DISTRIBUTION SHEET

To	From	Page 1 of 1
J. R. Bellomy	B. F. Norman/Equipment Stress Analysis/8D430	Date October 4, 1994
Project Title/Work Order		EDT No. 142181
Shot Loading Support Analysis/D2M9G		ECN No.

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
L. W. Bartholf	H5-60		X		
J. R. Bellomy	S6-12	X			
J. P. Harris	S6-12		X		
R. L. Jorissen	H5-53		X		
T. C. Mackey	S2-03		X		
B. F. Norman	H5-53	X			
R. B. Pan	H5-53	X			
Central Files		X			
OSTI (2)	L8-07	X			

OCT 24 1994 Sta #3 58

ENGINEERING DATA TRANSMITTAL

1. EDT 142181

2. To: (Receiving Organization) Single-Shell Tank Retrieval/J. P. Harris	3. From: (Originating Organization) Equipment Stress Analysis	4. Related EDT No.: N/A
5. Proj./Prog./Dept./Div.: Shot Loading Platform Analysis/D2M9G	6. Cog. Engr.: J. R. Bellomy	7. Purchase Order No.: N/A
8. Originator Remarks:		9. Equip./Component No.: N/A
		10. System/Bldg./Facility: N/A
11. Receiver Remarks:		12. Major Assm. Dwg. No.: H-2-83738
		13. Permit/Permit Application No.: N/A
		14. Required Response Date:

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Impact Level	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	WHC-SD-W320-DA-005		0	Shot Loading Platform Analysis	SQ	1	1	

16. KEY

Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
1, 2, 3, or 4 (see MRP 5.43)	1. Approval 4. Review 2. Release 5. Post-Review 3. Information 6. Dist. (Receipt Acknow. Required)	1. Approved 4. Reviewed no/comment 2. Approved w/comment 5. Reviewed w/comment 3. Disapproved w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Impact Level for required signatures)

(G) Reason	(H) Disp.	(J) Name	(K) Signature (M) MSIN	(L) Date	(J) Name	(K) Signature (M) MSIN	(L) Date	(G) Reason	(H) Disp.
1	1	Cog.Eng. J. R. Bellomy	[signature] S6-12	10/24/94	ESA Eng. B. F. Norman	[signature] H5-53		1	1
1	1	Cog. Mgr. J. P. Harris	[signature] S6-12	10/24/94					
1	1	QA J. J. Huston	For [signature] S6-12	10/24/94					
1	1	Safety G. E. McPherson	[signature] T4-10		S2-41		10-10-[illegible]		
1	1	ESA Mgr. R. B. Park	[signature] H5-53						

18.	19.	20.	21. DOE APPROVAL (if required)
[signature] 10-7-94 Signature of EDT Originator Date B. F. Norman	[signature] 10/24/94 Authorized Representative for Receiving Organization Date J. R. Bellomy	[signature] 10/24/94 Cognizant/Project Engineer's Manager Date J. P. Harris	Ltr. No. [] Approved [] Approved w/comments [] Disapproved w/comments

BD-7400-172-2 (07/91) GEF097

RELEASE AUTHORIZATION

Document Number:	WHC-SD-W320-DA-005, REV 0
Document Title:	SHOT LOADING PLATFORM ANALYSIS
Release Date:	10/24/94

* * * * * * * * * * * * *

This document was reviewed following the procedures described in WHC-CM-3-4 and is:

APPROVED FOR PUBLIC RELEASE

* * * * * * * * * * * * *

WHC Information Release Administration Specialist:

Kara Broz	October 24, 1994
(Signature)	**(Date)**

A-6001-400.2 (09/94) WEF256

SUPPORTING DOCUMENT

1. Total Pages 28

2. Title

Shot Loading Platform Analysis

3. Number

WHC-SD-W320-DA-005

4. Rev No.

0

5. Key Words

Loading Platform
Funnels
Hopper

APPROVED FOR PUBLIC RELEASE

KMB 10/24/94

6. Author

Name: B. F. Norman

B. F. Norman

Signature

Organization/Charge Code Equipment Stress Analyis/D2M9G

7. Abstract

This document provides the wind/seismic analysis and evaluation for the shot loading platform. Hand calculations were used for the analysis. AISC and UBC load factors were used in this evaluation. The results show that the actual loads are under the allowable loads and all requirements are met.

9. Impact Level SQ

10. RELEASE STAMP

OFFICIAL RELEASE 58
BY WHC
DATE OCT 2 4 1994
Sta. #3

A-6400-073 (11/91) (EF) WEF124

MASTER

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SPOOL ASSEMBLY SUPPORT ANALYSIS

OCTOBER 1994

PREPARED BY: ______________________ DATE: 10-7-94
B. F. Norman, Engineer
Equipment Stress Analysis

REVIEWED BY: ______________________ DATE: 10/7/94
R. L. Jorissen, Principal Engineer
Equipment Stress Analysis

APPROVED BY: ______________________ DATE: 10/7/94
R. B. Pan, Manager
Equipment Stress Analysis

Westinghouse Hanford Company
Hanford Operations and Engineering Contractor
for the
U.S. Department of Energy

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed WHC-SD-W320-DA-005, Rev. 0

Author B. F. Norman

Yes	No	NA	
[X]	[ ]	[ ]	Problem completely defined.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[ ]	[ ]	[X]	Computer codes and data files documented.
[X]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[X]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[X]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[ ]	[ ]	[X]	Models appropriate and used within range of validity or use outside range of established validity justified.
[X]	[ ]	[ ]	Hand calculations checked for errors.
[ ]	[ ]	[X]	Code run streams correct and consistent with analysis documentation.
[ ]	[ ]	[X]	Code output consistent with input and with results reported in analysis documentation.
[X]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[X]	[ ]	[ ]	Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

MANDATORY Software QA Log Number N/A

Randy Jorissen
Reviewer/R. L. Jorissen

10/7/94
Date

DESIGN VERIFICATION METHOD

The need for design verification has been reviewed with the method selected as indicated below: (ESR/Work Plan # WP-23480-289).

X	Independent Review
	Alternative Calculations
	Qualification Testing
	Formal Design Review

R. B. Pan
Cognizant/Project/Design Manger

SD # WHC-SD-W320-DA-005

ECN # __________

DWG(S) # __________

CONTENTS

APPENDICES

SHOT LOADING PLATFORM ANALYSIS

1.0 INTRODUCTION

Equipment Stress Analysis was asked to design a support system that would be able to transfer shot from a hopper into containers resting on the flatbeds of trucks. This support system also had to have shielding capability to protect workers from radiation exposure. A wind and seismic analysis was performed on the support system to determine member sizes. Hand calculations were used to determine stresses and overturning forces in the support structure.

The design is in accordance with SDC 4.1 (HPS) and is safety class 3SQ. The design and fabrication is in accordance with American Institute of Steel Construction, Manual of Steel Construction (AISC 1989). All welding and weld inspection is in accordance with AWS D1.1. The applied loads to the shot support system were in accordance with the UBC (ICBO 1991) and ASCE 7-88 (ASCE 1988).

Results of the analysis appear in Section 2.0. Loadings and configurations appear in Section 3.0. Section 4 discusses the stress analysis process, and the appendices contain the calculations.

2.0 RESULTS

The allowable loads and stresses for members were based on the *American Institute of Steel Construction* (AISC 1989). Overturning moments and restoring moments are based on the *Uniform Building Code* (UBC)(ICBO 1991).

The support structure was checked for overturning along its two main axes. Calculations indicate a safety factor greater than 1.5; therefore overturning will not occur.

The bending stresses in the shot support structure that result from lateral and gravity loads are acceptable. The bending stresses in the funnels are acceptable for the applied loads.

The hopper was provided by the GAR-BRO Company, Heber Springs, Arkansas. No structural analysis was performed on this piece of equipment by WHC engineering. Analysis was performed by GAR-BRO.

During operation, the maximum applied loads to the assembly are as follows: ten cubic feet of lead shot in the hopper, 2 personnel with associated equipment, and 1,000 lb of lead blankets spread over a minimum of 10 ft^2 area.

3.0 CONFIGURATIONS AND LOADINGS

3.1 CONFIGURATIONS

The drawings listed below document the configurations for the shot loading platform assembly and the funnels:

- H-2-83738 Shot Loading Platform
- H-2-83745 & H-2-83756 Tank 241-C-106 Funnels
- H-2-83751 Tank 241-SY-101 Funnels.

The configurations and dimensions of the components analyzed appear in Appendix A along with the calculations.

3.2 LOADINGS

The loading criteria were based on the amount of shielding required to keep exposure limits to a minimum. Discussion of the weights and applied loads appears in Appendix A along with the calculations.

