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Course Description

Session L4: Fatigue and Fracture Design

November 2, 2017

This session will provide an introduction to fatigue and fracture concepts as applicable to steel bridges. The nominal stress approach to fatigue design and evaluation, as used in the AASHTO LRFD, will be presented with illustrative examples. A review of how fatigue has been treated in previous versions of the AASHTO Specifications will also be provided. The session will also include a basic introduction to fracture mechanics along with some simple numerical examples. The objectives of the AASHTO/AWS fracture control plan will be presented, and guidance on identifying a member as a Fracture Critical Member (FCM) will be provided. The session will also cover basic fatigue repair and retrofit concepts.

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Learning Objectives

- Become familiar with the nominal stress approach to fatigue design and evaluation as applicable to steel bridges, used in the AASHTO LRFD.
- Become familiar with the basics of fracture mechanics, reinforced with numerical examples.
- Understand the objectives of the AASHTO/AWS fracture control plan and understand how to identify a Fracture Critical Member (FCM).
- Gain an understanding of basic fatigue repair and retrofit concepts.

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Introduction to Steel Bridge Design

Session L4: Fatigue and Fracture Design

Presented by:
Robert J. Connor
Purdue University
West Lafayette, IN

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Introduction to Steel Bridge Design

- R1: Introduction to Bridge Engineering
- R2: Introduction and History of AASHTO LRFD Bridge Design Specifications
- R3: Steel Material Properties
- R4: Loads and Analysis

- L1: Steel Bridge Fabrication
- L2: Plate Girder Design and Stability
- L3: Effects of Curvature and Skew
- **L4: Fatigue and Fracture Design**

9

Session L4 Learning Objectives

- Recognize difference between fatigue and fracture
- Introduction to the nominal stress range approach for fatigue design
- Discuss influences of:
  - Detail geometry
  - Residual stress
- Discuss AASHTO LRFD Bridge Design Specifications approach to fatigue design
- Concept of Fracture Critical Members (FCMs)

10

What is fatigue?

- Process by which cracks initiate and grow by cyclic loading
  - Cyclic loading meaning trucks passing over bridge
  - Cars & light trucks (<20 kips) don't contribute
- Member loses capacity as a result of loss of cross section at the crack
  - Crack grows… less section
- The stress ranges producing these cracks do not need to be large
  - Poor fatigue category
  - When cracks are already present

11

Fatigue life

- Fatigue life- Generally refers to interval of time during which no *significant cracking* is expected
  - *Significant cracking* is based on laboratory testing and is not a unique value
    - Could be ½" crack, or 5% of stiffness lost, etc.
    - Does not mean member fractures
  - Fatigue life is measured in number of cycles
    - Typically converted to years

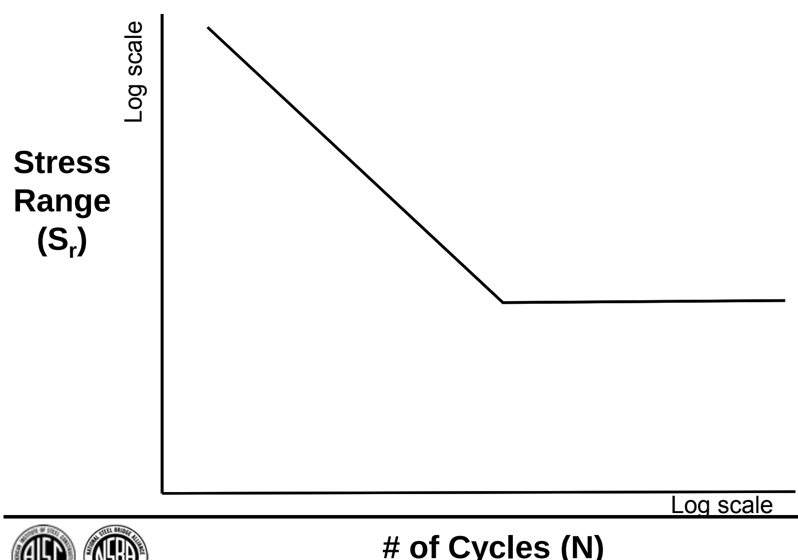
12

Fatigue life cont.

- Two regions of fatigue life:
  - **Infinite life**
    - Cracking due to fatigue not expected to occur
    - Constant-amplitude Fatigue Limit (CAFL): Boundary between finite and infinite life
      - Also Constant-amplitude Fatigue Threshold (CAFT)
  - **Finite life**
    - 2.5% probability of cracking at the end of fatigue life, or 97.5% probability of negligible fatigue cracking
    - Based on stress range (S_r), # cycles (N), and detail category (to be discussed further)

13

AASHTO Fatigue Curves



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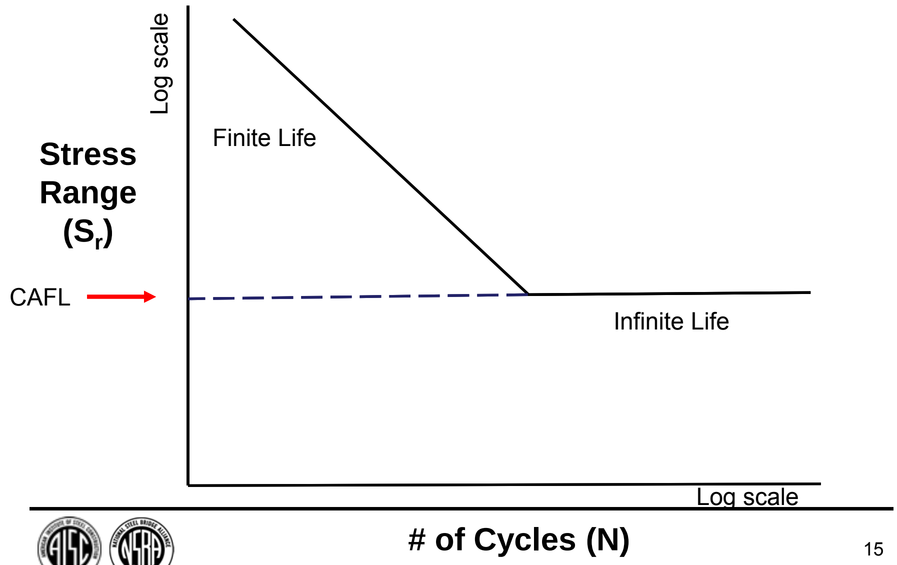
AASHTO Fatigue Curves



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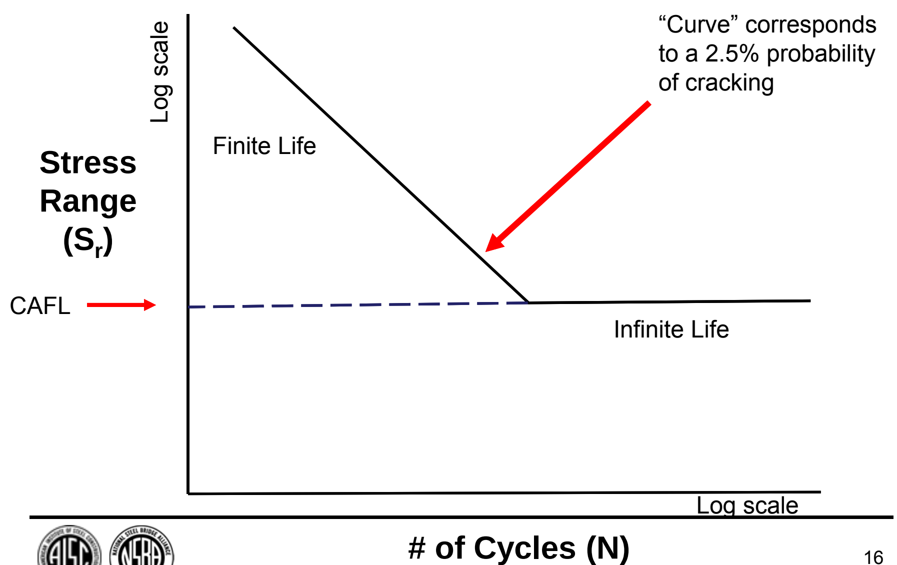
AASHTO Fatigue Curves



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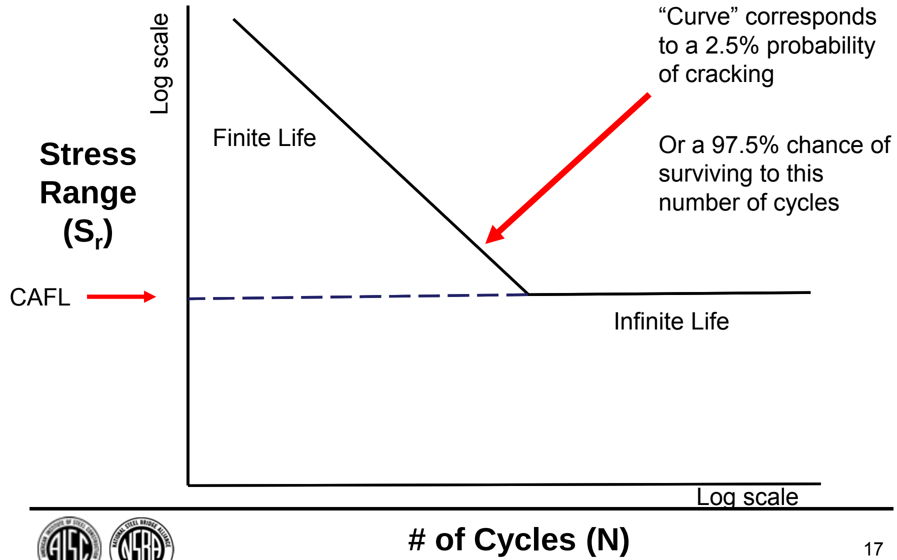
AASHTO Fatigue Curves



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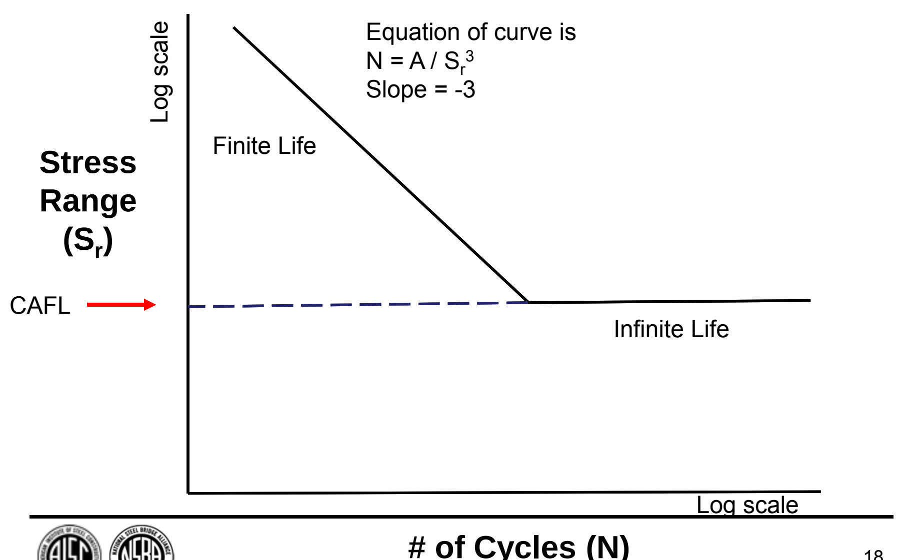
AASHTO Fatigue Curves



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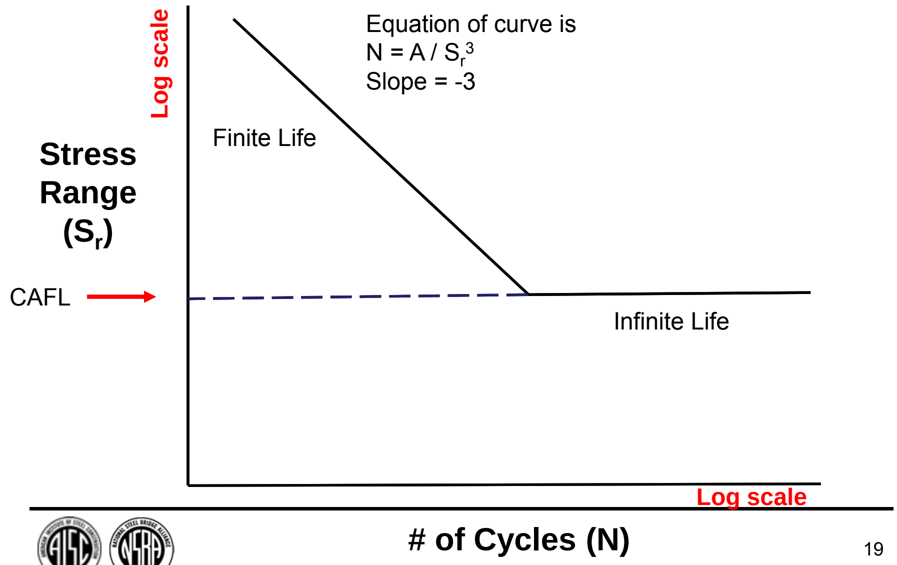
AASHTO Fatigue Curves



