OBG PRESENTS:

Design for Fatigue of Structural Steel

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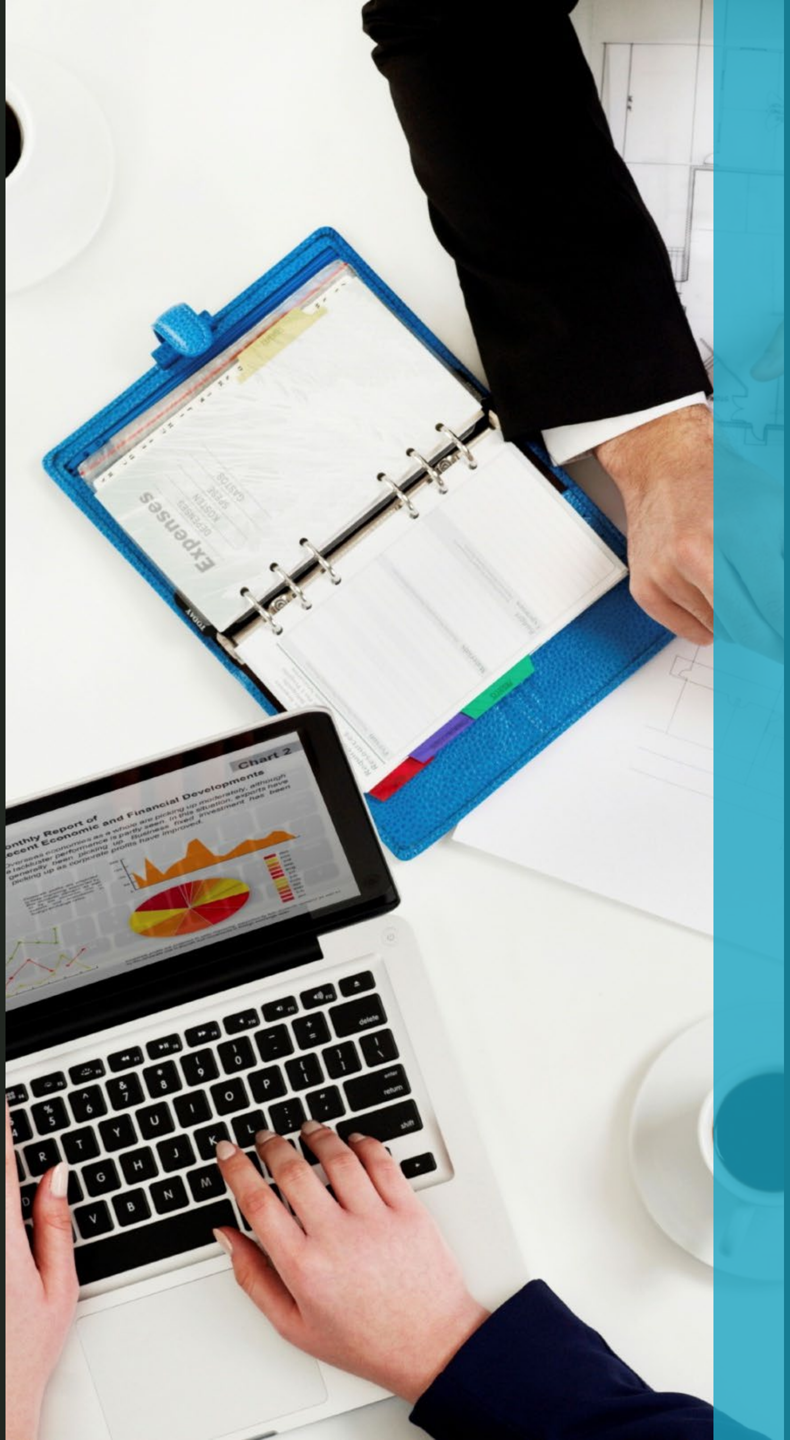


AGENDA

- What is fatigue?
    - Examples of steel subjected to fatigue
- What triggers fatigue design?
    - Illustration of the “*Stress Range*” concept
    - Explanation of the “*Threshold Stress*” term
- Allowable stress range equation (A-3-1) from AISC
    - Overview of Fatigue Design Parameter tables
- Considerations for bolted / welded connections
- 6 Worked Questions

Safety Moment

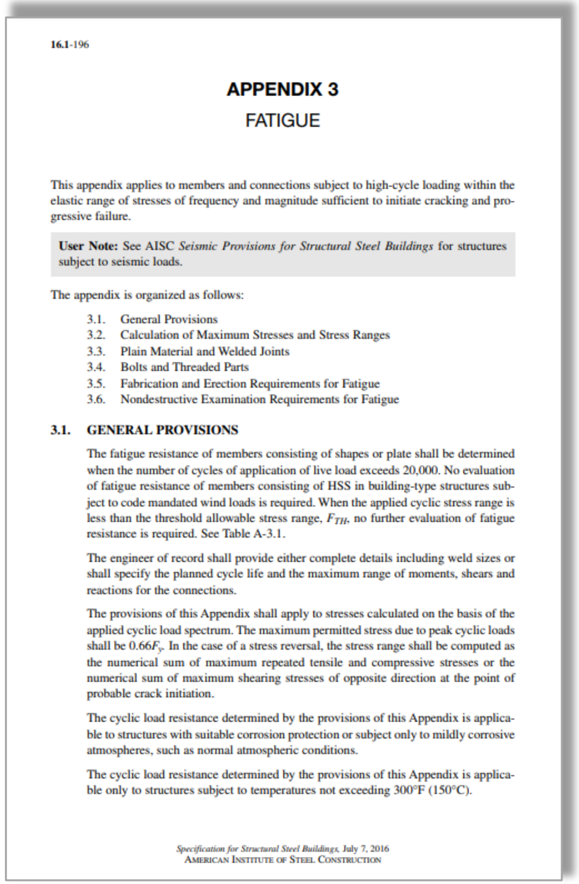
Structural Steel Erection

- Use of proper fall protection equipment is mandated by OSHA
- Recent changes in OSHA regulations regarding fall protection
- When on site, if you see something, say something

What is fatigue ?

What is fatigue?

- Applies to members and connections subject to high-cycle loading that induce sufficient stresses to initiate cracking and progressive failure from service live loads.
- Addressed in Appendix 3 of AISC 360-16 “Specification for Structural Steel Buildings” (and Commentary).


16.1-196

APPENDIX 3

FATIGUE

This appendix applies to members and connections subject to high-cycle loading within the elastic range of stresses of frequency and magnitude sufficient to initiate cracking and progressive failure.

User Note: See AISC *Seismic Provisions for Structural Steel Buildings* for structures subject to seismic loads.

The appendix is organized as follows:

3.1. General Provisions
3.2. Calculation of Maximum Stresses and Stress Ranges
3.3. Plain Material and Welded Joints
3.4. Bolts and Threaded Parts
3.5. Fabrication and Erection Requirements for Fatigue
3.6. Nondestructive Examination Requirements for Fatigue

3.1. GENERAL PROVISIONS

The fatigue resistance of members consisting of shapes or plate shall be determined when the number of cycles of application of live load exceeds 20,000. No evaluation of fatigue resistance of members consisting of HSS in building-type structures subject to code mandated wind loads is required. When the applied cyclic stress range is less than the threshold allowable stress range, F_{TH}, no further evaluation of fatigue resistance is required. See Table A-3.1.

The engineer of record shall provide either complete details including weld sizes or shall specify the planned cycle life and the maximum range of moments, shears and reactions for the connections.

The provisions of this Appendix shall apply to stresses calculated on the basis of the applied cyclic load spectrum. The maximum permitted stress due to peak cyclic loads shall be $0.66F_y$. In the case of a stress reversal, the stress range shall be computed as the numerical sum of maximum repeated tensile and compressive stresses or the numerical sum of maximum shearing stresses of opposite direction at the point of probable crack initiation.

The cyclic load resistance determined by the provisions of this Appendix is applicable to structures with suitable corrosion protection or subject only to mildly corrosive atmospheres, such as normal atmospheric conditions.

The cyclic load resistance determined by the provisions of this Appendix is applicable only to structures subject to temperatures not exceeding 300°F (150°C).

Specification for Structural Steel Buildings, July 7, 2016
AMERICAN INSTITUTE OF STEEL CONSTRUCTION

What is fatigue?

