treatment. (b) Filler wires used are those recommended in Table 3. Ultimate tensile values are ASME weld-qualification-test values. (c) 0.2% offset in 250-mm (10-in.) gage length across a butt weld. (d) Values are for welding with 5183, 5356 or 5556 filler wire, regardless of thickness. Values also apply to thicknesses less than 9.5 mm (0.375 in.) when welding is done with 4043, 5554 or 5654 filler wire. (e) Values are for welding with 4043, 5554 or 5654 filler wire.

thickness to 6 mm (¼ in.) thick, or butt joints in aluminum wire and rod from 0.6 to 10 mm (0.025 to ⅜ in.) in diameter, and for joining aluminum to other metals.

Explosive welding is accomplished by the energy released from detonation of high explosives. This is a lap welding process that allows aluminum to be joined to itself or to other metals without loss of strength, and is used to produce transition joints between aluminum and dissimilar metals. Explosive welding has been useful in joining aluminum pipes and bus bars in the field.

Friction (inertia) welding is a butt welding process in which a spinning part is pushed against a stationary part and the frictional heat and force generated produce a solid-state bond at the interface. Aluminum alloys can be joined by friction welding to similar or dissimilar aluminum alloys and to other metals. When alloy 6061-T6 is fusion welded to 304 stainless steel, a brittle intermetallic compound is formed, but when 6061-T6 is friction welded to 304 it forms a satisfactory joint for cryogenic and heat-transfer applications.

Ultrasonic welding resembles resistance welding in the general configuration of equipment used. Overlapping parts to be joined are clamped between tips to weld them at a spot, or between rolls to weld a seam. No heat energy, as such, is supplied. The weld is made without fusion in the ordinary sense of the term. An intense, localized, mechanical wiping does occur where the parts are pressed together. This action scrubs away oxides or other impurities, rearranges the metallic structural configuration at both surfaces, and merges them to form a sound metallurgical bond.

Ultrasonic welding is well suited for handling material having thicknesses in the lower part of resistance welding's range—for aluminum, the range is from foil thicknesses (less than 0.005 mm, or 0.0002 in.) up to about 2.4 mm (3/32 in.). Furthermore, with ultrasonic welding very thin aluminum foil can be joined to very thick aluminum, and aluminum can be joined to many dissimilar metals.

Although it is not formed by general fusion of metal, the bond achieved by ultrasonic welding is an intimate metallurgical union. Strength is proportional to weld size. When tested to destruction, ultrasonic welds in hard alloys usually fail in shear. Those in softer alloys usually pull out a button. Weld strength data for electric-resistance spot welds may be used for design. Testing done so far indicates this would be conservative. Some test results are published in ASME paper No. 60-WA-332 in the table entitled "Comparison of Ultrasonic Strength with Resistance Welds on Aluminum Alloy Applications for Ultrasonic Welding of Aluminum."

Indentation caused by clamping force seldom exceeds 5% of metal thickness. It is greater with the softer aluminum alloys than with the harder materials.

Adjacent or overlapping welds can be made, and proximity to an already completed weld spot does not downgrade the quality or strength of the next one. When lap seams are made to join foil, the joints can be trimmed simply by tearing off the excess lap adjacent to the weld seam.

Resistance of aluminum alloys to corrosion is not adversely affected by ultrasonic welding, but the usual precautions should be taken whenever dissimilar metals are joined.

Electron beam welding applies heat by means of a concentrated beam of high-velocity electrons. Magnetic fields focus and accelerate electrons from an incandescent filament. The beam and the work are usually under high vacuum—in the order of one micron. While the size of the work is limited by the available vacuum chamber, this environment is ideal for preventing weld contamination. Equipment for welding in low vacuum and in air also has been developed.

Well-fitted joint preparation is essential, and high concentration of energy in a focused beam makes very narrow, single-pass welds possible. Welding has little or no effect on the heat-treated or cold-worked structure of the base metal, and weld contamination is nil.

Because equipment cost is high, this method is useful only where sound, high-strength joints are more important than low welding cost. Apparatus is avalable to handle parts 9 m (30 ft) or more in diameter, and aluminum alloy thicknesses up to 100 mm (4 in.) have been welded.

Laser Beam Welding. The word "laser" means light amplification by stimulated emission of radiation. Laser welding has developed into a high-volume production process for joining and cutting metals. The high-intensity light beam from a fused laser is highly collimated and has good wavelength purity. Because of the resultant high power density, material in a local area of a workpiece can be melted and/or vaporized with little or no effect on the adjacent material. One of the disadvan-

Table 6 Minimum expected tensile strengths at various temperatures for butt welded aluminum alloys

Alloy and temper	Filler-metal alloy	Tensile strength in MPa (ksi) at: −185 °C (−300 °F)	−129 °C (−200 °F)	73 °C (−100 °F)	38 °C (100 °F)	150 °C (300 °F)(a)	260 °C (500 °F)(a)
2219-T37(b)	2319	334 (48.5)	275 (40)	250 (36)	240 (35)	215 (31)	130 (19)
2219(c)	2319	445 (64.5)	410 (59.5)	380 (55)	345 (50)	260 (38)	150 (22)
3003	1100	190 (27.5)	148 (21.5)	121 (17.5)	97 (14)	66 (9.5)	34 (5)
5052	5356	260 (38)	215 (31)	183 (26.5)	170 (25)	145 (21)	72 (10.5)
5083	5183	375 (54.5)	315 (46)	280 (40.5)	275 (40)	...	...
5086	5356	330 (48)	280 (40.5)	245 (35.5)	240 (35)	...	...
5454	5554	305 (44)	255 (37)	220 (32)	215 (31)	180 (26)	105 (15)
5456	5556	385 (56)	328 (47.5)	293 (42.5)	290 (42)	...	...
6061-T6(b)	4043	238 (34.5)	205 (30)	183 (26.5)	165 (24)	150 (20)	41 (6)
6061(c)	4043	380 (55)	341 (49.5)	315 (46)	290 (42)	217 (31.5)	48 (7)

(a) Alloys not listed at 150 °C (300 °F) and 260 °C (500 °F) are not recommended for use at sustained operating temperatures of over 65 °C (150 °F). (b) As welded. (c) Heat treated and aged after welding.

