Safety acceptance criteria for existing structures

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Ice-stadium Bad Reichenhall, January 2006

Earthquake damage, Turkey 1999

Bridge Inspection

Building Inspection after earthquake

When is reassessment of an existing structure necessary?

- Deviations from original design
- Doubts about safety
- Adverse inspection results
- Change of use
- Lifetime extension
- 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 is the acceptable risk?

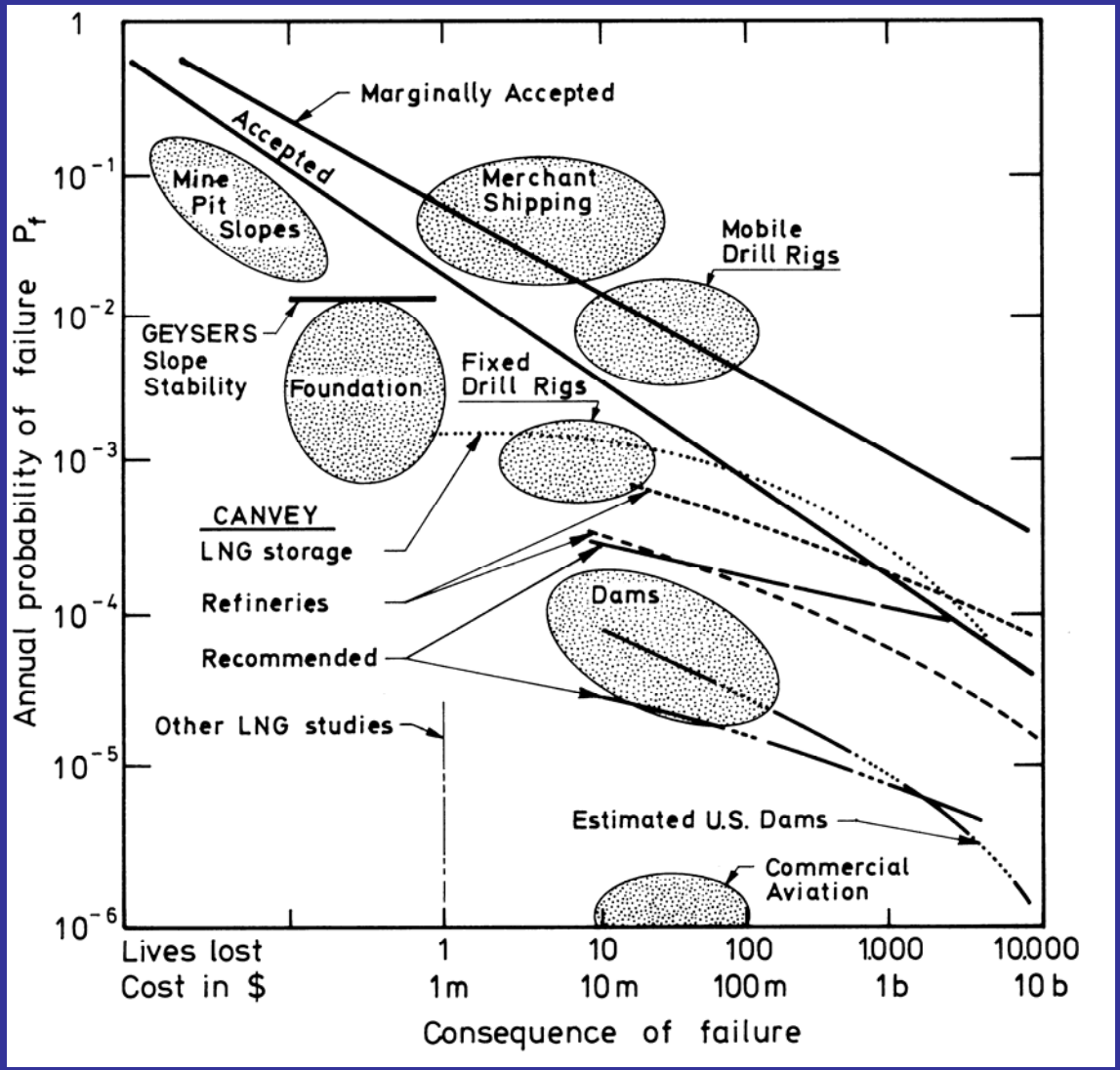
Safety Verification

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

Guidelines (Examples)

