UNIVERSITY OF CAMBRIDGE

= FIF1 =

Future Infrastructure Forum

EPSRC
Engineering and Physical Sciences Research Council

EPSRC Network for Resilient & Sustainable Infrastructure

Structural & Geotechnical Engineering Research Cambridge University

Professor Campbell Middleton
Director - Laing O'Rourke Centre for Construction Engineering & Technology

26 - 27th September 2011

crm11@cam.ac.uk

Innovation and Knowledge Centre (IKC) for Smart Infrastructure and Construction

Construction Sector

EPSRC

Technology Strategy Board
Driving Innovation

LAING O'ROURKE · ARUP · SKANSKA · itm Instrumentation Testing & Monitoring Ltd · Sol Data

geothermal international · ATKINS · COSTAIN · WSP · PB 125 YEARS · Mott MacDonald

CAPITA SYMONDS · bre · Halcrow

Infrastructure Client Sector

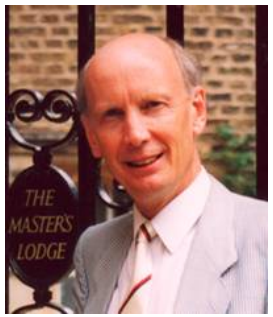
Thames Water · Transport for London · HIGHWAYS AGENCY · Tube Lines · UNDERGROUND

HUMBERBRIDGEBOARD · TRANSPORT SCOTLAND · TRL

Manufacturing, Electrical & Information Technology Sectors

RolaTube™ · IBM · RedBite · THALES · zühlke empowering ideas

TOSHIBA Leading Innovation >>> · GE Aviation · Omnisense · Senceive · Jennic TECHNOLOGY FOR A CHANGING WORLD · OpenHub digital architect digital developer



Robert Mair
Geotech. Engineering

Paul Heffernan
IfM

Kenichi Soga
Civil Engineering

Roberto Cipolla
Info. Engineering

Duncan McFarlane
Service Engineering

Ashwin Seshia
MEMS design

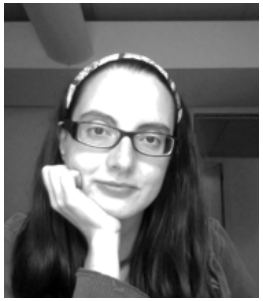
Campbell Middleton
Centre for Construction
Engineering &
Technology

Julian Allwood
Low Carbon and
Materials Processing

Marcial Echenique
Land Use and
Transport Studies

Yin Jin
Energy efficient cities

Jon Crowcroft
Networked Systems

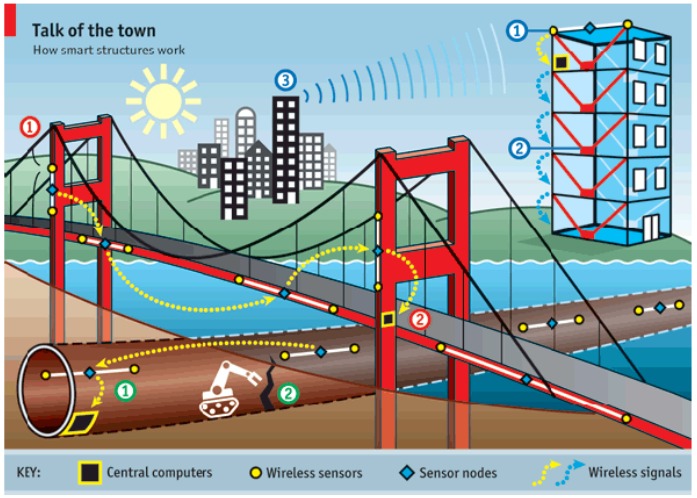


Cecilia Mascolo
Mobile systems

Stefan Scholtes
Management &
Building Services

The IKC Vision

- Smart infrastructure to transform industry
- Cradle-to-grave through whole life cycle
- Develop and commercialize emerging technologies
- Interdisciplinary
- Exploitation in very large market
- Dissemination & knowledge transfer



Laing O'Rourke Centre for Construction Engineering & Technology

- Partnership to promote innovation and change
- Advanced materials
- Smart infrastructure
- Manufacturing processes in construction

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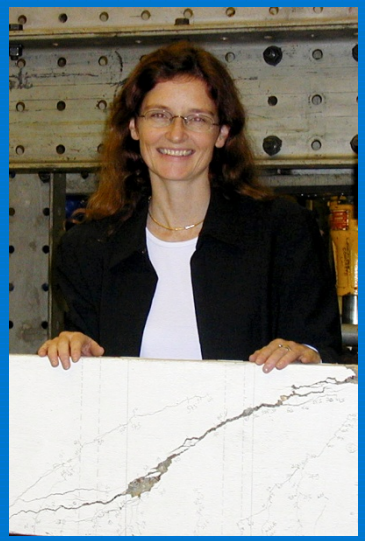
800 YEARS
1209–2009

Lifetime extension for existing and new construction



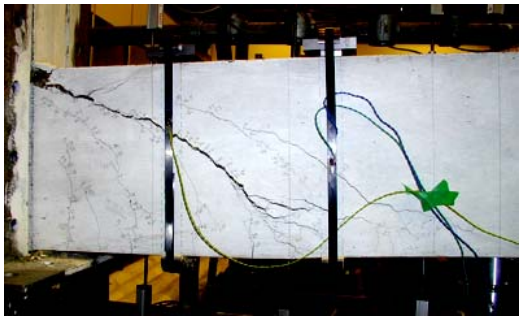
Dr Janet Lees - Structures Group

jml1010@cam.ac.uk

Cambridge University Engineering Department

Strengthening and repair

- External FRP reinforcement to strengthen RC
  - Flexure
  - Shear
    - Carbon FRP (CFRP) bonded sheets*
    - Unbonded CFRP prestressed strap system



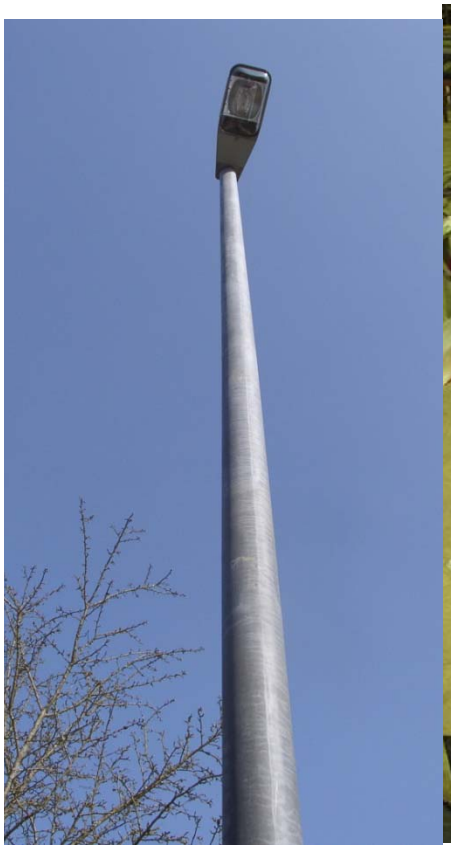
* EPSRC project with University of Bath in collaboration with:

ARUP CRL CONCRETE REPAIRS LIMITED CONCRETE SOCIETY HIGHWAYS AGENCY mouchel PARSONS BRINCKERHOFF Tony Gee

Durable structures for aggressive environments

- Concrete prestressed with internal carbon fibre reinforced polymer tendons

- Pole structures
  - durability of FRP tendons



EMPA
Materials Science & Technology

SACAC

Connected fundamental themes at material and structural level

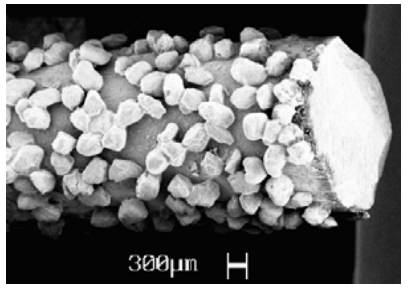
- Long-term material behaviour

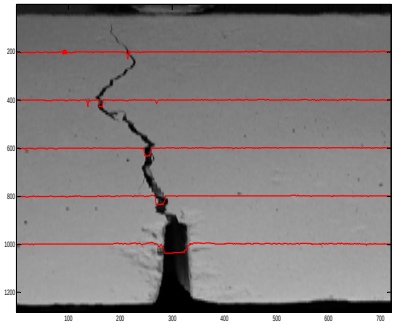
  concrete, FRP

- Fracture mechanics

  reinforcement bridging across cracks

  size effects





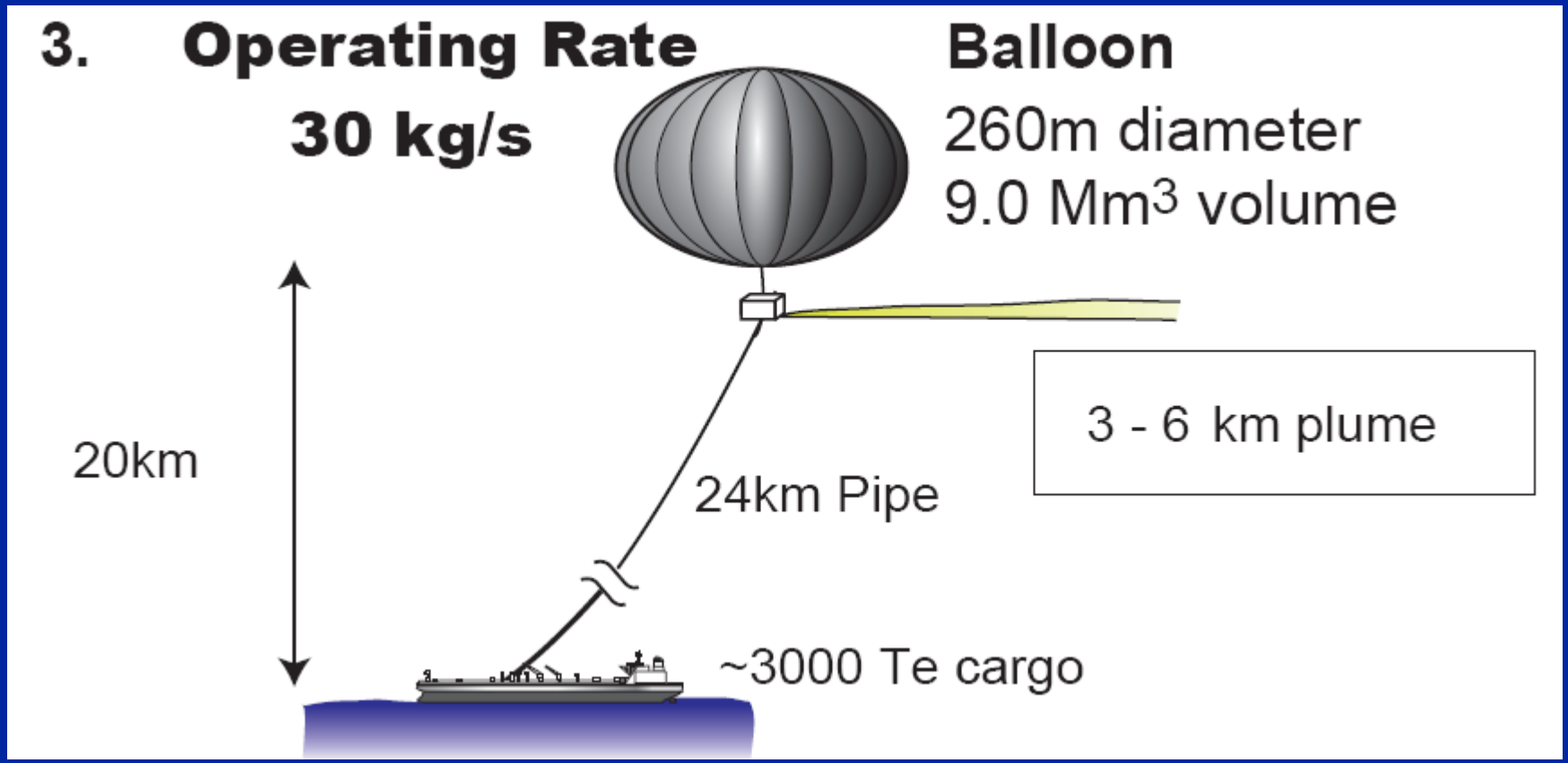
- Transport mechanisms of solution through concrete and fibre reinforced polymer materials

