CE 382 Reinforced Concrete Fundamentals

Structural Safety and Design

Design Process

In ancient times

- Intuition
- Experience
- Time & economy → not primary factors

Hammurabi Rules

- If the builder has built a house for a man and has not made his work sound, and if the house, which he has built, has collapsed and so caused the death of the owner, the builder shall be put to death.
- If it causes the death of owner's son, a son of the builder shall be put to death.
- If it causes the death of a slave of the owner of the house, the builder shall give to the owner a slave of equal value.
- If it destroys property, the builder shall restore whatever is destroyed and because the house, which he built has collapsed, he shall rebuild the house at his own expense.
- If a builder built a house for a man and did not make its construction meet the requirements and a wall fell in, that builder shall strengthen the wall at his own expense.

Concept of Structural Safety

- To provide **economically** a structural system, which will remain **functional** under external effects (**loads)** foreseen for that structure.
- Functional → no collapse & remain serviceable
- Failure → Collapse or unserviceable
- Unserviceable:
  - Excessive deformations (deflection, displacement, etc.)
  - Excessive vibrations
  - Excessive cracking

Concept of Structural Safety

- Failure → can cause loss of property and human life
- Safety → both on design calculations & on the supervision on site

$$R \geq F$$

Resistance ≥ Load effect

Strength external action

against deflection

or cracking

- Moment (capacity) ≥ applied external moment
- Shear (capacity) ≥ external or applied shear

Working Stress Design

- Elastic Design
- Apply a Factor of Safety (F.S.) to the limiting strength
- As time passed:
  - Design techniques improved
  - More sophisticated analysis methods became available
  - Material, member & system behavior better understood
  - Computers → speed up → more analysis
- ➔ F.S. ⇘ → new approaches: probabilistic or semi-probabilistic approaches

Variation of the Design Load

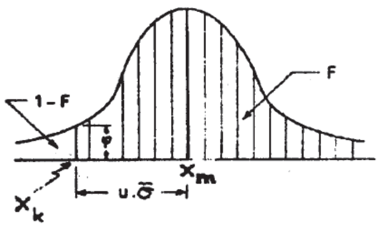
- Load Effect, F
- In the past → no adequate data → recommended values higher than expected values
- Today → load can be represented by statistical distributions.
- Adequate data to realistically establish design load.
- Earthquake load → data limited.

Variation of Resistance, R

- Variation in strength of material
  - Steel → ±5%
  - Concrete → ±20%
- Variation in dimensions
  - 800 mm deep beam → 15 mm error, not critical
  - 100 mm slab → 15 mm error, critical
- Steel area can differ
- The real behavior of the structure can be different from the idealized behavior
- Approximations & assumptions made in developing the analytical methods.
- Behavior & strength can change as a function of time

Normal Distribution

- Variation in Resistance can be represented with reasonable accuracy using the normal distribution
- Variation in Load, generally, has unsymmetrical distribution → assume normal distribution for simplicity.
- $x_m = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \bar{\sigma} = \sqrt{\frac{\sum(x_i - x_m)^2}{n-1}}$



x_m: mean value
$\bar{\sigma}$: standard deviation
n: # of observations
x_i: magnitude of i^{th} value
u: coefficient related to the probability