- ISO TC 98
- SIA 462 (Switzerland)
- Danish Technical Research Council
- ACI 437R
- JCSS (Joint Committee of Structural Safety)
- Dutch Recommendations

Experienced risk for various structures



Our Approach

1. review of current criteria for existing structures in seismic regions in the USA (performance-based design)
2. Interpretation of European standards/practice
3. analysis of the recommendations given by the Joint Committee on Structural Safety (JCSS)
4. Conclusions from our industrial experience in various projects (buildings, offshore structures, tunnels, etc.)

Probability Based Design
Performance objectives

Performance Level NEHPR (ATC, 1996)	Performance Level Vision 2000	Short Description
Operational	Fully Functional	No significant damage to structural and non-structural components
Immediate Occupancy	Operational	No significant damage to structure; non-structural components are secure and most could function if utilities available
Life Safety	Life Safety	Significant damage to structural elements; non-structural elements are secured but may not function
Collapse Prevention	Near Collapse	Substantial structural and non-structural damage; limit margin against collapse

EQ Probability levels

EQ -Level	Event	Annual Exceedance Probability	Mean Return Period
I	Frequent	4%	25
II	Occasional	1.4%	72
III	Rare	0.125% - 0.4%	250 - 800
IV	Max Con-sidered	0.04% - 0.125%	800 - 2500

PBD criteria

$$p_E \cdot p_{NP|E} < p_A$$

p_E : propability of event

$p_{NP|E}$: conditional probability of no performance given event

p_A : acceptable probability

PBD criteria (new structure)

$$p_E \cdot p_{NP|E} < p_A$$

p_E : 2% in 50 years

$p_{NP|E}$: 10%

p_A : 4×10^{-5} per year

PBD criteria (old structure)

$$p_E \cdot p_{NP|E} < p_T$$

p_E : 4% in 50 years

$p_{NP|E}$: 25%

p_T : 2×10^{-4} per year (5 times larger)

Limit State Design
Reliability Index

$$\beta = -\Phi^{-1}(p_F)$$

p_F: is the probability of exceeding limit state condition (here failure)

Φ^{-1}: is the inverse Gaussian distribution

JCSS Recommendations for Existing Structures

- Preface
- Part 1: General (Guidelines, Codification)
- Part 2: Reliability Updating
- Part 3: Acceptability Criteria
- Part 4: Examples and case studies
- Annex:Reliability Analysis Principles

JCSS (2001) proposal

$$\beta_E = \beta_N - 0.5$$

β_E : acceptable reliability index for an existing structure

β_N : target reliability index for a new structure

Target Reliability (1 year ref. Period)

Cost of safety	Consequences: Minor	Consequences: Moderate	Consequences: Large
Large	2.6	2.8	3.2
Normal	3.2	3.7	3.9
Small	3.7	3.9	4.2

Application of FORM

$$T \approx 1 / \Phi(\alpha\beta)$$

- T is the mean return period
- $\Phi(\,)$ is standard normal integral
- α is the sensitivity factor
- β is the target reliability index

Various other proposals

Explicit targets:

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

Procedures (optimization)

