

Date Distributed: June 20, 2012



**THE  
NATIONAL  
BOARD**  
OF BOILER AND  
PRESSURE VESSEL  
INSPECTORS

## **SUBGROUP ON HISTORICAL BOILERS**

### *AGENDA*

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*Meeting of July 16, 2012  
Columbus, Ohio*

The National Board of Boiler & Pressure Vessel Inspectors  
1055 Crupper Avenue  
Columbus, Ohio 43229-1183  
Phone: (614)888-8320  
FAX: (614)847-1828

1. **Call to Order – 10:00 a.m.**
2. **Announcements**
3. **Adoption of the Agenda**
4. **Approval of Minutes**
5. **Review of the Roster (Attachment 1)**
6. **Action Items (Attachment 3)**

**NB10-0103 Part 3 Part 3 S2.13.9.2 SG on Historical Boilers** - Resolve conflict of text and figure S2.13.9.2. A task group of T. Dillon and M. Wahl has been assigned. (No attachment)

January 2010

A task group was assigned.

July 2010

Mr. Dillon reported with a handout. The proposed wording was unanimously approved at the SG level. The wording needed more work according to the SC on Repairs and Alterations. (No attachment)

January 2011

A progress report was presented.

July 2011

No progress

January 2012

A progress report was presented by Mr. Wahl.

July 2012

Mr. Wahl is expected to report.

**NB10-1004 Part 3 Figure S2.13.13.1 SG on Historical Boilers** - Figure and title are incorrect. Figure should show caulking of seam and rivet heads. The title should reflect caulking of seam and rivet heads also. New drawing will be supplied to committee members by Tom Dillon for review and approval. (No Attachment)

July 2010

A progress report was given.

January 2011

Mr. Dillon gave a progress report.

July 2011

No progress.

January 2012

Mr. Wahl reported that there was no progress on this item.

July 2012

Mr. Wahl is expected to report.

**NB11-0201- Part 2 S2, SG on Historical Boilers** Limits for bulged stayed firebox sheets. (No Attachment)

July 2010

A task group of R. Bryce (Chair), D. Cook and F. Johnson was assigned.

January 2011

A progress report was given.

July 2011

Mr. Cook gave a progress report. Finite Element Analysis (FEA) is being considered as a tool for establishing limits.

January 2012

Dr. Bryce gave a detailed progress report along with handout. After discussion, the Task Group was reaffirmed with the addition of D. Rupert.

July 2012

Dr. Bryce is expected to report.

**NB11-0203 Part 2, S2.13.9. SG on Historical Boilers** - Revise text and Figure to incorporate the correct percentage of wasting allowed. (No Attachment)

July 2010

A task group of M. Wahl and T. Dillon was assigned.

January 2011

Mr. Wahl gave a progress report.

July 2011

No progress.

January 2012

A progress report was given by Mr. Wahl.

July 2012

Mr. Wahl is expected to report.

**NB11-0204 Parts 2 & 3 Supplement 2 SG on Historical Boilers** - Review NDE requirements of stayed areas. (No Attachment)

July 2010

A task group of M. Wahl (Chair), J. Larson and F. Johnson was assigned.

January 2011

Mr. Wahl gave a progress report.

July 2011

No progress.

January 2012

A progress report was given by Mr. Wahl.

July 2012

Mr. Wahl is expected to report.

**NB11-0901 Part 2 S2 SG on Historical Boilers** - This section should be revised to provide chart(s) and formula(s) for calculating maximum allowable working pressure for cylindrical components under external pressure. (Attachment 2, p. 1)

January 2011

A task group of T. Dillon and S. Torkildson was assigned.

July 2011

No progress.

January 2012

There was no progress on this item.

July 2012

Mr. Dillon is expected to report.

**NB11-1101 Part 2, S2.6.2 b) SG on Historical Boilers** - This section should be revised to provide more guidance for evaluating local pitting corrosion versus general corrosion. (Attachment 2, pp. 2-3)

January 2011

Mr. Wahl gave a progress report.

July 2011

Don Cook and Dennis Rupert were added to the task group.

January 2012

A progress report was given by Mr. Wahl.

July 2012

Mr. Rupert is expected to report.

**NB11-1601 Part 2 S2 Table S2.10.4.1 SG on Historical Boilers** - This chart contains errors in formula and nomenclature and should be revised. (Attachment 2, pp. 4-12)

January 2011

A report was given by Dr. Bryce.

July 2011

New charts by Dr. Bryce were approved by the subgroup but they were not approved by the subcommittee at the meeting.

January 2012

A report was given by Dr. Bryce. A Task Group of R. Reetz, F. Johnson and R. Bryce was assigned.

July 2012

Dr. Bryce is expected to report.

**NB11-1603 Part 2, S2.10.2 SG on Historical Boilers-** Define deteriorated rivet heads. (Attachment 2, pp.13-21)

July 2011

A task group of Dr. Bryce and Dennis Rupert was assigned.

January 2012

Dr. Bryce gave a progress report and presented a proposal on corroded rivet heads. After discussion, the task group will continue to work.

**NB12-1201 Part 2, S2.10.2 SG on Historical Boilers** – Review requirements for stayed areas. (Attachment 3, pp. 22-25)

January 2012

A task group of D. Cook, T. Dillon, and R. Bryce was assigned.

July 2012

Dr. Bryce is expected to report.

**7. New Business**

**8. Future Meetings**

January 14-18. Mobile, Alabama

July 15-19, 2013, Columbus, Ohio

**9. Adjournment**

Respectfully Submitted,

Bill Smith

Secretary

# Attachment 1

## NBIC Subgroup on Historical Boilers

Member	Title	Expiration Date	Interest Category
Reetz, Robert	Chair	08/27/2012	Jurisdictional A
Cook, Don		01/19/2015	Jurisdictional A
Wahl, Mike		01/30/2015	General Interes
Larson, James P.		01/30/2015	Auth Inpection
Rupert, Dennis		01/19/2015	General Interes
Babcock, Bruce E.		04/30/2012	General Interes
Dillon, Tom	Vice Chair	08/27/2012	Manufacturer
Bryce, Robert W		08/13/2013	General Interes
Johnson, Frank		01/30/2015	Users
Smith, Bill	Secretary		
<b><u>Total Members:</u></b>		<b><u>9</u></b>	

NB11-0901

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MINNESOTA DEPARTMENT OF  
**LABOR & INDUSTRY**

(651) 284-5005  
1-800-DIAL-DLI  
TTY: (651) 297-4198

October 4, 2010

Secretary, NBIC Committee  
The National Board of Boiler and Pressure Vessel Inspectors  
1055 Crupper Ave  
Columbus, OH 43229

Subject: Historical Boiler internals under external pressure.

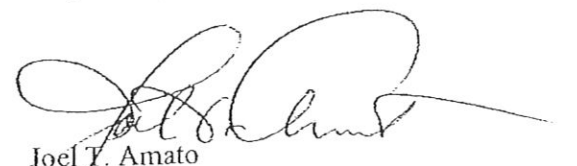
Dear Committee Members,

I am writing to request an addition to the NBIC Part 2, Section 6. The current NBIC contains charts and formulas to determine the maximum allowable working pressure for cylindrical components and stayed surfaces under internal pressure.

I believe the NBIC committee should also add chart(s) and formula(s) for calculating the maximum allowable working pressure for cylindrical components under external pressure. We have many return flue and vertical boilers in which inspectors need to calculate the maximum allowable working pressures for these components.

Thank you for your consideration.

Respectfully,

  
Joel T. Amato  
Chief Boiler Inspector  
Minnesota Department of Labor and Industry

NB11-1101

New Item

Request for Code Change below to address thickness readings for adjusting MAWP if general or localized pitting is observed.

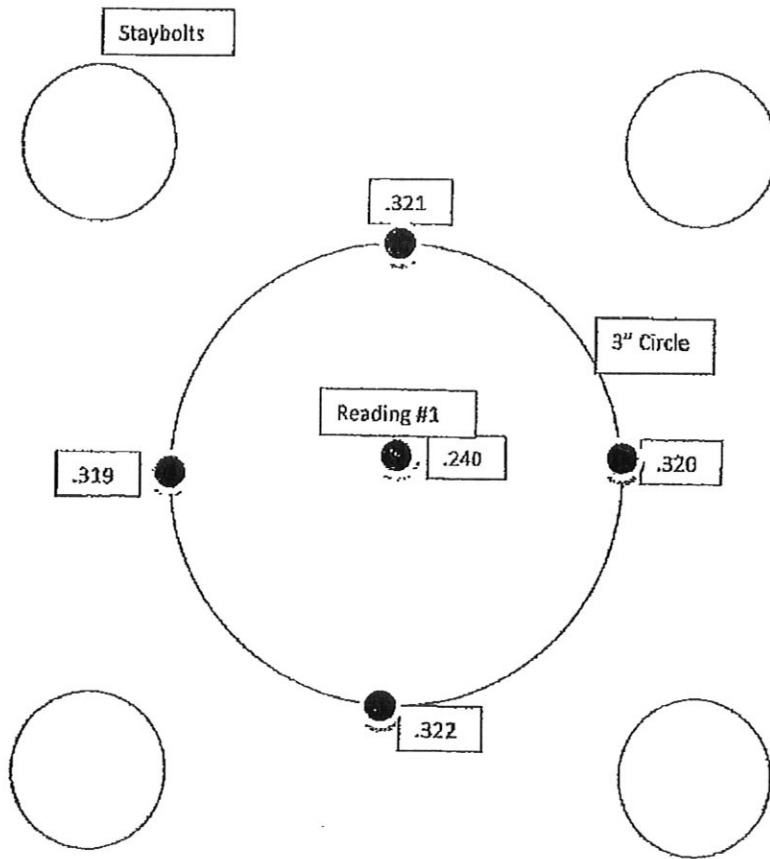
Part II, Section 6, Paragraph S2.6.2 b) should be revised to provide more guidance for evaluating local pitting corrosion versus general corrosion. See example below;

Once region of corrosion pitting is detected by UT (.240" in the attached illustration), a three-inch circle should be drawn around the pitted region. After four readings around the perimeter of the circle are determined by UT and show significant difference with the original lowest reading, the lowest of the four readings should be used as the actual thickness for that particular subsection of the boiler (e.g., the staybolt quadrant as shown, or the grid section of the barrel).

