On the Assessment of Robustness:

A General Framework

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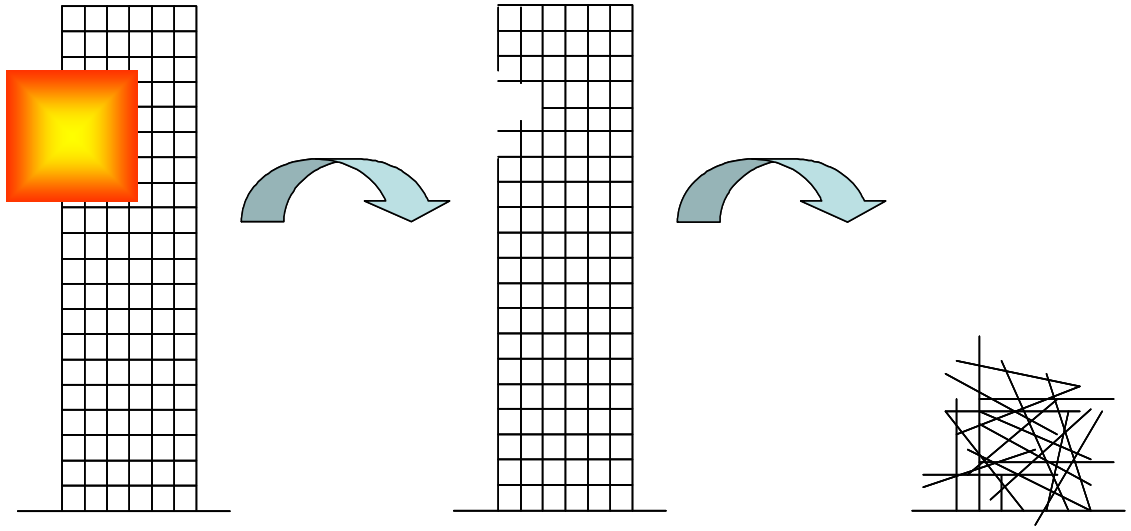
Introduction

- Robustness is generally accepted as a principle of good system design
- Objective quantification of robustness is needed
- A risk-based method for measuring robustness is proposed here
- Robustness is interpreted here as damage tolerance: "the consequences of structural failure should not be disproportional to the effect causing the failure" (EC)

This concept is also the idea behind the Eurocodes:

"the consequences of structural failure should not be disproportional to the effect causing the failure"



Which are the attributes of robustness:

The material loss cost consequences due to the collapse of the two WTC towers only comprised ¼ of the total costs due to damaged or lost material

It seems relevant to include consequences in the robustness assessment !

and these are scenario dependent !