4.0 STRESS ANALYSIS

The applied loads to the shot support system were in accordance with the UBC (ICBO 1991) and ASCE 7-88 (ASCE 1988). Hand calculations were used to verify structural member sizes and weld sizes. Appendix A discusses the applied loads in depth, as well as the actual and allowable loads.

5.0 REFERENCES

AISC, 1989, *Manual of Steel Construction, Allowable Strength Design*, Ninth edition, American Institute of Steel Construction, Chicago, Illinois.

ASCE, 1988, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-88, American Society of Civil Engineers, New York, New York.

ICBO, 1991, *Uniform Building Code*, International Conference of Building Officials, Whittier, California.

APPENDIX A

SHOT LOADING PLATFORM

ANALYTICAL CALCULATIONS

Subject: LEAD SHOT SUPPORT ASSEMBLY (LSSA)

Originator: B F NORMAN Date: 4-20-94

Checker: Randy Jones Date: 9/28/94

OBJECTIVE: A DESIGN WAS REQUIRED TO LOAD ~~LEAD~~ OR STEEL SHOT INTO CONTAINERS LAYING ON FLATBED TRUCKS. THE SUPPORT HAD TO BE ABLE TO VARY IN HEIGHT, AND BE EASILY DISASSEMBLED TO BE MOVED FROM SITE TO SITE. ON THE FOLLOWING PAGES YOU WILL FIND THE ANALYSIS FOR A THREE PART SUPPORT SYSTEM WHICH HAS THE CAPEABILITY TO MEET THE REQUIREMENTS. WE HAVE ONE PLATFORM ASSEMBLY AND TWO INDEPENDENT SIDE SUPPORTS. A STATIONARY HOPPER WAS ALSO ANALYSED TO PREVENT LEAD SHOT FROM BEING SPILLED DURING THE TRANSFER

BD-6400-060.1 (07/93)

ANALYTICAL CALCULATIONS

Subject: LEAD SHOT SUPPORT ASSEMBLY
Originator: BF NORMAN   Date: 4-4-94
Checker: Randy Jönssen   Date: 9/28/94

WIND LOADS   ASCE 7-88   SAFETY CLASS 3 CLASSIFICATION

$F = q_z G_h C_f A_f$

$q_z = 0.00256\ K_z (IV)^2$

$K_z =$ Exp. C 20' HGT $= 0.87$
$V = 70$ mph
$I = 1.07 \rightarrow$ SDC 4.1 REV 12

$q_z = 0.00256(.87)(1.07 \cdot 70)^2$

$q_z = 12.49 = 12.5$

$G_h = 1.29$ Exp C Hgt = 20'

WIND DIRECTED @ SIDE WHERE VERTICLE LEAD SHIELDING IS ← $C_f =$ H=12 W=10 = 1.2 < 3
SEE PG 6

$C_f = 1.2$

$F = 12.5(1.29)(1.2)\ A_F$

$F = 19.35\ A_F$

USE 20 PSF WIND LOAD

SEISMIC LOADS   UBC-1991

$F_p = Z I C_p W_p$ → SDC 4.1 REV 12 Z = .12 (CONSERVATIVE)

$Z = 0.20$ ZONE 2B (TABLE 23-I)
$I = 1.25$ OCC. 4 CATAGORY (TABLE 23-L) VS SDC 4.1 REV 12
$C_p = 0.75$ III EQUIPMENT (TABLE 23-P)

$F_p = 0.19\ W_p$ → COMPONENT WGT.

SINCE THIS IS A TEMPORARY STRUCTURE SEISMIC WILL BE LOOKED @ FOR OVERTURNING ONLY. NO STRUCTURAL COMPONENTS WILL BE DESIGNED TO RESIST SEISMIC LATERAL LOADING.

BD-6400-060.1 (07/93)

ANALYTICAL CALCULATIONS

Subject: LEAD SHOT SUPPORT ASSEMBLY
Originator: BF NORMAN Date: 4-7-94
Checker: Randy Jonisson Date: 9/28/94

TOP PLATFORM ANALYSIS

- SEE APPENDIX A FOR LEAD SHIELDING REQUIREMENTS
- WORKER DOSE RATE 10 – 15 mr/hr (VERIFIED)
- DOSE RATE OF 14 mr/hr = 3.5 CM OF LEAD

3.5 CM = 1.38" OF LEAD

- GEOFFRY PETER (KEH ENGINEER) SAYS 1.0" LEAD = 1.5" STEEL

S.G. LEAD = 11.37 RATIO = 1.45 ≈ 1.50
S.G. STEEL = 7.85

$\frac{1.0}{1.5} = \frac{1.38}{?}$? = 2.07" STEEL

★★ 2 1/8" THK PL STEEL = 86.79 PSF

★★ (DESIGN WILL USE 2 1/8" PLATE BUT ACTUAL THICKNESS WILL BE 2". THIS WILL ALLOW FOR LEAD BLANKETS TO BE ADDED IF RAD LIMITS ARE HIGHER THAN EXPECTED = 536# USED FOR LEAD BLANKETS.)

PLATFORM = 10' x 10'-6" = 105 FT²

SNOW LOAD = 20 PSF PER SDC 4.1 REV 12 NOT APPLIED SIMULTANEOUSLY W/ LIVE LOAD

LIVE LOAD/SNOW LOAD = 20 PSF → (PEOPLE, RAILINGS, CONNECTIONS, MISC WGT)

CONSIDERING PLATFORM AS A ROOF STRUCTURE W/ NO ADDED EQUIPMENT BUT WHAT IS SHOWN.

TOTAL = 107 PSF

WGT OF PLATFORM = 11,235 # + 2'(2')(3 SIDES)(86.79) – 2'(2')(86.79) ← HOLE IN FLOOR (VERTICAL SHIELDING)

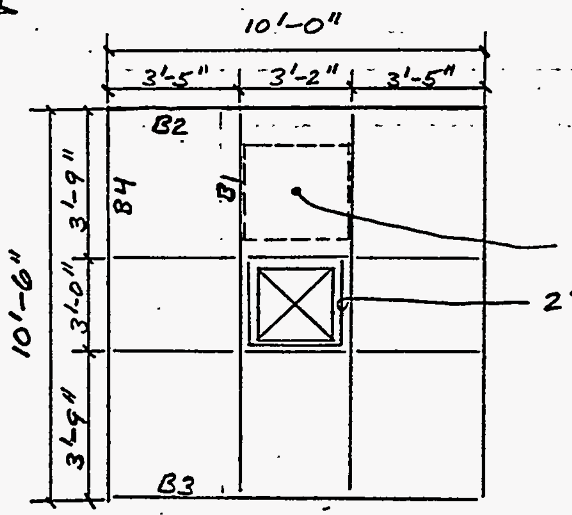
WGT = 11,930 #

HOPPER WGT = 750 # FROM GAR-BRO COMPANY
10 cu ft of shot = 4,300 #

TOTAL = 5,050 #
#/LEG = 1,262 #

PLATFORM IS IN SYMMETRY ANALYSE ONE SIDE & MIRROR TO OTHER.

- STRUCTURE OF PLATFORM CONSISTS OF 6x6x1/4 TS



HOPPER LOCATION

2' HIGH SHIELDING 3 SIDES

LL ≤ 2,000 POUNDS
TWO MEN & PERSONAL EQUIP = 1,000 #

LEAD BLANKETS = 1,000 # WHEN CONTAINERS ARE BEING LOADED.

∴ USE 1000 # OF LEAD BLANKETS SPREAD OVER 10 ft² AREA OR 100 PSF MAX.