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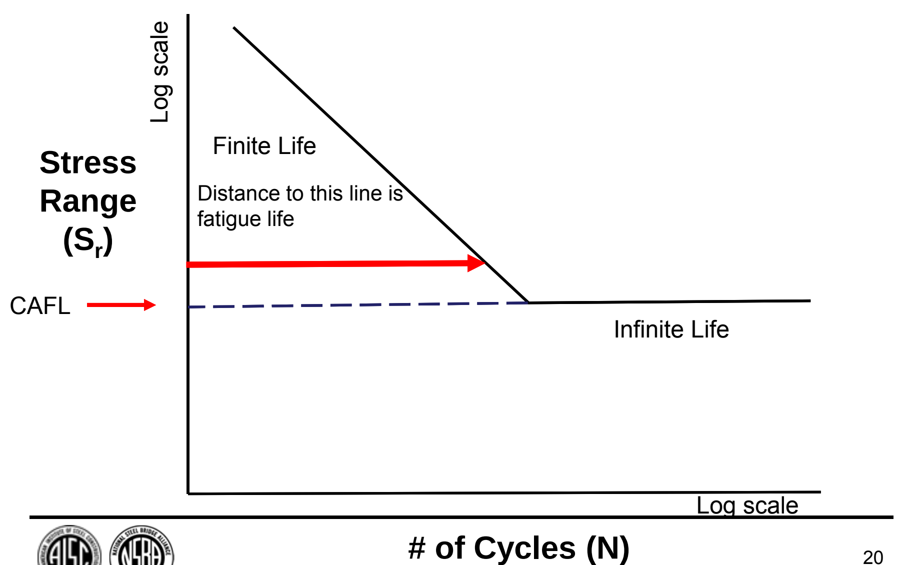
AASHTO Fatigue Curves



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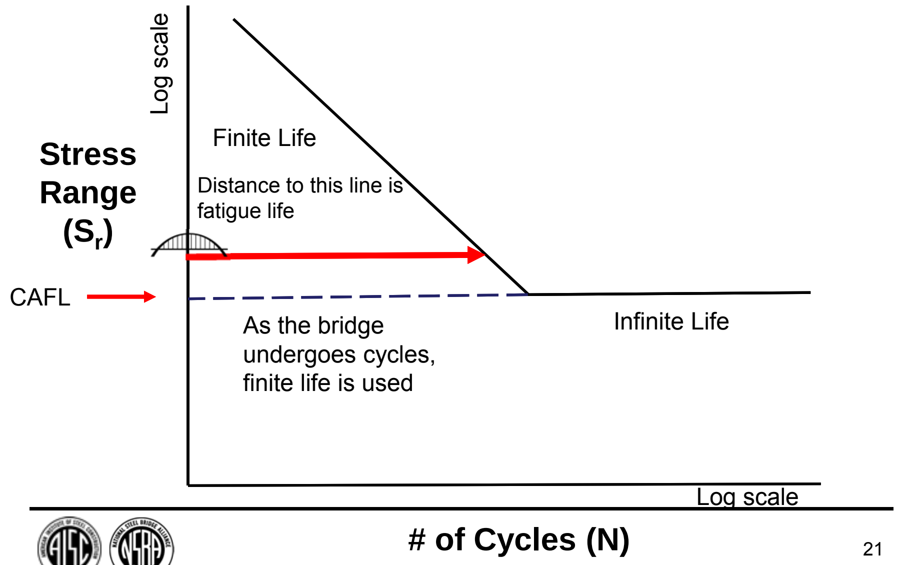
AASHTO Fatigue Curves



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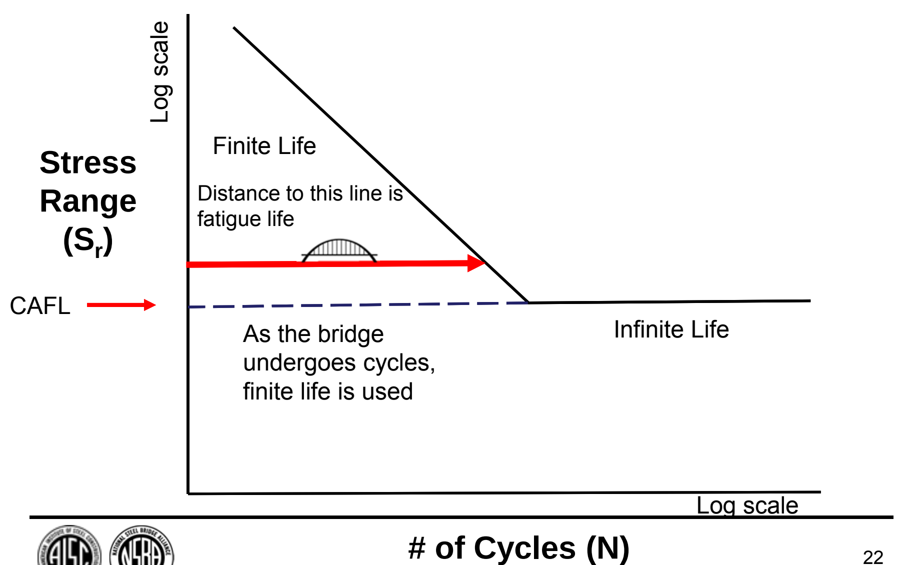
AASHTO Fatigue Curves



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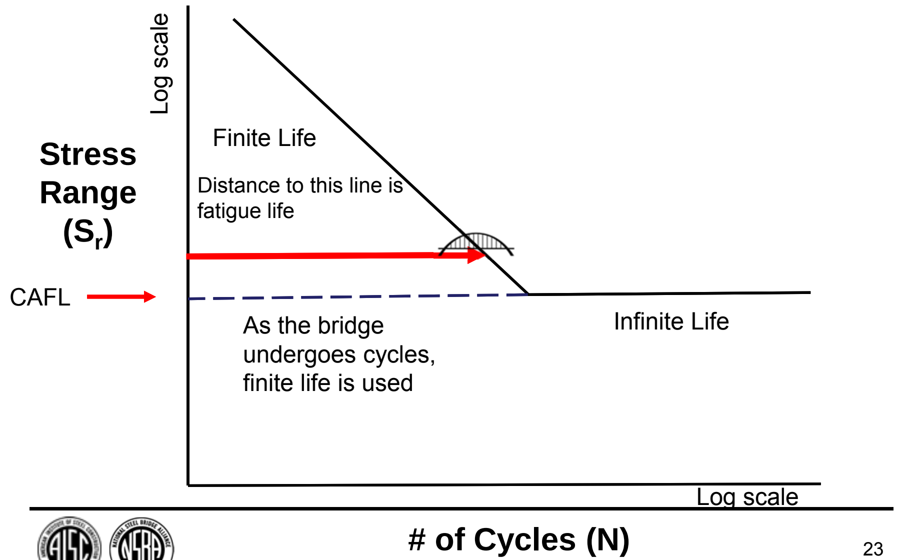
AASHTO Fatigue Curves



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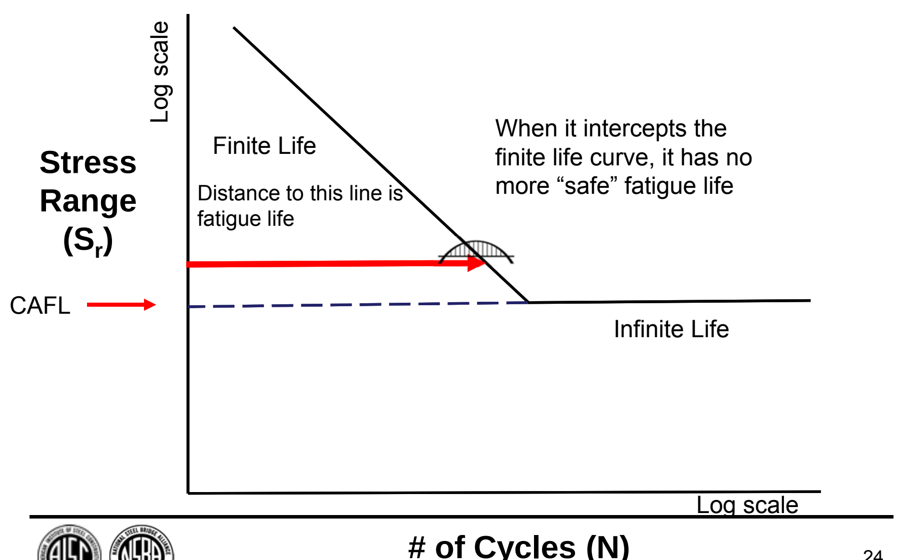
AASHTO Fatigue Curves



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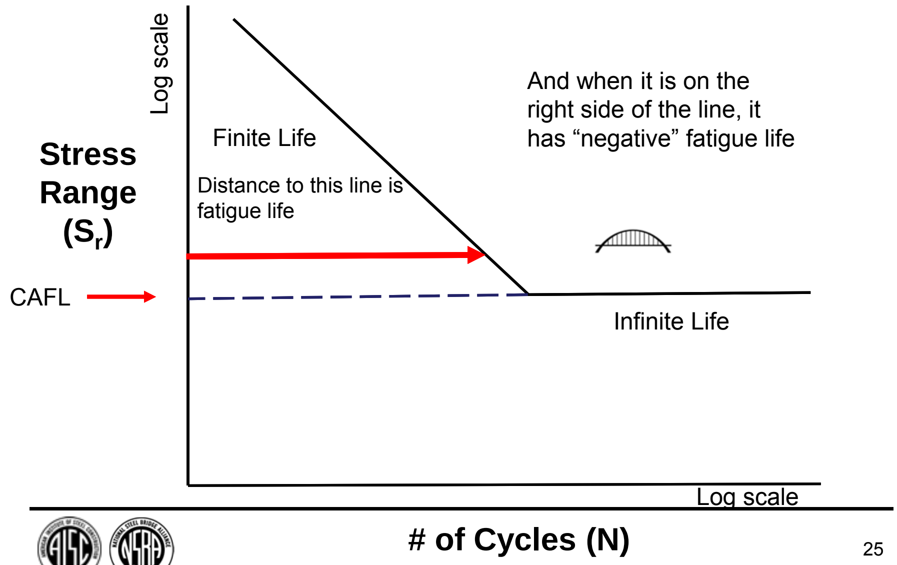
AASHTO Fatigue Curves



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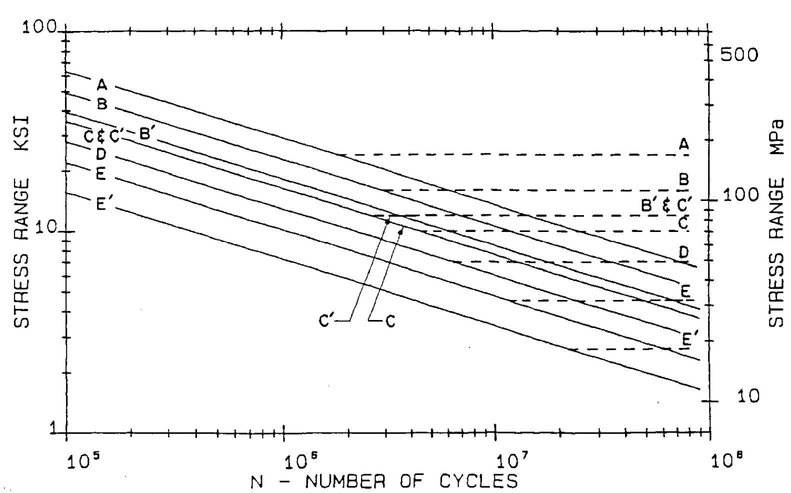
Modern AASHTO S-n curves



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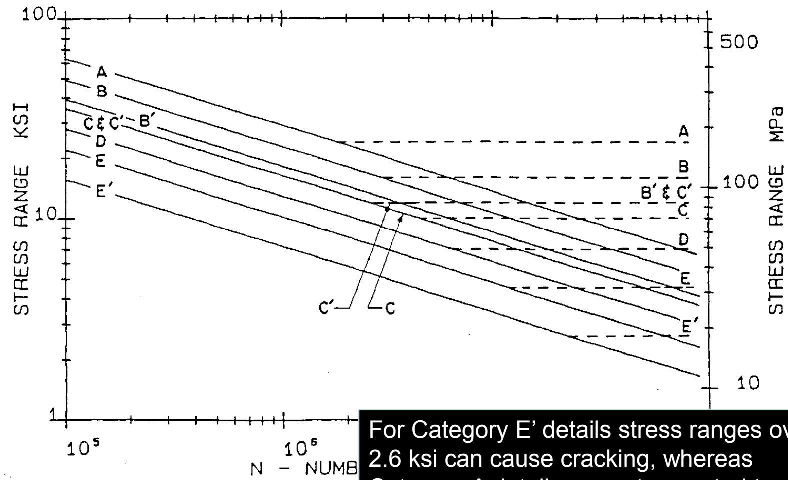
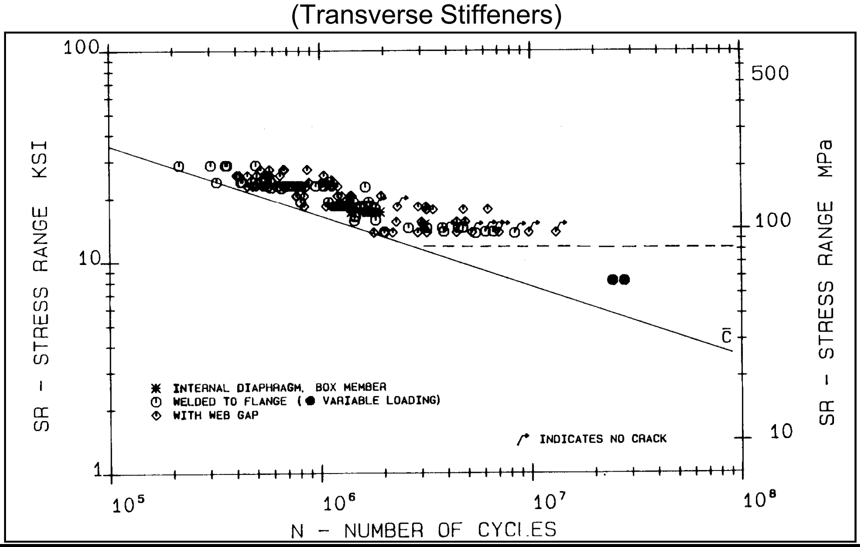
Modern AASHTO S-n curves



