COST 601: Robustness of Structures

Working Group 3
Activity 6: Measures to Improve Robustness
Activity 7: Representation of Consequences
Activity 8: Case Studies

Presentation by M K Chryssanthopoulos, Coimbra, March 2009

Assessment of Robustness

- Event / Scenario Modelling
- Structural Vulnerability
- **Consequence Analysis**
- **Mitigation Measures**
- Decision-making

} **WG3**

WG3: Scope of Work

- State-of-practice guidance
  - Buildings
  - Bridges
  - Offshore
  - Tunnels
- Towards risk-based robustness
  - Consequence Modelling
  - Mitigation Measures
- Case studies

Consequence Modelling

- In relation to triggering event
  - Direct (confined to local damage)
  - Indirect (escalating due to progressive collapse)

- In relation to type/nature
  - Human fatalities / injuries
  - Structural loss
  - Environmental impact
  - Functional loss / Downtime
  - Loss of reputation

Consequence Modelling

- In relation to time frame
  - Short-term (during the event)
  - Long-term (for how many years?)

- In relation to system boundaries
  - Structural System
  - Network
  - Societal system (structure +network+…)

Consequence Modelling

- Methodology for direct consequences
  - Analysis of past failures
  - Engineering judgement
- Methodology for indirect consequences
  - Limited experience
  - Subjectivity / Perception
  - How large is the system?
  - How long is the time frame?

Collapse of I35-W

- Built in 1964 at a cost of ~$5.2m
- ADT 140,000, ~5,700 commercial vehicles
- About 330m of its span collapsed on 01/08/2007, all within few seconds
- At the time, undergoing repair work, including replacement of top 2'' of concrete deck
- Causes of collapse:
  - design error in gusset plate dimensions
  - weight increases due to modifications
  - distribution of traffic and concentrated construction load

Consequences

- 13 deaths, 145 injuries
- Closure of main road artery

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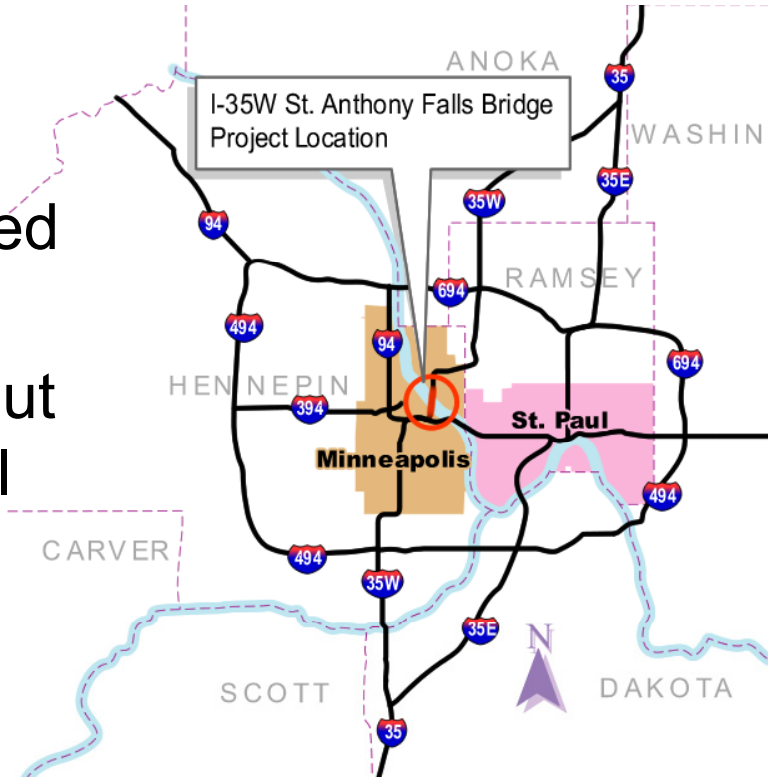
- Cost of replacement
- Cost of detours
- Loss to regional economy
- Environmental impact
- Impact on professional practice
- Effect on public confidence

Replacement project

- Completed 18/09/08, ~60 wks after collapse
- Two concrete bridges side-by-side
- *“New bridge provides superior durability which contributes to multiple levels of redundancy. Concrete has lower maintenance costs than other materials, which will add up over the bridge's expected lifespan of a century”*
- Cost of ~$234m

Regional impact

- Regional econometric model using MnDoT data on ADT and vehicle mix
- Both direct and indirect or ‘spin-off’ costs considered
- Detours $400,000 per day, estimated at ~$120m over 60 wks
- Reduction of state’s economic output estimated at 0.01% pa, ~$60m until replacement
- Job losses?
- Emissions?



