Risk analysis of bridges using a new reliability-based robustness assessment methodology

Thesis Plan

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Outline

• Motivation
• Robustness of structures
• Literature Review
• Research Objectives
• Research Plan
• Current Status
Motivation

... Role of transport infrastructures systems
Motivation

... Road infrastructure investments have steadily increased in the last years
Motivation

... Focusing on bridges

Asset importance

Significant national investment
Impact on road infrastructure resilience during disasters
Strategic importance

Challenging issues

Lifespan of existing structures
Deterioration processes
Limited available funds
Motivation

... Learning from past bridges failures

Motivation

... Need for rational decisions in bridge management

Component level analysis → Global performance analysis

Consequences of deferring maintenance → Compare decision alternatives

Risk-informed decision making
- Risk-ranking decisions
- Acceptable risk criteria

Decò and Frangopol (2011)
Zhu and Frangopol (2012)
Robustness of structures
Concept of robustness

… from the structural perspective

The consequences of structural failure should not be disproportional to the effect causing the failure
Robustness and modern codes

... Major gaps in code-based structural design

- Structural component-centric design philosophy
- Inexplicit approaches to achieve adequate robustness
- Dependency between failure modes is ignored

Narasimhan (2012)

COST TU0601 (2011)

Revised ISO 2394 (2015)
Literature Review
Robustness assessment

... Quantitative approaches

- Deterministic index based on structural measures
- Probabilistic index based on probabilities of failure
- Risk-based index based on risk analysis

... Exposure scenarios
- Performance evaluation of a given scenario
- Reliability or risk under multi hazards
## Robustness assessment

... Proposed measures

<table>
<thead>
<tr>
<th>Nature</th>
<th>Source</th>
<th>Range</th>
<th>Scenario</th>
<th>Attribute</th>
<th>Measure</th>
<th>Target Reliabilities verification</th>
<th>Increasing robustness</th>
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<tr>
<td>Probabilistic</td>
<td>Frangopol and Curley (1987) Fu and Frangopol (1990)</td>
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<td>Damaged vs Intact</td>
<td>Redundancy Reliability</td>
<td>Stiffness-based Damage-based Energy released</td>
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<td>Increasing robustness</td>
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Most complete measure: **Increasing robustness**
Risk-based robustness

... JCSS Risk Management Framework, JCSS (2008)
Risk-based robustness

... JCSS Risk Management Framework

- Consistent treatment of uncertainty
- Structural Reliability Theory
- System Effects analysis
- Bayesian Updating
- Bayesian Probabilistic Nets
Risk-based robustness

... Event trees

Direct Risks

\[ R_{dir} = \iint_{x,y} C_{dir} f_{D|E}(y|x) f_E(x) \, dx \, dy \]

Indirect Risks

\[ R_{ind} = \iint_{x,y} C_{ind} P(F|D=y) f_{D|E}(y|x) f_E(x) \, dx \, dy \]

Robustness Index

\[ I_{rob} = \frac{R_{dir}}{R_{dir} + R_{ind}} \]

Baker et al. (2008)
Research Objectives
Research Focus

- Nonlinear FEA
- Advanced Structural Reliability Analysis

System performance under extreme events
- Post failure behaviour
- Interactions between failure modes
- Follow up consequences

Time dependent robustness
- Time dependency
  - Loads
  - Deterioration
- Model Updating
  - Experimental Data
Research Questions

Which are the most critical hazards involving robustness quantification?

How to realistically model the system behavior under hazardous events while considering uncertainty?

How to achieve a time-dependent performance indicator?

How can the two levels of performance evaluation be integrated in a risk assessment methodology?