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

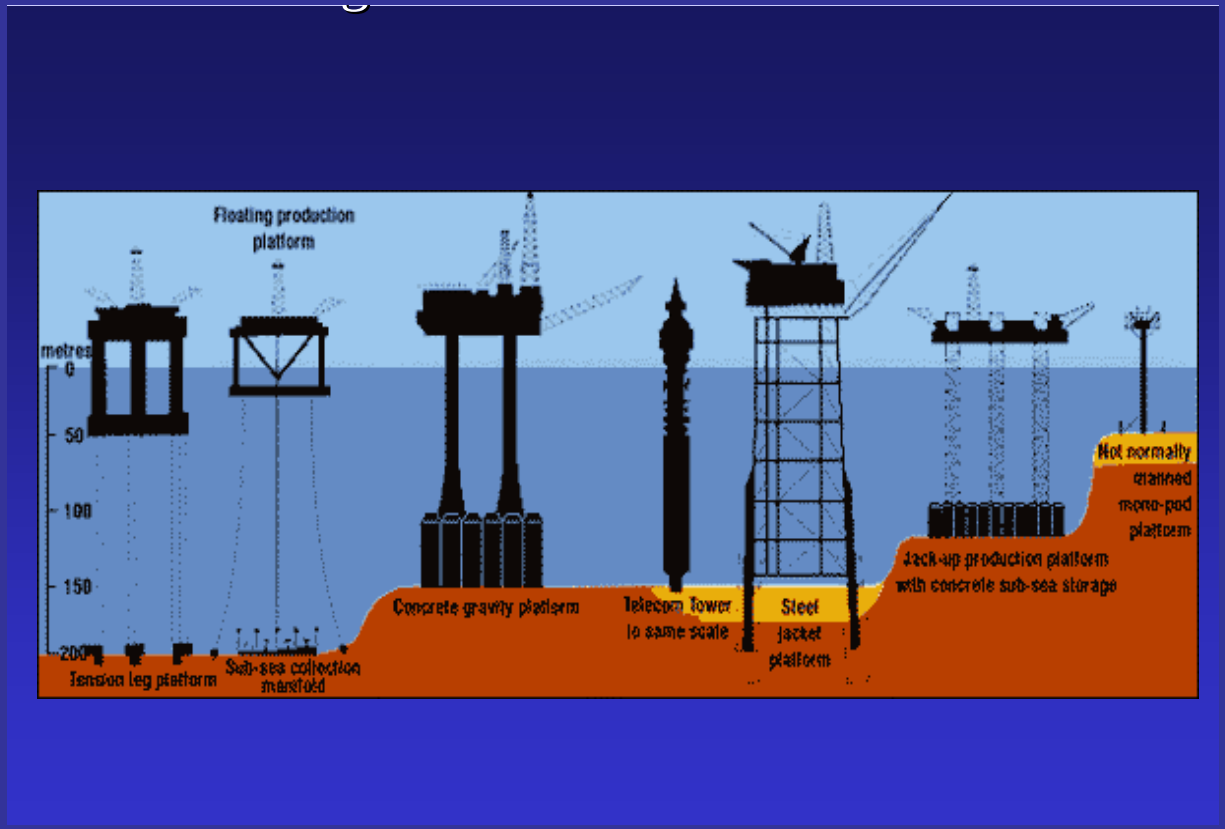
Industrial experience

- Offshore structures
- Bridges
- Nuclear structures
- Office buildings
- Tunnels
- Residencial buildings