Impact on professional practice

- Insufficient quality control procedures
  - new checks and verifications introduced in design
- Lack of guidance with regard to placement of construction loads during maintenance and repair
  - new guidelines to be drafted and followed
- Inadequate use of inspection technology for gussets in fracture critical bridges
  - revision of inspection manuals
- Additional assessment checks for all non-load-path-redundant steel truss bridges
  - more lengthy / complex assessments
- Cost over entire US network, say in next 10 years??

Public confidence

- Risk perception: need to re-assure public

  MnDot: *“structural integrity is paramount”*
- Acceleration of rehabilitation of ‘similar’ bridges
- Reduced priority for other measures:
  - Crash protection
  - Highway improvements
- Cost of upgrading US network estimated at $140bn – how much is expedited as a result of I35W collapse?
- Additionally, what is the cost incurred from NOT undertaking other measures?
- Cost over entire US network, say in next 10 years??

I35-W Summary

- Casualties: Deaths & Injuries
- Cost of replacement: ~$234m

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- Cost of detours: ~$120m
- Regional economic cost: ~$60m
- Cost from changes in professional practice, ??
- Cost from accelerated rehabilitation, ??
- Cost from not doing other things as a result, ??

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- In addition:
  - Increased environmental impact, emissions?
  - Job losses, permanent economic damage
  - Loss of reputation, cost of fearing the next accident…