- What about dead load, wind loads, seismic loads?
  - Dead load is not cyclic ’ always present
  - Wind load is cyclic but not usually strong enough to initiate cracking
  - Seismic design events are very infrequent
- Does this work for LRFD design or only ASD?
  - This is a *service load* stress check
    - Treat similar to deflection checks

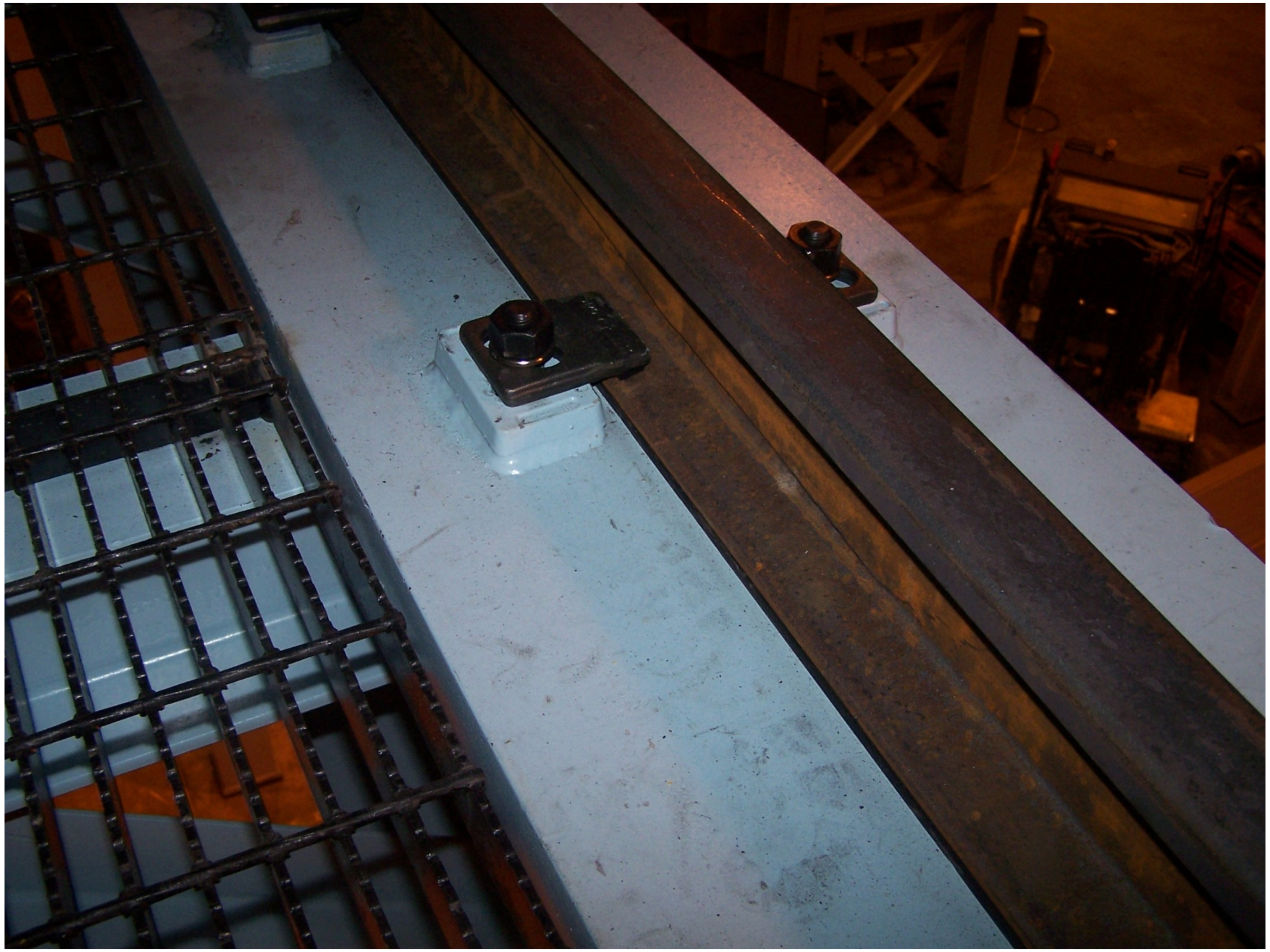
Examples of Steel Subjected to Fatigue

Examples of Steel Subjected to Fatigue

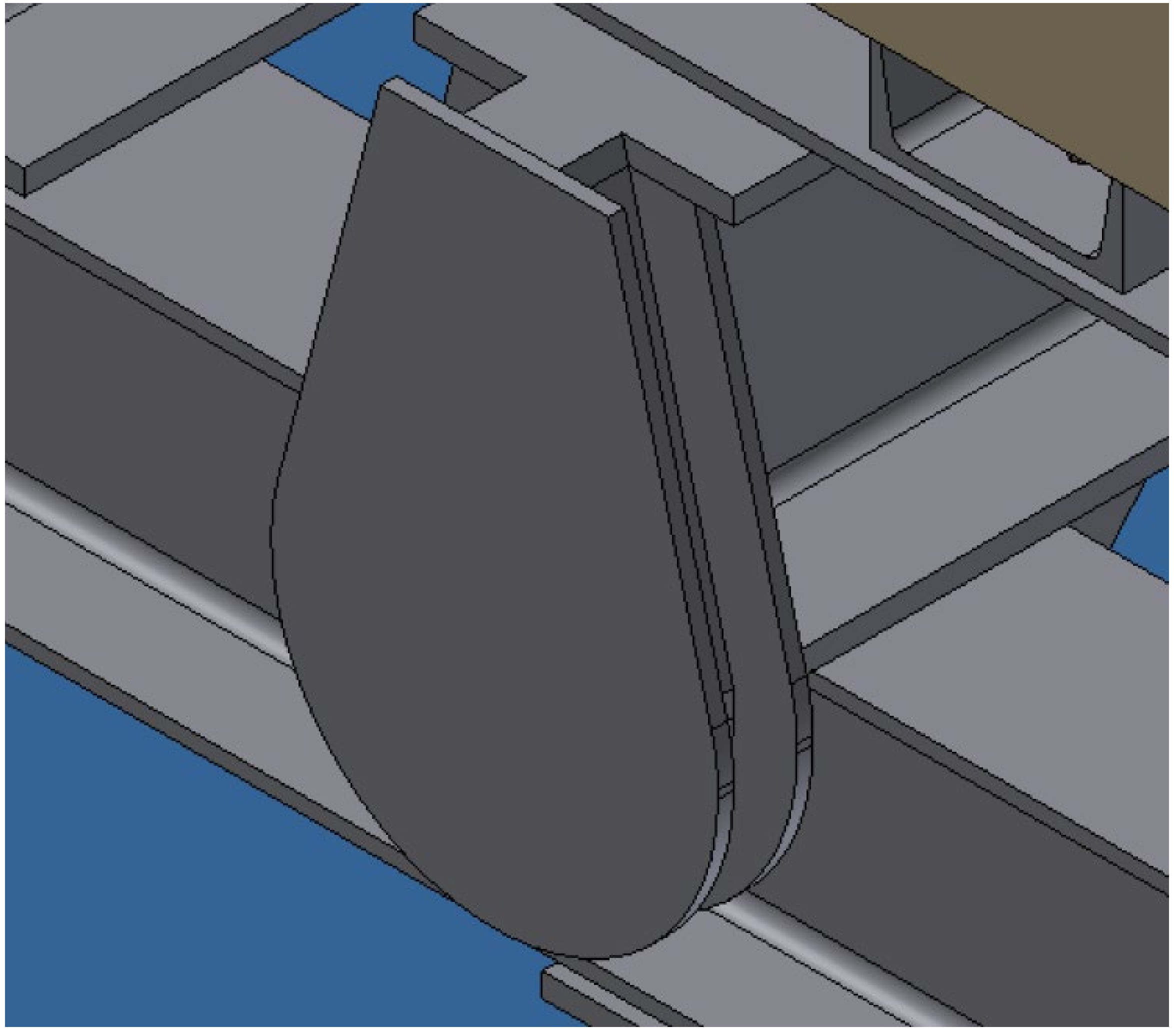
- Manufacturing sector with highly cyclic live loading:
  - Bridge Cranes, Crane Runways, Monorails, Manufacturing Equip.
- Transportation sector:
  - Steel Bridges

