Reliability of existing structures - Some Practical Aspects

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Prag, November 2007

Ice-stadium Bad Reichenhall, January 2006

Parthenon

From 448B.C - 2007

Why reassess an existing structure?

- Deviations from original design
- Doubts about safety
- Adverse inspection results
- Change of use
- Lifetime prolongation
- Inadequate serviceability

Typical questions

- What type of inspections are necessary?
- What analyses shall be performed?
- What is the future risk in using the structure?
- What kind of actions (decisions are necessary ?)

Bridge inspection

How to find the Answers

- No classical code approach
- New information becomes available
- New techniques can be implemented
- New material technologies can be used
- New decision criteria under new uncertainties

Decision Criteria

- Economical considerations
- Residual Lifetime
- Sociopolotical aspects
- Acceptable Safety

Cracks in buildings

Standards

- **ISO 13822**
- **SIA 462 (Schweiz)**
- **Danish Technical Research Council**
- **ACI 437R**
- **JCSS (Joint Committee Structural Safety)**

ISO 13822

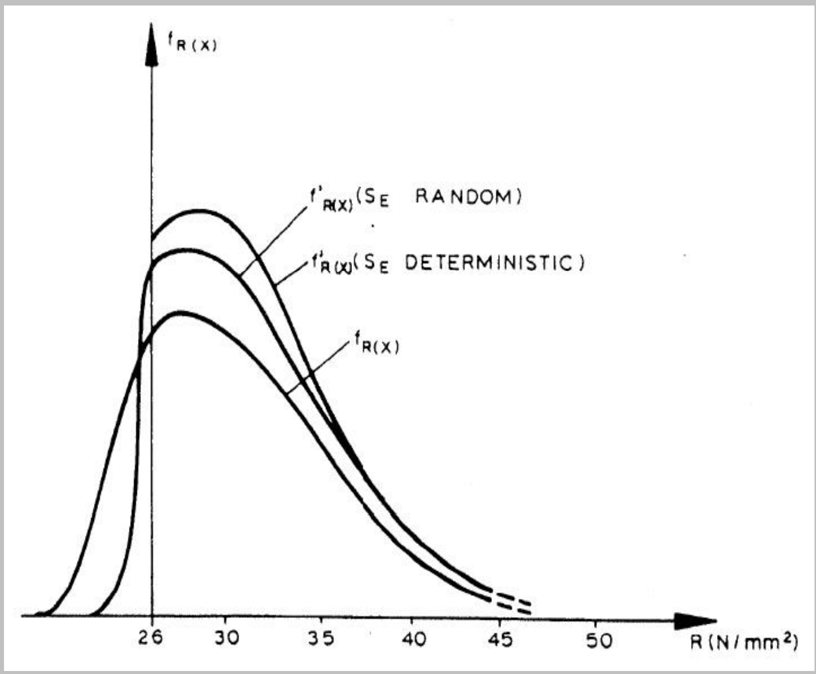
- General Framework of Assessment
- Data for assessment
- Structural Analysis
- Verification (Limit State)
- Assessment based on satisfactory past performance
- Interventions
- Report
- Judgement and Decisions

New Information (Updating)

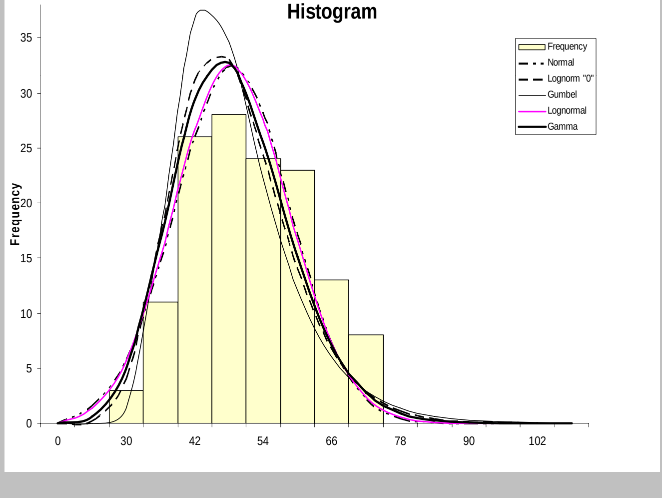
A) Proof loading

B) Variables (concrete strength)