For Category E' details stress ranges over 2.6 ksi can cause cracking, whereas Category A details are not expected to crack until stress range exceeds 24 ksi

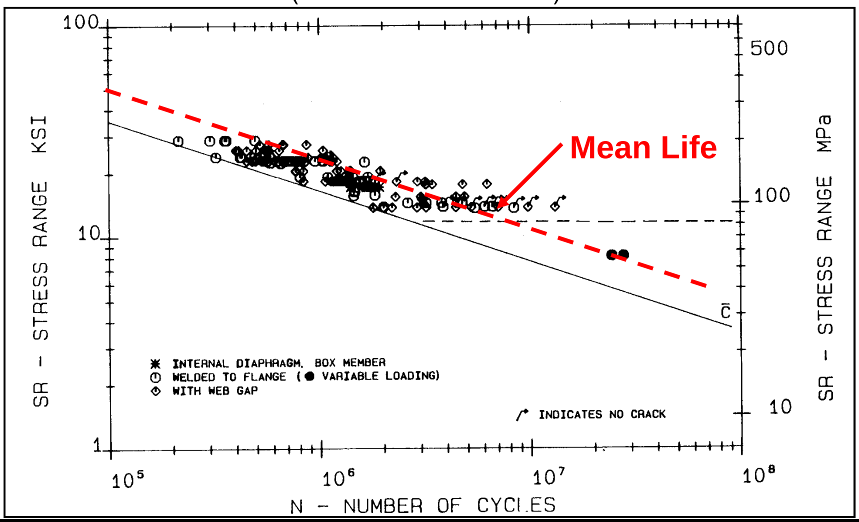
Safe Life vs. Mean Life

(Transverse Stiffeners)



Safe Life vs. Mean Life

(Transverse Stiffeners)



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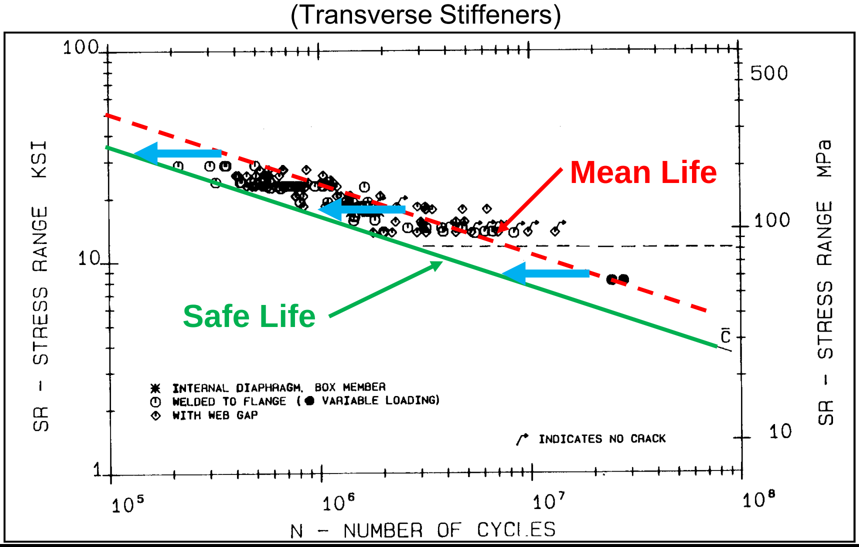
Safe Life vs. Mean Life

(Transverse Stiffeners)



30

Influence of Loads

- Magnitude of load (S_r)
  - How large is the stress range?
  - Stress range = S_r
- Frequency of occurrence (N)
  - How often are cycles applied?
  - ADTT (average daily truck traffic)
- *Above parameters define load-range or stress-range spectrum*

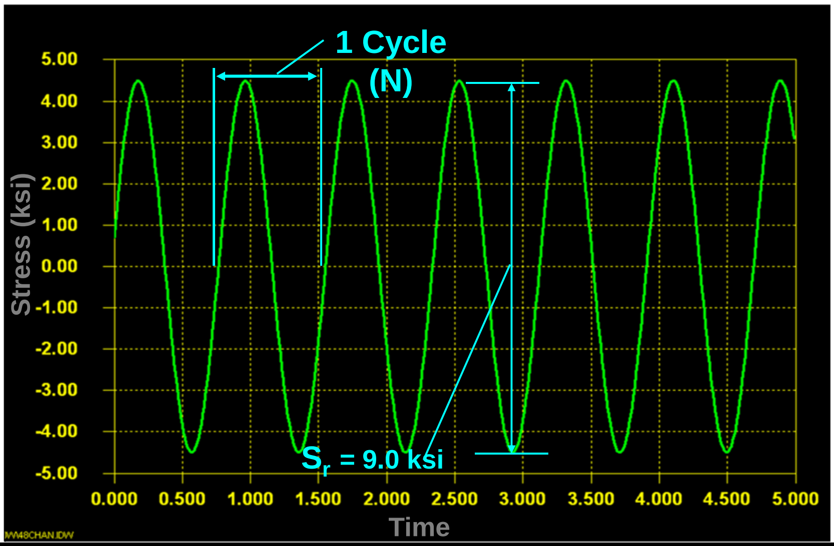
31

How do we define and determine…

- Stress Range (S_r)?
- Number of Cycles (N)?

32

Stress range and cycles



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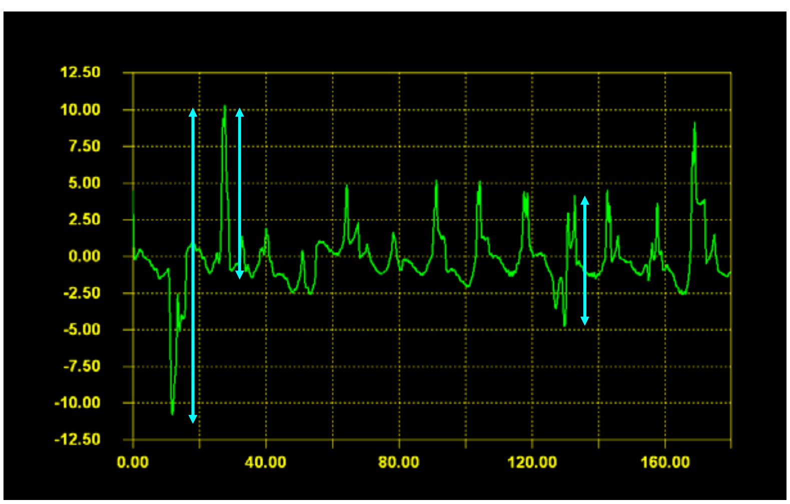
Real stress range spectrums



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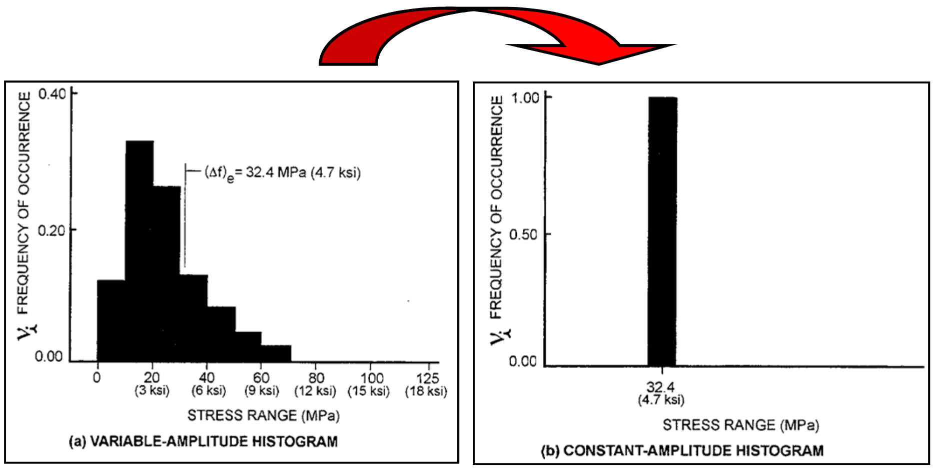
Conversion to equivalent constant amplitude



35

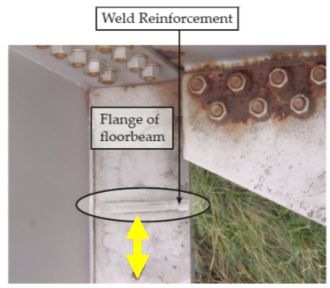
Resistance - Detail Categories

- Grouped into categories from A to E’
  - A is most fatigue resistant (e.g., base metal)
  - E’ is least fatigue resistant (e.g., cover plate termination)
- Detail categories account for variables which are difficult to quantify analytically
  - Weld discontinuities
  - Local stress concentrations due to geometry of detail
  - Residual stresses

36

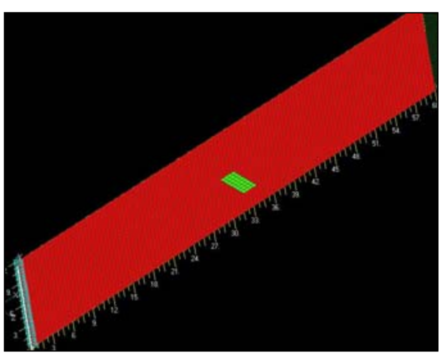
Resistance - Detail Categories

- Usually a link between cracking mode and stress concentration within each category
  - Transverse connection plates and transverse butt welds when reinforcement is not removed, are both Category C
    - Both are short attachments transverse to primary stresses
    - Weld toe cracking controls
    - Stress concentrations are similar

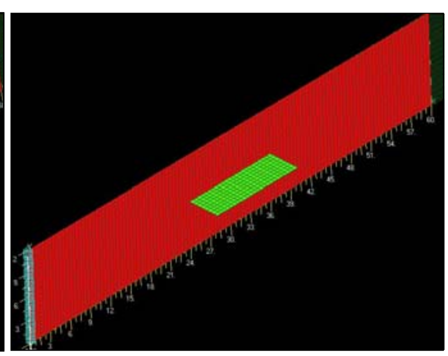


37

Influence of Attachment Length on Detail Category



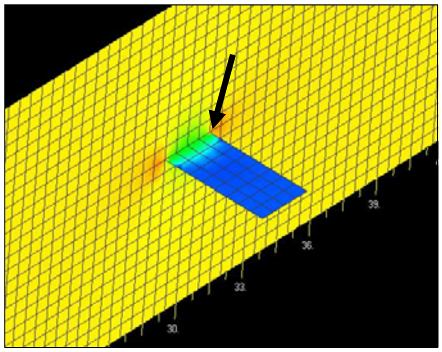
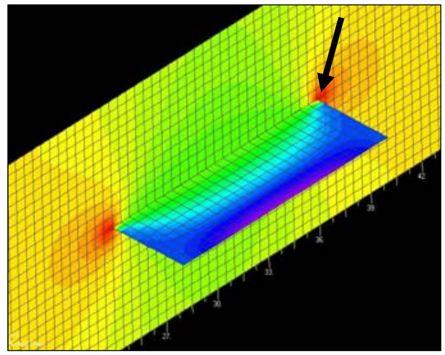
Short Attachment



Long Attachment

38

Influence of Attachment Length on Detail Category

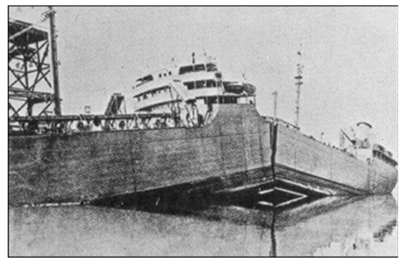
Longer attachments "attract" more stress resulting in increased stress concentration at terminations (i.e., weld toe!)

Introduction to Brittle Fracture

What is brittle fracture?