  permeability, diffusion

Research by Chris Burgoyne

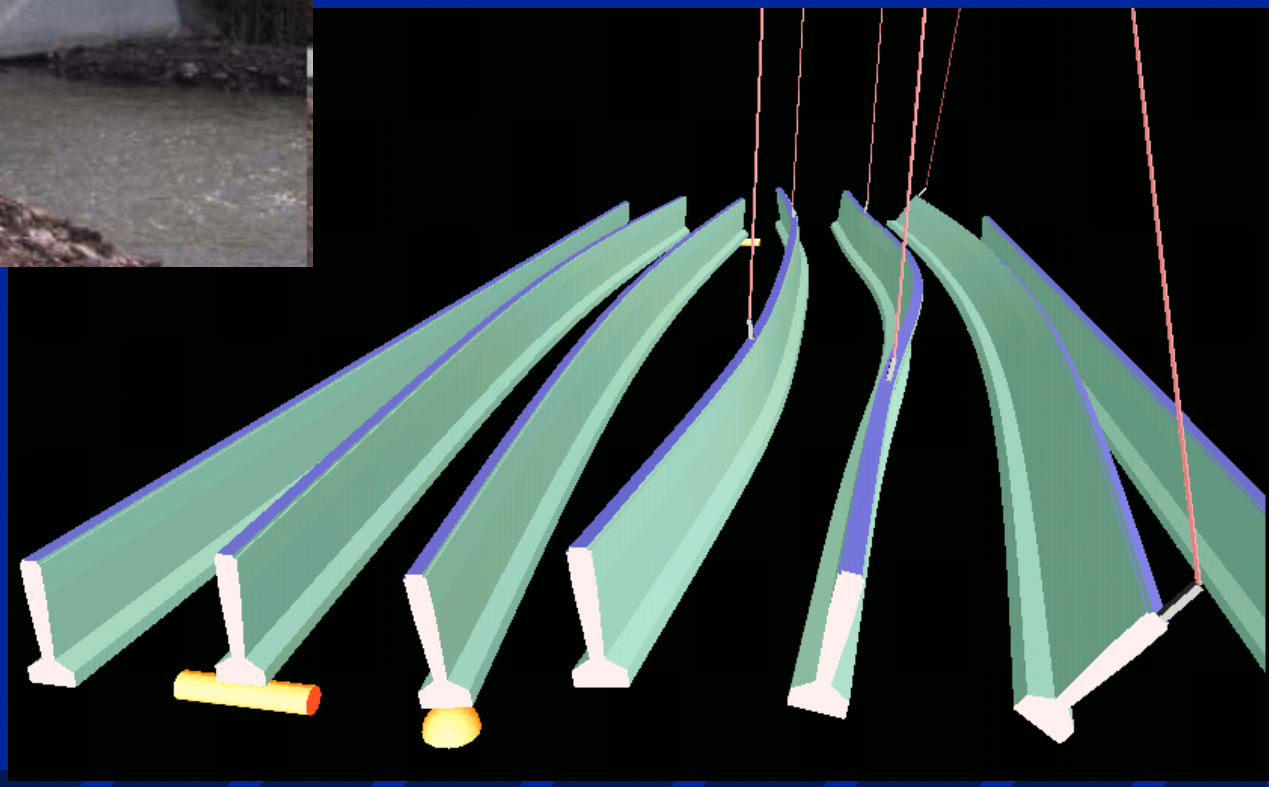
Relevant Research Themes

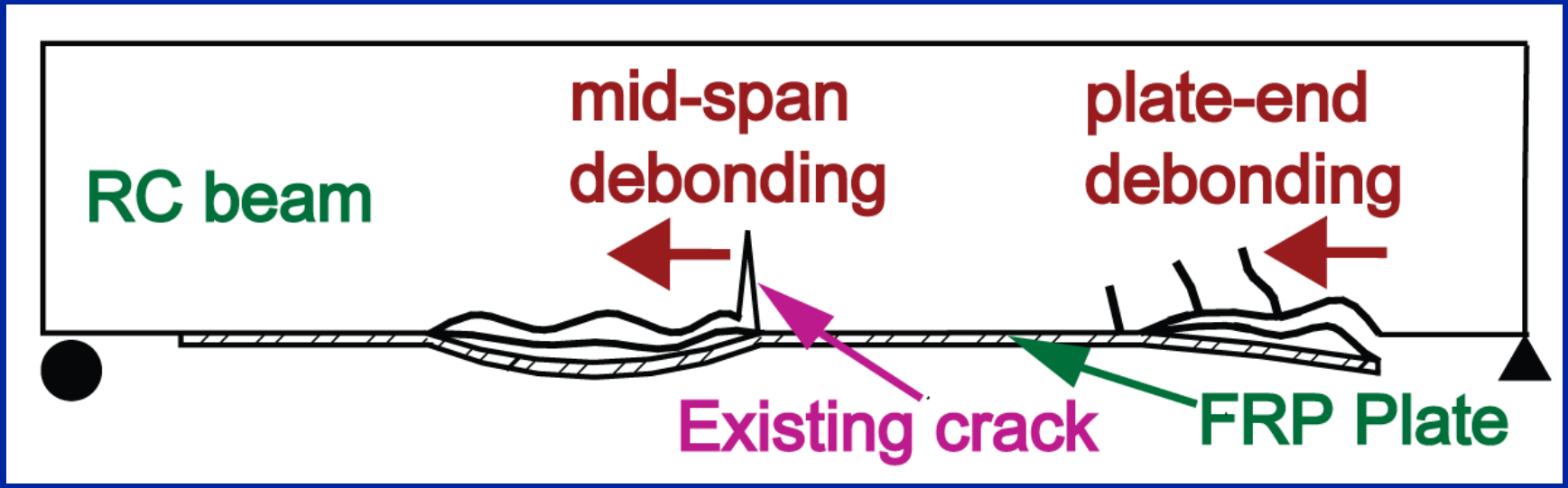
Geoengineering



SPICE project – aramid tether

Precast Beam Buckling





CFRP debonding

Behaviour governed by Fracture Mechanics, not by stresses

MRI of Concrete

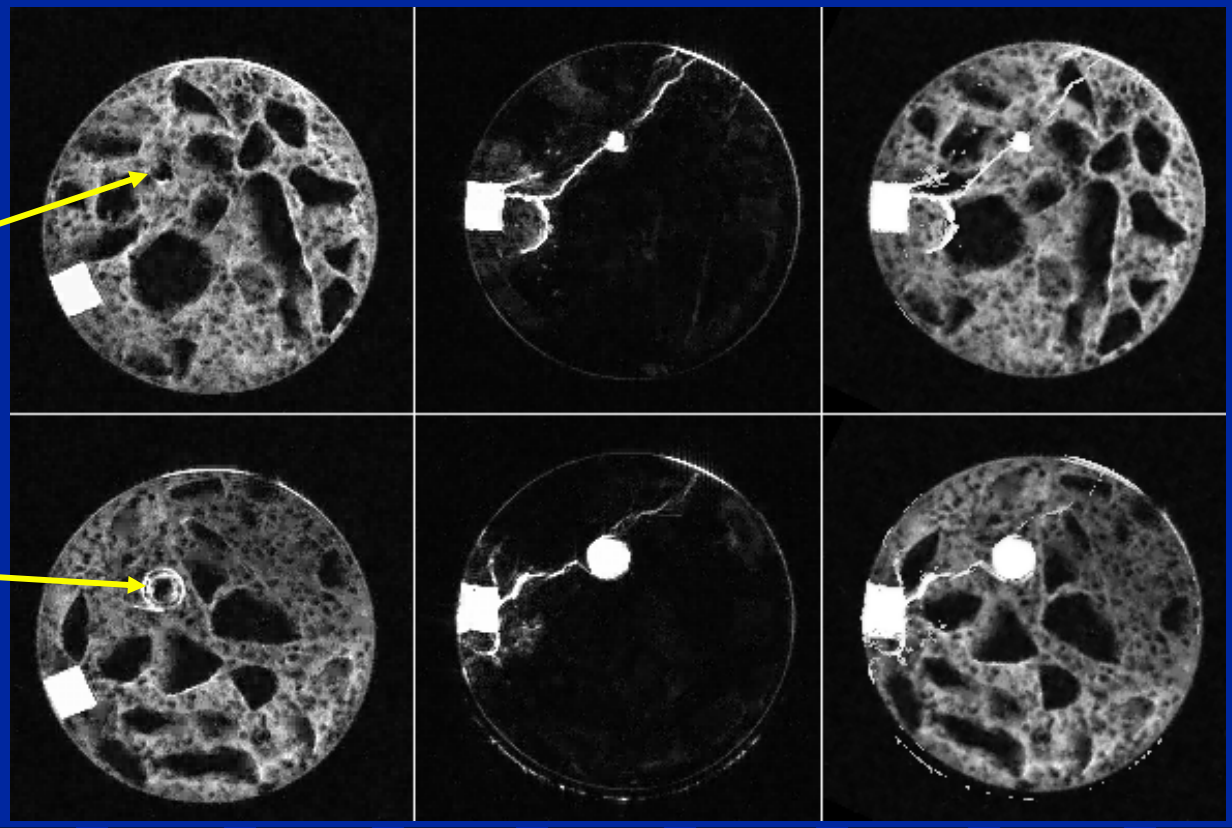
Allows internal structure *and* fractures to be observed

