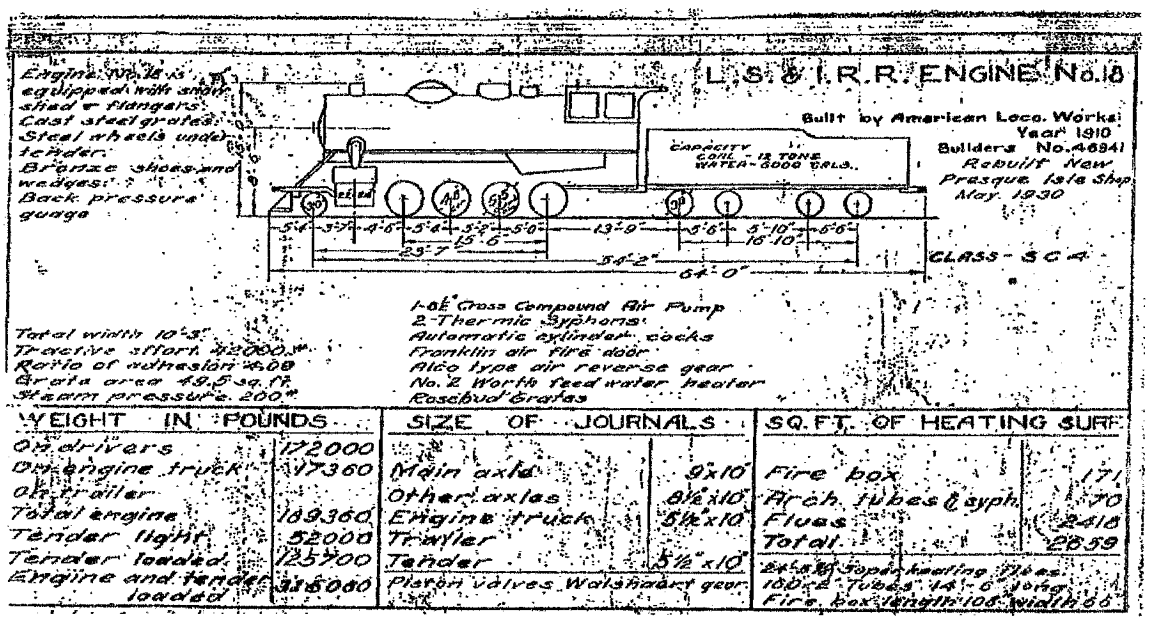
Form 4 and Supporting Engineering Calculations for Fleming Locomotive Company #18



WEIGHT IN POUNDS		SIZE OF JOURNALS		SQ. FT. OF HEATING SURF.	
On drivers	172000				
On engine truck	17360	Main axle	9"x10"	Fire box	171
On trailer		Other axles	8½"x10"	Arch. tubes & syph.	70
Total engine	189360	Engine truck	5½"x10"	Flues	2418
Tender light	52000	Trailer		Total	2659
Tender loaded	125700	Tender	5½"x10"	[illegible] Superheating Flues	
Engine and tender loaded	315060	Piston valves Walshaert gear		180-2" Tubes 14'-6" long	
				Fire box length 108" width 66"	

20 June, 2007

Document Purpose

This document contains the Federal Railroad Administration (FRA) Form 4 for the Fleming Locomotive Company #18. This is in support of the requirements of the Code of Federal Regulations Title 49, Part 230. The document begins with an easy to read summary of the calculations, then presents the official Form 4, then proceeds with the detailed calculations followed by the survey of thicknesses and other geometry measurements, and a tensile strength discussion. Last, is a tutorial on how to recreate this document from individual spreadsheets and other material.

Table of Contents

Summary of Results

The actual calculations are all embodied in an interlocking set of spreadsheets. The "Main" sheet is used to set the desired working pressure and allowed plate tensile strength for all other sheets. This "Main" sheet also pulls all the answers and measurements from the other sheets, and then performs the comparisons. What follows is this summary:

Summary			
WP = working pressure (set here to propagate everywhere)	200 psi		
TS = tensile strength of plate (set here to propagate)	55000 psi		
Minimum Thicknesses	**Calculated**	**Survey**	**Status**
Front Flue Sheet	0.4034 in	0.4560 in	OK
Dry Pipe	0.1785 in	0.2800 in	OK
Tubes - Small	0.0936 in	0.1200 in	OK
Tubes - Large	0.1418 in	0.1500 in	OK
Longitudinal Joints & Seams Course 1	0.5849 in	0.7430 in	OK
Boiler Course Not At Seam Course 1	0.4982 in	0.7430 in	OK
Longitudinal Joints & Seams Course 2	0.5992 in	0.7550 in	OK
Boiler Course Not At Seam Course 2	0.5091 in	0.7550 in	OK
Steam Dome - Cap Dish	0.2257 in	1.2500 in	OK
Steam Dome - Cap Flange	1.1610 in	1.2500 in	OK
Steam Dome - Cylindrical Portion	0.4527 in	0.5050 in	OK
Steam Dome - Manhole Opening Reinforcement	0.5091 in	0.8060 in	OK
Outside Throat Sheet	0.3043 in	0.7410 in	OK
Inside Throat Sheet	0.3043 in	0.3860 in	OK
Rear Flue Sheet	0.2259 in	0.3860 in	OK
Roof Sheet	0.5468 in	0.6430 in	OK
Crown Sheet	0.3162 in	0.3910 in	OK
Side Wrapper Sheet	0.3233 in	0.6200 in	OK
Firebox Side Sheets	0.3360 in	0.3770 in	OK
Door Sheet	0.2965 in	0.3700 in	OK
Backhead	0.2853 in	0.5060 in	OK
Thermic Syphon - Plate	0.3162 in	0.3860 in	OK
Thermic Syphon - Neck	0.0640 in	0.3780 in	OK
Thermic Syphon - Staybolts	0.8871 in	1.0000 in	OK
Throat Sheet Staybolts (flexible)	0.9110 in	1.0000 in	OK
Throat Sheet Staybolts (solid)	0.8871 in	1.0000 in	OK
Side Sheet Staybolts (flexible)	0.9554 in	1.0000 in	OK
Side Sheet Staybolts (solid)	0.9554 in	1.0000 in	OK
Door Sheet Staybolts (flexible)	0.9096 in	1.0000 in	OK
Door Sheet Staybolts (solid)	0.9096 in	1.0000 in	OK
Crown Sheet Staybolts	0.8832 in	1.0020 in	OK

Summary of Results (Continued)

Stresses	Calculated	Maximum	Status
Front Flue Brace (small)	6310 psi	9000 psi	OK
Front Flue Brace (large)	4188 psi	9000 psi	OK
Throat Sheet Braces	2667 psi	9000 psi	OK
Backhead Brace (small)	5581 psi	9000 psi	OK
Backhead Brace (large)	5757 psi	9000 psi	OK
Thermic Syphon - Staybolts	5559 psi	7500 psi	OK
Throat Sheet Staybolts (flexible)	5947 psi	7500 psi	OK
Throat Sheet Staybolts (solid)	5559 psi	7500 psi	OK
Side Sheet Staybolts (flexible)	6700 psi	7500 psi	OK
Side Sheet Staybolts (solid)	6700 psi	7500 psi	OK
Door Sheet Staybolts (flexible)	5924 psi	7500 psi	OK
Door Sheet Staybolts (solid)	5924 psi	7500 psi	OK
Crown Sheet Staybolts	5567 psi	7500 psi	OK
Circumferential Seams	**Calculated SF**	**Required SF**	**Status**
Front (Flue / 1st Course)	27.94	4.00	OK
Middle (1st Course / 2nd Course)	4.51	4.00	OK
Top Steam Dome	7.85	4.00	OK
Bottom Steam Dome	8.21	4.00	OK
Heating Surfaces	**Relief**	**Capacity**	**Status**
Pressure Relief and Steam Generating Capacity	26000 lbs/hr	25486 lbs/hr	OK

FRA Form 4

The next few pages are FRA Form. These Form 4 pages actually exist as a stand alone master file so that they can be modified directly and printed separately, if needed. The version here is automatically pulled from that master file.

FRA Form 4

BOILER SPECIFICATION CARD

Locomotive No. 18 **; Boiler No.** 46941 **; Date built** 1910
Boiler built by: ALCO
Owned by: Brian Fleming
Operated by: Fleming Locomotive Company
Type of boiler: Radial Stayed **; Dome, where located:** On Second Course

BOILER SURVEY DATA

Where **condition** is called for, use: **New** - New material at the time of the boiler survey; **Good** - Little or no wear and/or corrosion; **Fair**- Obvious wear and/or corrosion.

Boiler Shell Sheets

Material:	Type of Material (wrought iron, carbon steel, or alloy steel)	Carbon Content	Condition
1st course (front)	Carbon Steel	(in progress)	Good
2nd course	Carbon Steel	(in progress)	Good
3rd course	n/a	n/a	n/a
Rivets	Steel	n/a	n/a

Documentation of how material was determined shall be attached to this form.

Measurements:		At Seam	Thinnest		
Front flue sheet,	thickness	n/a	0.456”		
1st course,	thickness	0.743”	0.743”	ID 68.5000”	ID 68.5000”
2nd course,	thickness	0.755”	0.755”	ID 70.0000”	ID 70.0000”
3rd course,	thickness	n/a	n/a	ID n/a	ID n/a

When courses are not cylindrical give ID at each end

Is boiler shell circular at all points? Yes

If shell is flattened, state location and amount n/a

Are all flattened areas of shell stayed adequately for the pressure allowed by this form? n/a

Water Space at Mud Ring: Sides 4”, Front 4”, Back 4”
Width of water space at sides of fire box measured at center line of boiler: Front 5 ¾”, Back 6”

Firebox and Wrapper Sheets

Firebox sheets:	Thickness	Material	Condition
Rear flue sheet	0.386”	Carbon Steel	Good
Crown	0.391”	Carbon Steel	Good
Sides	0.377”	Carbon Steel	Good
Door	0.370”	Carbon Steel	Good
Combustion chamber	n/a	n/a	n/a
Inside throat	0.386”	Carbon Steel	Good
Wrapper sheets:			
Throat	0.741”	Carbon Steel	Good
Back head	0.506”	Carbon Steel	Good
Roof	0.643”	Carbon Steel	Good
Sides	0.620”	Carbon Steel	Good

Steam Dome

Dome is made of___ Three ___pieces (not including seam welts, if any), Top opening diameter__ 18.00" ___
Middle cylindrical portion – ID__ 31.13" __, Opening in boiler shell, longitudinally - __ 26.00" ___

Dome sheets:	Thickness	Material	Condition
Base	1.211"	Carbon Steel	Good
Middle cylindrical portion	0.505"	Carbon Steel	Good
Top	1.179"	Carbon Steel	Good
Lid	1.250"	Carbon Steel	New
Boiler shell liner for steam dome opening:	0.806"	Carbon Steel	Good

Is liner part of longitudinal seam?__ No __

Arch Tubes, Flues, Circulators, Thermic Siphons, Water Bar Tubes, Superheaters, and Dry Pipe

Arch tubes: OD__ n/a __, wall thickness__ n/a __; number__ n/a __; condition__ n/a __

Flues:
OD_ 2.0000" _, wall thickness_ 0.120" _, length_ 175.0000" _; number_ 162 _; condition_ new _
OD_ 5.3750" _, wall thickness_ 0.150" _, length_ 175.0000" _; number_ 24 _; condition_ good _
OD_ n/a _, wall thickness_ n/a _, length_ n/a _; number_ n/a _; condition_ n/a _

Circulators: OD__ n/a __, wall thickness__ n/a __; number__ n/a __; condition__ n/a __

Thermic siphons: number__ 2 __; plate thickness_ 0.386" _; condition_ Good _
neck OD_ 8.0000" _, neck thickness_ 0.378" _; condition_ Good _

Water bar tubes: OD__ n/a __, wall thickness__ n/a __

Superheater units directly connected to boiler with no intervening valve:
Type_ n/a _, Tube OD_ n/a _, wall thickness_ n/a _; number_ n/a _; condition_ n/a _

Dry pipe subject to pressure:
OD_ 6.5000" _, wall thickness_ 0.280" _, material_ Steel _; condition_ Good _

Stay Bolts, Crown Bar Rivets, and Braces

Stay bolts:
Smallest crown stay diameter_ 1.002" _, avg. spacing_ 4" _ X _ 4" _; condition_ Good _
Smallest stay bolt diameter_ 1.000" _, avg. spacing_ 4" _ X _ 4" _; condition_ Good _
Smallest combustion chamber stay bolt dia._ n/a _,
avg. Spacing_ n/a _ X _ n/a _; condition_ n/a _

Measurement at smallest diameter

Crown bar bolts & rivets:
Roof sheet rivets, smallest dia._ n/a _, ave. Spacing_ n/a _ X _ n/a _; condition_ n/a _
Roof sheet bolts, smallest dia_ n/a _, ave. spacing_ n/a _ X _ n/a _; condition_ n/a _
Crown sheet rivets, smallest dia._ n/a _, ave. Spacing_ n/a _ X _ n/a _; condition_ n/a _
Crown sheet bolts, smallest dia._ n/a _, ave. Spacing_ n/a _ X _ n/a _;condition_ n/a _

Braces:

	Number	Total Area Stayed	Total Cross Sectional Area of Braces Actual	Equivalent Direct Stay
Backhead	20	1086.05 in sq	38.81 in sq	38.03 in sq
Throat sheet	10	196.00 in sq	18.75 in sq	18.75 in sq
Front tube sheet	20	961.84 in sq	41.04 in sq	40.62 in sq

Safety Valves, Heating Surface, and Grate Area

Safety valves: Total number of safety valves on locomotive 2

Valve Size	Manufacturer	No. valves of this size and manufacture
3 1/2"	Coale	2

Heating Surface:
Heating surface, as part of a circulating system in contact on one side with water or wet steam being heated and on the other side with gas or refractory being cooled, shall be measured on the side receiving heat.

Firebox and Combustion Chamber	171.00	square feet
Flue Sheets (less flue ID areas)	25.87	square feet
Flues	1554	square feet
Circulators	n/a	square feet
Arch Tubes	n/a	square feet
Thermic Siphons	70.00	square feet
Water Bar Tubes	n/a	square feet
Superheaters (front end throttle only)	n/a	square feet
Other	n/a	square feet
Total Heating Surface	1820	square feet

Grate area: 49.9 square feet

Water Level Indicators, Fusible Plugs, and Low Water Alarms

Height of lowest reading of gauge glasses above crown sheet: 4 ½" 4 ½"

Height of lowest reading of gauge cocks above crown sheet: 4.0"

Is boiler equipped with fusible plug(s)? no, number n/a

Is boiler equipped with low water alarm(s)? no, number n/a

Calculations

Staybolt stresses:

Stay bolt under greatest load, maximum stress	5924	psi
Location: Side Sheets		
Crown stay, crown bar rivet, or crown bar bolt under greatest load, max. stress	5567	psi
Location: Uniform		
Combustion chamber stay bolt under greatest load, maximum stress	n/a	psi
Location: n/a		

Braces:

Round or rectangular brace under greatest load, maximum stress	6310	psi
Location: Front Tube Sheet – Small Braces		
Gusset brace under greatest load, maximum stress	n/a	psi
Location: n/a		

Shearing stress on rivets:

Greatest shear stress on rivets in longitudinal seam	6260	psi
Location (course #): Two ; Seam Efficiency: 84.96%		

Boiler shell plate tension:

Greatest tension on net section of plate in longitudinal seam	10913	psi
Location (course #): Two ; Seam Efficiency: 84.96%		

Boiler plate and components, minimum thickness required @ tensile strength:

Front tube sheet	0.4034" @ 55000psi	Rear flue sheet	0.2259" @ 55000psi
1st course at seam	0.5849" @ 55000psi	1st course not at seam	0.4982" @ 55000psi
2nd course at seam	0.5992" @ 55000psi	2nd course not at seam	0.5091" @ 55000psi
3rd course at seam	n/a @ n/a	3rd course not at seam	n/a @ n/a
Roof sheet	0.5468" @ 55000psi	Crown sheet	0.3162" @ 55000psi
Side wrapper sheets	0.3233" @ 55000psi	Firebox side sheets	0.3360" @ 55000psi
Back head	0.2853" @ 55000psi	Door sheet	0.2965" @ 55000psi
Throat sheet	0.3043" @ 55000psi	Inside throat sheet	0.3043" @ 55000psi
Combustion chamber	n/a @ n/a	Dome, top	0.2109" @ 55000psi
Dome, middle	0.4527" @ 55000psi	Dome, base	0.2336" @ 55000psi
Arch tubes	n/a @ n/a	Dome, lid	1.1610" @ 50000psi
Water bar tubes	n/a @ n/a	Thermic siphons	0.3162" @ 50000psi
Dry pipe	0.1785" @ n/a	Circulators	n/a @ n/a

Notes. 1. **If tensile strength used is greater than 50,000 psi for steel or greater than 45,000 psi for wrought iron, supporting documentation must be furnished.**

2. **Any shell dimension less than 1/4" in thickness may not be adequate for support of or by other structures, particularly where threads or staybolts are concerned. Applicable codes should be consulted.**

Boiler Steam Generating Capacity: 25486 pounds per hour

The following may be used as a guide for estimating steaming capacity:

Pounds of Steam Per Hour Per Square Foot of Heating Surface:

Hand fired	8 lbs. per hr.
Stoker fired	10 lbs. per hr.
Oil, gas or pulverized fuel fired	14 lbs. per hr.