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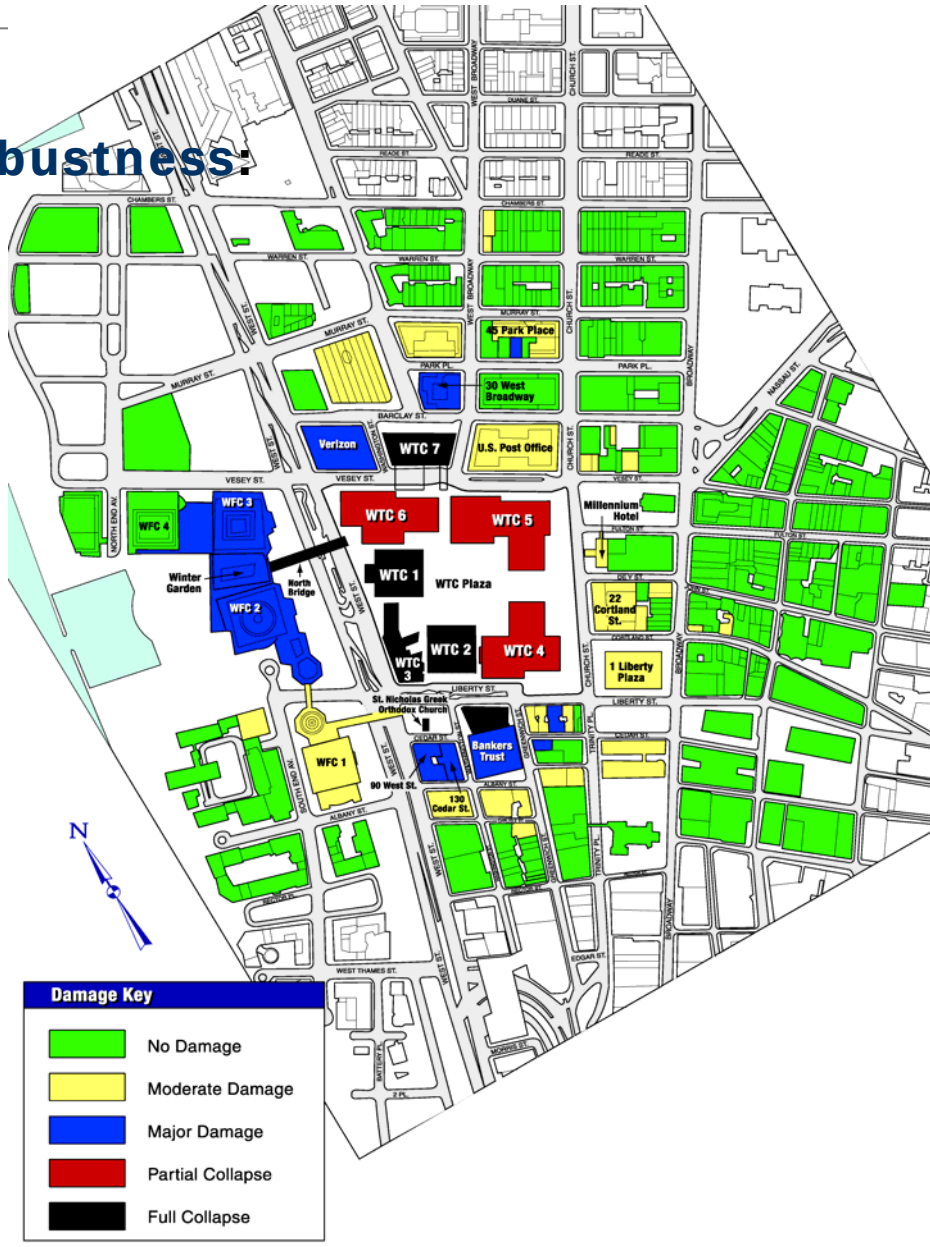
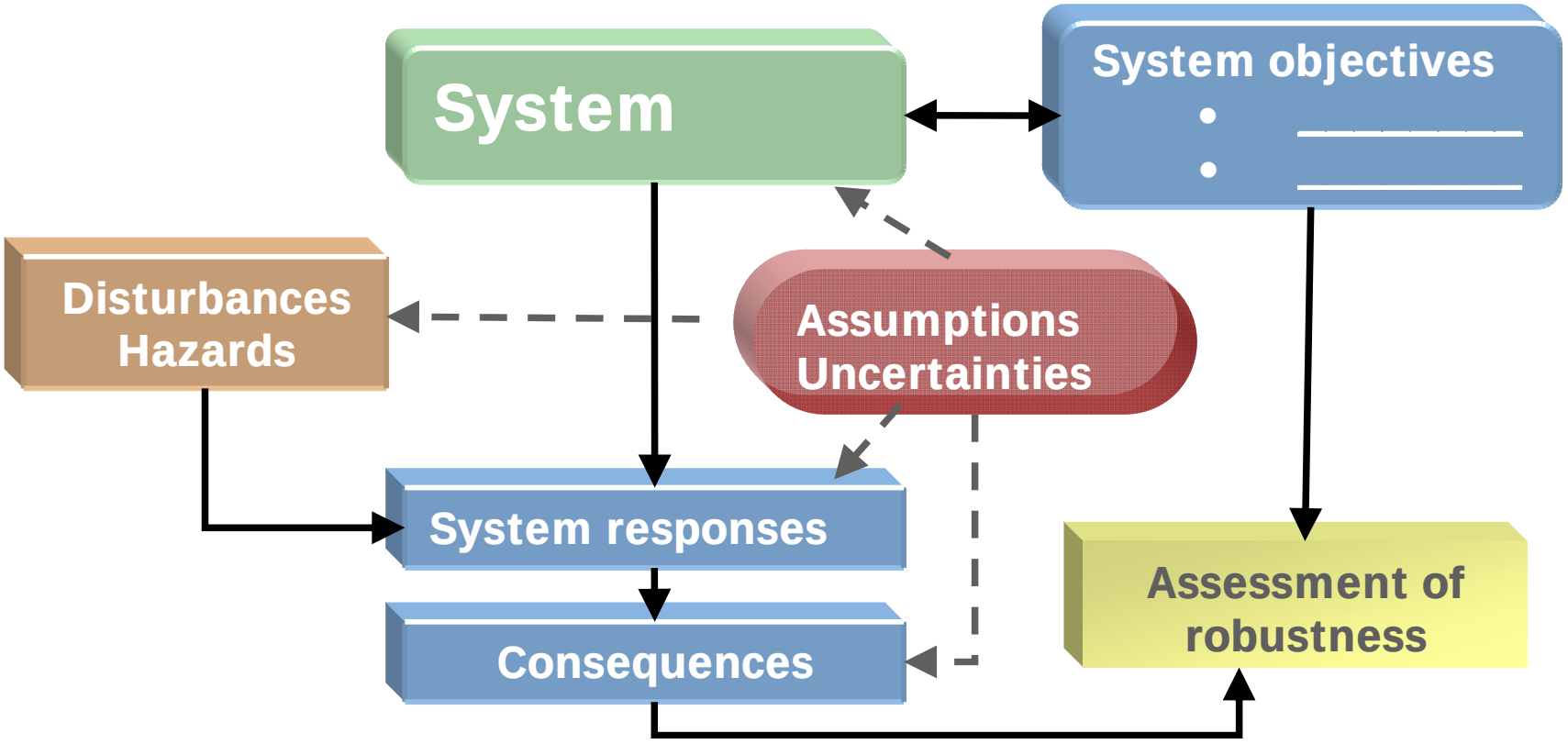
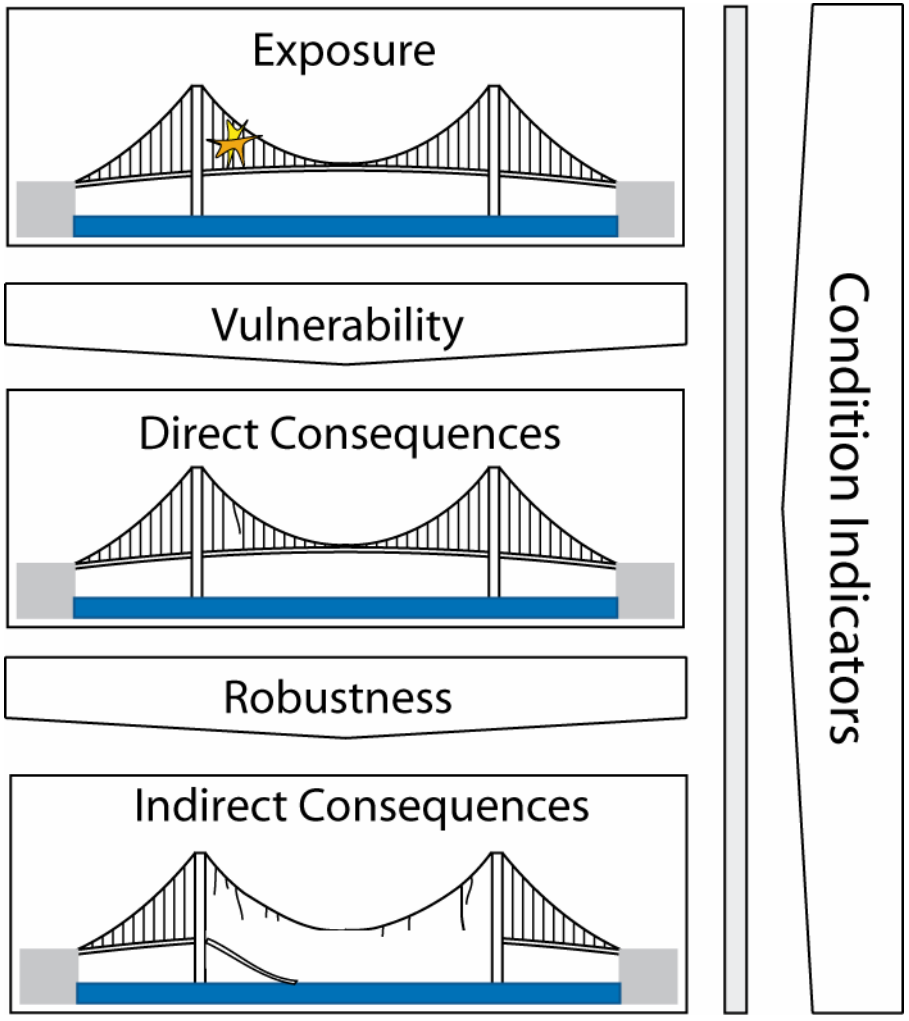