Specimen is not destroyed in the process

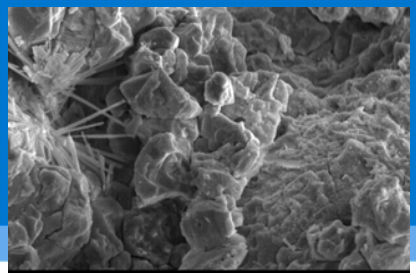
Structure Fracture Combined

AFRP bar

AFRP bar (debonded)

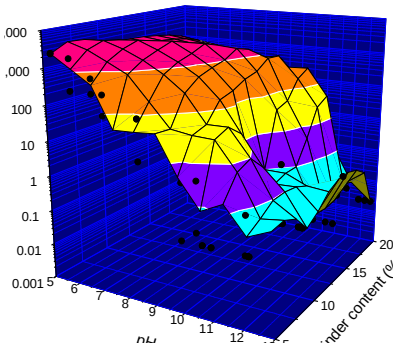


Materials for Resilient and Sustainable Infrastructure



Advanced and innovative structural and geotechnical materials with enhanced mechanical performance, durability, longevity, resilience in extreme and aggressive conditions, responsiveness to harsh environments and with reduced carbon footprint:

- Cements and blended materials
- By-products & waste reuse in cements & aggregates
- Waste as a resource and waste management
- Materials for carbon capture & storage applications
- Advanced grouts and soil amendments
- Damage tolerant and self-healing materials
- Biomimetic structural materials, nanomaterials
- Phase changing materials
- Sustainable production routes for materials



- Integrated design and construction systems
- Data management systems for design optimisation
- Close collaboration with industry
- International collaborations

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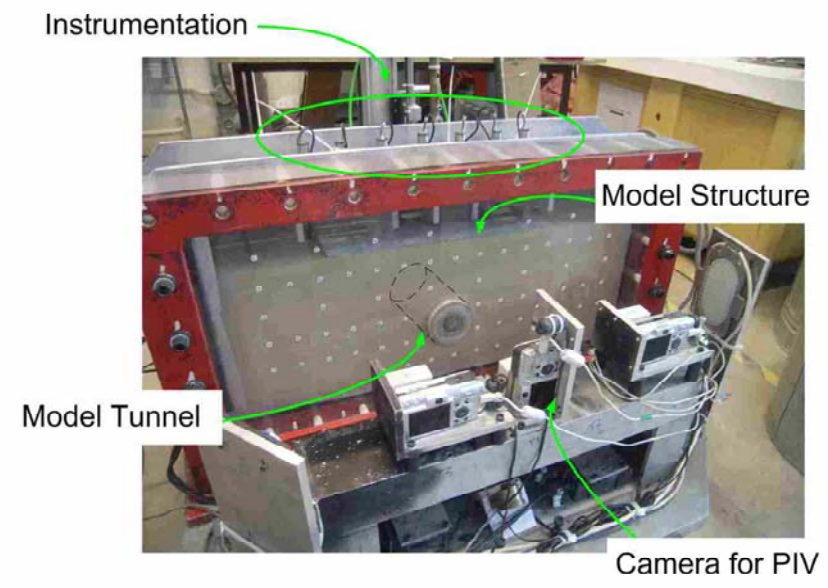
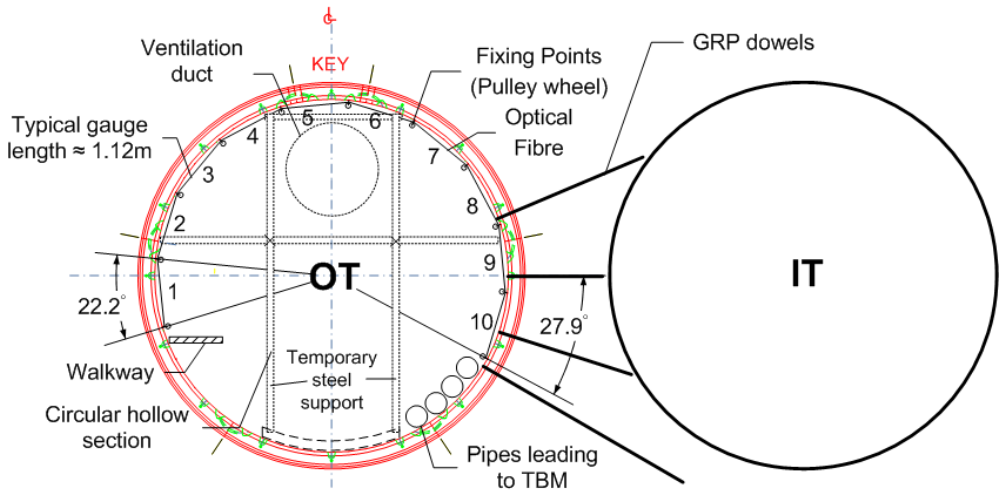
Dr Abir Al-Tabbaa
Geotechnical and Environmental Group

Professor Robert Mair

Underground Construction
Geotechnical Engineering
Smart Infrastructure and Construction

- Building response to tunnelling and deep excavations
- Effects of tunnelling on pipelines and piles
- Centrifuge modelling and field measurements
- Innovative sensor technologies for monitoring performance of infrastructure during construction and throughout design life





Kenichi Soga

Professor of Civil Engineering

- Infrastructure
  - Innovative sensing technologies (Computer vision, Distributed fibre optics, MEMS, WSN)
  - Monitoring of the performance of piles, pipes, tunnels, walls, embankments, cuttings, slopes, soil nails, etc
    - EPSRC Smart Foundation, Highways Agency, Industry
  - Assessment of ageing underground infrastructure
    - EPSRC Underground M3, EPSRC Smart Infrastructure, Industry
  - Whole life cycle analysis- Embodied energy and carbon of geotechnical infrastructure
    - ICASE studentships
  - Innovation and Knowledge Centre for Smart Infrastructure and Construction (EPSRC&TSB)

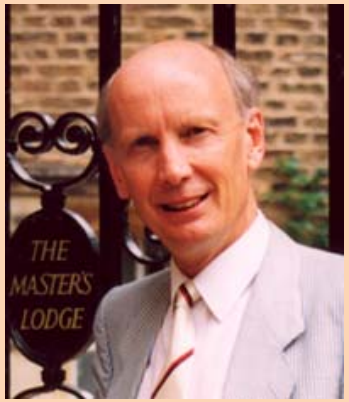
- Energy
  - Methane gas recovery from hydrates
    - deep sea and permafrost regions (Industry)
  - Geothermal
    - Deep geomechanics (Industry)
    - Ground source heat pumps (Industry)
    - Building scale to City scale (Industry)
  - Deep sea oil&gas recovery
    - Wellbore construction processes (Industry)
    - Submarine landslides (Industry)

- New Materials
  - Engineered geomaterials utilising microbially induced geochemical processes

