Fundamentals of Structural Design Part of Steel Structures

Civil Engineering for Bachelors
133FSTD

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Syllabus of lectures

1. Introduction, history of steel structures, the applications and some representative structures, production of steel
2. Steel products, material properties and testing, steel grades
3. Manufacturing of steel structures, welding, mechanical fasteners
4. Safety of structures, limit state design, codes and specifications for the design
5. Tension, compression, buckling
6. Classification of cross sections, bending, shear, serviceability limit states
7. Buckling of webs, lateral-torsional stability, torsion, combination of internal forces
8. Fatigue
9. Design of bolted and welded connections
10. Steel-concrete composite structures
11. Fire and corrosion resistance, protection of steel structures, life cycle assessment

Fatigue

When the structure is exposed to large number of loading/unloading cycles, the strength of the structure is reduced by cracks

This can be avoided by proper design of structures, especially by structural detailing

Fatigue crack

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Fatigue – crane girders

Crane girders

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Fatigue

Fatigue is a problem every time the structure is exposed to repeated loading

- Crane runways
- Technological platforms supporting various industrial applications - mills, pumps, etc with rotating (moving) parts
- Bridges

Creation of fatigue crack involves:

- Generation of microscopic crack at zone of stress concentration (notch)
- Propagation of the crack
- Weakening of the cross section leads to higher stress concentration and further crack propagation
- Fatigue fracture can be eventually observed

The design is therefore based on careful structural detailing without zones of stress concentration, however, "perfect structure" will never be possible

The choice of convenient detailing with limited effect of stress concentration improve fatigue resistance

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Fatigue

These parameters have significant effect on fatigue resistance of the structure

- Type of structural detailing
  (notches, where stress concentration occurs, should be avoided)
- Number of load cycles in the design lifetime
  (higher number of cycles leads to lower fatigue resistance)
- Stress range
  (Not the absolute stress but the stress range i.e. the difference between minimum and maximum stress is important)

Fatigue is not important and does not need to be considered in these cases

- Low stress range
- Small number of load cycles

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Notches

Notches represent zones of stress concentration

- Sudden changes of geometry of specimen
  change of width or thickness of a plate, holes
- Defects in material or welds
  porosity, cracks, slag embedded the weld
- Surface deficiency of material
  Scratches, scores, not worked surface of the weld, burrs
- Residual stresses (especially tension)
  The cracks easily propagate in tension zones, the notches in compression zones are less important

Higher steel grades are more sensitive to notches than steel with lover strength, therefore both have very similar fatigue strength

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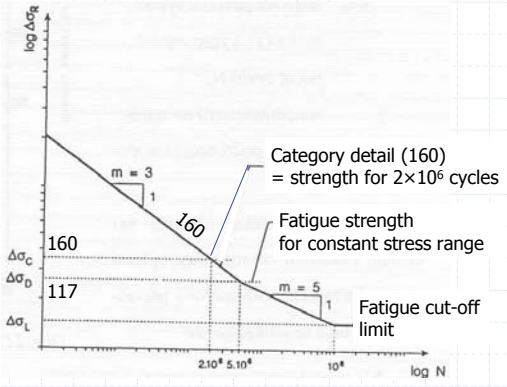
Fatigue resistance - Wöhler's curve

Wöhler's curve represents the basic curve for fatigue resistance check
It relates the maximum allowed stress range to number of load cycles
It has been prepared for various structural detailing according to their fatigue resistance = sensitivity to crack initiation
It is usually plot in logarithmic scale (log $\Delta\sigma_R$, log N)



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Wöhler's curve in Eurocode

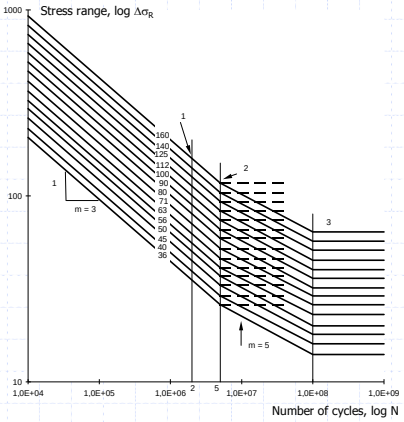
$$\log N = \log a - m \log \Delta\sigma_R$$

tri-linear curve

$\Delta\sigma_R$ fatigue strength

N number of cycles

log a constant depending on structural detail



36, 40, 45, 50, … 140, 160 is the category of the structural detail

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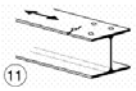
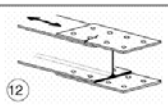
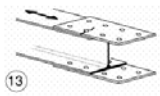
Category of fatigue details in Eurocode

