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

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ANALYSIS AND MITIGATION OF RISKS IN INFRASTRUCTURES | INFRARISK-

Outline

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

... Role of transport infrastructures systems



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



... Focusing on bridges

Lifespan of existing structures

Deterioration processes

Limited available funds

Asset importance

Challenging issues

Significant national investment

Impact on road infrastructure resilience during disasters

Strategic importance

... Learning from past bridges failures



Causes of 1062 total bridge failures, US Survey (1980-2012) [Lee et al.(2013)]

... 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

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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

Narasimhan (2012)

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



Literature Review

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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

Complexity

Robustness assessment

... Proposed measures

Frangopol and Curley (1987) Ghosn and Baker et al. **Biondini and** ISO (2007) Lind (1995) Starossek (2008) Cavaco (2013) Fu and Frangopol Moses (1998) (2008)Restelli (2008) (1990) Nature Probabilistic Probabilistic **Probabilistic** Deterministic Deterministic **Risk-based** Deterministic Det. or Prob. Stiffness-based Vulnerability Performance Performance Performance Redundancy Robustness Redundancy Damage-based Atribute Reliability Damage Tolerance indicator indicator indicator index **Energy** released Target [1,α] [0,∞] Reliabilities [0,1] [0,1] _ [0,1] [0,1]Range [0,∞] [α⁻¹,1] verification Damaged vs Damaged vs Damaged vs Damaged vs Damaged vs Spectrum of Limit states Multi hazard Scenario Intact Intact Intact **Damage States** Intact Intact



Most complete measure

Risk-based robustness

... JCSS Risk Management Framework, JCSS (2008)

System representation



Risk-based robustness

... JCSS Risk Management Framework



Risk-based robustness

... Event trees



Research Objectives

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Research Focus

System performance under extreme events

- Post failure behaviour
- Interactions between failure modes
- Follow up consequences

Risk-informed decision making

Robustness Assessment

Adva Nonlinear Struc FEA Relia Ana

Advanced Structural Reliability Analysis

Time dependent robustness

- Time dependency
 - Loads
 - Deterioration
- Model Updating
 - Experimental Data

Research Questions



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 perfomance 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

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Research Plan

		1st Year											2nd Year									3rd Year											4th Year											
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T1	Literature review																																											
Т2	Risk assessment: hazard identification and assessment																																											
Т3	Probabilistic-based methods for anaylsing progressive collapse and structural robustness																																											
Т4	Time dependent reliability-based perfomance indicators																																											
T5	Case studies analysis												00000																															
Т6	Development of a reliability-based robustness assessment framework			ļ																																								
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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

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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
 - Literature probabilistic models for loads and resistance. Probabilistic Model Code (JCSS, 2001)
 - 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 funtion
- 4. Structural reliability analysis
 - Application of FORM for the obtained limit state function

Monte Carlo Method Approach

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
 - Redution of predition error estimate using a stepwise regression linear model
 - RS for each selection criteria SSE, AIC, BIC and R_{adj}^2
- 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

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