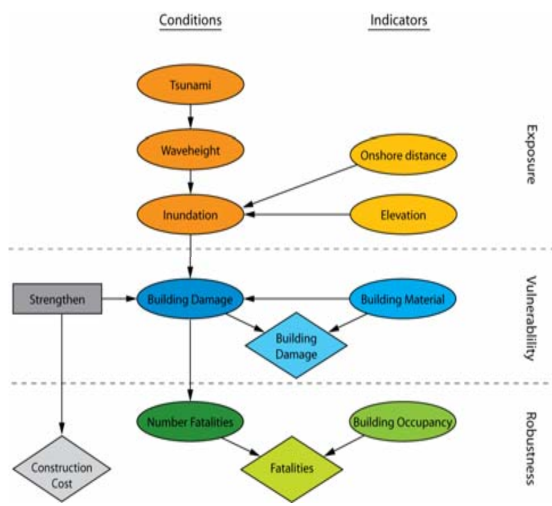


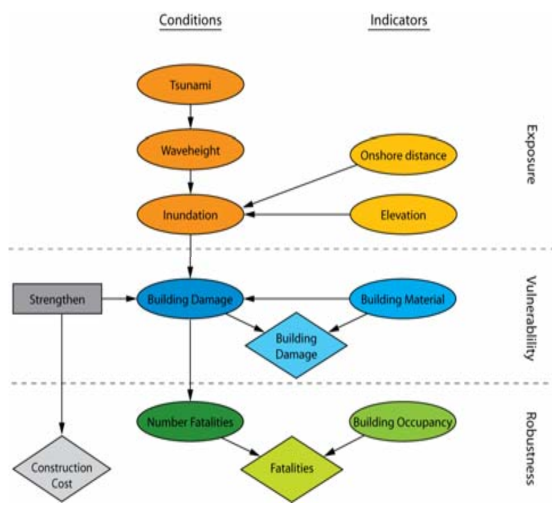
COST C26 Urban Habitat Constructions Under Catastrophic Events
Workshop, Prague,
March 30-31, 2007

Presentations from WG4

Resistance to Infrequent Loads

WG 4 - Presentations

- Framework for risk assessment of structural systems, M.H. Faber.
- Urban habitat constructions around Vesuvius: environmental risk and engineering challenges, F. Dobran.
- ~~Identification and classification of exposure events and scenarios, J.P. Muzeau & V. Sesov.~~
- Identification and classification of exposure characteristics, C. Arion, D. Lungu & C. Coelho.
- Identification and classification of constructions, M. Indirli.
- „Free“ discussion.



COST C26 Urban Habitat Constructions Under Catastrophic Events
Workshop, Prague,
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Framework for Risk Assessment of Structural Systems

M. H. Faber

Chair of Risk and Safety.
Institute of Structural Engineering, ETH.

ETH *Swiss Federal Institute of Technology, Zurich*

Contents of Presentation

What is the Problem?

- Despite modernization of design codes the engineering profession is still facing problems in terms of

  - collapsing structures and building

  - steady increase of insured damages

What is the Problem?

- Examples of collapses

  Bad Reichenhalle
  Germany, 2006

What is the Problem?

- Examples of collapses

  Siemens arena
  Denmark, 2003

What is the Problem?

- Examples of collapses

  Oklahoma City bombing
  USA, 1995

What is the Problem?

- Examples of collapses

  World Trade Center
  USA, 2001

What is the Problem?

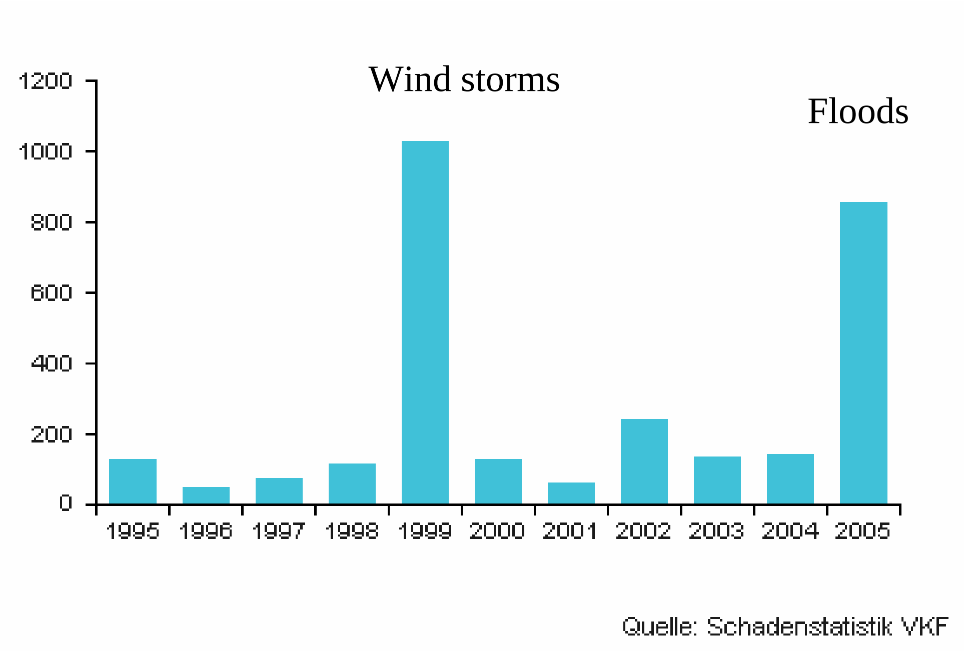
- Examples of collapses

  Charles de Gaulle
  France, 2004

What is the Problem?

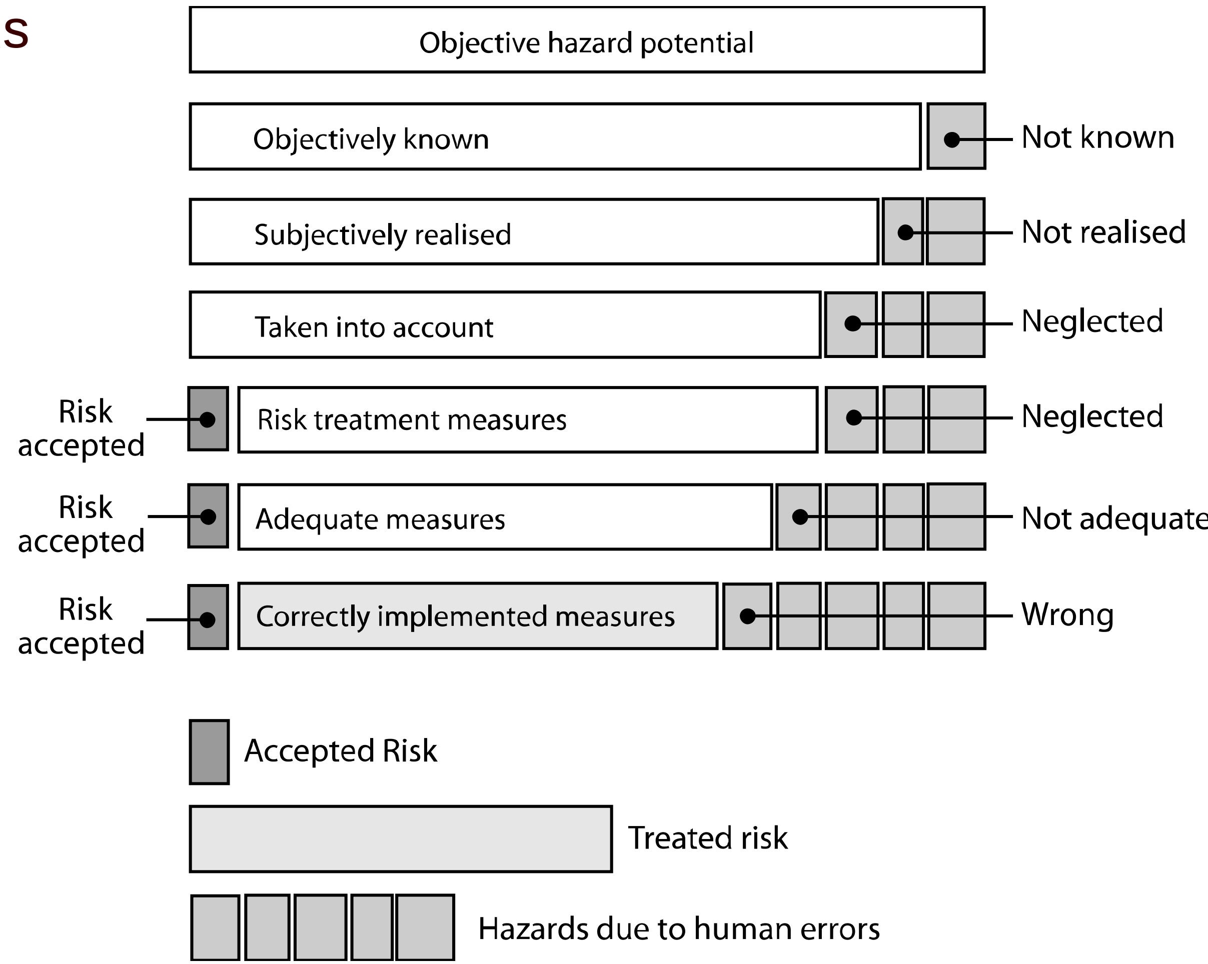
- Insured losses due to building failures

  IRV Interkantonaler Rückversicherungs-verband, Switzerland



What is the Problem?

- Where do the risks come from?



What is the Problem?

- What is a catastrophic event?

  - an event related to an infrequent hazard?

  - an event related to spectacular hazards?

  - an event related to extreme consequences?

- In principle the issue to be concerned about are:

  all events/scenarios which we do not consider specifically in present engineering design and assessment

What is the Problem?

- Present codes and practices are targeting design and assessment of normal structures under normal conditions

  - Ultimate limit state conditions

  - Serviceability limit conditions

  - Accidental/extraordinary limit conditions

- However, the design and assessment codes address structural reliability from a component perspective

  - system performance is only accounted for implictely !

What is the Problem?

- System performance is codified through requirements to:

  - spatial/global stability

  - system robustness

  - joint performance

- According to typical design codes structures should be robust!

- Little or no guidance is provided in regard to what robustness really is – and how much is required!

What is the Problem?