Consequence Modelling

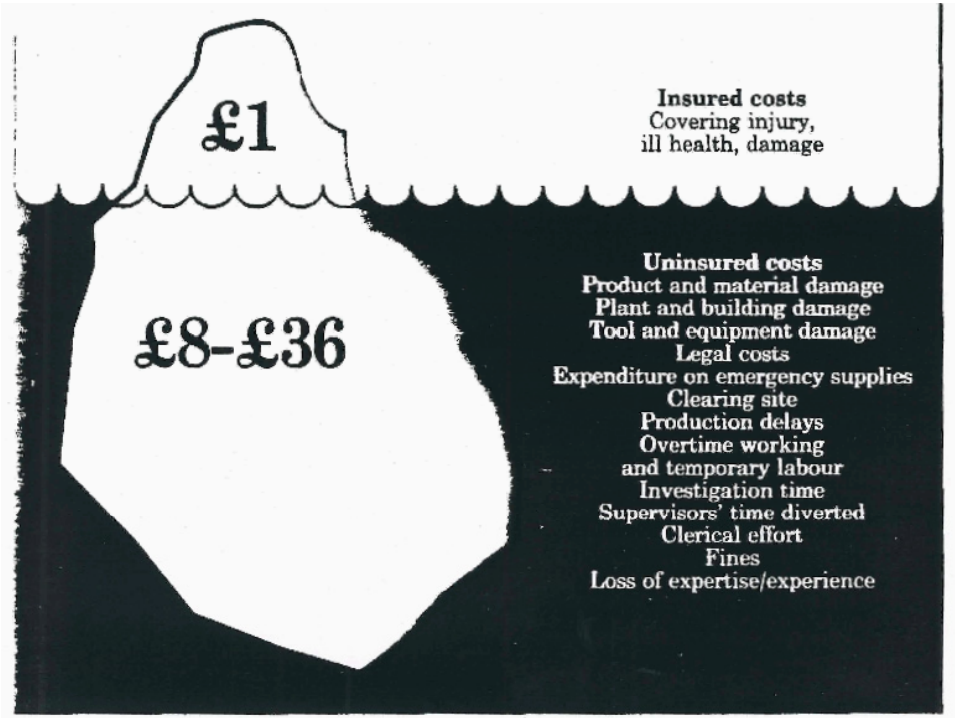


Figure 12 Accident iceberg - the hidden cost of accidents

HSE
Health & Safety
Executive

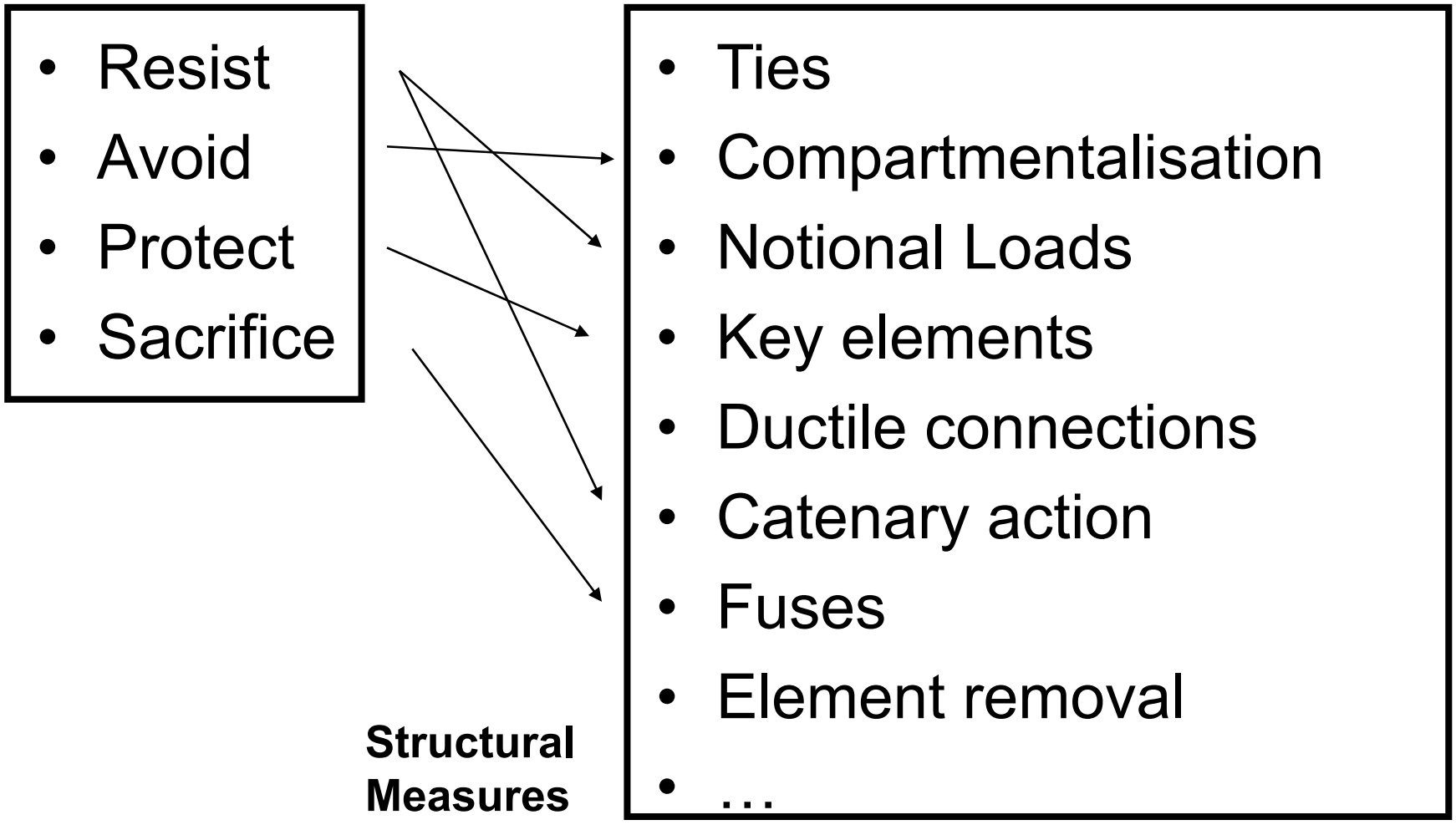
Iceberg concept

Magnitude of 'hidden losses' far exceeds the insured costs

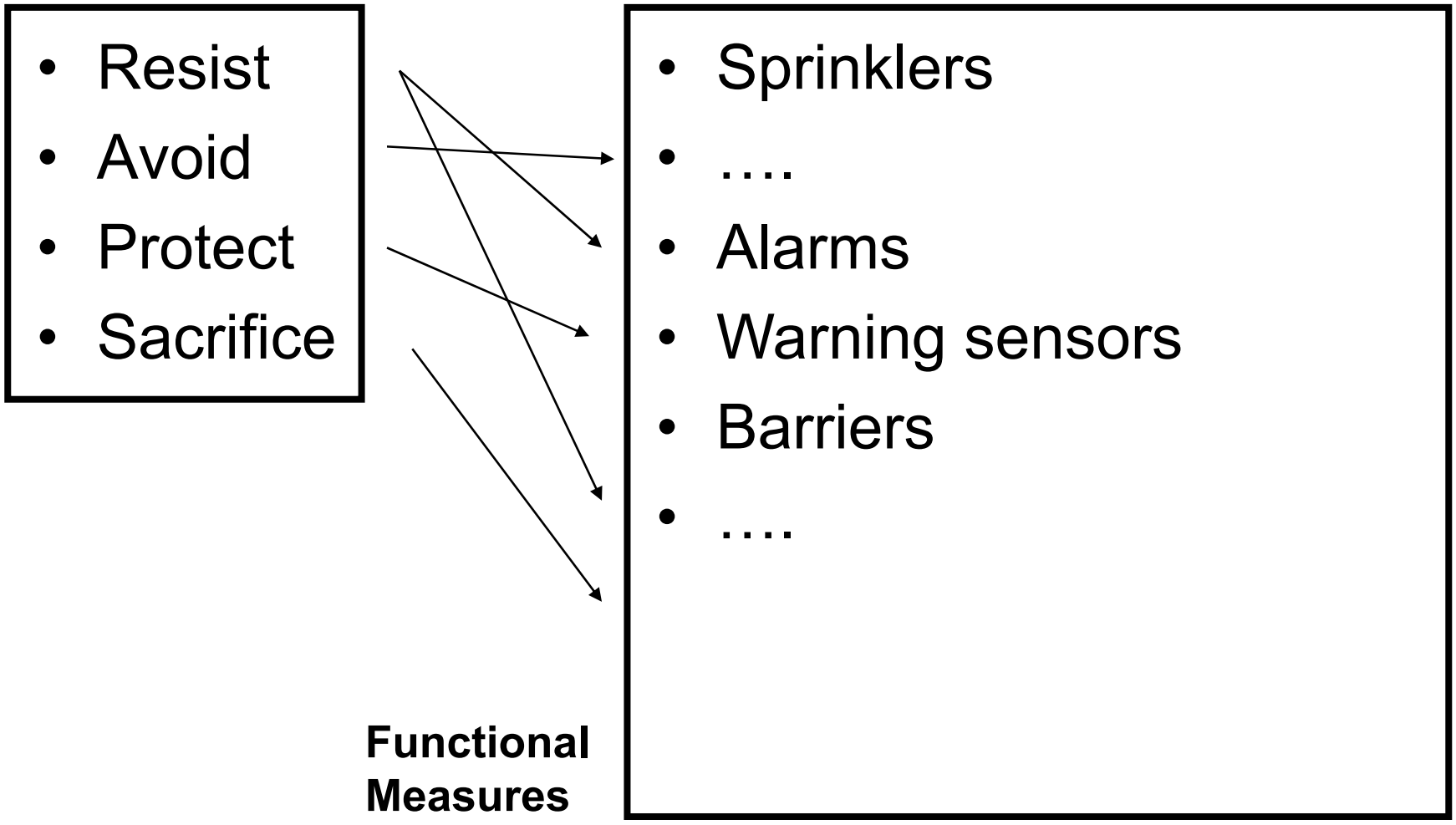
Consequence Modelling

- Change in societal trends:
  - Population growth, urbanisation
  - Network density / intensity / inter-dependency
  - Economic factors: supply chains, pace of development, …
  - Perception: risk-averse society
  - Insurance and litigation
- Change in exposure factors
  - Global warming
  - Population resilience

Measures to Improve Robustness



Measures to Improve Robustness



National Initiatives

- UK Institution of Structural Engineers: Practical Guide to Structural Robustness and Disproportionate Collapse in Buildings
  - Class 1 to 2B buildings
  - Principles and Definitions of Robustness
  - Prescriptive Measures for each main construction form/material
  - No coverage of Class 3 (>15 storeys or high importance): quantitative risk assessment
  - Expected completion 2009

WG3: Proposed Work

- Develop case studies and a position paper on consequence modelling for risk-based robustness assessment
- Review robustness requirements / criteria in existing codes, regulations and best-practice documents for different structural systems (buildings, bridges,…)
- Matrix of improvement / mitigation measures based on a generic classification (R-A-P-S)* and practical measures given in state-of-practice guidance documents

*** Resist-Avoid-Protect-Sacrifice**

WG3: Proposed Work

- Robustness requirements / criteria in codes, regulations and best-practice documents [Diamantidis, Casciati/Baratono, Chryssanthopoulos]
- Consequence modelling:
  - Analysis of damages/consequences in selected mid-rise buildings through EQ databases; identification and categorisation of positive and negative features; emphasis on public buildings [Inel, Agarwal]
  - Analysis of consequences from bridge failures [Imam, Neves, Chryssanthopoulos]
- Improvement of Robustness through monitoring and smart materials/devices [Casciati, Faravelli]
- Contribution to the benchmarking example defined by WG2 [?,?]
- Avoid duplication of effort – information exchange with C26