Record of Alterations

Description of Alteration	Date of Alteration
Firebox fitted with Nicholson Thermic Syphons. The crown stay spacing given applies to the area outside the syphon openings. The siphons are constructed of 3/8" plate and stayed with 1" diameter hollow staybolts and applied to firebox with welded butt joints. Radial stays with 1-1/16" bodies and 1-1/4" ends are applied thru syphon flanges to roof sheet.	circa 1930

Record of Waivers

Waiver No.	Section No. Affected	Scope and Content of Waiver

Calculations done by:______Jon Brewster______; Verified by:____________________

Data used to verify the foregoing specifications is current and accurate. Based upon the information contained in this document and all necessary calculations, this boiler of Locomotive (Initial & number)___#18___ is safe for a working pressure of___200___psi.

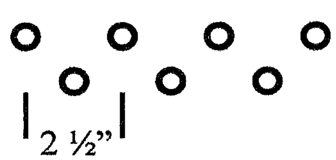
____________________ Date__________; ____________________ Date__________

Locomotive Owner **Locomotive Operator**

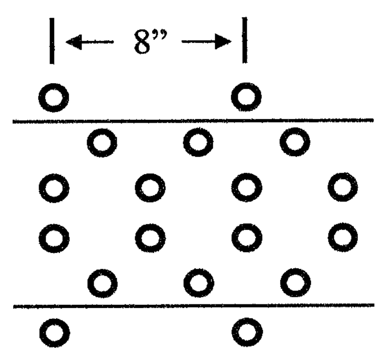
Make working sketch here or attach drawing of longitudinal and circumferential seams used in shell of boiler, indicating on which courses used and give calculated efficiency of weakest longitudinal seam.

Circumferential seam for the front of course 1.

Circumferential seam for course 1 / course 2.



Longitudinal seam for 1st and 2nd Courses. (Steam dome is not involved). 2nd course is weakest at 84.96%.



Calculations

Calculation Approach

The bulk of this document describes the approach used for calculating and filling out the Form 4. In general, this is a four step process:

1. Select the relevant areas of calculation, engineering strategies, and formulas from the many comprehensive and less comprehensive sources. Set the formulas up, and test them.

2. Acquire the engine specific input data to the selected formulas. This is from direct measurement of primary geometries, and examination of specifications and blueprints.

3. Calculate minimum thicknesses, maximum stresses, and maximum pressures.

4. Take a detailed material thickness survey and compare with the calculation results.

We've chosen the formulas and interpretations of them based on reviews of the ESC (Engineering Standards Committee) document, other Form 4 work, and research at the Oregon State University engineering library. We also have access to current and old ASME sections, and a good many individuals who have been involved with locomotive refurbishment.

Direct measurements have been taken for the geometry input to the formulas. However we also have some specifications from the original work.

The following sections are the detailed calculation spreadsheets.

Plate Thicknesses of Flat Stayed Surfaces

Plate Thickness of Flat Stayed Surfaces

Ref. ASME Code, Section III, 1952; L-31

Inputs & Basics

Tmin = p x SQRT(WP / C)
However the output is in sixteenths of an inch, so divide answers by 16

WP = max. allowable working pressure	200 psi	desired
C = 125 for stays screw through plates not over 7/16" in thickness with ends riveted over.	125	
C = 135 for stays screw through plates over 7/16" in thickness with ends riveted over.	135	
C = 150 for stays screwed through plates and fitted with single nuts outside of plate.	150	
C = 165 for stays with heads not less than 1.3 times the diameter of the stays, screwed through plates or made a taper fit and having the heads formed on the stays before installing them and not riveted over, said heads being made to have a true bearing on the plate.	165	

Note: If stays are welded, the code of original construction should be consulted for formulas and factors.

Unique to FLUE SHEETS:

ref ASME Section 1, 1971
PFT-30.2 Stays shall be used in the tube sheets of a firetube boiler if the distance between the edges of the tube holes exceeds the maximum pitch of staybolts for the corresponding plate thickness and pressure given in PG-46.

(Note that pitch for flue sheets is edge of tube to edge tube not center to center.)

C = 112 for stays screwed thru plates less than 7/16" riveted over	112
C = 120 for stays screwed thru plates over 7/16" riveted over	120

Plate Thicknesses of Flat Stayed Surfaces (Continued)

Calculate Minimum Plate Thickness

Front Flue Sheet: (look at pitch between brace points as well)	spec'd thickness	0.5000 in	
	selected C	120	flue sheet
	pitch p	5.0000 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.4034 in	
Outside Throat Sheet:	spec'd thickness	0.7500 in	
	selected C	135	
	pitch p	4.0000 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.3043 in	
Inside Throat Sheet:	spec'd thickness	0.5000 in	
	selected C	135	
	pitch p	4.0000 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.3043 in	
Rear Flue Sheet:	spec'd thickness	0.5000 in	
	selected C	120	flue sheet
	pitch p	2.8000 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.2259 in	
Crown Sheet:	spec'd thickness	0.3750 in	
	selected C	125	
	pitch p	4.0000 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.3162 in	
Side Wrapper Sheets:	spec'd thickness	0.6250 in	
	selected C	135	
	pitch p	4.2500 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.3233 in	
Firebox Side Sheets	spec'd thickness	0.3750 in	
	selected C	125	
	pitch p	4.2500 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.3360 in	
Thermic Syphon Plate	spec'd thickness	0.3750 in	
	selected C	125	
	pitch p	4.0000 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.3162 in	
Door Sheet	spec'd thickness	0.3750 in	
	selected C	125	
	pitch p	3.7500 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.2965 in	
Backhead (look at pitch between brace points as well)	spec'd thickness	0.5625 in	
	selected C	135	
	pitch p	3.7500 in	measured
	*Tmin = p * SQRT(WP / C) / 16*	0.2853 in	

Diagonal Braces – Front Flue Sheet

Front Flue Sheet Brace Calculations

The load on each individual stay shall be determined by the area supported by that stay. The overall area of the sheet will be calculated then the stress on each brace will be determined by analyzing relative percentages of area held by each stay size using smallest measured cross sections.

P = max. allowable working pressure	200 psi	desired

Area to be stayed

ref. ASME Code Section 1, 1971

PFT - 31.1 The area of a segment of a flanged head to be stayed shall be the area enclosed by lines drawn 2 in. from the tubes and a distance d from the shell. The value of d used may be the larger of the following values:

d = the outer radius of the flange	1.7500 in	measured
not exceeding 8 times the thickness of the head = 8t	3.6480 in	
d = ***80t / SQRT(P)***	2.5795 in	
where d = unstayed distance from shell		
t = thickness of head	0.4560 in	linked to survey

PFT - 31.2 The area of a segment of a flanged head to be stayed shall be the area enclosed by the shell and a line drawn 2 in. from the tubes

$$A = 4(H - d - 2)^2 / 3 * SQRT(2(R-d) / (H-d-2) - .608)$$

PFT - 31.3.2 Net area to be stayed in segment of unflanged head:

$$A = 4(H - 2)^2 / 3 * SQRT((2R) / (H-2) - .608)$$

d = zero for unflanged heads (input 0, or force a d by inputting any value, else "n/a" for flanged d above)	n/a in	flanged
H = distance from tubes to shell	26.4000 in	mean
R = radius of boiler head	34.2500 in	linked to survey
d = distance determined from PFT - 31.1, and PFT - 31.3.2	2.5795 in	
A = area to be stayed from PFT - 31.1, and PFT - 31.3.2	961.70 in^2	
dd = diameter of dry pipe through flue sheet	6.5000 in	measured
AH = half the area (one side) to be braced = $(A - pi*dd^2 / 4) / 2$	464.26 in^2	

True formula for "Segment" (implement with h = H-2-d, and R = R - d to account for offset above tubes, and inward from shell).

$AT = R^2 \cos^{-1}\left(\frac{R-h}{R}\right) - (R-h)\sqrt{2Rh - h^2}$	961.84 in^2	
ATH = half the area (one side) to be braced = $(AT - pi*dd^2 / 4) / 2$	464.33 in^2	

Diagonal Braces – Front Flue Sheet (Continued)

Stress on Braces

Determine the area, supported by each size brace. Multiply this area by the maximum allowable working pressure. Divide this by the smallest measured cross sectional, in square inches, of the brace supporting the section of plate considered. The result will be the stress in pounds per square inch on the brace. Divide by Cos of the angle to get true stress. This stress must not exceed **9,000 psi**.

Small Braces

bd = smallest measured brace diameter	1.2500 in	linked to survey
pl = percent load carried by this size brace	25 %	measured
n = number of this size brace on one side	3	actual
ba = brace angle	2 deg	actual
a = cross sectional area of single brace = ***pi * bd² / 4***	1.23 in^2	
As = area supported by single brace = ***AH * (pl / 100) / n***	38.69 in^2	
S = stress on straight brace = ***P * As / a***	6305 psi	
Sba = stress with angle, not to exceed 9,000 psi = ***S / Cos(ba)***	6309 psi	
ATs = area supported by single brace = ***ATH * (pl/100) / n***	38.69 in^2	
ST = stress on straight brace = ***P * ATs / a***	6306 psi	
STba = stress with angle, not to exceed 9,000 psi = ***ST / Cos(ba)***	6310 psi	

Large Braces

bd = smallest measured brace diameter	1.7500 in	linked to survey
pl = percent load carried by this size brace	75 %	measured
n = number of this size brace on one side	7	actual
ba = brace angle	9 deg	actual
a = cross sectional area of single brace = ***pi * bd² / 4***	2.41 in^2	
As = area supported by single brace = ***AH * (pl / 100) / n***	49.74 in^2	
S = stress on straight brace = ***P * As / a***	4136 psi	
Sba = stress with angle, not to exceed 9,000 psi = ***S / Cos(ba)***	4188 psi	
ATs = area supported by single brace = ***ATH * (pl / 100) / n***	49.75 in^2	
ST = stress on straight brace = ***P * ATs / a***	4137 psi	
STba = stress with angle, not to exceed 9,000 psi = ***ST / Cos(ba)***	4188 psi	

Additional Form 4 Entries

total number of stays	20
total actual area of brace	41.04 in^2
total equivalent direct stay (apply Cos ba to each of the above)	40.62 in^2

Dry Pipe

Dry Pipe Calculations

The following applies to steel dry pipes with dome type throttles that are subjected to external pressure when the throttle is closed

Inputs

WP = working pressure	200 psi	desired
t = thickness of the wall	0.2800 in	linked to survey
D = outside diameter of pipe	6.5000 in	linked to survey

Calculate Maximum Allowable Working Pressure

ref. ASME Code Section 1, 1971

PFT - 15 The maximum allowable working pressure for seamless or welded flues (dry pipes) over 5 in. in diameter, and including 18 in. in diameter, shall be determined by one of the following formulas:

0.023 * D (used below to test which equation to use)	0.1495 in
15.1 Where the thickness of the wall is not greater than 0.023 times the diameter	
$MAWP = (10{,}000{,}000 * t^3) / D^3$	N/A psi
15.2 Where the thickness of the wall is greater than 0.023 times the diameter	
$MAWP = (17{,}300 * t) / D - 275$	470 psi
MAWP selected from above	470 psi

Calculate Minimum Thickness at Working Pressure

Back solve 15.1 Where the thickness of the wall is not greater than 0.023 times the diameter	
$Tmin = (P * D^3 / 10{,}000{,}000)^{1/3}$	N/A in
Back solve 15.2 Where the thickness of the wall is greater than 0.023 times the diameter	
$Tmin = (P + 275) * D / 17{,}300$	0.1785 in
Tmin selected from above	0.1785 in

Tubes

Tube Calculations - Small Tubes

Formulas from 1952 ASME Section III

Inputs

WP = working pressure	200 psi	desired
D = outside diameter of pipe	2.0000 in	linked to survey
t = thickness of the wall	0.1200 in	linked to survey
E = efficiency	85.00%	for welded tubes

Calculations

Maximum Allowable Working Pressure ***MAWP = 14,000 x (t - 0.065) / D***	385 psi
Minimum Wall Thickness ***Tmin = (D x WP / 14,000) + 0.065***	0.0936 in

Tube Calculations - Large Tubes

Formulas from 1952 ASME Section III

Inputs

WP = working pressure	200 psi	desired
D = outside diameter of pipe	5.3750 in	linked to survey
t = design thickness of the wall	0.1500 in	linked to survey
E = efficiency	85.00%	for welded tubes

Calculations

Maximum Allowable Working Pressure ***MAWP = 14,000 x (t - 0.065) / D***	221 psi
Minimum Wall Thickness ***Tmin = (D x WP / 14,000) + 0.065***	0.1418 in

Circumferential Joints & Seams – Flue Sheet / 1^{st} Course

Circumferential Joints & Seams - Flue Sheet / 1st Course

Inputs & Basics

WP = working pressure	200 psi	desired
t= thickness of thinner shell plate	0.7430 in	linked to survey
TS = tensile strength of plate	55000 psi	attested
tfs = thickness of flue sheet	0.4560 in	linked to survey
d = dia. Of rivet hole = driven rivet dia.	1.0000 in	
c = crush strength of plate	95000 psi	from ASME code
nl = total number of rivets in one row in single shear	110	counted
nt = total number of rivets in entire seam in single shear	110	counted
D = inside diameter of larger shell course	68.5000 in	linked to survey
CP = circumference of larger shell I.D. = ***D * pi***	215.20 in	
F = total longitudinal force = ***WP * D^2 * pi / 4***	737057 lbs	
a = cross sectional area of driven rivet = ***d^2 * pi / 4***	0.7854 in^2	
s= shear strength rivet in single shear = ***a * 44000*** (rivet tensile strength of 44,000 psi)	34558 psi	

Rivet Shear, Bearing Stress, Plate Tension

AR = cross sect. Area of rivets in shear entire seam = nt x a	86.39 in^2
SR = rivet shear stress = F/AR	8531 psi
RR = total bearing area of rivets in entire seam (substitute tfs for t when tfs<t and)	50.16 in^2
nt x d x t	81.73 in^2
nt x d x tfs	50.16 in^2
RB = Rivet Bearing Stress = ***F / RR***	14694 psi
PT = plate tension = ***F / (CP * t * E')***	9430 psi

Strength of Seam

ref. From 1971 ASME Sect. I, A-2 & A-3 Lap Joint

A = strength of solid plate = ***CP * t * TS***	8794111 lbs
B = strength of plate between rivet holes in 1 row = ***[CP - (d * n1)] * t * TS***	4298961 lbs
C = shear strength all rivets in single shear = ***nt * s * a***	2985555 lbs
D = crush strength of plate in front of all rivets (substitute tfs for t when tfs < t)	4765200 lbs
nt * d * t * c	7764350 lbs
nt * d * tfs * c	4765200 lbs
SC = minimum strength of entire seam = A, B, Ç, or D whichever is least	2985555 lbs