Optical Fibre Instrumentation in Construction

Mohammed Elshafie

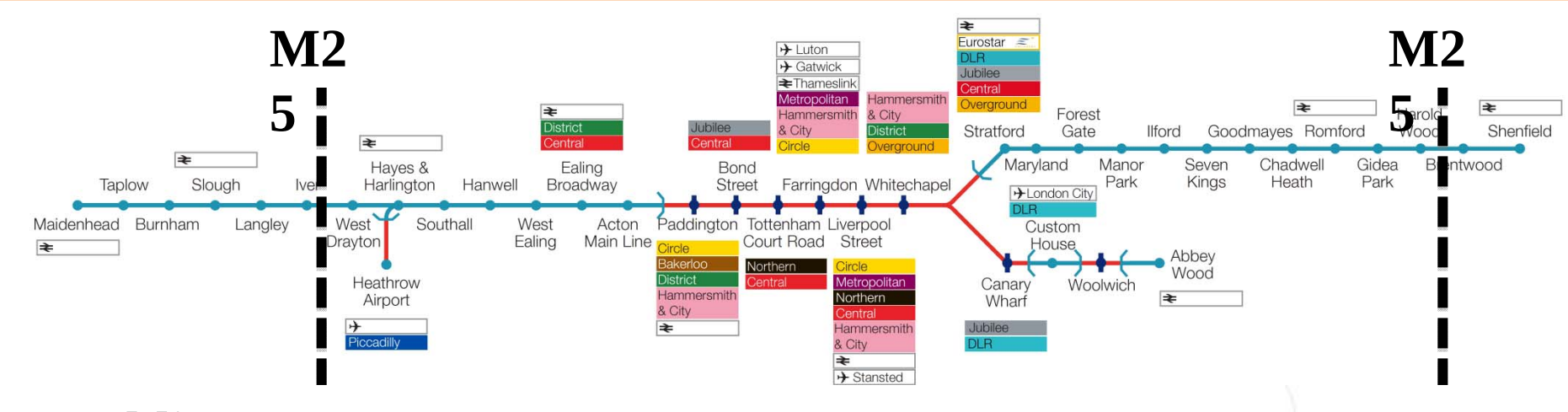
Kenichi Soga



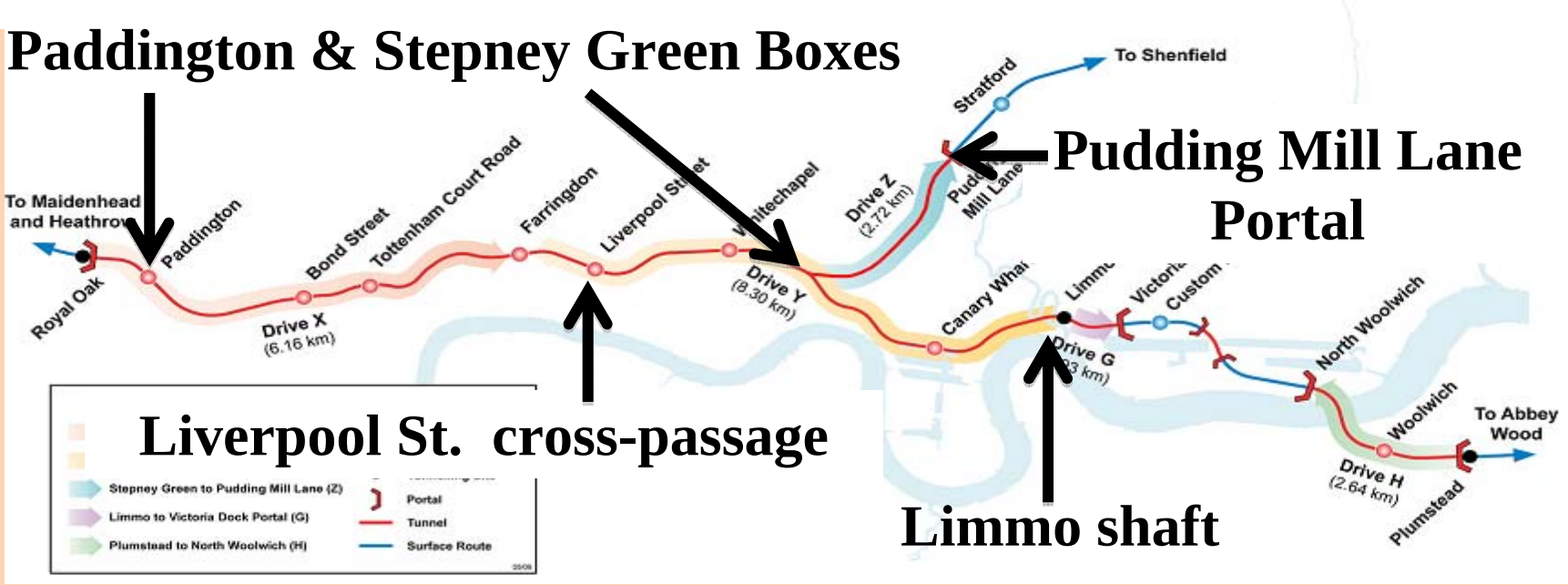
Robert Mair

Current Projects

Crossrail



Paddington & Stepney Green Boxes

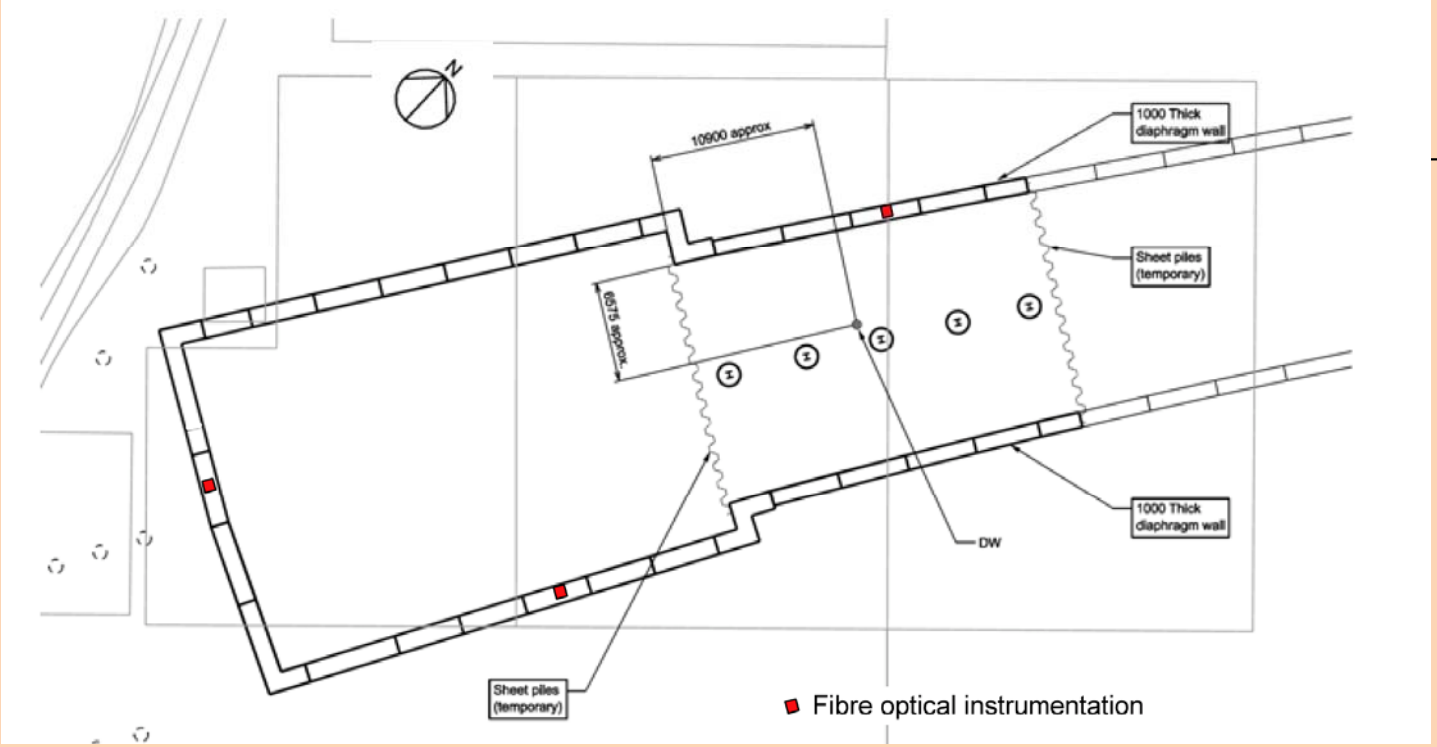


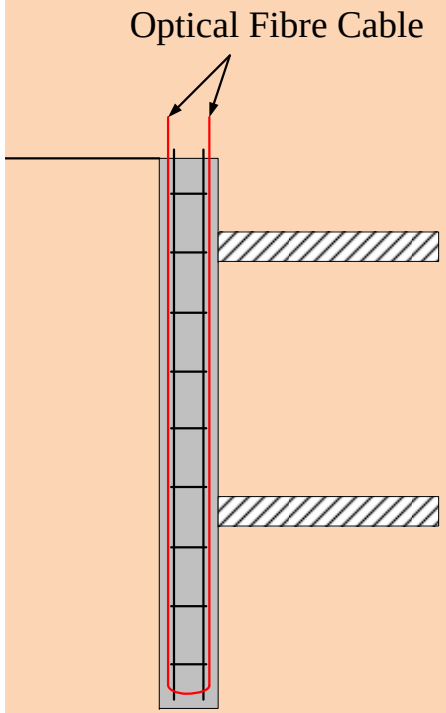
Pudding Mill Lane Portal

Liverpool St. cross-passage

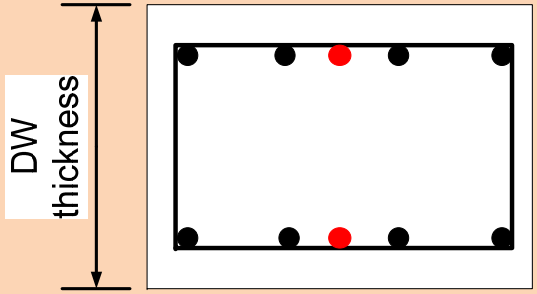
Limmo shaft

Pudding Mill Lane Portal

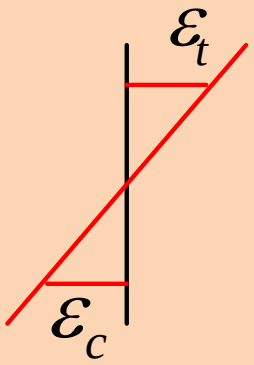




Retained Side



Excavation Side



Strain Diagram

➡ **Stresses**

➡ **Deflections**

Distributed Information & Automation Lab Themes

Professor Duncan McFarlane

AUTOMATION

- Distributed, Intelligent Systems
- Multi agent control
- Reconfigurable Systems
- RFID/ Auto ID Systems

INFORMATION THEMES

- Value of Information
- Sensing Strategy
- Track and Trace
- Service Information
- Asset Management

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IfM

Other research

- Facades – Mauro Overend
- Design processes – EDC – John Clarkson
- Masonry structures – Matt DeJong
- Energy efficient cities – Ruchi Chaudry
- Materials optimisation & low carbon construction – Julian Allwood
- Design flexibility – Stefan Scholtes (Judge Business School)
- Sustainability – Peter Guthrie / Dick Fenner / Heather Cruikshank
- Cambridge Nuclear Energy Centre – CUED /JBS et al. Bill Nuttall

Innovative solutions for bridge infrastructure

Campbell Middleton – Laing O'Rourke Professor of Construction Engineering

1. Advanced Structural Analysis
2. 'Smart' Infrastructure
3. VIM - Virtual Information Modelling
4. Sustainability
5. Risk & reliability
6. Asset management – data, procurement, policy