A) Example: Proof Loading (Survival of a load)
> Updating of resistance



B) Example: Concrete strength data



Approximate Safety Assessment

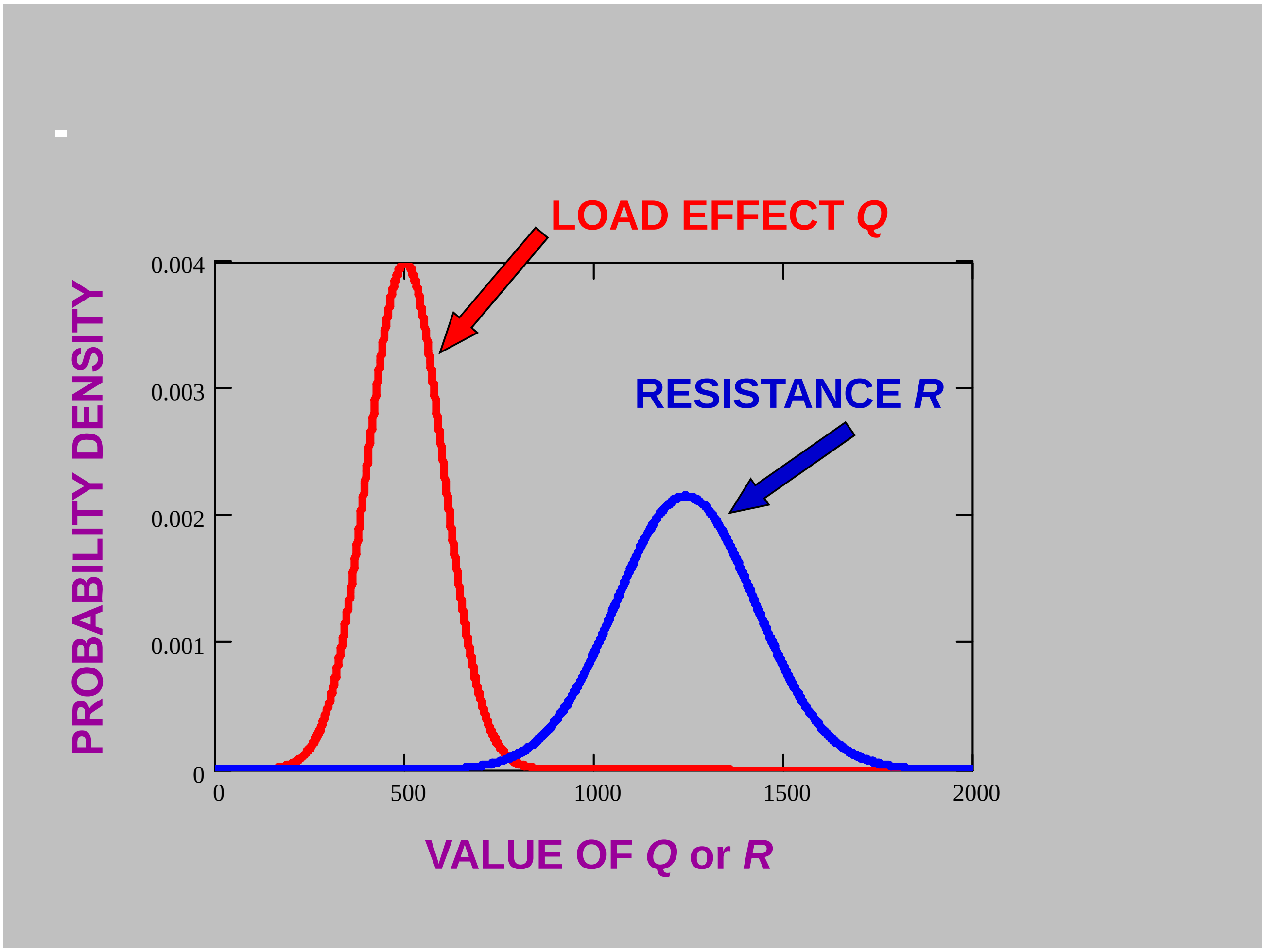
z.B. Scoring Systems

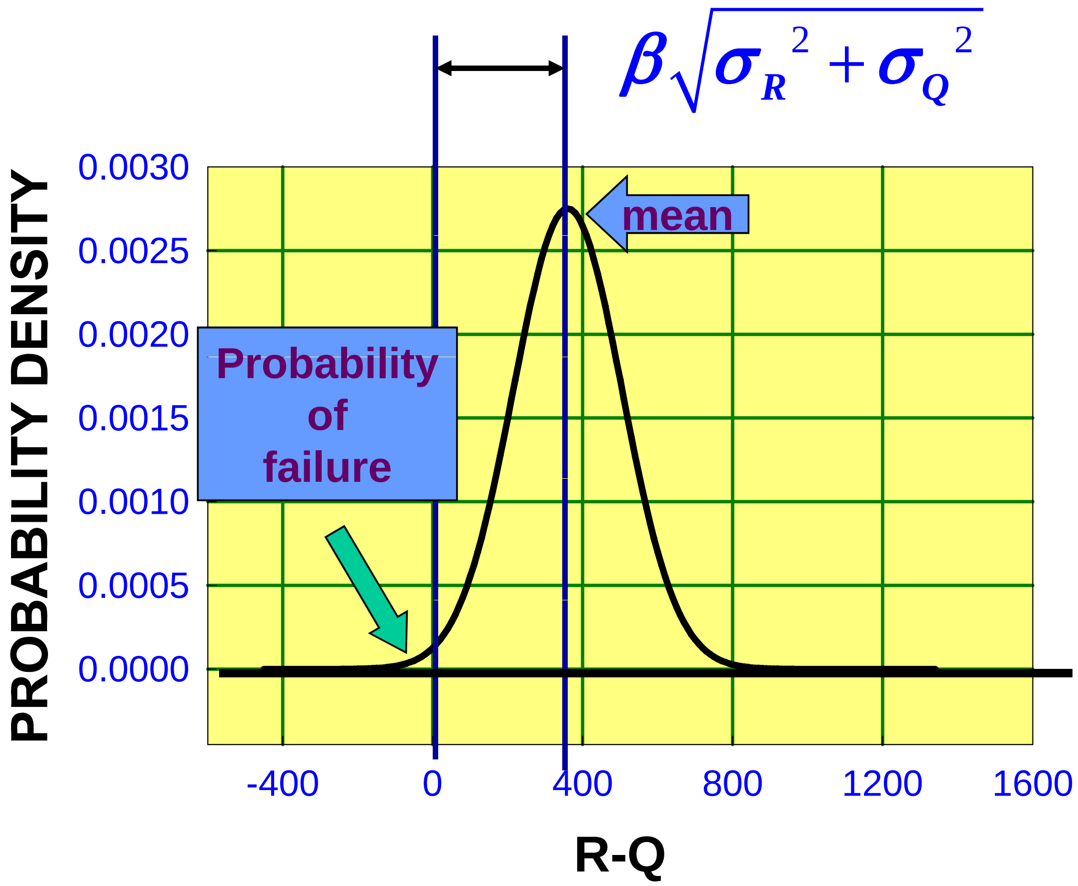
- Design time (which standard?)
- Structural status (cracks, deformations)
- Robustness
- Loading criteria
- Loading modifications

Further Safety Verification

- Computation of reliability (index)
- Comparison with acceptance criteria
- Implementation of safety measures

Decisions!Actions!