Structural Standards	The consequences of structural failure are not disproportional to the effect causing the failure [2].
Software Engineering	The ability…to react appropriately to abnormal circumstances (i.e., circumstances "outside of specifications"). A system may be correct without being robust [17].
Product Development and QC	The measure of the capacity of a production process to remain unaffected by small but deliberate variations of internal parameters so as to provide an indication of the reliability during normal use.
Ecosystems	The ability of a system to maintain function even with changes in internal structure or external environment [18].
Control Theory	The degree to which a system is insensitive to effects that are not considered in the design [19].
Statistics	A robust statistical technique is insensitive against small deviations in the assumptions [20].
Design Optimization	A robust solution in an optimization problem is one that has the best performance under its worst case (max-min rule) [21].
Bayesian Decision Making	By introducing a wide class of priors and loss functions, the elements of subjectivity and sensitivity to a narrow class of choices, are both reduced [22]
Language	The robustness of language…is a measure of the ability of human speakers to communicate despite incomplete information, ambiguity, and the constant element of surprise [23].

What is the Problem?

- Design codes have so far focussed on inherent properties of the structures (components)

  - redundancy
  - ductility

- More recently focus has been directed on

  - system performance (removal of members)
  - structural ties

What is the Problem?

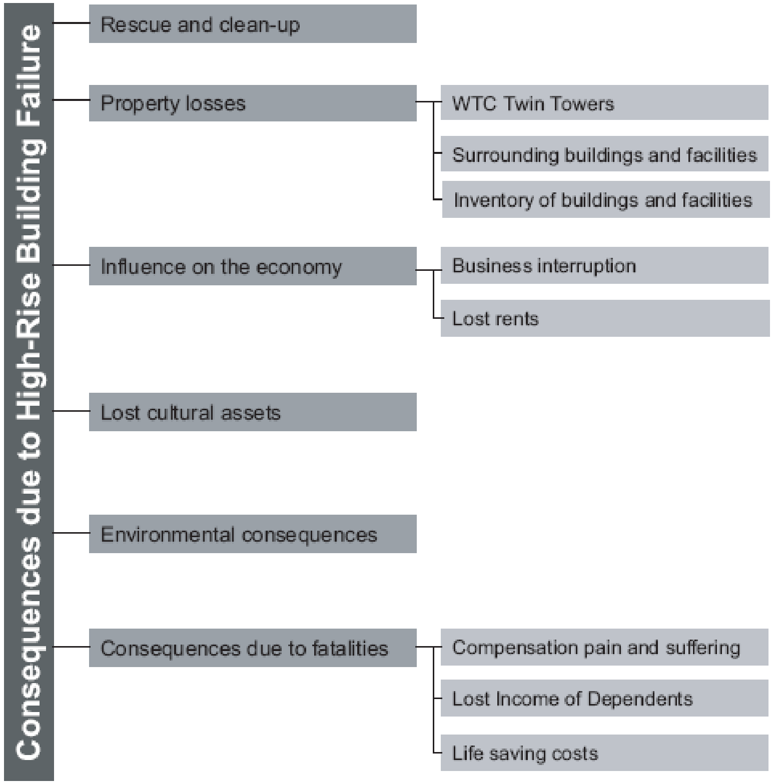
The material loss cost consequences due to the collapse of the two WTC towers only comprised ¼ of the total costs due to damaged or lost material

It seems relevant to include consequences in the robustness equation !

and these are scenario dependent !

What is the Problem?

- The system definition is important because it defines the consequences following structural failures



On the Assessment of Risk of Systems

How do engineers make decisons?

Options

Models of real world

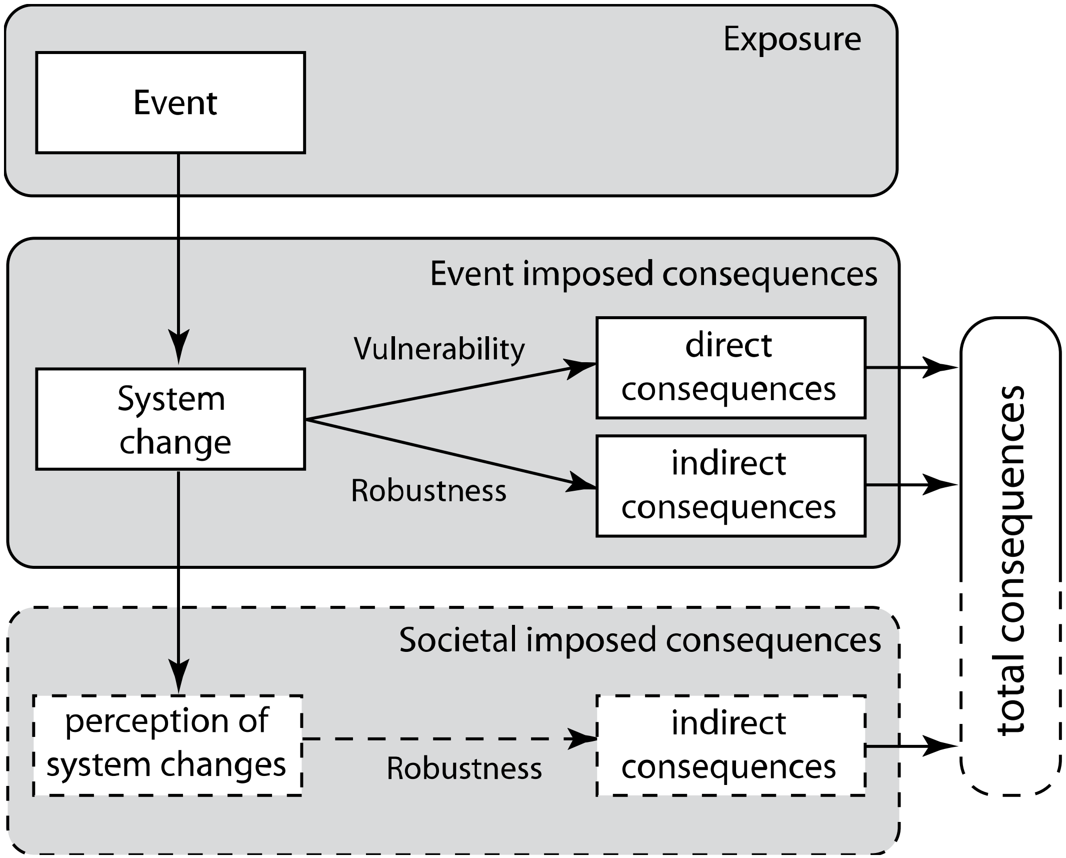
$$U(\mathbf{a}(\mathbf{T})) = \sum_{i=1}^{n} \delta(t_i) \left[\int_{t_i}^{t_{i+1}} \upsilon_{G_i}(\tau, \mathbf{a}(t_i), t_i) \gamma(\tau - t_i) d\tau \right]$$

Indicators

Real World

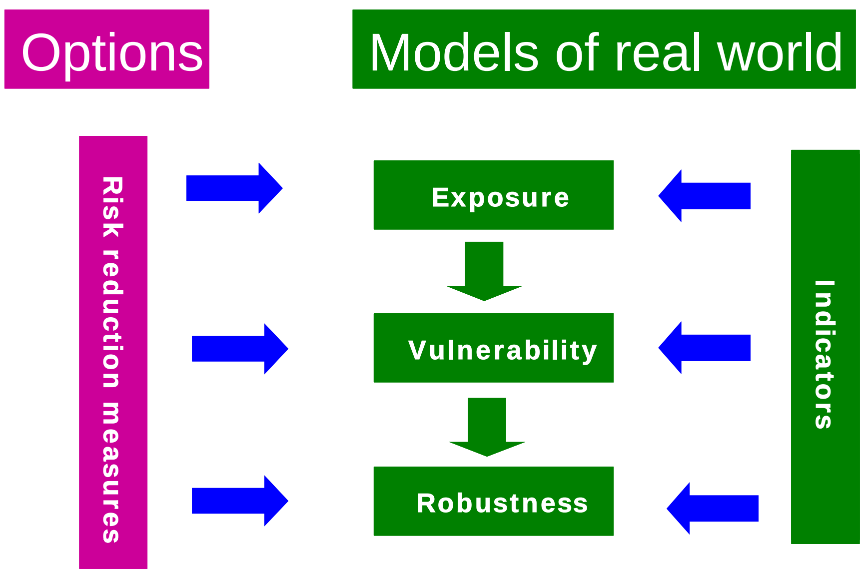
Modeling of Consequences

How are consequences generated?



Modeling of Consequences

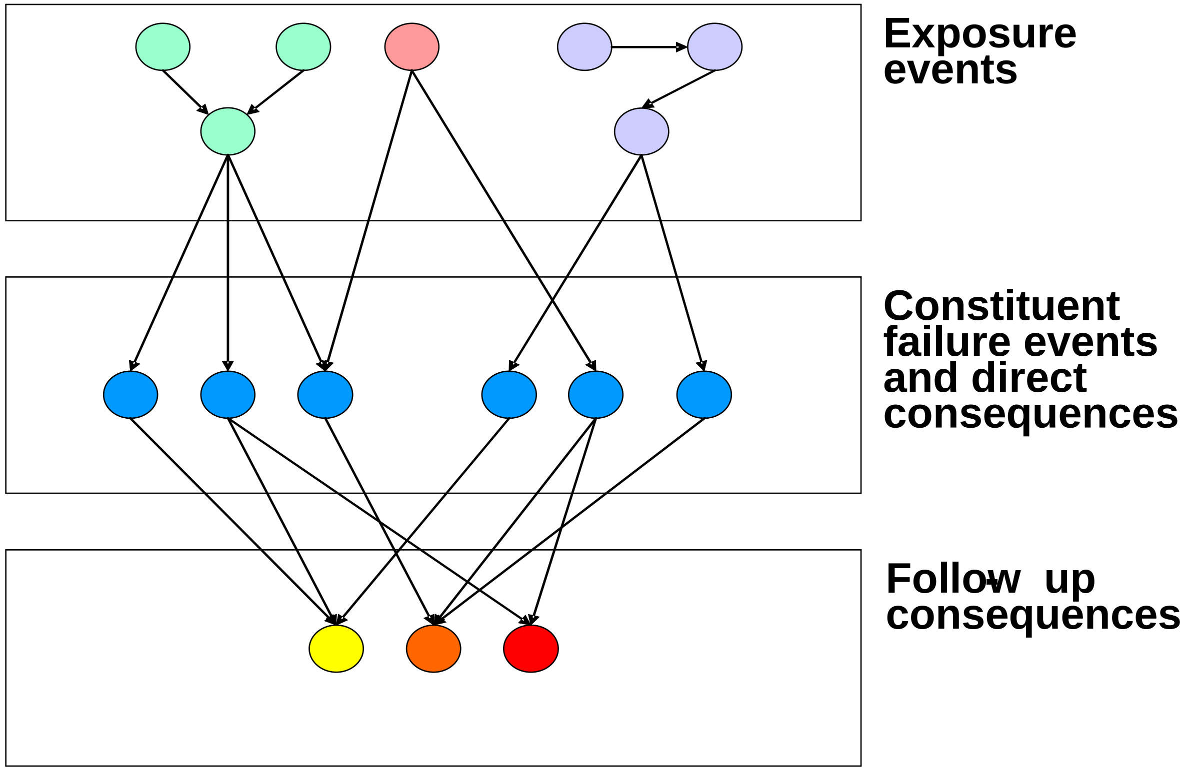
Engineered systems exhibit generic characteristics