The lowest center reading is assumed to be a localized pit, and can be disregarded in the MAWP calculation because of surrounding material that provides some level of reinforcement.

Sample Readings

Exhibit 1



2/2

**Subject:** 2010 Edition, Part 2, Supplement 2, S2.10.4.1 – Staybolts

**File Number:** NB11-1601

**Prop. Page:** 141

**Proposal:**

Update the text and reference tables in S2.10.4.1 for two purposes:

- Correct errors in equations (both typographical and mathematical)
- Introduce consideration for, and distinction between, iron and steel staybolts

**Current wording:**

**A08 S2.10.4.1 STAYBOLTS**

Table S2.10.4.1 may be used to determine the MAWP for corroded staybolts. The table A09 is based on a stress value of 7,500 psi (51.7 MPa) for staybolts that was the value used in the ASME Section 1, 1971 Edition. The table identifies a calculated MAWP based on measuring the staybolt spacing on the crown sheet and the minimum diameter of the corroded staybolt. See Table S2.10.4.1.

Thickness of Stayed Surface, in.	Staybolt Spacing (Maximum Pitch), in.																				
	3.5	3.625	3.75	3.875	4	4.125	4.25	4.375	4.5	4.625	4.75	4.875	5	5.125	5.25	5.375	5.5	5.625	5.75	5.875	6
0.19	85	80	74	70	65	61	58	55	52	49	46	44	42	40	38	36	35	33	32	30	29
0.2	95	88	82	77	72	68	64	61	57	54	51	49	46	44	42	40	38	37	35	34	32
0.21	104	97	91	85	80	75	71	67	63	60	57	54	51	49	46	44	42	40	39	37	36
0.22	115	107	100	93	88	82	78	73	69	66	62	59	56	53	51	49	46	44	42	41	39
0.23	125	117	109	102	96	90	85	80	76	72	68	65	61	58	56	53	51	48	46	44	43
0.24	136	127	119	111	104	98	92	87	82	78	74	70	67	64	61	58	55	53	50	48	46
0.25	148	138	129	121	113	106	100	95	89	85	80	76	72	69	66	63	60	57	55	52	50
0.26	160	149	139	130	122	115	108	102	97	92	87	82	78	75	71	68	65	62	59	57	54
0.27	172	161	150	141	132	124	117	110	104	99	94	89	85	80	77	73	70	67	64	61	59
0.28	185	173	162	151	142	134	126	119	112	106	101	96	91	87	82	79	75	72	69	66	63
0.29	199	185	173	162	152	143	135	127	120	114	108	103	97	93	88	84	81	77	74	71	68
0.3	213	198	185	174	163	153	144	136	129	122	116	110	104	99	95	90	86	82	79	76	72
0.31	227	212	198	185	174	164	154	146	138	130	123	117	111	106	101	96	92	88	84	81	77
0.32	242	226	211	198	185	174	164	155	147	139	132	125	119	113	108	103	98	94	90	86	82
0.33	258	240	224	210	197	185	175	165	156	148	140	133	126	120	115	109	104	100	95	91	88
0.34	273	255	238	223	209	197	185	175	165	157	148	141	134	128	122	116	111	106	101	97	93
0.35	290	270	252	236	222	209	197	185	175	166	157	149	142	135	129	123	117	112	107	103	99
0.36	307	286	267	250	235	221	208	196	185	176	166	158	150	143	136	130	124	119	114	109	104
0.37	324	302	282	264	248	233	220	207	196	185	176	167	159	151	144	137	131	125	120	115	110
0.38	342	318	298	279	262	246	232	219	207	196	185	176	167	159	152	145	138	132	127	121	116
0.39	360	335	313	294	275	259	244	230	218	206	195	185	176	168	160	153	146	139	133	128	122
0.4	379	353	330	309	290	273	257	242	229	217	206	195	185	177	168	160	153	147	140	134	129
0.41	398	371	346	324	304	286	270	255	241	228	216	205	195	185	177	169	161	154	147	141	135
0.42	417	389	364	340	320	300	283	267	252	239	227	215	204	195	185	177	169	162	155	148	142
0.43	437	408	381	357	335	315	297	280	265	251	237	225	214	204	194	185	177	169	162	155	149
0.44	480	447	418	391	367	345	325	307	290	275	261	247	235	224	213	203	194	186	178	170	163
0.45	502	468	437	409	384	361	340	321	304	287	272	259	246	234	223	213	203	194	186	178	171
0.46	524	489	457	428	402	378	356	336	317	300	285	270	257	245	233	222	212	203	194	186	178
0.47	547	510	477	447	419	394	371	350	331	314	297	282	268	255	243	232	222	212	203	194	186
0.48	571	532	497	466	437	411	387	365	345	327	310	294	280	266	254	242	231	221	212	203	194

TS = Tensile Strength 55 000 psi  
t = Thickness of Stayed Surface, in.  
S = 13 800 psi

$$P = t^2 \cdot S \cdot C / p^2$$

For Thicknesses 0.4375 and less, C = 2.1  
For Thicknesses larger than 0.4375, C = 2.2  
MAWP is expressed in psi

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**Proposed wording:**

**S2.10.4.1 STAYBOLTS**

The maximum allowable working pressure for symmetrically spaced corroded staybolts will be calculated using the formula provided in either of the 2 following paragraphs or the accompanying tables. Equations calculate MAWP based on measuring the staybolt spacing on the stayed surface and the minimum diameter of the corroded staybolt.

**a) IRON STAYBOLTS**

Staybolts which are of iron or of unknown material shall be calculated using the following formula or Table S2.10.4.1.a. The table is based on a stress value of 7,500 psi (51.7 MPa) for staybolts. Refer to ASME Section 1, 1971 Edition, Table PG-23.3 for allowable loads for all staybolts.

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 S}{p^2}, S = 7,500 \text{ (51.7 MPa)}$$

**b) STEEL STAYBOLTS**

Staybolts of known, steel material shall be calculated using the following formula or Table S2.10.4.1.b. The table is based on a stress value of 11,300 psi (78.0 MPa) for staybolts. Refer to ASME Section 1, 1971 Addenda for allowable loads for all staybolts.

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 S}{1.1 \times p^2}, S = 11,300 \text{ (78.0 MPa)}$$