A general framework for assessing structural robustness :



System Representation:



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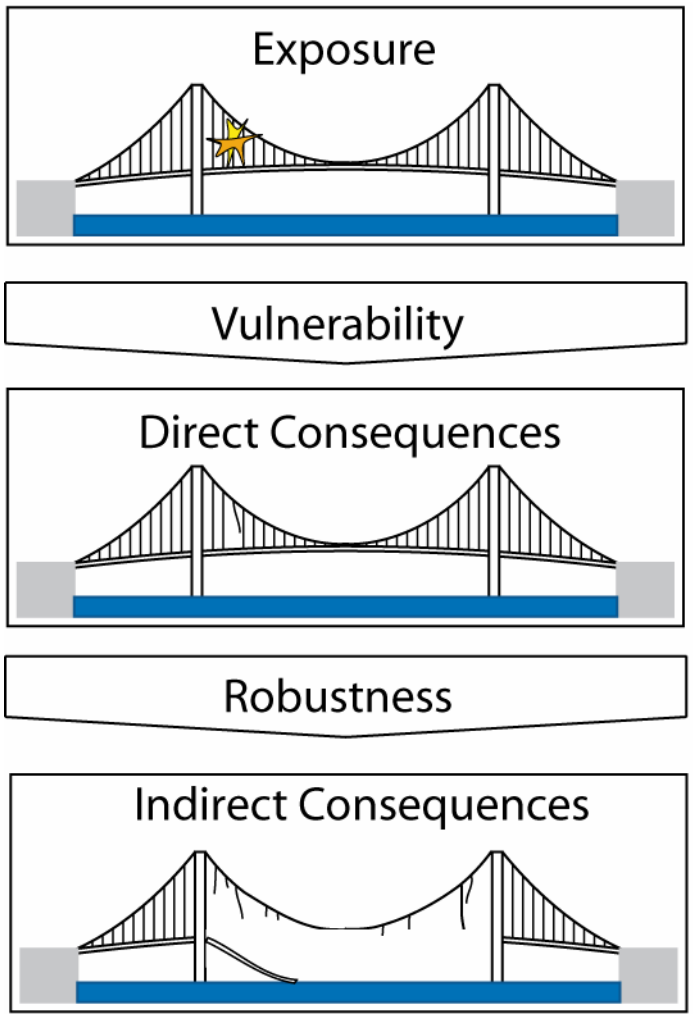