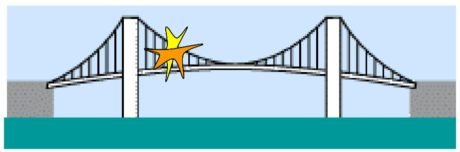
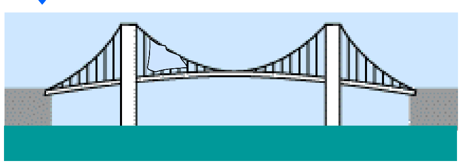
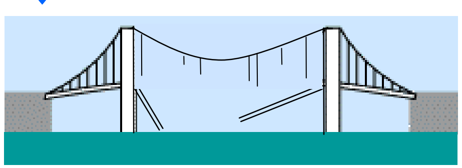
Real World

Modeling of Consequences

How may systems be modeled?

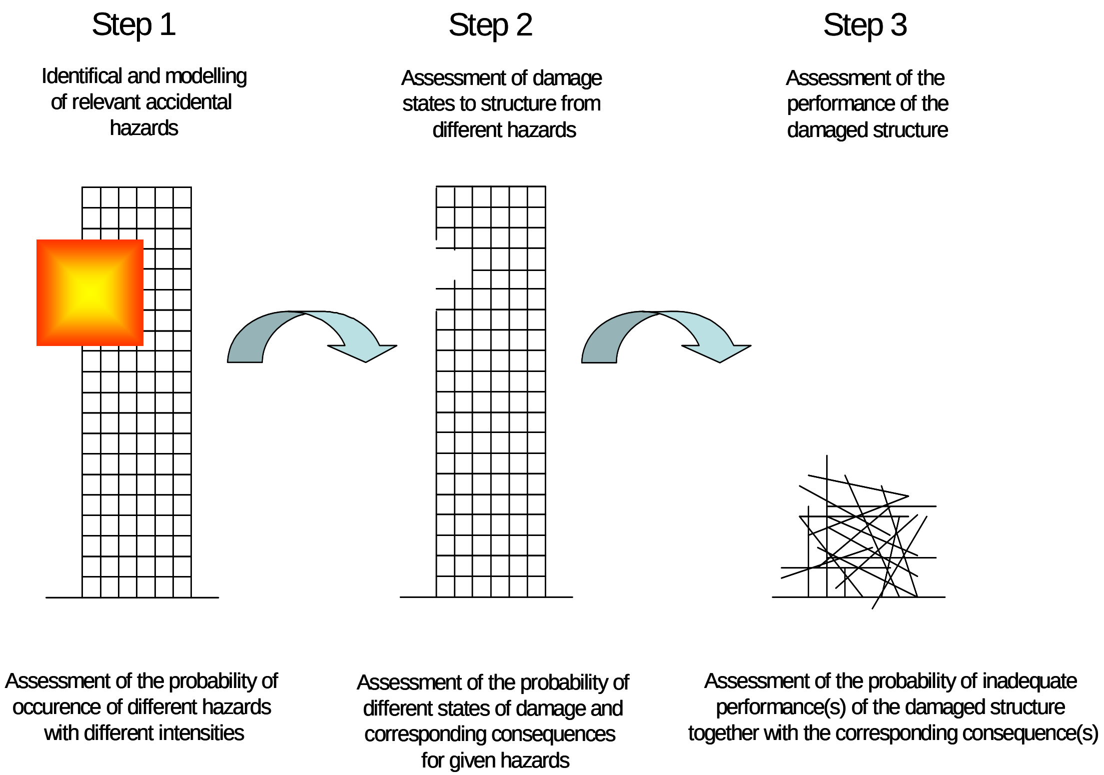


Modeling of Consequences

Scenario representation	Physical characteristics	Indicators	Potential consequences
Exposure 	Flood Ship impact Explosion/Fire Earthquake Vehicle impact Wind loads Traffic loads Deicing salt Water Carbon dioxide	Use/functionality Location Environment Design life Societal importance	
Vulnerability 	Yielding Rupture Cracking Fatigue Wear Spalling Erosion Corrosion	Design codes Design target reliability Age Materials Quality of workmanship Condition Protective measures	**Direct consequences** Repair costs Temporary loss or reduced functionality Small number of injuries/fatalities Minor socio-economic losses Minor damages to environment
Robustness 	Loss of functionality partial collapse full collapse	Ductility Joint characteristics Redundancy Segmentation Condition control/monitoring Emergency preparedness	**Indirect consequences** Repair costs Temporary loss or reduced functionality Mid to large number of injuries/fatalities Moderate to major socio-economic losses Moderate to major damages to environment

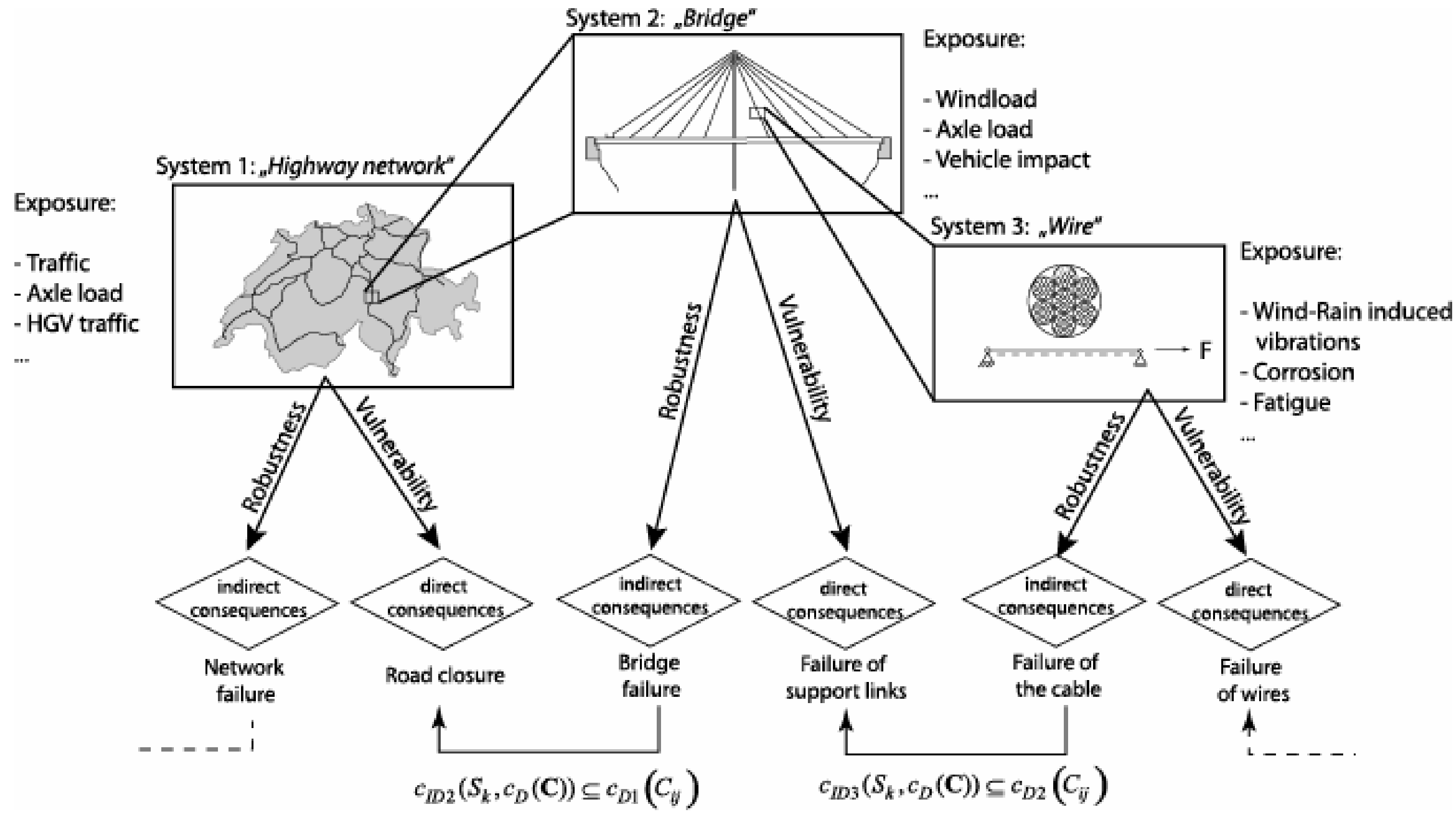
Modeling of Consequences

- This concept is also the idea behind the Eurocodes



Modeling of Consequences

Engineered systems exhibit generic characteristics



Robustness of Structures

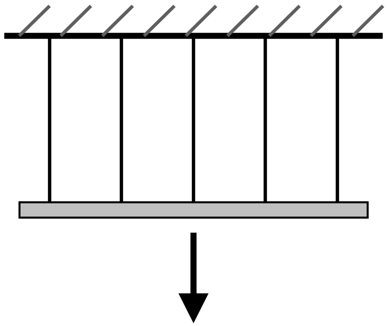
- Desirable properties of a robustness measure

  - Applicable to general systems

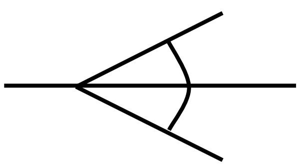
  - Allows for ranking of alternative systems