Divided B, C, or D (whichever is least) by A, and the quotient will be the efficiency

E= efficiency of circumferential seam lap Joint	33.95%
E' = lowest efficiency of seam considering ***plate tearing only*** = ***B / A***	48.88%

Factor of Safety

ref. 1971 ASME Sect. I, PR-17

R = inside radius of boiler course at circumferential seam = ***D / 2***	34.25 in^2	
F = total longitudinal force on circumferential seam = ***pi * R^2 * WP***	737057 lbs	
SF = strength factor = ***SC / F***	4.05	
SCn = minimum strength of circumferential seam required by FRA for a safety factor of 4 without considering the reduction of area or holding of flues and tubes = ***F x 4***	2948228 lbs	
Calculate total area of tube sheet supported by tube pack by describing a line 2 inches from the outside edge of the tube pack and completely surrounding the tube pack. Solve for the area inside this line, re. 1952 ASME Sect. III, L-44		
Atp = area of sheet supported by flues and/or braces, sq. in.	3151 in^2	survey&brace calcs
TA = total area of tube sheet, sq. in.	3685 in^2	
If area supported by tube pack is 50% or more of (***pi x R^2***) then the minimum strength of the circumferential seam must be at least 70% of SCn		
F1 = Force supported by the seam with flues	106842 lbs	
FS = Factor of Safety = ***SC/F1*** (considers support of tube pack and braces if appropriate)	27.94	

Longitudinal Joints & Seams – 1st Course

Longitudinal Joints & Seams - Course 1 (Front Course)

Inputs & Basics

WP = working pressure	200 psi	desired
TS = tensile strength of plate	55000 psi	attested
t = thickness of plate	0.7430 in	min near seam
b = thickness of thinnest (and usually wider, inner) buttstrap	0.6120 in	linked to survey
w = thickness of outer (usually thicker, and narrow) buttstrap	0.6150 in	linked to survey
P = pitch of rivets, row with greatest pitch	8.0000 in	measured
d = diameter of rivet hole = driven rivet diameter		
single shear	1.1250 in	measured
double shear	1.1250 in	measured
a = cross sectional area of driven rivet = $d^2 * pi / 4$		
single shear	0.9940 in^2	
double shear	0.9940 in^2	
s = shear strength of rivet in single shear = ***a * 44000*** (rivet tensile strength 44,000)	43737 psi	
S = shear strength of rivet in double shear = ***a * 44000*** (rivet tensile strength 44,000)	87474 psi	
n = number of rivets single shear unit length of joint	1	actual
N = number of rivets double shear unit length of joint	4	actual
AR = total cross sect. Area of rivets in pitch P of seam subjected to shear stress	8.9462 in^2	
RR = total area of rivets in pitch P of seam subjected to bearing stress	4.0320 in^2	
D = largest inside diameter of shell course	68.5000 in	linked to survey
c = crush strength of plate	95000 psi	ASME code

Butt and Double Strap Joint Double Riveted Seam Efficiency

REF. 1971 ASME CODE SECT. I
ref. A-6, page 9, Form 4 calc. Booklet

A = strength of solid plate = ***P x t x TS***	326920 lbs
B = strength of plate between rivet holes outer row = ***(P-d) x t x TS***	280947 lbs
C = shearing strength of two rivets in double shear, plus the shearing strength of one rivet in single shear	391278 lbs
D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row	278449 lbs
E = strength of plate between rivet holes in the second row, plus the crushing strength of buttstrap in front of one rivet in the outer row	300381 lbs
F = crushing strength of plate in front of two rivets, plus the crushing strength of buttstrap in front of one rivet	383040 lbs
G = crushing strength of plate in front of two rivets, plus the shearing strength of one rivet in single shear	361108 lbs
H = strength of buttstraps between rivet holes in the inner row	388039 lbs

Divide B,C,D,E,F,G,or H (whichever is the least) by A, and the quotient will be the efficiency of a butt- and double-strap joint, double riveted.

E = lowest efficiency of longitudinal joint	85.17%
Ept = efficiency where plate tearing is a consideration = A divided by the least of B, D, E, or H	85.17%

Longitudinal Joints & Seams – 1st Course (Continued)

Calculate the Key Values

Plate tension at design pressure and thickness ***PT = (WP * D) / (2 * Ept * t)***	10824 lbs
Maximum allowable working pressure at design thickness, and FS set to 4 ***MAWP = (TS * t * E) / (D/2 * FS)***	254 psi
Factor of Safety at design thickness and pressure ***FS = (TS x t x E) / (D/2 x WP)***	5.08
Minimum Thickness at working pressure and safety factor of 4 ***Tmin = (WP * D * FS) / (2 * TS * E)***	0.5849 in
Rivet shear stress ***SR = (D x WP x P) / (AR * 2)***	6126 psi
Rivet bearing stress ***RB = (D x WP x P) / (RR * 2)***	13591 psi

Boiler Courses Not at Seams – 1^{st} Course

Boiler Courses Not At Seams - 1st Course (Front Course)

Ref. ASME 1952 Section III, L 21
The maximum allowable working pressure on the shell of a boiler shall be determined by the strength of the weakest course, computed from the thickness of the plate, the tensile strength…,the efficiency of the longitudinal joint, the inside diameter of the course, and the factor of safety.

Inputs

WP = working pressure	200 psi	desired
TS = tensile strength of plate	55000 psi	attested
t = thickness of shell plates	0.7430 in	linked to survey
E = efficiency	100.00%	no seam
R = inside radius of shell	34.2500 in	large end
FS = minimum required Factor of Safety	4.00	minimum

Calculations

Calculate Maximum Working Pressure ***MAWP = (TS x t x E) / R x FS***	298 psi
Minimum shell thickness required for Factor of Safety ***Tmin = WP x R x FS / (TS x E)***	0.4982 in
Plate Tension at Working Pressure ***PT = (WP x R) / (E x t)***	9219 psi
Factor of Safety at Working Pressure ***FS = (TS x t x E) / (R x WP)***	5.97

Circumferential Joints & Seams – 1st Course / 2nd Course

Circumferential Joints & Seams - 1st Course / 2nd Course

Inputs & Basics

WP = working pressure	200 psi	desired
t= thickness of thinner shell plate	0.7430 in	calc'd from links
TS = tensile strength of plate	55000 psi	attested
tfs = thickness of flue sheet	0.0000 in	none
d = dia. Of rivet hole = driven rivet dia.	1.0000 in	
c = crush strength of plate	95000 psi	from ASME code
nl = total number of rivets in one row in single shear	64	counted
nt = total number of rivets in entire seam in single shear	128	counted
D = inside diameter of larger shell course	70.0000 in	linked to survey
CP = circumference of larger shell I.D. = ***D * pi***	219.91 in	
F = total longitudinal force = ***WP * D^2 * pi / 4***	769690 lbs	
a = cross sectional area of driven rivet = ***d^2 * pi / 4***	0.7854 in^2	
s= shear strength rivet in single shear = ***a * 44000*** (rivet tensile strength of 44,000 psi)	34558 psi	

Rivet Shear, Bearing Stress, Plate Tension

AR = cross sect. Area of rivets in shear entire seam = nt x a	100.53 in^2	
SR = rivet shear stress = F/AR	7656 psi	
RR = total bearing area of rivets in entire seam (substitute tfs for t when tfs<t and)	95.10 in^2	
nt x d x t	95.10 in^2	
nt x d x tfs	0.00 in^2	
RB = Rivet Bearing Stress = ***F / RR***	8093 psi	
PT = plate tension = ***F / (CP * t * E')***	6644 psi	

Strength of Seam

ref. From 1971 ASME Sect. I, A-2 & A-3 Lap Joint

A = strength of solid plate = ***CP * t * TS***	8986683 lbs	
B = strength of plate between rivet holes in 1 row = ***[CP - (d * n1)] * t * TS***	6371323 lbs	
C = shear strength all rivets in single shear = ***nt * s * a***	3474101 lbs	
D = crush strength of plate in front of all rivets (substitute tfs for t when tfs < t)	9034880 lbs	
nt * d * t * c	9034880 lbs	
nt * d * tfs * c	0 lbs	
SC = minimum strength of entire seam = A, B, C, or D whichever is least	3474101 lbs	

Divided B, C, or D (whichever is least) by A, and the quotient will be the efficiency

E= efficiency of circumferential seam lap Joint	38.66%	
E' = lowest efficiency of seam considering ***plate tearing only*** = ***B / A***	70.90%	

Factor of Safety

ref. 1971 ASME Sect. I, PR-17

R = inside radius of boiler course at circumferential seam = ***D / 2***	35.00 in^2	
F = total longitudinal force on circumferential seam = ***pi * R^2 * WP***	769690 lbs	
SF = strength factor = ***SC / F***	4.51	
SCn = minimum strength of circumferential seam required by FRA for a safety factor of 4 without considering the reduction of area or holding of flues and tubes = ***F x 4***	3078761 lbs	

Calculate total area of tube sheet supported by tube pack by describing a line 2 inches from the outside edge of the tube pack and completely surrounding the tube pack. Solve for the area inside this line, re. 1952 ASME Sect. III, L-44

Atp = area of sheet supported by flues and/or braces, sq. in.	0.00 in^2	no sheet
TA = total area of tube sheet, sq. in.	3848 in^2	

If area supported by tube pack is 50% or more of (***pi x R^2***) then the minimum strength of the circumferential seam must be at least 70% of SCn

F1 = Force supported by the seam with flues	769690 lbs	
FS = Factor of Safety = ***SC/F1*** (considers support of tube pack and braces if appropriate)	4.51	

Longitudinal Joints & Seams – 2nd Course

Longitudinal Joints & Seams - Course 2 (Dome Course)

Inputs & Basics

WP = working pressure	200 psi	desired
TS = tensile strength of plate	55000 psi	attested
t = thickness of plate	0.7550 in	min near seam
b = thickness of thinnest (and usually wider, inner) buttstrap	0.6120 in	linked to survey
w = thickness of outer (usually thicker, and narrow) buttstrap	0.6220 in	linked to survey
P = pitch of rivets, row with greatest pitch	8.0000 in	measured
d = diameter of rivet hole = driven rivet diameter		
single shear	1.1250 in	measured
double shear	1.1250 in	measured
a = cross sectional area of driven rivet = ***d^2 * pi / 4***		
single shear	0.9940 in^2	
double shear	0.9940 in^2	
s = shear strength of rivet in single shear = ***a * 44000*** (rivet tensile strength 44,000)	43737 psi	
S = shear strength of rivet in double shear = ***a * 44000*** (rivet tensile strength 44,000)	87474 psi	
n = number of rivets single shear unit length of joint	1	actual
N = number of rivets double shear unit length of joint	4	actual
AR = total cross sect. Area of rivets in pitch P of seam subjected to shear stress	8.9462 in^2	
RR = total area of rivets in pitch P of seam subjected to bearing stress	4.0860 in^2	
D = largest inside diameter of shell course	70.0000 in	linked to survey
c = crush strength of plate	95000 psi	ASME code

Butt and Double Strap Joint Double Riveted Seam Efficiency

REF. 1971 ASME CODE SECT. I
ref. A-6, page 9, Form 4 calc. Booklet

A = strength of solid plate = ***P x t x TS***	332200 lbs
B = strength of plate between rivet holes outer row = ***(P-d) x t x TS***	285484 lbs
C = shearing strength of two rivets in double shear, plus the shearing strength of one rivet in single shear	391278 lbs
D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row	282244 lbs
E = strength of plate between rivet holes in the second row, plus the crushing strength of buttstrap in front of one rivet in the outer row	304176 lbs
F = crushing strength of plate in front of two rivets, plus the crushing strength of buttstrap in front of one rivet	388170 lbs
G = crushing strength of plate in front of two rivets, plus the shearing strength of one rivet in single shear	366238 lbs
H = strength of buttstraps between rivet holes in the inner row	390253 lbs

Divide B,C,D,E,F,G,or H (whichever is the least) by A, and the quotient will be the efficiency of a butt- and double-strap joint, double riveted.

E = lowest efficiency of longitudinal joint — 84.96%

Ept = efficiency where plate tearing is a consideration = A divided by the least of B, D, E, or H — 84.96%

Longitudinal Joints & Seams – 2nd Course (Continued)

Calculate the Key Values

Plate tension at design pressure and thickness ***PT = (WP * D) / (2 * Ept * t)***	10913 lbs
Maximum allowable working pressure at design thickness, and FS set to 4 ***MAWP = (TS * t * E) / (D/2 * FS)***	252 psi
Factor of Safety at design thickness and pressure ***FS = (TS x t x E) / (D/2 x WP)***	5.04
Minimum Thickness at working pressure and safety factor of 4 ***Tmin = (WP * D * FS) / (2 * TS * E)***	0.5992 in
Rivet shear stress ***SR = (D x WP x P) / (AR * 2)***	6260 psi
Rivet bearing stress ***RB = (D x WP x P) / (RR * 2)***	13705 psi

Boiler Courses Not at Seams – 2nd Course

Boiler Courses Not At Seams - 2nd Course (Dome Course)

Ref. ASME 1952 Section III, L 21
The maximum allowable working pressure on the shell of a boiler shall be determined by the strength of the weakest course, computed from the thickness of the plate, the tensile strength…,the efficiency of the longitudinal joint, the inside diameter of the course, and the factor of safety.

Inputs

WP = working pressure	200 psi	desired
TS = tensile strength of plate	55000 psi	attested
t = thickness of shell plates	0.7550 in	linked to survey
E = efficiency	100.00%	no seam
R = inside radius of shell	35.0000 in	linked to survey
FS = minimum required Factor of Safety	4.00	minimum

Calculations

Calculate Maximum Working Pressure ***MAWP = (TS x t x E) / R x FS***	297 psi
Minimum shell thickness required for Factor of Safety ***Tmin = WP x R x FS / (TS x E)***	0.5091 in
Plate Tension at Working Pressure ***PT = (WP x R) / (E x t)***	9272 psi
Factor of Safety at Working Pressure ***FS = (TS x t x E) / (R x WP)***	5.93

Circumferential Joints & Seams – Dome Top

Circumferential Joints & Seams - Dome Top Seam

Inputs & Basics

WP = working pressure	200 psi	desired
t= thickness of thinner shell plate	0.5050 in	calc'd from links
TS = tensile strength of plate	55000 psi	attested
tfs = thickness of flue sheet	0.0000 in	none
d = dia. Of rivet hole = driven rivet dia.	1.0000 in	measured
c = crush strength of plate	95000 psi	from ASME code
nl = total number of rivets in one row in single shear	44	counted
nt = total number of rivets in entire seam in single shear	44	counted
D = inside diameter of larger course	31.1250 in	linked to survey
CP = circumference of larger shell I.D. = ***D * pi***	97.78 in	
F = total longitudinal force = $WP * D^2 * pi / 4$	152173 lbs	
a = cross sectional area of driven rivet = $d^2 * pi / 4$	0.7854 in^2	
s= shear strength rivet in single shear = ***a * 44000*** (rivet tensile strength of 44,000 psi)	34558 psi	

Rivet Shear, Bearing Stress, Plate Tension

AR = cross sect. Area of rivets in shear entire seam = nt x a	34.56 in^2
SR = rivet shear stress = F/AR	4403 psi
RR = total bearing area of rivets in entire seam (substitute tfs for t when tfs<t and)	22.22 in^2
nt x d x t	22.22 in^2
nt x d x tfs	0.00 in^2
RB = Rivet Bearing Stress = ***F / RR***	6848 psi
PT = plate tension = ***F / (CP * t * E')***	5603 psi

Strength of Seam

ref. From 1971 ASME Sect. I, A-2 & A-3 Lap Joint

A = strength of solid plate = ***CP * t * TS***	2715897 lbs
B = strength of plate between rivet holes in 1 row = ***[CP - (d * n1)] * t * TS***	1493797 lbs
C = shear strength all rivets in single shear = ***nt * s * a***	1194222 lbs
D = crush strength of plate in front of all rivets (substitute tfs for t when tfs < t)	2110900 lbs
nt * d * t * c	2110900 lbs
nt * d * tfs * c	0 lbs
SC = minimum strength of entire seam = A, B, C, or D whichever is least	1194222 lbs