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Staybolt Spacing, in.	Actual Diameter of Corroded Iron Staybolts, in.																																															
	0.35	0.375	0.4	0.425	0.45	0.475	0.5	0.525	0.55	0.575	0.6	0.625	0.65	0.675	0.7	0.725	0.75	0.775	0.8	0.825	0.85	0.875	0.9	0.35	0.375	0.4	0.425	0.45	0.475	0.5	0.525	0.55	0.575	0.6	0.625	0.65	0.675	0.7	0.725	0.75	0.775	0.8	0.825	0.85	0.875	0.9		
3.5	59	68	77	87	97	108	120	133	145	159	173	188	203	219	236	253	270	289	308	327	347	368	389	59	68	77	87	97	108	120	133	145	159	173	188	203	219	236	253	270	289	308	327	347	368	389		
3.625	55	63	72	81	91	101	112	124	136	148	161	175	189	204	220	236	252	269	287	305	324	343	363	55	63	72	81	91	101	112	124	136	148	161	175	189	204	220	236	252	269	287	305	324	343	363		
3.75	51	59	67	76	85	95	105	115	127	138	151	164	177	191	205	220	236	252	268	285	303	321	339	51	59	67	76	85	95	105	115	127	138	151	164	177	191	205	220	236	252	268	285	303	321	339		
3.875	48	55	63	71	79	89	98	108	119	130	141	153	166	179	192	206	221	236	251	267	283	300	318	48	55	63	71	79	89	98	108	119	130	141	153	166	179	192	206	221	236	251	267	283	300	318		
4	45	52	59	66	75	83	92	101	111	122	133	144	156	168	180	194	207	221	236	251	266	282	298	45	52	59	66	75	83	92	101	111	122	133	144	156	168	180	194	207	221	236	251	266	282	298		
4.125	42	49	55	63	70	78	87	95	105	114	125	135	146	158	170	182	195	208	222	236	250	265	280	42	49	55	63	70	78	87	95	105	114	125	135	146	158	170	182	195	208	222	236	250	265	280		
4.25	40	46	52	59	66	74	82	90	99	108	117	127	138	149	160	171	183	196	209	222	236	250	264	40	46	52	59	66	74	82	90	99	108	117	127	138	149	160	171	183	196	209	222	236	250	264		
4.375	38	43	49	56	62	69	77	85	93	102	111	120	130	140	151	162	173	185	197	209	222	236	249	38	43	49	56	62	69	77	85	93	102	111	120	130	140	151	162	173	185	197	209	222	236	249		
4.5	36	41	47	53	59	66	73	80	88	96	105	114	123	133	143	153	164	175	186	198	210	223	236	36	41	47	53	59	66	73	80	88	96	105	114	123	133	143	153	164	175	186	198	210	223	236		
4.625	34	39	44	50	56	62	69	76	83	91	99	108	116	125	135	145	155	165	176	187	199	211	223	34	39	44	50	56	62	69	76	83	91	99	108	116	125	135	145	155	165	176	187	199	211	223		
4.75	32	37	42	47	53	59	65	72	79	86	94	102	110	119	128	137	147	157	167	178	189	200	211	32	37	42	47	53	59	65	72	79	86	94	102	110	119	128	137	147	157	167	178	189	200	211		
4.875	30	35	40	45	50	56	62	68	75	82	89	97	105	113	121	130	139	149	159	169	179	190	201	30	35	40	45	50	56	62	68	75	82	89	97	105	113	121	130	139	149	159	169	179	190	201		
5	29	33	38	43	48	53	59	65	71	78	85	92	100	107	115	124	133	142	151	160	170	180	191	29	33	38	43	48	53	59	65	71	78	85	92	100	107	115	124	133	142	151	160	170	180	191		
5.125	27	32	36	41	45	51	56	62	68	74	81	88	95	102	110	118	126	135	144	153	162	172	182	27	32	36	41	45	51	56	62	68	74	81	88	95	102	110	118	126	135	144	153	162	172	182		
5.25	26	30	34	39	43	48	53	59	65	71	77	83	90	97	105	112	120	128	137	145	154	164	173	26	30	34	39	43	48	53	59	65	71	77	83	90	97	105	112	120	128	137	145	154	164	173		
5.375	25	29	33	37	41	46	51	56	62	67	73	80	86	93	100	107	115	122	130	139	147	156	165	25	29	33	37	41	46	51	56	62	67	73	80	86	93	100	107	115	122	130	139	147	156	165		
5.5	24	27	31	35	39	44	49	54	59	64	70	76	82	89	95	102	110	117	125	133	141	149	158	24	27	31	35	39	44	49	54	59	64	70	76	82	89	95	102	110	117	125	133	141	149	158		
5.625	23	26	30	34	38	42	47	51	56	62	67	73	79	85	91	98	105	112	119	127	135	143	151	23	26	30	34	38	42	47	51	56	62	67	73	79	85	91	98	105	112	119	127	135	143	151		
5.75	22	25	29	32	36	40	45	49	54	59	64	70	75	81	87	94	100	107	114	121	129	136	144	22	25	29	32	36	40	45	49	54	59	64	70	75	81	87	94	100	107	114	121	129	136	144		
5.875	21	24	27	31	35	39	43	47	52	56	61	67	72	78	84	90	96	103	109	116	123	131	138	21	24	27	31	35	39	43	47	52	56	61	67	72	78	84	90	96	103	109	116	123	131	138		
6	20	23	26	30	33	37	41	45	49	54	59	64	69	75	80	86	92	98	105	111	118	125	133	20	23	26	30	33	37	41	45	49	54	59	64	69	75	80	86	92	98	105	111	118	125	133		
6.125	19	22	25	28	32	35	39	43	47	52	57	61	66	72	77	83	88	94	100	107	113	120	127	19	22	25	28	32	35	39	43	47	52	57	61	66	72	77	83	88	94	100	107	113	120	127		
6.25	18	21	24	27	31	34	38	42	46	50	54	59	64	69	74	79	85	91	97	103	109	115	122	18	21	24	27	31	34	38	42	46	50	54	59	64	69	74	79	85	91	97	103	109	115	122		
6.375	18	20	23	26	29	33	36	40	44	48	52	57	61	66	71	76	82	87	93	99	105	111	117	18	20	23	26	29	33	36	40	44	48	52	57	61	66	71	76	82	87	93	99	105	111	117		
6.5	17	20	22	25	28	31	35	38	42	46	50	54	59	64	68	73	78	84	89	95	101	107	113	17	20	22	25	28	31	35	38	42	46	50	54	59	64	68	73	78	84	89	95	101	107	113		
6.625	16	19	21	24	27	30	34	37	41	44	48	52	57	61	66	71	75	81	86	91	97	103	109	16	19	21	24	27	30	34	37	41	44	48	52	57	61	66	71	75	81	86	91	97	103	109		
6.75	16	18	21	23	26	29	32	36	39	43	47	51	55	59	63	68	73	78	83	88	93	99	105	16	18	21	23	26	29	32	36	39	43	47	51	55	59	63	68	73	78	83	88	93	99	105		
6.875	15	18	20	23	25	28	31	34	38	41	45	49	53	57	61	66	70	75	80	85	90	95	101	15	18	20	23	25	28	31	34	38	41	45	49	53	57	61	66	70	75	80	85	90	95	101		
7	15	17	19	22	24	27	30	33	36	40	43	47	51	55	59	63	68	72	77	82	87	92	97	15	17	19	22	24	27	30	33	36	40	43	47	51	55	59	63	68	72	77	82	87	92	97		

S = 7,500 psi  
P = MAWP psi

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 S}{p^2}$$

d = Minimum diameter of corroded staybolt, in.  
P = staybolt spacing, in.

Table S2.10.4.1.a [US Customary Units]

Maximum Allowable Working Pressure Based on the Load Carrying Capacity of a Single Corroded Iron Staybolt

4/9-20

Staybolt Spacing, mm	Actual Diameter of Corroded Iron Staybolts, mm																								
	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22
90	501	553	607	663	722	783	847	914	983	1054	1128	1204	1283	1365	1449	1535	1624	1716	1810	1906	2005	2107	2211	2317	2426
92.5	475	523	574	628	683	742	802	865	930	998	1068	1140	1215	1292	1371	1453	1538	1624	1713	1805	1898	1994	2093	2194	2297
95	450	496	544	595	648	703	760	820	882	946	1012	1081	1152	1225	1300	1378	1458	1540	1624	1711	1800	1891	1984	2080	2178
97.5	427	471	517	565	615	667	722	778	837	898	961	1026	1093	1163	1234	1308	1384	1462	1542	1624	1709	1795	1884	1974	2067
100	406	448	491	537	585	634	686	740	796	854	914	976	1039	1105	1173	1244	1316	1390	1466	1544	1624	1706	1791	1877	1965
102.5	386	426	468	511	557	604	653	704	758	813	870	929	989	1052	1117	1184	1252	1323	1395	1470	1546	1624	1704	1787	1871
105	368	406	446	487	530	575	622	671	722	774	829	885	943	1003	1064	1128	1193	1261	1330	1400	1473	1548	1624	1702	1783
107.5	351	387	425	465	506	549	594	640	689	739	791	844	900	957	1015	1076	1138	1203	1268	1336	1405	1477	1550	1624	1701
110	336	370	406	444	483	524	567	612	658	706	755	806	859	914	970	1028	1087	1149	1211	1276	1342	1410	1480	1551	1624
112.5	321	354	388	424	462	501	542	585	629	675	722	771	821	873	927	983	1039	1098	1158	1220	1283	1348	1415	1483	1553
115	307	339	372	406	442	480	519	560	602	646	691	738	786	836	887	940	995	1051	1108	1167	1228	1290	1354	1419	1486
117.5	294	324	356	389	424	460	497	536	576	618	662	707	753	801	850	901	953	1007	1062	1118	1176	1236	1297	1360	1423
120	282	311	341	373	406	441	477	514	553	593	634	677	722	768	815	864	914	965	1018	1072	1128	1185	1244	1303	1365
122.5	271	298	327	358	390	423	457	493	530	569	609	650	693	737	782	829	877	926	977	1029	1082	1137	1193	1251	1310
125	260	287	314	344	374	406	439	474	509	546	585	624	665	708	751	796	842	889	938	988	1039	1092	1146	1201	1258
127.5	250	275	302	330	360	390	422	455	490	525	562	600	639	680	722	765	809	855	902	950	999	1050	1102	1155	1209
130	240	265	291	318	346	375	406	438	471	505	541	577	615	654	694	736	778	822	867	914	961	1010	1060	1111	1163
132.5	231	255	280	306	333	361	391	422	453	486	520	556	592	630	668	708	749	792	835	879	925	972	1020	1069	1119
135	223	246	270	295	321	348	377	406	437	468	501	535	570	607	644	682	722	763	804	847	891	936	983	1030	1078
137.5	215	237	260	284	309	336	363	391	421	452	483	516	550	585	621	658	696	735	775	817	859	903	947	993	1039
140	207	228	251	274	298	324	350	378	406	436	466	498	530	564	599	634	671	709	748	788	829	871	914	958	1003
142.5	200	220	242	264	288	312	338	364	392	420	450	480	512	544	578	612	648	684	722	760	800	840	882	924	968
145	193	213	234	255	278	302	326	352	379	406	435	464	494	526	558	591	626	661	697	734	773	812	852	893	935
147.5	187	206	226	247	269	292	315	340	366	392	420	448	478	508	539	572	605	639	674	710	747	784	823	863	903
150	180	199	218	239	260	282	305	329	354	379	406	434	462	491	522	553	585	618	651	686	722	758	796	834	873
152.5	175	192	211	231	251	273	295	318	342	367	393	419	447	475	505	535	566	598	630	664	698	734	770	807	845
155	169	186	205	224	243	264	286	308	331	355	380	406	433	460	488	518	548	578	608	643	676	710	745	781	818
157.5	164	180	198	216	236	256	277	298	321	344	368	393	419	446	473	501	530	560	591	622	655	688	722	757	792
160	159	175	192	210	228	248	268	289	311	333	357	381	406	432	458	486	514	543	573	603	634	667	699	733	768
162.5	154	170	186	203	221	240	260	280	301	323	346	369	394	419	444	471	498	526	555	585	615	646	678	711	744
165	149	164	180	197	215	233	252	272	292	314	336	358	382	406	431	457	483	510	538	567	597	627	658	689	722
167.5	145	160	175	191	208	226	245	264	284	304	326	348	371	394	418	443	469	495	522	550	579	608	638	669	700
170	141	155	170	186	202	220	237	256	275	295	316	338	360	383	406	430	455	481	507	534	562	590	620	649	680
172.5	136	150	165	180	197	213	231	249	267	287	307	328	349	372	394	418	442	467	493	519	546	573	602	631	660
175	133	146	160	175	191	207	224	242	260	279	298	319	339	361	383	406	430	454	479	504	530	557	585	613	642
177.5	129	142	156	170	186	201	218	235	253	271	290	310	330	351	372	395	418	441	465	490	516	542	568	596	624
180	125	138	152	166	180	196	212	228	246	263	282	301	321	341	362	384	406	429	452	477	501	527	553	579	607

