Lecture 7

STR403 - Metallic Bridges
"Fatigue"

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Previous lecture – Details

- **Splices.**
  - Welded.
  - Bolted.
- **Bracing.**
  - Deck Bridges.
  - Through Bridges.

Lecture 7: FATIGUE

Topics

- Introduction/Definitions.
- Fatigue Loading
- Basic Fatigue Principles.
- Factors Affecting Fatigue.
- Fatigue Assessment Process.

INTRODUCTION

Main Idea:

Fluctuating Loads are more dangerous than monotonic loads.

Proof:

Comet Airliner, designed for a cabin pressure differential of 60 kg/cm^2, and failed under a differential pressure of 25 kg/cm^2 (Safety factor more than 2) due to cyclic loading.

INTRODUCTION

A bridge member may respond to applied loads in one of the following three ways:

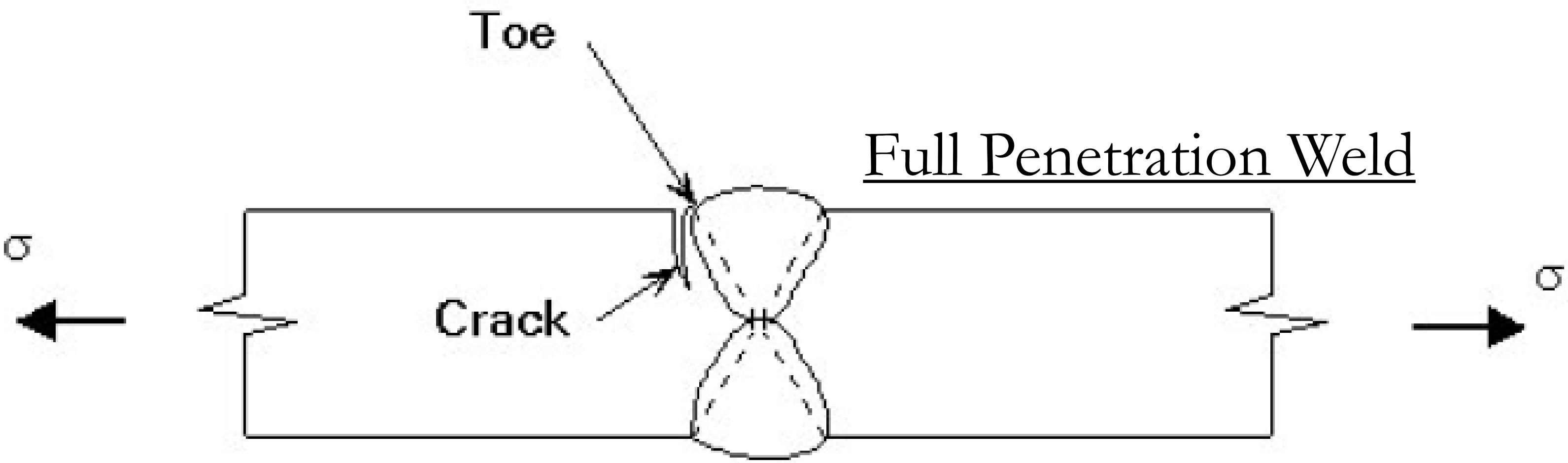
(a) deform elastically, or (b) deform plastically, or (c) break.

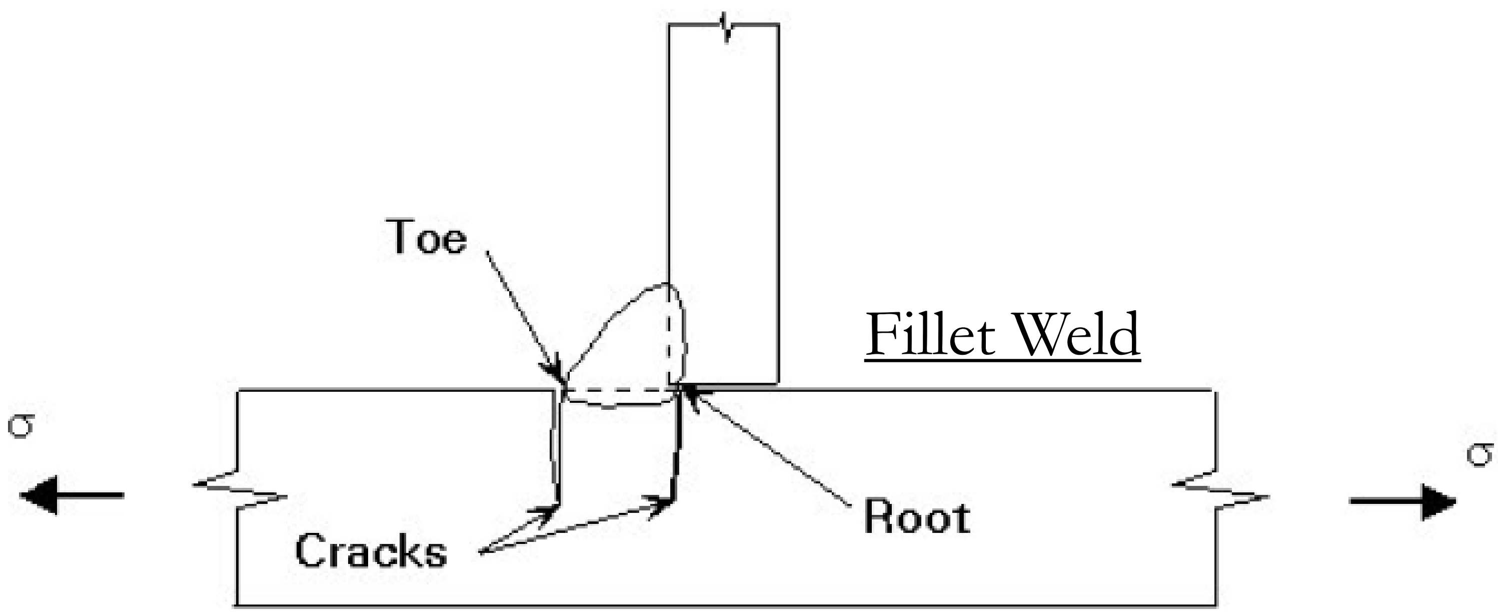
Since steel is a ductile material, failure of steel members is normally preceded by a considerable amount of elastic or plastic deformations. This amount depends on the magnitude of applied loads (below or above the yield level) and on the repetitive and cyclic nature of the load.