Divided B, C, or D (whichever is least) by A, and the quotient will be the efficiency

E= efficiency of circumferential seam lap Joint	43.97%
E' = lowest efficiency of seam considering ***plate tearing only = B / A***	55.00%

Factor of Safety

ref. 1971 ASME Sect. I, PR-17

R = inside radius of boiler course at circumferential seam = ***D / 2***	15.56 in^2	
F = total longitudinal force on circumferential seam = $pi * R^2 * WP$	152173 lbs	
SF = strength factor = ***SC / F***	7.85	
SCn = minimum strength of circumferential seam required by FRA for a safety factor of 4 without considering the reduction of area or holding of flues and tubes = ***F x 4***	608693 lbs	
Calculate total area of tube sheet supported by tube pack by describing a line 2 inches from the outside edge of the tube pack and completely surrounding the tube pack. Solve for the area inside this line, re. 1952 ASME Sect. III, L-44		
Atp = area of sheet supported by flues and/or braces, sq. in.	0.00 in^2	no sheet
TA = total area of tube sheet, sq. in.	761 in^2	
If area supported by tube pack is 50% or more of ($pi \times R^2$) then the minimum strength of the circumferential seam must be at least 70% of SCn		
F1 = Force supported by the seam with flues	152173 lbs	
FS = Factor of Safety = ***SC/F1*** (considers support of tube pack and braces if appropriate)	7.85	

Circumferential Joints & Seams – Dome Bottom

Circumferential Joints & Seams - Dome Bottom Seam

Inputs & Basics

WP = working pressure	200 psi	desired
t= thickness of thinner shell plate	0.5050 in	calc'd from links
TS = tensile strength of plate	55000 psi	attested
tfs = thickness of flue sheet	0.0000 in	none
d = dia. Of rivet hole = driven rivet dia.	1.0000 in	measured
c = crush strength of plate	95000 psi	from ASME code
nl = total number of rivets in one row in single shear	53	counted
nt = total number of rivets in entire seam in single shear	53	counted
D = inside diameter of larger course	32.1250 in	linked to survey
CP = circumference of larger shell I.D. = ***D * pi***	100.92 in	
F = total longitudinal force = ***WP * D^2 * pi / 4***	162109 lbs	
a = cross sectional area of driven rivet = ***d^2 * pi / 4***	0.7854 in^2	
s= shear strength rivet in single shear = ***a * 44000*** (rivet tensile strength of 44,000 psi)	34558 psi	

Rivet Shear, Bearing Stress, Plate Tension

AR = cross sect. Area of rivets in shear entire seam = nt x a	41.63 in^2	
SR = rivet shear stress = F/AR	3894 psi	
RR = total bearing area of rivets in entire seam (substitute tfs for t when tfs<t and)	26.77 in^2	
nt x d x t	26.77 in^2	
nt x d x tfs	0.00 in^2	
RB = Rivet Bearing Stress = ***F / RR***	6057 psi	
PT = plate tension = ***F / (CP * t * E')***	6698 psi	

Strength of Seam

ref. From 1971 ASME Sect. I, A-2 & A-3 Lap Joint

A = strength of solid plate = ***CP * t * TS***	2803155 lbs	
B = strength of plate between rivet holes in 1 row = ***[CP - (d * n1)] * t * TS***	1331080 lbs	
C = shear strength all rivets in single shear = ***nt * s * a***	1438495 lbs	
D = crush strength of plate in front of all rivets (substitute tfs for t when tfs < t)	2542675 lbs	
nt * d * t * c	2542675 lbs	
nt * d * tfs * c	0 lbs	
SC = minimum strength of entire seam = A, B, C, or D whichever is least	1331080 lbs	

Divided B, C, or D (whichever is least) by A, and the quotient will be the efficiency

E= efficiency of circumferential seam lap Joint	47.49%	
E' = lowest efficiency of seam considering ***plate tearing only*** = ***B / A***	47.49%	

Factor of Safety

ref. 1971 ASME Sect. I, PR-17

R = inside radius of boiler course at circumferential seam = ***D / 2***	16.06 in^2	
F = total longitudinal force on circumferential seam = ***pi * R^2 * WP***	162109 lbs	
SF = strength factor = ***SC / F***	8.21	
SCn = minimum strength of circumferential seam required by FRA for a safety factor of 4 without considering the reduction of area or holding of flues and tubes = ***F x 4***	648435 lbs	
Calculate total area of tube sheet supported by tube pack by describing a line 2 inches from the outside edge of the tube pack and completely surrounding the tube pack. Solve for the area inside this line, re. 1952 ASME Sect. III, L-44		
Atp = area of sheet supported by flues and/or braces, sq. in.	0.00 in^2	no sheet
TA = total area of tube sheet, sq. in.	811 in^2	
If area supported by tube pack is 50% or more of (***pi x R^2***) then the minimum strength of the circumferential seam must be at least 70% of SCn		
F1 = Force supported by the seam with flues	162109 lbs	
FS = Factor of Safety = ***SC/F1*** (considers support of tube pack and braces if appropriate)	8.21	

Longitudinal Joints & Seams – Steam Dome

Longitudinal Joints & Seams - Dome

Inputs & Basics

WP = working pressure	200 psi	desired
TS = tensile strength of plate	55000 psi	attested
t = thickness of plate	0.5050 in	min near seam
P = pitch of rivets	2.2500 in	measured
d = diameter of rivet hole = driven rivet diameter	1.1250 in	measured
a = cross sectional area of driven rivet = ***d^2 * pi / 4***	0.9940 in^2	
s = shear strength of rivet in single shear = ***a * 44000*** (rivet tensile strength 44,000)	43737 psi	
n = number of rivets in single shear per unit length of joint	1	actual
N = number of rivets double shear unit length of joint	0	actual
AR = total cross sect. Area of rivets in pitch P of seam subjected to shear stress	0.9940 in^2	
D = largest inside diameter of shell course	31.1250 in	linked to survey
c = crush strength of plate	95000 psi	ASME code

Lap Joint Longitudinal Single Riveted Seam Efficiency

REF. 1971 ASME CODE SECT. I

A = strength of solid plate = ***P x t x TS***	62494 lbs
B = strength of plate between rivet holes outer row = ***(P-d) x t x TS***	31247 lbs
C = shearing strength of one rivet in single shear = ***n x s x a***	43475 lbs
D = crush strength of plate in front of 1 rivet = ***d x t x c***	53972 lbs

Divide B,C,or D (whichever is the least) by A, and the quotient will be the efficiency of a single riveted lap joint.

E = lowest efficiency of longitudinal joint	50.00%
Ept = efficiency where plate tearing is a consideration = ***B / A***	50.00%

Calculate the Key Values

Plate tension at design pressure and thickness ***PT = (WP * D) / (2 * Ept * t)***	12327 lbs
Maximum allowable working pressure at design thickness, and FS set to 4 ***MAWP = (TS * t * E) / (D/2 * FS)***	223 psi
Factor of Safety at design thickness and pressure ***FS = (TS x t x E) / (D/2 x WP)***	4.46
Minimum Thickness at working pressure and safety factor of 4 ***Tmin = (WP * D * FS) / (2 * TS * E)***	0.4527 in
Rivet shear stress ***SR = (D x WP x P) / (AR * 2)***	7045 psi

Dome Cylinder

Cylindrical Portion of Dome

Ref. ASME Section III, 1952, L-21

Inputs & Basics

WP = working pressure	200 psi	desired
TS = tensile strength of plate	55000 psi	attested
If cylindrical section has a forge-welded longitudinal joint use 35,000 (ref L-29)		
tt = thickness of shell top plate	1.1790 in	linked to survey
tm = thickness of shell middle plate	0.5050 in	linked to survey
tb = thickness of shell bottom plate	1.2110 in	linked to survey
Et = efficiency of longitudinal joint for top	100.00%	no seam
Em = efficiency of longitudinal joint for middle	50.00%	linked to calculat
Eb = efficiency of longitudinal joint for bottom	100.00%	no seam
Rt = inside radius of cylindrical section (top)	14.5000 in	measured
Rm = inside radius of cylindrical section (middle)	15.5625 in	measured
Rb = inside radius of cylindrical section (base)	16.0625 in	measured
FS = factor of safety	4.00	required

Calculations

Top

Maximum allowable working pressure

MAWP = (TS x t x E) / (R x FS) = 1118 psi

Minimum thickness for cylinder

Tmin = (WP x R x FS) / (TS x E) 0.2109 in

Middle

Maximum allowable working pressure

MAWP = (TS x t x E) / (R x FS) = 223 psi

Minimum thickness for cylinder

Tmin = (WP x R x FS) / (TS x E) 0.4527 in

Base

Maximum allowable working pressure

MAWP = (TS x t x E) / (R x FS) = 1037 psi

Minimum thickness for cylinder

Tmin = (WP x R x FS) / (TS x E) 0.2336 in

Dome Manhole Opening

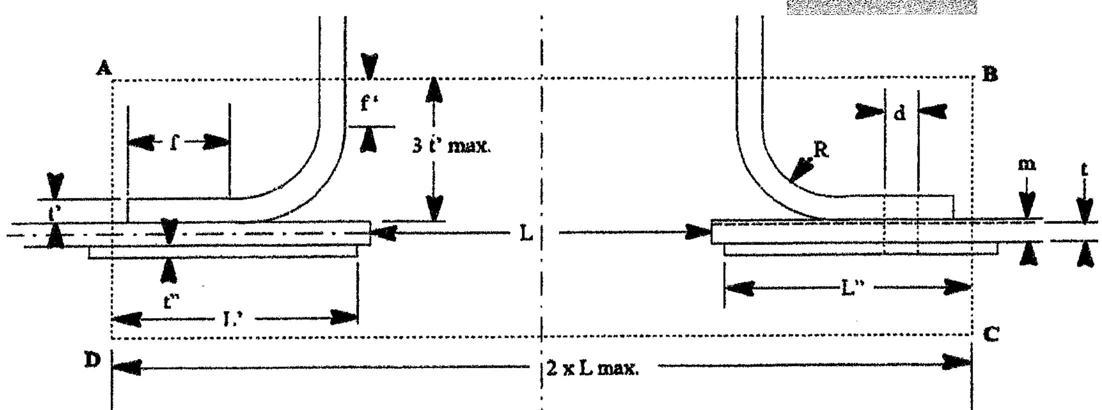
Steam Dome / Manhole Opening Reinforcement

Ref. ASME Code Section III, 1952 Locomotive Boilers
L-30, para. 3 - When boiler shells are cut to apply steam domes or manholes, the net area of metal, after rivet holes are deducted, in flange and liner, if used, must be not less than the area required by these rules for a length of boiler shell equal to the length removed. A height of vertical flange equal to 3 times the thickness of the flange shall be included in the area of the flange.

Since these are design calculations the shell thickness t is assumed to be that which is required for a given efficiency. If the dome is at the longitudinal seam the efficiency used to calculate t shall be the efficiency of the seam, otherwise 1.00 shall be used for E.

Inputs

WP = working pressure	200 psi	desired
TS = tensile strength of plate	55000 psi	attested
E = efficiency	100.00%	not on seam
IR = largest inside radius of shell at dome opening	35.0000 in	linked to survey
FS = Factor of safety = (supply for FS desired)	4.00	minimum



t' = flange thickness	1.2110 in	linked to survey
t" = liner thickness	0.8060 in	linked to survey
L = dome opening	26.0000 in	measured
L' = liner length front	12.5000 in	measured
L" = liner length rear	14.6750 in	measured
f = flange bottom	6.0000 in	measured
R = inside radius of flange	1.0000 in	measured
f' = flange top	n/a in	not used
d = rivet hole dia.	1.1250 in	measured

Dome Manhole Opening (Continued)

Calculations

shell thickness required in dome opening area ***t = IR x FS x WP/ (TS x E)***	0.5091 in
Ref. ASME Code Section III, 1952, Locomotive Boilers, L-30	
area of shell material on longitudinal center line requiring compensation ***MR = L x t***	13.24 in^2
flange bend area allowed for compensation ***RA = [(R+t')^2 x pi] - [R^2 x pi] / 2***	6.11 in^2
vertical portion of flange allowed for compensation ***VA = 2(t' x 3 t' - t' x (t' + R))***	3.44 in^2
horizontal portion of flange allowed for compensation = ***FA = 2[(f-d) x t']***	11.81 in^2
liner area allowed for compensation - since the liner boundary is unstated it will be assumed that the liner extends no further than L distance longitudinally on either side of vertical center of shell opening ***LA = (L' x t" + L" x t") - 2 dt"***	20.09 in^2
total compensation available ***TC = LA + FA + VA + RA***	41.45 in^2
TC must be equal to or greater than MR	OK

Top Dome Flange

Top Dome Flange

The dome flange will be analyzed as an unsupported flange from the start of the radius on the cylindrical portion of the dome to the gasket centerline on the top of the flange.

Area to be stayed

P = max. allowable working pressure	200 psi	desired

ref. ASME Code Section I, 1971
PFT - 31.1 The area of a segment of a flanged head to be stayed shall be the area enclosed by lines drawn through the center of dome and a distance d from the shell as shown in Fig. 1.
The value of d used may be the larger of the following values:

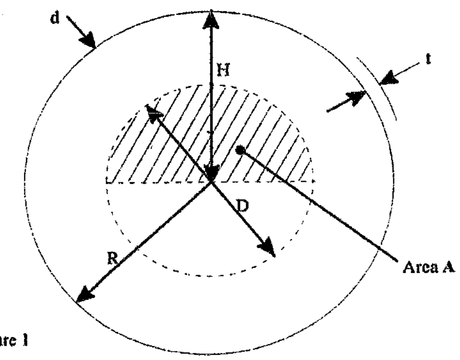


Figure 1

d = the outer radius of the flange	4.5000 in	measured
not exceeding 8 times the thickness of the head = 8t	9.4320 in	
d = ***80t / SQRT(P)***	6.6694 in	
where d = unstayed distance from shell		
t = thickness of head	1.1790 in	linked to survey

PFT - 31.3.1 Net area to be stayed in segment of flanged head:

$$A = 4(H - d)^2 / 3 * SQRT(2(R-d) / (H-d) - 0.608)$$

H = distance from chord to shell (radius in this case)	14.5000 in	linked to survey
R = radius of dome just at start of flange	14.5000 in	linked to survey
d = distance determined from PFT - 31.1, and PFT - 31.3.2	6.6694 in	
A = half the area to be stayed PFT - 31.3.1	96.46 in^2	
AS = area to stayed = ***2 * A***	192.92 in^2	

Find the diameter of the circle encompassing area AS:
D = 2 * SQRT(AS / pi) — 15.67 in

Evaluation

If D is smaller than the diameter of the gasket centerline, the flange cover (dome lid) in combination with the torus (top dome flange) must be adequate to support the load. If D is larger than the diameter of the gasket centerline, redesign is required.

G = diameter of gasket centerline	19.0000 in	linked to survey
Test for acceptable design (D < G)	OK	

Dome Cap

Dome Cap - Dish Portion

Dome Cap Thickness - Calculation for Dished Head		
Ref. ASME Section I, 1971, PG-29 DISHED HEADS		
The thickness of a blank unstayed head with the pressure on the concave side, when it is a segment of a sphere, shall be calculated by the following formula: ***Tmin = (5 * WP * L) / (4.8 * S * E)***		
Inputs & Basics		
WP = maximum allowable working pressure *(hydrostatic head loading need not be included)*	200 psi	desired
L = radius to which the head is dished, measured on the concave side of the head (calculated below)		
S = maximum allowable stress, psi, using values given in Table PG-23.1 (for FRA locomotives, ref. 49 CFR, Part 230.24(a); The maximum allowable stress value on any component of a steam locomotive boiler shall not exceed 1/4 of the ultimate tensile strength of its material.)	12500 psi	new
E = efficiency of weakest joint used in forming the head; for seamless heads = 100 percent (1.00 unity)	100%	seamless
C = inside dish chord length	17.0000 in	measured
b = bump of head (inside top of dish to chord)	3.0000 in	measured
Calculations		
Calculation of radius of sphere of concave side of dished dome head		
make radius L = hypotenuse of right triangle then, ***L squared = (C / 2) *(C / 2) + (L - b) * (L - b)*** ***2 Lb = (C * C) / 4 + (b * b)*** ***L = (C * C) / 8b + b / 2***	13.5417 in	
Minimum thickness of plate ***Tmin = (5 x WP x L) / (4.8 x S x E)***	0.2257 in	

Dome Cap - Flange Portion

The twisting forces on the flange are due to the bolt circle being outside the gasket. We will perform the calculations in the classic ESC manner and generate a Tmin. This will be followed by a couple of check calculations.

