Safety acceptance criteria for existing structures

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March 2007
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

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

<table>
<thead>
<tr>
<th>EQ -Level</th>
<th>Event</th>
<th>Annual Exceedance Probability</th>
<th>Mean Return Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Frequent</td>
<td>4%</td>
<td>25</td>
</tr>
<tr>
<td>II</td>
<td>Occasional</td>
<td>1.4%</td>
<td>72</td>
</tr>
<tr>
<td>III</td>
<td>Rare</td>
<td>0.125% - 0.4%</td>
<td>250 - 800</td>
</tr>
<tr>
<td>IV</td>
<td>Max Considered</td>
<td>0.04% - 0.125%</td>
<td>800 - 2500</td>
</tr>
</tbody>
</table>
PBD criteria

\[ p_E \cdot p_{NP|E} < p_A \]

\( p_E \) : probability 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%
- \( p_A \): \( 4 \times 10^{-5} \) per year
PBD criteria (old structure)

\[ p_E \cdot p_{\text{NP}|E} < p_T \]

- \( p_E \): 4\% in 50 years
- \( p_{\text{NP}|E} \): 25\%
- \( p_T \): \( 2 \times 10^{-4} \) 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)
$\Phi^{-1}$: 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

\[ \beta_E = \beta_N - 0.5 \]

- \( \beta_E \): acceptable reliability index for an existing structure
- \( \beta_N \): target reliability index for a new structure
## Target Reliability (1 year ref. Period)

<table>
<thead>
<tr>
<th>Cost of safety</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td>Large</td>
<td>2.6</td>
</tr>
<tr>
<td>Normal</td>
<td>3.2</td>
</tr>
<tr>
<td>Small</td>
<td>3.7</td>
</tr>
</tbody>
</table>
Application of FORM

\[ T \approx 1 / \Phi(\alpha \beta) \]

- \( T \) is the mean return period
- \( \Phi() \) is standard normal integral
- \( \alpha \) is the sensitivity factor
- \( \beta \) 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
  - 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 fulfill EU recommendations
Flood in Prague, 2002
Flood statistics, Prague

Discharge [m³/s]
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