Category of detail	Structural detail	Description	Requirements	
90		11) Load bearing element with bolt holes, loaded by bending moment or axial force	11) Δσ is evaluated for net section	Bolt end spacing $e_1 \geq 1{,}5\ d$ Bolt edge spacing $e_2 \geq 1{,}5\ d$ Bolt spacing $p_1 \geq 2{,}5\ d$ $p_2 \geq 2{,}5\ d$ Symbols according to Figure 3.1 in EN 1993-1-8
80		12) Connection with single cover plate and fit or injected bolts	12) Δσ is evaluated for net section	
50		13) Connection with single cover plate or symmetrical connection with two plates and bearing type bolts in standard bolt holes. Alternating load is not allowed.	13) Δσ is evaluated for net section	
40		5) Welded, without transition radius		

Example of category of details form EN 1993-1-9

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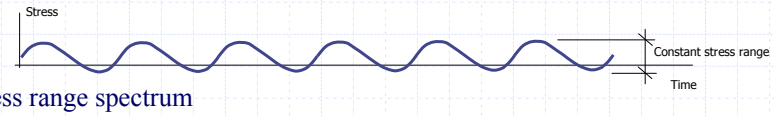
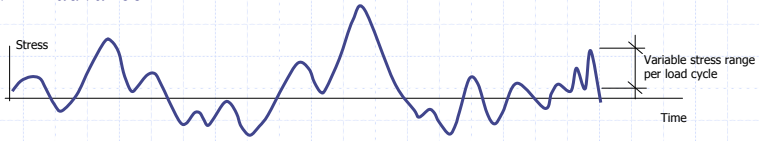
Check of fatigue resistance in Eurocode

Two cases of fatigue load are considered:

- Constant amplitude stress range
  This is usually represented by harmonic loading following the sinus curve, which is typical for situations when eccentric rotating parts create variable (repeating) load



- Stress range spectrum
  This is typical for bridges, where the number of cycles (number of vehicles passing over the bridge) and the stress range (weight of the vehicle) is not known in advance



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Constant amplitude stress range

Fatigue resistance for constant amplitude stress range

$$\gamma_{Ff}\,\Delta\sigma \le \frac{\Delta\sigma_R}{\gamma_{Mf}}$$

$\Delta\sigma$ applied stress range
γ_{Ff} load partial safety factor for fatigue
$\Delta\sigma_R$ fatigue strength for given number of cycles N
γ_{Mf} material partial safety factor for fatigue

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Variable stress range

Palmgren-Miner's hypothesis is used to evaluate the total damage of the structural detail

Analysis of load spectrum, i.e. the number of load cycles with the corresponding stress range needs to be evaluated first

The damage from various stress ranges accumulate

$$D_d = \sum \left(\frac{n_i}{N_i} \right) \leq 1$$

n_i number of cycles with range of stress $\Delta\sigma_i$ within the structural life

N_i number of cycles with the design stress range ($\gamma_{Ff}\, \gamma_{fM}\, \Delta\sigma_i$) necessary to damage the considered detail, determined from the Wöhler's curve of the corresponding detail

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Design rules of with respect to fatigue

- Structural details
  - welds represent the most significant notches ⇒ quality of welding is important
  - replacement of welded details by other solution
  - placing of welds in locations with smaller stress range
- Optimization of production cost
  - details without notches are more expensive

  but
  - simple details with notches lead to lower fatigue resistance
- Selection of the steel type is not very important

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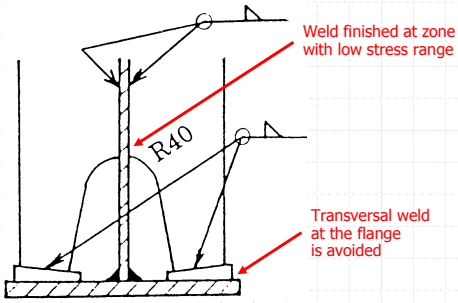
Design rules of with respect to fatigue



Structural detail modified to increase fatigue resistance

Thank you for your attention