ANALYTICAL CALCULATIONS

Subject ______________________

Originator BF NORMAN Date 4-7-94

Checker [signature] Date 9/28/94

BEAM #1

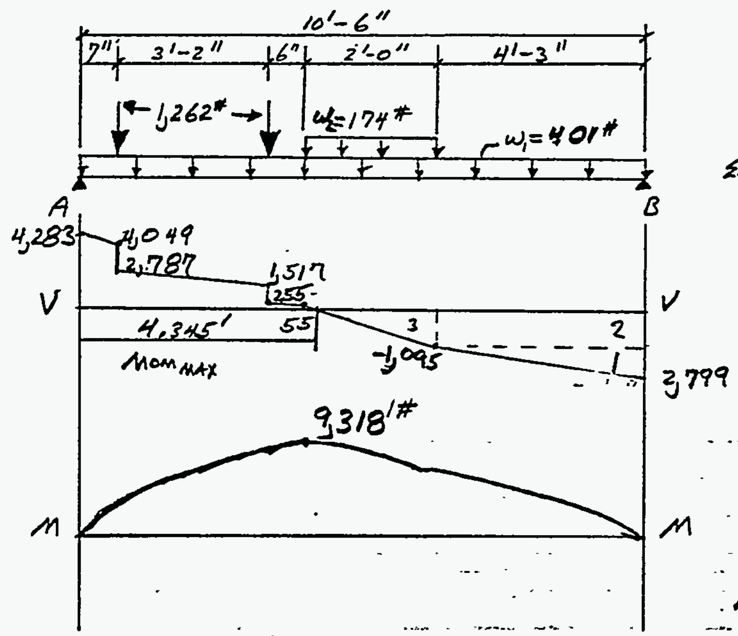
★★★ ADD 25% IMPACT LOAD TO BEAM 1

USE BEAMS AS SIMPLY SUPPORTED

$321^{\#}(1.25) = 401$

$\omega_1 = 3'$ TRIB $(107) = 321\ ^{\#}/ft$

$\omega_2 = 2'$ HEIGHT $(87) = 174\ ^{\#}/ft$



$\Sigma M_A = 1{,}262(.58') + 1{,}262(3.75)$
$+ 401(10.5)(5.25)$
$+ 174(2)(5.25)$
$= B(10.5)$
$B = 2{,}799\ \#$

$\Sigma F_y \quad A = 4{,}283\ \#$

AREA 1 $= 1{,}704(4.25)(1/2)$
$1 = 3{,}621$

AREA 2 $= 1{,}095(4.25)$
$2 = 4{,}654$

AREA 3 $= 1{,}095(1.905)(1/2)$
$3 = 1{,}043$

SUM AREAS 1, 2, 3
SUM $= 9{,}318'\#$

TRY 6x6x1/4 TS $S_x = 10.1\ in^3$ $I = 30.3\ in^4$

$f_b = M/S = 9{,}318(12)/10.1$

$f_b = 11{,}071$ psi

$F_b = .6(46) = 27.6 > 11.1$ ∴ OK

DEFLECTION CHECK – FIND MAX ALLOWABLE ω FOR L/240 DEFLECTION (SEE NOTE)

$L/240 = (10'\text{-}6")(12)/240 = 0.525"$

NOTE: L/240 ALLOWABLE ROOF DEFLECTION UBC 1991

$$.525 = \frac{5\,\omega\,(126)^4}{384(29e^6)(30.3)}$$

$141 = \omega/12 \qquad \omega = 1{,}687$ PLF

DUE TO LARGE ALLOWABLE ω & POSITIONING OF POINT LOADS, DEFLECTION IS OK FOR TUBE.

BD-6400-060.1 (07/93)

ANALYTICAL CALCULATIONS

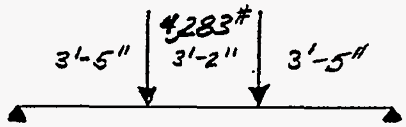
Subject ______

Originator BF NORMAN   Date 4-7-94

Checker Randy Jonsen   Date 9/28/94   2

BEAM #2

$r = V = 4{,}283^{\#}$



$M_{MAX} = Pa = 4{,}283\ (3'\text{-}5") = 14{,}633\ '^{\#}$

$f_b = M/S = 14{,}633\,(12)/10.1 = 17{,}386\ psi$

$F_b = .6(46) = 27.6 > 17.4 \therefore OK$

$\Delta_{MAX} = \frac{Pa}{24EI}\ (3\ell^2 - 4a^2)$

$= \frac{4{,}283\,(41)}{24\,(29e^6)(303)}\ (3(120)^2 - 4(41)^2) = 0.30\,in$

$\therefore$ OK FOR DEFLECTION

$\therefore$ BEAM IS OK

BEAM #3

SAME AS BEAM 2 BUT W/ 2,799 POUND POINT LOADS

$M = 2{,}799^{\#}\,(3'\text{-}5") = 9{,}563\ '^{\#}$

$f_b = 9{,}563\,(12)/10.1 = 11{,}362\ psi < 27.6^{KSI} \therefore OK$

DEFLECTION IS OK

$V = R = 2{,}799^{\#}$

BEAM 4 WILL BE ANALYSED AFTER A TOTAL FREEBODY DIAGRAM HAS BEEN DESIGNED AND THE REACTIONS ANALYSED

FORCES DUE TO WIND LOAD.

AREA FROM 2" PLATE $= 10' \times 10' = 100\,ft^2$

AREA FROM EQUIPMENT & PLATFORM $= 20\,ft^2$

$120\,ft^2$

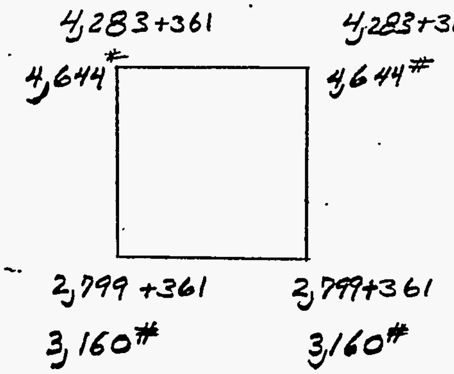
$120\,(20) = 2{,}400^{\#}$

- APPLY WIND LOAD AT TOP OF PLATFORM (CONS)
  SPLIT LOAD BETWEEN TWO COLUMNS ON SIDE SUPPORT.
  $F = 1{,}200^{\#}$/SUPPORT

ANALYTICAL CALCULATIONS

Subject: LEAD SHOT SUPPORT ASSEMBLY
Originator: BF NORMAN — Date: 5-4-94
Checker: Randy Jonsison — Date: 9/28/94

VERT LOADS AT CORNERS DUE TO B1, B2, B3



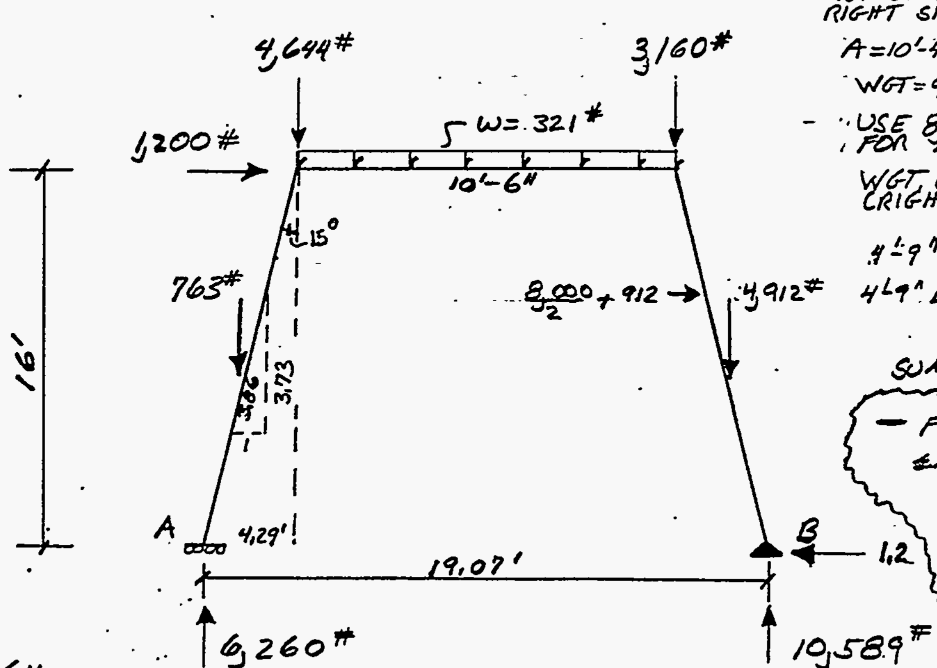
6x6x1/4 ST 76 LN FT
WGT = 1,445 #

DISTRIBUTE TO 4 CORNERS
361 #/CORNER

FREE BODY DIAGRAM

1) LOOK @ ONE SIDE OF SUPPORT & ANALYSE WORST CASE.
2) UNIFORM LOAD ON TOP BEAM IS FROM 3' TRIBUTARY AREA OF PLATFORM.

WGT. OF SIDE SUPPORT (LEFT)
19'-6" 6x6x3/8 TS @ 27.48 #/FT = 536 #
8' OF 5x5x1/2 TS @ 28.43 #/FT = 227
SUM = 763 #



– WGT OF STEEL PLATE RIGHT SIDE
A = 10'-4" x 8'-9 3/4" = 91 ft²
WGT = 91 • 87 = 7,917#
– USE 8,000# TO ACCT FOR MISC. WGT.