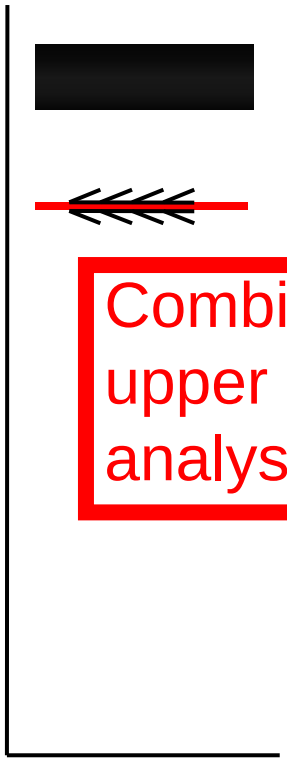
The prediction of RC slab capacity

Andrew Jackson

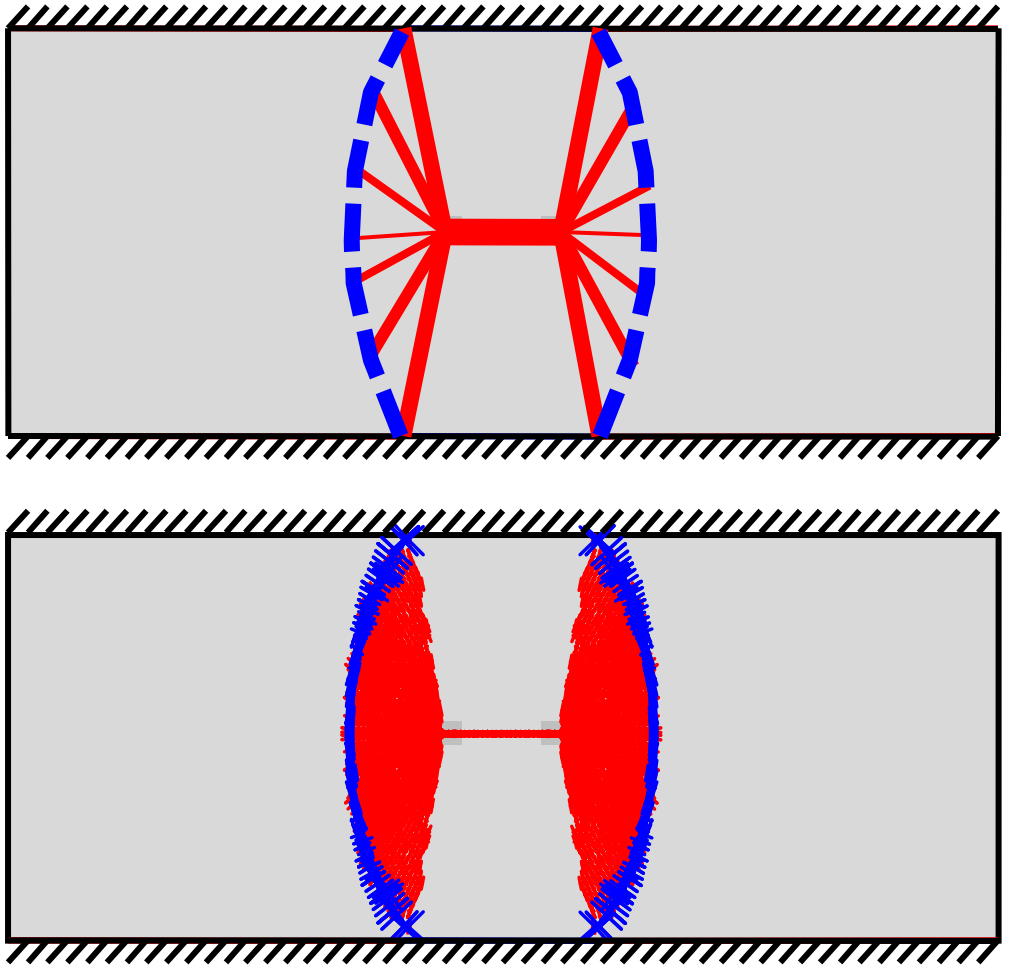
PhD researcher

Independent Lower and Upper Bound Plastic Analysis

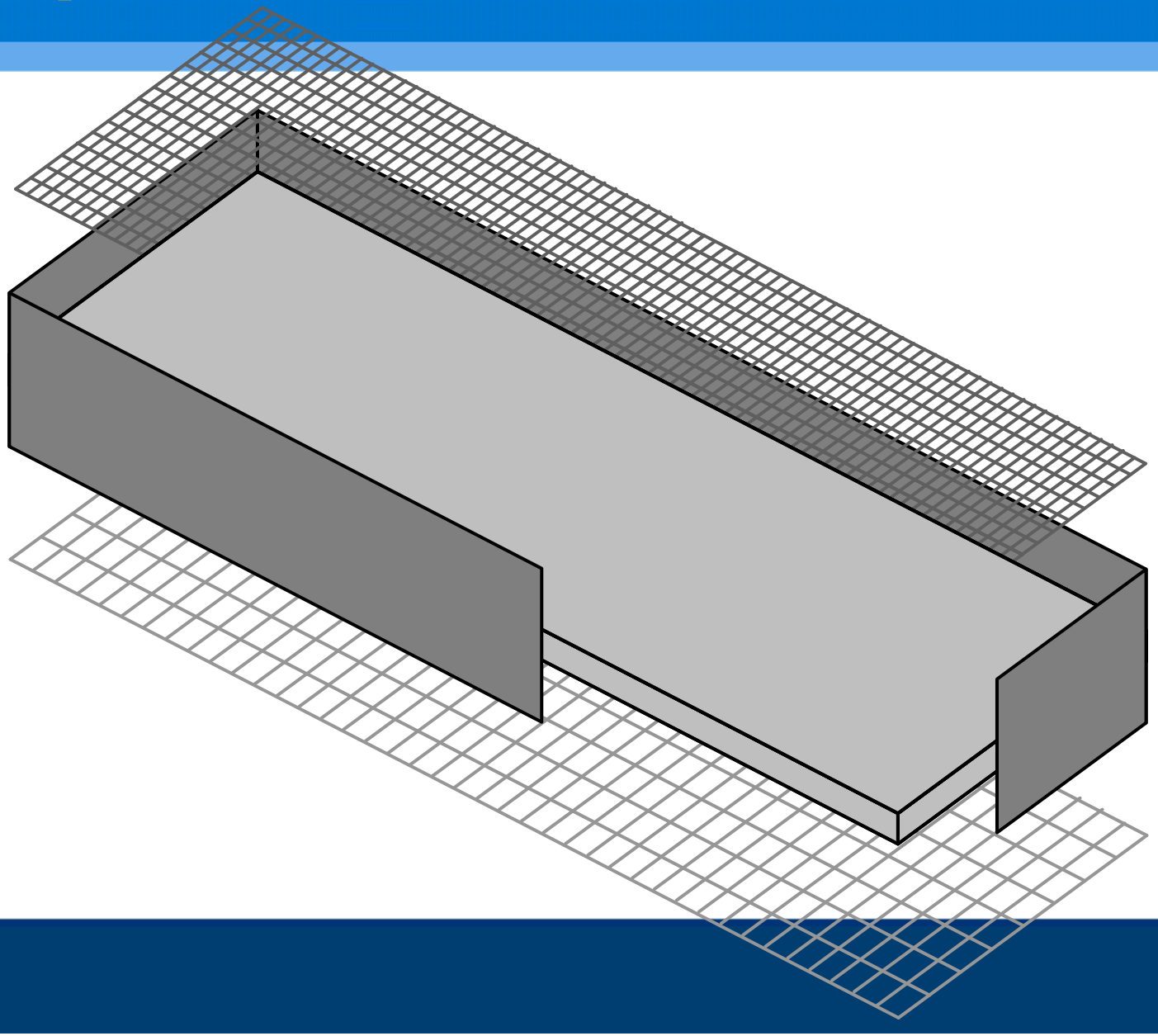
Collapse load



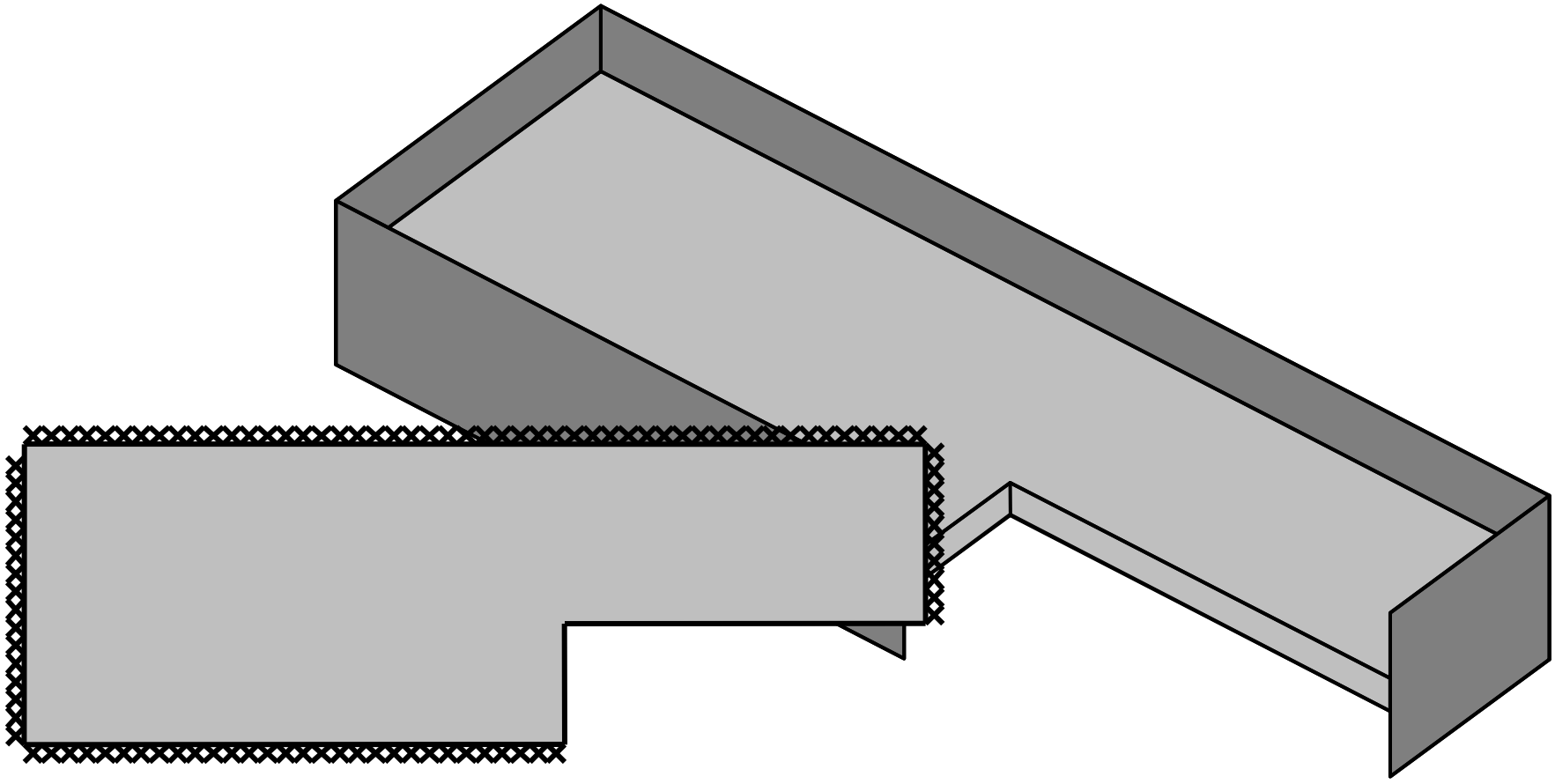
Combined lower and upper bound plastic analysis