Bridge Crane

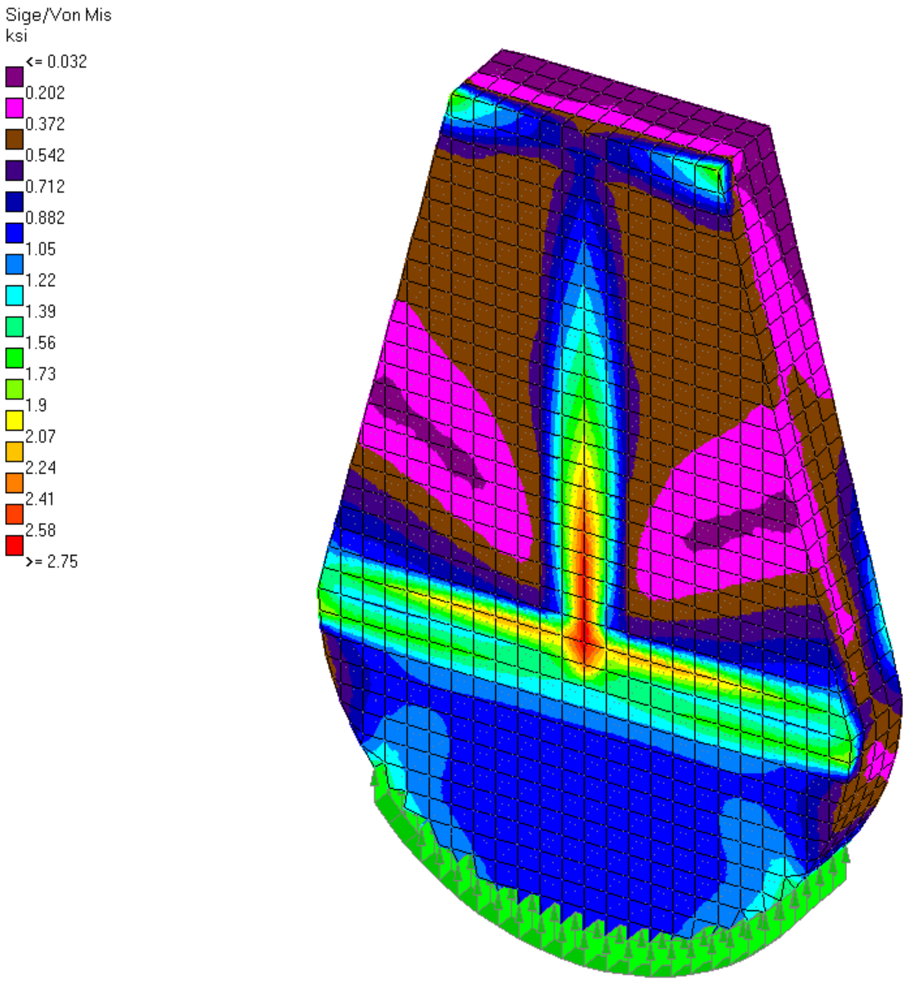
Bridge Crane



Lifting Eye



Lifting Eye



Sige/Von Mis
ksi
<= 0.032
0.202
0.372
0.542
0.712
0.882
1.05
1.22
1.39
1.56
1.73
1.9
2.07
2.24
2.41
2.58
>= 2.75

Lifting Eye (Video)

Steel Bridges

What Triggers Design for Fatigue (per AISC) ?

AISC Answer:

Steel members and connections subject to high-cycle loading within the elastic range of stresses of frequency and magnitude sufficient to initiate cracking and progressive failure

What triggers fatigue design?

- But….
  - If the number of lifetime live load cycles < 20,000
    - fatigue consideration is *not* required
  - If the live load stress range is less than the threshold stress, F_{TH}
    - *no fatigue evaluation required*
  - If the stress range is in full compression
    - *no fatigue evaluation required*

- Note that the provisions of Appendix 3 apply only to structures subject to temperatures less than 300°F.

Some Perspective on Load Cycles

- What does 20,000 live load cycles look like?

  - Design life of 25 years, crane is heavily loaded 1x per day x 5 days a week

    = 6,500 cycles (*fatigue check not required*)

  - Design life of 25 years, crane is heavily loaded 3x per day x 5 days a week

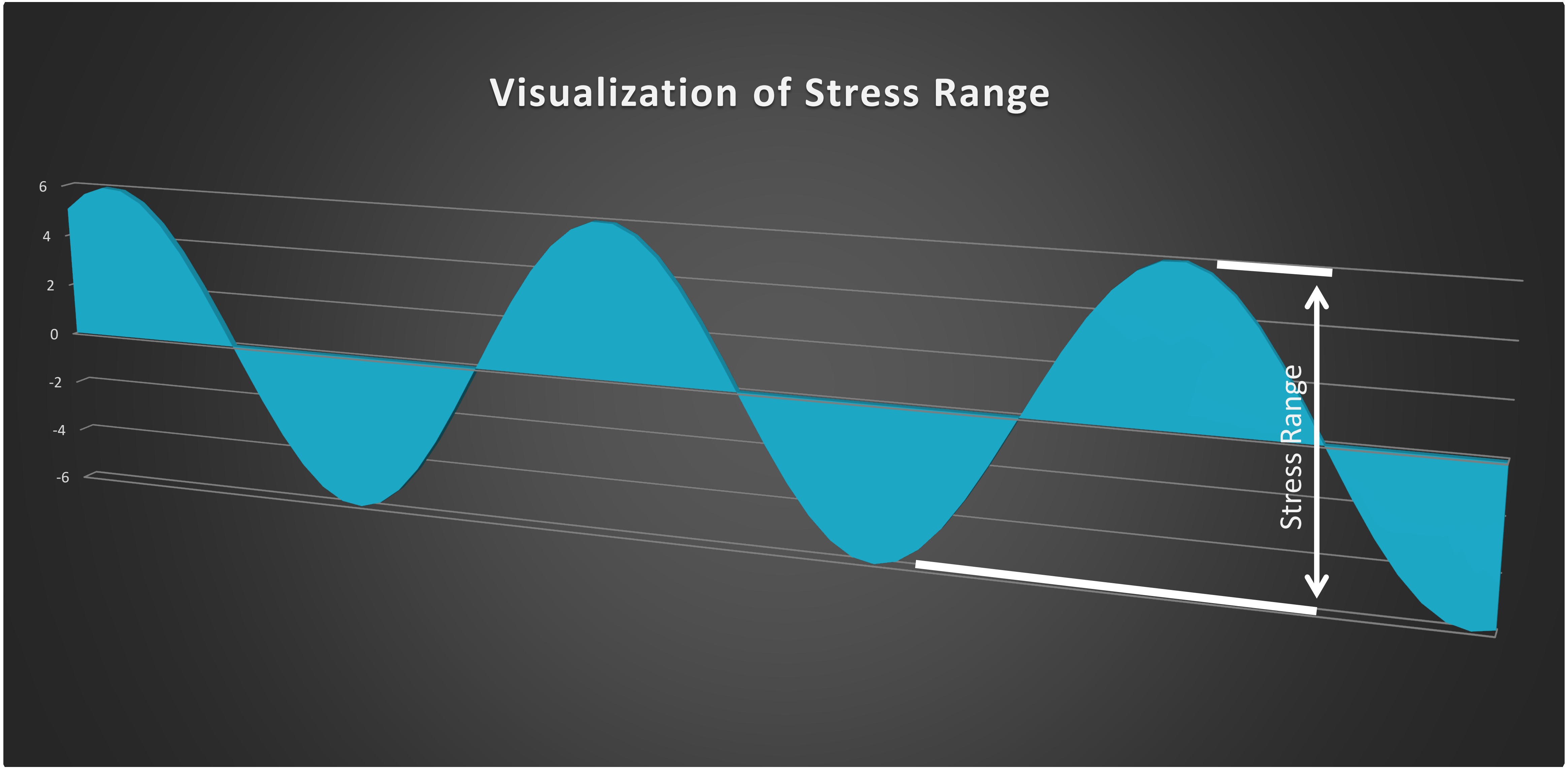
    = 19,500 cycles (fatigue check *not technically* required, < 20,000 cyles)

  - Design life of 50 years, crane is heavily loaded 15x per shift x 2 shifts x 5 days a week

    = 390,000 cycles (fatigue check *required!!)*

Stress Range

- For elements in complete compression or tension under cyclic loading or shear applied in single direction:
  - » Stress Range = (Tmax or Cmax or V_{max}) – 0
- For elements that see both tension & compression or shear in opposing directions, the stress range is the absolute value of the difference of the extreme values (using negative for one and positive for the other):
  - » Stress Range = $|T_{max} - C_{max}|$ or $|V_{max, +ve} - V_{max,-ve}|$