INTRODUCTION

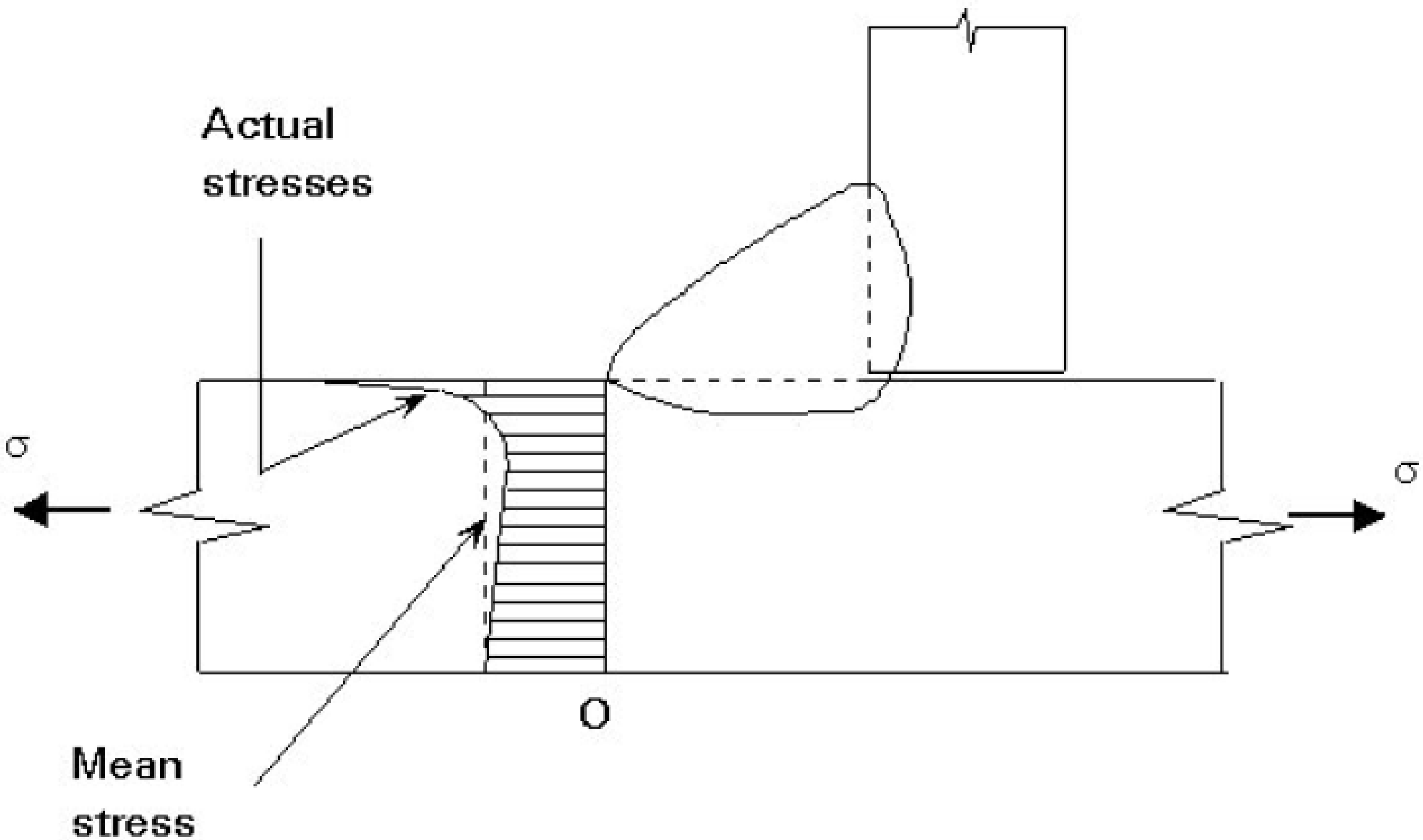
Sometimes, however, certain types of steel members may fail suddenly in the form of brittle fracture. It was found that this failure mode starts from the presence of very small defect and cracks in the member during fabrication due to rolling, cutting, drilling, and or welding. The presence of these defects causes stress concentration around them. The stress concentration around the defects causes them, although initially undetected, to increase in size and eventually propagate to failure when the member is subjected to a large number of stress cycles.