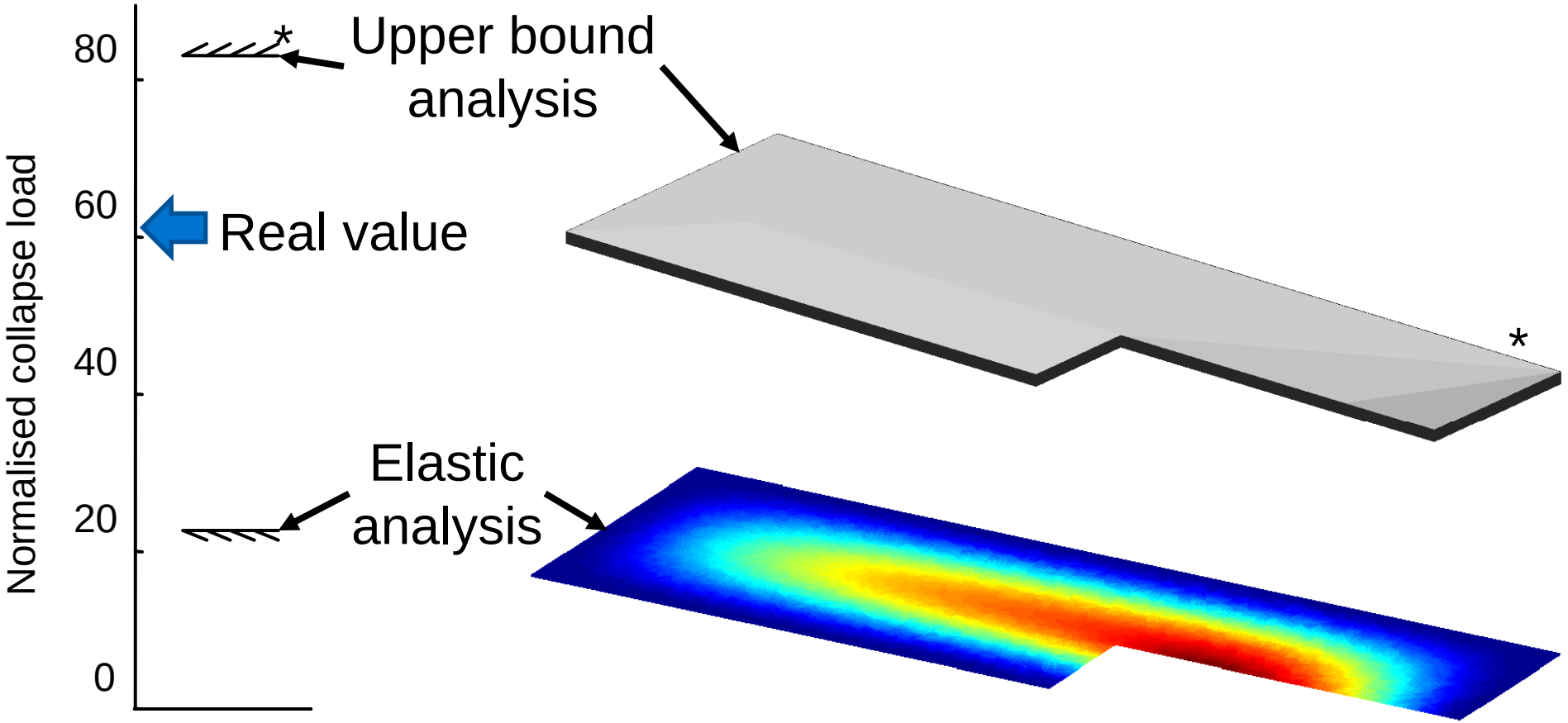
An example slab



An example slab

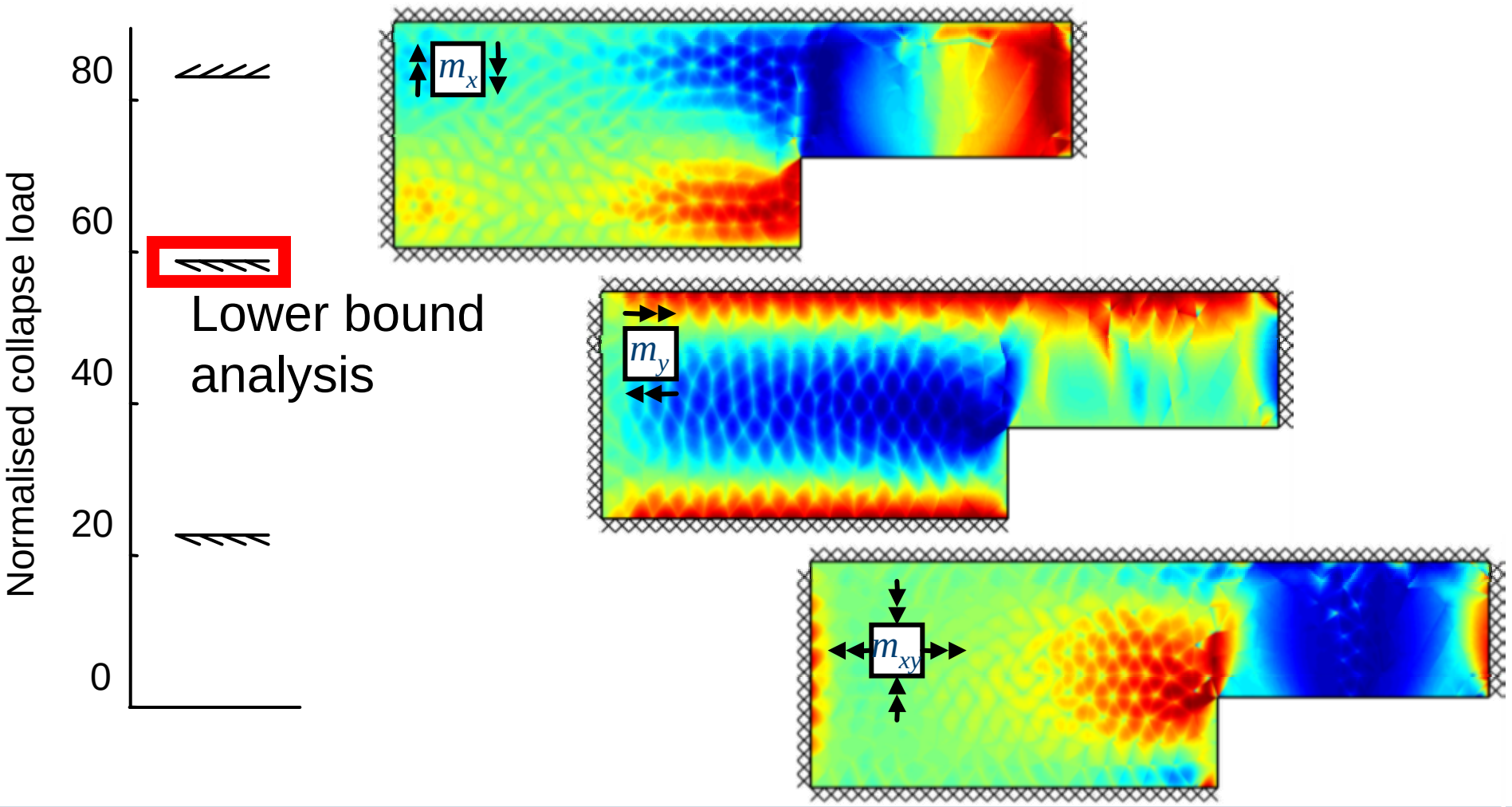


An example: existing methods



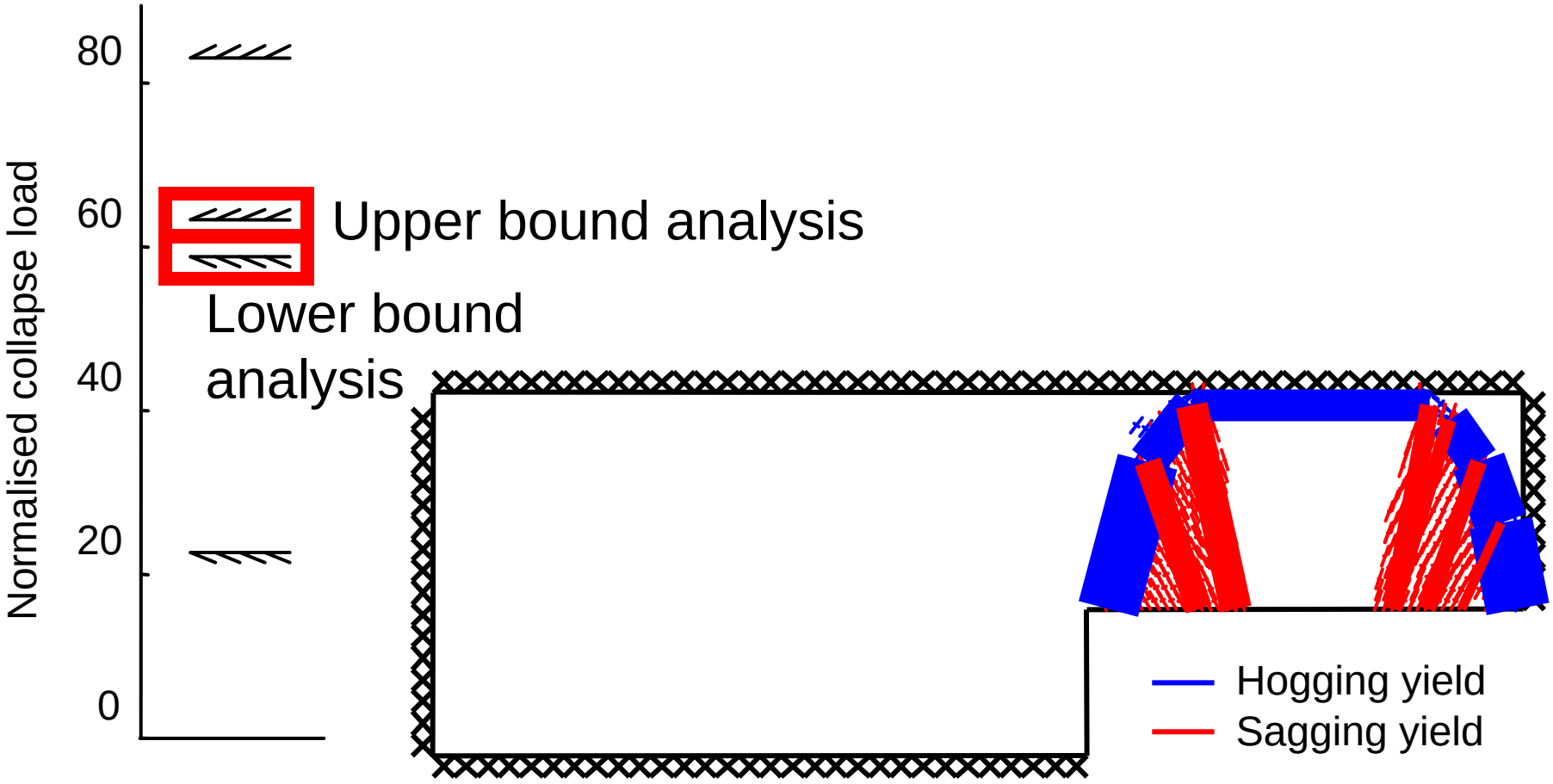
* S. Islam and R. Park, *Yield-line Analysis of Two Way Reinforced Concrete Slabs with Openings*, 1971