Visualization of Stress Range
6
4
2
0
-2
-4
-6
Stress Range

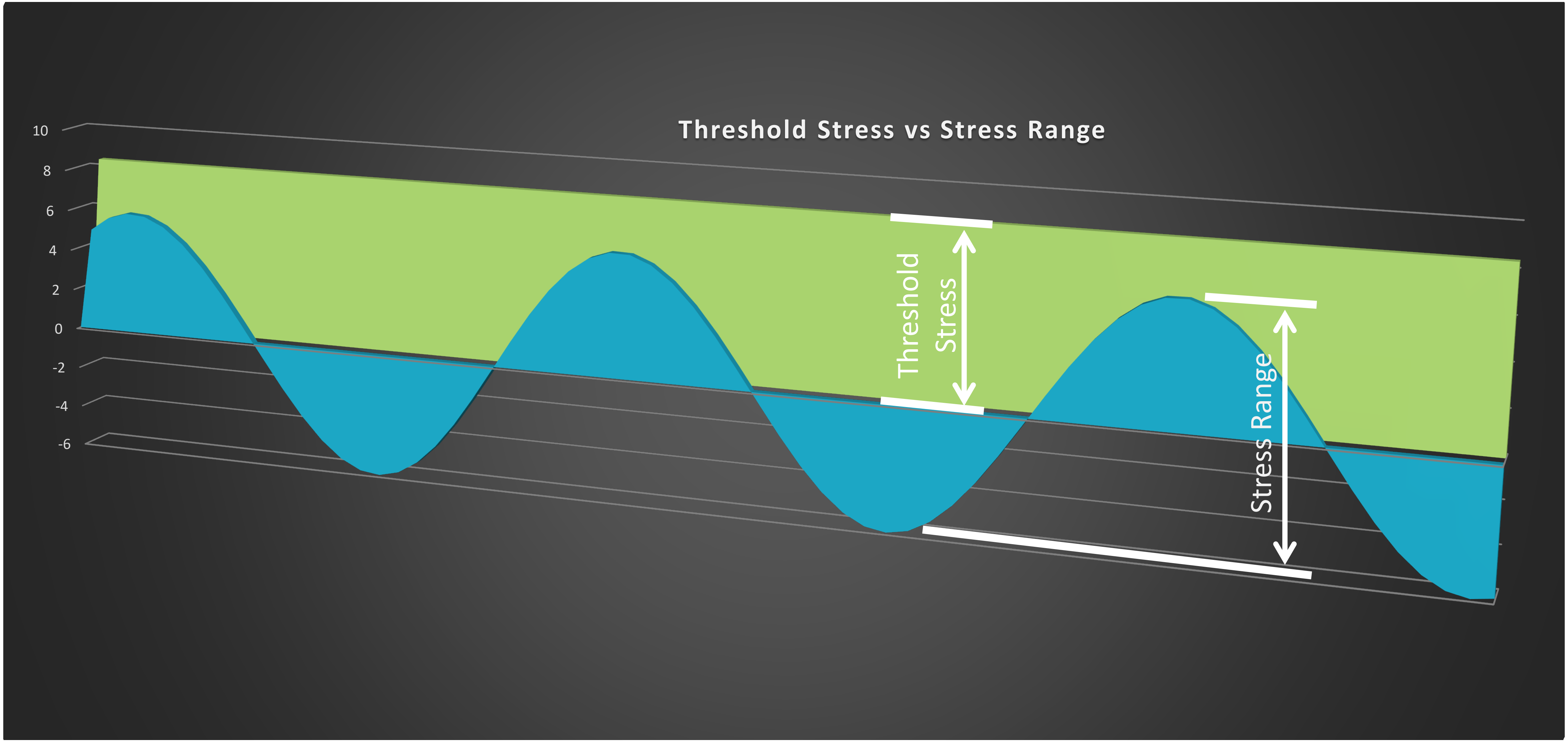
Threshold Stress

- The Threshold Stress (F_{TH}) or threshold allowable stress range is the stress level below which fatigue design does not need to be considered.

- From Table A-3.1 (shown later), threshold stress varies for each type of component/connection and varies from 24 ksi → 2.6 ksi

Put it another way:

"Threshold allowable stress range is the maximum stress range for indefinite design life."



Threshold Stress vs Stress Range
10
8
6
4
2
0
-2
-4
-6
Threshold Stress
Stress Range

Allowable stress range equation

Allowable Stress Range

In plain material and welded joints, the range of stress due to the applied cyclic loads shall not exceed the allowable stress range computed as follows.

(a) For stress categories A, B, B′, C, D, E and E′, the allowable stress range, F_{SR}, shall be determined by Equation A-3-1 or A-3-1M, as follows:

$$F_{SR} = 1{,}000\left(\frac{C_f}{n_{SR}}\right)^{0.333} \geq F_{TH} \quad \text{(A-3-1)}$$

$$F_{SR} = 6\,900\left(\frac{C_f}{n_{SR}}\right)^{0.333} \geq F_{TH} \quad \text{(A-3-1M)}$$

where

C_f = constant from Table A-3.1 for the fatigue category

F_{SR} = allowable stress range, ksi (MPa)

F_{TH} = threshold allowable stress range, maximum stress range for indefinite design life from Table A-3.1, ksi (MPa)

n_{SR} = number of stress range fluctuations in design life

*Updated in AISC 360-16

Allowable Stress Range

(b) For stress category F, the allowable stress range, F_{SR}, shall be determined by Equation A-3-2 or A-3-2M as follows:

$$F_{SR} = 100\left(\frac{1.5}{n_{SR}}\right)^{0.167} \geq 8 \text{ ksi} \qquad \text{(A-3-2)}$$

$$F_{SR} = 690\left(\frac{1.5}{n_{SR}}\right)^{0.167} \geq 55 \text{ MPa} \qquad \text{(A-3-2M)}$$

*Updated in AISC 360-16

Allowable Stress Range

16.1-198 PLAIN MATERIAL AND WELDED JOINTS [App. 3.3.

(c) For tension-loaded plate elements connected at their end by cruciform, T or corner details with partial-joint-penetration (PJP) groove welds transverse to the direction of stress, with or without reinforcing or contouring fillet welds, or if joined with only fillet welds, the allowable stress range on the cross section of the tension-loaded plate element shall be determined as the lesser of the following:

(1) Based upon crack initiation from the toe of the weld on the tension-loaded plate element (i.e., when $R_{PJP} = 1.0$), the allowable stress range, F_{SR}, shall be determined by Equation A-3-1 or A-3-1M for stress category C.

(2) Based upon crack initiation from the root of the weld, the allowable stress range, F_{SR}, on the tension loaded plate element using transverse PJP groove welds, with or without reinforcing or contouring fillet welds, the allowable stress range on the cross section at the root of the weld shall be determined by Equation A-3-3 or A-3-3M, for stress category C′ as follows:

$$F_{SR} = 1{,}000 R_{PJP} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \quad \text{(A-3-3)}$$

$$F_{SR} = 6\,900 R_{PJP} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \quad \text{(A-3-3M)}$$

where

R_{PJP}, the reduction factor for reinforced or nonreinforced transverse PJP groove welds, is determined as follows:

$$R_{PJP} = \frac{0.65 - 0.59\left(\frac{2a}{t_p}\right) + 0.72\left(\frac{w}{t_p}\right)}{t_p^{0.167}} \le 1.0 \quad \text{(A-3-4)}$$

$$R_{PJP} = \frac{1.12 - 1.01\left(\frac{2a}{t_p}\right) + 1.24\left(\frac{w}{t_p}\right)}{t_p^{0.167}} \le 1.0 \quad \text{(A-3-4M)}$$

$2a$ = length of the nonwelded root face in the direction of the thickness of the tension-loaded plate, in. (mm)
t_p = thickness of tension loaded plate, in. (mm)
w = leg size of the reinforcing or contouring fillet, if any, in the direction of the thickness of the tension-loaded plate, in. (mm)

If $R_{PJP} = 1.0$, the stress range will be limited by the weld toe and category C will control.

(3) Based upon crack initiation from the roots of a pair of transverse fillet welds on opposite sides of the tension loaded plate element, the allowable stress range, F_{SR}, on the cross section at the root of the welds shall be determined by Equation A-3-5 or A-3-5M, for stress category C″ as follows:

$$F_{SR} = 1{,}000 R_{FIL} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \quad \text{(A-3-5)}$$

$$F_{SR} = 6\,900 R_{FIL} \left(\frac{4.4}{n_{SR}} \right)^{0.333} \quad \text{(A-3-5M)}$$

where

R_{FIL} = reduction factor for joints using a pair of transverse fillet welds only

$$= \frac{0.06 + 0.72(w/t_p)}{t_p^{0.167}} \le 1.0 \quad \text{(A-3-6)}$$

$$= \frac{0.103 + 1.24(w/t_p)}{t_p^{0.167}} \le 1.0 \quad \text{(A-3-6M)}$$

If $R_{FIL} = 1.0$, the stress range will be limited by the weld toe and category C will control.