$$S = 51,700 \text{ kPa}$$

$$P = \text{MAWP kPa}$$

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 S}{p^2}$$

$$d = \text{Minimum diameter of corroded staybolt, mm}$$

$$p = \text{staybolt spacing, mm}$$

Table S2.10.4.1.a [Metric Units]

Maximum Allowable Working Pressure Based on the Load Carrying Capacity of a Single Corroded Iron Staybolt

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Staybolt Spacing, in.	Actual Diameter of Corroded Steel Staybolts, in.																						
	0.35	0.375	0.4	0.425	0.45	0.475	0.5	0.525	0.55	0.575	0.6	0.625	0.65	0.675	0.7	0.725	0.75	0.775	0.8	0.825	0.85	0.875	0.9
3.5	81	93	105	119	133	149	165	182	199	218	237	257	278	300	323	346	370	396	422	448	476	504	533
3.625	75	86	98	111	124	139	153	169	186	203	221	240	259	280	301	323	345	369	393	418	444	470	497
3.75	70	81	92	104	116	129	143	158	174	190	207	224	242	261	281	302	323	345	367	390	415	439	465
3.875	66	76	86	97	109	121	134	148	163	178	193	210	227	245	263	282	302	323	344	366	388	411	435
4	62	71	81	91	102	114	126	139	153	167	182	197	213	230	247	265	284	303	323	343	364	386	408
4.125	58	67	76	86	96	107	119	131	143	157	171	185	200	216	232	249	267	285	303	323	343	363	384
4.25	55	63	71	81	90	101	112	123	135	148	161	174	189	204	219	235	251	268	286	304	323	342	362
4.375	52	59	67	76	85	95	105	116	128	139	152	165	178	192	207	222	237	253	270	287	305	323	341
4.5	49	56	64	72	81	90	100	110	121	132	143	156	168	182	195	209	224	239	255	271	288	305	323
4.625	46	53	60	68	76	85	94	104	114	125	136	147	159	172	185	198	212	227	241	257	273	289	306
4.75	44	50	57	65	72	81	89	99	108	118	129	140	151	163	175	188	201	215	229	243	258	274	290
4.875	42	48	54	61	69	77	85	94	103	112	122	133	143	155	166	178	191	204	217	231	245	260	275
5	40	45	52	58	65	73	81	89	98	107	116	126	136	147	158	170	182	194	207	220	233	247	261
5.125	38	43	49	55	62	69	77	85	93	102	111	120	130	140	151	161	173	184	197	209	222	235	249
5.25	36	41	47	53	59	66	73	81	89	97	105	114	124	133	143	154	165	176	187	199	211	224	237
5.375	34	38	45	50	57	63	70	77	84	92	101	109	118	127	137	147	157	168	179	190	202	214	226
5.5	33	38	43	48	54	60	67	74	81	88	96	104	113	122	131	140	150	160	171	182	193	204	216
5.625	31	36	41	46	52	58	64	70	77	84	92	100	108	116	125	134	143	153	163	174	184	195	207
5.75	30	34	39	44	49	55	61	67	74	81	88	95	103	111	120	128	137	147	156	166	176	187	198
5.875	29	33	37	42	47	53	58	64	71	77	84	91	99	107	115	123	131	140	150	159	169	179	189
6	27	32	36	40	45	51	56	62	68	74	81	88	95	102	110	118	126	135	143	153	162	172	182
6.125	26	30	34	39	44	49	54	59	65	71	77	84	91	98	105	113	121	129	138	146	155	165	174
6.25	25	29	33	37	42	47	52	57	62	68	74	81	87	94	101	109	116	124	132	141	149	158	167
6.375	24	28	32	36	40	45	50	55	60	66	71	78	84	90	97	104	112	119	127	135	143	152	161
6.5	23	27	31	34	39	43	48	53	58	63	69	75	81	87	94	100	107	115	122	130	138	146	155
6.625	23	26	29	33	37	41	46	51	56	61	66	72	78	84	90	97	103	110	118	125	133	141	149
6.75	22	25	28	32	36	40	44	49	54	59	64	69	75	81	87	93	100	106	113	121	128	136	143
6.875	21	24	27	31	35	39	43	47	52	56	61	67	72	78	84	90	96	103	109	116	123	131	138
7	20	23	26	30	33	37	41	45	50	54	59	64	70	75	81	87	93	99	105	112	119	126	133

$S = 11,300 \text{ psi}$

$P = \text{MAWP psi}$

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 S}{1.1 \times p^2}$$

$d = \text{Minimum diameter of corroded staybolt, in.}$

Table S2.10.4.1.b [US Customary Units]

Maximum Allowable Working Pressure Based on the Load Carrying Capacity of a Single Corroded Steel Staybolt

6/9/09

Staybolt Spacing, mm	Actual Diameter of Corroded Steel Staybolts, mm																								
	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22
90	688	758	832	909	990	1074	1162	1253	1348	1446	1547	1652	1760	1872	1987	2106	2228	2353	2482	2614	2750	2889	3032	3178	3328
92.5	651	718	788	861	937	1017	1100	1186	1276	1368	1465	1564	1666	1772	1881	1993	2109	2228	2350	2475	2604	2735	2870	3009	3150
95	617	680	747	816	889	964	1043	1125	1209	1297	1388	1483	1580	1680	1783	1890	1999	2112	2228	2346	2468	2593	2721	2852	2987
97.5	586	646	709	775	844	915	990	1068	1148	1232	1318	1407	1500	1595	1693	1794	1898	2005	2115	2228	2343	2462	2584	2708	2835
100	557	614	674	737	802	870	941	1015	1092	1171	1253	1338	1426	1516	1609	1706	1804	1906	2010	2118	2228	2340	2456	2574	2695
102.5	530	584	641	701	763	828	896	966	1039	1114	1193	1274	1357	1443	1532	1623	1717	1814	1914	2016	2120	2228	2338	2450	2566
105	505	557	611	668	727	789	854	921	990	1062	1137	1214	1293	1375	1460	1547	1637	1729	1824	1921	2021	2123	2228	2335	2445
107.5	482	531	583	637	694	753	814	878	945	1013	1084	1158	1234	1312	1393	1476	1561	1649	1740	1833	1928	2025	2125	2228	2332
110	460	507	557	609	663	719	778	839	902	968	1036	1106	1178	1253	1330	1410	1491	1575	1662	1750	1841	1934	2030	2128	2228
112.5	440	485	532	582	634	688	744	802	862	925	990	1057	1126	1198	1272	1348	1426	1506	1589	1673	1760	1849	1941	2034	2130
115	421	464	510	557	606	658	712	767	825	885	947	1012	1078	1146	1217	1290	1364	1441	1520	1601	1684	1770	1857	1947	2038
117.5	403	445	488	533	581	630	682	735	791	848	908	969	1033	1098	1166	1235	1307	1381	1456	1534	1614	1695	1779	1865	1952
120	387	426	468	511	557	604	654	705	758	813	870	929	990	1053	1118	1184	1253	1324	1396	1471	1547	1625	1706	1788	1872
122.5	371	409	449	491	534	580	627	676	727	780	835	892	950	1010	1073	1137	1202	1270	1340	1411	1484	1560	1637	1716	1796
125	356	393	431	471	513	557	602	650	699	749	802	856	912	970	1030	1092	1155	1220	1287	1355	1426	1498	1572	1648	1725
127.5	343	378	415	453	493	535	579	624	671	720	771	823	877	933	990	1049	1110	1173	1237	1303	1370	1440	1511	1584	1658
130	330	363	399	436	475	515	557	601	646	693	741	792	844	897	952	1009	1068	1128	1190	1253	1318	1385	1453	1523	1595
132.5	317	350	384	420	457	496	536	578	622	667	714	762	812	864	917	971	1028	1086	1145	1206	1269	1333	1399	1466	1535
135	306	337	370	404	440	477	516	557	599	642	688	734	782	832	883	936	990	1046	1103	1162	1222	1284	1348	1413	1479
137.5	295	325	356	390	424	460	498	537	577	619	663	708	754	802	851	902	954	1008	1063	1120	1178	1238	1299	1362	1426
140	284	313	344	376	409	444	480	518	557	597	639	683	727	774	821	870	921	972	1026	1080	1137	1194	1253	1313	1375
142.5	274	302	332	363	395	429	463	500	538	577	617	659	702	747	793	840	889	939	990	1043	1097	1153	1209	1268	1327
145	265	292	321	350	381	414	448	483	519	557	596	636	678	721	766	811	858	907	956	1007	1060	1113	1168	1224	1282
147.5	256	282	310	339	369	400	433	467	502	538	576	615	655	697	740	784	829	876	924	973	1024	1076	1129	1183	1239
150	248	273	299	327	356	387	418	451	485	520	557	595	634	674	715	758	802	847	894	941	990	1040	1092	1144	1198
152.5	239	264	290	317	345	374	405	436	469	503	539	575	613	652	692	733	776	820	864	911	958	1006	1056	1107	1159
155	232	256	280	307	334	362	392	422	454	487	522	557	593	631	670	710	751	793	837	881	927	974	1022	1072	1122
157.5	225	248	272	297	323	351	379	409	440	472	505	539	575	611	649	688	727	768	810	854	898	943	990	1038	1087
160	218	240	263	288	313	340	368	396	426	457	489	523	557	592	629	666	705	745	785	827	870	914	959	1006	1053
162.5	211	233	255	279	304	330	356	384	413	443	475	507	540	574	610	646	683	722	761	802	844	886	930	975	1021
165	205	226	248	271	295	320	346	373	401	430	460	491	524	557	591	626	663	700	738	778	818	860	902	946	990
167.5	199	219	240	263	286	310	335	362	389	417	447	477	508	540	574	608	643	679	717	755	794	834	875	918	961
170	193	212	233	255	277	301	326	351	378	405	434	463	493	525	557	590	624	660	696	733	771	810	850	891	933
172.5	187	206	226	248	270	292	316	341	367	394	421	450	479	510	541	573	606	641	676	712	749	787	825	865	906
175	182	200	220	240	262	284	307	331	356	382	409	437	466	495	526	557	589	622	656	691	727	764	802	841	880
177.5	177	195	214	234	255	276	299	322	346	372	398	425	453	481	511	541	573	605	638	672	707	743	780	817	856
180	172	190	208	227	248	269	290	313	337	361	387	413	440	468	497	526	557	588	621	654	688	722	758	795	832