WGT OF SIDE SUPPORT (RIGHT)
763#
4'-9" TS 6x6x3/8 = 130#
4'-9" L 2½x2½x¼ @ 4.1, 19#
SUM RIGHT = 912#

– FOR NO WIND
ΣM+ = SAME EQ MINUS WIND FACTOR
RB = 9,582#
RA = 7,266#

$+\circlearrowright \Sigma M_A = 0$

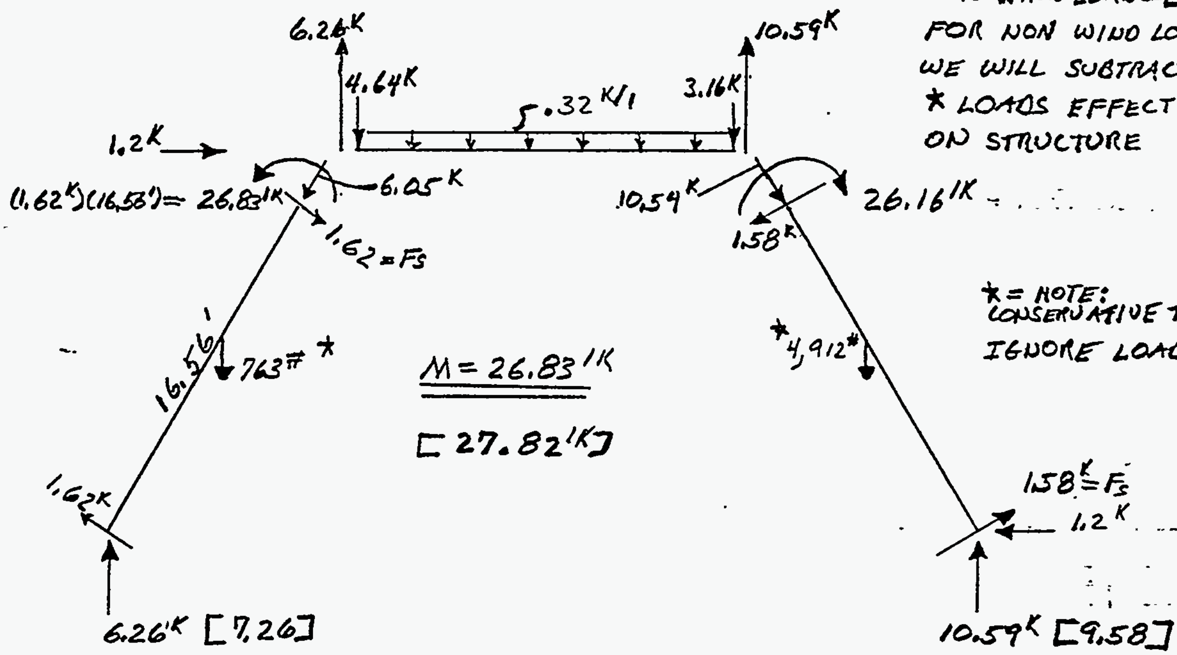
1,200 (16) + 763(2) + 4644 (4.29) + 321 (10.5) 9.54 + 3,160(14.78)
+ 4,912 (16.78) = RB (19.07)

RB = 10,589
RA = 6,260

ANALYTICAL CALCULATIONS

Subject: LEAD SHOT SUPPORT ASSEMBLY
Originator: RF NORMAN   Date: 5-5-94
Checker: Randy Johnson / TW Fuller   Date: 9/28/94

NON WIND LOADS = [ ]
FOR NON WIND LOADS WE WILL SUBTRACT * LOADS EFFECT ON STRUCTURE



* = NOTE: CONSERVATIVE TO IGNORE LOADS.

$F_A = \frac{3.73}{3.86}(6.26) = 6.05^K \ [7.01^K]$

$F_S = \frac{1}{3.86}(6.26) = 1.62^K \ [1.68^K]$

$F_A = \frac{1}{3.86}(1.2) + \frac{3.73}{3.86}(10.59)$

$F_A = 10.54^K \ [9.25^K]$

$F_S = \frac{1}{3.86}(10.59) - \frac{3.73}{3.86}(1.2)$

$F_S = 1.58^K \ [1.47^K]$

CHECK LOADS SEEN BY 6X6X3/8 TS $A = 8.08 in^2$ $S = 13.9 in^3$ $r = 2.27 in$

COMBINED WORSE CASE LOADS FROM EACH LEG. (CONS)

$f_b = M/S = 26.83(12)/13.9 = 23.16$ Ksi   [24.01]

$F_b = .6(F_y) = .6(46) = 27.6 > 23.16$ ∴ OK

$f_a = 10.54^K / 8.08 = 1.31$ Ksi   [1.18 Ksi]

$F_a = Kl/r = (1.2)(10')(12)/2.27 = 63.45$

COMPARE W/ A-36 STEEL - AISC 9th edition (PG 3-16)

$F_a = 17.04$ Ksi

COMBINED LOADS

WIND — $23.16/27.6 + 1.3/17.04 = 0.92 < 1.33$ (INCLUDES 1/3 INCREASE FOR LATERAL LOADS)

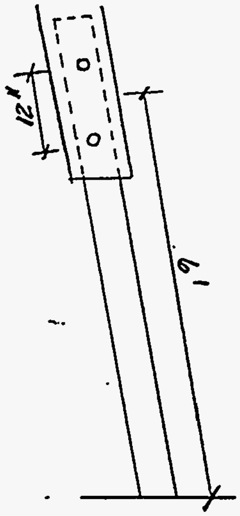
NO WIND — $24.01/27.6 + 1.18/17.04 = 0.94 < 1.0$

USE 6X6X3/8 TS FOR SIDE SUPPORTS

ANALYTICAL CALCULATIONS

Subject: LEAD SHOT SUPPORT ASSEMBLY
Originator: BF NORMAN   Date: 5-6-94
Checker: [signature]   Date: 9-28-94

CHECK 5X5X½ TS (TELESCOPING INSIDE 6X6X3/8)



PG#7

MOM ON BOLTS $M = 6'(1.68) = 10.08^{K'}$

2 BOLTS = FORCE COUPLE $= 10.08^{K'}/1' = 10.08^{K}$ COUPLE

← 10.08

→ 10.08

Force axial $= 10.54^{K}$

ASSUME ONE BOLT TAKES ALL AXIAL LOAD

$f_r = [(10.54)^2 + (10.08)^2]^{1/2} = 14.58^{K}$

TRY 3/4"Ø A325 BOLTS (AISC 9th ed pg 4-5)

BOLTS ARE IN DOUBLE SHEAR

$F_{SHEAR} = 18.6^{K}$ PER BOLT → (CONS USE N TYPE BEARING CONNECTION)

$F_{TEN} = 19.4\ K$ (NOMINAL DIAMETER) — (NO TENTION PRESENT)

$F_{SHEAR} = 14.58^{K} < 18.6^{K}$ ∴ OK USE 3/4"Ø A325 BOLTS

CHECK 5X5X½ ST

– TAKE REACTION FROM TOP OF 6X6 TS & TRANSFER TO 5X5

PG.7

$M\ (1.68)(10') = 16.8^{'K}$

TS 5X5X½

$A = 8.36 in^2$ $S = 10.8 in^3$ $r = 1.80 in$

$f_b = M/S = 16.8(12)/10.8 = 18.66$ ksi

$F_b = .6(46) = 27.6$ (NO LATERAL LOAD ADDITIVES) CONS.

> 17.66 ∴ OK

$f_a = 10.54^{K}/8.36 in^2 = 1.26$ ksi

$F_a = Kl/r = 2.0(6 \cdot 12)/1.80 = 80$

COMPARE W/ A-36 STEEL ALLOWABLES

$Kl/r = 80$ $F_a = 15.36$ (AISC 9th ed)

COMBINED LOADS

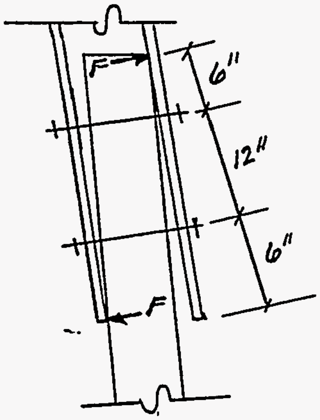
$18.66/27.6 + 1.26/15.36 = 0.76 < 1.0$ ∴ OK (NO LATERAL LOAD ADD ONS) (CONS)

USE 5X5X½ TS FOR TELESCOPING SUPPORTS

ANALYTICAL CALCULATIONS

Subject LEAD SHOT SUPPORT ASSEMBLE
Originator BF NORMAN Date 5-7-94
Checker TW Fort Date 9-28-94