(c) For tension-loaded plate elements connected at their end by cruciform, T or corner details with partial-joint-penetration (PJP) groove welds transverse to the direction of stress, with or without reinforcing or contouring fillet welds, or if joined with only fillet welds, the allowable stress range on the cross section of the tension-loaded plate element shall be determined as the lesser of the following:

Fatigue Design Parameter Tables

- See Table A-3.1 starting on page 16.1-196 *

(8 sections over 10 pages + accompanying diagrams)

- Section 1 – Plain material away from any welding
- Section 2 – Connected material in mechanically fastened joints
- Section 3 – Welded joints joining components of built-up members
- Section 4 – Longitudinal filled welded end connections
- Section 5 – Welded joints transverse to direction of stress
- Section 6 – Base metal at welded transverse member connections
- Section 7 – Base metal at short attachments
- Section 8 - Miscellaneous

TABLE A-3.1
Fatigue Design Parameters

Description	Stress Category	Constant C_f	Threshold F_{TH}, ksi (MPa)	Potential Crack Initiation Point
SECTION 1—PLAIN MATERIAL AWAY FROM ANY WELDING				
1.1 Base metal, except noncoated weathering steel, with as-rolled or cleaned surfaces; flame-cut edges with surface roughness value of 1,000 μin. (25 μm) or less, but without reentrant corners	A	25	24 (165)	Away from all welds or structural connections
1.2 Noncoated weathering steel base metal with as-rolled or cleaned surfaces; flame-cut edges with surface roughness value of 1,000 μin. (25 μm) or less, but without reentrant corners	B	12	16 (110)	Away from all welds or structural connections
1.3 Member with reentrant corners at copes, cuts, block-outs or other geometrical discontinuities, except weld access holes				At any external edge or at hole perimeter
$R \geq$ 1 in. (25 mm), with radius, R, formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface	C	4.4	10 (69)	
$R \geq$ 3/8 in. (10 mm) and the radius, R, need not be ground to a bright metal surface	E′	0.39	2.6 (18)	
1.4 Rolled cross sections with weld access holes made to requirements of Section J1.6				At reentrant corner of weld access hole
Access hole $R \geq$ 1 in. (25 mm) with radius, R, formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface	C	4.4	10 (69)	
Access hole $R \geq$ 3/8 in. (10 mm) and the radius, R, need not be ground to a bright metal surface	E′	0.39	2.6 (18)	
1.5 Members with drilled or reamed holes				In net section originating at side of the hole
Holes containing pretensioned bolts	C	4.4	10 (69)	
Open holes without bolts	D	2.2	7 (48)	

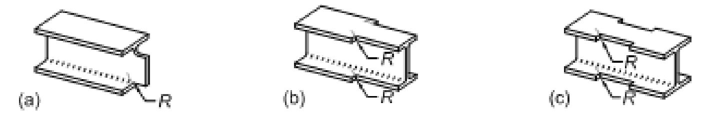
TABLE A-3.1 (continued)
Fatigue Design Parameters

Illustrative Typical Examples

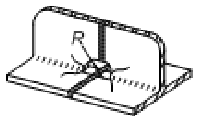
SECTION 1—PLAIN MATERIAL AWAY FROM ANY WELDING

1.1 and 1.2

1.3



1.4



1.5

TABLE A-3.1 (continued)
Fatigue Design Parameters

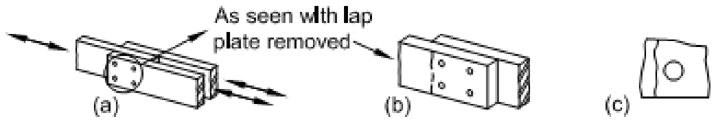
Description	Stress Category	Constant C_f	Threshold F_{TH}, ksi (MPa)	Potential Crack Initiation Point
SECTION 2—CONNECTED MATERIAL IN MECHANICALLY FASTENED JOINTS				
2.1 Gross area of base metal in lap joints connected by high-strength bolts in joints satisfying all requirements for slip-critical connections	B	12	16 (110)	Through gross section near hole
2.2 Base metal at net section of high-strength bolted joints, designed on the basis of bearing resistance, but fabricated and installed to all requirements for slip-critical connections	B	12	16 (110)	In net section originating at side of hole
2.3 Base metal at the net section of riveted joints	C	4.4	10 (69)	In net section originating at side of hole
2.4 Base metal at net section of eyebar head or pin plate	E	1.1	4.5 (31)	In net section originating at side of hole

TABLE A-3.1 (continued)
Fatigue Design Parameters

Illustrative Typical Examples

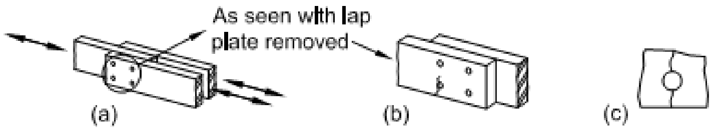
SECTION 2—CONNECTED MATERIAL IN MECHANICALLY FASTENED JOINTS

2.1



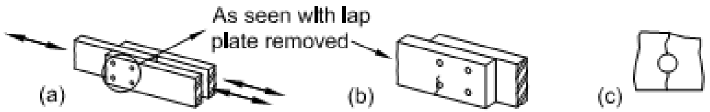
(Note: Figures are for slip-critical bolted connections.)

2.2



(Note: Figures are for bolted connections designed to bear, meeting the requirements of slip-critical connections.)

2.3



(Note: Figures are for snug-tightened bolts, rivets, or other mechanical fasteners.)

2.4

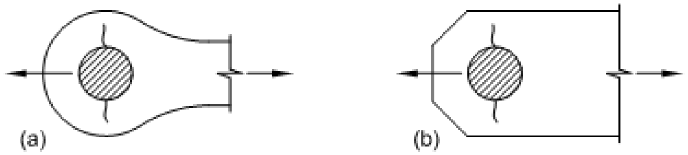


TABLE A-3.1 (continued)
Fatigue Design Parameters

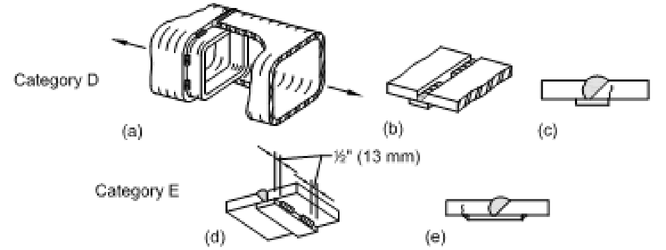
Description	Stress Category	Constant C_f	Threshold F_{TH}, ksi (MPa)	Potential Crack Initiation Point
SECTION 5—WELDED JOINTS TRANSVERSE TO DIRECTION OF STRESS				
5.5 Base metal and weld metal in or adjacent to transverse CJP groove welded butt splices with backing left in place				From the toe of the groove weld or the toe of the weld attaching backing when applicable
Tack welds inside groove	D	2.2	7 (48)	
Tack welds outside the groove and not closer than ½ in. (13 mm) to the edge of base metal	E	1.1	4.5 (31)	
5.6 Base metal and weld metal at transverse end connections of tension-loaded plate elements using PJP groove welds in butt, T- or corner-joints, with reinforcing or contouring fillets; F_{SR} shall be the smaller of the toe crack or root crack allowable stress range				
Crack initiating from weld toe	C	4.4	10 (69)	Initiating from weld toe extending into base metal
Crack initiating from weld root	C′	See Eq. A-3-3 or A-3-3M	None	Initiating at weld root extending into and through weld
5.7 Base metal and weld metal at transverse end connections of tension-loaded plate elements using a pair of fillet welds on opposite sides of the plate; F_{SR} shall be the smaller of the weld toe crack or weld root crack allowable stress range				
Crack initiating from weld toe	C	4.4	10 (69)	Initiating from weld toe extending into base metal
Crack initiating from weld root	C″	See Eq. A-3-5 or A-3-5M	None	Initiating at weld root extending into and through weld
5.8 Base metal of tension-loaded plate elements, and on built-up shapes and rolled beam webs or flanges at toe of transverse fillet welds adjacent to welded transverse stiffeners	C	4.4	10 (69)	From geometrical discontinuity at toe of fillet extending into base metal