  - Provides a criterion for identifying acceptable robustness

Robustness of Structures

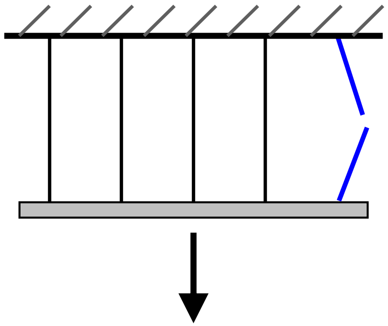


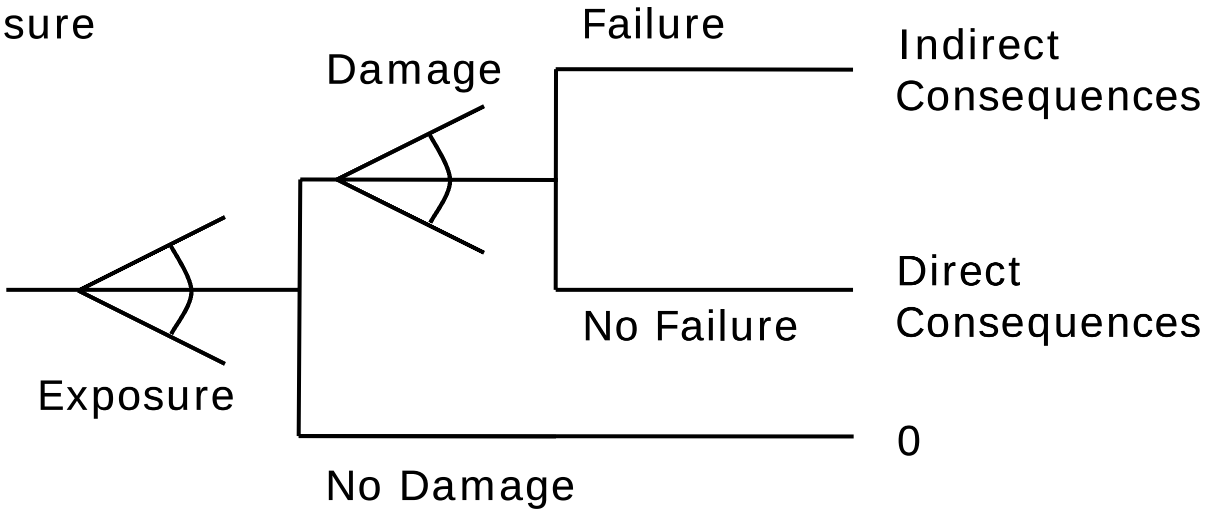
An assessment framework



Robustness of Structures

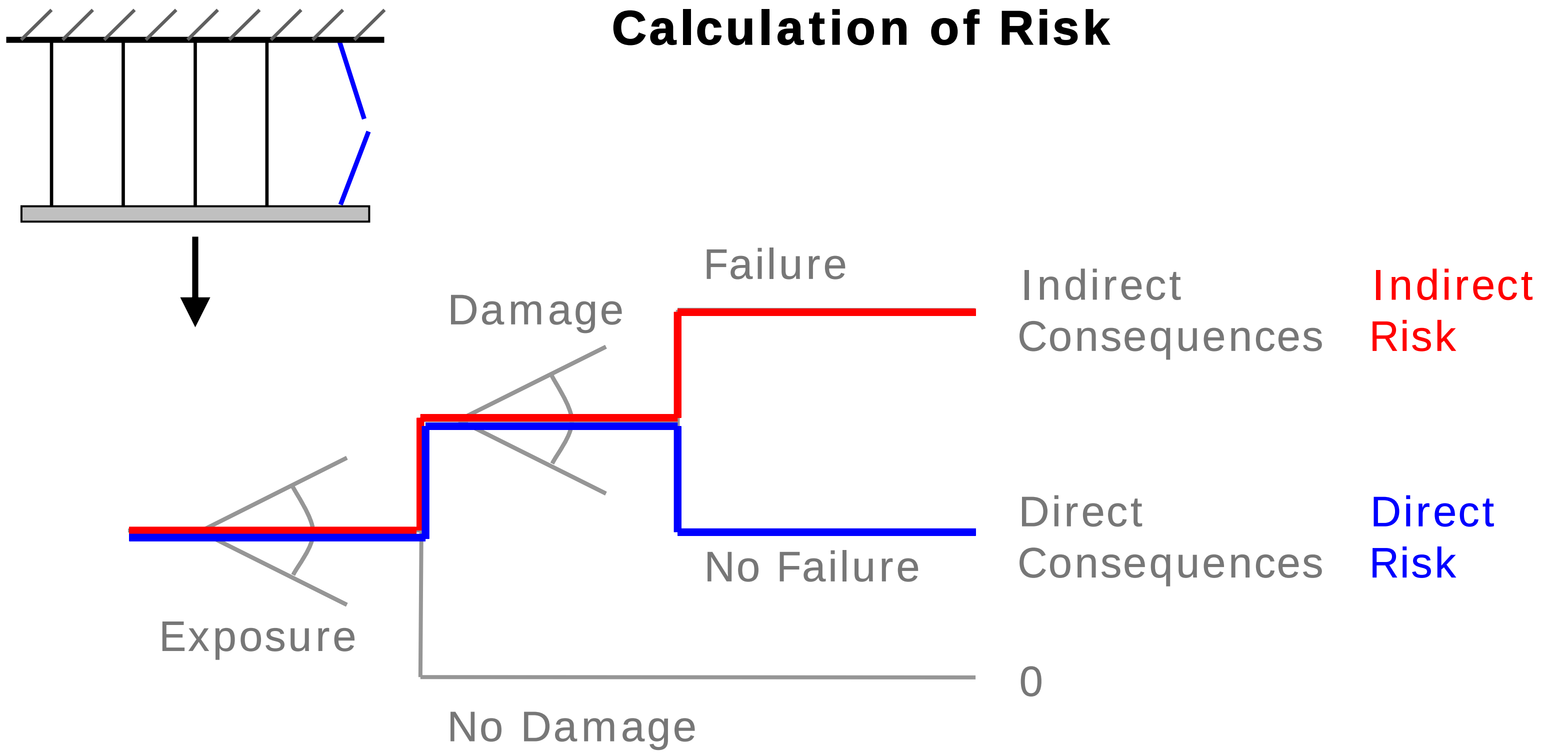
An assessment framework





Robustness of Structures

Calculation of Risk



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

Robustness of Structures

Features of the proposed index

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

- Assumes values between zero and one

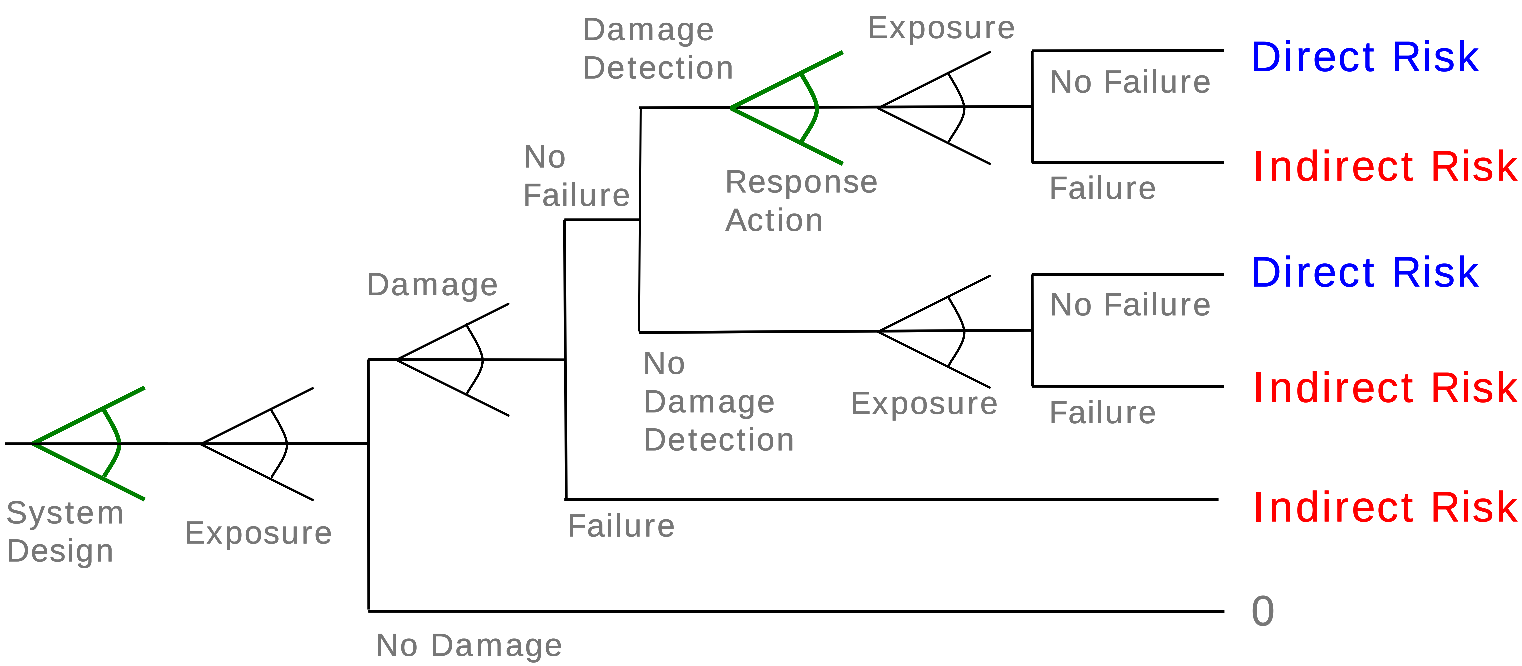
- Measures relative risk only

- Dependent upon the probability of damage occurrence

- Dependent upon consequences

Robustness of Structures

- The framework easily facilitates decision analysis
  - Choice of the physical system
  - Choice of inspection and repair
  - Choices to reduce consequences