CHECK INTERNAL BENDING DUE TO TELESCOPING MEMBERS



- WORST CASE ANALYSIS
- CHECK PUNCHING SHEAR F=10.08^K FROM PG 8

AREA OF CONTACT = 5" x 1" OF TUBE FACE
$f_v = P/A = 10.08/5(3/8"$ TUBE WALL$) = 5.38$
$F_v = .4(F_y) = 18.4^K$
$18.4^K > 5.38^K$
∴ OK IN SHEAR

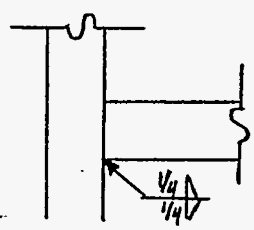
CHECK HORIZONTAL TS WITH ℞ RESTING ON IT

SIDE ℞ → 10'-4" X 8'-9¾" = 91 ft² • 87 = 7,917 #
WGT PER LN/FT = 766 #/LN FT

- MEMBER'S FIXED @ EACH END $M = wl^2/12$
$= 766(9.5)^2/12 = 5,761$ '#

$f_b = M/s = 5,761(12)/139 = 4,973$ psi
$F_b = .6(F_y) = 27.6 > 4.97$ ∴ OK FOR BENDING

- CAPACITY OF WELD JOINT



5"
6"

$S_w = bd = 30$
$A_w = 10"$

$f_b = M/s = 4,973(12)/30 = 1,989$ psi
$f_y = 3,958 / 10 = 395.8$ lbs/inch
$f_r = [(1,989)^2 + (395.8)^2]^{1/2}$
$f_r = 2,028$ #/in

TRY ¼" FILLET .3(70,000) E70 ELECTRODES
.707(21,000)(.25) = 3,712

3,712 > 2,028

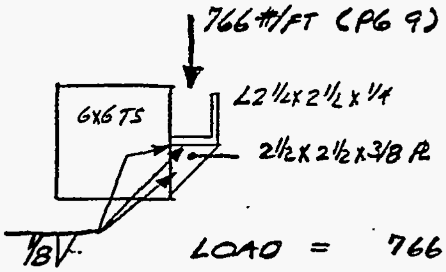
USE ¼" FILLET TOP & BOTTOM

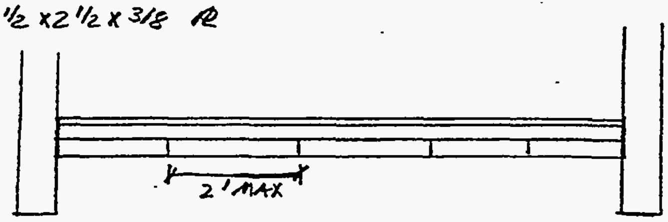
ANALYTICAL CALCULATIONS

Subject LEAD SHOT SUPPORT ASSEMBLY
Originator B F NORMAN Date 5-7-94
Checker Y W [signature] Date 9-28-94

CHECK 2½ ANGLE USED AS SHELF SUPPORT FOR PLATE

-ANGLE WILL BE TOTALLY WELDED ALONG BOTTOM EDGE
- GUSSET PLATES 2½x2½x3/8 PL





LOAD = 766 # (1.25) = 957 #/FT w/ IMPACT LOADS FOR ENTIRE LENGTH OF ANGLE

$A = 1.19\ in^2$
$S = .394\ in^3$

- USE 2' SPACING FOR GUSSETS

$M = wl^2/8 = 479$ 1#

$fb = M/S = 479'^{\#} (12)''/.394 in^3$ 14,599 psi

(.6)(36) = Fb = 21.6 Ksi > 14.6 Ksi ∴ OK

- TRY 1/8" FILLET WELD ALL ALONG BOTTOM

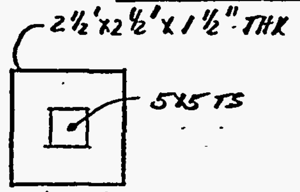
- LOAD = 957/12 = 80 #/in

1/8" = .707(21,000)(1/8) = 1,856 #/in (.3(70,000) → E70 ELECTRODES)

GUSSET PL
LOAD = 2w
= 1,914 #
- USE 1/8" WELDS
MIN 2" LENGTH
GUSSET PL IS OK BY ENGINEERING JUDGEMENT

USE 1/8" WELD ALONG BOTTOM (AROUND GUSSET PL

CHECK BOTTOM PLATE



A = 2½'·2½' = 6.25'

CHECK SHEAR 10.54 K (PG #7)

A = 1.5 (20") = 30 in² PUNCTURE SHEAR AREA

fv = 351 psi

fv << Fv For Fy = 36 Ksi

- CHECK BENDING
- SUPPOSEDLY NO MOMENT SINCE MOMENT IS BEING RESISTED BY TOP CONNECTION
- (CONS) USE FULL MOMENT ON PL

M = 27.82 'K $S = 1/6 (2'-6")(1.5)^2 = 11.25 in^3$

Fb = .75 (36) = 27 Ksi   fb = 27.82 'K (12")/11.25 in³ = 29.67 Ksi > 27

NEW Fb   - INCREASE 1/3 DUE TO LATERAL LOADS [UBC 1991]

(27)(1.33) = 36 Ksi > 29.67 ∴ OK   PLATE IS OK FOR APPLIED MOMENT

- CHECK SOIL PRESSURE

10.54 Ksi / 6.25 'D = 1,686 PSF < 2,000 PSF

SOIL BEARING PRESSURE IS OK.

ANALYTICAL CALCULATIONS

Page 11 of 14

Subject: LEAD SHOT SUPPORT ASSEMBLY
Originator: BF NORMAN Date: 5-17-94
Checker: [signature] Date: 9-28-94

PLATE CONNECTIONS BETWEEN PLATFORMS & POSTS
(DWG H-2-83738 SH #2) SECTION K, L & DETAIL 1

- USE 1" PLATE FOR CONNECTIONS

$M = 27.82'^{K}$ (PG. #7)

S PL vertical sides $= S = 1/6\, b h^2$ $\quad S = 1/6\,(1")(5)^2$ $\quad S = 4.166$ / plate

S PL Horizontal top $1/6\,(6)(1)^2 = 1.0$

S PL Horizontal bottom $= 1/6\,(7)(1)^2 = 1.166$

S PL VERTICAL BACK $= 1/6\,(1")(6)^2 = 6.0$

$S\ TOTAL = 2(4.166) + 1.0 + 1.166 + 6.0$

$S = 16.49$

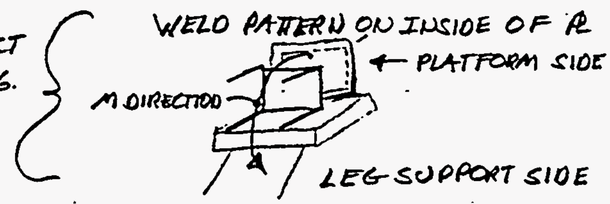
- S AS SUM OF THE INDIVIDUAL PIECES. (MOST CONSERV.)
- IF STRENGTH OF WELDS ARE ADAQUATE THEN ANALYSE END CONFIGURATION AS A HOLLOW RECTANGLE

$$- S = \frac{bd^3 - b_1 d_1^3}{6d} = \frac{6(7)^3 - 4(5)^3}{6(7)} = 37.09$$

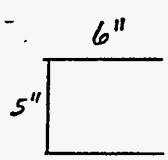
$f_b = M/S = (27.82)(12)/37.09 = 9{,}000\ psi$

$F_b = .75(F_y) = 27.6\ ksi > 9.0\ ksi \therefore OK$

SEE SECT L ON DWG.



CHECK WELDS



TWO SEPARATE WELDS [+ [TO GET TOTAL REQUIRED STRENGTH

$S_w = bd + d^2/6 = 6(5) + 25/6 = 34.16$

$S_{TOT} = 2(34.16) = 68.33$

$f_b = M/S = 27.82\,(12)/68.33 = 4{,}885\ psi$

WELD $r = 4{,}885/.707(21{,}000) = 0.329"$

$3/8" = .375 > .329"$

USE 3/8" WELDS FOR PL.

☆ WE ALSO HAVE EXTERNAL WELDS WHICH WILL HELP IN MOMENT & SHEAR CAPACITIES.