TABLE A-3.1 (continued)
Fatigue Design Parameters

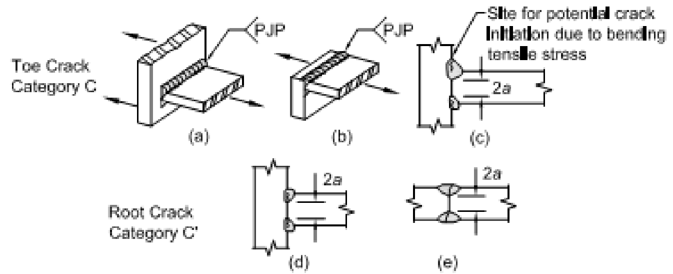
Illustrative Typical Examples

SECTION 5—WELDED JOINTS TRANSVERSE TO DIRECTION OF STRESS

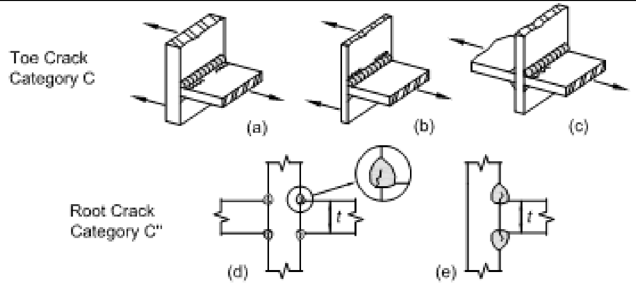
5.5



5.6



5.7



5.8

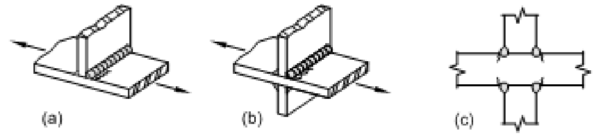


TABLE A-3.1 (continued)
Fatigue Design Parameters

Description	Stress Category	Constant C_f	Threshold F_{TH}, ksi (MPa)	Potential Crack Initiation Point
SECTION 8—MISCELLANEOUS				
8.1 Base metal at steel headed stud anchors attached by fillet weld or automatic stud welding	C	4.4	10 (69)	At toe of weld in base metal
8.2 Shear on throat of any fillet weld, continuous or intermittent, longitudinal or transverse	F	See Eq. A-3-2 or A-3-2M	See Eq. A-3-2 or A-3-2M	Initiating at the root of the fillet weld, extending into the weld
8.3 Base metal at plug or slot welds	E	1.1	4.5 (31)	Initiating in the base metal at the end of the plug or slot weld, extending into the base metal
8.4 Shear on plug or slot welds	F	See Eq. A-3-2 or A-3-2M	See Eq. A-3-2 or A-3-2M	Initiating in the weld at the faying surface, extending into the weld
8.5 High-strength bolts, common bolts, threaded anchor rods, and hanger rods, whether pretensioned in accordance with Table J3.1 or J3.1M, or snug-tightened with cut, ground or rolled threads; stress range on tensile stress area due to applied cyclic load plus prying action, when applicable	G	0.39	7 (48)	Initiating at the root of the threads, extending into the fastener

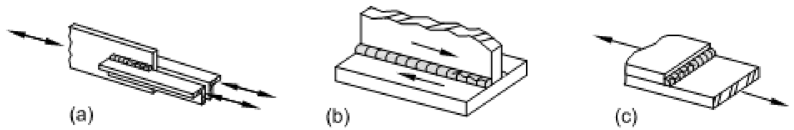
TABLE A-3.1 (continued)
Fatigue Design Parameters

Illustrative Typical Examples

SECTION 8—MISCELLANEOUS

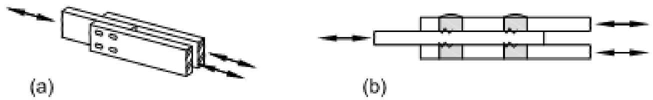
8.1

8.2

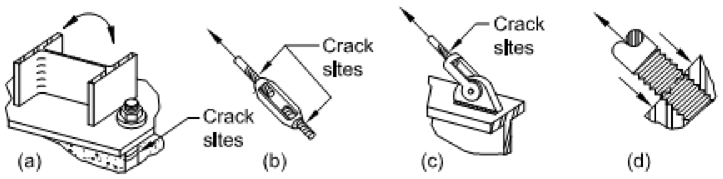


8.3

8.4



8.5



Bolts and Threaded Parts

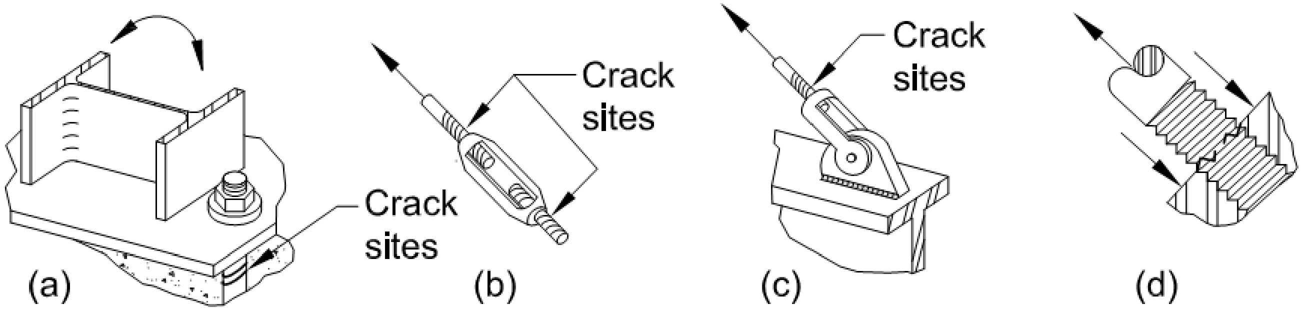
Bolts and Threaded Parts

- Section 3.4:
  - For mechanically fastened connections loaded in shear, use Section 2 of Table A-3.1
  - For bolts (or anchor rods), the maximum range of tensile stress from axial load + moment + prying action shall follow equation A-3-1 and use C_f and F_{TH} from Stress Category G, Case 8.5
    - Use net tensile area from applied axial load, moment, and prying action

Bolts and Threaded Parts

8.5 High-strength bolts, common bolts, threaded anchor rods, and hanger rods, whether pretensioned in accordance with Table J3.1 or J3.1M, or snug-tightened with cut, ground or rolled threads; stress range on tensile stress area due to applied cyclic load plus prying action, when applicable	G	0.39	7 (48)	Initiating at the root of the threads, extending into the fastener

8.5



Welded Components

Welded Components

- Welds frequently feature in fatigue design
- 4 out of 8 sections of Table A-3.1 have “weld” in the title and the misc. section has 4 weld sub-sections

Fatigue Design Parameter Tables (Review)

- See Table A-3.1 starting on page 16.1-196 *

(8 sections over 10 pages + accompanying diagrams)

- Section 1 – Plain material away from any welding
- Section 2 – Connected material in mechanically fastened joints
- Section 3 – Welded joints joining components of built-up members
- Section 4 – Longitudinal filled welded end connections
- Section 5 – Welded joints transverse to direction of stress
- Section 6 – Base metal at welded transverse member connections
- Section 7 – Base metal at short (welded) attachments
- Section 8 – Miscellaneous (4 out of 5 sub-categories are welded connections)

Welded Components

- Good design practice for weld design is to remain below the threshold stress in the weld and in the connected parts near the weld

3.1. GENERAL PROVISIONS

The fatigue resistance of members consisting of shapes or plate shall be determined when the number of cycles of application of live load exceeds 20,000. No evaluation of fatigue resistance of members consisting of HSS in building-type structures subject to code mandated wind loads is required. When the applied cyclic stress range is less than the threshold allowable stress range, F_{TH}, no further evaluation of fatigue resistance is required. See Table A-3.1.

The engineer of record shall provide either complete details including weld sizes or shall specify the planned cycle life and the maximum range of moments, shears and reactions for the connections.

The provisions of this Appendix shall apply to stresses calculated on the basis of the applied cyclic load spectrum. The maximum permitted stress due to peak cyclic loads shall be $0.66F_y$. In the case of a stress reversal, the stress range shall be computed as the numerical sum of maximum repeated tensile and compressive stresses or the numerical sum of maximum shearing stresses of opposite direction at the point of probable crack initiation.

The cyclic load resistance determined by the provisions of this Appendix is applicable to structures with suitable corrosion protection or subject only to mildly corrosive atmospheres, such as normal atmospheric conditions.

The cyclic load resistance determined by the provisions of this Appendix is applicable only to structures subject to temperatures not exceeding 300°F (150°C).

"EOR shall provide complete details including weld sizes or shall specify the planned cycle life and max. range of moments, shears and reactions for the connections."

Worked Questions (6)

Question 1:
A component will be cyclically loaded 5 times per day, every day, for 10 years. Design for fatigue is required, true or false? (Why / Why not?)

$n_{SR} = 5 \times 365 \times 10 = 18{,}250$

TRUE	FALSE
	Fatigue consideration not required

What triggers fatigue design? (Review)

- But….
  - If the number of lifetime live load cycles < 20,000,

    fatigue consideration is _not_ required
  - If the live load stress range is less than the threshold stress, F_{TH}, _no fatigue evaluation is needed_
  - Stress ranges that are full in compression require

    no fatigue evaluation
- Note that the provisions of Appendix 3 apply only to structures subject to temperatures less than 300°F.

Question 2:
A compression-only column will be cyclically loaded 5 times per day for 25 years. Design for fatigue is required, true of false?
Why / Why not?

$n_{SR} = 5 \times 365 \times 25 = 45{,}625$

TRUE	FALSE
	Fatigue consideration not required

What triggers fatigue design? (Review)

- But….
  - If the number of lifetime live load cycles < 20,000,

    fatigue consideration is ***not*** required
  - If the live load stress range is less than the threshold stress, F_{TH}, ***no fatigue evaluation is needed***
  - Stress ranges that are full in compression require

    no fatigue evaluation
- Note that the provisions of Appendix 3 apply only to structures subject to temperatures less than 300°F.

Question 3:
The threshold stress for a steel component is 16 ksi with 50,000 cycles of loading over its lifetime. The stress of the component fluctuates between 5 ksi in compression and 14 ksi in tension. Design for fatigue is required, true or false? Why / why not?

1: n_{SR} =50,000

2: Actual stress range = difference between 14 ksi (tension) and 5 ksi (compression).