$$S = 78,000 \text{ kPa}$$

$$P = MAWP \text{ kPa}$$

$$P = \frac{\pi \left[ \frac{d_1^2}{2} \right] S}{1.1 \times p^2}$$

$$p = \text{staybolt spacing, mm}$$

$$d = \text{Minimum diameter of corroded staybolt, mm}$$

Table S2.10.4.1.b [Metric Units]

Maximum Allowable Working Pressure Based on the Load Carrying Capacity of a Single Corroded Steel Staybolt

## Explanation:

Since 2007, Table S2.10.4.1 itemizing the maximum allowable load for staybolts (currently on page 141) in NBIC has changed almost yearly. The current equation is written (after typographical corrections) as:

$$P = \frac{\pi d^2 TS}{FS \times 4 \times p^2}$$

Where:

- $P$  = Maximum allowable working pressure (psi)
- $d$  = minimum diameter of corroded staybolt (inches)
- $p$  = maximum staybolt pitch (inches)
- $TS$  = tensile strength (7,500psi)
- $FS$  = factor of safety (1.1)

This equation has a variety of errors:

- $TS$  as it is used here should be corrected to maximum allowable stress (assumed to be taken from Table PG-23.3 from ASME 1971). This value was consistent in all ASME editions prior to ASME 1971 addenda.
  - ASME 1971: 7,500psi (steel)
  - ASME 1971 addenda: 11,300psi (SA-31 steel)
  - ASME 2002: 15,200psi (SA-36 steel)
- $FS$  as it is defined here is not a factor of safety, but is intended to be a simple multiplier of 1.1 found in ASME PG-49.1. This multiplier was introduced in the ASME 1971 addenda and exists today. This multiplier did not exist prior to the 1971 addenda.
- The equation mixes two different generations of equations and their coefficients from different eras of ASME (pre- and post- 1971 addenda). This mixture is inconsistent with ASME and should be deemed incorrect.

## ASME Equation

ASME 1971 (pre-addenda) PFT-27.1, PG-49.1 define the following equation:

$$P = \frac{\pi \left[\frac{d}{2}\right]^2 S}{p^2 - \pi \left[\frac{d}{2}\right]^2}, S = 7,500$$

Where:

- $P$  = Maximum allowable working pressure
- $d$  = diameter at bottom of thread (PG-49.2)
- $S$  = maximum allowable stress (Table PG-23.3) (7,500 psi)
- $p$  = maximum staybolt pitch (inches) (PFT-27.1 states "full pitch dimensions" which we simplify to maximum staybolt dimensions)

ASME 1971 (post-addenda) defines the following equation:

$$P = \frac{\pi \left[\frac{d}{2}\right]^2 S}{1.1 \times (p^2 - \pi \left[\frac{d}{2}\right]^2)}, S = 11,300$$

given the same definitions as above, but  $S = 11,300$  instead of 7,500.

ASME 1971 Addenda granted a net *increase* of allowable staybolt pressure of ~35%. No change in material specification for steel staybolts was made, but allowance for iron staybolt material was dropped. Logic would dictate that the lower allowable load was only applicable to iron staybolts.

The assumed steel staybolt material (SA-31) is assumed to have a tensile strength (TS) of 50,000-60,000.

**ASME 1914:**

NEW INSTALLATIONS, PART I, SECTION I, POWER BOILERS 19

**SPECIFICATIONS FOR STAYBOLT STEEL**

REQUIREMENTS FOR ROLLED BARS

63 Steel for staybolts shall conform to the requirements for Boiler Rivet Steel specified in Pars. 40 to 62, except that the tensile properties shall be as follows:

Tensile strength, lb. per sq. in. ....	50,000-60,000
Yield point, min., lb. per sq. in. ....	0.5 tens. str. 1,500,000
Elongation in 8 in., min., per cent. ....	----- Tens. str.

Also with the exception that the permissible variations in gage shall be as follows:

*Permissible Variations in Gage.* The bars shall be truly round within 0.01 in. and shall not vary more than 0.005 in. above, or more than 0.01 in. below the specified size.

**Cdn Interprov. Rules, 1931:**

**SPECIFICATIONS FOR STAYBOLT STEEL**

**Solid or Hollow Staybolts**

72. Steel for solid or hollow bars for staybolts shall conform to the requirements for boiler rivet steel, except as follows:

*Tension Tests*—The bars shall conform to the following requirements as to tensile properties:

Tensile strength, maximum, pounds per square inch . . .	60,000
Yield point minimum pounds per square inch . . . . .	26,000
Elongation in 8 inches minimum per cent . . . . .	1,500,000

Tensile strength

*Variation in Gauge*—Solid or hollow bars for staybolts, not exceeding 1¼ inch in diameter, which are to be threaded as rolled, shall be truly round within 0.01 inch and shall not vary more than 0.005 inches under or more than 0.01 inches over.

All other bars for staybolts shall conform to the specified tolerances for steel bars.

Given these rules, our factors of safety for steel staybolts are are:

- ASME 1914 - 1971 pre-addenda =  $\frac{50,000}{7,500} = FS = 6.67:1$
- ASME 1971 post-addenda =  $\frac{50,000}{\left(\frac{11,300}{1.1}\right)} = FS = 4.87:1$
- Current NBIC =  $\frac{50,000}{\left(\frac{7,500}{1.1}\right)} = FS = 7.33:1$
- Canadian Historic Code =  $\frac{50,000}{8,000} = FS = 6.25:1$

## Recommendations:

- Drop removal of staybolt area from sheet area because sheet thicknesses and staybolt diameters will vary due to corrosion

- Pre-addenda equation becomes

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 S}{p^2}, S = 7,500$$

- Post-addenda equation becomes

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 S}{1.1 \times p^2}, S = 11,300$$

- Apply pre-addenda equations to iron staybolts or staybolts of unknown material. This rule satisfies historic loading limits for this material (6:1 safety factor or better). Reference to PG-23.3 is necessary for correct stress values for through-stays and diagonal stays.
- Apply post-addenda equations to staybolts which are known to be of steel material. This rule is consistent with ASME's choice to apply a higher loading factor for steel material. It also remains at least a ~5:1 safety factor.

**Subject:** 2010 Edition, Part 2, Supplement 2, S2.10.2 – Define Deteriorated Rivet Heads

**File Number:** NB11-1603

**Prop. Page:** 133

**Proposal:** Update text in S2.10.2 to include guidelines for decayed rivets.

**Current Wording:**

**S2.10.2 RIVETS**

When the diameter of the rivet holes in the longitudinal joints of a boiler is not known, the diameter of rivets, after driving, may be ascertained from the Table S2.10.2.

**Proposed Wording:**

**S2.10.2 Rivets and Rivet Heads**

When the diameter of the rivet holes in the longitudinal joint of a boiler is not known, the diameter of the rivets, after driving, may be ascertained from Table S2.10.2.