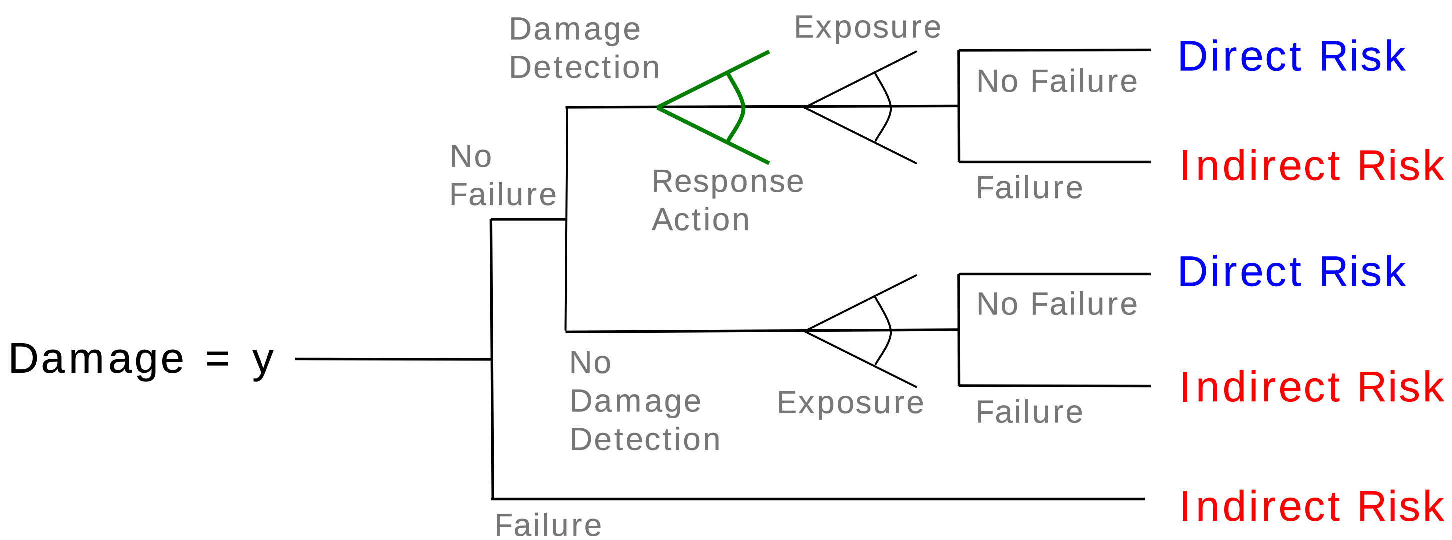


Robustness of Structures

- “Conditional robustness” is a useful extension of the framework Helpful for events such as terrorist attacks

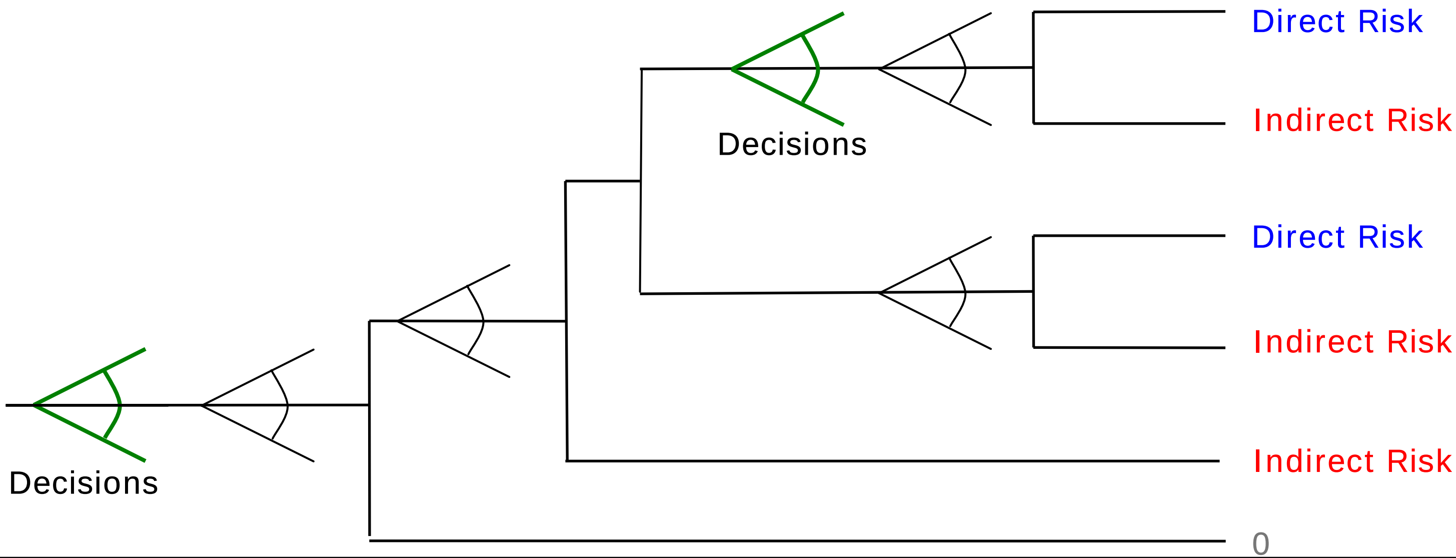
  - Helpful for communication, using a scenario event

  - Can be easily used to calculate (marginal) robustness



Robustness of Structures

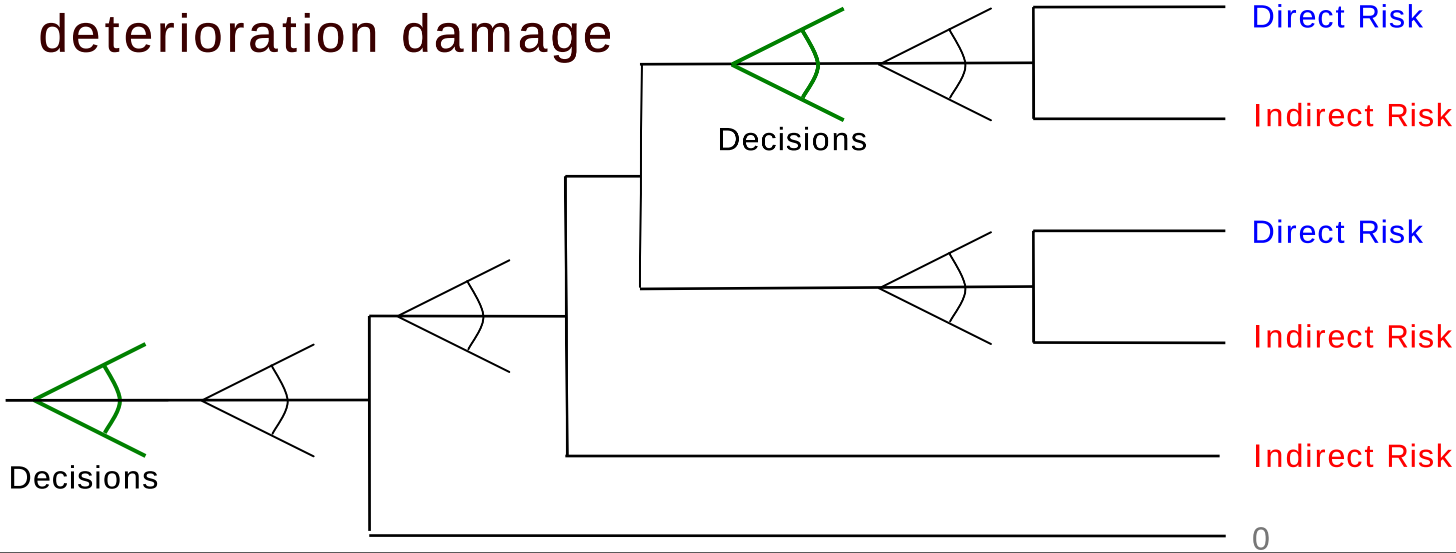
- Robustness-based design
  - Acceptable levels of direct risk are achieved by other design requirements
  - Here the goal is indirect risk-reduction
  - Choices are facilitated using the decision trees in this framework
  - The choices can be framed as an optimization problem



Robustness of Structures

- Robustness-based design options:

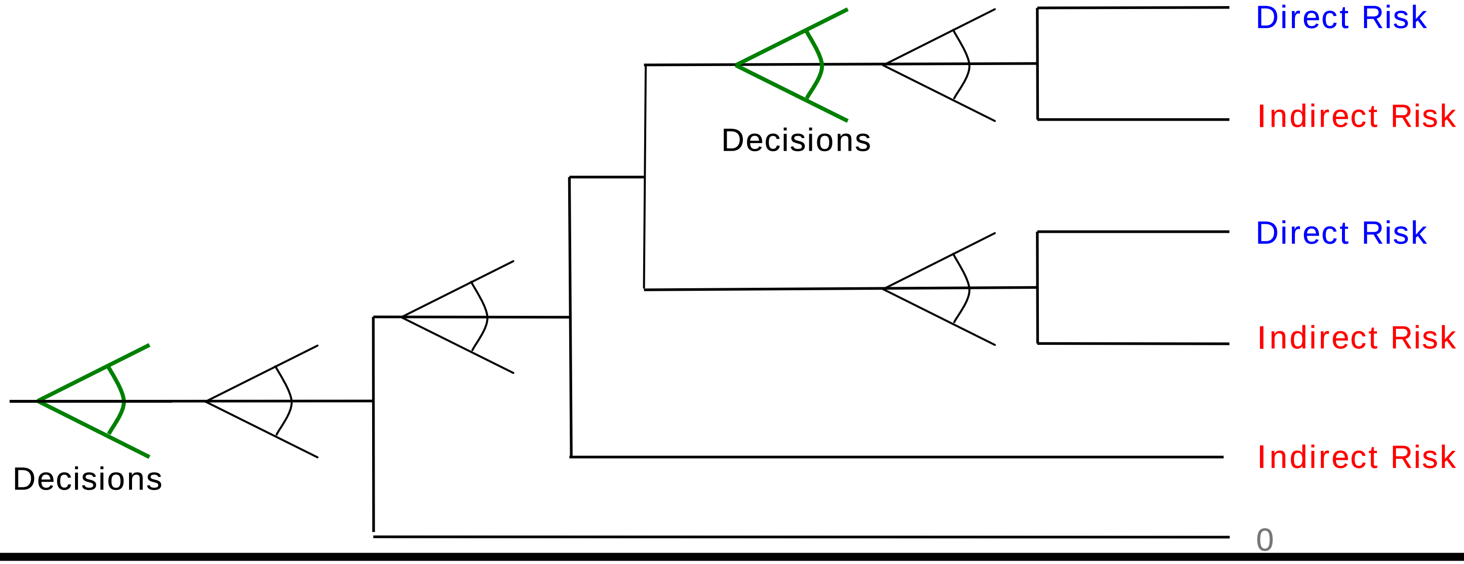
  - Change structural detailing to provide load transfer
  - Increase redundancy of elements
  - Reduce consequences of failure
  - Reduce exposures
  - Add inspection and maintenance to address deterioration damage