INTRODUCTION

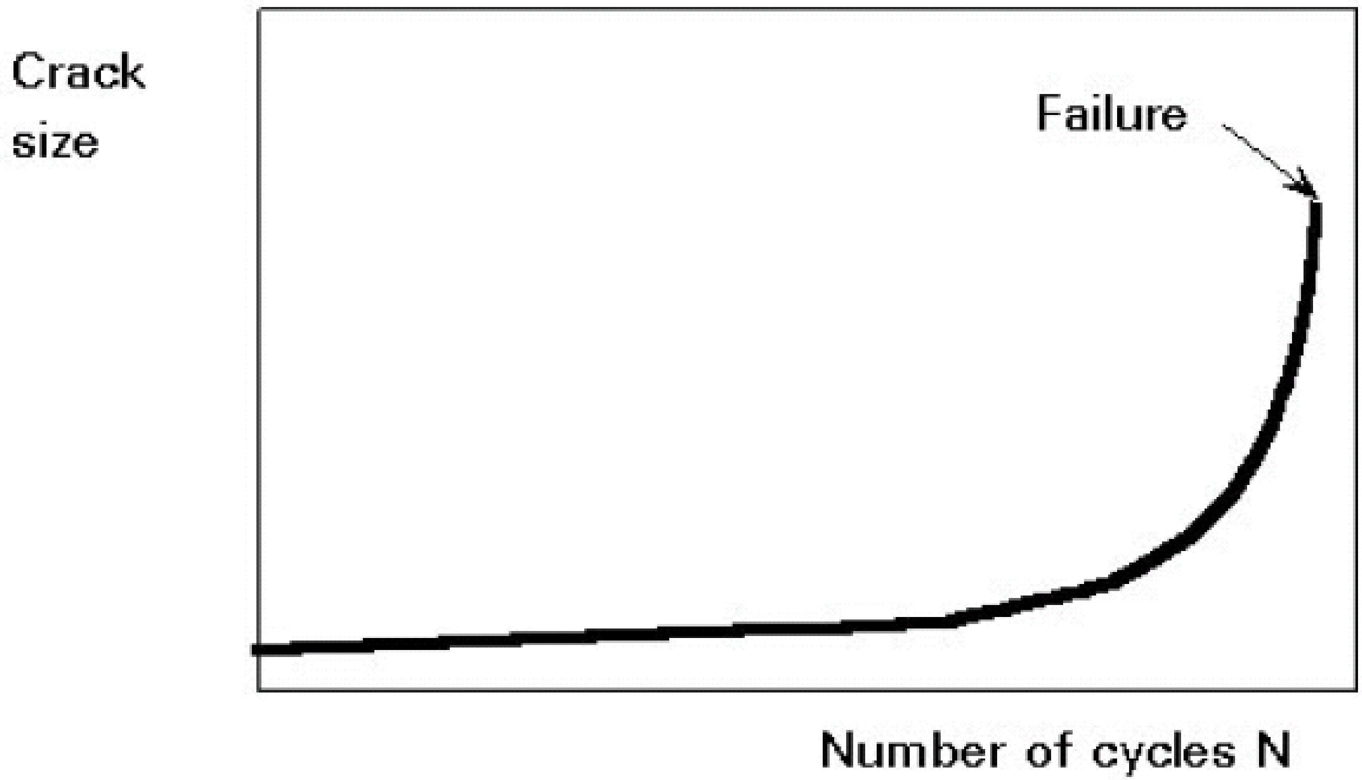




INTRODUCTION



INTRODUCTION



INTRODUCTION

Fatigue cracks will almost certainly start to grow from welds, rather than other details, because:

- Most welding processes leave metallurgical discontinuities from which cracks may grow. As a result, the initiation period, which is normally needed to start a crack in plain wrought material, is either very short or no-existent. Cracks therefore spend most of their life propagating, i.e. getting longer.

INTRODUCTION

Fatigue cracks will almost certainly start to grow from welds, rather than other details, because:

- Sharp changes of direction generally occur at the toes of butt welds and at the toes and roots of fillet welds. These points cause local stress concentrations. Small discontinuities close to these points will therefore react as though they are in a more highly stressed member and grow faster.

DEFINITIONS

- **Fatigue:** Damage in a structural member through gradual crack propagation caused by repeated stress fluctuations.
- **Design Life:** The period in which a structure is required to perform safely with an acceptable probability that it will not fail or require repair.
- **Stress Range:** The algebraic difference between two extreme values or nominal stresses due to fatigue loads. This may be determined through standard elastic analysis.

DEFINITIONS

- **Fatigue Strength:** The stress range determined from test data for a given number of stress cycles.

- **Fatigue Limit:** The maximum stress range for constant amplitude cycles that will not form fatigue cracks

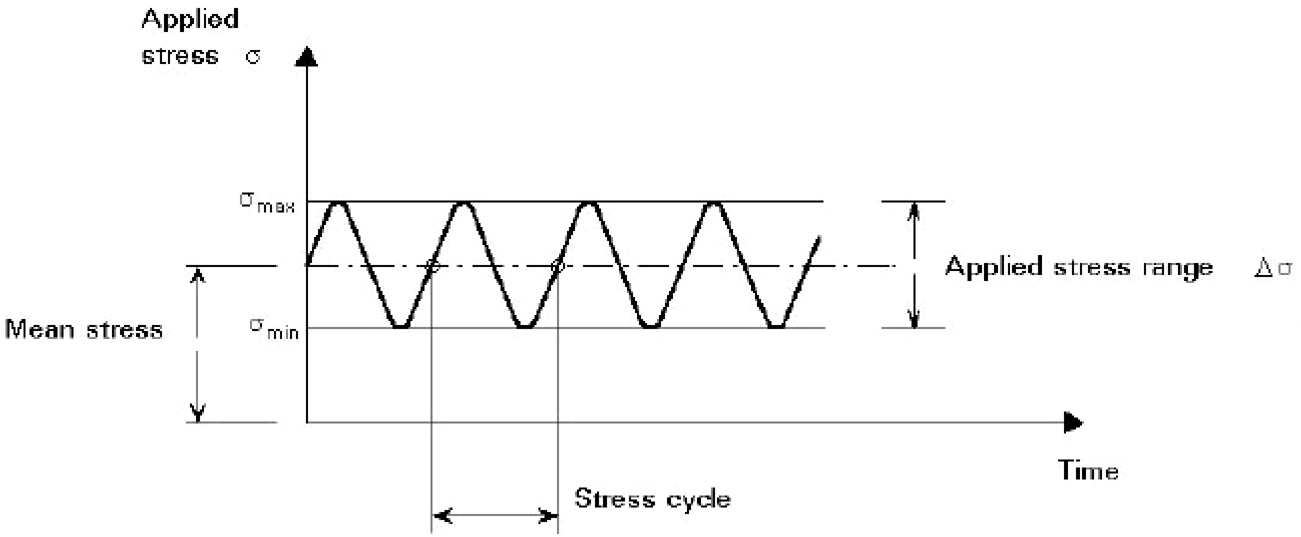
- **Detail Category:** The designation given to a particular joint or welded detail to indicate its fatigue strength. The category takes into consideration the local stress concentration at the detail, the size and shape of the maximum acceptable discontinuity, the loading condition, metallurgical effects, residual stresses, fatigue crack shapes, the welding procedure, and any post-welding improvement.