- Waves, wind
- Live load
- Earthquake
- Live load
- Fire
- Flood, snow

EXISTING OFFSHORE STRUCTURES

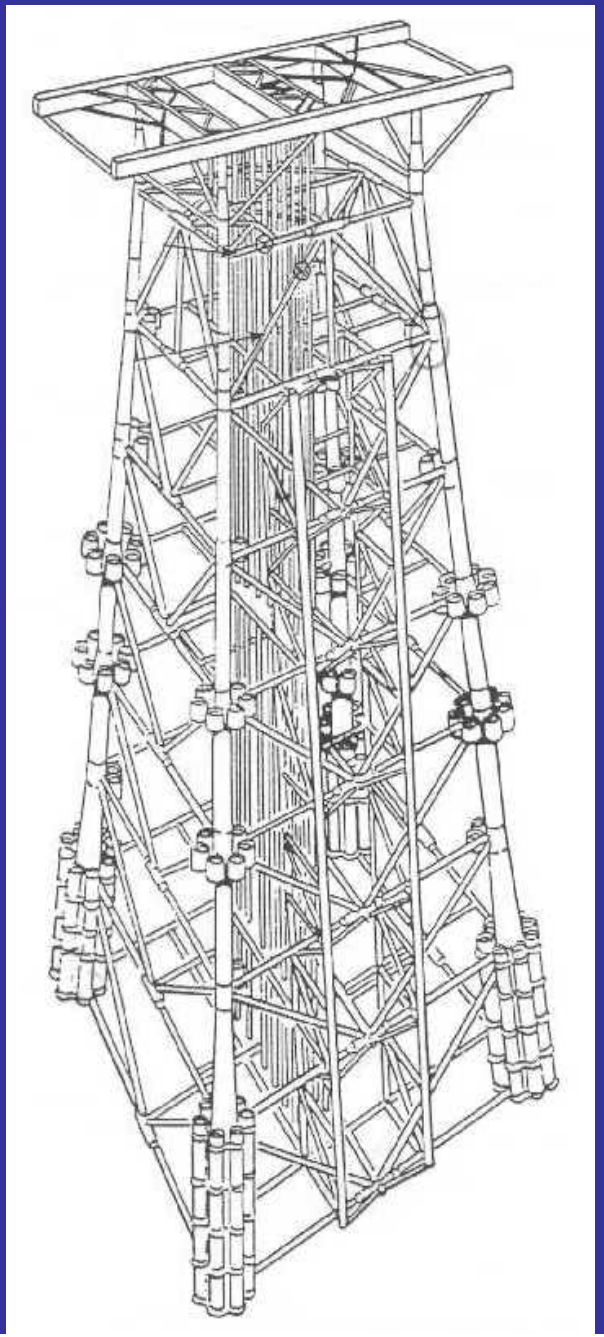
(North Sea, Adriatic Sea, Gulf of Guinea, Gulf of Mexico)



Steel Jacket Structure

25 years old platform

- **Foundation (pile capacity limit state)**
- **New data available**
- **Reliability index is higher compared to design phase**



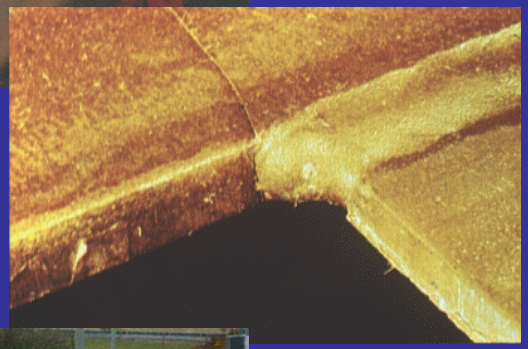
Steel bridges

Typical limit states

- extreme load

- Fatigue

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



Bridges: Safety measures

1. Load truncation
2. Weld toe grinding
3. Load truncation + weld toe grinding

R.C. Buildings in Germany

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

Existing road tunnels in Europe

- Several accidents in Europe
- Hazardous goods
- Bidirectional traffic
- Increasing traffic volume
- Large consequences

➢ new standards (2004)