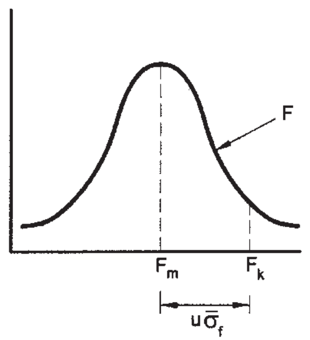
Normal Distribution

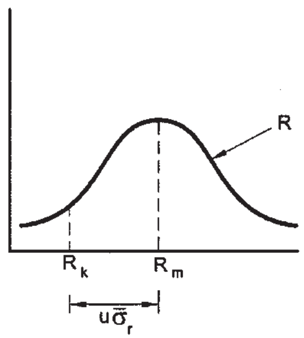
u	φ	F	1 - F
0,000	0,399	0,500	0,500
0,253	0,389	0,600	0,400
0,500	0,352	0,691	0,309
0,524	0,347	0,700	0,300
0,842	0,280	0,800	0,200
1,000	0,242	0,841	0,159
1,282	0,176	0,900	0,100
1,500	0,129	0,933	0,067
1,645	0,103	0,950	0,050
1,960	0,058	0,975	0,025
2,000	0,054	0,977	0,023
2,326	0,027	0,990	0,010
2,500	0,018	0,994	0,006
3,000	$4,43 \cdot 10^{-3}$	$1 - 1,35 \cdot 10^{-3}$	$1,35 \cdot 10^{-3}$
3,500	$8,73 \cdot 10^{-4}$	$1 - 2,33 \cdot 10^{-4}$	$2,33 \cdot 10^{-4}$
4,000	$1,34 \cdot 10^{-4}$	$1 - 3,17 \cdot 10^{-5}$	$3,17 \cdot 10^{-5}$
4,500	$1,60 \cdot 10^{-5}$	$1 - 3,40 \cdot 10^{-6}$	$3,40 \cdot 10^{-6}$
5,000	$1,49 \cdot 10^{-6}$	$1 - 2,87 \cdot 10^{-7}$	$2,87 \cdot 10^{-7}$
6,000	$6,08 \cdot 10^{-9}$	$1 - 9,87 \cdot 10^{-10}$	$9,87 \cdot 10^{-10}$
7,000	$9,14 \cdot 10^{-12}$	$1 - 1,28 \cdot 10^{-12}$	$1,28 \cdot 10^{-12}$
8,000	$5,05 \cdot 10^{-15}$	$1 - 6,22 \cdot 10^{-16}$	$6,22 \cdot 10^{-16}$

Characteristic values

- $F_k = F_m + u\bar{\sigma}$
- $R_k = R_m - u\bar{\sigma}$
- Failure probability of 10%
  - (1-F=1.0) → u=1.282

F_k: characteristic load effect which can be exceeded by a predetermined probability (10%)
R_k: characteristic resistance, below which a small percentage will fall (10%)



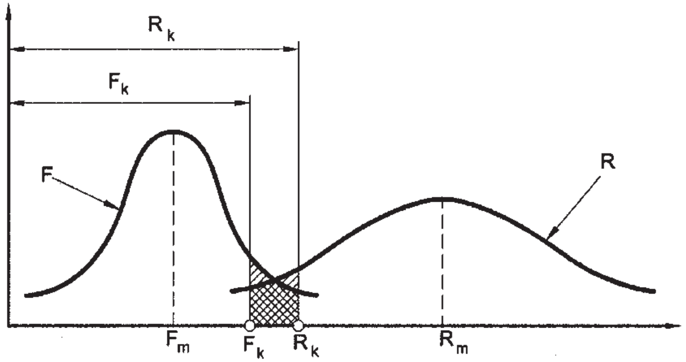


Limit State Design

- The local or overall behavior at all stages is considered
  - Elastic
  - Plastic
  - Cracked
  - Ultimate
- According to Turkish Code TS 500-2000
  - Ultimate limit state
  - Serviceability limit state

Safety

- $R_k \geq F_k$



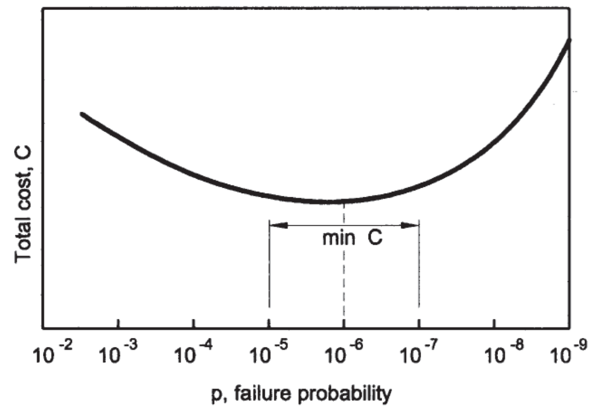
characteristic values are not adequate:

- $\dfrac{R_k}{\gamma_m} \geq F_k \gamma_f$

$\gamma_m \geq$ material factor
$\gamma_f \geq$ load factor

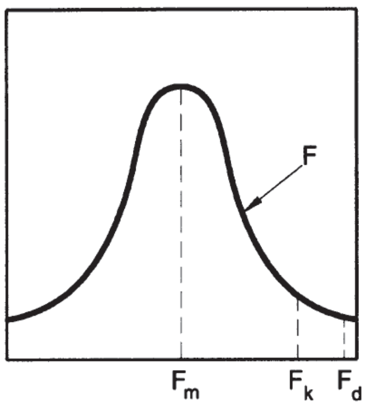
Safety

- Prof. Rüsch → for office building
- Total Cost = capital expenditure + probable cost of failure or other damage