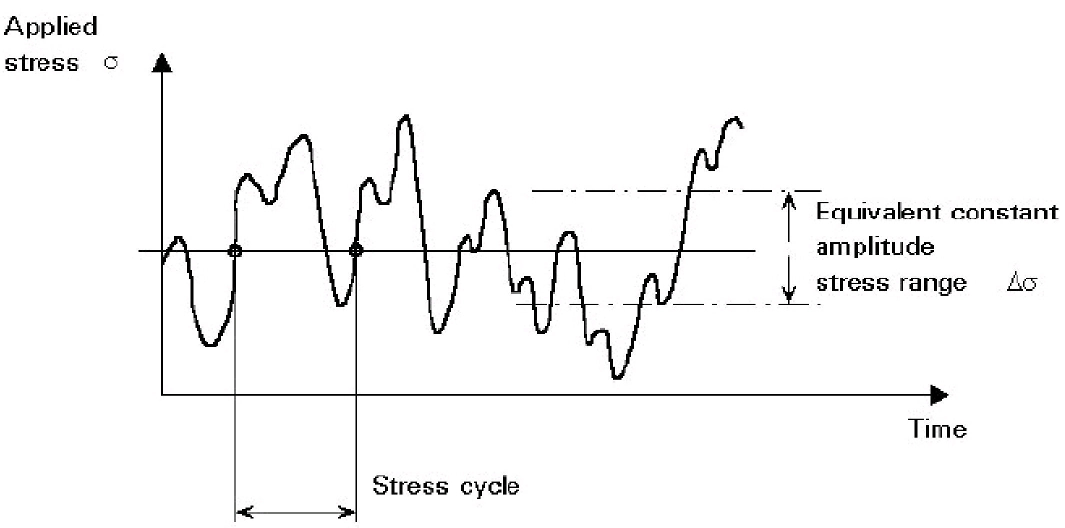
Lecture 7: FATIGUE

Topics

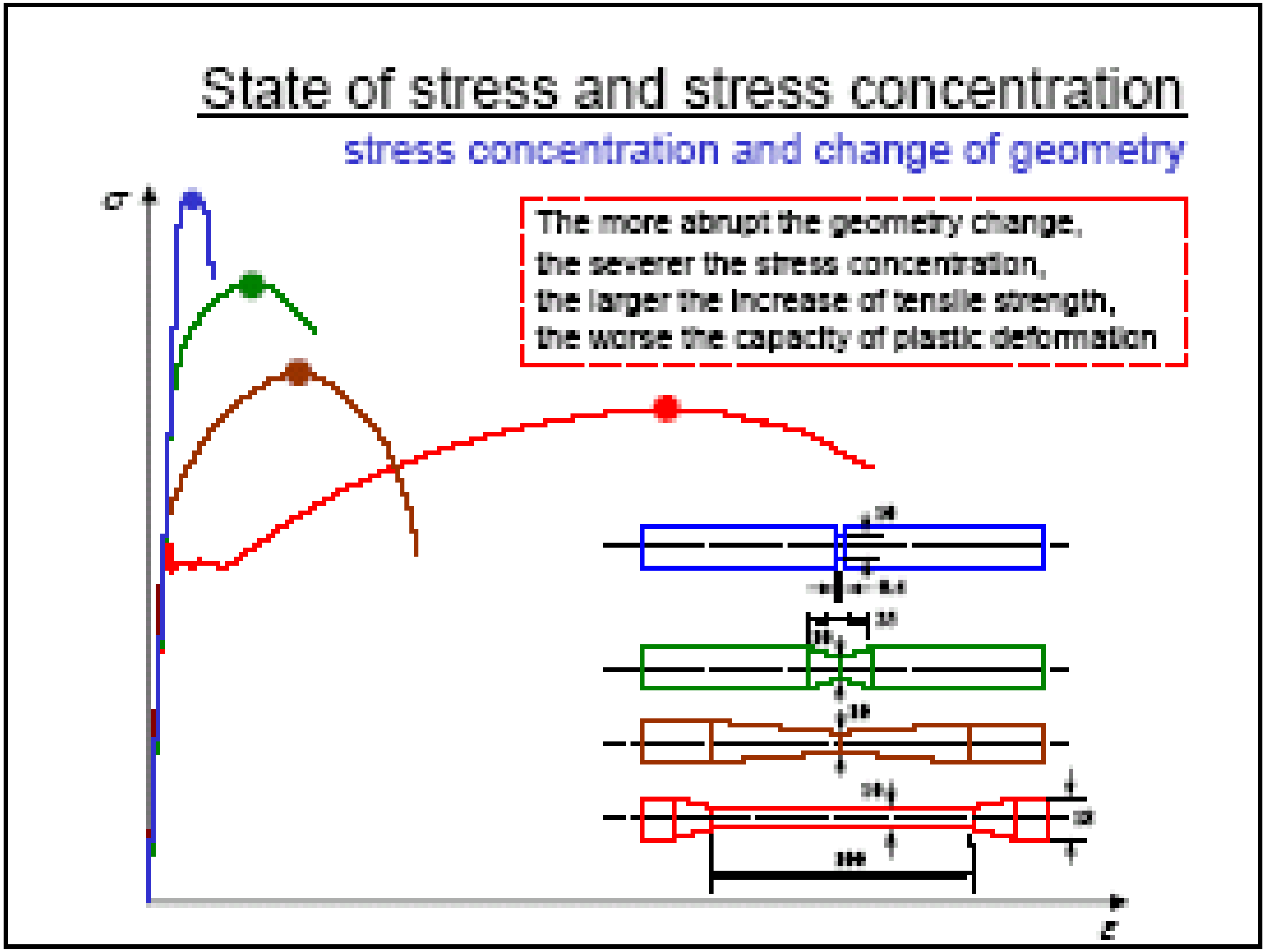
- Introduction/Definitions.
- **Fatigue Loading**
- Basic Fatigue Principles.
- Factors Affecting Fatigue.
- Fatigue Assessment Process.

