Second European Conference on Earthquake Engineering and Seismology
Istanbul August 24-29, 2014

A joint event of the
15th EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING &
34th GENERAL ASSEMBLY OF THE EUROPEAN SEISMOLOGICAL COMMISSION

Developing Fragility Functions for Roadway Bridges using System Reliability and Support Vector Machines

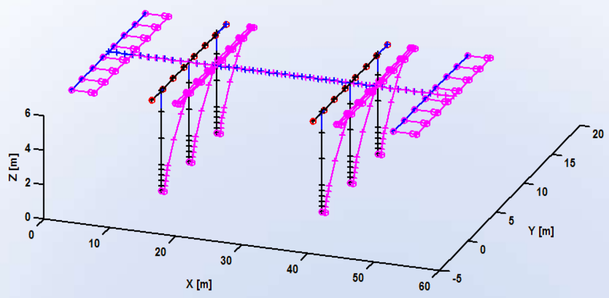
P. Gehl (*p.gehl@ucl.ac.uk*)**, K. Taalab, D. D'Ayala, T. Cheng**
EPICentre, University College London, UK

INFRARISK project: *http://www.infrarisk-fp7.eu*

Context - Objectives

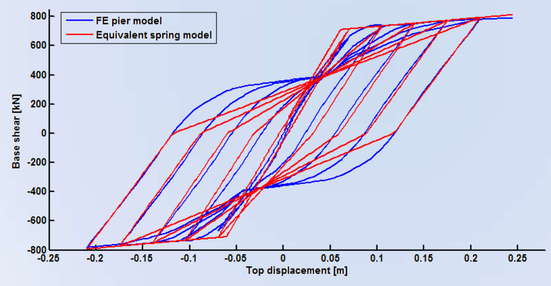
- *In the frame of the INFRARISK project, the derivation of fragility functions for infrastructure components is a key element of the stress-test strategy*
- *The accuracy of simplified numerical models is tested in order to minimize computational costs*
- *System reliability approach (Song and Kang, 2009) is applied as a promising way to assess the fragility of complex structural systems, while accounting for cross-correlation between the components*
- *An alternative method ("Component-based approach") is proposed: the aim is to account for the specific "system damage states" that are actually reached during the simulations and to derive damage-specific fragility curves for each component ➔ these curves could then be fed into a Bayesian Network formulation*
- *Parallel to these analytical developments, the use of empirical Support Vector Machine models is explored as a way to quickly obtain fragility estimations of unknown bridge typologies*

Modelling of the Bridge System

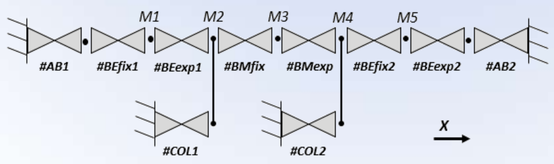


Full Finite Element Model (MSSSC bridge from Nielson, 2005)

Non-linear Time-History Analyses



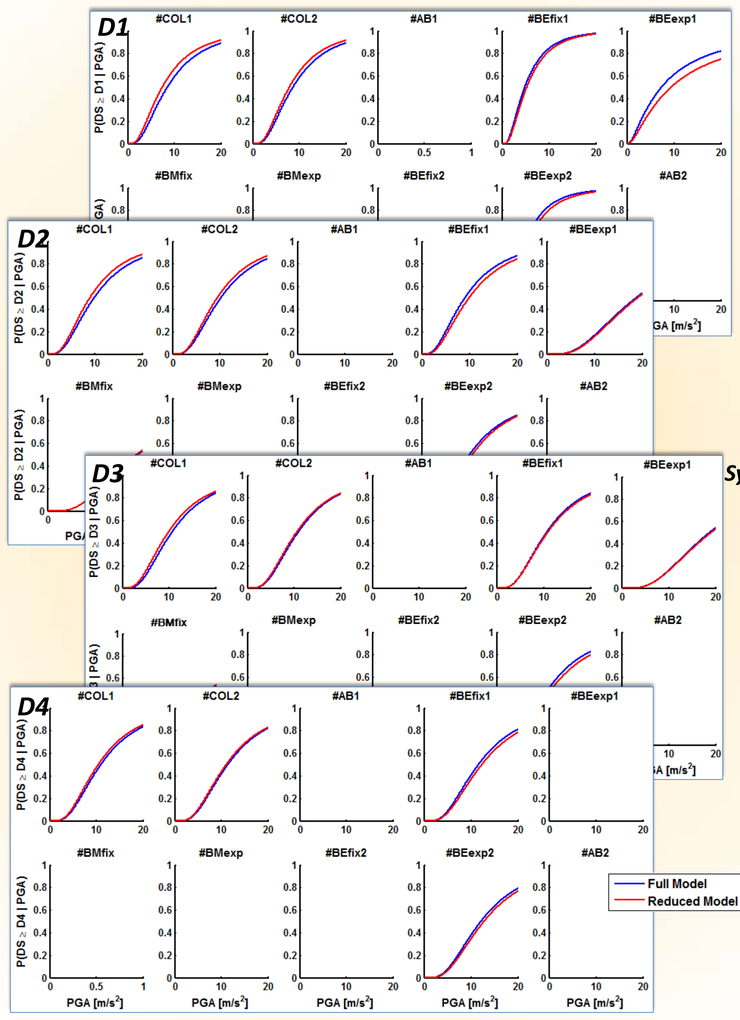
Reduced degrees of freedom for the pier (three-column bent)