- PLATES WILL HAVE WELDS ON ALL SIDES $\therefore$ OK

ANALYTICAL CALCULATIONS

Subject LEAD SHOT SUPPORT ASSEMBLY
Originator BF NORMAN Date 5-1994
Checker TW [signature] Date 9-28-94

LIFTING LUG ANALYSIS

WGT OF PLATFORM

78' OF 6X6X 1/4"	@ 19.02	=	1,484
87' OF 6X6X 3/8"	@ 27.48	=	2,391
32' OF 5X5X 1/2"	@ 28.43	=	910
25' OF 1 1/2" PL	@ 61.26	=	1,532
7' OF 1" PL	@ 40.84	=	286
		SUM =	6,603

LIFTING LUGS ARE @ 4 CORNERS OF PLATFORM (SEE DWG H-2-83738 FOR LOCATION)

2 LIFTING LUGS TO SUPPORT LOAD = 3,302 #/LUG

CHECK PLATE

$f_b = M/S$ $M = PL/4 = 3{,}302(6)/4$
$M = 4{,}953$ "#

$f_b = 4{,}953$ psi $S = 1/6\,(6)(1)^2 = 1.0$

$f_b << F_b$ ∴ PLATE IS OK

USE 5,000# LOAD RATED HOIST RING → MIN. RATING REQUIRED FROM CERTIFIED LIFTING LUG VENDOR.

TOP PLATFORM (H-2-83738 SH 3)

10'-5" x 10'-5" = 110.25 − 4 (HOLE OPENING)

WGT = 81.68 (106.25) = 8,679#

TOTAL WGT = 8,679#   LOAD ACTS OVER TWO LUGS

#/LUG = 4,339#

USE 10,000# LOAD RATED HOIST RING

* SAME FOR SIDE 2" STEEL PANEL *

USE 10,000# LOAD RATED HOIST RINGS FOR SIDE PLATE

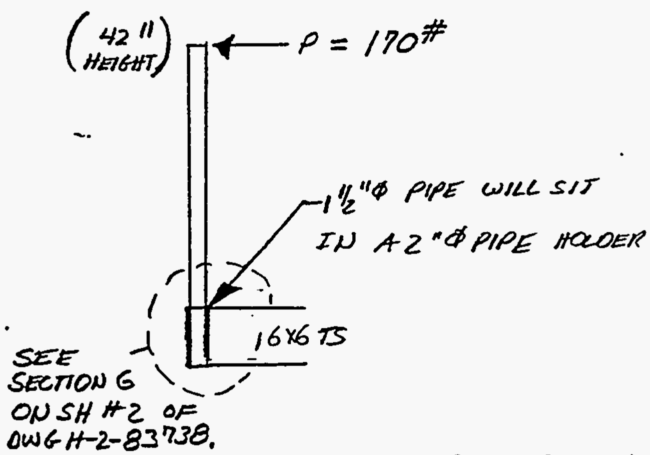
ANALYTICAL CALCULATIONS

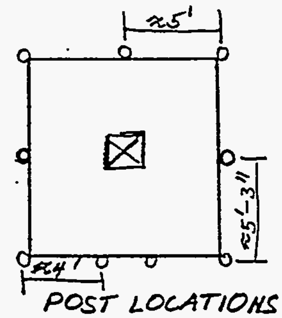
Subject SHOT PLATFORM ASSEMBLY
Originator B F NORMAN Date 4-13-94
Checker TW [signature] Date 9-28-94

HR I

HAND RAIL POST SUPPORTS [SEE H-2-83738 SH #2, 4]

- USE VERTICAL SUPPORTS 6' SPACING MAX
- HORIZONTAL BARS
- WITHSTAND 200 # LATERAL FORCE @ TOP RAILING
- TOP OF GUARDRAIL MIN 42" ABOVE FLR.
- DESIGN SO SPHERE 12" CANNOT PASS THROUGH





- DESIGN SIDE POST RAILINGS FOR TWO SPAN SITUATION

END POST OF 2 SPAN = 85% OF APPLIED LOAD (SEE ATT #.B)

$P = 200 \cdot .85 = 170^{\#}$

- USE A500 B SCHED 40 PIPE → USE SCHD 80 FOR HANDRAILS, HAVE MATERIAL AVAILABLE
- TRY 1½" PIPE $S = .326$ $A = 2.72$ $I = .310$ (CONS. #5)

$f_b = M/s = 170(42)/.326 = 21{,}902$ psi

$F_b = .6(46) = 27.6$ $27.6 > 21.9$ ∴ OK

USE 1½"Φ SCHD 40 PIPE

- CHECK WELDS 3/8" = b d = 4" $S_w = d^2/3$ $S_w = 16/3 = 5.33$
- WELD ALONG BOTH SIDES OF PIPE

$f_b = M/s = 170(42)/5.33 = 1{,}340$ psi

WELD REQUIRED $1{,}340/(21)(.707) = 0.09''$

USE 3/16" FLARE BEVEL WELD MIN BOTH SIDES OF TUBE

ANALYTICAL CALCULATIONS

Subject: LEAD SHOT SUPPORT ASSEMBLY

Originator: BF NORMAN | Date: 5-20-94

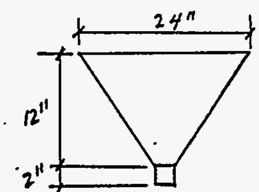
Checker: [signature] | Date: 9-28-94

FUNNEL ANALYSIS

- FUNNELS WILL BE MADE OUT OF STAINLESS STEEL
- DIMENSIONS WILL BE 12" HIGH AND 24" Ø OPENING ON TOP TO A TWO INCH OPENING ON BOTTOM - MAX SIZE, SOME FUNNELS WILL BE SMALLER (i.e. THEY ARE OK BY ENGINEERING JUDGEMENT)

$F_y = 30{,}000$ psi $F_u = 80{,}000$ psi

- LEAD SHOT = 450 #/cu FT (CONS - ≈ 430 #/cu FT)
- STAINLESS ST = 504 #/cu FT



VOLUME OF FUNNEL $= \pi/12\ h\ (D^2 + Dd + d^2)$

$= \pi/12\ (12)\ (24^2 + 2(24) + 2^2)$

$= 1{,}973\ in^3 \rightarrow 1.14\ ft^3$

WGT = 1.14 (450) = 513 #

IMPACT LOAD 25% - APPLY LOAD FOR DROP INTO FUNNEL

LOAD = 642 #

FUNNEL CAN ALSO ATTACH TO A 4" COUPLING. LOADS CHANGE SLIGHTLY BUT CLASSIFY OK BY ENGINEERING JUDGEMENT

- LOAD ACTS OVER AN AREA OF 10 in² @ BOTTOM OF FUNNEL, APPLY THAT LOAD TO TOP OF FUNNEL FOR ANALYSIS (CONS)

$P = 642 / 10 = 64.2\ lbs/in^2$

hoop stress $= pr/t$

USE MINIMAL Fb AFTER WELDED

$\sigma = .6(30) = 18{,}000$ psi

$t = 64.2\ (12) / 18{,}000 = 0.0428" \Rightarrow$ USE MIN. 18 GUAGE MATERIAL

AREA OF FUNNEL SHELL

$\pi/2\ (17)(24 + 2) = 694\ in^2 = 4.82\ ft^2$

WGT OF FUNNEL w/ 18 GUAGE WALLS

$4.82 \cdot .0428/12 = 0.0172\ ft^3$

WGT = 8.66 # MINIMAL WGT

- CJP WELDS FOR TWO SIDE PIECES & WELD TO 2" STAINLESS STEEL PIPE 2" LONG.
- PLATE MATERIAL WILL THEN GOVERN FOR BENDING.
  - ASSUME 6" OFFSET FOR LOAD $M = 642\#(6") = 3{,}852"\#$

$S = 3.14\ in^3$ $f_b = 3{,}852/3.14 = 1{,}226$ psi $< 18{,}000$ ∴ OK

D. B. Calmus 22570-HJG-019
Page 3
September 7, 1993

The problem was run utilizing the program ISOSHLD on a Cray mainframe computer. The hardware was modeled as a cylinder of waste of density ρ=1.2 g/cm^3, surrounded by a cylinder of air, two shielding cylinders, and a steel cylinder whose thickness equaled the sum of the two packages. The shielding cylinders were run as an inner cylinder of lead and an outer cylinder of air. The thicknesses of these two cylinders were varied from all air to almost all lead. In all cases, the thickness of these two cylinders combined remained the same. The exposure rate was taken at the center of the length of these cylinders at the outer surface.

The Results

ISOSHLD Results
Results are in rem/hr rather than the Sv/hr required by WHC

Lead Thickness (cm)	106-C Heel Pump	106-C Transfer Pump	102-AY Agitator Pump
No Lead	1.130	0.1458	0.07419
0.5	0.5840	0.0741	0.03631
1.0	0.3036	0.03800	0.02129
1.5	0.15907	0.01969	0.01326
2.0	0.08437	0.01036	0.008543
2.5	0.04552	0.005556	0.005634
3.0	0.02511	0.003053	0.003780
3.5	0.01422	0.001724	0.002568
4.0	0.008291	0.001003	0.001763
4.5	0.004983	0.0006026	0.001292
5.0	0.003088	0.0003731	0.0008491
5.5	0.001969	0.0002377	0.0005946
6.0	0.001287	0.0001552	0.0004185
6.5	0.0008597	0.0001036	0.0002958
7.0	0.0005844	0.00007034	0.0002098
7.5	0.0004028	0.00004843	0.0001494
8.0	0.0002808	0.00003372	0.0001067

APP A.