FATIGUE LOADING

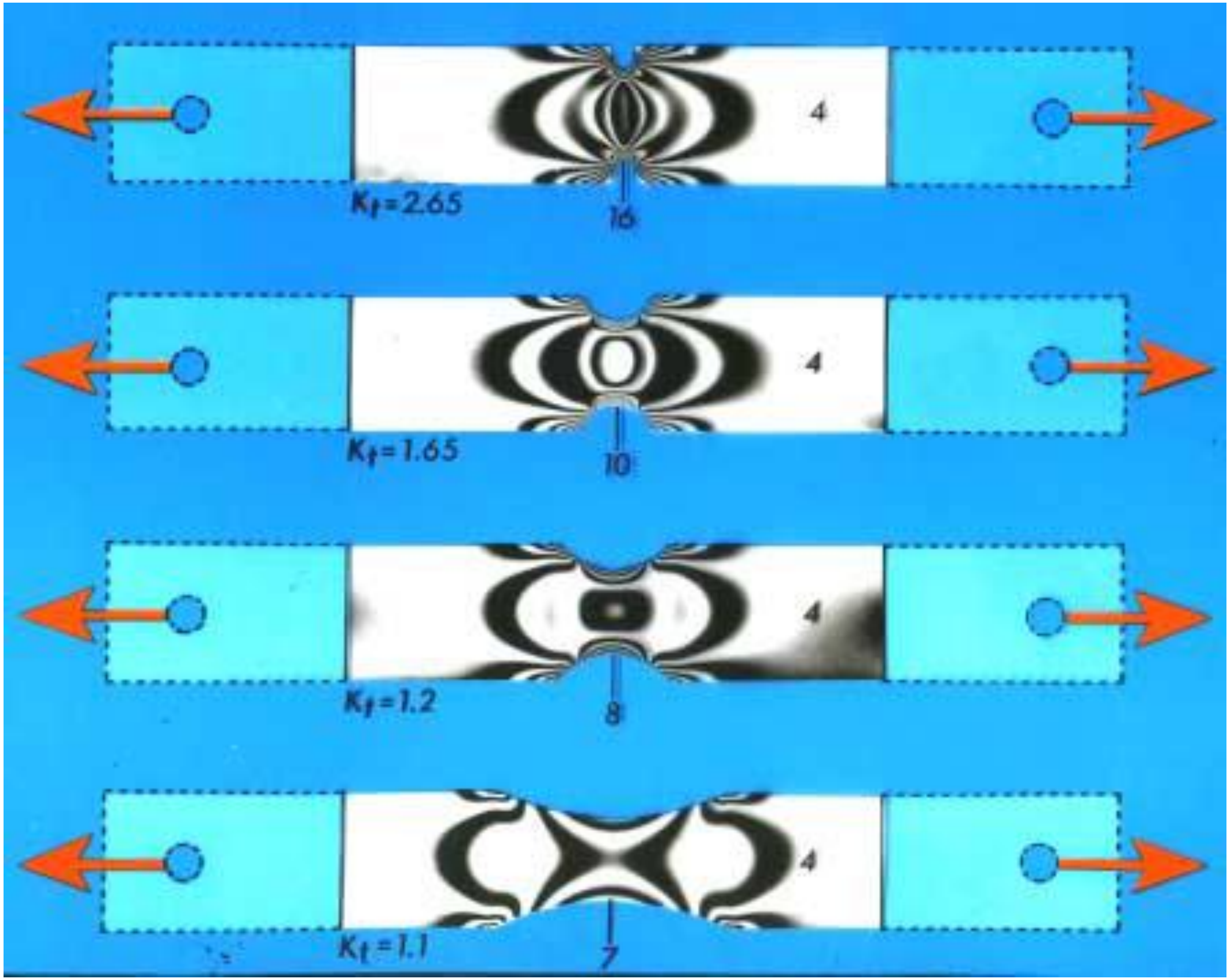




FATIGUE LOADING



FATIGUE LOADING



Lecture 7: FATIGUE

Topics

- Introduction/Definitions.
- Fatigue Loading
- **Basic Fatigue Principles.**
- Factors Affecting Fatigue.
- Fatigue Assessment Process.

BASIC FATIGUE PRINCIPLES

1- The differences in fatigue strength between grades of steel are small (negligible).

2- The differences in fatigue damage between stress cycles having different values of mean stress but same value of stress range may be neglected.

3- Cracks generally occur at welds or at stress concentration due to sudden changes of cross-sections. Very significant improvements in fatigue strength can be achieved by reducing the severity of stress concentrations at such points.

BASIC FATIGUE PRINCIPLES

4- Members subjected to stresses resulting from wind forces only, shall be designed so that the maximum unit stress does not exceed the basic allowable unit stress given in the Code.

5- Cracks that may form in fluctuating compression regions are self-arresting. Therefore, these compression regions are not subjected to fatigue failure.

6- When fatigue influences the design of a structure, details should be precisely defined by the designer and should not be amended in any way without the designer's prior approval. Similarly, no attachments or cutouts should be added to any part of the structure without notifying the designer.