e.g. wind, moisture, impact, deterioration

-> indicated e.g. by climate, use functionality

e.g. rupture, cracking, decay, deflection

-> indicated by examination, design codes, materials, age

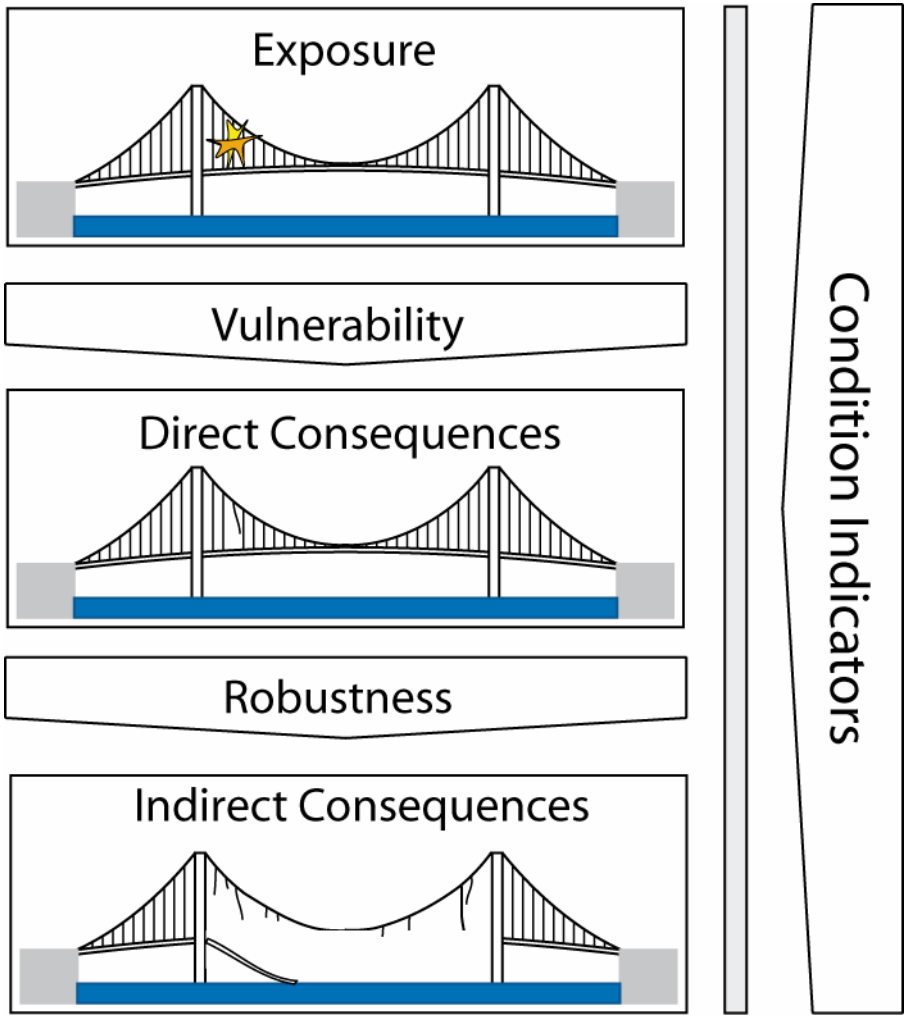
-> followed by repair cost, temporary loss or reduced functionality, causalities

e.g. partially collapse, full collapse

-> indicated by redundancy, ductility, joint characteristics

-> followed by replacing cost, temporary loss or reduced functionality, fatalities, causalities

System Representation:

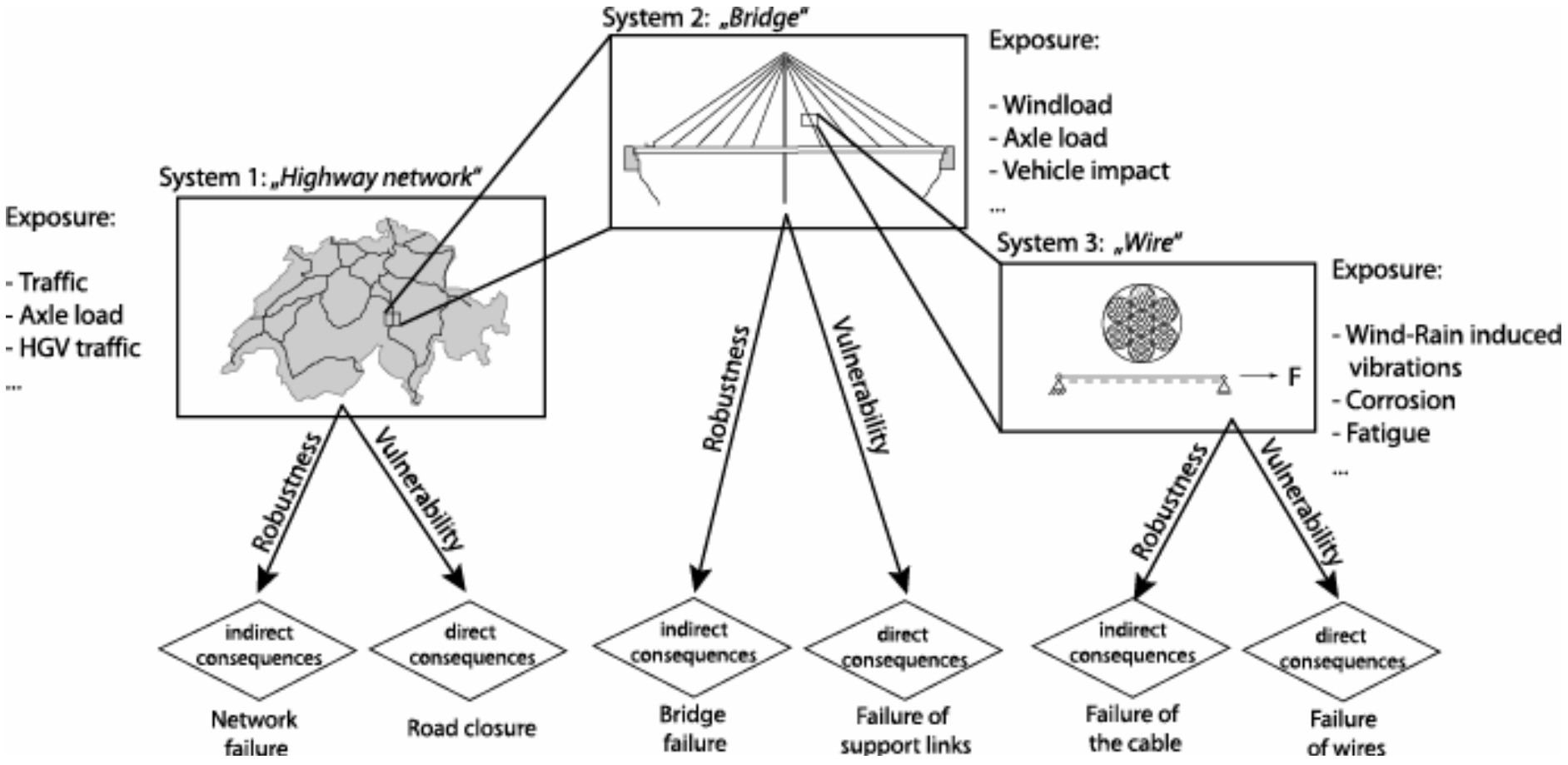


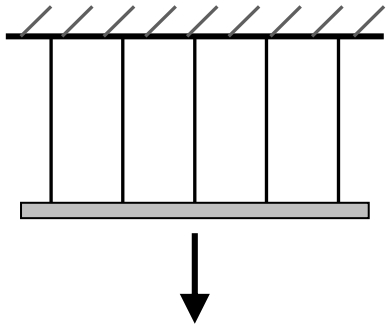
$$p(EX)$$

$$p(C_{ij}|EX)c_D(C_{ij})$$

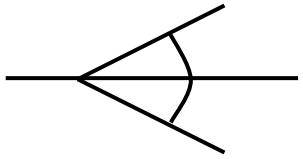
$$p(S_k|\mathbf{C},EX)c_{ID}(S_k,c_D(\mathbf{C})C_{ij})$$

Robustness on different scales:





An assessment framework



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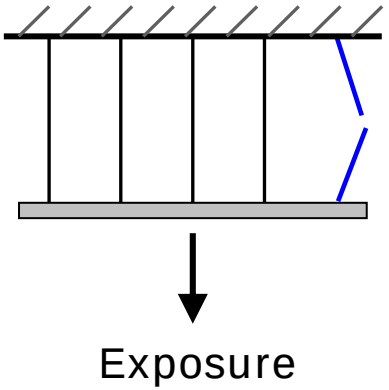
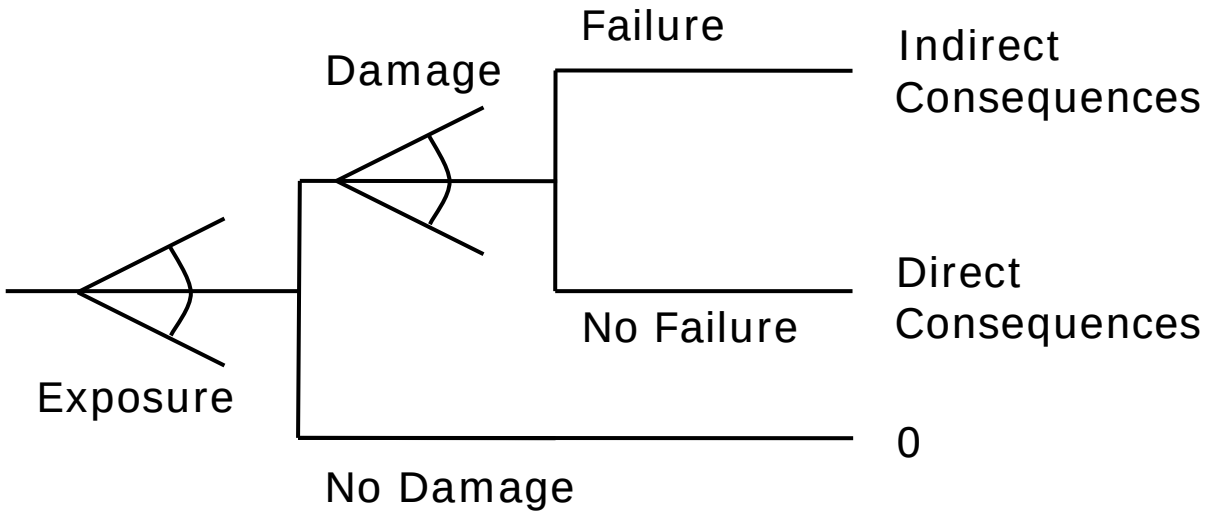
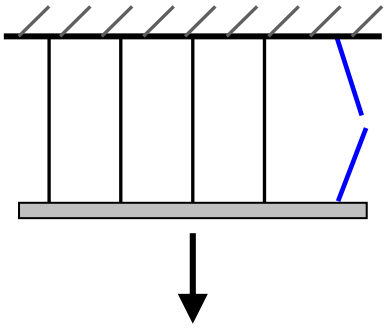
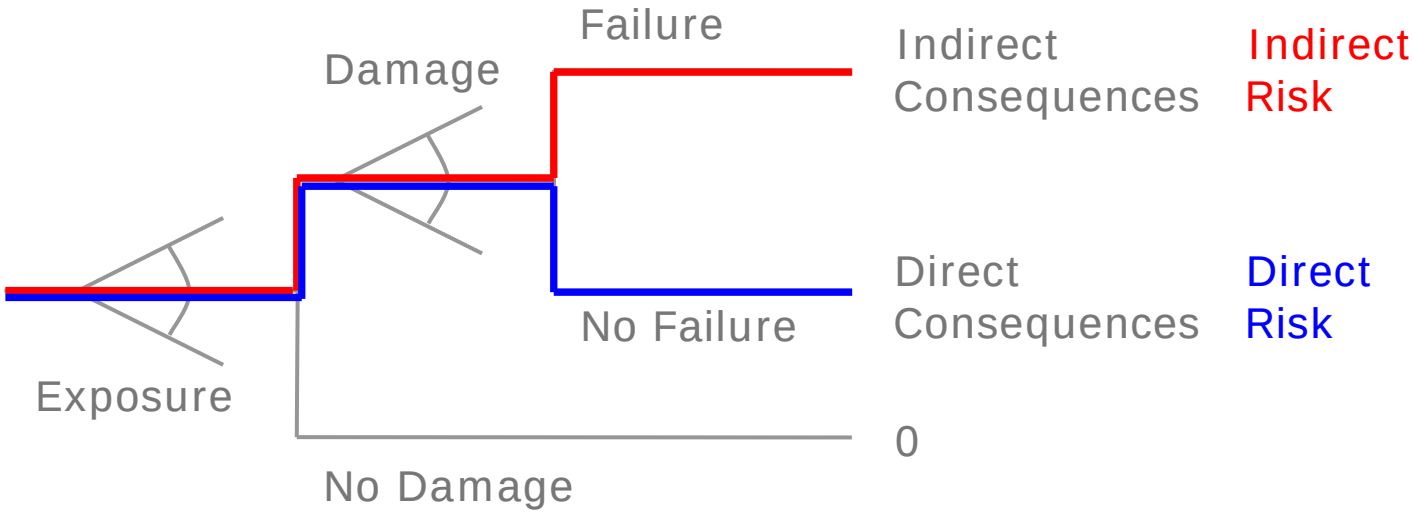