Design Load

- $F_d = \gamma_g G + \gamma_q \{Q_{\ell k} + \sum \psi_{oi} Q_{ik}\}$
- F_d: Design load
- G: Dead load
- $Q_{\lambda k}$: Basic live load
- Q_{ik}: other live load
- γ_g: load factor for dead load
- γ_q: load factor for live load
- ψ_{oi}: combination factor ≤ 1.0



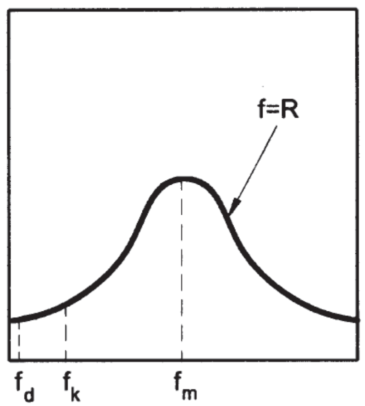
Load Factors & Load Combinations in TS500-2000

- $F_d = 1.4G + 1.6Q$
- $F_d = 1.0G + 1.2Q + 1.2T$
- $F_d = 1.0G + 1.0Q + 1.0E$
- $F_d = 0.9G + 1.0E$
- $F_d = 1.0G + 1.3Q + 1.3W$
- $F_d = 0.9G + 1.3W$
- $F_d = 1.4G + 1.6Q + 1.6H$
- $F_d = 0.9G + 1.6H$

G: Dead Load
Q: Live Load
T: load due to imposed deformations, temperature change, shrinkage, support settlement
E: Earthquake Load
W: Wind Load
H: Earth Pressure

Design Strength

- $f_d = \frac{f_k}{\gamma_m}$
- for steel:
- $f_{yd} = \frac{f_{yk}}{\gamma_{ms}}$ $\gamma_{ms} = 1.15$
- for concrete:
- $f_{cd} = \frac{f_{ck}}{\gamma_{mc}}$ $\gamma_{mc} = 1.5$
- 1.4 for precast concrete



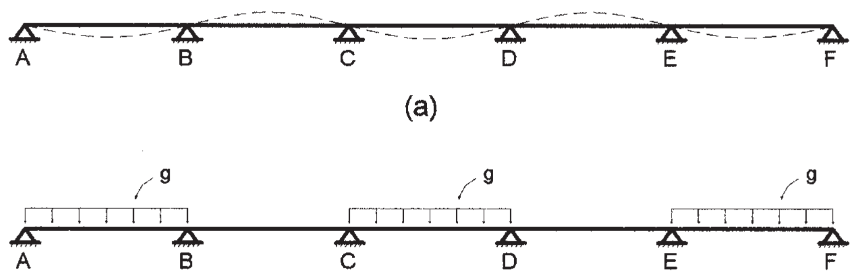
Coefficient of variation

- $f_{cm} = f_{ck} + u\bar{\sigma}$ for 10% u=1.28
- $\upsilon = \frac{\bar{\sigma}}{f_{cm}}$ ν: coefficient of variation
- $f_{cm} = \frac{f_{ck}}{1-u\upsilon}$
- $\upsilon \leq 0.10$ excellent quality control
- $0.1 < \upsilon < 0.15$ good quality control
- $0.15 \leq \upsilon \leq 0.2$ average quality control
- $\upsilon > 0.2$ inadequate quality control
- $f_{cm} = f_{ck} + \Delta f_c$ Δf_c=4 MPa for C16, C18
  =6 MPa for C20 to C30
  =8 MPa for C35 to C50

Live Load Arrangement

- Dead load exists on all spans of the structure
- Live load may or may not be present on a given span
- Live load should be arranged in such a way as to produce the maximum internal force at that point
- For continuous beams → checker board loading → maximum span moment

