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

Scope of the lecture

- ➡ Design methods and safety of structures
- Limit state design
- Standards for design of structures

Design methods

- Experience of the designer
- Permissible stress design (in USA allowable stress design)

  The designer ensures that the stresses developed in a structure due to service loads do not exceed the elastic limit. This limit is usually determined from maximum allowed stress (yield limit) divided by factors of safety (factor >1).
- ➡ Partial safety factors method (in USA load and resistance factor design)

  The designer has to use a set of safety factors, these increase the effect of loads (i.e. stresses) and decrease the resistance (i.e. yield limit). The structure is assumed to be safe when the “magnified" loads are amaller than the relevant “reduced" resistances.

  Semi-probabilistic method

  It is the principle of European codes for the design of structures
- Probabilistic design methods

  The designer has to deal with probability of the factors entering the calculation

  Not commonly used at the moment

Loads

The loads are usually based on statistical observation and evaluation

The probability of the load is shown on the picture

The minimum a maximum loads are obtained by

$$F_{k,max} = \gamma_{F,max} \, F_k$$

$$F_{k,min} = \gamma_{F,min} \, F_k$$

The factors γ_F were chosen in such a way that the index of safety is

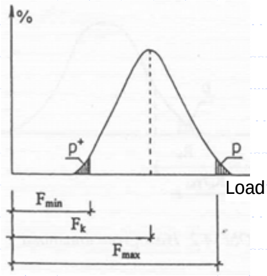
$$\beta = \frac{\mu_z}{\sigma_z}$$

μ_z - the average

σ_z - standard deviation of random variable Z

$\beta = 3{,}8$ for ultimate resistance limit state

$\beta = 1{,}5$ for serviceability limit state



This is done for design life of structure (usually 80 years)

Resistance

The resistance (of an element loaded in tension here) is evaluated from

$$R_k = A \, f_y$$

A is the cross-sectional area

f_y is the yield limit of steel

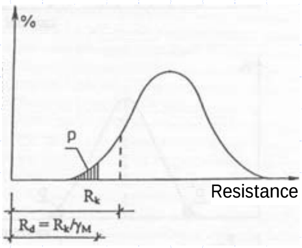
The resistance can be evaluated experimentally and set of values is obtained

The smallest resistance is obtained when both the yield limit and the area are smaller than average, however, the element is not defective because may still fit within manufacturing tolerances

In addition, there might be effect of non-accurate model for calculation of the resistance

The design value of the resistance is obtained by

$$R_d = \frac{A \, f_y}{\gamma_M} = \frac{R_k}{\gamma_M}$$



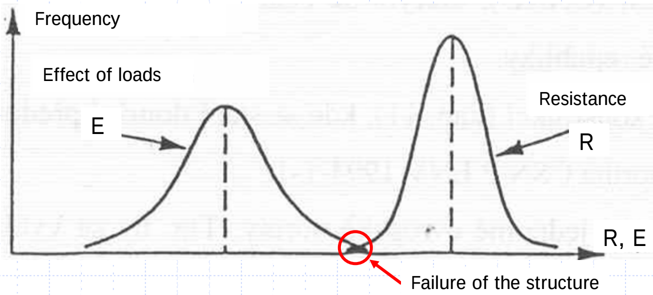
Principle of reliability

$$E_k \, \gamma_F \leq \frac{R_k}{\gamma_M}$$

$$E_d \leq R_d$$

E_d biggest possible effect of design loads

R_d smallest possible design resistance of structure



Partial safety factors

Characteristic values

- Partial safety factors γ
- Reduction combination factors ψ

Design values

Partial factors γ take into account variation of the properties

- Disadvantageous deviations from characteristic values
- Inaccuracy of design model (theoretical model to evaluate stresses, deformations, etc.)
  - Material factors γ_M
  - Load factors γ_F

Reduction combination factors ψ take into account simultaneous application of several variable loads

- When single variable load is applied, no reduction is considered
- when more than one exists at the same time, there is very low probability they act the maximum (i.e. design) value - reduction applies

Scope of the lecture

Design methods and safety of structures

➡ Limit state design

Standards for design of structures

Limit states

A limit state is a condition of a structure beyond which it no longer fulfills the relevant design criteria.