Designing Metal Guard and Hand Rails

by William Thurnauer
Julius Blum & Company

Design Considerations:

There are five major considerations in the structural design of railings:

- Structural loading and dimensional criteria as established by local building codes, regulatory agencies or special design requirements.
- Mechanical properties of handrail materials and their allowable design stresses.
- Elements of sections of railing components.
- Load stress and deflection relationships as expressed in formulae for engineering design.
- Proper attachment and sound supporting structure.

Code Requirements

Local building code requirements for dimensions and loading of railings can vary greatly. For most applications (except low rise residential buildings) OSHA requirements must be complied with. They state that railings "shall be capable of withstanding a load of at least 200 lbs. applied in any direction at any point of the top rail." Local building codes take precedence when established structural loading criteria exceed OSHA requirements.

The absence of uniform loading criteria among building codes is partly due to the wide range of applications and traffic exposures and partly due to the absence of objective data from which reliable or generally acceptable live loading factors can be determined.

An ambiguity also arises from the OSHA phrase *"withstanding a load."* This phrase may be interpreted conservatively as the design limit based on allowable stress of the material. However, most railings built to conventional standards and demonstrated to be safe in many years of use do not conform under that interpretation.

Often, the OSHA standard is interpreted to mean that a railing must not fail totally under the specified loading but that a permanent deformation may be tolerated. The theory is that a railing, even though somewhat deformed, still provides safety and can be repaired if need be.

The more conservative interpretation may well result in overdesign and higher cost, but the more liberal interpretation, in case of a failure involving injury to persons, might lead to serious problems of liability. Thus, until the expression "to withstand a load" is either changed or officially defined, the more conservative interpretation should be applied.

Mechanical Properties of Materials and Allowable Stresses:

To provide proper safety factors, the engineering profession assigns to each metal an allowable design stress which is defined as the minimum yield strength divided by 1.65. "Minimum strength" is defined as the test value exceeded by 99% of a large number of specimens. The "yield point" for metals other than carbon steel is indeterminate and therefore, according to ASTM, it is arbitrarily defined as the point of stress at which permanent set is 0.2% of gauge length of the test piece (see Figure A).

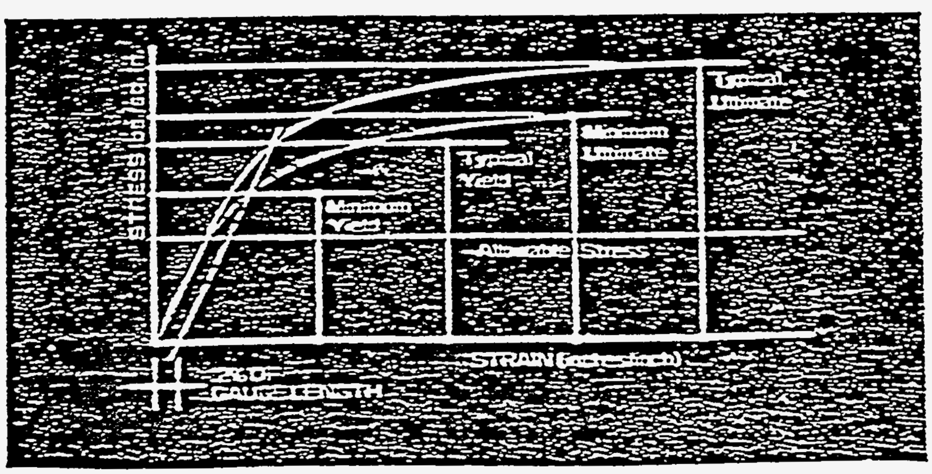
This rule applies to metals such as aluminum, bronze and stainless steel which are commonly used in railings. Mechanical properties of materials used in metal guard rails and handrails are shown in Figure B.

Elements of Sections

Properties of many sizes of bars, shapes, pipe and tubing used in railing construction can be found in tables issued by industry associations and by some of the suppliers of these products. For proprietary sections such as handrail mouldings and ornamental railing posts check manufacturers' catalogs. Figure C lists the engineering properties of a few sizes of pipe commonly used for railings in steel, aluminum, bronze or stainless steel.

Railing Formulae

The loading characteristics of any specific railing design can be computed, given the mechanical properties



Appd B-1

of the material, the engineering properties of the structural components and the dimensions, including post height and post spacing (rail spans) of the completed structure. The formulae follow conventional engineering design procedures. Stresses are calculated from bending moments and section properties, using the flexure formula (explanation of symbols shown in Figure D):

$$f = \frac{M \times c}{I} \text{ or } \frac{M}{S}$$

Posts

Posts act as vertical cantilever beams in resisting horizontal thrust applied at the top rail. Bending moment produced by horizontal thrust normally controls design, and stresses may be calculated by the formula:

$$f = \frac{w/12 \times L \times h}{S} \text{ for uniform loading}$$

or

$$f = \frac{F_H \times h}{S} \text{ for concentrated loading}$$

Rails

Distribution of loads through multiple spans decreases maximum bending moment in horizontal members. Calculation of stresses for different numbers of spans is accomplished by varying the bending moment constant. The following formulae apply:

For uniform vertical or horizontal loads:

$$f = \frac{w/12 \times L^2}{S \times K}$$

K = 8 for one or two spans
K = 9.5 for three or more spans

For concentrated loads, applied at mid-span:

$$f = \frac{F \times L}{S \times K}$$

K = 4 for one span
K = 5 for two or more spans

Any of these equations can be solved for allowable load, post spacing or rail span, or for the required metal properties or section modulus. (For the purpose of these calculations it is assumed that connections between posts and rails are free of pivot and that railings run in a straight line.)

Load Distribution

In most railing installations, the load applied to the rail at any one post is distributed in part to other posts on either side of the post under loading. Therefore, in many instances, railing posts may be designed for an allowable load (F_H), which is less than the total required loading of the railing.

Load distribution is dependent on the stiffness of the rail relative to the stiffness of the posts and on the total number of spans in the run. For a straight run of railing, the load proportion factor may be determined from the graph in Figure E, once the stiffness ratio has been calculated.

The formula used in determining this graph assumes that all posts are of identical material and section. If one or both ends of the railing are free standing, the "end loaded" condition must be assumed. If both ends of the run are laterally braced by a change in direction or attachment to a firm structure, the "center loaded" load proportion factor may be used.

In pipe railings, where posts and rails are of identical material and section

(continued on next page)

Material	Allowable Stress (psi)	Minimum Yield (psi)	Modulus of Elasticity (psi × 10⁶)
Aluminum 6061-T6	21,000	35,000	10.0
Aluminum 6061-T6 (pipe)	24,000*	35,000	10.0
Aluminum 6063-T52	9,500	16,000	10.0
Aluminum 6063-T52 (pipe)	11,500*	16,000	10.0
Aluminum 6063-T6	15,000	25,000	10.0
Aluminum 6063-T832 (pipe)	24,000*	35,000	10.0
Bronze (alloy 385)	11,500	19,000	14.0
Red Brass (alloy 230) (annealed pipe)	7,200	12,000	17.0
Red Brass (alloy 230) (drawn square and rectangular tubing)	11,000	18,000	17.0
Type 304 Stainless Steel (annealed)	18,000	30,000	28.0
Type 304 Stainless Steel Tubing (as welded)	30,000	50,000**	28.0
Carbon Steel Structural Tubing ASTM A500 Grade B	25,500	42,000	29.0
Carbon Steel C1010	17,000	28,000	29.0
Elyria Steel Structural Tubing ASTM A370	30,000	50,000	29.0
Acrylic Wood	3,750	4,875	1.8

*Allowable = min. yield × 1.17 − 1.65 (Ref. ASCE and Alum. Assn.)
**Guaranteed by producing manufacturers of Stainless Tubing.

Figure B

Nominal Pipe Size	OD	ID	Thickness	Area	I	S
SCHEDULE 5						
1¼	1.660	1.530	.065	.326	.104	.125
1½	1.900	1.770	.065	.375	.158	.166
SCHEDULE 10						
1¼	1.660	1.442	.109	.531	.161	.193
1½	1.900	1.682	.109	.614	.247	.260
SCHEDULE 40						
1	1.315	1.049	.133	.494	.087	.133
1¼	1.660	1.380	.140	.669	.195	.235
1½	1.900	1.610	.145	.800	.310	.326
2	2.375	2.067	.154	1.075	.666	.561

Figure C

and where post spacing usually varies between 3 feet and 6 feet, load distribution is fairly uniform and the greatest proportion of a concentrated load carried by any one post can be estimated as follows:

End posts:
of a 2 span railing — 85%
of 3 or more spans — 82%

Intermediate posts:
of a 2 span railing — 65%
of 3 or more spans — 60%

Thus, if a 200 lb. concentrated load is specified, actual design load to be applied at the top of the end post is 82% of 200 lbs. or 164 lbs; design load to be applied to intermediate posts is 60% of 200 lbs. or 120 lbs.