Calculation of Risk





An index of robustness: $I_{Rob} = \frac{\text{Direct Risk}}{\text{Direct Risk} + \text{Indirect Risk}}$

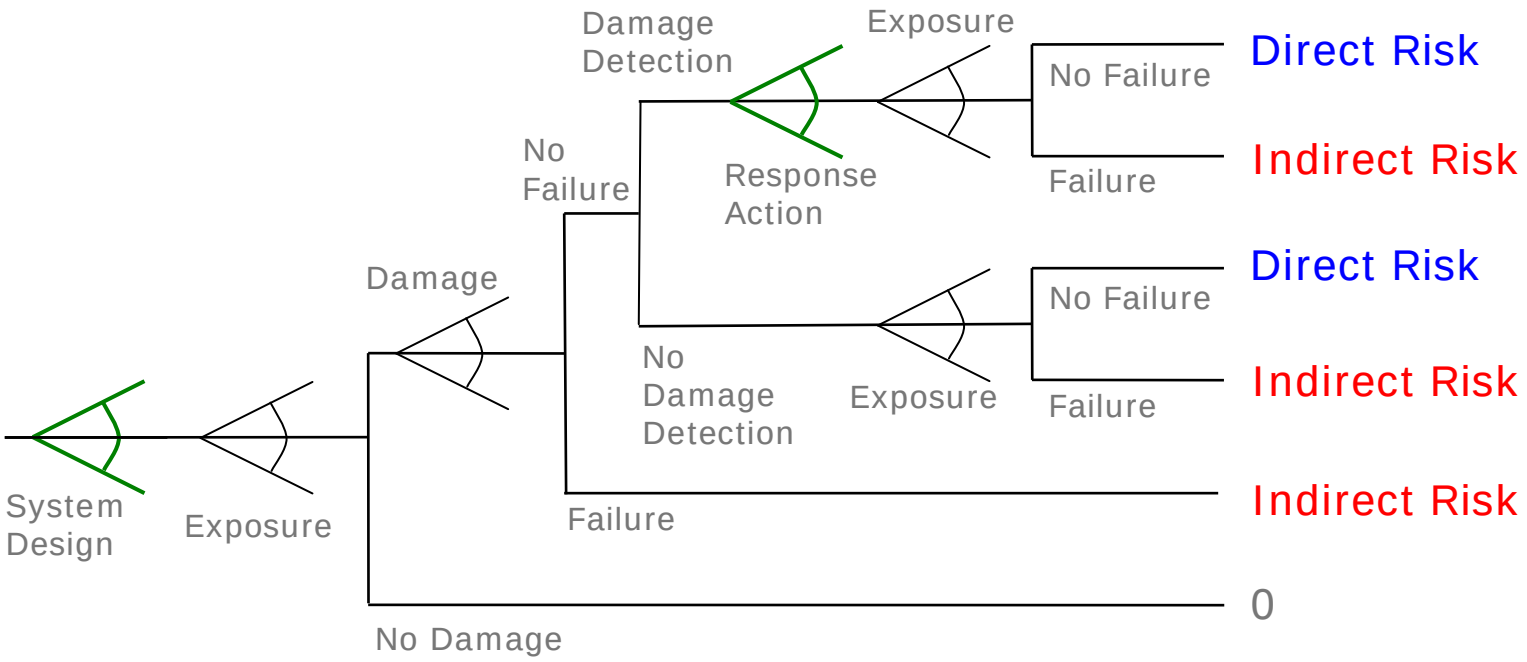
Features of the proposed index

$$I_{Rob} = \frac{\text{Direct Risk}}{\text{Direct Risk} + \text{Indirect Risk}}$$

- Assumes values between zero and one
- Measures relative risk only
- Dependent upon the probability of damage occurrence
- Dependent upon consequences