Definition:

"Catastrophic failure in a material that usually occurs without any plastic deformation"



41

Characteristics of Brittle Fracture

- Applied stress ≤ yield stress
- Propagates at extremely high velocity
  - 7,000 ft/s (speed of sound ≈ 1,100 ft/s)
- Little or no shear
- Fracture surface appears "flat"
  - Rough texture
- If detail is susceptible to brittle fracture, you can't inspect for it!!

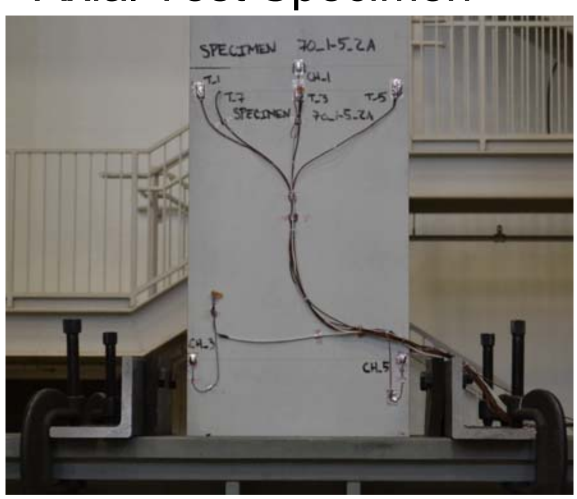
42

Fracture Mechanics

- What is Fracture Mechanics?
  - Mathematical analysis of solids with notches, cracks, or defects
- Like any other limit state
  - Strength, deflection, buckling, etc.

43

Brittle Fracture
Axial Test Specimen



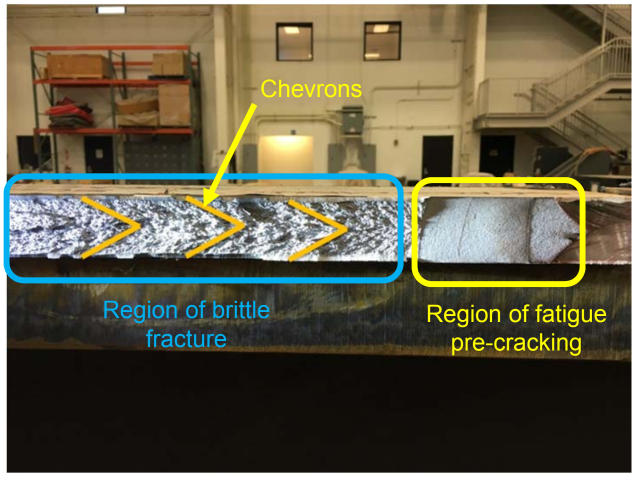
44

Brittle Fracture

Axial Test Specimen

45

Fatigue vs Fracture Surfaces



46

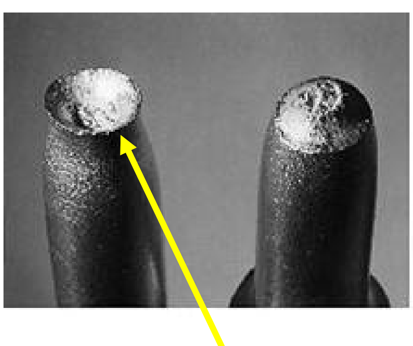
Likelihood of Fracture

- Influenced by
  - Material toughness
  - Applied stress
  - Presence of cracks or crack-like defects
- Material toughness influenced by
  - Temperature
  - Load rate
  - Alloy / steel composition / processing

47

Ductile Fracture

BRITTLE FRACTURE



Notice the shear lips

48

Example of Brittle Fracture

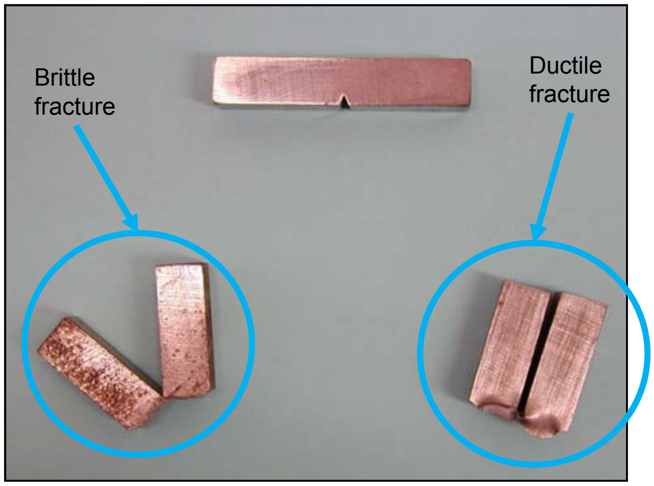
49

How Do We Measure a Material's Resistance to Fracture?

- Direct measure of fracture toughness
  - Compact Tension (CT) Test
  - Single-Edge Bend (SE(B)) Test
- Indirect with Charpy impact test
  - Most common test
  - Measure of energy absorption

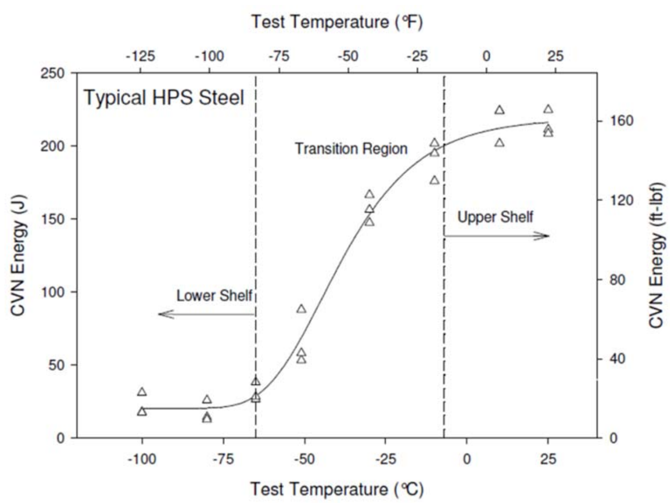
50

Charpy Testing



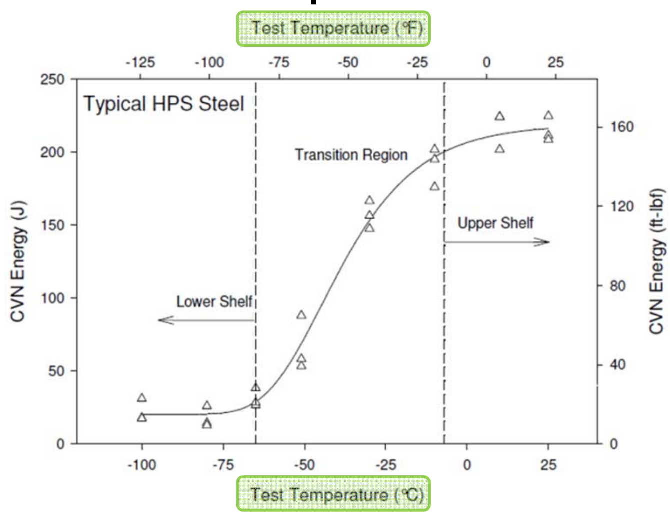
51

Example Data



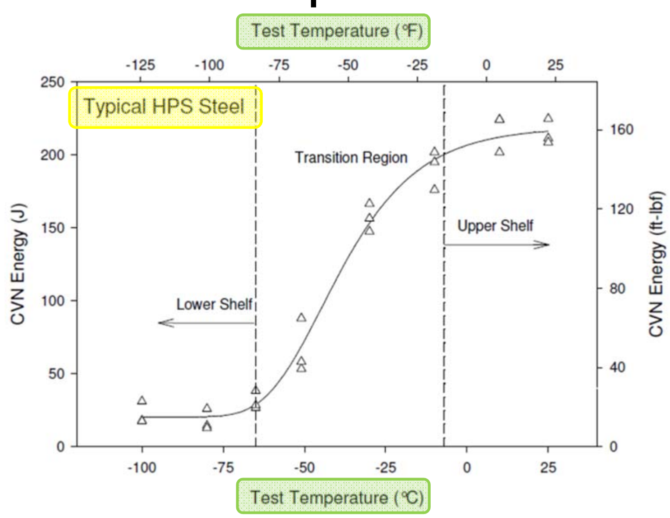
52

Example Data



53

Example Data



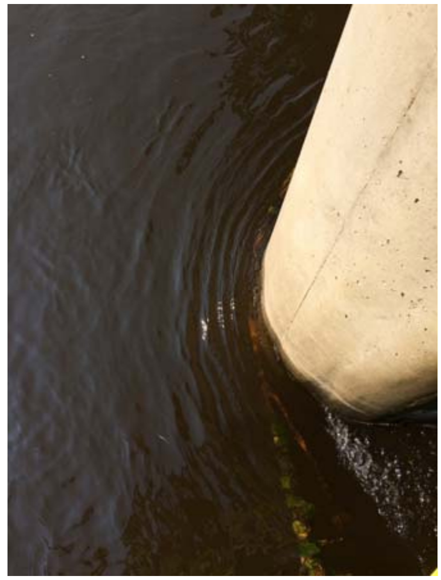
54

Fatigue vs Brittle Fracture

- Fatigue
  - Slow, stable crack growth over time
  - If live load is removed, growth stops
  - Crack growth is independent of material properties
  - You can inspect for fatigue damage
  - Fatigue is explicitly addressed (calculations) in AASHTO LRFD
- Fracture
  - Brittle or explosive instantaneous cracking
  - Potential for fracture is influenced by material properties
    - Properties influenced by thermal effects
  - Even if live load is removed, fracture can still occur
    - Drop in temperature -> decrease in toughness
  - Cannot inspect for brittle fracture
    - Generally, you find fractures <u>after</u> they occur
  - Fracture control is addressed indirectly in AASHTO LRFD
    - Material selection, detailing, fabrication, weld consumables
    - No explicit calculations

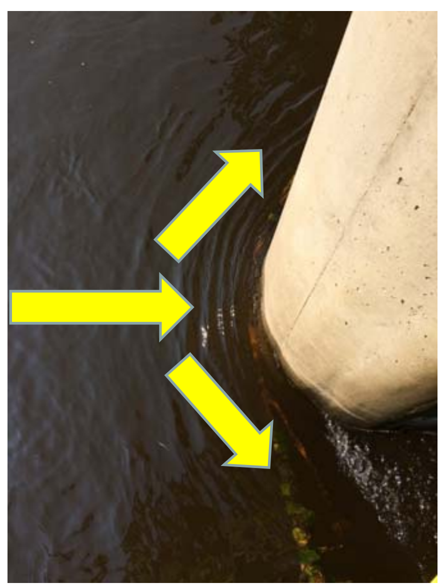
Effects of geometry and residual stresses