1. Between the bolts, the forces on the lid push up on the flange. Model a circumferential unit section as a beam with a fixed end point at a bolt and a guided endpoint in the middle of the gap that lifts up but whose end point remains horizontal (diagram provided). Assume Tmin from the classic ESC calculation, and calculate stress and flexure.

2. From the bolts radially inward to the start of the dish is an upward force. Model a radial unit section as a cantilevered beam (diagram provided). Assume Tmin from the classic ESC calculation, and calculate stress and flexure.

If it turns out that the stresses are low and the flexing negligible for check cases #1 and #2, then the ESC twisting forces analysis is good. If the stresses are high and / or the flexing significant, we will need to consider an alternate approach.

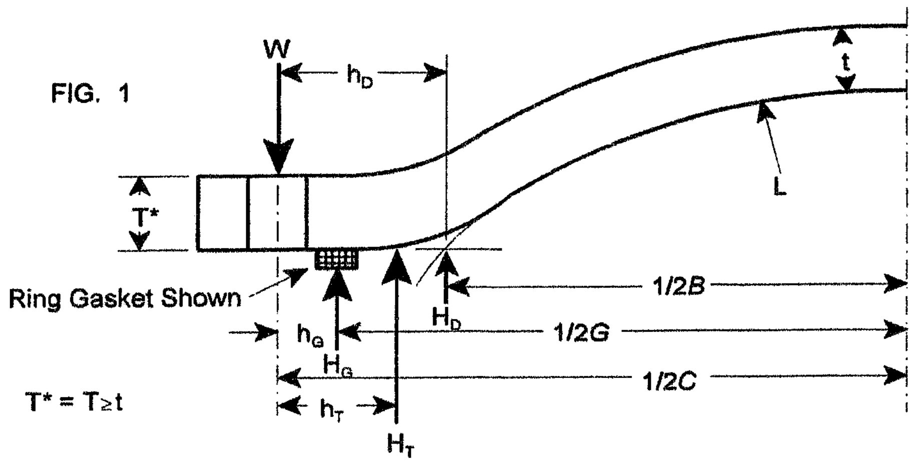
Note that the ESC calculations did show that the original cap / lid flange was undersized for a safety factor of 4. The test formula also showed that the stress levels were too high. A new lid with a thicker flange has been constructed to meet these requirements. As it is of "unknown steel", 50,000 psi is assumed for the tensile strength.

Flange Thickness Due to Twisting Forces

Dome Cap Flange Thickness Considering Twisting Forces

Ref. ASME Section VIII, 1995, 1-6, 2-6 Dished Heads

FIG. 1



T* = T≥t

Inputs & Basics

WP = maximum allowable working pressure	200 psi	desired
G = diameter of gasket centerline	19.0000 in	measured
b = effective gasket seating surface width	0.3750 in	measured
L = inside spherical or crown radius of curvature.	13.5417 in	linked
B = chord length between intersection points of arc L with bottom face of flange	17.0000 in	measured
C = bolt circle centerline diameter	21.0000 in	measured
S = stress value at design temperature, psi (for FRA locomotives, ref. 49 CFR, Part 230.24(a); The maximum allowable stress value on any component of a steam locomotive boiler shall not exceed 1/4 of the ultimate tensile strength of its material) -{ 50,000 psi for unknown steel}	12500 psi	new
total number of dome bolts	24	counted
minimum diameter of bolts (bottom of thread if that's least size)	0.6750 in	measured
A_b = total area of bolts	8.5883 in^2	
m = gasket factor = 4.75 for soft copper or brass	4.75	soft copper
y = gasket or joint-contact-surface unit seating load (13,000 for soft copper)	13000 psi	soft copper
S_a = allowable bolt stress at atmospheric temperature (ref. 49 CRF Part 230.24(a) =	9000 psi	
S_b = allowable bolt stress at design temperature (CFR 49 230.24a	9000 psi	

Flange Thickness Due to Twisting Forces

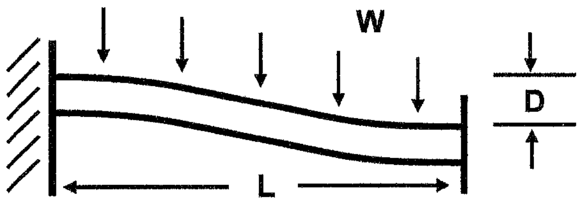
Calculations

H = total hydrostatic end force = $pi * G^2 / 4 * WP$	56706 lbs
H_D = hydrostatic end force on area inside of flange = $pi * B^2 / 4 * WP$	45396 lbs
H_G = gasket load (difference between flange design bolt load and total hydrostatic end force) = ***W - H*** (using the higher value of W below)	127437 lbs
H_P = total joint-contact surface compression load = ***2b * pi * GmP***	42529 lbs
H_T = difference between total hydrostatic end force and hydrostatic end force on the area inside of flange. = $H - H_D$	11310 lbs
h_D = radial distance from bolt circle, to the circle on which H_D acts = ***(C - B) / 2***	2.0000 in
h_G = radial distance from gasket load reaction to the bolt circle = ***(C - G) / 2***	1.0000 in
h_T = radial distance from the bolt circle to the circle on which H_T acts. = $(h_D + h_G) / 2$	1.5000 in
W_{m1} = minimum required bolt load for the operating conditions $W_{m1} = H + H_P$	99235 lbs
W_{m2} = minimum required bolt load for gasket seating $W_{m2} = pi * bGy$	290990 lbs
A_{m1} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions, = W_{m1}/S_b	11.03 in^2
A_{m2} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating = W_{m2}/S_a (This value may be higher than the actual bolt area available, A_b, reflecting the higher stress imparted during gasket seating. This value should not be so high as to indicate that the stress in the bolts cause them to reach the yield strength of the bolt material.)	32.33 in^2
A_m = total required cross-sectional area of blots, taken as the greater of A_{m1} and A_{m2}	32.33 in^2
flange design bolt load W	
$W = W_{m1}$ for operating conditions;	99235 lbs
$W = ((A_m + A_b)S_a) / 2$ for gasket seating	184142 lbs
M_D = component of moment due to H_D. = $H_D * h_D$	90792 in lbs
M_G = component of moment due to H_G. = $H_G * h_G$	127437 in lbs
M_T = component of moment due to H_T. = $H_T * h_T$	16965 in lbs
M_O = the higher value obtained considering gasket seating or operating conditions.	235193 in lbs
M_O total moment for operating conditions = $M_D + M_G + M_T$	235193 in lbs
M_O for gasket seating = ***W * ((C-G) / 2)***	184142 in lbs
Q = (PL/4S) x ((C + B) / (7C - 5B))	0.0332 in
Tmin = Q + SQRT ((1.875 M_O ***(C + B)) / SB(7C - 5B))***	1.1610 in

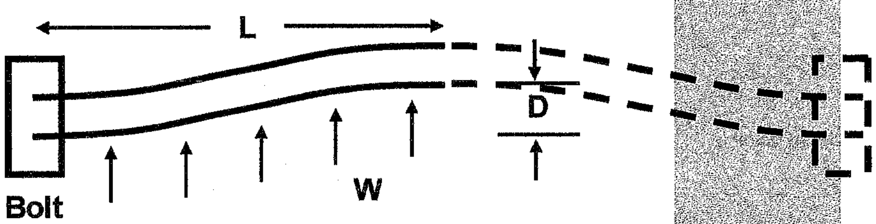
Between adjacent bolts as a Beam

Dome Cap Flange Thickness - Check for Behavior Between Bolts

One of the classic beam types is fixed on one end and guided on the other. The load, W, is distributed.



If we flip the diagram around and model our flange from bolt to bolt as below, we can calculate possible lift off the gasket and maximum flange stresses (The diagram below looks like a dished head. It is not. It is the potential lifting up of the flange edge between bolts).



Equations of interest (from www.engineersedge.com):

Highest stress (at the bolt, or fixed end of the "beam")
$S = W * L / (3 * Z)$
Deflection at the free end (mid point between bolts)
$D = W * L^3 / (24 * E * M)$
Moment of inertial (second moment of area)
$M = b * h^3 / 12$
E = Young's modulus of elasticity
Z = section modulus of the cross-section of the "beam"
$Z = M / d$
d = distance from the neutral axis to extreme fiber (edge)

Some assumptions for this "beam" analysis:

1. The "beam" will be the section of flange along the bolt centerline to the midway point between bolts. This beam will be analyzed as fixed at the bolt end and guided at midpoint. That is, both "ends" remain horizontal. The center point between the bolts is trying to lift up.
2. The load carried between the bolts by the flange will include the upward force from the working pressure on the lid plus the gasket sealing force.
3. Divide the whole load by the number of bolts and again in half (since the "beam" is only to the half way point). Use the resulting load as a distributed load on the "beam".
4. Assume the cross section of the flange is the only material taking all the stress. No additional rigidity due to the dish material is used. This is worse that the real case.
5. Using the minimum thickness from the classic twisting forces based calculation, determine the stresses, and deviations.

Between adjacent bolts as a Beam (Continued)

Inputs & Basics

Young's modulus of elasticity (E) for carbon steel	2.90E+07	psi	conservative
L = length (from bolt to center of "span")	1.3744	in	calc from links
b = base (width of flange from outer edge to start of dish)	4.50	in	measured
h = height (thickness of flange)	1.1610	in	minimum
d = distance from the neutral (no stress) axis to extreme fiber (edge)	0.5805	in	symmetrical cross sec
W = load on span (total force on lid / # of bolts) / 2	2067	lbs	calculated from links

Calculations

Moment of inertial (second moment of area) $M = b * h^3 / 12$	0.5868 in^4
Section modulus of the cross-section of the flange $Z = M / d$	1.0109 in^3
Highest stress $S = W * L / (3 * Z)$	937 psi
Deflection at mid point between bolts $D = W * L^3 / (24 * E * M)$	0.000013 in

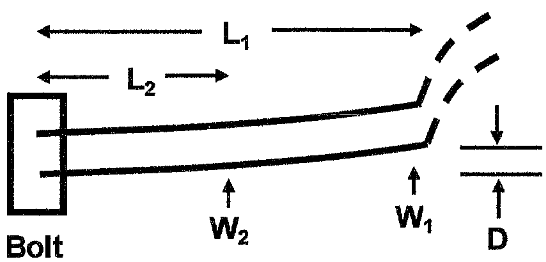
<u>Conclusion:</u> stress is well below strength for this material, and the lift off amount is negligible. No loss of seal will occur.

Between the bolts and dish edge as a Beam

Dome Cap Flange Thickness - Check for Behavior Between Bolts and Dish

One of the classic beam types is cantilevered with the load W on the end.

If we flip the diagram around and model our flange from bolt to edge of the dish, we can calculate possible lift at the dish start, and maximum flange stresses. Load 1 will be the force from the working pressure. Load 2 will be from the gasket.



Equations of interest (from www.engineersedge.com):

Highest stress (at the bolt, or fixed end of the "beam")
$S = W * L / Z$
Deflection at the unsupported end (start of dish)
$D = W * L^3 / (3 * E * M)$
Moment of inertial (second moment of area)
$M = b * h^3 / 12$
E = Young's modulus of elasticity
Z = section modulus of the cross-section of the "beam"
$Z = M / d$
d = distance from the neutral axis to extreme fiber (edge)

Some assumptions for this "beam" analysis:

1. The "beam" will be the section of flange from the bolt centerline to the start of the dished section. This beam will be analyzed as a cantilever fixed at the bolt end and free at the dish end.
2. The results will be a super-position of the working pressure and gasket loads.
3. Divide the loads by the number of bolts. Use the resulting loads as point loads at the respective places.
4. Using the minimum thickness from the classic twisting forces based calculation, determine the stresses, and deviations.

Between the bolts and dish edge as a Beam (Continued)

Inputs & Basics		
Young's modulus of elasticity (E) for carbon steel	2.90E+07 psi	conservative
b = base (distance between bolts)	2.7489 in	calc from links
h = height (thickness of flange)	1.1610 in	minimum
d = distance from the neutral (no stress) axis to extreme fiber (edge)	0.5805 in	symmetrical cross sec.
L_1 = length (from bolt to start of dish)	2.0000 in	calc from links
W_1 = hydrostatic end force = ***pi * G^2 / 4 * WP / # of bolts***	2363 lbs	calculated from links
L_2 = length (from bolt to gasket)	1.0000 in	calc from links
W_2 = joint-contact surface compression load = ***2b * pi * GmP / # of bolts***	1772 lbs	calculated from links

Calculations	
Moment of inertial (second moment of area) $M = b * h^3 / 12$	0.3585 in^4
Section modulus of the cross-section of the flange $Z = M / d$	0.6175 in^3
Highest stress is at the bolt	
$S_1 = W_1 * L_1 / Z$	7652 psi
$S_2 = W_2 * L_2 / Z$	2870 psi
$S = S_1 + S_2$ (Superposition)	10522 psi
Deflection at inner edge of flange	
$D_1 = W_1 * L_1^3 / (3 * E * M)$	0.000606 in
$D_2 = W_2 * L_2^3 / (3 * E * M)$	0.000057 in
$D = D_1 + D_2$ (Superposition)	0.000663 in

Conclusion: stress is below strength for this material, and the deflection is negligible.

Conclusion for Flange Calculations

The results are that the ESC flange thickness due to twisting forces calculation does give a conservative Tmin for the flange.

Throat Sheet Braces

Throat Sheet Brace Calculations

The load on each individual stay shall be determined by the area supported by that stay. In this case, the throat stay that supports the largest area will analyzed along with the smallest stay cross sectional area.

This stress must not exceed **9,000 psi**.

Inputs & Basics

WP = working pressure	200 psi	desired
A = maximum area supported by one brace	25.00 in^2	measured
a = smallest measured brace cross section	1.8750 in^2	linked to survey
AS = allowable stress	9000 psi	maximum

Calculations

Maximum allowable working pressure at maximum stress
MAWP = AS * a / A — 675 psi

Stress at desired working pressure
S = WP * A / a — 2667 psi

Additional Form 4 Entries

AT = total area stayed	196.00 in^2	WxH measured
n = number of stays	10	counted
at = total area of brace = ***n * a***	18.75 in^2	

Wrapper Sheet – Roof

Roof Sheet Thickness Calculations

Ref. ASME Code, Section III, 1952;
L -43 (a) The maximum allowable working pressure for any curved stayed surface subject to internal pressure shall be obtained by the three following methods, and the minimum value obtained shall be used:

General Inputs & Basics

WP = Desired working pressure	200 psi	desired
TS = tensile strength of wrapper sheet	55000 psi	attested
FS = factor of safety = 4 minimum	4	minimum
SA = allowable stress in plate = ***TS / FS***	13750 psi	
R = inside radius of wrapper sheet	35.7500 in	measured
t = thickness of wrapper sheet	0.6430 in	linked to survey
T = thickness of wrapper sheet in sixteenths of an inch	10.29 16ths	
p = minimum longitudinal pitch	4.0000 in	measured
d = maximum diameter of holes through sheet for staybolts, staybolts sleeves, or rivets	1.7500 in	measured
E = equivalent longitudinal efficiency of weakest part of wrapper sheet (example: through staybolt holes of roof sheet) ref. ASME 1971, PG-52 ***E = (p - d) / p***	56.25%	

Method 1 for Maximum Allowable Working Pressure

Method (1) Maximum allowable working pressure shall be computed without allowing for the holding power of the stays, due allowance being made for the weakening effect of the holes for the stays or riveted longitudinal joint or other construction (P1). To this pressure there shall be added the pressure secured by the formula for braced and stayed surfaces given in Pr. L-31, using 80 for the value of C (P2).

ref. L-21

P1 = (TS x t x E) / (R x FS)	139 psi	

ref. L-31

p = maximum pitch measured between straight lines passing through the centers of the staybolts in the different rows, which lines may be horizontal, vertical, or inclined	8 in	measured
C = 80	80	given
P2 = C x (T^2 / p^2)	132 psi	
MAWP = P1 + P2	271 psi	

Wrapper Sheet – Roof (Continued)

Method 2 for Maximum Allowable Working Pressure

L-43 (a) Method (2)
The maximum allowable working pressure shall be computed without allowing for the holding power of the stays, due allowance being made for the weakening effect of the holes for the stays or riveted longitudinal joint or other construction. To this pressure there shall be added the pressure corresponding to the strength of the stays or braces for stresses given in Table (1), each stay or brace being assumed to resist the steam pressure acting on the full area of the external surface supported by the stay or brace.