Note: If end posts differ from intermediate posts in strength, the load distribution pattern becomes indeterminate and end posts should then be designed to carry 100% of the concentrated load. Intermediate posts may then be designed to the "center loaded" condition.

In single span railings, each post must be designed to carry the full concentrated load.

The stiffness of a rail or post is:

$$k = \frac{E \times I}{L} \text{ for the rail}$$

$$k = \frac{E \times I}{h} \text{ for the post}$$

Stiffness ratio is determined as:

$$R = \frac{k \text{ rail}}{k \text{ post}} = \frac{\frac{E \times I}{L}}{\frac{E \times I}{h}}$$

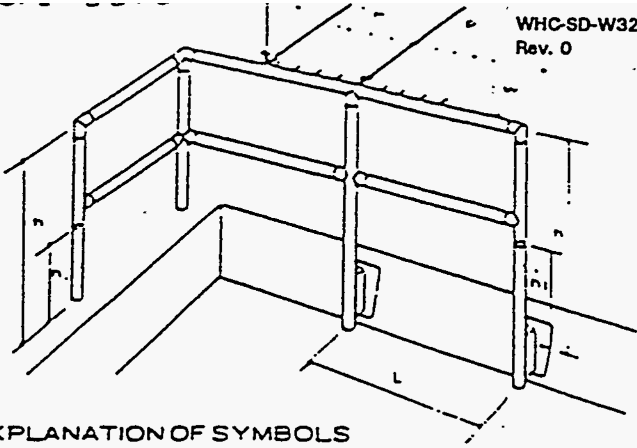
The stiffness ratio (R) is then plotted on a graph to obtain Load Proportion Factor (Pf). (See Figure E). When the load proportion factor has been determined, it is multiplied by the total load to determine the load one post must sustain.

(The Figure E graph has been determined by computer analysis and confirmed by laboratory test.)

Load Tests

In a typical test of a railing designed by the above method, permanent deformation will occur at about twice the design load, and failure will usually occur at about 2½ times the design load.

(continued on next page)

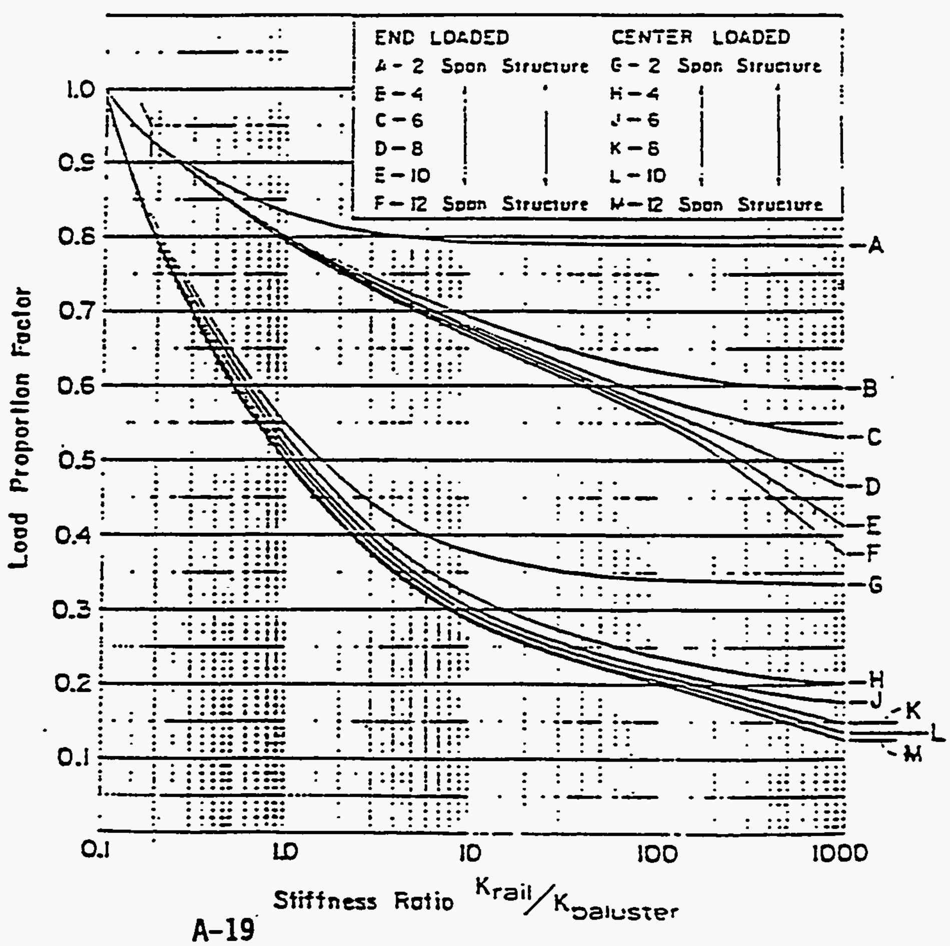


EXPLANATION OF SYMBOLS

- w — Uniform horizontal loading, lbs/ft (perpendicular to the rail).
- L — Span between centerlines of posts, or brackets (inches).
- P — Horizontal force, perpendicular to rail applied at top of post (lbs).
- F_H — Horizontal force, perpendicular to rail at any point along the railing (lbs).
- F_V — Vertical force, perpendicular to rail at any point between posts (lbs).
- h — Height of post. Distance from point of load application above top of attachment (in).
- M — Bending moment (in. lbs.)
- f — Unit stress (psi.)
- f — Allowable fiber stress for design (psi.)
- S_x — Section modulus (in.^{3})
- I_x — Moment of inertia (in.^{4})
- k — Stiffness of member
- K — Bending moment constant
- c — Distance from the neutral axis to the extreme fiber of any section (in.)
- E — Modulus of elasticity (psi.)
- Δ — Deflection (in.)

NOTE: Values for "w" (uniform load in lbs./ft.) are converted to lbs./in. by dividing by 12.

Figure D



Deflection Considerations

Despite an absence of deflection criteria for railings, elastic deflection under load should be considered by the designer. Even though installations meet strength requirements, excessive deflection under load can produce a psychological feeling of structural inadequacy. On the other hand, a certain ductility in the rail helps to absorb the shock of an impact. Where there is no ductility, as in a concrete railing, the shock of an impact is much greater and there is increased risk of a person being injured by a fall against the rail.

In a recent government research project which attempted to determine the impact of a falling human body on a guard rail, ductility of the rail was not considered and the test set-up was of a completely rigid design. Accordingly, the test results showed unreasonably high impact loads and the loading criteria recommended by that agency were far beyond accepted practice and reasonable economics.

The decision of how much elastic deflection is reasonable is left with the designer. Lateral deflection of posts and horizontal or vertical deflection of rails are computed as follows:

For posts:

$$\Delta = \frac{w/12 \times L \times h^3}{3 \times E \times I} \text{ or } \frac{P \times h^3}{3 \times E \times I}$$

For rails:

Concentrated load at center of span:

$$\Delta = \frac{F \times L^3}{48 \times E \times I}$$

Uniform loading:

$$\Delta = \frac{5 \times w/1q \times L^4}{384 \times E \times I}$$

Conclusion

It is important to keep in mind that the engineering calculations apply only to the structural members of the railing itself and that a number of other factors are essential to a safe railing which complies with codes and regulations:

- Connections within the railing, whether welded or mechanical, must be properly designed and executed.
- Ends and changes of direction must be properly supported, avoiding excessive overhang and unsupported turns.
- Mounting hardware, such as brackets, floor flanges and facia flanges must be so designed as to sustain whatever load they may normally be subjected to. Test reports should be available from the manufacturers of these parts.
- Fasteners, used for anchoring must be of the proper size and type for the required loading and must be corrosion resistant if exposed to the elements or to corrosive conditions. The manufacturer of proprietary anchoring devices usually publishes tables of allowable loads and applicable factors of safety.
- The supporting structure must be sound so as to provide proper anchorage for the railing and give it adequate support.

Engineering design is only one phase in the construction of a safe railing. Good workmanship, suitable accessories and proper installation on a sound supporting structure are all essential. Failure in any one of these areas may cause serious problems.