Water flow analogy



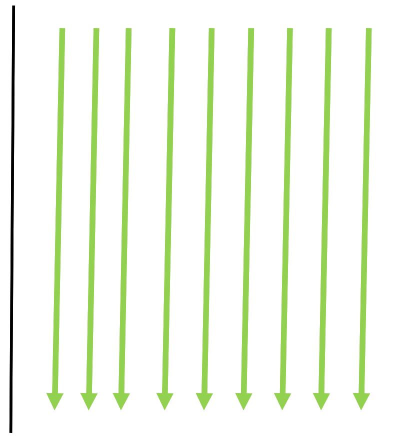
57

Water flow analogy



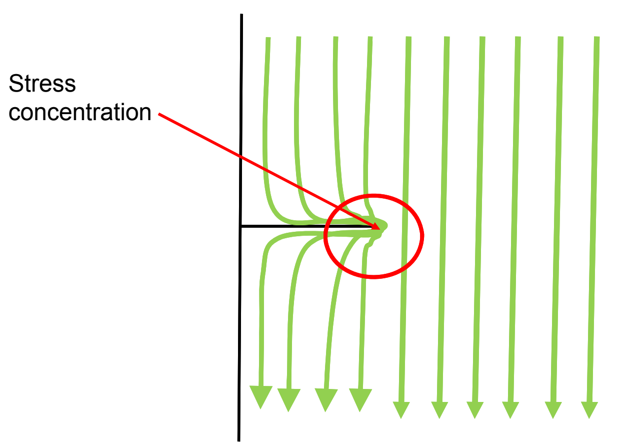
58

Stress flow without defect



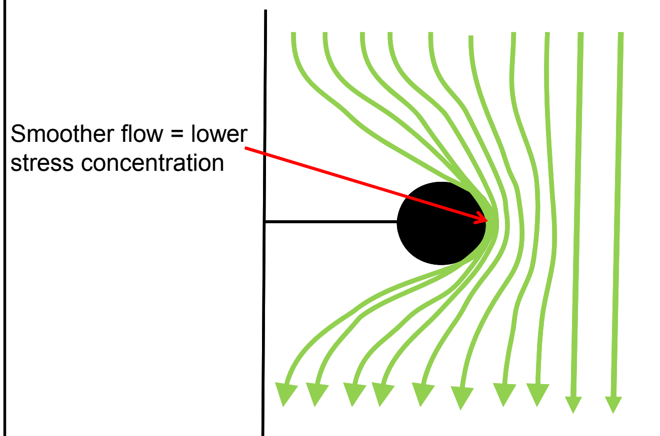
59

Stress flow with defect



60

Stress flow with hole

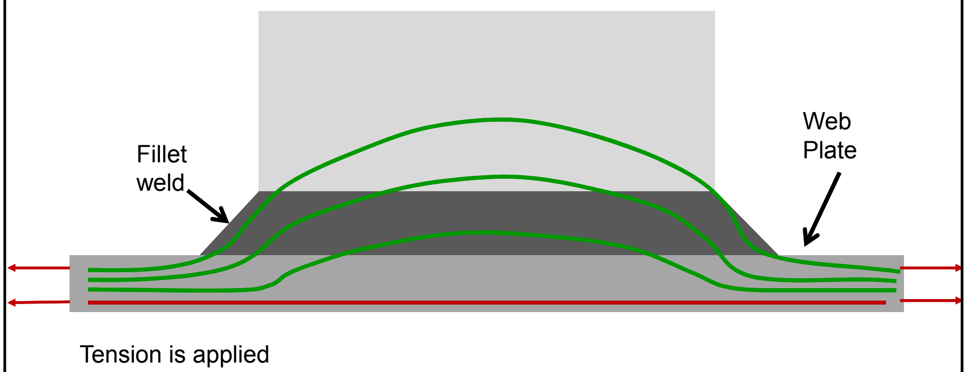


61

Stress flow through welded attachment

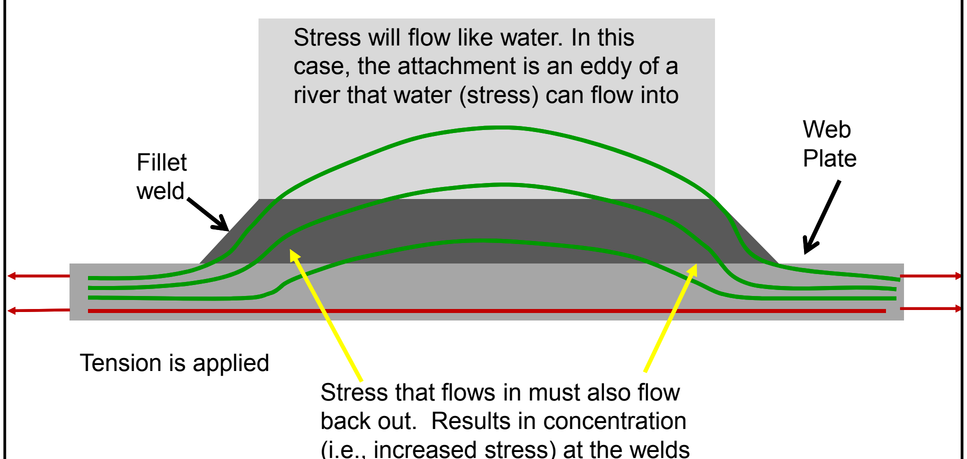
62

Stress flow through weld



63

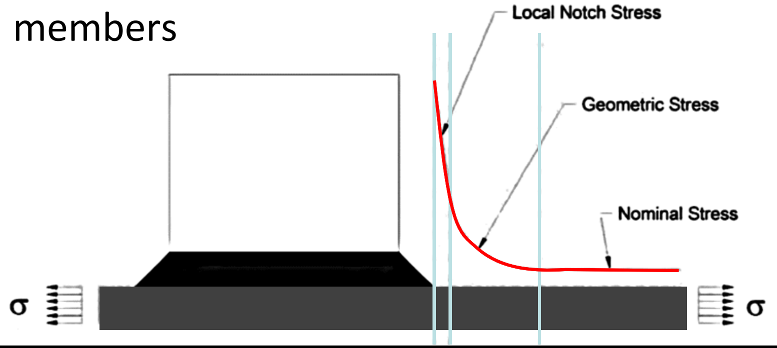
Stress flow through weld



64

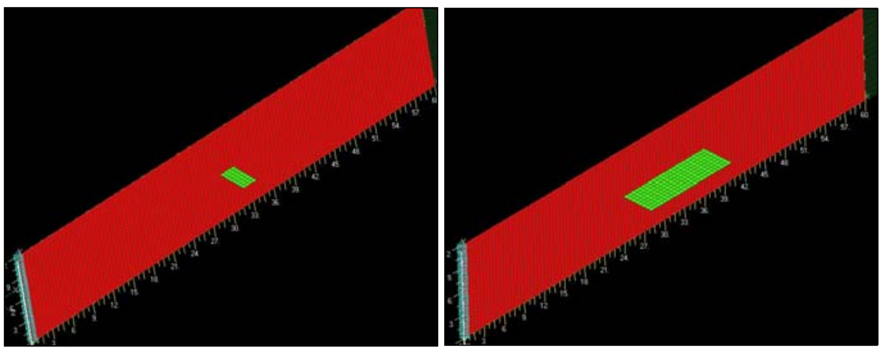
Stress concentrations

- Stress concentrations exist at weld toes
- Welds must transfer stress between two members



65

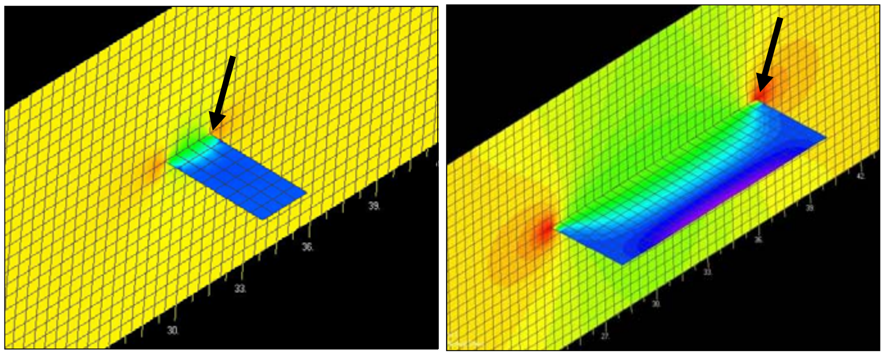
Influence of Attachment Length on Detail Category



Short Attachment   Long Attachment

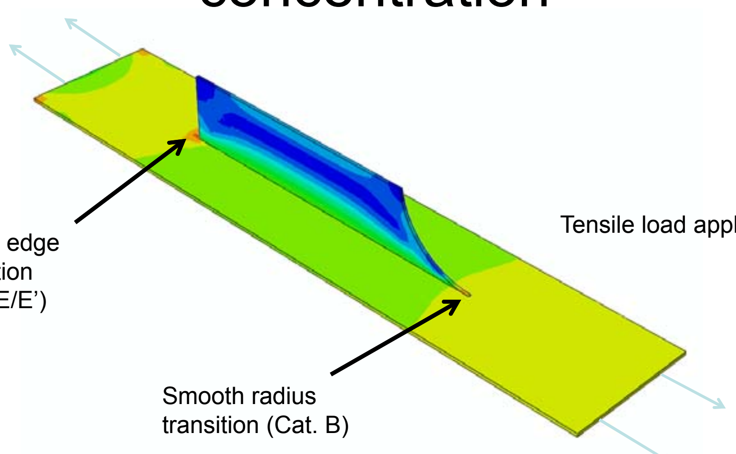
66

Influence of Attachment Length on Detail Category

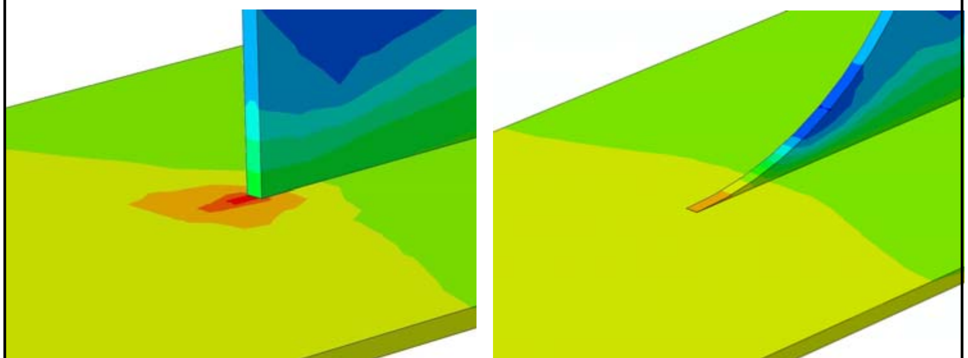


Longer attachments “attract” more stress resulting in increased stress concentration at terminations

Effect of termination on stress concentration



Stress concentration comparison



69

Influence of residual stress

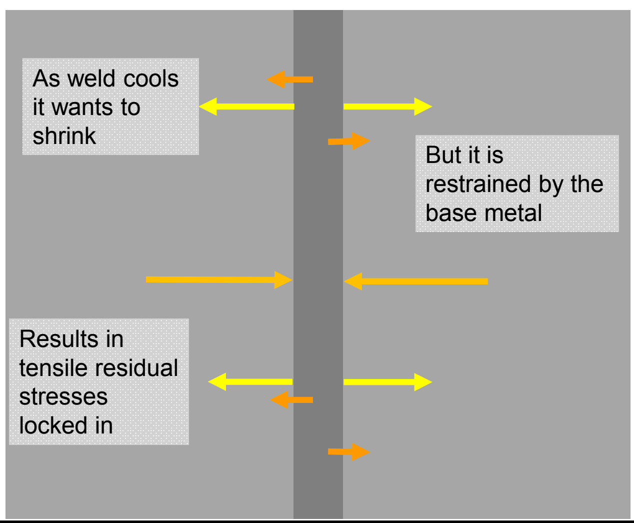
70

Residual Stresses

- "Locked in" stresses induced by rolling, welding, or other fabrication techniques
  - Result of weld shrinkage due to cooling
  - Leads to remaining (*residual*) tensile stresses near weld
  - Magnitude influenced by uneven cooling, weld procedure, restraint, etc.

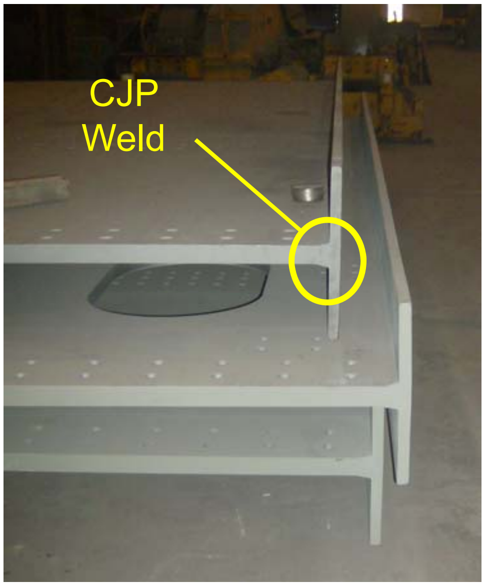
71

Residual stress- butt weld



72

Example of Residual Stresses



73

Flange Plates Bent Prior to Placing Full Penetration Weld

74

Flange Plates Flat after Placing Full Penetration Weld

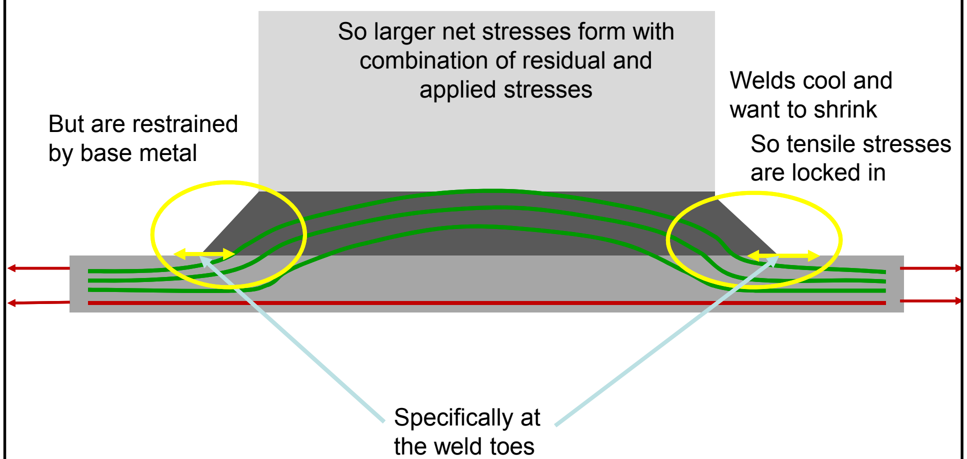
75

Residual Stresses

- Magnitude typically approaches yield strength of material
- Residual stresses are tensile within portions of welds
  - Some portions must be in compression to satisfy equilibrium
- Worst case when applied and residual stresses are in same direction and tensile
  - Transverse welds and weld terminations