Table (1) ref. CFR 49 230.3(a)
Maximum staybolt stress, psi. = 7,500
Maximum brace stress, psi. = 9,000

ref. L-43(a)(2): (does not reference the formula)

A = largest area of wrapper sheet supported by staybolt, sq. in. =	32.00 in^2	HxW measured
a = area of smallest section of staybolt (get from staybolt calc and survey)	0.5777 in^2	linked
S = max. allowable stress from Table (1)	7500 psi	given
pressure corresponding to the strength of the stays or braces ***P2 = (S * a) / A***	135 psi	
PR2 = P1 + P2	275 psi	

Wrapper Sheet – Roof (Continued)

Method 3 for Maximum Allowable Working Pressure

oc = angle any crown stay makes with vertical axis of boiler
s = transverse spacing of crown stays in crown sheet — 4.0000 in — measured
Σ(s x sin oc) = summated value of transverse spacing (s x sin oc) for all stays considered in one transverse plane and on one side of vertical axis of boiler.

Stay #	OC (deg)	*s * sin OC*	
1 (inboard)	4	0.2790 in	measured
2	6	0.4181 in	measured
3	9	0.6257 in	measured
4	11	0.7632 in	measured
5	14	0.9677 in	measured
6	27	1.8160 in	measured
7	42	2.6765 in	measured
8	55	3.2766 in	measured
9 (outboard)	71	3.7821 in	measured

Σ(s * sin OC) — 14.6050 in

P3 = (TS / FS) x ((t x E) / R - Σ(s x sin oc)) — 235 psi

The above formula applies to the longitudinal center section of the roof sheet, and in cases where E is reduced at another, the MAWP based on the strength at that section (from the formula) may be increased in the proportion that the distance from the roof sheet to the top of the crown sheet at the center bears to the distance, measured on a radial line, through the other section from the roof sheet to a line tangent to the crown sheet and at right angles to the radian line, or:

POA = P3 * X / Y

This table will not be filled out since it will show areas where increased pressure is allowed. We only care about the worst care, which we already have.

Final MAWP and Minimum Thickness

MAWP is the least of the above calculations — 235 psi

Tmin = WP * (R - Σ(s * Sin OC)) / (SA * E) — 0.5468 in

Thermic Syphon

The Nicholson Thermic Syphon can be modeled as flat stayed surfaces and a pipe under pressure (the neck). The flat stayed surface calculations are in the Plate Thicknesses of Flat Stayed Surfaces section. The staybolt calculations are in the Staybolts section. The following calculations are for the Neck minimum thickness.

Thermic Syphon - Neck

The neck of the thermic syphon can be modeled as a small cylinder under pressure.
The equations found in the "boiler courses not at seams" are suitable.

Inputs

WP = working pressure	200 psi	desired
TS = tensile strength of plate	50000 psi	unknown steel
t = thickness of shell plates	0.3780 in	linked to survey
E = efficiency	100.00%	no seam
R = inside radius of shell	4.0000 in	survey
FS = minimum required Factor of Safety	4.00	minimum

Calculations

Calculate Maximum Working Pressure ***MAWP = (TS x t x E) / R x FS***	1181 psi
Minimum shell thickness required for Factor of Safety ***Tmin = WP x R x FS / (TS x E)***	0.0640 in
Plate Tension at Working Pressure ***PT = (WP x R) / (E x t)***	2116 psi
Factor of Safety at Working Pressure ***FS = (TS x t x E) / (R x WP)***	23.63

Staybolts

Staybolts		

Ref. 49 CFR Part 230.25
The maximum allowable stress per square inch of net cross sectional area on fire box and combustion chamber stays shall be 7,500 psi. The maximum allowable stress per square inch of net cross sectional are on round, rectangular, or gusset braces shall be 9,000 psi.

Inputs & Basics		

Main equation:
S = (A x WP) / a

WP = working pressure	200 psi	desired
A = largest area supported by a staybolt		
a = smallest cross sectional area of staybolt supporting A		
S = stress at smallest cross sectional area of staybolt		
AS = allowable stress	7500 psi	staybolts

ref. ASME Section I, 1971, A-8
The allowable loads based on the net cross-sectional areas of staybolts with V-threads are computed from the following formulas. The use of Whitworth threads with other pitches is permissible.

D = diameter of staybolt over the threads		
n = number of threads per inch	12 t / in	measured
P = pitch of threads = ***1 / n***	0.0833 in / t	
tt = tell tail diameter	0.1875 in	measured
ta = tell tail area = $pi * tt^2 / 4$	0.0276 in^2	

The formula for the diameter of a staybolt at the bottom of a V-thread is:
d = D - (P * 1.732)

When ANSI Standard threads are used, the formula becomes:
d = D - (P * 1.732 x .75)

In calculating the area supported by a staybolt, the staybolt area must be subtracted from the area as the staybolt is self-supporting. The area under stress must be reduced by the area of any tell tale. The following equations are drawn from the above with a bit of algebra and substitution:

smallest cross sectional area including threads and tell tales
$at = (pi * d^2 / 4) - ta$
smallest cross sectional area above the threads (ignore tell tales)
$a = pi * D^2 / 4$
Maximum Allowable Working Pressure at design diameter
MAWP = AS * at / A
Stress at smallest area at desired working pressure
S = A * WP / at
Minimum diameter above threads at working pressure
Tmin = SQRT(((A * WP / AS) + ta) * 4 / pi) + (P * 1.732)

Staybolts (Continued)

Throat Sheet (Flexible)

PV = Vertical Pitch of largest area	5.2500 in	measured
PH = Horizontal Pitch of largest area	3.2500 in	middle outside
D = Diameter of staybolt over threads	1.0000 in	linked to survey
at = smallest cross sectional area including threads and tell tales	0.5474 in^2	
a = smallest cross sectional area above the threads (ignore tell tales)	0.7854 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	16.28 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	252 psi	
S = Stress at smallest area at desired working pressure	5947 psi	
Tmin = Minimum diameter above threads at working pressure	0.9110 in	

Throat Sheet (Solid)

PV = Vertical Pitch of largest area	4.2500 in	measured
PH = Horizontal Pitch of largest area	4.2500 in	middle outside
D = Diameter of staybolt over threads	1.0000 in	linked to survey
at = smallest cross sectional area including threads and tell tales	0.5474 in^2	
a = smallest cross sectional area above the threads (ignore tell tales)	0.7854 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	17.28 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	238 psi	
S = Stress at smallest area at desired working pressure	6312 psi	
Tmin = Minimum diameter above threads at working pressure	0.9329 in	

Side Sheet (Flexible)

PV = Vertical Pitch of largest area	4.5000 in	measured
PH = Horizontal Pitch of largest area	4.2500 in	measured
D = Diameter of staybolt over threads	1.0000 in	linked to survey
at = smallest cross sectional area including threads and tell tales	0.5474 in^2	
a = smallest cross sectional area above the threads (ignore tell tales)	0.7854 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	18.34 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	224 psi	
S = Stress at smallest area at desired working pressure	6700 psi	
Tmin = Minimum diameter above threads at working pressure	0.9554 in	

Side Sheet (Solid)

PV = Vertical Pitch of largest area	4.5000 in	measured
PH = Horizontal Pitch of largest area	4.2500 in	measured
D = Diameter of staybolt over threads	1.0000 in	linked to survey
at = smallest cross sectional area including threads and tell tales	0.5474 in^2	
a = smallest cross sectional area above the threads (ignore tell tales)	0.7854 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	18.34 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	224 psi	
S = Stress at smallest area at desired working pressure	6700 psi	
Tmin = Minimum diameter above threads at working pressure	0.9554 in	

Staybolts (Continued)

Thermic Syphon

PV = Vertical Pitch of largest area	4.0000 in	measured
PH = Horizontal Pitch of largest area	4.0000 in	measured
D = Diameter of staybolt over threads	1.0000 in	linked to survey
at = smallest cross sectional area including threads and tell tales	0.5474 in^2	
a = smallest cross sectional area above the threads (ignore tell tales)	0.7854 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	15.21 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	270 psi	
S = Stress at smallest area at desired working pressure	5559 psi	
Tmin = Minimum diameter above threads at working pressure	0.8871 in	

Door Sheet (Flexible)

PV = Vertical Pitch of largest area	4.2500 in	measured
PH = Horizontal Pitch of largest area	4.0000 in	measured
D = Diameter of staybolt over threads	1.0000 in	linked to survey
at = smallest cross sectional area including threads and tell tales	0.5474 in^2	
a = smallest cross sectional area above the threads (ignore tell tales)	0.7854 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	16.21 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	253 psi	
S = Stress at smallest area at desired working pressure	5924 psi	
Tmin = Minimum diameter above threads at working pressure	0.9096 in	

Door Sheet (Solid)

PV = Vertical Pitch of largest area	4.2500 in	measured
PH = Horizontal Pitch of largest area	4.0000 in	measured
D = Diameter of staybolt over threads	1.0000 in	linked to survey
at = smallest cross sectional area including threads and tell tales	0.5474 in^2	
a = smallest cross sectional area above the threads (ignore tell tales)	0.7854 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	16.21 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	253 psi	
S = Stress at smallest area at desired working pressure	5924 psi	
Tmin = Minimum diameter above threads at working pressure	0.9096 in	

Crown Sheet (equations modified for no tell tales)

PV = Vertical Pitch of largest area	4.0600 in	measured
PH = Horizontal Pitch of largest area	4.1550 in	measured
D = Diameter of staybolt over threads	1.0020 in	linked to survey
at = smallest cross sectional area including threads	0.5777 in^2	
a = smallest cross sectional area above the threads	0.7885 in^2	
A = largest area supported by a stay = ***(PV * PH) - a***	16.08 in^2	
MAWP = Maximum Allowable Working Pressure at design diameter	269 psi	
S = Stress at smallest area at desired working pressure	5567 psi	
Tmin = Minimum diameter above threads at working pressure	0.8832 in	

Diagonal Braces – Back Head

Back Head Brace Calculations

The load on each individual stay shall be determined by the area supported by that stay. The overall area of the sheet will be calculated then the stress on each brace will be determined by analyzing relative percentages of area held by each stay size using smallest measured cross sections.

P = max. allowable working pressure	200 psi	desired

Area to be stayed

ref. ASME Code Section 1, 1971

PFT - 31.1 The area of a segment of a flanged head to be stayed shall be the area enclosed by lines drawn 2 in. from the tubes and a distance d from the shell. The value of d used may be the larger of the following values:

d = the outer radius of the flange	2.0000 in	measured
not exceeding 8 times the thickness of the head = 8t	4.0480 in	
d = ***80t / SQRT(P)***	2.8624 in	
where d = unstayed distance from shell		
t = thickness of head	0.5060 in	linked to survey

PFT - 31.2 The area of a segment of a flanged head to be stayed shall be the area enclosed by the shell and a line drawn 2 in. from the tubes

A = 4(H - d - 2)^2 / 3 * SQRT (2(R-d) / (H-d-2) - .608)

PFT - 31.3.2 Net area to be stayed in segment of unflanged head:

A = 4(H - 2)^2 / 3 * SQRT ((2R) / (H-2) - .608)

d = zero for unflanged heads (input 0, or force a d by inputting any value, else "n/a" for flanged d above)	n/a in	flanged
H = distance from tubes to shell	28.3000 in	mean
R = radius of boiler head	35.7500 in	measured
d = distance determined from PFT - 31.1, and PFT - 31.3.2	2.8624 in	
A = area to be stayed from PFT - 31.1, and PFT - 31.3.2	1085.97 in^2	
dd = diameter of dry pipe through flue sheet	0.0000 in	none on back head
AH = half the area (one side) to be braced = ***(A - pi*dd^2 / 4) / 2***	542.99 in^2	

True formula for "Segment" (implement with h = H-2-d, and R = R - d to account for offset above tubes, and inward from shell).

$$AT = R^2 \cos^{-1}\left(\frac{R-h}{R}\right) - (R-h)\sqrt{2Rh-h^2}$$

AT	1086.05 in^2	
ATH = half the area (one side) to be braced = ***(AT - pi*dd^2 / 4) / 2***	543.03 in^2	

Diagonal Braces – Back Head (Continued)

Stress on Braces

Determine the area, supported by each size brace. Multiply this area by the maximum allowable working pressure.
Divide this by the smallest measured cross sectional, in square inches, of the brace supporting the section of plate considered.
The result will be the stress in pounds per square inch on the brace. Divide by Cos of the angle to get true stress.
This stress must not exceed **9,000 psi**.

Small Braces

bd = smallest measured brace diameter	1.2540 in	linked to survey
pl = percent load carried by this size brace	25 %	measured
n = number of this size brace on one side	4	actual
ba = brace angle	10 deg	measured
a = cross sectional area of single brace = $\boldsymbol{pi * bd^2 / 4}$	1.24 in^2	
As = area supported by single brace = ***AH * (pl / 100) / n***	33.94 in^2	
S = stress on straight brace = ***P * As / a***	5496 psi	
Sba = stress with angle, not to exceed 9,000 psi = ***S / Cos(ba)***	5580 psi	
ATs = area supported by single brace = ***ATH * (pl/100) / n***	33.94 in^2	
ST = stress on straight brace = ***P * ATs / a***	5496 psi	
STba = stress with angle, not to exceed 9,000 psi = ***ST / Cos(ba)***	5581 psi	

Large Braces

bd = smallest measured brace diameter	1.7520 in	linked to survey
pl = percent load carried by this size brace	75 %	measured
n = number of this size brace on one side	6	actual
ba = brace angle	12 deg	measured
a = cross sectional area of single brace = $\boldsymbol{pi * bd^2 / 4}$	2.41 in^2	
As = area supported by single brace = ***AH * (pl / 100) / n***	67.87 in^2	
S = stress on straight brace = ***P * As / a***	5631 psi	
Sba = stress with angle, not to exceed 9,000 psi = ***S / Cos(ba)***	5757 psi	
ATs = area supported by single brace = ***ATH * (pl/100) / n***	67.88 in^2	
ST = stress on straight brace = ***P * ATs / a***	5631 psi	
STba = stress with angle, not to exceed 9,000 psi = ***ST / Cos(ba)***	5757 psi	

Additional Form 4 Entries

total number of stays	20
total actual area of brace	38.81 in^2
total equivalent direct stay (apply Cos ba to each of the above)	38.03 in^2

Heating Surface and Steam Generating Capacity

Heating Surface

Compare the calculations below with the safety valve capacity.		
WP = working pressure	200 psi	desired

Calculate Heating Surface

n = number of tubes	162	linked to survey
D = outside diameter of tubes (front flue sheet)	2.0000 in	linked to survey
Dr = outside diameter of tubes (rear flue sheet)	2.0000 in	linked to survey
t = wall thickness	0.1200 in	linked to survey
L = Length of tubes	175.0000 in	linked to survey
Heating surface for these tubes = ***n * L * pi * (D - 2t) / 144***	1089 ft^2	
n = number of tubes	24	linked to survey
D = outside diameter of tubes (front flue sheet)	5.3750 in	linked to survey
Dr = outside diameter of tubes (rear flue sheet)	4.5000 in	linked to survey
t = wall thickness	0.1500 in	linked to survey
L = Length of tubes	175.0000 in	linked to survey
Heating surface for these tubes = ***n * L * pi * (D - 2t) / 144***	465 ft^2	
Total tube heating area	1554 ft^2	
Firebox	171.00 ft^2	total
Total Firebox	171.00 ft^2	
Thermic Siphons	70.00 ft^2	total
Total Thermic Siphons	70.00 ft^2	
End area of all tubes at front flue sheet (use ID at front)	6.11 ft^2	(cell is equation)
End area of all tubes at rear flue sheet (use ID at rear)	5.05 ft^2	(cell is equation)
Front flue sheet (minus tubes and dry pipe)	19.25 ft^2	(cell is equation)
Rear flue sheet (minus throat and tubes)	6.62 ft^2	(cell is equation)
Total flue sheets	25.87 ft^2	
Total heating surface	1820 ft^2	