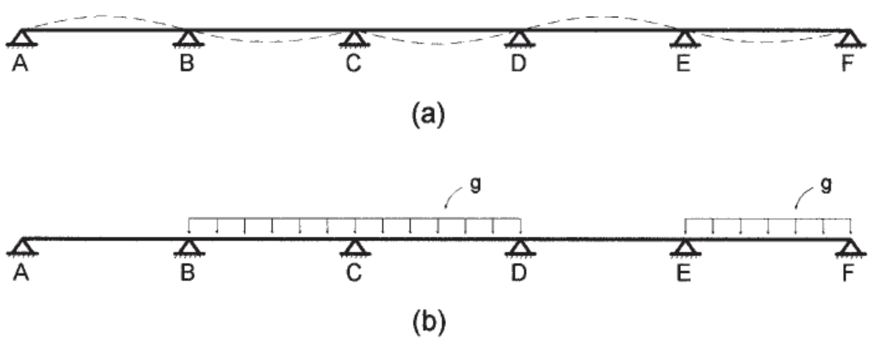
Maximum span moment



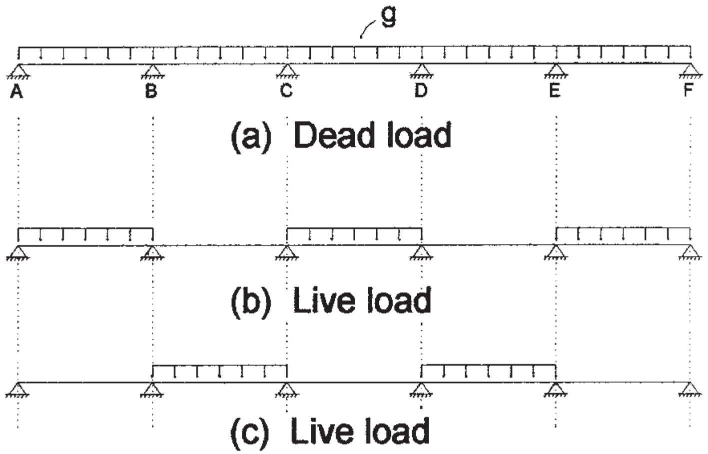
(a)

(b)

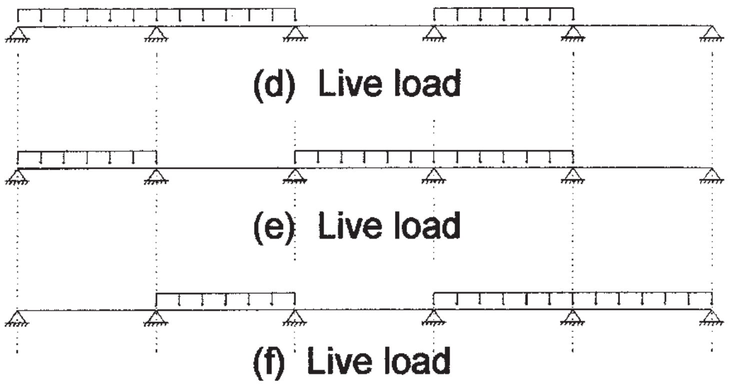
Maximum support moment



Live Load Arrangement



Live Load Arrangement



Fundamentals of Design

- Reinforced Concrete Members exhibit:
  - Inelastic
  - Nonlinear
  - Time Dependent Behavior
- Determining the state of stress and deformations is a challenging task
- Including all the variables in design is challenging!
- Engineer should make reasonable simplifying assumptions considering important variables based on knowledge and experience.
- Consider safety, economy, practicality
- Avoid sophistication and oversimplification
- Accuracy in math calculations may turn out to be useless

SIMPLE BUT NOT SIMPLER

Steps in the Design of RC Structures

- *Select the Structural System*:

Consider structural behavior, economic factors, architectural concerns. Visualize the load path.

- *Estimate the Loads:*

Remember that this is just an estimation. Use relevant codes/standards (TS 498, DBYBHY2007). Do not forget construction loads.

- *Conduct Structural Analysis:*

Compute internal member forces for a number of combinations (reversed etc.)

- *Proportion members and conduct detailing*

Ensure safety by checking deflections, cracking, ultimate strength.

"Devil is in the details"

Dilemma in Design

- We have to know member sizes in order to be able to conduct structural analysis.
- Preliminary Design is essential.

<u>Preliminary Design:</u> Estimation of member sizes with very simple and approximate procedures (rule of thumbs, experience, judgment).

<u>Final Design:</u> Decision on sizes, details based on more sophisticated methods of analysis.