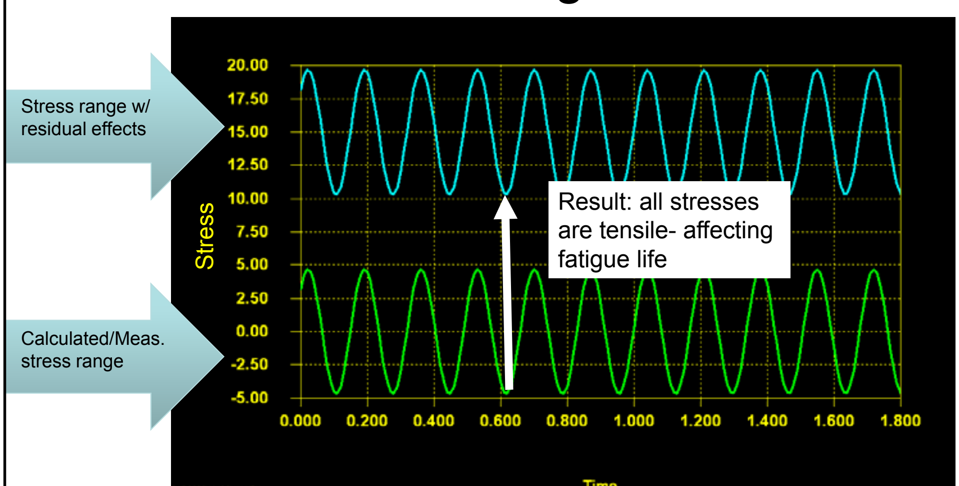
76

Residual stress



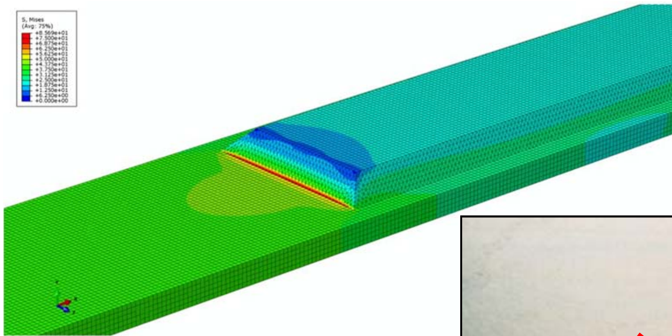
77

Effect of Residual Stresses on Applied Stress Range



78

Result: weld toes susceptible to cracking



79

AASHTO
Fatigue Design

80

First….Must Distinguish between Loads for Fatigue vs Other Limit-states

Limit State:

"Condition beyond which the bridge or component ceases to satisfy the provisions for which it was designed"

(from AASHTO LRFD)

81

Common Limit-states

- Strength limit-state
  - Relates strength & stability
  - Extensive distress & structural damage
  - Structural integrity is maintained
- Service limit-state
  - Relates to stress, deformation, cracking, etc.
  - Relies somewhat on experience

82

Fatigue Limit-state

- Considers stresses induced by repeated loads…*millions of cycles*
- Maximum loading conditions not appropriate for fatigue design
  - e.g., permit loads in all lanes
- However, fatigue damage is the result of the entire variable load spectrum

83

Design Loads for any Limit-state

- Desirable to use a minimum number of different trucks
- Design vehicles should produce reasonably similar effects as real trucks
  - Concept of "notional" load

84

Loads for Fatigue Limit-state

- Desirable to use one vehicle
  - This results in constant amplitude fatigue
  - Easiest to work with
  - Consistent with laboratory test data
- Vehicle must produce the same equivalent fatigue damage as entire variable live load spectrum

Development of "Fatigue Truck"

- Developed based on:
  - WIM studies
  - FHWA loadometer data
  - Field testing of in-service bridges
- Led to truck proposed in NCHRP Report 299
  - Developed for longitudinal and transverse members of girder bridges

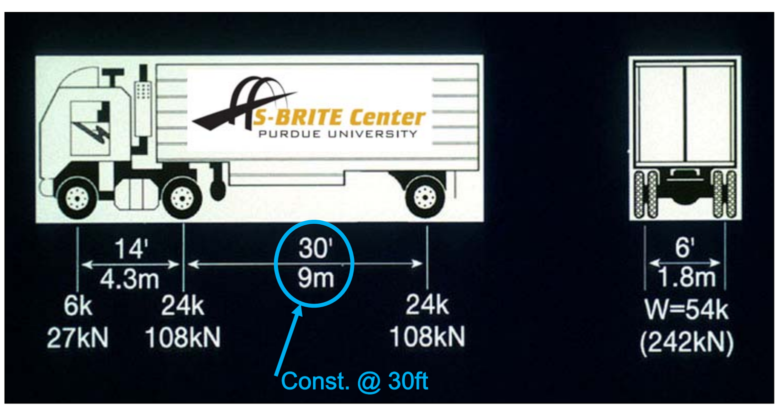
Fatigue Truck

- Truck which produces equivalent fatigue damage as variable amplitude spectrum
  - Does not include panel, pick-up, & other 2-axle 4-wheel vehicles
    - Only vehicles w/ GVW > 20 kips
  - These contribute little to fatigue damage

87

"Fatigue Truck" = HS20 x 0.75

(Equivalent to HS15 w/ fixed trailer length)



88

How should the Fatigue Truck be applied?

- Depends on bridge and element
- Most short to medium span bridges damage caused by individual trucks
  - One primary cycle produced per truck
- Use only a single truck for fatigue
  - No lane loading
- Multiple presence can be considered if necessary

89

Fatigue Limit-State-Load

(as of 2017 will Appear in 8th Edition)

- 0.8xHS20 results in effective stress range (S_{reff})
  - i.e., equivalent cumulative damage
- However, need to recognize that many trucks in the spectrum are heavier than HS15 (i.e., 0.8xHS20)
  - Obviously these produce fatigue damage
  - Not acceptable for infinite life
- Addressed through the "Fatigue Limit-state Load"
  - Research has shown that this is equivalent to 1.75xHS20
- Thus must keep stress range produced by 1.75xHS20 below CAFL to ensure infinite life design

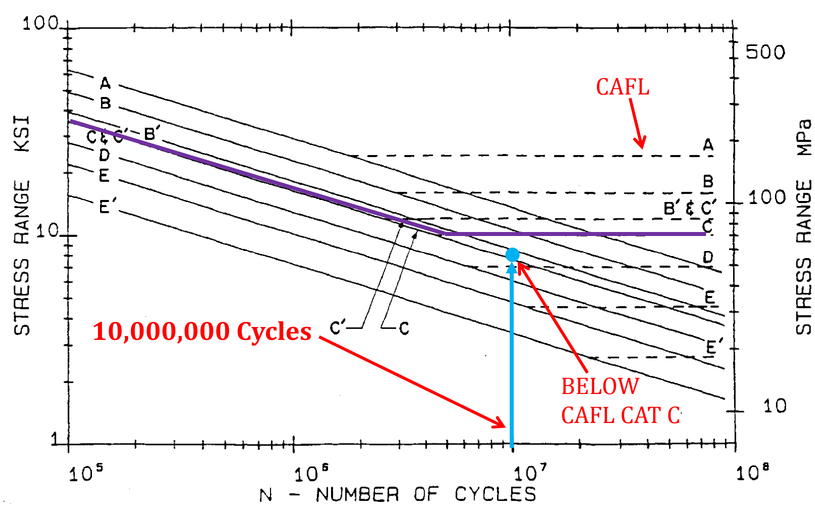
90

Finite Life Design Concepts

- Design for specific life
  - Years or cycles
- Must accurately forecast expected loading spectrum
  - Stress range and # cycles
  - 0.8xHS-20 truck yields effective stress range
  - Use it just like a constant amplitude stress range with the S-N curve for number of cycles desired
  - *Finite-life only useful if ADTT less than various levels for each detail*

91

Limits on Finite Life Design



92

Infinite Life Concepts

- Essentially all stress range cycles less than CAFL
  - No need to worry about number of applied cycles
- AASHTO Specification approach:
  - Design so that fatigue limit-state stress range is below the constant-amplitude fatigue limit (CAFL)
- Cracks will not propagate in the life of the structure
- Highly recommended for Fracture Critical Members (FCMs)

93

Fatigue Limit States

(2016)

2.2

- FATIGUE I — Fatigue and fracture load combination related to infinite load-induced fatigue life.

The load factor for the Fatigue I load combination applied to a single design truck having the axle spacing specified in Article 3.6.1.4.1, reflects load levels found to be representative of the maximum stress range of the truck population. The maximum stress range in the random variable spectrum is taken as twice the effective stress range caused by the Fatigue II load combination.

- FATIGUE II—Fatigue and fracture load combination related to finite load-induced fatigue life.

The load factor for the Fatigue II load combination, applied to a single design truck, reflects a load level found to be representative of the effective stress range of the truck population with respect to a large number of stress range cycles and to their cumulative effects in steel elements, components and connections.

94

Load Distribution

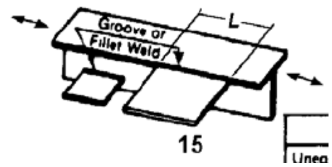
(AASHTO LRFD)

- LRFD contains most refined equations to estimate load distribution than any previous specification
- Recognizes fatigue is result of individual trucks
  - Use distribution factors for one loaded lane

Use of the AASHTO Fatigue Illustrations - Table 6.6.1.2.3-1

REVISED FATIGUE ILLUSTRATIONS

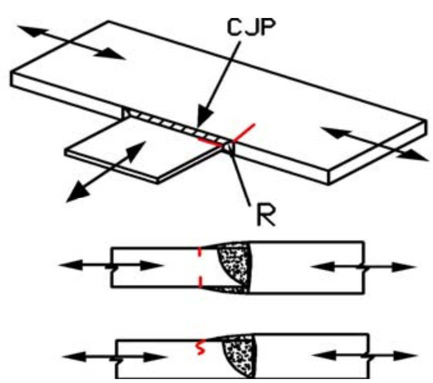
What we had



97

REVISED FATIGUE ILLUSTRATIONS

WHAT WE HAVE NOW



98

AASHTO Table 6.6.1.2.3-1

- First, consider title of the table?
  - "Detail Categories for Load-Induced Fatigue"
- What does this mean?
- Sort of confusing, as all fatigue is "load" induced
- Really means "live loads that produce stress ranges that we calculate"
  - Includes Mc/I & P/A
  - "Nominal Stresses"

99

AASHTO Table 6.6.1.2.3-1

- Second, what loading (i.e., stress range) is not considered?
  - Out-of-plane distortion
  - Secondary stresses
  - etc.
- We don't calculate these stresses
- These stresses also are very complex and local in nature
  - Details based on nominal stress, not local stress

100

AASHTO Table 6.6.1.2.3-1

- Third, must understand what defects are not included in the details
  - Categories don't include specific defects
    - Existing cracks
    - Gouges
    - Corrosion
    - Impact damage
  - Thus, if a member is cracked, details/categories in the table don't apply
    - Need to use fracture mechanics

Info. Included in the Table

- Illustration of "typical" detail
  - Trick is mapping your detail to an illustration
- Orientation of nominal stress range that is being checked
- Specific information regarding detail constants and CAFL
  - For finite life calculations
- Location where cracking is expected
  - Useful when mapping your detail to illustration

Steps to using Table

- Determine the nominal LL stress range orientation in the member
- Compare relative orientation of detail to that stress range
  - E.g. "longitudinally loaded" vs. "transversely loaded"

Steps to using Table

- Attempt to determine where cracks will form
  - Weld toe?
  - Inside of the weld?
  - At rivet hole?
- Maybe more than one location per detail

Steps to Using Table

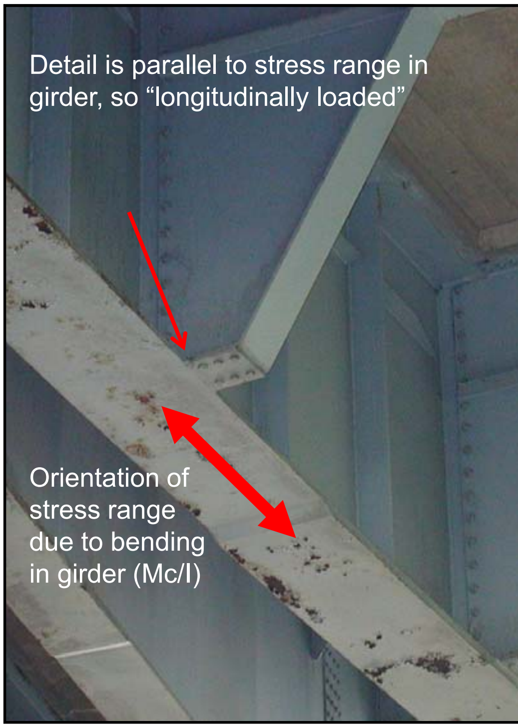
- Welded details
  - Determine weld type and length
  - Determine orientation of weld axis
- Determine orientation of weld toe to applied stress range
  - For welded details, cracking will almost always occur at weld toes oriented perpendicular to applied stress range
  - True even if ground smooth
  - Still must check portion that is parallel, but always a better category

105

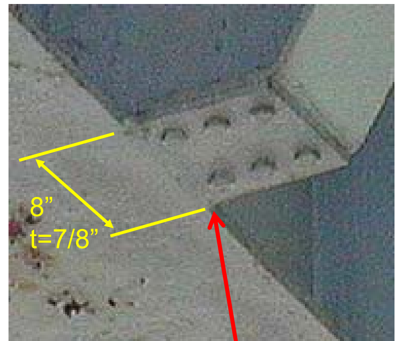
Steps to using Table

- Bolted/riveted details
  - Orientation w.r.t holes
    - Circles …. so pretty easy!