An example: lower bound

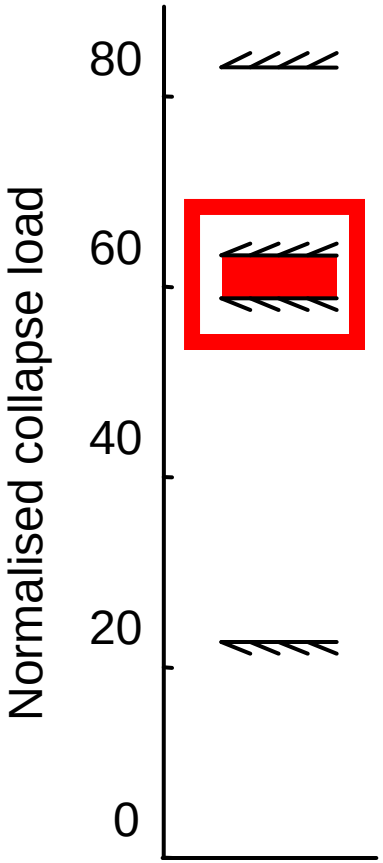


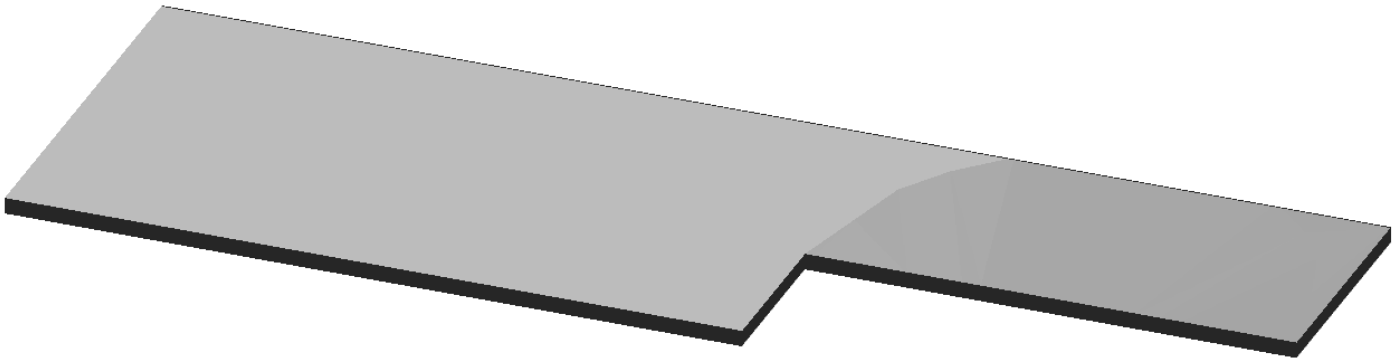
Initial method: K. Krabbenhoft and L. Damkilde, *Lower bound limit analysis of slabs with nonlinear yield criteria*, 2002

An example: lower bound



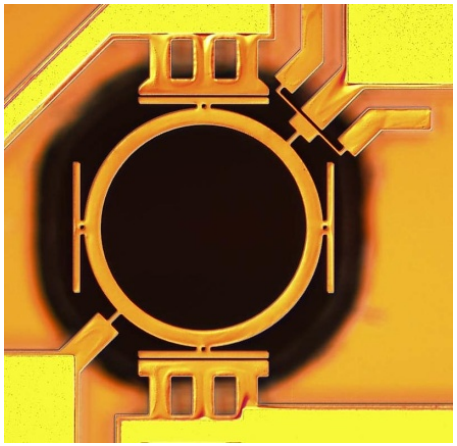
An example: yield line



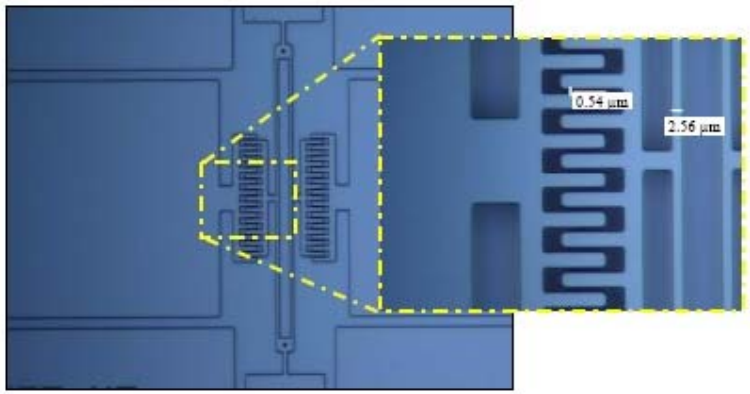


	Lower bound	Upper bound
Safe	✓	
Economical		✓
General	✓	
Checkable		✓

2. ‘Smart’ Infrastructure



MEM Sensors and Power Harvesters



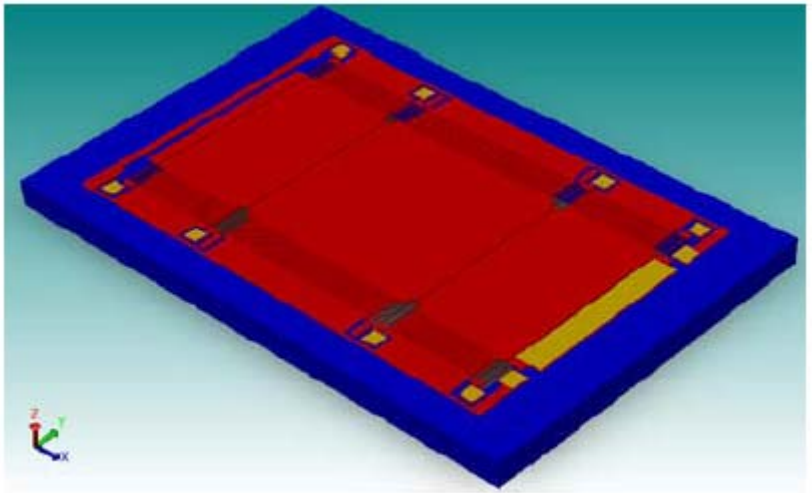


Figure 1. Illustration of the power harvester

Wireless sensor networks

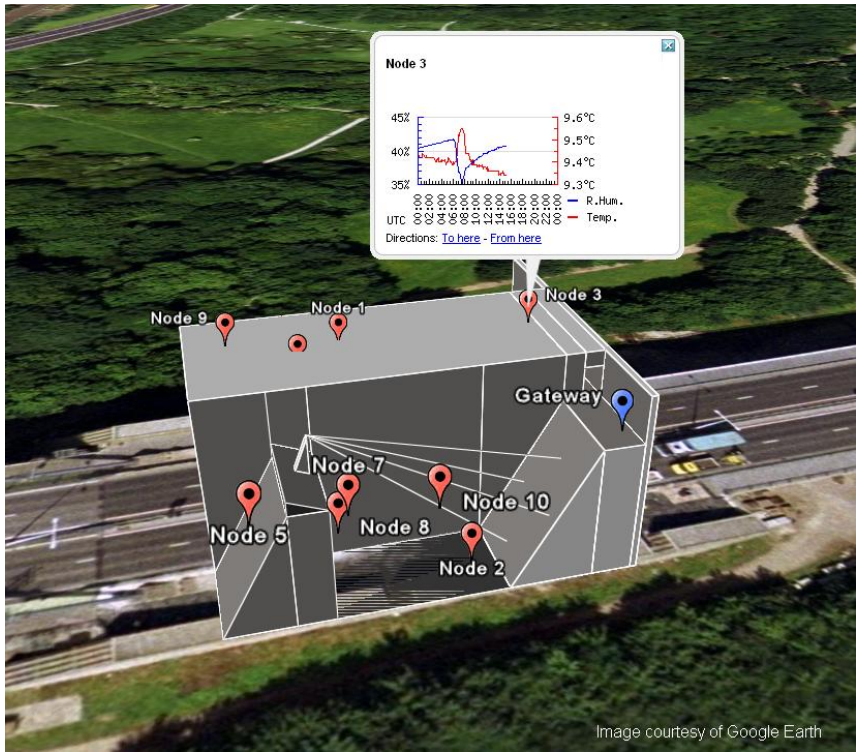
Smart Humber

Welcome to the Humber Bridge Structural Health Monitoring page. This page has been developed as part of an EPSRC funded collaboration between the University of Cambridge and Imperial College London as well as critical infrastructure partners including the Humber Bridge Board.

Available health monitoring systems:

- Hessle Anchorage environmental monitoring
- Ferriby Road Bridge support bearings (to be installed)

Humber Bridge Anchorage



Ferriby Road Bridge

Hammersmith flyover & station

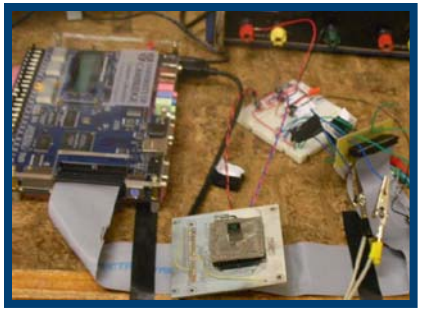
Hammersmith Flyover

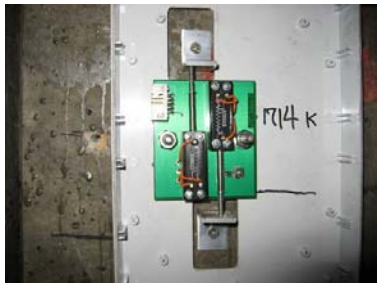
Movement?