Calculate Steam Generating Capacity

C = minimum pounds of steam per hour per square foot of heating surface: If Locomotive is hand fired with Coal, C = 8 If Locomotive is Stoker fired with Coal, C = 10 If Locomotive is Oil fired, C = 14	14 lbs / hr / ft^2	Oil fired
Boiler steam generating capacity = Heating Surface * C	25486 lbs / hr	

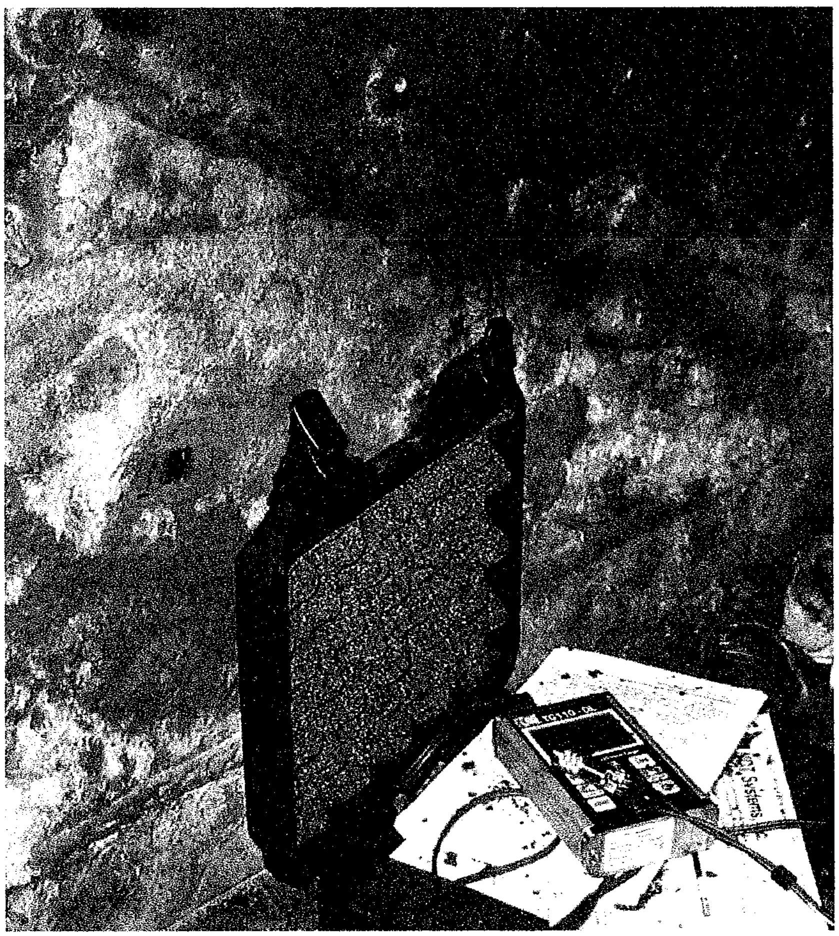
Compare to Pressure Relief Through Safety Valves

Coale 3-1/2" type D set to 200 psi	13000 lbs / hr	spec
Coale 3-1/2" type D set to 200 psi	13000 lbs / hr	spec
Total relief through safety valves	26000 lbs / hr	
Total relief should be larger than steam generating capacity	OK	

Thickness Measurements

A full survey has been done, however only the minimum values have been included in these spreadsheets. For boiler courses where a minimum at seam is required, the overall minimum has been used, as this is a worst case.

The thickness measurements were taken with an ultrasonic instrument. All measurements for all areas are in inches.



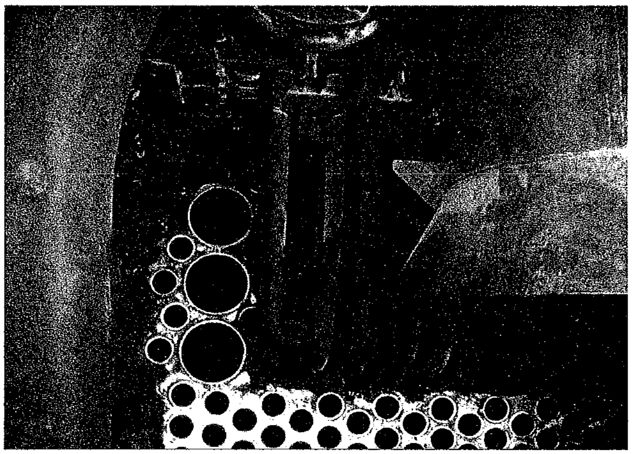
Front Flue Sheet

Front Flue Sheet Thicknesses

Minimum:	0.456		Spec:	1/2" =	0.5000

Engineer Side — Fireman Side

	1	2	3	4	5	6	7	8	9
A									
B									
C									
D			0.456						
E									
F									
G									



Braces

Front Brace (small):	1.250		Spec:	=

	Front			Rear
	1	2	3	4
Fireman side				1.250
Engineer side				

Front Brace (large):	1.750		Spec:	=

	Front		Rear
	1	2	3
Fireman side			1.750
Engineer side			

Braces (Continued)

Throat Sheet Braces:	1.875		Spec:		=

	Engineer side				Fireman Side
	1	2	3	4	5
W	2.500				
H	0.750				
Area	1.875				

Braces (Continued)

Back Head Braces (small):	1.254		Spec:	=

	Front		Rear
	1	2	3
Fireman side E	1.254		
Fireman side C			
Engineer side C			
Engineer side E			

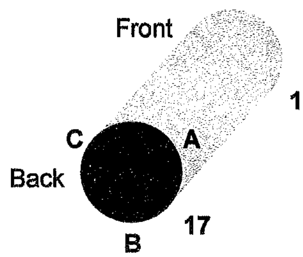
Back Head Braces (large):	1.752		Spec:	=

	Front	Rear
	1	2
Fireman side G	1.752	
Engineer side G		
Spec for F and H		

Dry Pipe

Dry Pipe Thicknesses

Straight pipe



Minimum:	0.280
Spec:	=
OD:	6.5000 (measured)

Front ... Rear

	1	2	3	4	5	6	7	8	9	10	11	12	13
A													
B			0.280										
C													

Cast piece at bottom of throttle assembly

Front ... Rear

	14	15	16	17
A				
B		0.747		
C				

Minimum:	0.747
Spec:	=

Tubes

Tube Thicknesses

Small Minimum:	0.120
Large Minimum:	0.150

Spec:	11 gauge	0.1200
Spec:		

Length (in):	175.0000

Small Tube (samples, all new material)

	1	2	3	4
A	0.120			

Outside Diameter (in)	2.0000
Tube Count:	162

Large Tube

	1	2	3	4
A	0.150			

Outside Diameter (in)	5.3750
Outside Diameter Rear End (in)	4.5000
Tube Count:	24

1st Course

1st Course (Front Course) Sheet Thicknesses

Minimum:	0.743	Spec:	3/4" = 0.7500	Front ID:	68.5000
Seam Minimum:	0.743			Rear ID:	68.5000

Rear — Engineer Side — Front

	14	13	12	11	10	9	8	7	6	5	4	3	2	1
A														
B														
C														
D														
E														
F														
G														
H														
I														
J			0.743											
K														
L														
M														
N														
O														
P														
Q														
R														

Butt Straps

Outer Minimum:	0.615	Spec:	=

Rear — Front

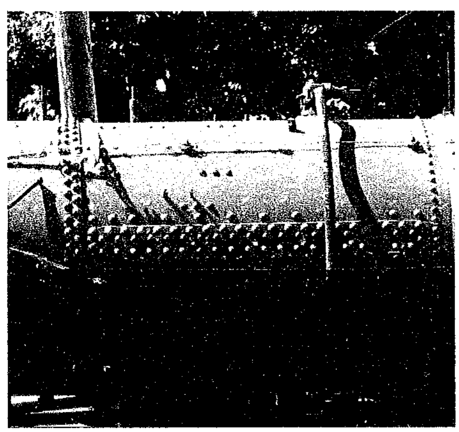
	6	5	4	3	2
B		0.615			

Note: seam is at the far engineer's side.
Not on top.

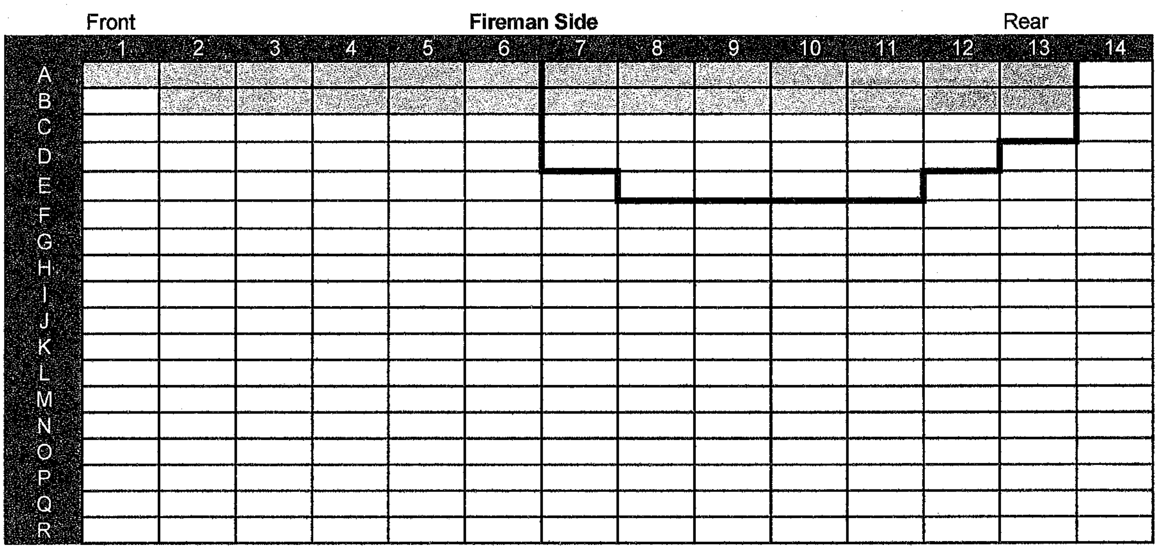
Inner Minimum:	0.612	Spec:	=

Rear — Front

	6	5	4	3	2
B		0.612			



1st Course (Continued)



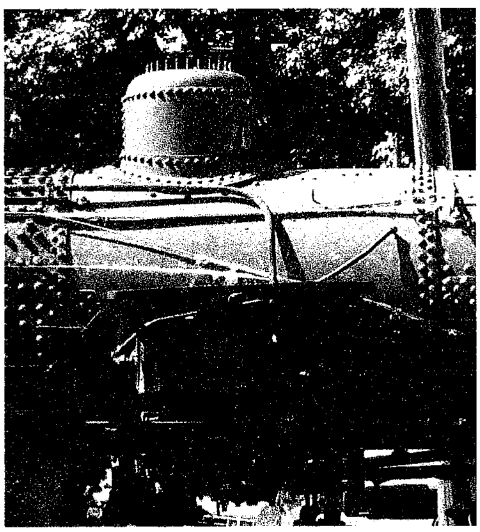
2nd Course

2nd Course (Dome Course) Sheet Thicknesses

Minimum:	0.755
Seam Minimum:	0.755
Spec:	3/4" = 0.7500
Course ID:	70.0000

Rear | **Engineer Side** | Front

	13	12	11	10	9	8	7	6	5	4	3	2	1
A													
B													
C													
D													
E													
F													
G													
H													
I													
J													
K													
L													
M													
N													
O													
P													
Q													
R													



Butt straps

Outer Minimum:	0.622
Spec:	=

Rear | Front

	13	12		2	1
A	0.622				

Inner Minimum:	0.612
Spec:	=

Rear | Front

	13	12		2	1
A	0.612				

Note: seam is at the far fireman's side.
Not on top.

2nd Course (Continued)

	Front					Fireman Side						Rear	
	1	2	3	4	5	6	7	8	9	10	11	12	13
A													
B													
C													
D													
E													
F													
G													
H													
I													
J				0.755									
K													
L													
M													
N													
O													
P													
Q													
R													

Dome Cap

Dome Cap Thicknesses

Dish Minimum:	1.250	Spec:	1 1/4" = 1.1250
Flange Minimum:	1.250	Spec:	1 1/4" = 1.1250

Forward

	2	3	4	5	6
A					
B					
C					
D					1.250
E					
G				1.250	
I					
J					
K					
L					
M					

Rear

Other Measured Geometry:

Diameter of bolt centerline:	21.0000
Diameter of gasket centerline:	19.0000
Inside dish chord:	17.0000
Inside top to chord:	3.0000

Note: new lid built to spec

Dome and Manhole

Dome Thicknesses

Cylindrical Minimum: 0.505

Spec: 1/2" = 0.5000

Seamed? yes ("yes" or "no")

Seam Minimum: 0.505

	Top 1	Middle 2	Middle 3	Bottom 4	Bottom 5
A	1.179	0.505		1.211	
B					
C					
D					
E					
F					
G					
H					
I					
J					
K					
L					
M					
N					
O					
P					

Inner Butt Strap: N/A

Outer Butt Strap: N/A

For Form 4 Usage:

Top Minimum: 1.179

Middle Minimum: 0.505

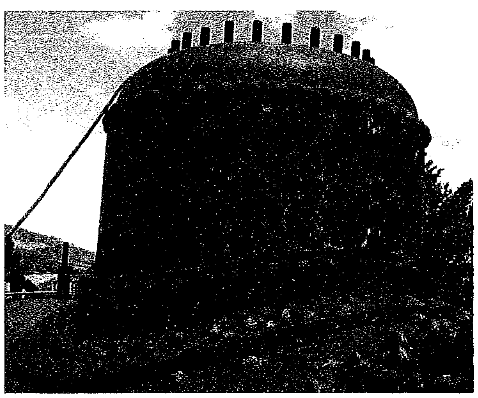
Bottom Minimum: 1.211

Manhole Minimum: 0.806 (dome liner)

Spec: 3/4" = 0.7500

	1	2	3	4
A	0.806			

Manhole Opening: 26.00
(through Course & Liner)



Other Measured Geometry:

Number of bolts: 24

Bolt diam w/threads: 0.6750

Top Opening: 18.00

Top ID: 29.00

Middle ID: 31.13

Base ID: 32.13

Outside Throat Sheet

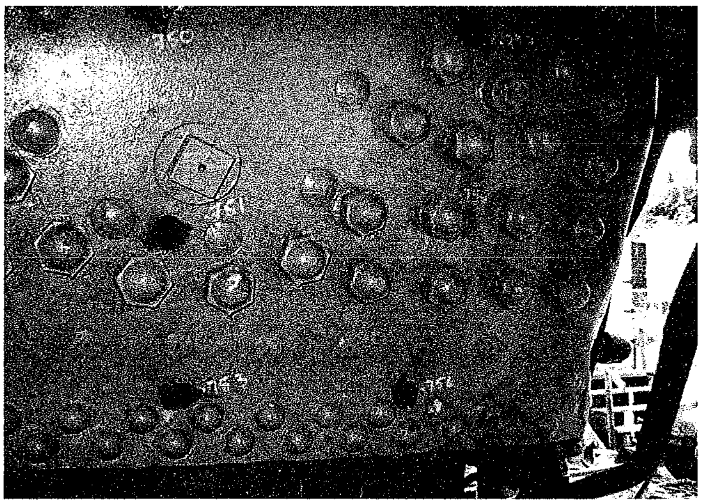
Outside Throat Sheet Thicknesses

Minimum:	0.741

Spec:	3/4" =	0.7500

Engineer Side — Fireman Side

	1	2	3	4	5	6	7	8	9
A	0.741								
B									
C									
D									
E									



Inside Throat Sheet

Inside Throat Sheet Thicknesses

Minimum:	0.386

Spec:	1/2" =	0.5000

	Fireman Side			Engineer Side	
	1	2	3	4	5
A					
B		0.386			
C					
D					

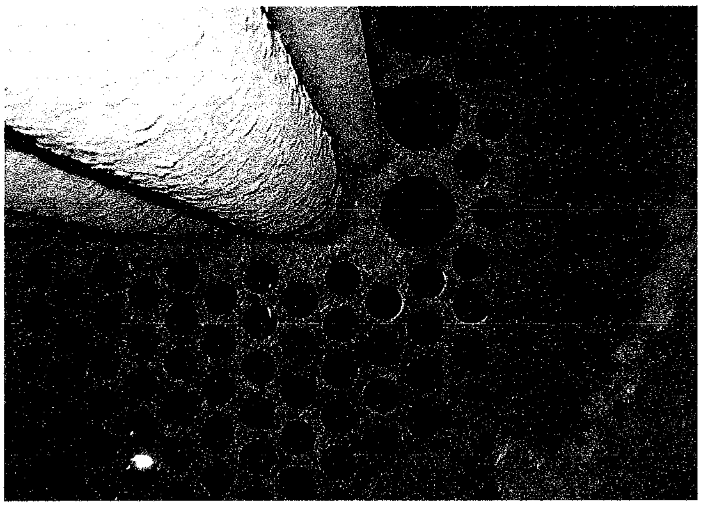
Rear Flue Sheet

Rear Flue Sheet Thicknesses

Minimum:	0.386

Spec:	1/2" =	0.5000

	Fireman Side			Engineer Side	
	1	2	3	4	5
A					
B		0.386			
C					
D					



Roof Sheet

Roof Sheet Thicknesses

Minimum: 0.643

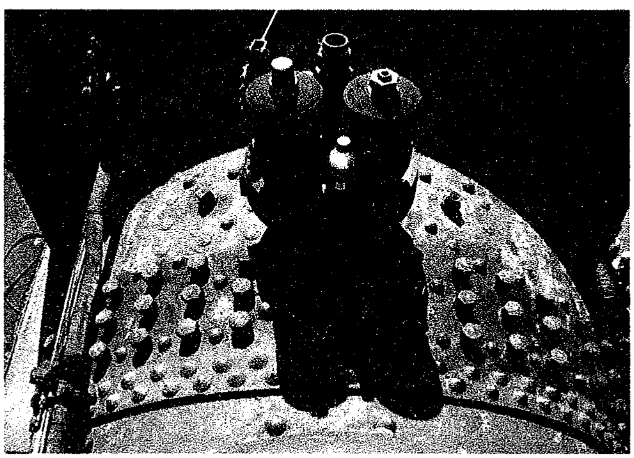
Spec: 5/8" = 0.6250

Engineer Side (Rear → Front)

	10	9	8	7	6	5	4	3	2	1
A					0.643					
B										
C										
D										
E										
F										
G										
H										
I										
J										

Fireman Side (Front → Rear)

	1	2	3	4	5	6	7	8	9	10
A										
B										
C										
D										
E										
F										
G										
H										
I										
J										



Crown Sheet

Crown Sheet Thicknesses

Minimum: 0.391

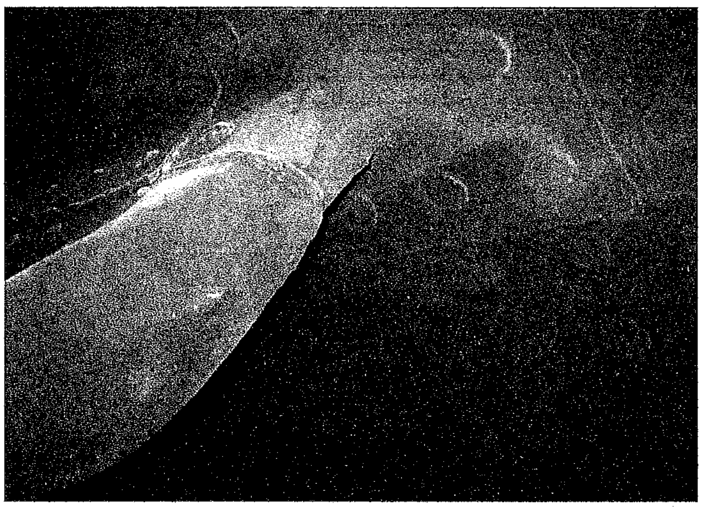
Spec: 3/8" 0.3750

Front — **Engineer Side** — Rear

	1	2	3	4	5	6	7	8	9
A			0.391						
B									
C									
D									
E									
F									

Rear — **Fireman Side** — Front

	9	8	7	6	5	4	3	2	1
A									
B									
C									
D									
E									
F									



Side Wrapper Sheets

Side Wrapper Sheet Thicknesses

Minimum: 0.620

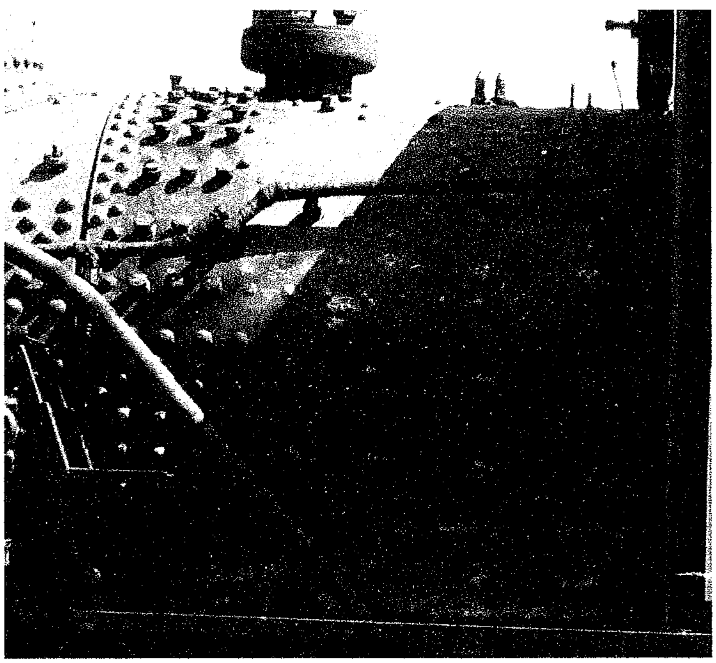
Spec: 5/8" = 0.6250

Engineer Side (Rear → Front)

	10	9	8	7	6	5	4	3	2	1
K				0.620						
L										
M										
N										
O										
P										
Q										
R										

Fireman Side (Front → Rear)

	1	2	3	4	5	6	7	8	9	10
K										
L										
M										
N										
O										
P										
Q										
R										



Firebox Side Sheets

Firebox Side Sheet Thicknesses

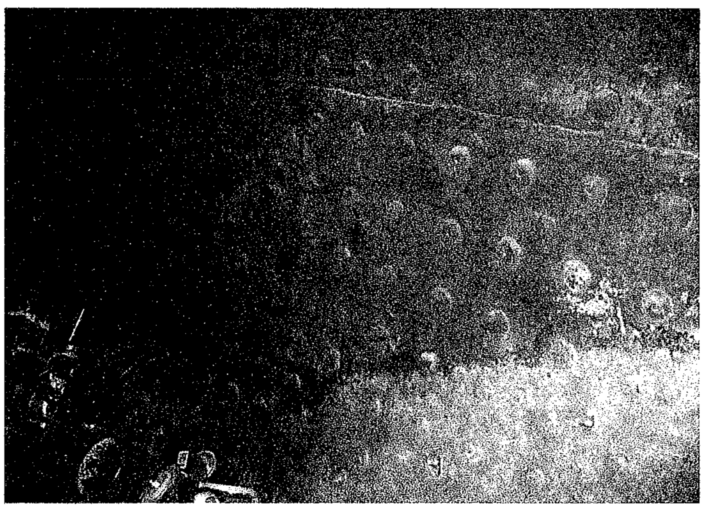
Minimum: 0.377 Spec: 3/8" = 0.3750

Front **Engineer Side** Rear

	1	2	3	4	5	6	7	8	9
G									
H									
I									
J									
M									
N									

Rear **Fireman Side** Front

	9	8	7	6	5	4	3	2	1
G			0.377						
H									
I									
J									
M									
N									



Thermic Syphon

Thermic Syphon

Plate Minimum:	0.386	Spec:	3/8" =	0.3750

Engineer Side (Front → Rear)

	1	2	3	4	5	6	7	8	9
A									
B				0.386					
C									
D									
E									
F									
G									

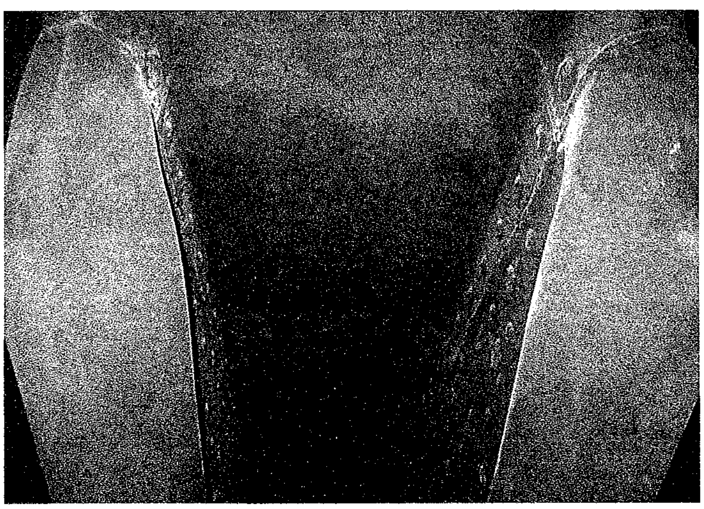
Fireman Side (Rear → Front)

	9	8	7	6	5	4	3	2	1
A									
B									
C									
D									
E									
F									
G									

Neck Minimum:	0.378	Spec:	3/8" =	0.3750

	1	2	3	4
A	0.378			
B				

Neck diameter	8.0000
Staybolt size	1.0000



Door Sheet

Door Sheet Thicknesses

Minimum:	0.370

Spec:	3/8" =	0.3750

Engineer Side / Fireman Side

	1	2	3	4	5	6	7	8	9
A			0.370						
B									
C									
D									
E									
F									
G									
H									
I									

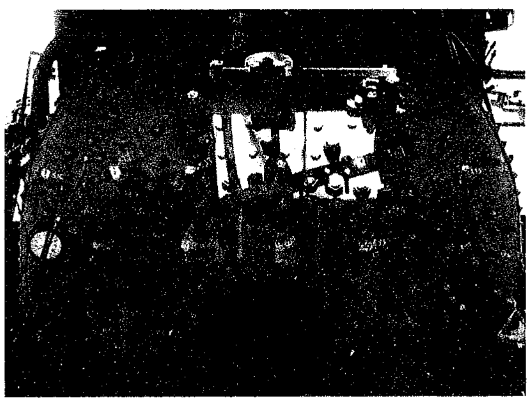
Back Head

Back Head Thicknesses

Minimum:	0.506	Spec:	9/16" =	0.5625

Fireman Side — Engineer Side

	1	2	3	4	5	6	7	8	9	10
A										
B										
C										
D										
E										
F				0.506						
G										
H										
I										
J										
K										
L										
M										
N										



Staybolts

Staybolt Thicknesses

Overall Staybolt Minimum:	1.000
Overall Crown Staybolt Minimum:	1.002

Throat Minimum (Flexible): 1.000 — Spec: 1" = 1.0000

	1	2	3	4
Flexible		1.000		

Throat Minimum (Solid): 1.000 — Spec: 1" = 1.0000

	1	2	3	4
Solid		1.000		

Side Minimum (Flexible): 1.000 — Spec: 1" = 1.0000

	1	2	3	4
Flexible		1.000		

Side Minimum (Solid): 1.000 — Spec: 1" = 1.0000

	1	2	3	4
Solid		1.000		

Door Minimum (Flexible): 1.000 — Spec: 1" = 1.0000

	1	2	3	4
Flexible		1.000		

Door Minimum (Solid): 1.000 — Spec: 1" = 1.0000

	1	2	3	4
Solid		1.000		

Crown Minimum: 1.002 — Spec: =

	1	2	3	4
Solid	1.002			

Tensile Strength of Plate

The FRA Form 4 requires that documentation exist for using tensile strengths greater than 50,000 psi. We find that there are stamps on the boiler plates and other plates attesting to the original material strengths. They read 55,000 psi.

Also the original paperwork for this engine says :

> "Records in the office of the engr. of tests. of the American Locomotive Company shoe that the lowest tensile strength of the sheets in the shell of this boiler is : 55,000 pounds per sq. in."

We've chosen to use 55,000 psi for calculations in areas with original steel. For unknown steel (as in the Thermic Syphon, and the new dome lid) we've used 50,000 psi..

How to Recreate This Document

This document is composed of several parts:

- The "Measurements.xls" file is composed of many separate worksheets for holding all the survey data. It also has images of each area, and finds the area minimums for auto-insertion into the various calculations later.
- A series of Excel spread sheets carry all the calculations of minimum allowable thicknesses, maximum pressures and stresses.
- The "Main.xls" file brings all the calculations and survey minimums together in one place. It also checks them against each other and delivers an OK or Not OK result for each area.
- A separate "FRA Form 4.doc" file is the actual Form 4. It is editable, but has all survey and calculation results pulled automatically from the above spreadsheets.
- This "Engineering Calculations" document pulls it all together.

All these files should remain in the same directory so that they will continue to pass data back and forth. Any of the documents can be opened, edited and printed separately, but to ensure that all data flows properly, a series of careful steps should be followed. The correct way to recreate this document and / or make changes to the base level data is:

1. Update survey data or other geometry information
    a. Load "Measurements.xls" into Excel. Add any new survey data. Leave it open.
    b. Load the "Main.xls" spreadsheet, answering "No" to the update request. Leave it open.
    c. Bring up all the other Excel spreadsheets, answering "No" to any update requests. (Excel will automatically update spreadsheets amongst themselves when they are jointly open. Saying "Yes" during loading just causes preliminary opens and closes that are unnecessary.)
    d. Make any changes to the spreadsheets. The adjustments will all be pushed around amongst each other and back to "Main". Input fields are white. Most interesting answers are black. Grey fields are intermediate calculations. Working pressure is set in "Main" for all other sheets.
2. Update the Form 4
    a. Open "FRA Form 4.doc" into Word answering "Yes" to the update request. (The Form 4 will now be up to date).
    b. Make other changes to the Form 4. However, when editing any Form 4 data directly, watch out for linked fields. They turn grey when the cursor is placed in them. Do not edit linked fields directly, or the link may be broken. The links point back to the Excel spreadsheet data. Make changes there.
3. Update the main document
    a. Open "Engineering Calculations.doc", answering "Yes" to the update request. The loading process will take a long time, as information will be updating.

b. Scroll to the Form 4 inclusion near the beginning. Right mouse click over any part of the Form 4 (it should turn grey as it is a "field"). Choose "Update Field". This will update any text changes. The calculated numbers will have been updated already.
c. Edits to the document are fine, but do not edit linked fields, or spreadsheet data directly. Instead, go to the originals as discussed above,
d. If changes to page numbers or section headings have occurred, then the Table of Contents will need to be refreshed. Right mouse click over the TOC, and choose "Update Field". In the dialog that comes up next, click "Update Entire Table".
e. The Form 4 pages should start on an odd page number if printing on both sides of the paper. This way it can be extracted whole from the main document. A good way to ensure this is to add or subtract a blank page just after the title page.

4. Clean up, Save and Print
    a. Save all spreadsheets. The easiest way to do this is to exit Excel and answer "Yes to All" on the first request.
    b. Save the Form 4 document. Print it also, if desired, for a clean Form 4 just on its own.
    c. Save and Print this document.
    d. Exit all applications.