Thickness of Place, inches (mm)	Diameter of Rivet after Driving, inches (mm)
1/4 (6)	11/16 (17)
9/32 (7)	11/16 (17)
5/16 (8)	3/4 (19)
11/32 (9)	3/4 (19)
3/8 (10)	13/16 (21)
13/32 (10)	13/16 (21)
7/16 (11)	15/16 (24)
15/32 (12)	15/16 (24)
1/2 (13)	15/16 (24)
9/16 (14)	1-1/16 (27)
5/8 (16)	1-1/16 (27)

**Rivet Head Types**

Finished rivet heads are shown in NBIC Part 3, Figure S2.13.13.4.

1/9  
13

Note that a riveted seam may have more than one type of rivet to, for example, provide necessary clearance during operation, or for provision for equipment assembly and maintenance.

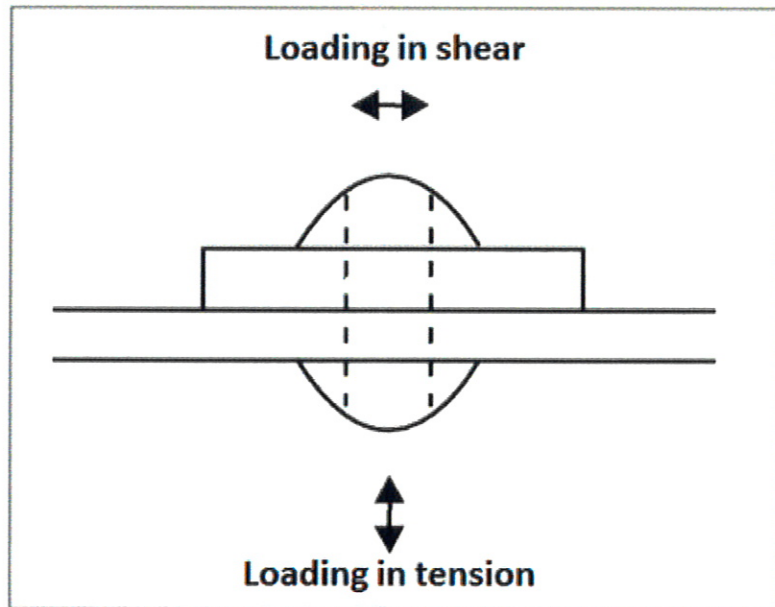
### **S2.10.2.1 Inspection of Corroded Rivets**

A riveted seam or joint is very redundant by design. Therefore, the following guidelines apply when generalized corrosion is present and consistent on a group of adjacent rivets (typically 4 or more), and not to individual rivets. The inspector must consider the frequency and consistency of corroded rivet heads, and condition, location, and type of riveted joint (and how it may fail) in determining allowable corrosion.

- a. Visually identify all connections containing rivets which show signs of significant corrosion.
- b. Categorize each connection as the type which loads the rivets in one of three possible modes (pure shear, pure tension, or combined shear and tension). Refer to Figure S2.10.2.
- c. A leak around a rivet head may be indicative of a rivet which is loose, broken, or otherwise failing to provide adequate clamping force and will require further inspection.
  - i. A rivet shall be deemed loose if it can be felt to move after being struck on the side of the head in a direction approximately perpendicular to its shank with a 40oz. engineer's hammer.
  - ii. NBIC Part 3, S2.13.13 defines procedures to address a leak around a rivet head.
- d. Allowable corrosion:
  - i. For rivets in pure shear load, the amount of measured head deterioration shall not exceed 80% of its total head volume. Where rivets have countersunk heads, the head diameter must be equal or greater than 65% of the original head diameter. Severe head corrosion will require further evaluation of the condition and thickness of the plate at the joint.
  - ii. For rivets in pure tension, the amount of measured head deterioration shall not exceed 35% of its total head volume. Where rivets have countersunk heads, the head diameter must be equal or greater than 85% of original head diameter. Application of this value shall take into consideration the consistency and frequency of adjacent rivets showing excessive corrosion.

- iii. For connections subjected to combined shear and tension loads, the amount of measured head deterioration shall not exceed 60% of its total head volume. Where rivets have countersunk heads, the head diameter must be equal or greater than 75% of original head diameter. Application of this value shall take into consideration the consistency and frequency of adjacent rivets showing excessive corrosion.

Figure S2.10.2



The condition of the plate surrounding the rivets including general wastage, pitting, and the condition of the caulking edge, must be considered.

## ***Explanation***

Supplement 1 (Locomotives) has a guideline for deteriorated rivet head acceptance/rejection [5]. Supplement 2 (Historical Boilers) does not have such a guideline. This report itemizes concerns and errors in Supplement 1 guidelines, and proposes a new Supplement 2 guideline.

## **Supplement 1 Errors & Omissions**

- 1.) No guidelines for rivets in shear.
- 2.) S1.4.2.1.L wording is unclear / self-contradictory. The first sentence discusses wastage, and the 2<sup>nd</sup> sentence discusses remaining height at shank diameter, both using 0.25D.

## **Discussion**

[1, 9] state “U.S. Navy rules require the repair or replacement of rivets when head thickness has been reduced by 25% for 40.8lb [1-inch thick] plate and smaller and by 20% in plate over this weight.”

[8] is heavily referenced, and states that current practice is to replace all rivets in connections subject to tensile or tensile-shear loading that have heads corroded to the point of losing 50% or more of their projection beyond the shank. An original copy of this publication could not be sourced, but this wording is consistent among all papers referencing this work.

[2] performs FEA on a 7/8” button head rivet, and recommends that the measured amount of head deterioration shall not exceed 35% of its total head volume.

### **Caveats:**

- [2] assumes A502 grade rivets, other reports do not appear to specify the grade of rivet. Historical boilers are using A-31 grade rivets.
- All referenced work assumes no change to the load of the rivets. NBIC is unique where the standard will degrade MAWP based on boiler condition, thus changing the load imposed on the rivet. However, FEA in [2] shows a rather sharp increase in stress when deterioration surpasses 35%. This increase is far greater than the reduction due to change in MAWP. The paper reports that measurements have shown rivet clamping force approaches yield load of the rivet.
- Where mentioned, only button head rivet designs are discussed in reference materials.

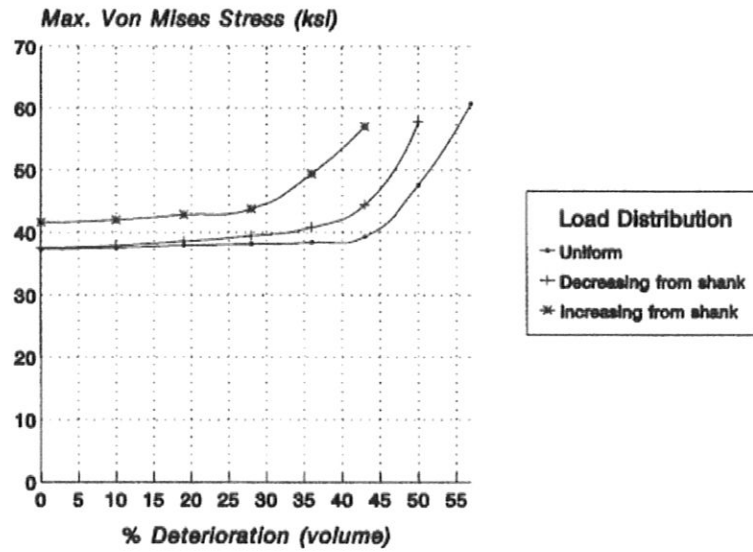


Figure 12 - Max. Stress Vs. Loss of Head Volume (Uniform Model)

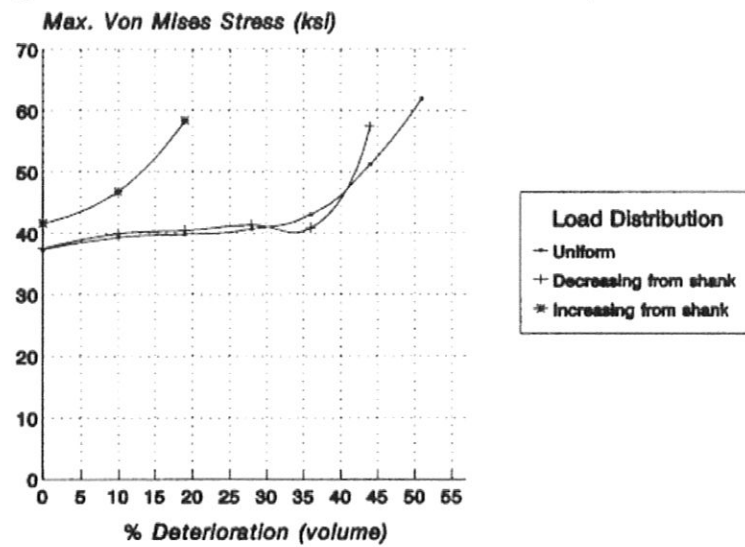
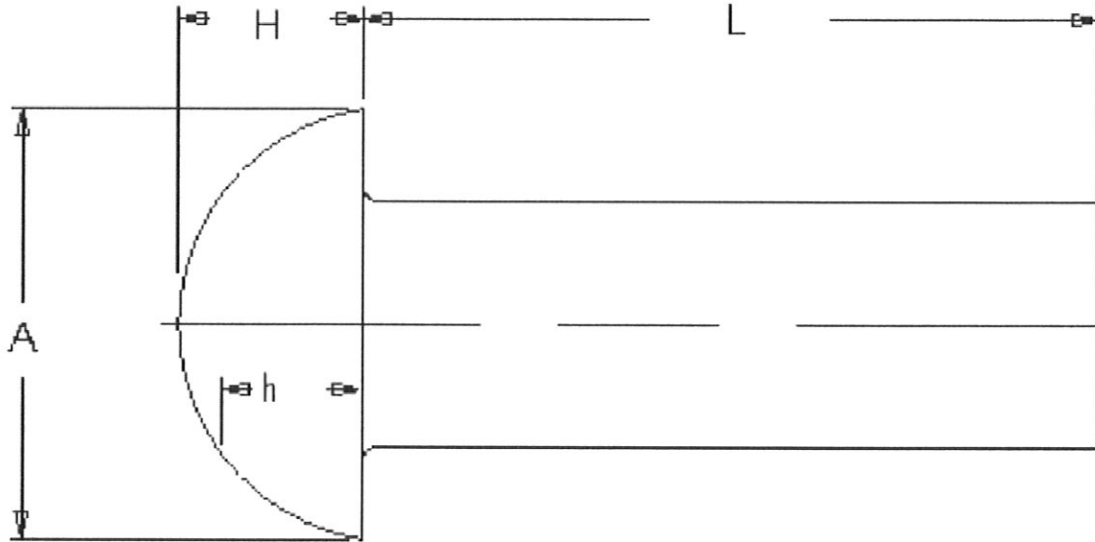