BASIC FATIGUE PRINCIPLES

7- Structures in which the failure of a single element could result in a collapse or catastrophic failure should receive special attention when fatigue cracks are a possibility. In such cases, the allowable stress ranges shall be limited to 0.8 times the values given in Tables.

8- Slotted holes shall not be used in bolted connections for members subjected to fatigue.

Lecture 7: FATIGUE

Topics

- Introduction/Definitions.
- Fatigue Loading
- Basic Fatigue Principles.
- **Factors Affecting Fatigue.**
- Fatigue Assessment Process.

FACTORS AFFECTING FATIGUE

1- **The applied stress range** resulting from the applied fatigue loads.

2- **The number of stress cycles**.

3- **The detail category** of the particular structural component or joint design.

FACTORS AFFECTING FATIGUE

1- Roadway Bridges:

The fatigue loads used to calculate the stress range are 60% of the standard design live loads including the corresponding dynamic effect.

2- Railway Bridges:

The fatigue loads used to calculate the stress range are the full standard design live loads.

3- For Bridges Carrying both Trucks and Trains, the fatigue load is the combined effect of the full railway live load and 60% of the traffic live loads.

Lecture 7: FATIGUE

Topics

- Introduction/Definitions.
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- Factors Affecting Fatigue.
- **Fatigue Assessment Process.**

FATIGUE ASSESSMENT PROCESS

1- The fatigue assessment procedure should verify that the effect of the applied stress range (f_{sra}) during cycles expected in the design life of the structure is less than the corresponding fatigue strength (Allowable Stress Range (F_{sr})). $\mathbf{(f_{sra}) < (F_{sr})}$

2- Fatigue loads should be positioned to give maximum straining actions at the studied detail. This is to calculate the maximum applied stress range (f_{sra}) that should not exceed the allowable stress range (F_{sr}).

FATIGUE ASSESSMENT PROCESS

3- In non-welded details, effective stress range to be used in fatigue assessment shall be determined by adding tensile portion of stress range and 60% of compressive portion of stress range.

4- In welded details, stress range to be used in fatigue assessment is the greatest algebraic difference between maximum stresses.

FATIGUE ASSESSMENT PROCESS

4- Fatigue strength of a structural part is characterized by allowable stress range (F_{sr}) for a specified number of constant cycles and particular detail category.

5- The number of constant stress cycles to be endured by the structure during its design life is given for roadway bridges and railway bridges. The number of cycles given is subject to modifications according to the competent authority requirements.

FATIGUE ASSESSMENT PROCESS

LOADING CYCLES FOR ROADWAY BRIDGES

Table (3.1a) Number of Loading Cycles – Roadway Bridges

Type of Road	ADTT *	Number of Constant Stress Cycles (N)	
		Longitudinal Members	Transverse Members
Major Highways and Heavily Travelled Main Roads	≥ 2500	2,000,000	Over 2,000,000
	< 2500	500,000	2,000,000
Local Roads and Streets		100,000	500,000

* ADTT = Average Daily Truck Traffic for 50 years design life

FATIGUE ASSESSMENT PROCESS

LOADING CYCLES FOR RAILWAY BRIDGES

Table (3.1b) Number of Loading Cycles – Railway Bridges

Member Description	Span Length (L) (m)	Number of Constant Stress Cycles (N)
Class I Longitudinal flexural members and their connections, or truss chord members including end posts and their connections.	L > 30	500,000
	$30 \geq L \geq 10$	2,000,000
	L < 10	Over 2,000,000
Class II Truss web members and their connections except as listed in class III	Two tracks loaded	200,000
	One track loaded	500,000
Class III Transverse floor beams and their connections or truss verticals and sub-diagonals which carry floor beam reactions only and their connections	Two tracks loaded	500,000
	One track loaded	over 2,000,000

FATIGUE ASSESSMENT PROCESS

6- In detailing highway bridges for design lives greater than **<u>50 years</u>**, the fatigue loads should be increased by a magnification factor, M, given by the following Table:

No. of Years	50	80	100	120
Magnification Factor, M	**1.00**	**1.10**	**1.15**	**1.20**

FATIGUE ASSESSMENT PROCESS

7- Each structural element has a particular **detail category** as shown in the following Tables. The classification is divided into four parts which correspond to the following four basic groups:

Group 1: Non-Welded Details, plain materials, and bolted plates.

Group 2: Welded Structural Elements.

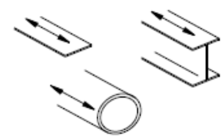
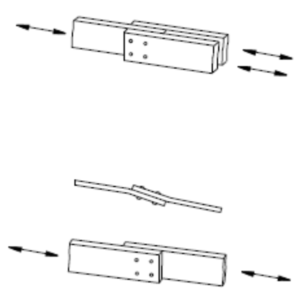
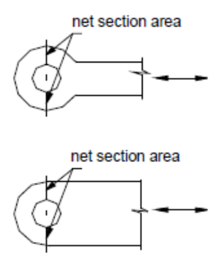
Group 3: Fasteners (welds and bolts).

Group 4: Orthotropic Deck Bridges.