106



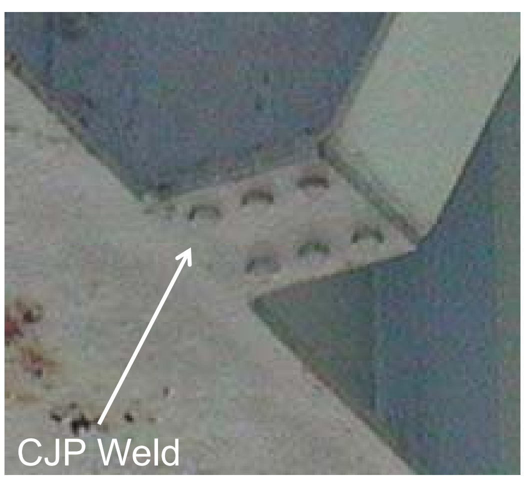
For Example



CJP Weld

107

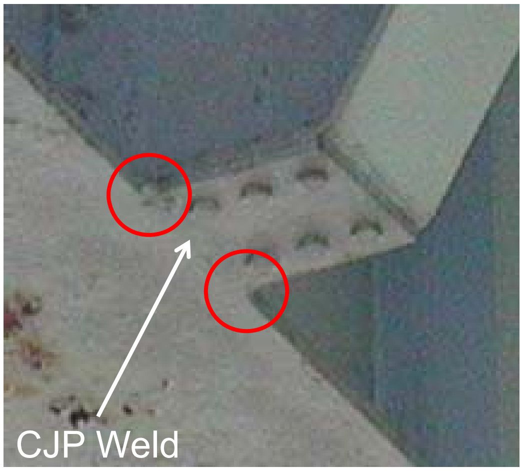
For Example



Where is weld toe that is perpendicular to applied stress range?

108

For Example



Where is weld toe that is perpendicular to applied stress range?

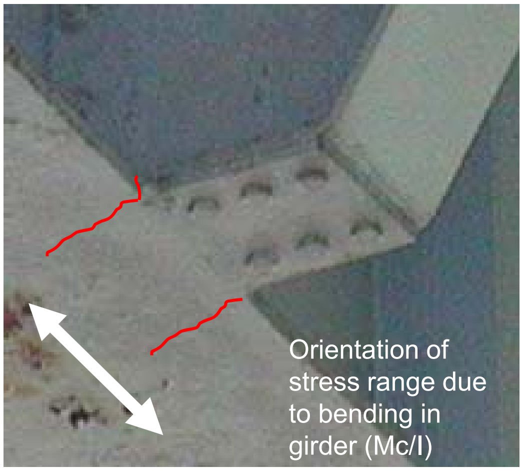
109

For Example

What is expected orientation of cracking?

110

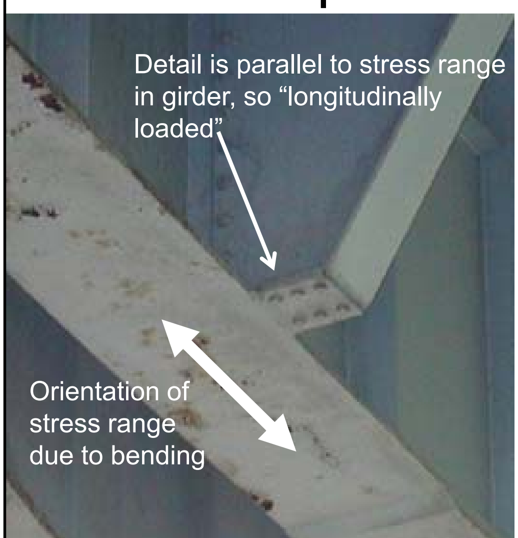
For Example

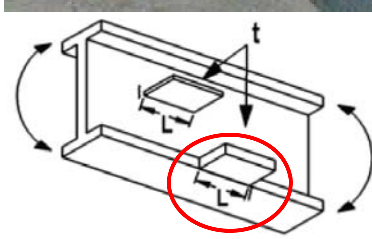


What is expected orientation of cracking?

111

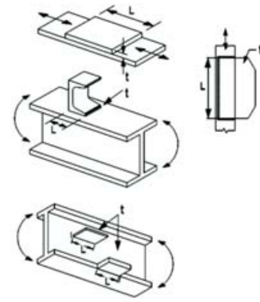
For Example





112

Section 7—Longitudinally Loaded Welded Attachments					
7.1 Base metal in a longitudinally loaded component at a detail with a length L in the direction of the primary stress and a thickness t attached by groove or fillet welds parallel or transverse to the direction of primary stress where the detail incorporates no transition radius:				In the primary member at the end of the weld at the weld toe	
$L < 2$ in.	C	44×10^8	10		
2 in. $\leq L \leq 12t$ or 4 in	D	22×10^8	7		
$L > 12t$ or 4 in.					
$t < 1.0$ in.	E	11×10^8	4.5		
$t \geq 1.0$ in.	E′	3.9×10^8	2.6		
(Note: see Condition 7.2 for welded angle or tee section member connections to gusset or connection plates.)					



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7.1 Base metal in a longitudinally loaded component at a detail with a length L in the direction of the primary stress and a thickness t attached by groove or fillet welds parallel or transverse to the direction of primary stress where the detail incorporates no transition radius:				In the primary member at the end of the weld at the weld toe	
$L < 2$ in.	C	44×10^8	10		
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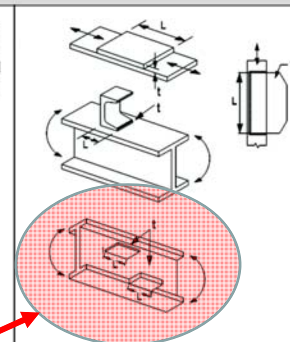

Section 7—Longitudinally Loaded Welded Attachments					
7.1 Base metal in a longitudinally loaded component at a detail with a length L in the direction of the primary stress and a thickness t attached by groove or fillet welds parallel or transverse to the direction of primary stress where the detail incorporates no transition radius:				In the primary member at the end of the weld at the weld toe	
$L < 2$ in.	C	44×10^8	10		
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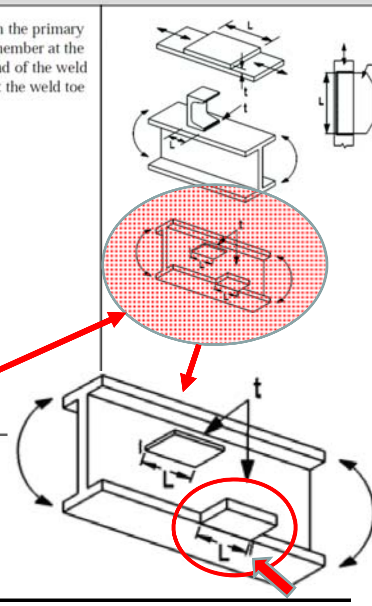

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$L < 2$ in.	C	44×10^8	10		
2 in. $\leq L \leq 12t$ or 4 in	D	22×10^8	7		
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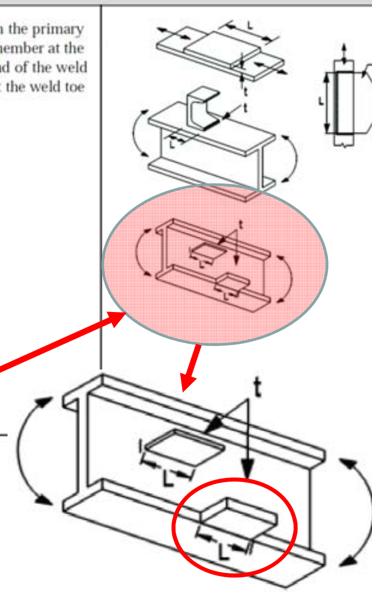

Section 7—Longitudinally Loaded Welded Attachments

7.1 Base metal in a longitudinally loaded component at a detail with a length L in the direction of the primary stress and a thickness t attached by groove or fillet welds parallel or transverse to the direction of primary stress where the detail incorporates no transition radius:				In the primary member at the end of the weld at the weld toe	
$L < 2$ in.	C	44×10^8	10		
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$t < 1.0$ in.	E	11×10^8	4.5		
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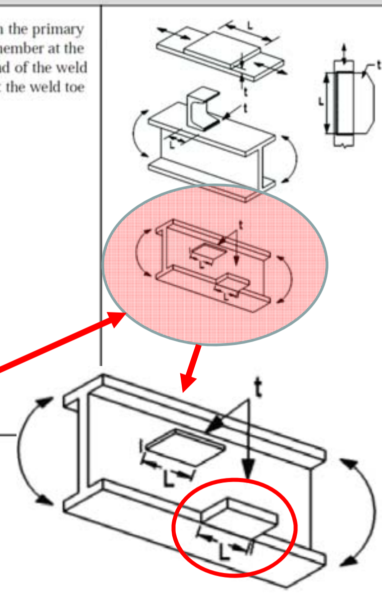

117

Section 7—Longitudinally Loaded Welded Attachments

7.1 Base metal in a longitudinally loaded component at a detail with a length L in the direction of the primary stress and a thickness t attached by groove or fillet welds parallel or transverse to the direction of primary stress where the detail incorporates no transition radius:				In the primary member at the end of the weld at the weld toe	
$L < 2$ in.	C	44×10^8	10		
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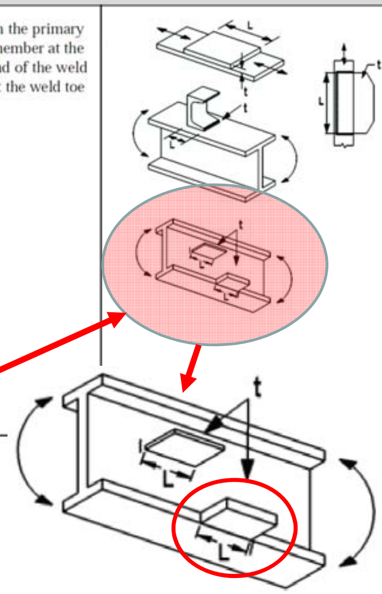
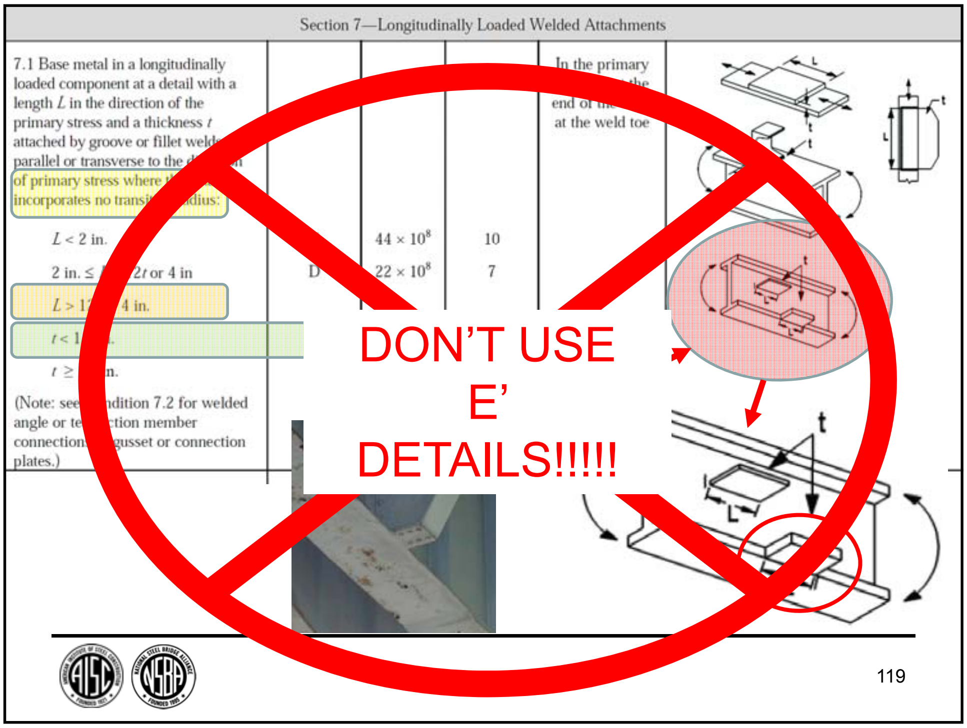


118



Fatigue Illustrations

- Most common details easy to identify
- Must think through stress flow, expected crack location, etc.
- Detail length important in welded details

120

Good Guidance

- Challenge is mapping your detail to the AASHTO illustrations
  - Good reference "*Fatigue and fracture library for the inspection, evaluation, and repair of vehicular steel bridges.*" Fish, P., Schroeder, C., Connor, R. J., & Sauser, P. (2015). West Lafayette, IN: Purdue University. http://dx.doi.org/10.5703/1288284315520
  - NCHRP 20-07/Task 387, *"Maintenance Actions to Address Fatigue Cracking in Steel Bridge Structures"* https://engineering.purdue.edu/CAI/SBRITE/Research/Publications