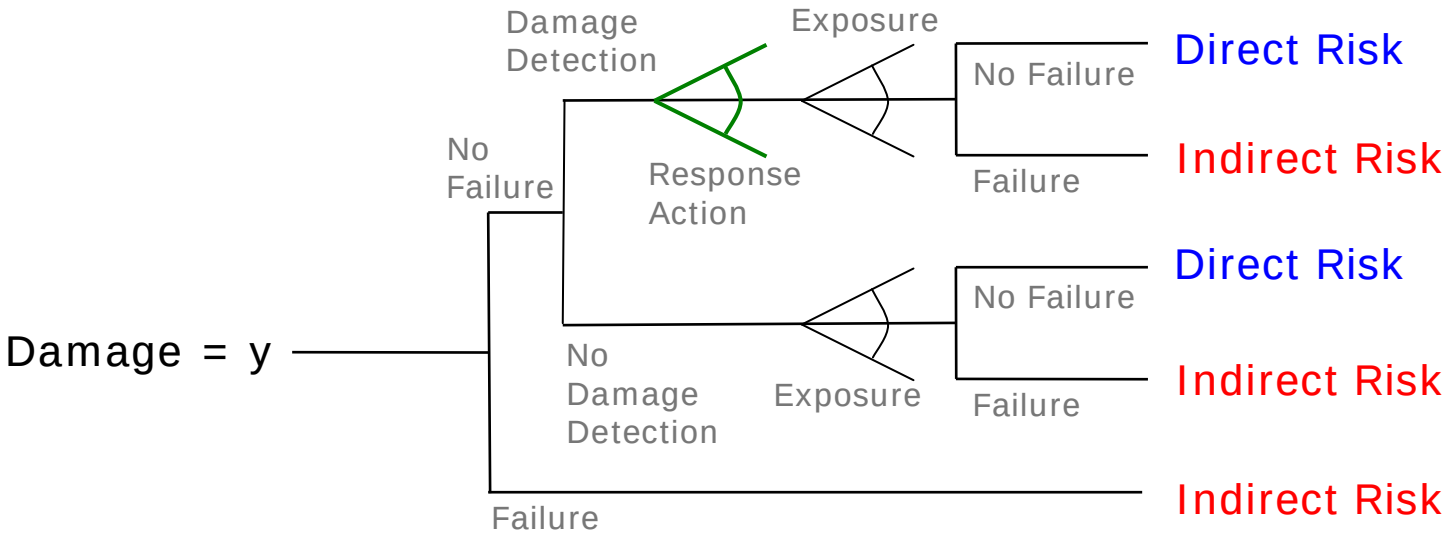
The framework easily facilitates decision analysis

- Choice of the physical system
- Choice of inspection and repair
- Choices to reduce consequences



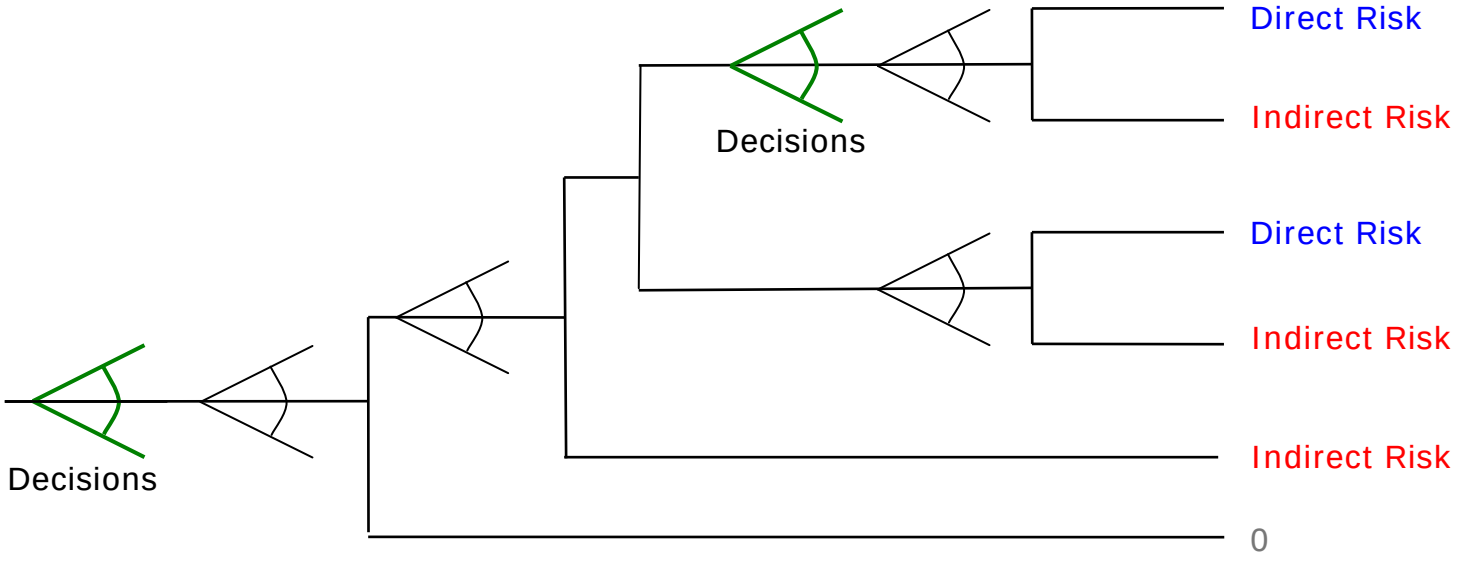
"Conditional robustness" is a useful extension of the framework

- Helpful for events such as terrorist attacks
- Helpful for communication, using a scenario event
- Can be easily used to calculate (marginal) robustness