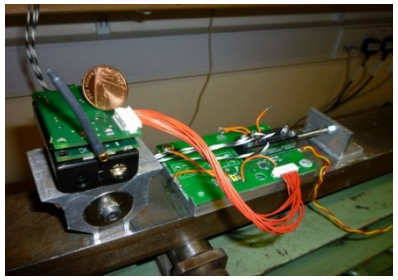
Bearing

Fibre optic sensors for strain
Deployment : Addenbrookes Bridge - Cambridge

Innovation: Sensors, Networks, Interpretation







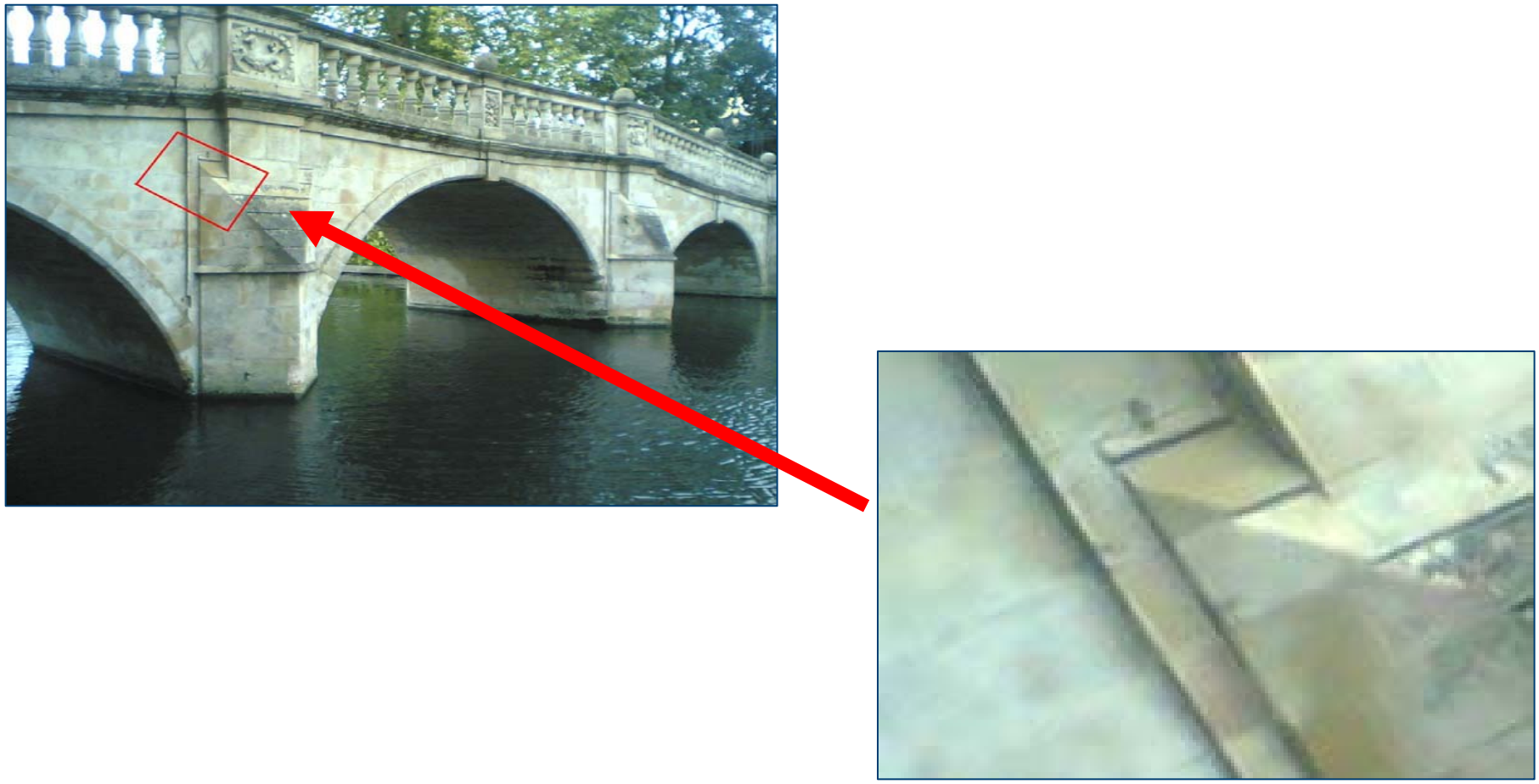
- Cracks
- Displacements
- Strain
- General surveillance
- MEMS strain gauges
- Acoustic Emission
- Fatigue
- Live load

3. VIM – Virtual Information Modelling

Computer vision for modelling infrastructure

Roberto Cipolla

Visual inspection database

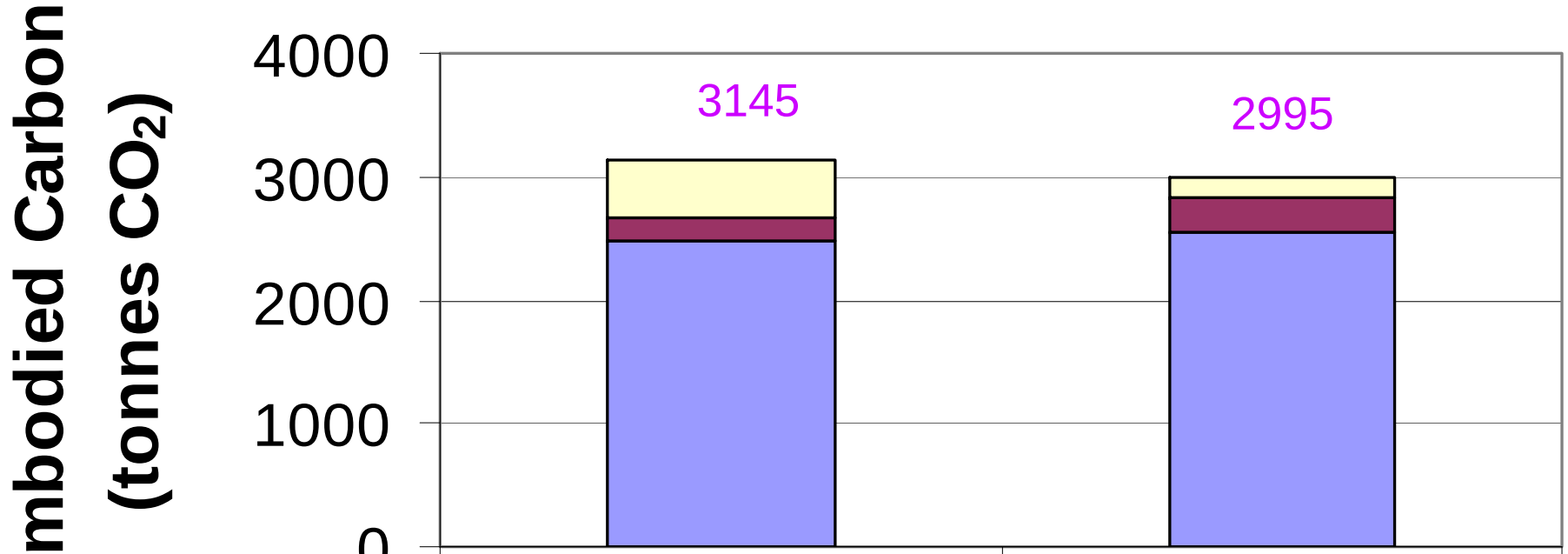


4. Sustainability - Carbon & Energy Footprints

Nine Wells Road Bridge, Cambridge

GE19 Rail Bridge, London

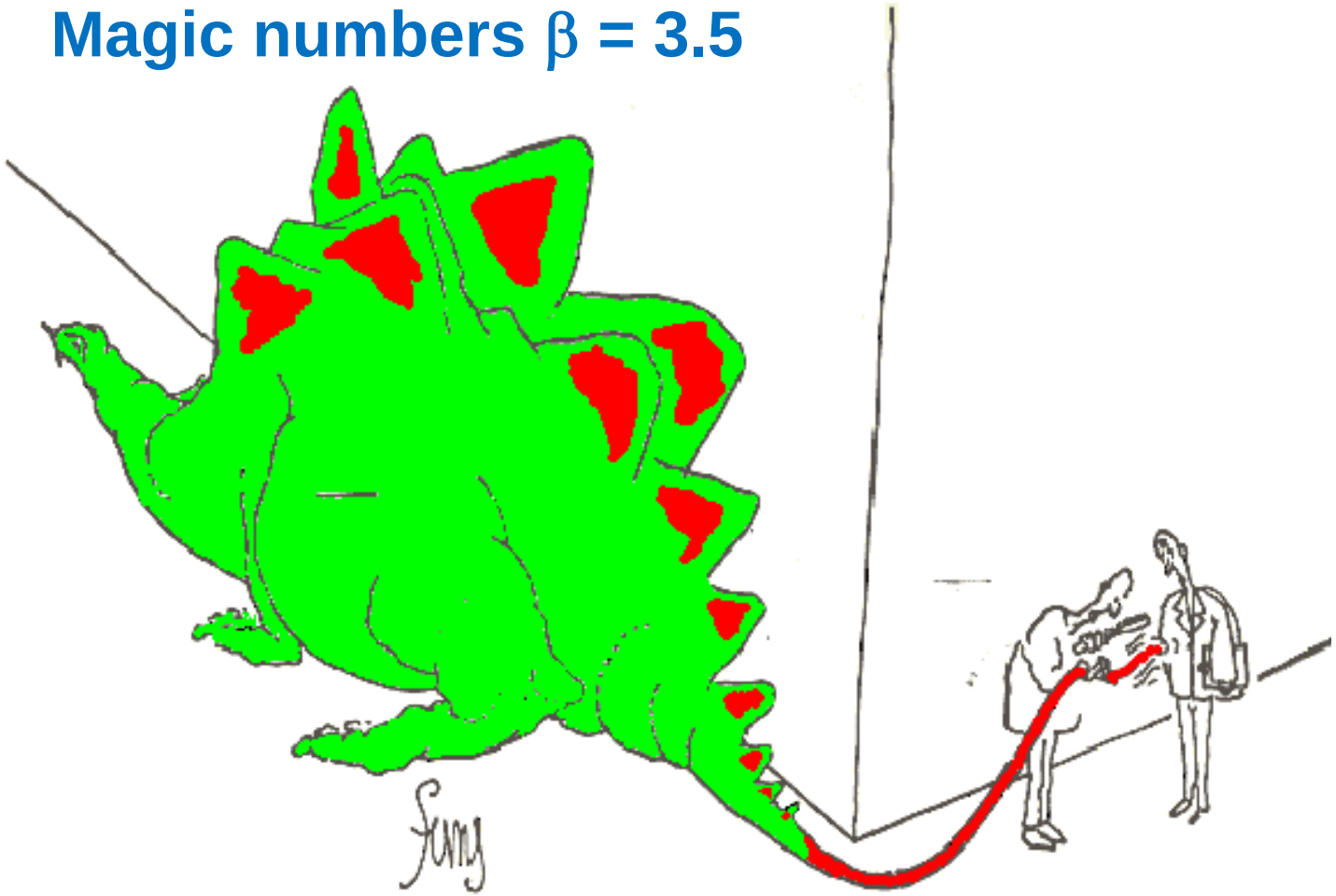
Carbon Footprint Results



	Nine Wells - Concrete	GE19 - Steel
Maintenance	469	157
Transport	201	286
Materials	2475	2552

5. Risk & reliability

Magic numbers $\beta = 3.5$



6. Asset management – data, procurement, policy

(with Judge Business School – Bill Nuttall / Stefan Scholtes)