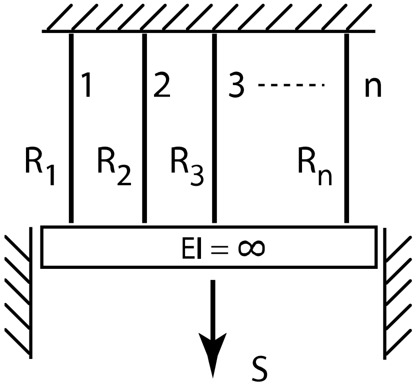
Robustness of Structures

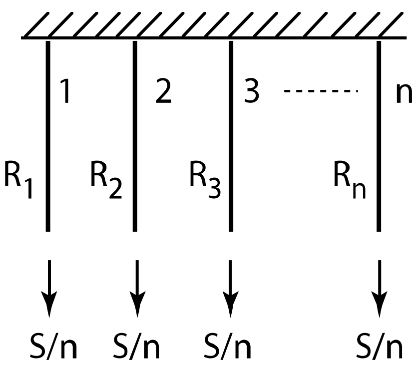
- Robustness-based design calibration

  - 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



Robustness of Structures



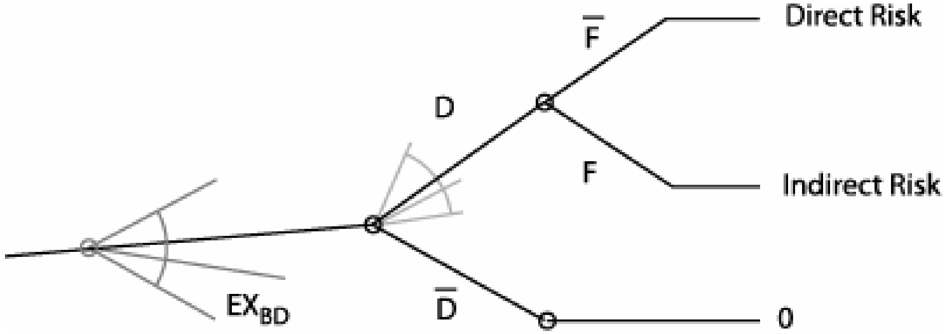


Example - Structural Systems

- Parallel system with *n* elements
- Subjected to different types of exposures
- Perfect ductile / brittle
- Load distribution after component failure
- Element damage / system failure
- The one element case represents series systems
- Consequences of system failure is set equal to 100 times the consequences of component failure

Robustness of Structures

A simplified event/decision tree is considered



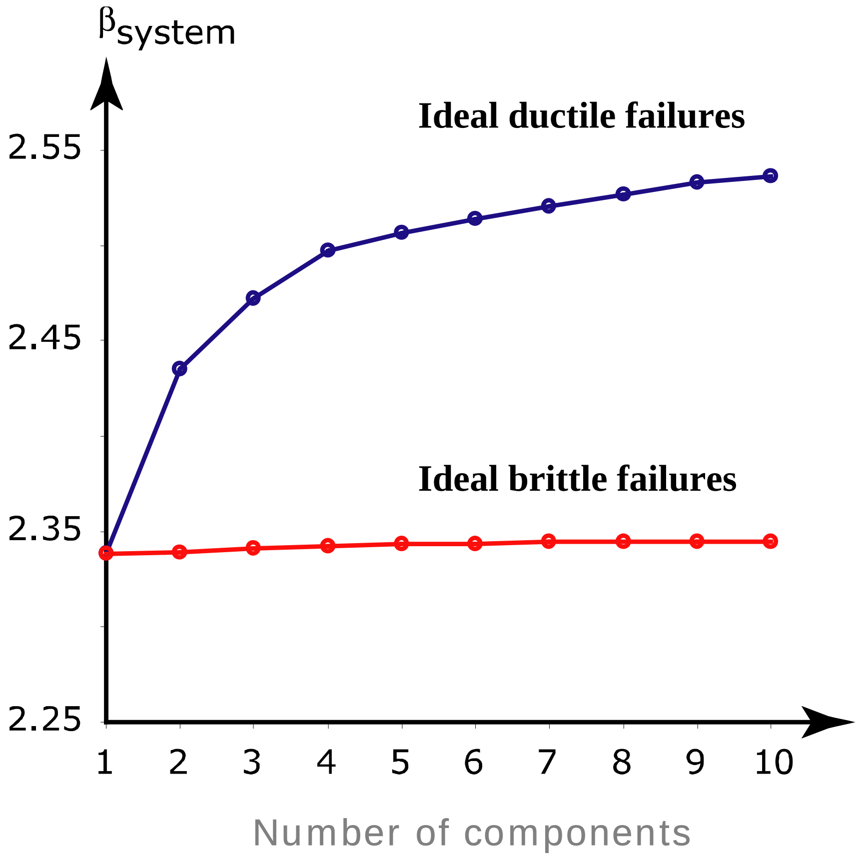
Robustness of Structures

Exposures

- Dead load and live load
  - Weibull distribution

- Applied load is the yearly maximum

- Each component has the same probability of failure



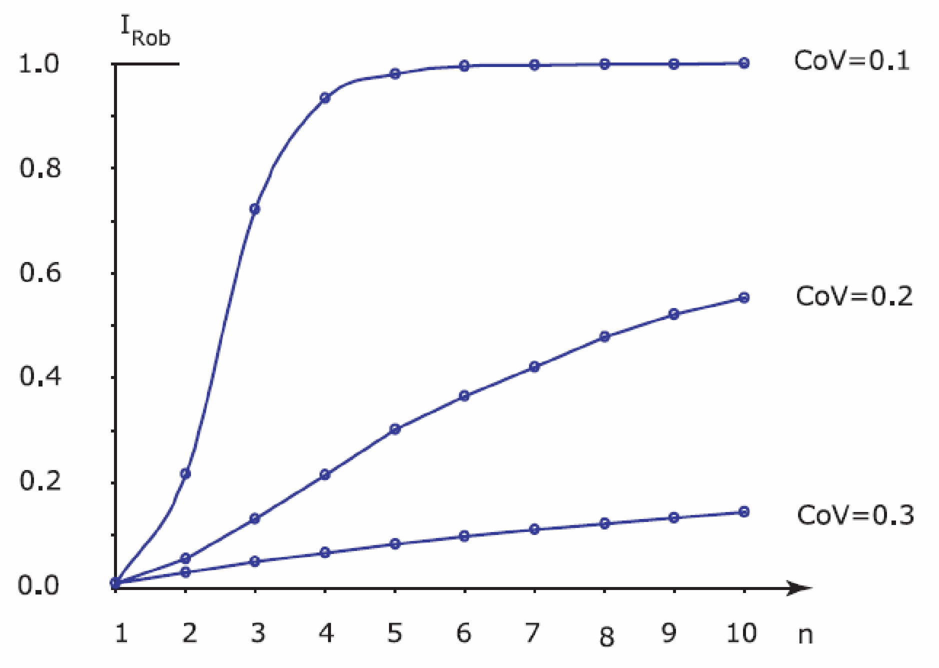
Robustness of Structures

Number of components – ductile material

- The greater the number of components, the more robust

- One component – Small robustness

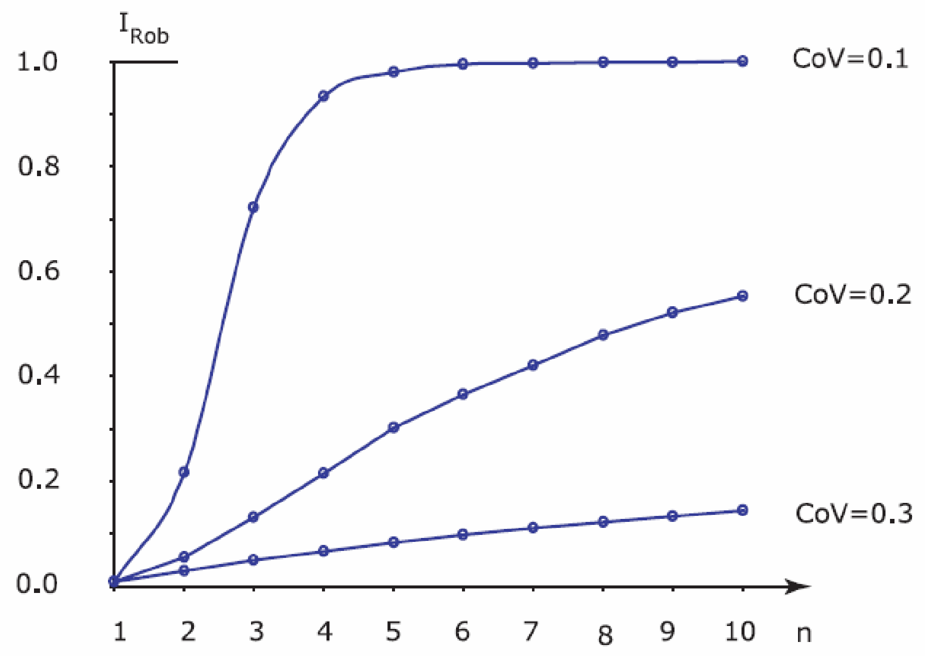
- One component – Series system



Robustness of Structures

Load variability – ductile material

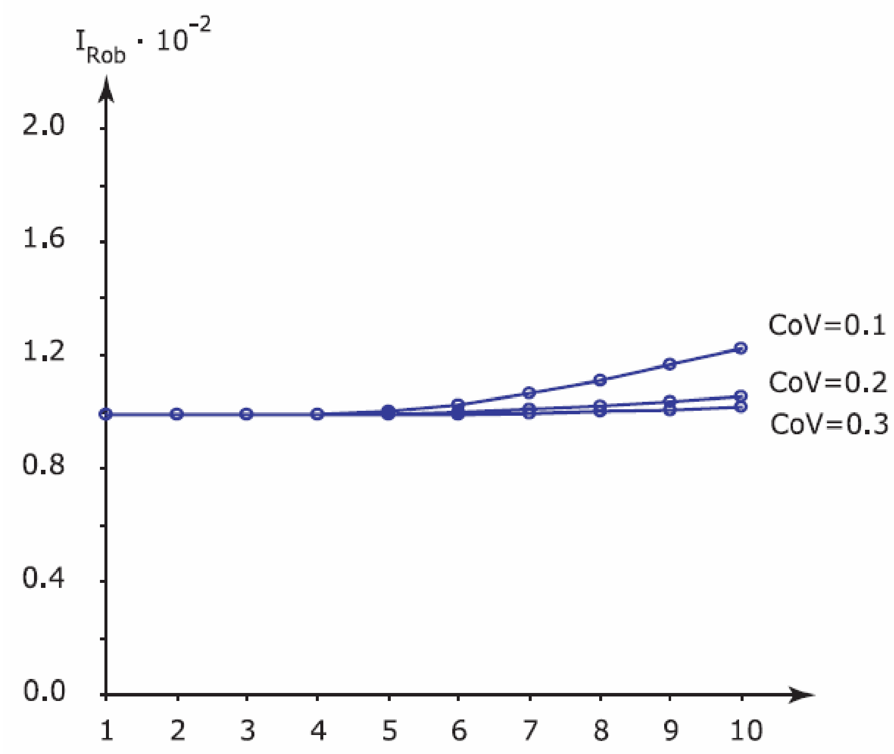
- Higher CoV leads to less robustness
- Higher Cov increases the probability that the system fails if one component is damaged
- Here uncorrelated resistance is assumed
- Correlation has the same effect as reducing the number of components