Reduced Bridge Model (connectors)

Non-linear Time-History Analyses

Component fragility curves



System Reliability Approach

System fragility curves

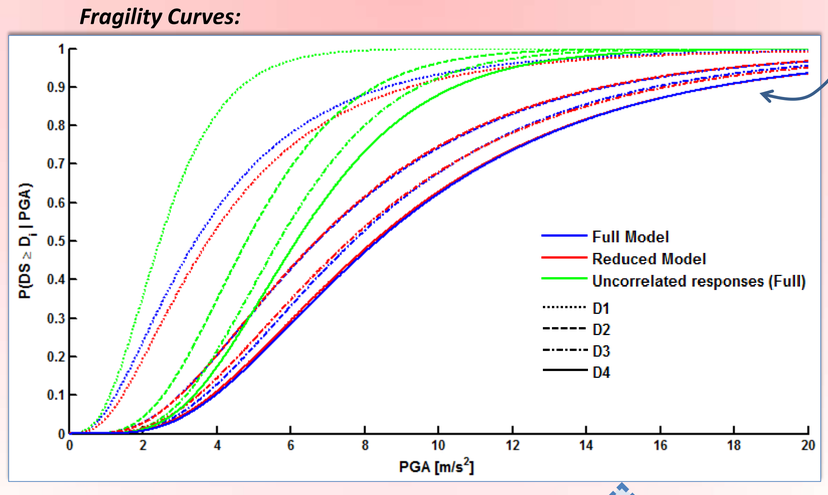
Correlation between the component responses:

Component	#AB1	#BEfix1	#BEexp1	#BMfix	#BMexp	#BEfix2	#BEexp2	#AB2	#COL1	#COL2
#AB1	1	0.6587	0.9298	0.7936	0.8767	0.6885	0.8348	0.8527	0.8534	0.8477
#BEfix1		1	0.6939	0.5979	0.8678	0.7272	0.8971	0.8659	0.9063	0.8974
#BEexp1			1	0.7599	0.8724	0.7571	0.8814	0.8685	0.8919	0.8885
#BMfix				1	0.8038	0.6264	0.7489	0.7574	0.7310	0.7558
#BMexp					1	0.7568	0.9346	0.9516	0.9511	0.9445
#BEfix2						1	0.7620	0.7488	0.7709	0.7669
#BEexp2							1	0.9249	0.9900	0.9962
#AB2								1	0.9436	0.9352
#COL1									1	0.9947
#COL2										1

Statistical dependence between components:

$$P(DS|IM) = 1 - \int_{-\infty}^{+\infty} \prod_{i=1}^{n} \left[1 - \phi\left(\frac{\log IM - \log \alpha_i + \beta_i r_i x}{\beta_i \sqrt{1 - r_i^2}} \right) \right] \varphi(x) dx$$

Fragility Curves:

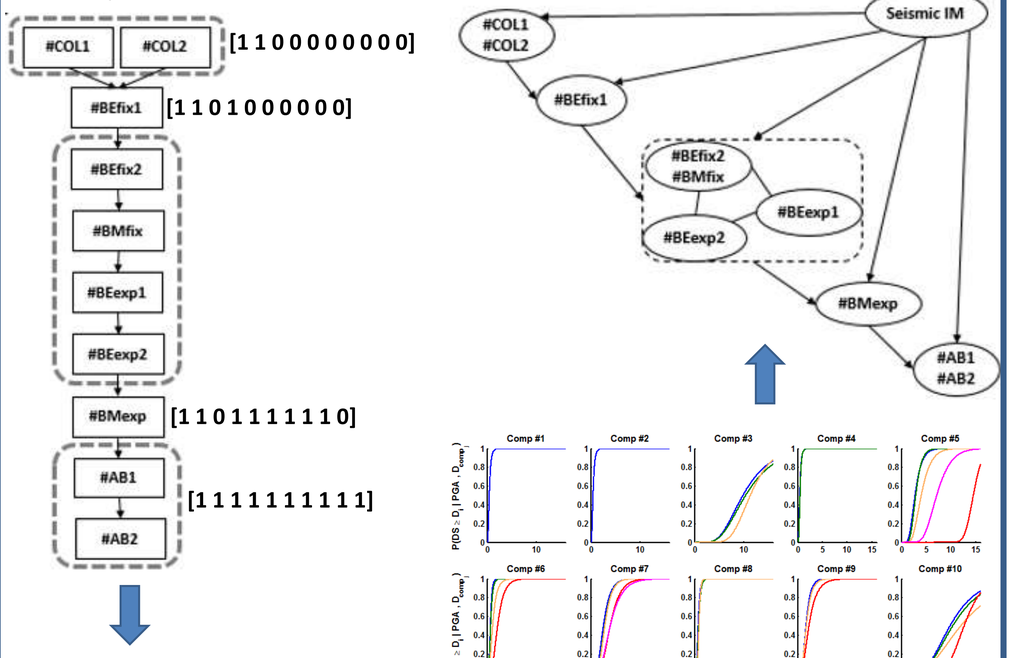


Empirical validation

Component-Based Approach

- *Model the response of each component "one-by-one" while the rest of the system is assumed to be in a given damage state*
- *Use of simplified assessment techniques (i.e. Direct Displacement-Based Assessment with Effective Modal Analysis, from Cardone, 2014)*

Failure Sequence of the components ⟷ *Bayesian Network structure*

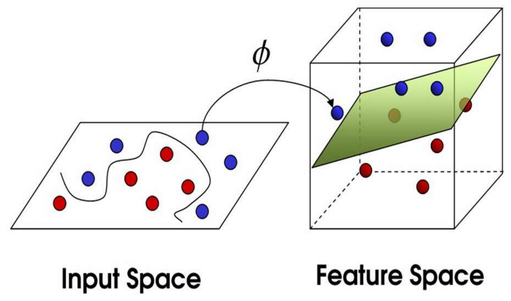


For each system damage state:
- *Effective modal shape*
- *Equivalent stiffness distribution*
- *Equivalent damping distribution*

"Conditional" component fragility curves = Probability of failure given the state of the other components

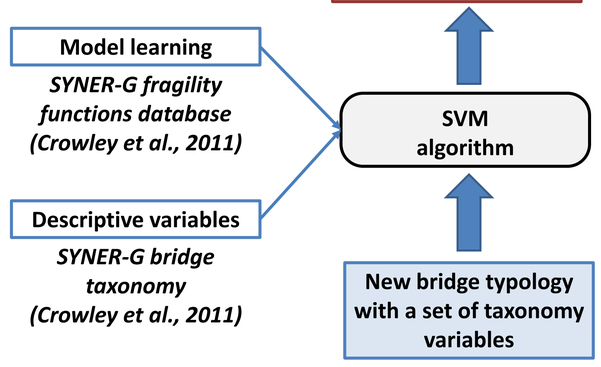
Support Vector Machine (SVM) Approach

SVM = empirical model performing a classification (i.e. regression) by constructing N-dimensional hyperplane that optimally separates data into categories (Hearst et al., 1998)



Input data

Linearly separable data transformed into an appropriate space



Future Work

- *Calibration / Verification of the "Component-based approach": Direct Displacement-Based Assessment coupled with Effective Modal Analysis ➔ Accuracy issues, Complexity of the components involved, What is the actual validity domain of this approach?*
- *Explore the link between the failure sequence of the components and the proposed Bayesian Network structure: use of Bayesian Network learning techniques*
- *Verification of the SVM approach for different bridge typologies (i.e. stability of the model with respect to the initial learning sample)*
- *Application of the proposed method to more complex bridge systems (e.g. real-life applications such as the Rio Torto Viaduct in Italy)*

References

- Cardone D (2014) "Displacement limits and performance displacement profiles in support of direct displacement-based seismic assessment of bridges", *Earthquake Engineering and Structural Dynamics*, 43(8):1239-1263
- Crowley H, Colombi M, Silva S, Monteiro R, Ozcebe S, Fardis M, Tsionis G, Askouni P (2011) "Fragility functions for roadway bridges", SYNER-G Report D3.6, www.syner-g.eu
- Hearst MA, Dumais ST, Osman E, Platt J, Scholkopf B (1998) "Support vector machines", *Intelligent Systems and their Applications, IEEE*, 13(4): 18-28
- Nielson BG (2005) Analytical fragility curves for highway bridges in moderate seismic zones, Ph.D. Thesis, Georgia Institute of Technology, US
- Song J and Kang WH (2009) "System reliability and sensitivity under statistical dependence by matrix-based system reliability method", *Structural Safety*, 31:148-156