LOAD EFFECT Q
RESISTANCE R
PROBABILITY DENSITY
0.004
0.003
0.002
0.001
0
0
500
1000
1500
2000
VALUE OF Q or R


$\beta\sqrt{\sigma_R^{\;2}+\sigma_Q^{\;2}}$
mean
Probability of failure
PROBABILITY DENSITY
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
-400
0
400
800
1200
1600
R-Q

Failure probability p_f and reliability index β

p_f	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
β	2,33	3,09	3,72	4,27	4,75	5,20	5,61	6,00

Safety Index and probability of failure an example: foundation failure design versus reassessment stage

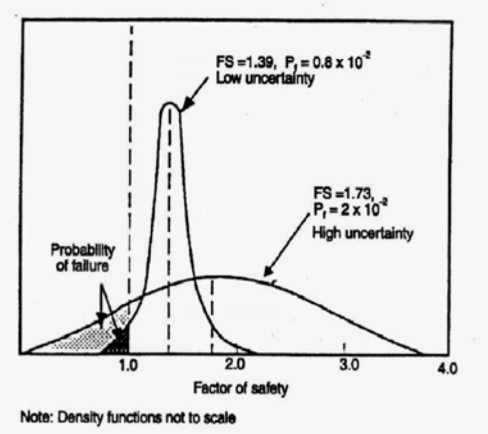


Figure 5. Illustration of safety factor and probability of failure of most loaded pile in example jacket.

a) **deterministic safety factor**

$\gamma = R/S$

based on mean values

b) **probability of failure**

$p_F = P[R/S < 1.0]$

based on probabilistic models

Safety Acceptance Criteria

- European Experience (limit state verification)
- New practice in the US (performance based design)
- Optimisation (cost-benefit)
- Judgement

TARGET SAFETY

Target Reliability (1 year ref. Period)
New structures (JCSS, 2000)

Cost of safety	Consequences: Minor	Moderate	Large
Large	3.1	3.3	3.7
Normal	3.7	4.2	4.4
Small	4.2	4.4	4.7

Target Reliability (1 year ref. Period)
new and existing existing buildings
normal costs of safety (JCSS, 2000)

	Consequences		
	minor	moderate	large
Existing	3.1	3.3	3.7
New	3.7	4.2	4.4

Performance Based Design (USA)

- high environmental loads (flood, earthquakes, snow)
- accidental loads

=>for existing structures a lower reliability is accepted

(5 times larger failure probability!)

Various other proposals

Implicit targets:

- **CSA (Canadian Standards Association, by D. Allen):**
- **Belgian research associations (L. Schueremans)**

Procedures (optimization)

- **Ang et al., Frangopol et al., Ellingwood, Rackwitz, etc**

Acceptable Safety: Conclusions

- **A lower safety level compared to a new structure is acceptable (cost reasons)**
- **Various criteria have been proposed**
- **Acceptance criteria depend on cost of safety, consequences of failure, desired residual lifetime**
- **Increase of acceptable p_F by a factor of 5 to 10 is recommended**

Old Railway Bridges
(single span systems)

Railway Bridges

- 100 years old
- Scoring system verification
  (foundation, corrosion, joints, supports)
- R (steel resistance) from code on old bridges
- S (train load) from DB
- Durability problems

Steel road bridges

Typical limit states

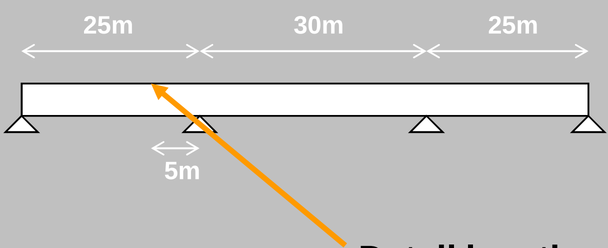
- extreme load

- Fatigue

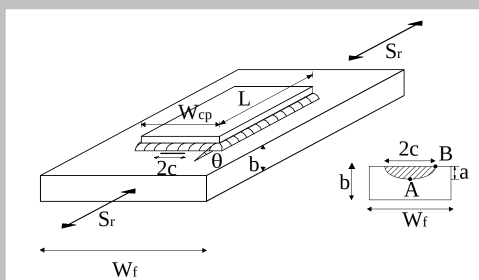
Which measures are necessary in order to meet acceptance criteria (residual life time 20 years)?