Figure 13 - Max. Stress Vs. Loss of Head Volume (Non-Uniform Model)

### New Button Head Rivet Dimensions

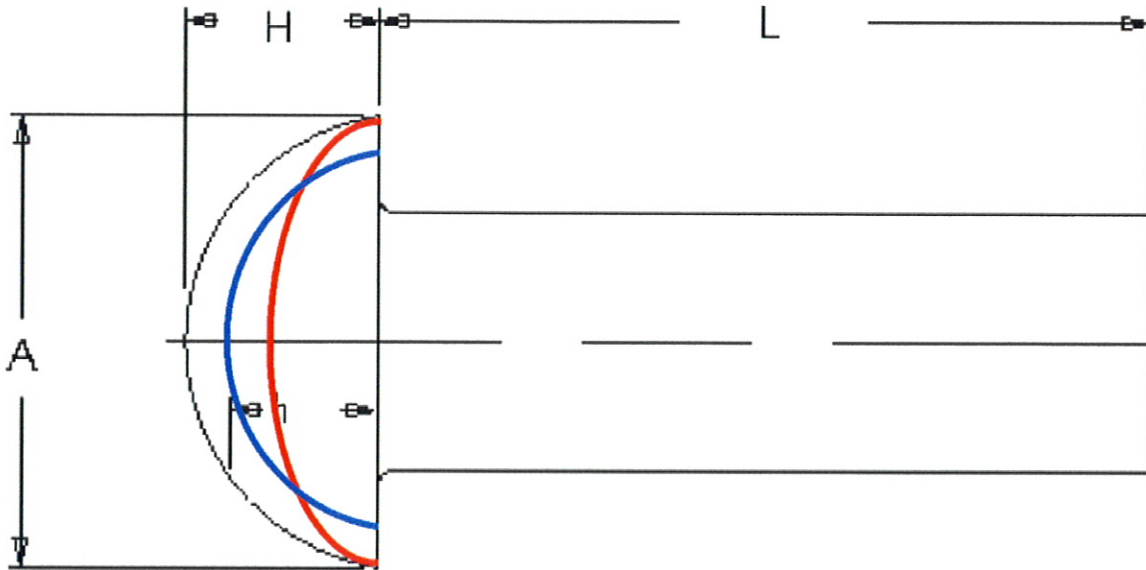
Values are taken from [6]. Calculated values below are based on equations from [7].



Shank Diameter	A Head Diameter	H Head Height	h Height at Shank Circumference (new)	Head Volume
0.500	0.875	0.375	0.298	0.140
0.625	1.094	0.469	0.372	0.274
0.750	1.312	0.562	0.446	0.473
0.875	1.531	0.656	0.521	0.752
1.000	1.750	0.750	0.595	1.123
1.125	1.969	0.844	0.670	1.600
1.250	2.188	0.938	0.745	2.200
1.375	2.406	1.031	0.818	2.918
1.500	2.625	1.125	0.893	3.790
1.625	2.844	1.219	0.968	4.820
1.750	3.062	1.312	1.041	6.013

### Deteriorated Button Head Rivet Dimensions

We will consider two types of generalized deterioration. All red values will represent even deterioration at the crown of the head, where the base of the rivet head remains intact. All blue values represent equal deterioration around the rivet head.



**NBIC S1.4.2.1: minimum  $h = 0.25 * \text{shank diameter}$**

Assuming even deterioration at the rivet head crown, but no deterioration at the edge of the rivet head (red line), **60%** of rivet head material is removed before the rivet must be replaced.

Assuming even deterioration (blue line) throughout the rivet head, **52.5%** of material is removed before the rivet must be replaced.

**US Navy [1, 9]: minimum  $H = 0.75 * \text{original } H$**

Assuming even deterioration at the rivet head crown, but no deterioration at the edge of the rivet head (red line), **31.5%** of rivet head material is removed before the rivet must be replaced.

Assuming even deterioration throughout the rivet head, **55%** of material is removed before the rivet must be replaced.

[8] is calculated in the same manner, except  $H = 0.5 * \text{original } H$ . Assuming even deterioration at the rivet head crown, but no deterioration at the edge of the rivet head (red line), **57.5%** of rivet head material is removed before the rivet must be replaced. However, assuming even deterioration throughout the rivet head, deterioration enters the rivet shank so these values are not considered. Given this result, [8] will not be further considered until a copy is attained to determine how to interpret its guidelines.

**US Army [2]: minimum head volume =  $0.65 * \text{original head volume}$**

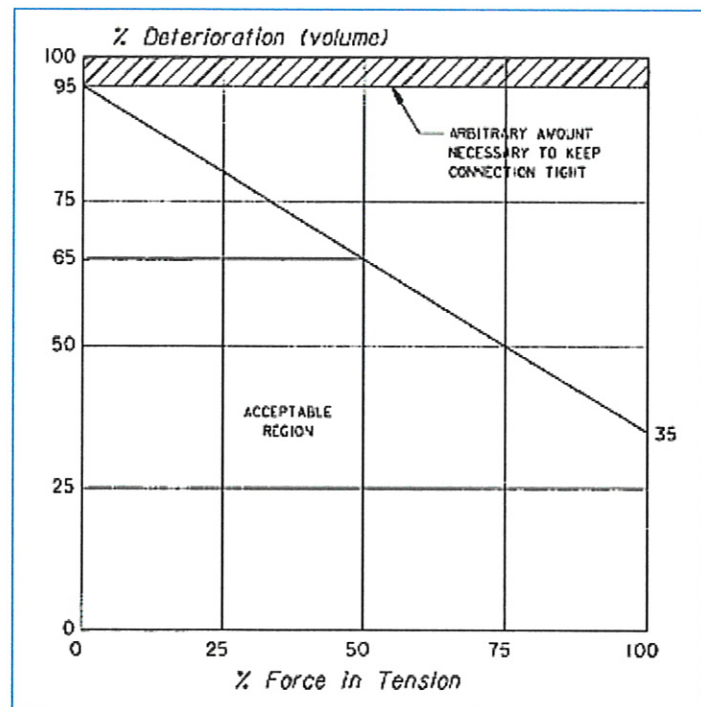
Assuming even deterioration at the rivet head crown, but no deterioration at the edge of the rivet head (red line), to obtain 35% removal of head volume, 'h' must only reduce by **20%** of its original height. Using NBIC S1.4.2.1 metrics, 'h' must be **40%** or greater than shank diameter.

Assuming even deterioration throughout the rivet head, to obtain 35% removal of head volume, 'h' must only reduce by 17.5% of its original height. Using NBIC S1.4.2.1 metrics, 'h' must be 46% or greater than shank diameter.

## Discussion

The FEA results [2] assumed even corrosion around the entire rivet head. These conclusions (35% volume removal) are similar to the rule-of-thumb U.S. Navy guidelines [1, 9] (31.5%) when corrosion is maximum at the crown of the rivet head. Given this consistency, this draft targets a maximum 35% volume removal threshold for rivets in pure tension.

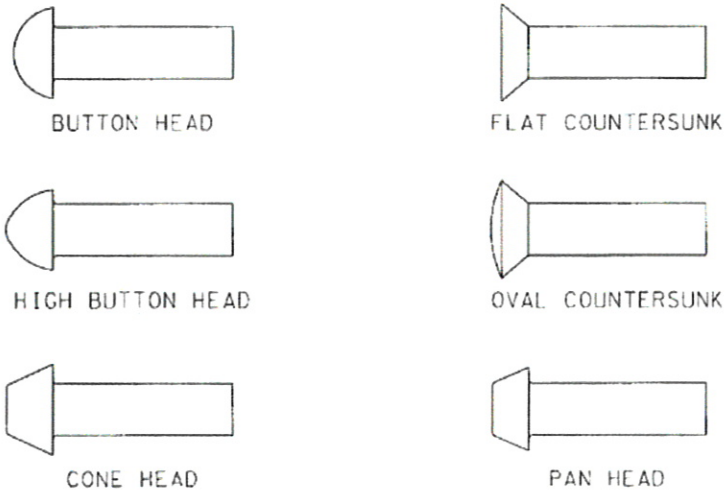
[2] also suggested that for rivets in pure shear, rivets do not need to be replaced as long as the corrosion has not extended into the shank and that the rivet is not loose. Furthermore, the ratio of total head volume removed may linearly scale from 35% (for 100% tension) to 95% (for 100% shear). Refer to below figure from [2].