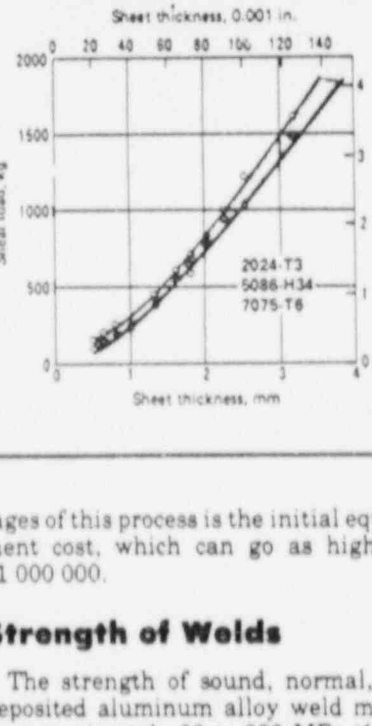
5

Table 7 Minimum expected shear strengths of fillet welds in aluminum alloys

Filler-metal alloy	Shear strength MPa	ksi
1100	52	7.5
2319(a)(b)	110	16
2319(c)	150	22
4043(a)	79	11.5
5052	52	7.5
5154	83	12
5554	115	17
5556	140	20
5654	83	12

(a) Naturally aged (two to three months). (b) Artificially aged after welding. (c) Heat-treated and aged after welding.

Fig. 4 Range of typical shear strengths for single spot welds in three high-strength aluminum alloys



tages of this process is the initial equipment cost, which can go as high as $1 000 000.

Strength of Welds

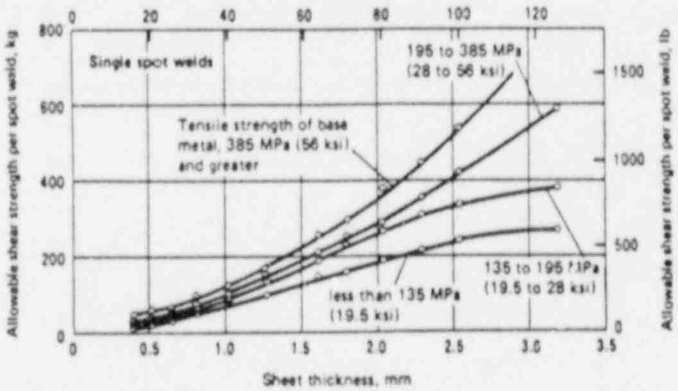
The strength of sound, normal, as-deposited aluminum alloy weld metal is approximately 80 to 280 MPa (12 to 40 ksi). Joints in non-heat-treatable alloys can be made so that they will fail in the base metal, rather than in the weld metal, by proper selection of the filler alloy. For hard-rolled tempers, the base metal in the heat-affected zone on either side of the joint is softened by the heat of welding, precluding the possibility of obtaining high joint efficiency. With heat treatable alloys of the 6xxx series, 100% efficiency can be obtained when the welded structure can be solution and precipitation heat treated after welding. Nearly 100% efficiency can be obtained when welding in the T4 temper by using one of the high-speed welding techniques, such as inert-gas-shielded metal-arc welding or electron beam welding, in which the amount of heat flowing into the base metal of the joint is limited, and by precipitation heat treating after welding. In the 2xxx and 7xxx series, such practice produces less improvement in joint efficiency. Alloy 2014 and especially alloy 2219 are widely welded for spacecraft boosters, where machined or chemically milled lands are provided to achieve adequate strength across the welded joints. Summaries of minimum expected butt-welded properties of commonly welded aluminum alloys are given in Tables 5 and 6. The minimum expected shear strength of fillet welded aluminum is given in Table 7.

The fatigue life of welded joints at high loads varies with the alloy. As the load is decreased, differences disappear until, at about one to ten million cycles of axial loading ($R = 0$), the fatigue strength of an arc-welded joint is approximately the same regardless of alloy and is 50 to 70% that of the unwelded alloy. Typical data are given in Fig. 3 for alloys 3003-O, 5154-H34 and 6061-T6.

Design criteria for resistance spot welded aluminum usually are based on the minimum reproducible shear strength (of single-spot specimens) obtainable under the established manufacturing conditions. Figure 4 presents such test data for three high-strength alloys. Figure 5 shows design-allowable shear strength in relation to the tensile strength and thickness of the alloy being welded.

Design allowables developed in single-spot shear specimens are applicable to multispot patterns, provided the distance between adjacent welds is not less than two nugget diameters. Closer distances will result in shunting current losses, which will reduce current density in the spot weld and reduce the size of the weld and its shear strength. Such losses, which increase with the thickness of the material, must be taken into account in design.

Fig. 5 Allowable shear strengths for single spot welds in aluminum alloys of different tensile strengths



In welding two sheets of unequal thickness, allowable shear strength is based on the thickness of the thinner sheet.

Brazing Processes

Brazing is a type of joining process in which coalescence is obtained by heating the base metal to a temperature below its solidus temperature and adding a filler alloy, using flux. The flux promotes wetting of the joint surface by the filler alloy, which is selected to have a liquidus temperature slightly below the solidus of the base metal. Although the base metal is not melted, there is definite diffusion between the base and filler metals.

Brazing can be used successfully on very thin material and on assemblies