TRUE	FALSE
True, number of cycles > 20,000 and stress range (19 ksi) > threshold stress range (= 16 ksi)	
✔	✖

Question 4:

For the previous question, what is the allowable design stress range according to equation A-3-1 assuming the component is plain material in Stress Category B?

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Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, C_f

TABLE A-3.1
Fatigue Design Parameters

Description	Stress Category	Constant C_f	Threshold F_{TH}, ksi (MPa)	Potential Crack Initiation Point
SECTION 1—PLAIN MATERIAL AWAY FROM ANY WELDING				
1.1 Base metal, except noncoated weathering steel, with as-rolled or cleaned surfaces; flame-cut edges with surface roughness value of 1,000 μin. (25 μm) or less, but without reentrant corners	A	25	24 (165)	Away from all welds or structural connections
1.2 Noncoated weathering steel base metal with as-rolled or cleaned surfaces; flame-cut edges with surface roughness value of 1,000 μin. (25 μm) or less, but without reentrant corners	B	12	16 (110)	Away from all welds or structural connections
1.3 Member with reentrant corners at copes, cuts, block-outs or other geometrical discontinuities, except weld access holes				At any external edge or at hole perimeter
$R \geq 1$ in. (25 mm), with radius, R, formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface	C	4.4	10 (69)	
$R \geq 3/8$ in. (10 mm) and the radius, R, need not be ground to a bright metal surface	E′	0.39	2.6 (18)	
1.4 Rolled cross sections with weld access holes made to requirements of Section J1.6				At reentrant corner of weld access hole
Access hole $R \geq 1$ in. (25 mm) with radius, R, formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface	C	4.4	10 (69)	
Access hole $R \geq 3/8$ in. (10 mm) and the radius, R, need not be ground to a bright metal surface	E′	0.39	2.6 (18)	
1.5 Members with drilled or reamed holes				In net section originating at side of the hole
Holes containing pretensioned bolts	C	4.4	10 (69)	
Open holes without bolts	D	2.2	7 (48)	

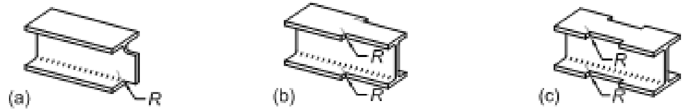
TABLE A-3.1 (continued)
Fatigue Design Parameters

Illustrative Typical Examples

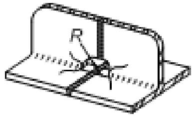
SECTION 1—PLAIN MATERIAL AWAY FROM ANY WELDING

1.1 and 1.2

1.3



1.4



1.5

Question 4:

For the previous question, what is the allowable design stress range according to equation A-3-1 assuming the component is plain material in Stress Category B?

Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, $C_f = 12$

Question 4:

For the previous question, what is the allowable design stress range according to equation A-3-1 assuming the component is plain material in Stress Category B?

Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, $C_f = 12$

2: Recall that N = 50,000 (from previous question)

$F_{SR} = (C_f / N)^{0.333} = 62$ ksi (!!)…note the small “N”

Question 4:

For the previous question, what is the allowable design stress range according to equation A-3-1 assuming the component is plain material in Stress Category B?

Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, $C_f = 12$

2: Recall that $n_{SR} = 50{,}000$ (from previous question)

→ $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333} = 62$ ksi (!!)…note the small "n_{SR}"

**Note that the maximum permitted stress due to peak cyclic loads is 0.66 F_y*

Question 5:

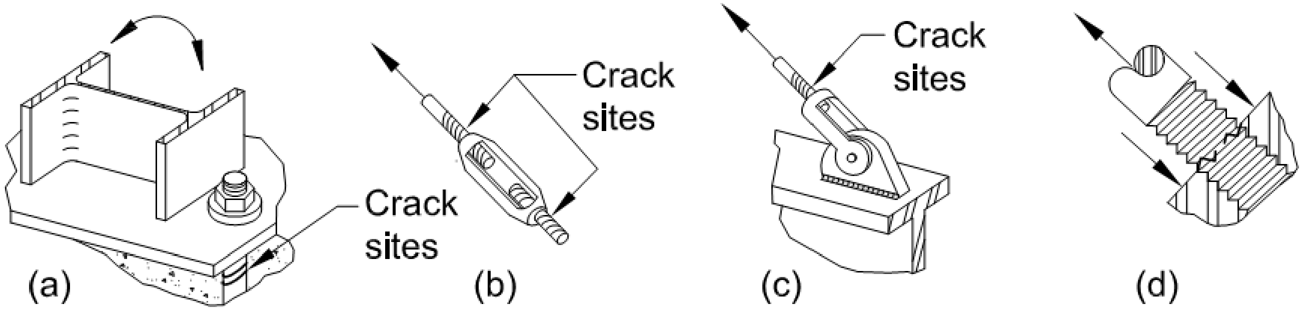
What is the design stress range for a ¾" dia. A325 bolt that is loaded 300,000 times cyclically? The bolt takes up to 5 kips in tension (3 kips from direct tension and 2 kips from moment)

Is the bolt OK?

Bolts and Threaded Parts (Review)

		C_f	F_{TH}	
8.5 High-strength bolts, common bolts, threaded anchor rods, and hanger rods, whether pretensioned in accordance with Table J3.1 or J3.1M, or snug-tightened with cut, ground or rolled threads; stress range on tensile stress area due to applied cyclic load plus prying action, when applicable	G	0.39	7 (48)	Initiating at the root of the threads, extending into the fastener

8.5



Question 5:

What is the design stress range for a ¾" dia. A325 bolt that is loaded 300,000 times cyclically? The bolt takes up to 5 kips in tension (3 kips from direct tension and 2 kips from moment)

Is the bolt OK?

Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, $C_f = 0.39$, $F_{TH} = 7$ ksi, $n_{SR} = 300{,}000$

Question 5:

What is the design stress range for a ¾" dia. A325 bolt that is loaded 300,000 times cyclically? The bolt takes up to 5 kips in tension (3 kips from direct tension and 2 kips from moment)

Is the bolt OK?

Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, $C_f = 0.39$, $F_{TH} = 7$ ksi, $n_{SR} = 300{,}000$

2: $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333} = 10.9$ ksi

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What is the design stress range for a ¾” dia. A325 bolt that is loaded 300,000 times cyclically? The bolt takes up to 5 kips in tension (3 kips from direct tension and 2 kips from moment)

Is the bolt OK?

Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, $C_f = 0.39$, $F_{TH} = 7$ ksi, $n_{SR} = 300{,}000$

2: $F_{SR} = 1000 \times (C_f / N)^{0.333} = 10.9$ ksi

3: Actual bolt stress range = 5 kips / A_{bolt} = 11.3 ksi

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What is the design stress range for a ¾" dia. A325 bolt that is loaded 300,000 times cyclically? The bolt takes up to 5 kips in tension (3 kips from direct tension and 2 kips from moment)

Is the bolt OK?

Recall that $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$

1: Look up Constant, $C_f = 0.39$, $F_{TH} = 7$ ksi, $n_{SR} = 300{,}000$

2: $F_{SR} = 1000 \times (C_f / N)^{0.333} = 10.9$ ksi

3: Actual bolt stress range = 5 kips / A_{bolt} = 11.3 ksi

→ Since actual stress = 11.3 ksi > F_{SR} BOLT NOT OK !

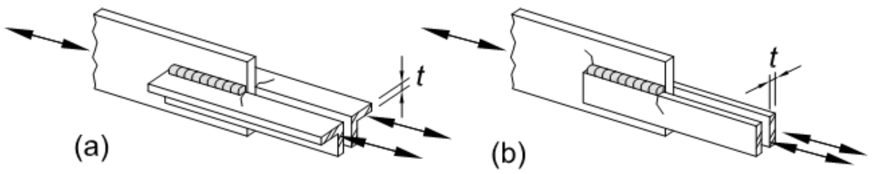
Question 6:

A diagonal brace on a piece of equipment experiences 1 ksi in compression and 2 ksi in tension. It is loaded approximately 5 times per minute, 24 hours per day, 7 days per week. The desired minimum design life is 10 years (n_{SR} = 26,280,000).

The brace (2L 6x4x7/8”) is longitudinally welded in an end connection to a gusset plate. What is the allowable stress range? Is the member sufficient at this connection?

SECTION 4—LONGITUDINAL FILLET WELDED END CONNECTIONS

4.1



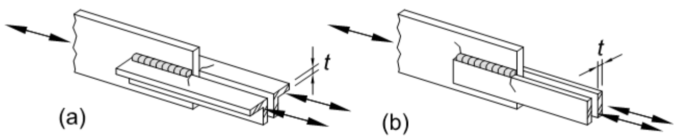
Question 6:

1: Stress range = 3ksi, n_{SR} = 26,280,000, longitudinally welded brace 2L 6x4x7/8”:

SECTION 4—LONGITUDINAL FILLET WELDED END CONNECTIONS				
4.1 Base metal at junction of axially loaded members with longitudinally welded end connections; welds are on each side of the axis of the member to balance weld stresses				Initiating from end of any weld termination extending into the base metal
$t_f \le$ 0.5 in. (13 mm)	E	1.1	4.5 (31)	
t_f > 0.5 in. (13 mm)	E′	0.39	2.6 (18)	
where t = connected member thickness, as shown in Case 4.1 figure, in. (mm)				

SECTION 4—LONGITUDINAL FILLET WELDED END CONNECTIONS

4.1



Question 6:

1: Stress range = 3ksi, n_{SR} = 26,280,000, longitudinally welded brace 2L 6x4x7/8".