However, in practicality, one must expect the plate to deteriorate with the rivet head. For example, when a flat countersunk rivet head is 20% of its original volume, the adjoining plate is 33% of its original thickness. So, in practice, it is reasonable to expect a repair that replaces both plate and rivets when severe rivet head decay is present.

Regardless of the type of corrosion, NBIC S1.4.2.1 allows more corrosion than all other approaches for rivets in pure tension. Research and references to peer reviewed documents for NBIC S1.4.2.1 is unknown so cannot be considered. However, due to the difficulties in determining the ratio of shear/tension load on a specific rivet, this draft

adopts the rule to apply equal 50/50% shear/tension. Given the above text, allowable head corrosion for rivets in combined shear/tension is 60%; consistent with NBIC S1.4.2.1.



We assume equal allowable wastage regardless of rivet head type because all known construction codes assume equal allowable loading regardless of rivet head type.

## References

- [1] "Atlantic Area Best Practices: Rivet Inspection Guidance", U.S. Department of Transportation, United States Coast Guard, 2000.
- [2] "Rivet Replacement Analysis", Erich Edward Reichle, U.S. Army Corps of Engineers, 1999.
- [3] "Inspection, Evaluation, and Repair of Hydraulic Steel Structures", U.S. Army Corps of Engineers, 2001.
- [4] "Guidelines for Assessing Condition of Riveted Spillway Gates", REMR Technical Note CS-ES-1.12, 1994
- [5] NBIC Supplement 1, Part 2, 2010.
- [6] ASME B18.1.2: American National Standard Large Rivets
- [7] [http://en.wikipedia.org/wiki/Spherical\\_cap](http://en.wikipedia.org/wiki/Spherical_cap)
- [8] "Rivet Replacement Criteria", Fazio, A.E., and R.N. Fazio, Second Bridge Engineering Conference. Washington, D.D. Transportation Research Board. Vol 1, TRR-950
- [9] "Procedures For Hull Inspection and Repair on Vessels Built of Riveted Construction", U.S. Department of Transportation, United States Coast Guard, 2001.

**Subject:** 2010 Edition, Part 2, Supplement 2, S2.10.4 – Average Staybolt Pitch

**File Number:** NB12-1201

**Prop. Page:** 140

**Proposal:** Update text in S2.10.4, S2.10.6 to include provisions and mathematics for rectangular staybolt patterns found on many historical boilers.

Current text:

**S2.10.4 STAYED SURFACES**

The maximum allowable working pressure for stayed flat plates and those parts which, by these rules, require staying as flat plates with stays or staybolts of uniform diameter symmetrically spaced, shall be calculated using the following formula or Tables S2.10.4 and S2.10.4.1:

$$A07 \quad P = \frac{T^2 \times S \times C}{p^2}$$

See definitions of nomenclature in S2.10.6

**A08 S2.10.4.1 STAYBOLTS**

Table S2.10.4.1 may be used to determine the MAWP for corroded staybolts. The table is based on a stress value of 7,500 psi (51.7 MPa) for staybolts that was the value used in the ASME Section 1, 1971 Edition. The table identifies a calculated MAWP based on measuring the staybolt spacing on the crown sheet and the minimum diameter of the corroded staybolt. See Table S2.10.4.1.

Reword as follows:

**S2.10.4 STAYED SURFACES**

The maximum allowable working pressure for stayed flat plates and those parts which, by these rules, require staying as flat plates with stays or staybolts of uniform diameter symmetrically spaced, shall be calculated using the following formula or Table S2.10.4.

$$P = \frac{t^2 \times S \times C}{p^2}$$

**S2.10.4.1 STAYBOLTS**

The maximum allowable working pressure for symmetrically spaced corroded staybolts shall be calculated using the following formula or Table S2.10.4.1. The table is based on

a stress value of 7,500 psi (51.7 MPa) for staybolts and identifies a calculated MAWP based on measuring the staybolt spacing on the crown sheet and the minimum diameter of the corroded staybolt. Refer to ASME Section I, 1971 Edition, Table PG-23.3 for allowable loads for all staybolts.

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 \times S}{p^2}$$

#### S2.10.4.2 UNEQUAL STAY PITCHES

When the pitches of stays are unequal and form a rectangle, alternative equations are to be used, where:

S2.10.4.2.a The equation for stayed surfaces, given in S2.10.4, is to be replaced with the following equation:

$$P = \frac{2 \times t^2 \times S \times C}{l^2 + w^2}$$

S2.10.4.2.b The equation for staybolts, given in S2.10.4.1, is to be replaced with the following equation:

$$P = \frac{\pi \left[ \frac{d}{2} \right]^2 \times S}{l \times w}$$

#### S2.10.6 NOMENCLATURE

[...]

- $p$  = 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, inches or mm
- $l$  = the pitch of stays in one row, passing through the centers of the staybolts, which line may be horizontal, vertical, or inclined, inches or mm
- $w$  = the distance between two rows of staybolts, inches or mm
- $d$  = minimum diameter of corroded staybolt, inches or mm

[...]

**Explanation:** All known course materials and interpretations of all editions of ASME interpret PG-46.1 (STAYED SURFACES) to require application of the largest dimension of the rectangular pattern as the dimension of ‘*p*’ in the familiar equation:

$$P = \frac{t^2 \times S \times C}{p^2}$$

(also used in S2.10.4). This wording and interpretation is duplicated in ASME Section VIII UG-47. However, ASME 1971 PFT-27.1 and ASME 2002 PFT-26.1 both use similar wording stating “*The full pitch dimensions of the stays shall be employed in determining the area to be supported by a stay...*”. We interpret this wording to mean true dimensions of a rectangle.

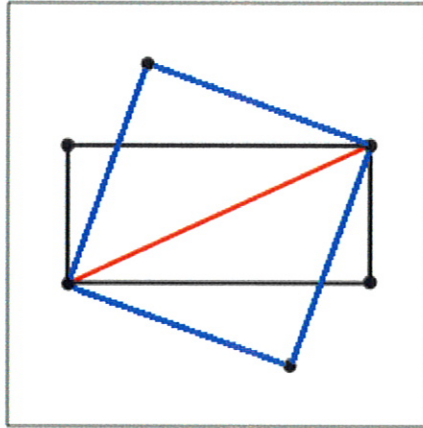
All editions of the Canadian Interprovincial Standard (1910-1938) provide a variation for the same equation for flat stayed surfaces. Specifically, the dimensions of a theoretical square with the same hypotenuse as that of the rectangle, is used. It is believed that, in this respect, the ASME code is a simplification of the older Canadian code and underlying theories. Additionally, traction engine blueprints and registration documents have shown that many historical boilers were built to this Canadian standard. For these reasons, this proposal is based on this precedent.

**Unequal Stay Pitches**

216. When the pitches of stays are unequal  $\frac{l^2 + w^2}{2}$  is to be taken instead of  $P^2$  in the formulae given in Section 213 to 215.

$l$  = the pitch of stays in inches in one row.  
 $w$  = distance in inches between two rows of stays.

As shown in the following diagram, the black rectangle and the blue square share the same hypotenuse, although the blue square actually covers more surface area. The origins of this theory appear to be based in consideration for *unsupported* area *and* distance between stays, not *supported* area of each stay.



When the staybolt pattern is square, both equations yield the same results. Most staybolt patterns are very close to being square.

**Example:** Representative boiler dimensions and thicknesses: dimensions retrieved from a historical boiler blueprints, stated thickness deteriorated to 0.300 inches, staybolt diameter deteriorated to 0.700 inches.

$$l = 4.375$$

$$w = 4.07$$

$$t = 0.300$$

$$d = 0.700$$

**Currently:**

$$\text{Plate: } P = \frac{t^2 \times S \times C}{p^2} \quad P = \frac{0.300^2 \times 13750 \times 2.1}{4.375^2} \quad P = 135.8 \text{ psi}$$

$$\text{Staybolt: } P = \frac{\pi \left[ \frac{d}{2} \right]^2 \times S}{p^2} \quad P = \frac{\pi \left[ \frac{0.700}{2} \right]^2 \times 7500}{4.375^2} \quad P = 150.8 \text{ psi}$$

**Rectangular equations:**

$$\text{Plate: } P = \frac{2 \times t^2 \times S \times C}{l^2 + w^2} \quad P = \frac{2 \times 0.300^2 \times 13750 \times 2.1}{4.375^2 + 4.07^2} \quad P = 145.6 \text{ psi}$$

$$\text{Staybolt: } P = \frac{\pi \left[ \frac{d}{2} \right]^2 \times S}{l \times w} \quad P = \frac{\pi \left[ \frac{0.700}{2} \right]^2 \times 7500}{4.375 \times 4.07} \quad P = 162.1 \text{ psi}$$

In this real-world example, the historical boiler MAWP has increased approximately 10psi, or about 7%.