FATIGUE ASSESSMENT PROCESS

CLASSIFICATION OF DETAILS

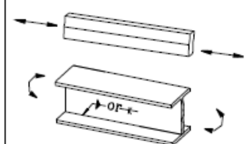
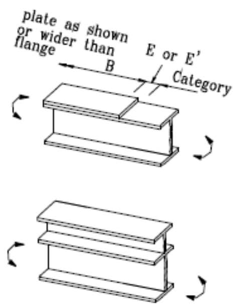
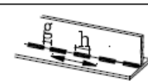
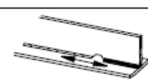
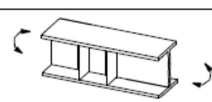
Group 1: Non-Welded Details

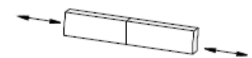
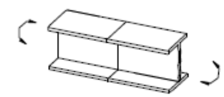
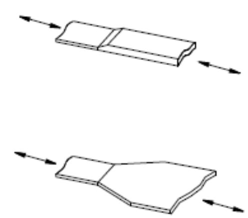
Description	Illustration	Class
1.1. Base metal with rolled or cleaned surfaces; flame cut edges with a surface roughness less than 25 μm		A
1.2. Base metal with sheared or flame cut edges with a surface roughness less than 50 μm		B
2.1. Base metal at gross section of high strength bolted slip resistant (friction) connections, except axially loaded joints which induce out of plane bending in connected material.		B
2.2. Base metal at net section of fully tensioned high strength bolted bearing type connections		B'
2.3. Base metal at net section of other mechanically fastened joints (ordinary bolts & rivets).		D
3. Base metal at net section of eye-bar head or pin plate.		E

FATIGUE ASSESSMENT PROCESS

CLASSIFICATION OF DETAILS

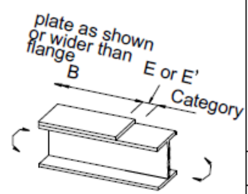
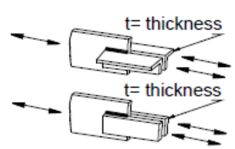
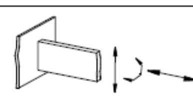
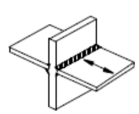
Group 2: Welded Structural Elements

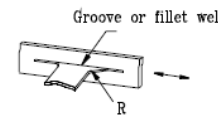
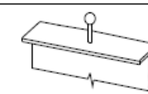
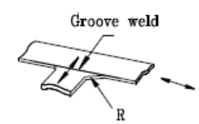
Description	Illustration	Class
4.1. Base metal in members without attachments, built up plates or shapes connected by continuous full penetration groove welds or by continuous fillet welds carried out from both sides without start stop positions parallel to the direction of applied stress.		B
4.2. Same as (4.1.) with welds having stop - start positions.		B'
4.3. Base metal in members without attachments, built-up plates or shapes connected by continuous full penetration groove welds with backing bars not removed, or by partial penetration groove welds parellel to the direction of applied stress.		B'
5. Base metal at continuous manual longitudinal fillet or full penetration groove welds carried out from one side only. A good fit between flange and web plates is essential and a weld preparation at the web edge such that the root face is adequate for the achievement of regular root penetration.		C
6. Base metal at zones of intermittent longitudinal welds with gap ratio g/h < 2.5		D
7. Base metal at zones containing copes in longitudinally welded T-joints.		D
8. Base metal at toe of welds on girder webs or flanges adjacent to welded transverse stiffeners.		C

Description	Illustration	Class
9.1. Base metal and weld metal at full penetration groove welded splices (weld made from both sides) of parts of similar cross sections ground flush, with grinding in the direction of applied stress and weld soundness established by radiographic or ultrasonic inspection.		B
9.2. Same as (9.1.) but with reinforcement not removed and less than 0.10 of weld width.		C
9.3. Same as (9.2.) with reinforcement more than 0.10 of weld width.		D
10.1. Base metal and weld metal at full penetration groove welded splices (weld made from both sides) at transitions in width or thickness, with welds ground to provide slopes no steeper than 1 to 2.5 with grinding in the direction of applied stress, and with weld soundness established by radiographic or ultrasonic inspection.		B'
10.2. Same as (10.1.) but with reinforcement not removed and less than 0.10 of weld width.		C
10.3. Same as (10.2.) with slopes more than 1 to 2.5		D
10.4. Same as (10.1.) to (10.3.) but with welds made from one side only.		E'

FATIGUE ASSESSMENT PROCESS

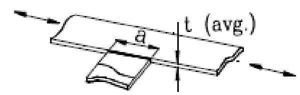
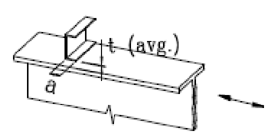
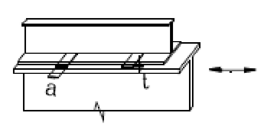
CLASSIFICATION OF DETAILS

Description	Illustration	Class
11.1. Base metal and weld metal at transverse full penetration groove welded splices on a backing bar. The end of the fillet weld of the backing strip is more than 10 mm from the edges of the stressed plate		D
11.2. Same as (11.1) with the fillet weld less than 10 mm from the edges of the stressed plate.		E
12.1. Base metal at ends of partial length welded cover plates narrower than the flange having square or tapered ends, with or without welds across the ends or wider than the flange with welds at the ends. Flange thickness ≤ 20 mm		E
Flange thickness > 20 mm		E'
12.2 Base metal at ends of partial length welded cover plates wider than the flange without end welds.		E'
13. Base metal at axially loaded members with fillet welded connections. t ≤ 25 mm		E
t > 25 mm		E'
14. Base metal at members connected with transverse fillet welds.		C
15.1. Base metal at full penetration weld in cruciform joints made of a special quality weld.		D
15.2. Same as (15.1) with partial penetration or fillet welds of normal quality.		E'

Description	Illustration	Class
16. Base metal at plug or slot welds.		E
17. Base metal and attachment at fillet welds or partial penetration groove welds with main material subjected to longitudinal loading and weld termination ground smooth R > 50 mm		D
R ≤ 50 mm		E
18. Base metal at stud- type shear connector attached by fillet weld or automatic end weld.		C
19.1. Base metal at details attached by full penetration groove welds subject to longitudinal loading with weld termination ground smooth. Weld soundness established by radiographic or ultrasonic inspection R > 610 mm		B
610 mm > R > 150 mm		C
150 mm > R > 50 mm		D
R < 50 mm		E
19.2. Same as (19.1.) with transverse loading, equal thickness, and reinforcement removed. R > 610 mm		B
610 mm > R > 150 mm		C
150 mm > R > 50 mm		D
R < 50 mm		E