Ultimate Limit States

$\gamma_M > 1$, $\gamma_F > 1$

- Strength
- Fatigue strength
- Brittle fracture
- Stability of position

Serviceability limit states

$\gamma_M = 1$, $\gamma_F = 1$

- Deflections
- Vibrations
- Esthetics

Ultimate limit states

Refer to extreme situation

Very low probability of exceeding

- Design yield strength … $f_{yd} = f_y / \gamma_M$
  - $\gamma_M \geq 1$
- Design load … $F_{Ed} = F_k \gamma_F$
  - $\gamma_F > 1$
- Nominal dimensions of structure
- Nominal material stiffness (E, G)

Example of limit state - stability of the position

$E_{d,dest} \leq E_{d,stab}$

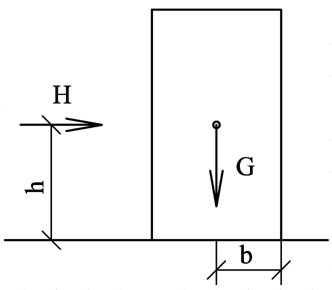
$E_{d,dest}$ design effects of destabilizing loads - increased horizontal force

$E_{d,dest} = H\, h \qquad H_{Ed} = H_k\, \gamma_F$

$E_{d,stab}$ design effects of stabilizing loads - decreased self weight of the block

$E_{d,stb} = G\, b$

G ... minimum value



Serviceability limit state

- Refer to everyday service
  - With service load ($\gamma_F = 1$)
  - With nominal dimensions of structure
- Material characteristics (f_y, E, G)
  - Nominal value (average, mean)

Classification of actions (loading)

Source
- Gravity action (self weight)
- Climatic (snow, wind, rain, rime, temperature elongation)
- Variable (load of ceiling in buildings)

Determination
- Precisely defined (e.g. bridge loading)
- Very indeterminate (e.g. wind)

Position
- Fixed (e.g. dead load)
- Movable (e.g. overhead crane, train/car on a bridge)

Acting
- At everyday service
- At the particular situation
- At natural catastrophes (earthquake)
- At disasters (fire, explosion)

Acceleration
- Static load
- Dynamic load (acceleration can not be omitted)

Combination of higher number of variable loads

$$\sum \gamma_{G,j}\, G_{k,j} + \gamma_{Q,1}\, Q_{k,1} + \sum_{i>1} \gamma_{Q,i}\, \psi_{0,i}\, Q_{k.i}$$

The load combination for Ultimate Limit State (ULS) takes into account:

- the design value of dead loads
- the design value of the dominant variable load $Q_{k,1}$
- the design values of other variable loads are reduced by combination factor ψ

In case of dynamic effects:

- dynamic analysis is performed
- quasi-static analysis can be performed for simple cases, increasing the results by dynamic factor δ

Scope of the lecture

Design methods and safety of structures

Limit state design

➡ Standards for design of structures

European codes

- These are usually product codes
- Design codes (Eurocodes) exist for design of structures
  - European codes started to be developed in about 1980 to have common method of design in Europe (to increase foreign trade, etc.)
  - European Committee for Standardization (CEN) was established in 1990
    - at the moment, the members are 19 European countries
    - the others are "associated members"
    - Czech Republic is a regular member since 1998
- Preliminary codes (ENV) were developed first
  - they were considered as "temporary" standards to evaluate the principles
  - national standards could be used at the same time
  - National Application Document (NAD) – was included to take into account specific approach and "national" values for partial safety factors, this was prepared by national specialists
  - are not valid any more
- European codes (EN)
  - these replaced the ENV and national codes
  - are the only standards used for design in Czech Republic
  - NA - National Annex, include national values of partial safety factors, etc.

European design codes

EN 1990 Eurocode 0 - Basis of Structural Design
EN 1991 Eurocode 1 - Actions on structures
EN 1992 Eurocode 2 - Design of concrete structures
EN 1993 Eurocode 3 - Design of steel structures
EN 1994 Eurocode 4 - Design of composite steel and concrete structures
EN 1995 Eurocode 5 - Design of timber structures
EN 1996 Eurocode 6 - Design of masonry structures
EN 1997 Eurocode 7 - Geotechnical design
EN 1998 Eurocode 8 - Design of structures for earthquake resistance
EN 1999 Eurocode 9 - Design of aluminium structures

These standards usually consist of more parts, i.e. EN 1993 consists of 12 parts

Partial safety factors

EN 1990

Load	Effect	Service load (SLS)	Design load (ULS)
Dead	favourable	$\gamma_G = 1{,}0$	$\gamma_{G,min} = 1{,}0$
	unfavourable	$\gamma_G = 1{,}0$	$\gamma_{G,max} = 1{,}35$
Variable		$\gamma_Q = 1{,}0$	$\gamma_Q = 1{,}50$

EN 1993

$\gamma_M = 1{,}00$ (for steel)

other values exist for connections, etc.

Thank you for your attention