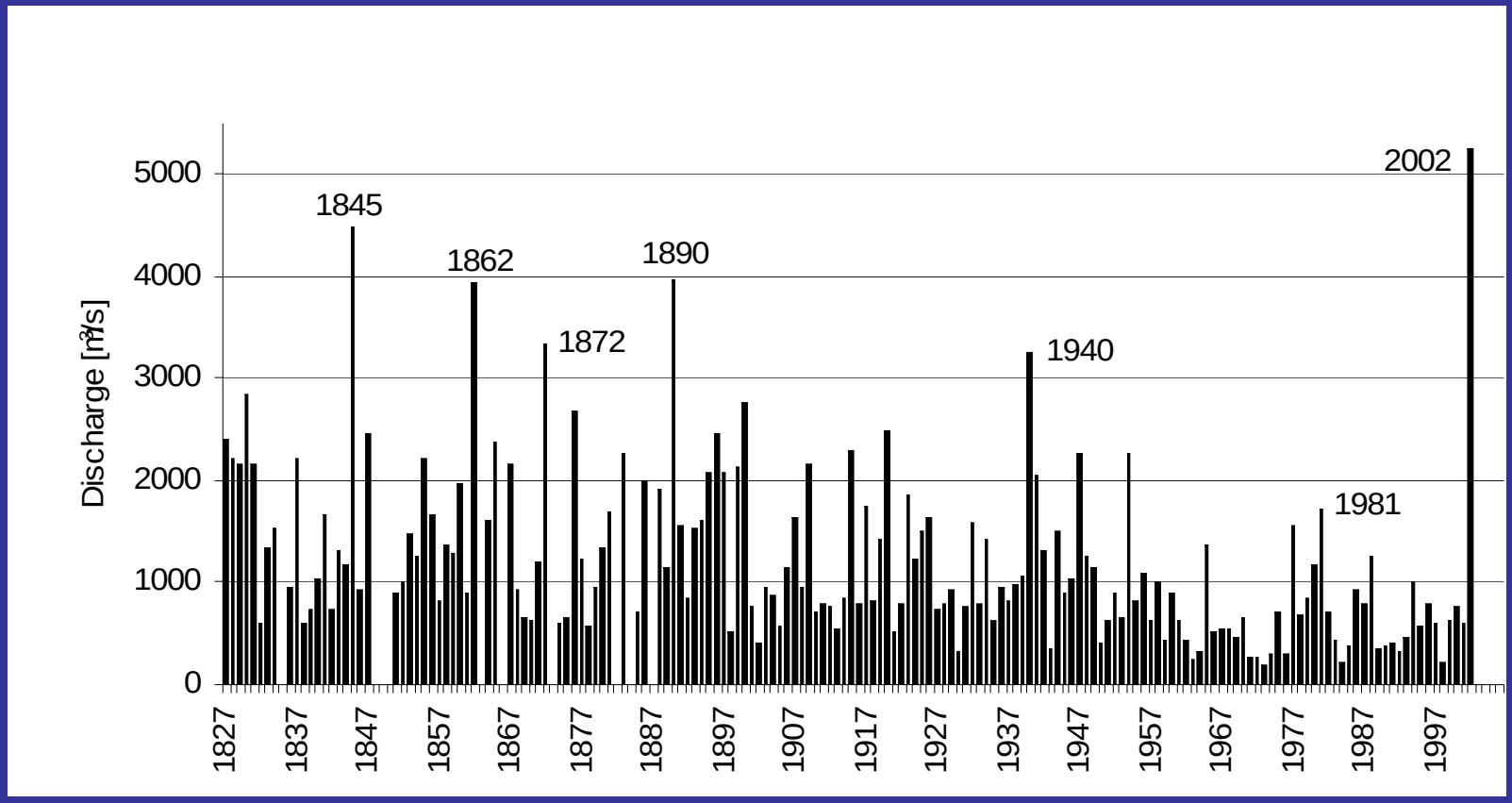
➢ Upgrading of existing tunnels?

road tunnel in Greece

- Korinth-Tripolis motorway.
- total length of 1365 m with longitudinal
- grading 1%.
- 20 years old
- Bidirectional traffic
- Safety evaluation since it does not fullfill EU recommendations

Flood in Prague, 2002

Flood statistics, Prague



Conclusions

- A lower safety level compared to a new structure is acceptable
- Various criteria have been proposed in the technical literature
- Acceptance criteria depend on cost of safety, consequences of failure, desired residual lifetime
- Increase of acceptable p_F by a factor of 2 to 10 is recommended

Stone bridge, Regensburg 860 years old