FATIGUE ASSESSMENT PROCESS

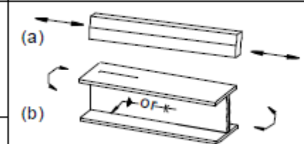
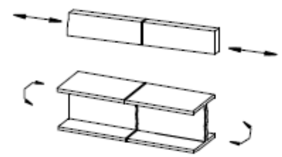
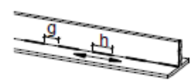
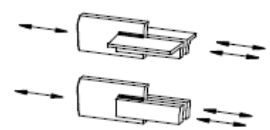
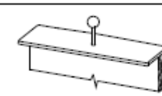
CLASSIFICATION OF DETAILS

Description	Illustration	Class
19.3. Same as (19.2.) but reinforcement not removed R > 610 mm		C
610 mm > R > 50 mm		C
150 mm > R > 50 mm		D
R > 50 mm		E
19.4. Same as (19.2.) but with unequal thickness R > 50 mm		D
R < 50 mm		E
19.5. Same as (19.4.) but with reinforcement not removed and for all R		E
20. Base metal at detail attached by full penetration groove welds subject to longitudinal loading 50-mm< a <12t or 100 mm		D
a >12t or 100 mm (t<25 mm)		E
a >12t or 100 mm (t>25 mm)		E’
21. Base metal at detail attached by fillet welds or partial penetration groove welds subject to longitudinal loading a < 50 mm		C
50 mm< a <12t or 100 mm		D
a >12t or 100 mm (t<25 mm)		E
a >12t or 100 mm (t>25 mm)		E’

FATIGUE ASSESSMENT PROCESS

CLASSIFICATION OF DETAILS

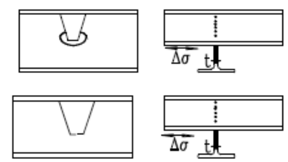
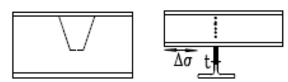
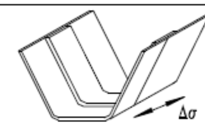
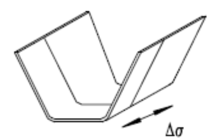
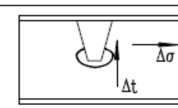
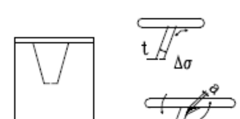
Group 3: Fasteners (Welds and bolts)

Description	Illustration	Class
22.1. Weld metal of full penetration groove welds parallel to the direction of applied stress (weld from both sides)		B
22.2. Same as (22.1.) but with weld from one side only.		C
22.3. Weld metal of partial penetration transverse groove weld based on the effective throat area of the weld.		F
23.1 Weld metal of continuous manual or automatic longitudinal fillet welds transmitting a continuous shear flow.		D
23.2 Weld metal of intermittent longitudinal fillet welds transmitting a continuous shear flow.		E
23.3 Weld metal at fillet welded lab joints.		E’
24. Transversally loaded fillet welds.		E’
25. Shear on plug or slot welds.		F
26. Shear stress on nominal area of stud-type shear connectors.(Failure in the weld or heat affected zone.)		F
27.1. Hight strength bolts in single or double shear (fitted bolt of bearing type).		C
27.2. Rivets and ordinary bolts in shear.		D
28. Bolts and threaded rods in tension (on net area)		F

FATIGUE ASSESSMENT PROCESS

CLASSIFICATION OF DETAILS

Group 4: Orthotropic Deck Bridges

Description	Illustration	Class
29.1. Base metal at continuous longitudinal rib with or without additional cutout in cross girder. (Bending stress range in the rib) t ≤ 12mm		C
29.2. Same as (29.1.) t > 12mm		D
30. Base metal at separate longitudinal ribs on each side of the cross girder. (Bending stress range in the rib)		E'
31. Base metal at rib joints made of full penetration weld with backing plate.(Bending stress range in the rib)		D
32.1. Base metal at rib joints made of full penetration weld without backing plate. All welds ground flush to plate surface in the direction of stress. Slope of thickness transition < 1:4. (Bending stress range in the rib)		B'
32.2. Same as (32.1.) with weld reinforcement ≤ 0.2		C
33. Base metal at connection of continuous longitudinal rib to cross girder. (Equivalent stress range in the cross girder web).		E'
34.1. Weld metal at full penetration weld connecting deck plate to rib section.		D
34.2. Weld metal at fillet weld connecting deck plate to rib section.		E'

FATIGUE ASSESSMENT PROCESS

Table (3.2) Allowable Stress Range (F_{sr}) for Number of Constant Stress Cycles (N)

Detail Category \ N	F_{sr} (t/cm^2)			
	100,000	500,000	2,000,000	Over 2,000,000
A	4.30	2.52	1.68	1.68
B	3.42	2.00	1.26	1.12
B'	2.77	1.62	1.02	0.85
C	2.48	1.45	0.91	0.70
D	1.92	1.12	0.71	0.49
E	1.53	0.89	0.56	0.32
E'	1.11	0.65	0.41	0.18
F	0.72	0.52	0.40	0.36

FATIGUE ASSESSMENT PROCESS

8- When subjected to tensile fatigue loading, the allowable stress range for **High Strength Bolts friction-type** shall not exceed the following values:

Number of Cycles (N)	Allowable Stress Range F_{sr} (t/cm^2)	
	Bolts Grade (8.8)	Bolts Grade (10.9)
$N \leq 20,000$	2.9	3.6
$20,000 < N \leq 500,000$	2.6	3.2
$500,000 < N$	2.0	2.5

Lecture 7: FATIGUE

Summary of Today's Topics

- Introduction/Definitions.
- Fatigue Loading
- Basic Fatigue Principles.
- Factors Affecting Fatigue.
- Fatigue Assessment Process.