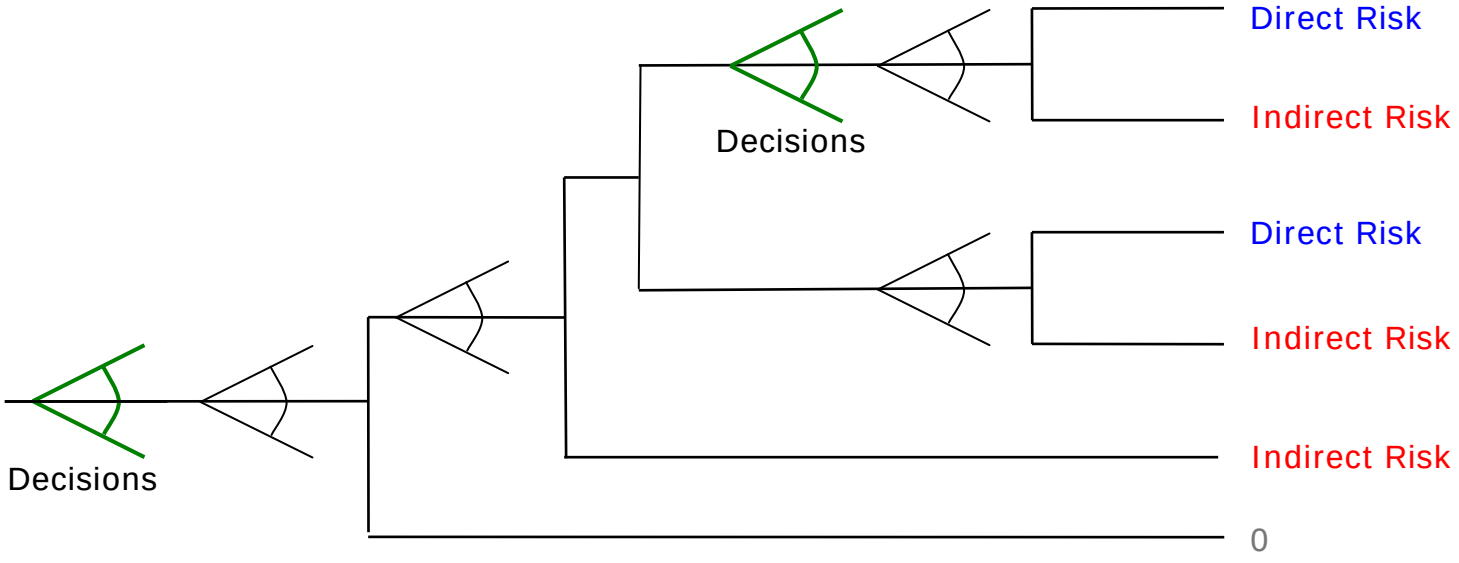
Robustness-based design

- Acceptable levels of direct risk are achieved by other design requirements
- Here the goal is indirect risk-reduction
- Choices are facilitated using the decision trees in this framework
- The choices can be framed as an optimization problem



Robustness-based design options:

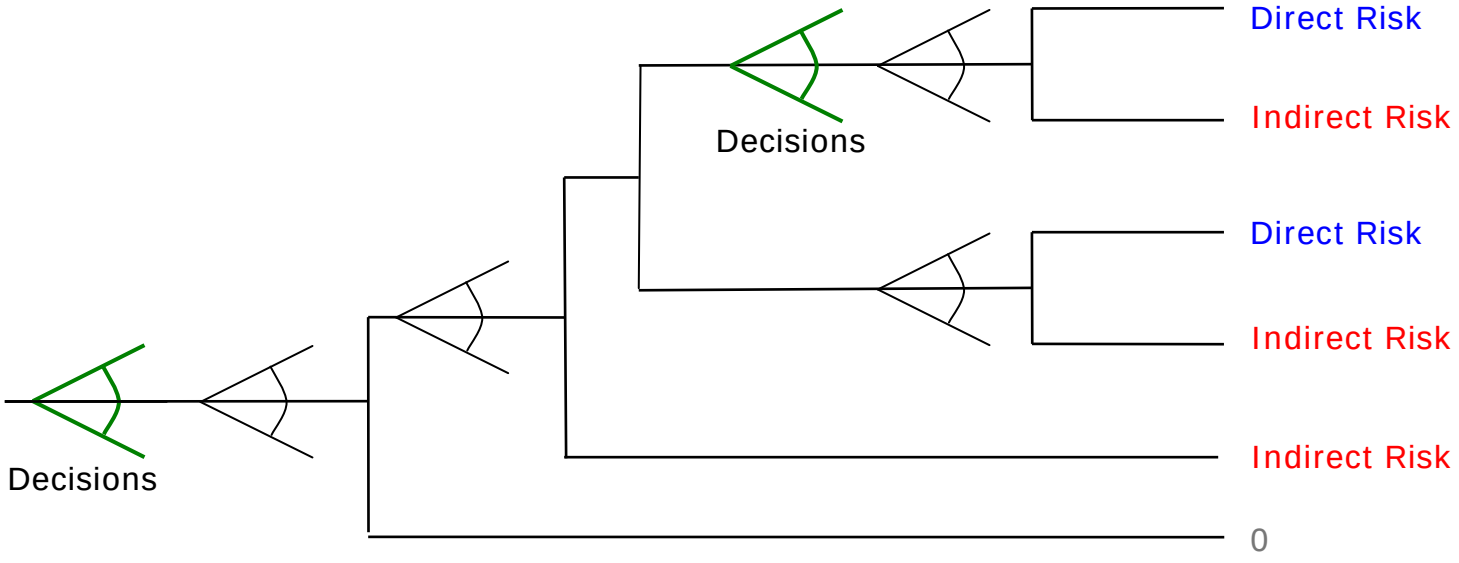
- Change structural detailing to provide load transfer
- Increase redundancy of elements
- Reduce consequences of failure
- Reduce exposures
- Add inspection and maintenance to address deterioration damage



Robustness-based design calibration

– By benchmarking the robustness of a variety of structures, general patterns can be found

– This should lead to simplified requirements that do not require complete risk assessments



Conclusions

- A risk-based assessment of robustness has several attractive properties
  - Application to general systems
  - Incorporates failure probabilities *and* consequences
  - Facilitates decision making

- The concept of conditional robustness is useful for assessment and communication of robustness

- Calibration studies with this objective framework could help with identification of effective code requirements