Fatigue models

- Fracture Mechanics approach
- Crack growth propagation
- Influence of inspections (measurement of cracks)



Detail location

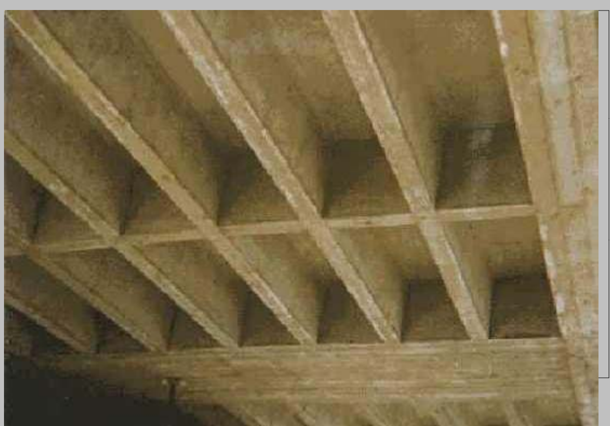


Cover plate detail

Fatigue assessment: scenarios

- Inspection and crack detection at T=30y
- Alternatives considered:
  1. Load truncation (LT)
  2. Weld toe grinding (G)
  3. Load truncation + weld toe grinding (LT+G)

R.C. Buildings in Germany



- Office building
- Concrete construction
- 70 years old
- Reduced load in order to satisfy minimum safety

Reassessment of r.c. floor structure

flexural limit state function

$$g = M_u - M_a$$

M_u: Ultimate Bending Moment

M_a: Acting Bending Moment

Two Cases for Updating

- Case a) Updating of random variables (due to destructive tests)
- Case b) proof load

Case a) Updating of random variables (due to destructive tests)

Variable	Distribution	c.o.v.
Steel strength	Lognormal	0.06
Concrete Strength	Lognormal	0.14
Cover thickness	Lognormal	0.25

Reliability index ß is increased from 3.70 (prior information) to 3.80, due to reduced variability of the parameters

Case b) proof load

- Partial proof test until collapse resulted to a considerable proof load
- Artificial limit state function

$$g = M_{proof} - M_u <= 0$$

- Computation of conditional failure probability

=> Reliability index ß is increased depending upon the proof load

Existing tunnels in Europe

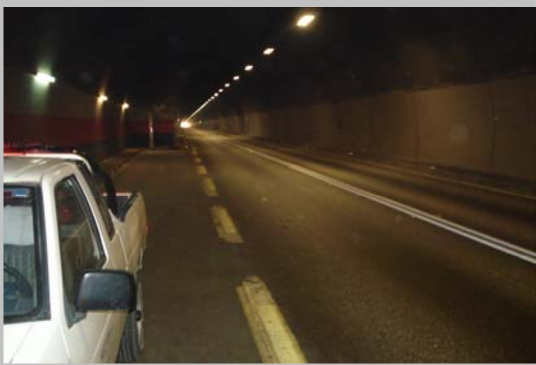
- Accidents in Europe (fire)
- Dangerous goods
- Bi-directional traffic
- Increasing traffic
- High consequences
- ➢ New standards (2004)
- ➢ Safety assessment!

Road Tunnel in Greece: the problem

- Korinth-Tripolis (PPP-Projekt)
- Bidirectional traffic (2-3 years)
- Length 1365m
- Inclination 1%.
- 20 years old

> safety reassessment

Tunnel in Greece: methodology



Road Tunnel in Greece: conclusions

- EU-standards NOT satisfied (escape routes)
- High Upgrading costs
- Safety is Acceptable (Risk Matrix Approach, Cost Benefit Analysis) for 3 years!
- Implementation of economical safety measures (illumination)

Concluding Remarks

- Decisions on existing structures depend on many factors
- structures which do not fullfil new codes have to be reexamined based on their performance
- generally a lower safety level compared to a new structure is acceptable (cost reasons)