2: $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$ where C_f = 1.1 or 0.39 depending on "t"

(…what was member thickness??)

since t > 0.5 in, C_f = 0.39 and F_{TH} = 2.6 ksi

→ F_{SR} = 2.47 ksi but since less than F_{TH}, F_{SR} = 2.6 ksi

SECTION 4—LONGITUDINAL FILLET WELDED END CONNECTIONS				
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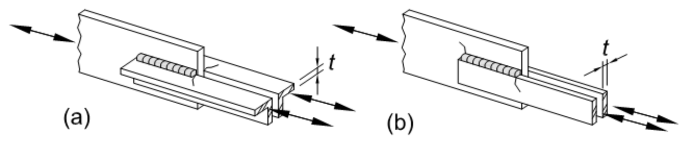
$t_f \le 0.5$ in. (13 mm)	E	1.1	4.5 (31)	
$t_f > 0.5$ in. (13 mm)	E′	0.39	2.6 (18)	
where t = connected member thickness, as shown in Case 4.1 figure, in. (mm)				

SECTION 4—LONGITUDINAL FILLET WELDED END CONNECTIONS

4.1



Question 6:

1: Stress range = 3ksi, n_{SR} = 26,280,000, longitudinally welded brace 2L 6x4x7/8".

2: $F_{SR} = 1000 \times (C_f / n_{SR})^{0.333}$ where C_f = 1.1 or 0.39 depending on "t"

(…what was member thickness??)

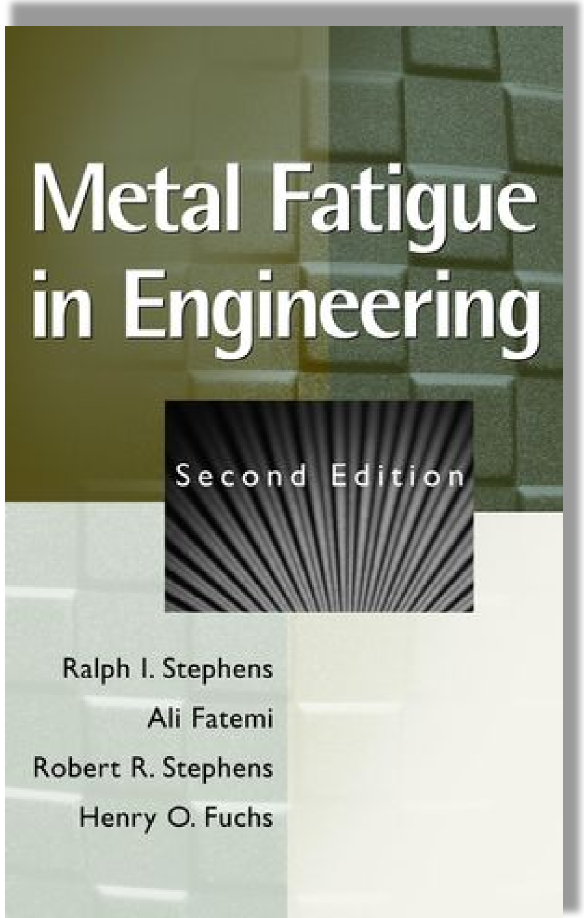
since t > 0.5 in, C_f = 0.39 and F_{TH} = 2.6 ksi

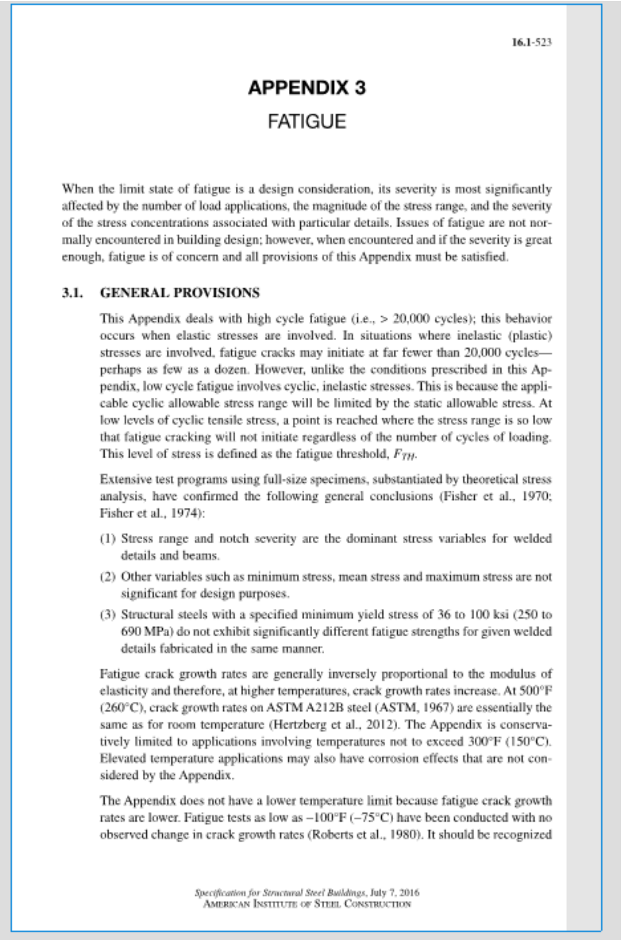
→ F_{SR} = 2.47 ksi but since less than F_{TH}, F_{SR} = 2.6 ksi

Is the brace adequately sized?

→ NO! Since actual stress range = 3 ksi > F_{SR} = 2.6 ksi

ADDITIONAL RESOURCES

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APPENDIX 3

FATIGUE

When the limit state of fatigue is a design consideration, its severity is most significantly affected by the number of load applications, the magnitude of the stress range, and the severity of the stress concentrations associated with particular details. Issues of fatigue are not normally encountered in building design; however, when encountered and if the severity is great enough, fatigue is of concern and all provisions of this Appendix must be satisfied.

3.1. GENERAL PROVISIONS

This Appendix deals with high cycle fatigue (i.e., > 20,000 cycles); this behavior occurs when elastic stresses are involved. In situations where inelastic (plastic) stresses are involved, fatigue cracks may initiate at far fewer than 20,000 cycles—perhaps as few as a dozen. However, unlike the conditions prescribed in this Appendix, low cycle fatigue involves cyclic, inelastic stresses. This is because the applicable cyclic allowable stress range will be limited by the static allowable stress. At low levels of cyclic tensile stress, a point is reached where the stress range is so low that fatigue cracking will not initiate regardless of the number of cycles of loading. This level of stress is defined as the fatigue threshold, F_{TH}.

Extensive test programs using full-size specimens, substantiated by theoretical stress analysis, have confirmed the following general conclusions (Fisher et al., 1970; Fisher et al., 1974):

(1) Stress range and notch severity are the dominant stress variables for welded details and beams.

(2) Other variables such as minimum stress, mean stress and maximum stress are not significant for design purposes.

(3) Structural steels with a specified minimum yield stress of 36 to 100 ksi (250 to 690 MPa) do not exhibit significantly different fatigue strengths for given welded details fabricated in the same manner.

Fatigue crack growth rates are generally inversely proportional to the modulus of elasticity and therefore, at higher temperatures, crack growth rates increase. At 500°F (260°C), crack growth rates on ASTM A212B steel (ASTM, 1967) are essentially the same as for room temperature (Hertzberg et al., 2012). The Appendix is conservatively limited to applications involving temperatures not to exceed 300°F (150°C). Elevated temperature applications may also have corrosion effects that are not considered by the Appendix.

The Appendix does not have a lower temperature limit because fatigue crack growth rates are lower. Fatigue tests as low as –100°F (–75°C) have been conducted with no observed change in crack growth rates (Roberts et al., 1980). It should be recognized

Specification for Structural Steel Buildings, July 7, 2016
AMERICAN INSTITUTE OF STEEL CONSTRUCTION

ADDITIONAL RESOURCES

REVIEW

- What is fatigue and where does it typically occur?
- What triggers fatigue design?
  - Illustration of the "*Stress Range*" concept
  - Explanation of the "*Threshold Stress*" term
- Allowable stress range equation (A-3-1) from AISC
  - Overview of Fatigue Design Parameter tables
- Considerations for bolted / welded connections
- Example questions

REVIEW

QUESTIONS AND DISCUSSION