Risk assessment

Structural Analysis & System Performance

Life-cycle engineering

Methodology
1. Risk assessment

• **Objective**
  – Qualitative and quantitative assessment of risks to the system

• **Main topics**
  – Identification of hazards which induce damage to the system and failure events
  – Probabilistic modelling of exposure conditions according to their nature and effects
  – Perform vulnerability analysis to assess damage tolerance at element level
  – Consequences analysis – event trees using Bayesian networks
2. Probabilistic assessment of system performance

• Objective
  – Probabilistic-based methods to assess post-damage behaviour

• Main topics
  – Probabilistic models of materials properties and geometry
  – Realistic bridge acting loads
  – Modelling damage scenarios
  – Nonlinear FE models to assess structural performance
  – Extension of advanced structural reliability techniques

  – Benchmarking different techniques to improve the efficiency of the probabilistic analysis
3. Time variant robustness

- **Objective**
  - Lifetime structural performance indicator

- **Main topics**
  - Stochastic modelling of degradation and life loads
  - Time dependent consequences
  - Value of new Information
  - Bayesian Updating – reduced uncertainty

  - Risk-based performance indicator to support decisions on interventions
4. Case Studies

- **Objective**
  - Integration and application of the developed methodologies
  - Analysis of different bridge typologies to compare risks and robustness indices
  - Definition of acceptable performance levels and assessment of life-cycle costs
5. Robustness assessment methodology

• Objective
  – Development of a reliability-based robustness assessment methodology with the aim of contributing to the new generation of risk-based bridge management system

  – Risk treatment and communication
    • Acceptable risk
    • Vulnerability reduction
    • Risk mitigation and preparedness policies

  – Improve the quality of decisions on interventions
Research Plan
# Research Plan

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<tr>
<th>Task</th>
<th>Task Denomination</th>
<th>1st Year</th>
<th>2nd Year</th>
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(Hugo Guimarães / Risk analysis of bridges using a new reliability-based robustness assessment methodology)
Study period abroad

- **STSM within the scope of COST TU1406 "BridgeSpec"**
  - WG1 - Performance indicators for road bridges
  - Robustness assessment
  - Prof. Alfred Strauss (BOKU University, Austria)

- **Lehigh University, USA**
  - Prof. Dan M. Frangopol
  - Robustness indicator during the life-cycle
Current Status
Framework for Structural reliability analysis: probabilistic non-linear analysis of RC structures

- Matlab algorithm to perform structural reliability analysis coupling a FE code
  - FE code ‘Plastd90’: model constructional phases and non-linearity of steel and concrete properties and also the time-dependency of material properties
  - FERUM (Finite Element Reliability Using Matlab): open-source routines to apply structure reliability techniques.

- Developed methodologies: incremental MCS simulation and adaptive RSM approach

- Combining the MCS with RSM – simulation in the Region of interest
Monte Carlo Method Approach

1. **Stochastic simulation** – random basic variables and dependent variables
   - Random field characterization – spatial variability.

2. **Structural analysis**
   - Nonlinear analysis of the structural performance.

3. **Statistical analysis**
   - Distribution fitting analysis
     - Expected value and variance
     - Linear regression model using stepwise regression
     - Quality examination of the fitted model – residuals analysis, diagnostic plots, ...
   - Explicit limit state function

4. **Structural reliability analysis**
   - Application of FORM for the obtained limit state function
Monte Carlo Method Approach

1. Stochastic simulation
2. Structural Analysis
3. Statistical Analysis
4. Convergence?
   - no
   - yes
   - additional samples
5. Reliability analysis
Response Surface Methodology Approach

1. Stochastic simulation, sensitivity analysis and screening procedures
   - Global sensitivity methods – sensitivity coefficients
   - Reduction of input random variables

2. Choice of initial Experimental Design
   - Latin Hypercube sampling with chosen spread, $\pm k\sigma$

3. Curve-fitting – RS according to a wise selection of terms
   - Reduction of prediction error estimate using a stepwise regression linear model
   - RS for each selection criteria SSE, AIC, BIC and $R^2_{adj}$

4. Reliability techniques to find the design point

5. New sampling points around the design point
   - Enriched ED by adding points with a smaller spread

6. Repeat the adaptive procedure until convergence criterion is satisfied
   - Relative error regarding the reliability index
References

References