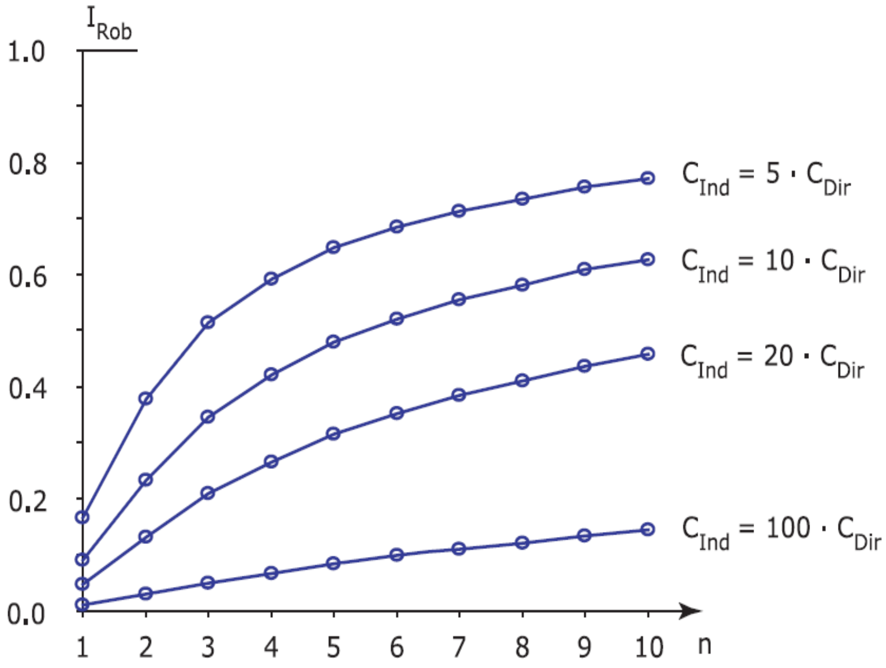
Robustness of Structures

Load variability – brittle material

- No residual carrying capacity
- Cascading system failure
- The robustness is close to zero
- Indirect risks are dominating
- Probabilities for damage states are low – or failure consequences high



Robustness of Structures



Failure Consequences

- The higher the indirect consequences, the lower the robustness

- Increase the robustness with

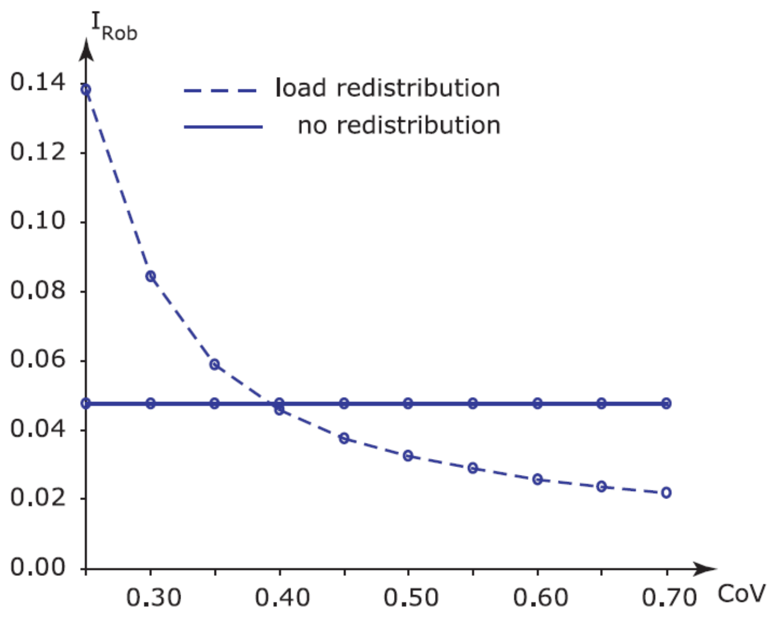
  - effective egress routes

  - decisions in rescue action

  - effective warning systems

- Effect of increasing the damage consequences
  - The robustness is related to reliability

Robustness of Structures

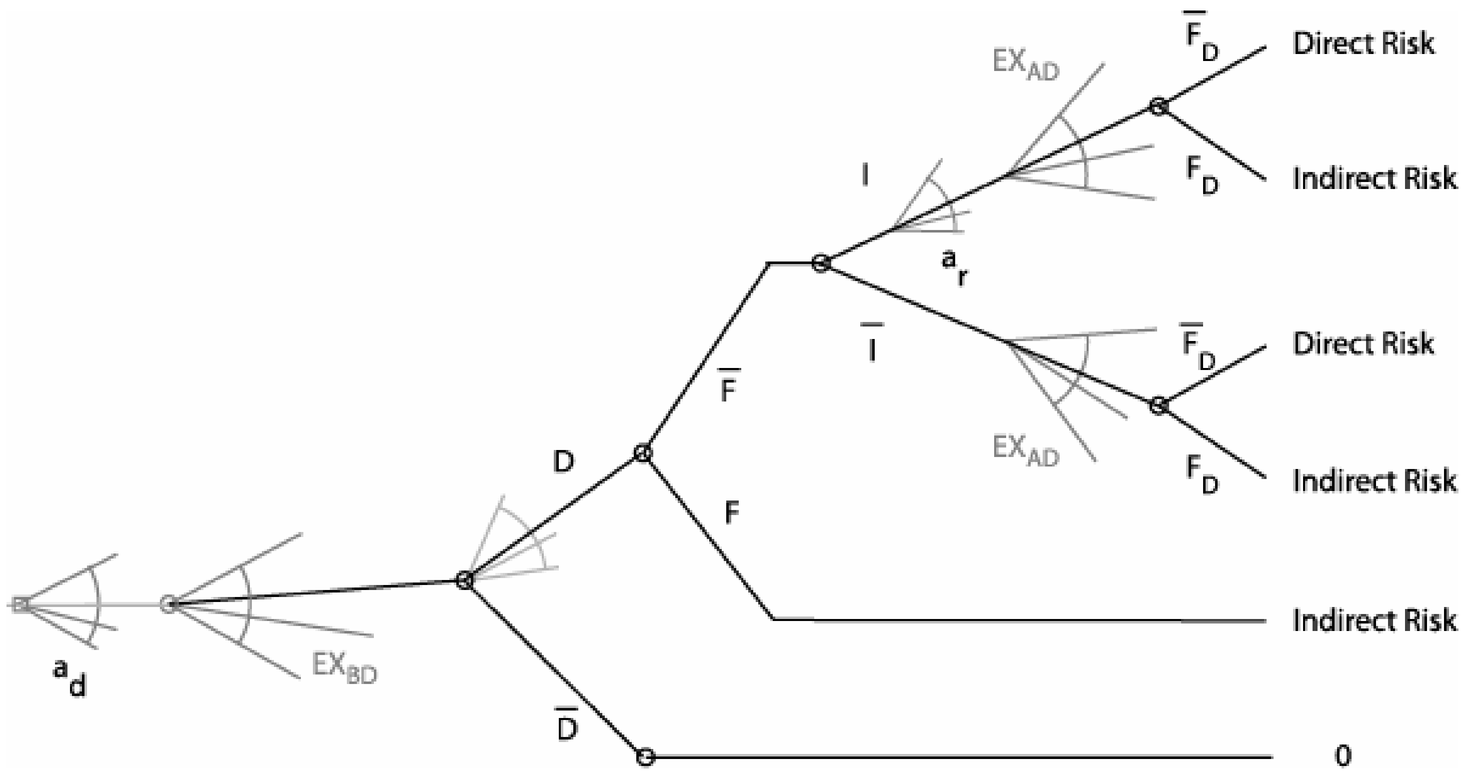


Load redistribution

- How is the load carried by the structure? Tie together or accept local failure?
- Load redistribution might increase system failure probability
- Indirect consequences occur in the case of local failure
- In some cases it is better to tie the structure together – but not in all cases.
- This robustness assessment can help to identify the proper strategy