121

Example: Finite Life

- *Given:*
  - Category E detail
    - CAFL 4.5 ksi
  - S_r = 5.0 ksi
    - Fatigue II Load Combo.
  - N_{DAY} = 1,755 cycles/day
- *What is estimated fatigue life in years?*

122

Example: Case I

- S_r > CAFL
  - Finite fatigue life
  - Calculate life using equations for S-N curve ($N = A/S_r^3$)

- For Category E
  - $A = 11.0 \times 10^8$

  Calculation of N_{LIFE} yields:
  - N = 8,800,000 Cycles

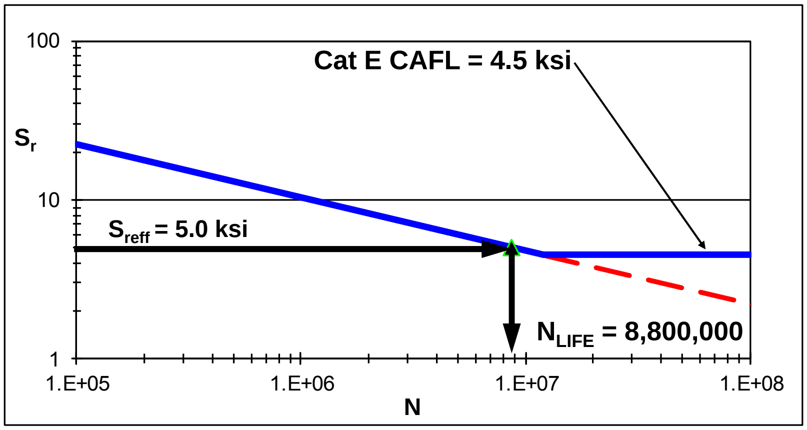
123

Example: Case I

- N_{LIFE}= 8,800,000 Cycles
- Life calculation in years:
  - Recall 1,755 cycles/day are applied
  - 8,800,000 ÷ 1,755 cycles/day = 5,014 days
  - 5,014 days ÷ 365 days/yr = **13.75 yrs**

124

Example: Case I



125

Example: Infinite Life

- *Given:*
  - Category C detail (CAFL 10 ksi)
  - S_r = 4.9 ksi
    - Loading from Fatigue I Load Combo.
  - N_{DAY} = 5,760 cycles/day
- *What is estimated fatigue life in years?*

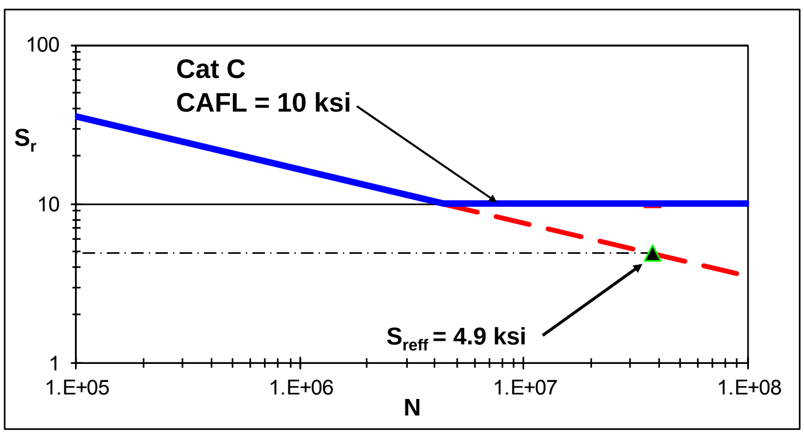
126

Example: Infinite Life

- S_r < CAFL
- Hence:
  - All cycles less than CAFL
  - No further action required
  - Infinite fatigue life

127

Example: Infinite Life



128

A few words about the concept of Fracture Critical

129

A few words about the concept of Fracture Critical

- Non-redundant tension members are classified as Fracture Critical Members
  - Require special considerations in fabrication
    - AASHTO/AWS Fracture Control Plan (FCP)
    - A709 "Non-redundant members" = higher CVN
  - Require costly arms-length inspection every 24 months (this is required by law)
- Introduced after some fractures observed in a few bridges designed and fabricated prior to 1970

130

Then Versus Now…

1960s & earlier

- Manual or Simple Computer Structural Analysis
- No Explicit Fatigue Design Provisions
- No Special Fabrication QA/QC
- High Toughness Materials Not Economically Feasible
- No Knowledge of Constraint Induced Fracture
- Limited Shop Inspection

2000s

- 3D Non-Linear Finite Element Analysis
- In-plane & Distortional Fatigue Problem Solved
- Fracture Critical Fabrication per AASHTO/AWS
- High Performance Steels Readily Available
- Know to Avoid Intersecting Welds and CIF Details
- Significant Advances in NDT

131

“Revisiting Concept of Fracture Critical”

- Much interest in FCM over past 10 years
  - 2004 FHWA workshop in Orlando

132

"Revisiting Concept of Fracture Critical"

- Much interest in FCM over past 10 years
  - 2004 FHWA workshop in Orlando
- Various workshops and research projects completed since 2004

133

"Revisiting Concept of Fracture Critical"

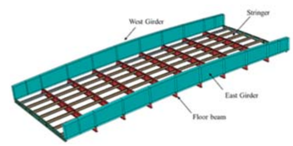
- Much interest in FCM over past 10 years
  - 2004 FHWA workshop in Orlando
- Various workshops and research projects completed since 2004

- ALL point to the fact the industry has progressed considerably since the 1970s

134

Advancements Since Introduction of FCP

- Advancements in:
- Material – HPS
- Fatigue design - Modern AASHTO provisions
- Analysis
  - Capability to perform 3-D system analysis
- NDE
- Fabrication
  - Better control and automation
  - Better understanding of processes
- Conclusion:
  - It is time to revisit the concept of FC

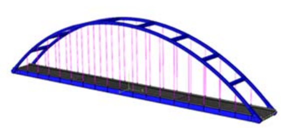


135

GOAL: Develop an Integrated FCP

Change how we (*you*)
think about fracture limit state

- If the fracture limit state is adequately addressed in <u>some</u> rational way, the term "fracture critical" has no meaning
  - For example, since we design for buckling, a non-redundant compression member is not referred to as "buckling critical"
- Today, using state-of-the-practice technology, fracture can be treated like any other limit state
  - Minimize Risk and achieve desired reliability



136

Other things to keep in mind…

- Overall, historical performance of "FC" bridges is excellent
  (*despite what your ~~mother~~ supervisor told you!*)
  - Even those built prior to modern fatigue provisions
  - Even those prior to FCP
  - Even when a fracture occurred
- NCHRP 354 found no cases where FC bridges collapsed due to failure from "pure" fatigue/fracture issues
  - Where current inspection "approaches" would help
  - Two girder bridges are routinely built in Europe & Japan without FC concerns.

137

More things to keep in mind…

- We perform hands-on inspection for safety…or so we think
  - Find cracks before they are an issue
  - What about Probability of Detection (POD)?
    - Existing data not very encouraging
    - Are we able to find what we think we can find?
- Recent INDOT study found the following:
  - The congested crash rate on all Indiana interstates in 2014 was found to be 24 times greater after 5 min. of queue
  - What about highway worker safety?

138

New AASHTO Provisions Focused Rational Evaluation of Redundancy

- TPF-5(253) Exploit member-level redundancy (MLR) of built-up members – resulting in proposed specifications on how to account for MLR specifications
  - Proposed Guide Specifications to be balloted in 2018
- System Analysis
  - NCHRP 12-87a Proposed specifications for system analysis NSBA Twin-tub girder research (completed Spring 2016)
  - Wisconsin DOT Twin tub girder study (beginning Fall 2016)
  - Proposed Guides Specifications to be balloted in 2018

139

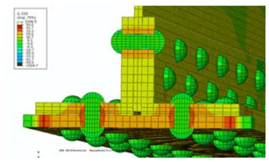
Outcomes of Integrated FCP

- Confidence/Life Safety
  - Treat fracture like any other limit state
    - Statistical understanding of fracture behavior
  - P_f and β can be quantified like other limit states
    - Approach fracture like other limit states in LRFD
- Economic
  - Set *rational* arms-length inspection interval w/o compromising reliability
  - Better allocation of inspection resources

140

So what does this mean?

- Concept of FC being re-evaluated on several fronts
  - System analysis
  - Ultra tough steel
  - Member level redundancy
- Developing integrated FCP
- Possible to effectively eliminate/mitigate concerns associated with fracture
- Allow reliable, innovative, & efficient designs and rational inspection criteria
- We don't build 1960s steel bridges anymore!!!!



141

Summary of Today's Session

- Fatigue
  - Slow stable crack growth
  - Driven by live load
  - Related S_r, N, and Detail category
  - CAFL = constant amplitude fatigue limit
  - $N=A/S_r^3$
- Fracture
  - Sudden unstable crack propagation
  - Driven by live load and dead load
  - Related to applied stress, toughness, crack size

142

Summary of Today's Session

- Fatigue Truck
  - Notional truck used to represent equivalent fatigue damage of all trucks on the road
  - Applied as single vehicle
  - Constant rear axle spacing of 30 feet
  - Developed from WIM etc.
    - 20 kip or greater
- Finite life use 0.75xHS20
- Infinite life use 1.5xHS20

143

Polling Question 1

What factors influence fatigue life? Choose all that apply.

- Stress range
- Number of applied cycles
- Compressive strength
- Dead load
- Tensile strength
- Detail category
- Yield strength

144

Polling Question 2

True or False: The AASHTO Fatigue Categories can be used in cases where cracks exist as long as they are pretty small.

- True
- False

Questions ?

Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

8-Session Package Registrants

CEU/PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.

8-Session Package Registrants

Course Resources

1. Log on to your AISC account and go to Course Resources.
   https://www.aisc.org/myaisc/course-resources/
2. Locate your course.
3. Access handouts, videos, quizzes, quiz scores and attendance records.

AISC > MYAISC > COURSE RESOURCES > STEEL BRIDGE DESIGN

Steel Bridge Design

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
R1: Introduction To Bridge Engineering	N/A	Handouts	View Passcode: RZNS141	Pass Score: 80	N/A
R2: Introduction and History of AASHTO Bridge Design	N/A	Handouts	Available 9/11/2017 5:00 PM EDT	Available 9/11/2017 5:00 PM EDT	N/A
R3: Steel Material Properties	N/A	Handouts	Available 9/11/2017 5:00 PM EDT	Available 9/11/2017 5:00 PM EDT	N/A
R4: Loads and Analysis	N/A	Handouts	Available 9/11/2017 5:00 PM EDT	Available 9/11/2017 5:00 PM EDT	N/A
L1: Steel Bridge Fabrication	Oct 12 2017 1:30PM EDT	Handouts	Available 10/14/2017 5:00PM EDT	Available 10/14/2017 5:00PM EDT	Pending
L2: Plate Girder Design and Stability	Oct 19 2017 1:30PM EDT	Handouts	Available 10/21/2017 5:00PM EDT	Available 10/21/2017 5:00PM EDT	Pending
L3: Effects of Curvature and Skew	Oct 26 2017 1:30PM EDT	Handouts	Available 10/28/2017 5:00PM EDT	Available 10/28/2017 5:00PM EDT	Pending
L4: Fatigue and Fracture	Nov 2 2017 1:30PM EDT	Handouts	Available 11/04/2017 5:00PM EDT	Available 11/04/2017 5:00PM EDT	Pending
Intro To Steel Bridge Design - Final Exam	Nov 23 2017 8:00AM EST			Available 11/25/2017 5:00PM EST	

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8-Session Package Registrants

Videos and Quizzes

Videos

- For Sessions R1 – R4, find access to recordings starting September 11. Recording access expires on November 23.
- For Sessions L1 – L4, find access to recordings within two days after the live air date. Recording access expires three weeks after the live session.

Quizzes

- For Sessions R1 – R4, find access to quizzes starting September 11. Quizzes are due on November 23.
- For Sessions L1 – L4, find access to quizzes within two days after the live air date. Quizzes are due three weeks after the live session.
- A final exam will also be given.
- Quiz scores are displayed in the Course Resources table.

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8-Session Package Registrants

Course Credit

Attendance and PDH Certificates

- For Sessions R1 – R4, you must pass the quiz to receive credit for the session.
- For Sessions L1 – L4, you have two options to receive credit for the session.
  - Option 1: Watch the session live. Credit for live attendance will be displayed in the Course Resources table within two days of the session.
  - Option 2: Watch the recording and pass the quiz.

EEU Certificates – Certificate of Completion

- In addition to PDH certificates earned for each individual session, an EEU (Equivalent Education Unit) certificate of completion will be issued for participants who complete the full course. Participants must pass at least 7 of 8 quizzes and the final exam to earn the EEU.

Distribution of Certificates

- All certificates (PDH and EEU) will be issued after the final session. Only the registrant will receive certificates for the course.

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8-Session Package Registrants
Final Exam

The final exam is due at 8 am EST on November 23, 2017.

Thank You

There's always a solution in steel.

Please give us your feedback!
Survey at conclusion of webinar.

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