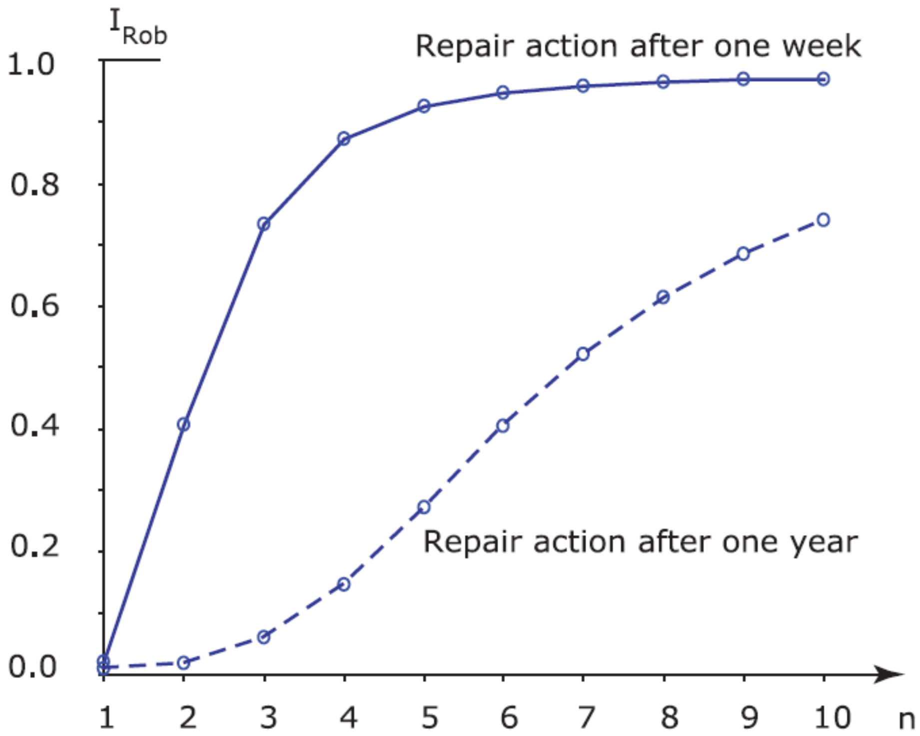
Robustness of Structures

Extraordinary loads / repair actions



Robustness of Structures

Extraordinary loads / repair actions

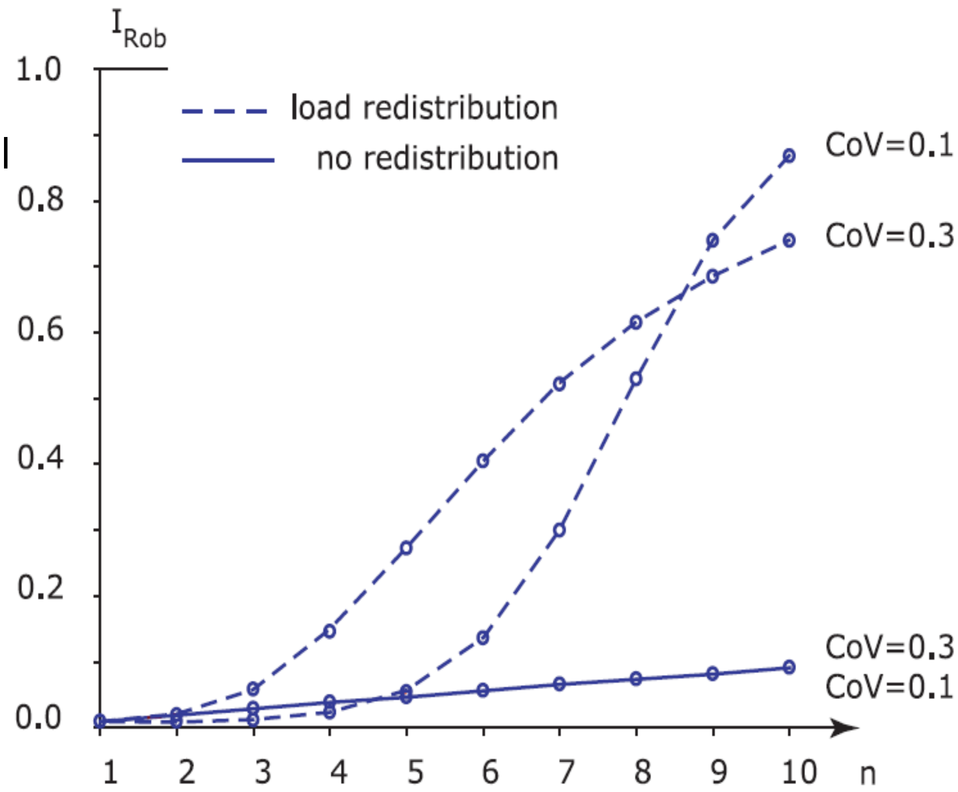


- Random load in time + accidental loss of one component
- The structure is more robust when damage can be detected
- The robustness is also affected by actions such as monitoring and repair
- Imperfect damage detection or partial repairs can easily be included

Robustness of Structures

Conditional robustness

- Loss of one component is assumed
- Provides information about structural performance
- Other damage states can be investigated
- Useful if the triggering event or the probability is unknown
- Different strategies can be investigated to identify highest conditional robustness



Implications for the COST C26 Project

- Yesterday and today we have seen many presentations which may be related to:

Exposure	Vulnerability	Robustness
Hardly anything	Almost everything	Very little

No presentation has addressed the modeling of consequences
- the specific complex interrelation of scenarios in dense urban habitats

Implications for the COST C26 Project

- All presentations have addressed either

  - structural members

  - joints/members

  - individual structures

  Classical perspective of present codes and standards!

- No presentation has addressed the main feature of urban habitats – complex interrelation of functionalities and building and lifelines!

Implications for the COST C26 Project

- Consistent decision making in regard to design and assessment of structures necessitates that

  - Exposures (hazards)

  - Vulnerability (member and joint performances)

  - Robustness (system performance)

  are brought into the context of risk (probability and consequences)

Implications for the COST C26 Project

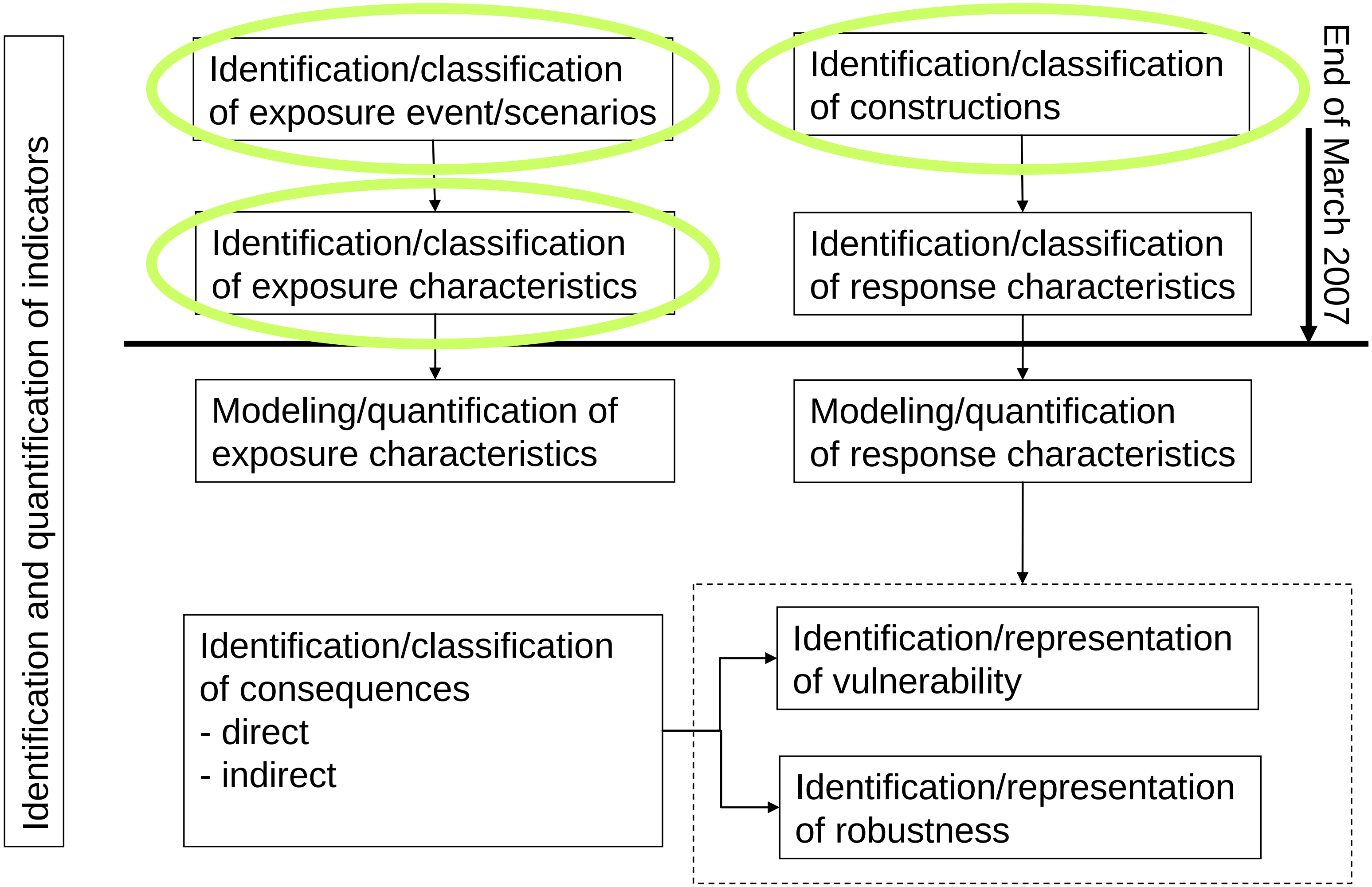
- In my perspective we need to establish:

  - Relevant events/scenarios of hazards (exposures)
  - Relevent events/scenarios of damages (vulnerability)
  - Models for consequences associated with damages (vulnerability) and collapses (robustness)

- For practical purposes we need to:

  - describe (indicators/metrics)
  - categorize (according to geography/building types, etc.)
  - model (member/joint/system analysis)

Implications for the COST C26 Project



Implications for the COST C26 Project

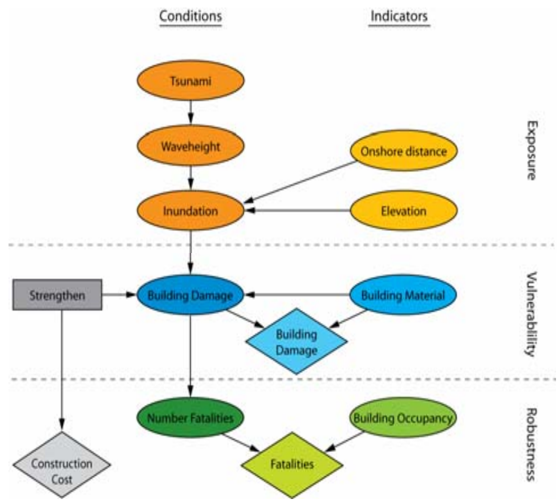
Where do we go from here ?

Suggestion:
For integration purposes – across the different WG's we suggest to define a „testbed" example case.

The present suggestion is to consider the Vesuvius eruption – and to pull this case through all aspects of the scope of C26.

WG4 will prepare a description of the „testbed" indicating where the different WG's may contribute untill the next meeting.

We should then reserve time at the next meeting to discuss the testbed in more detail.



Thanks for your attention ☺

ETH Swiss Federal Institute of Technology, Zurich