Resilient and Sustainable Infrastructure

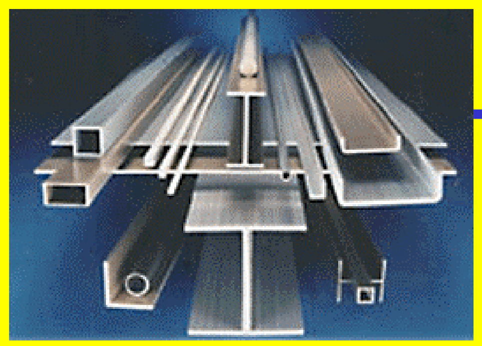
School of Engineering
University of Warwick

Theodore L. Karavasilis
Assistant Professor of Structural Engineering

Outline

- Professor Toby Mottram (FRPs in Structural Engineering, Thin Walled Structures)
- Dr Stana Zivanovich (Vibration Serviceability, Structural Dynamics)
- Dr Tak-Ming Chan (Stability of Metallic Structures, Composite Steel Structures and Connections)
- Dr. Theodore Karavasilis (Resilient Damage-Free Steel Structures, Self-centering Connections, Passive and Semi-active Dampers, Performance-based design)
- Dr. Stefano Utili (Geotechnical Engineering, Numerical methods, DEM, Slope Stability, Flood Defence)

Principal Structural Engineering Research Interest

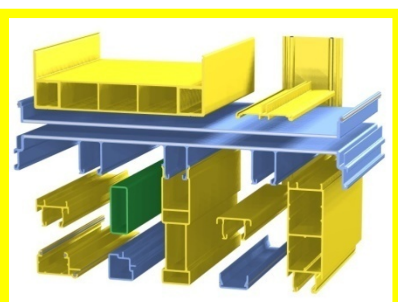


Standard shapes and bolted connections

Standard for Load Resistance Factor Design (LRFD) of Pultruded Fiber-Reinforced Polymer (FRP) Structures

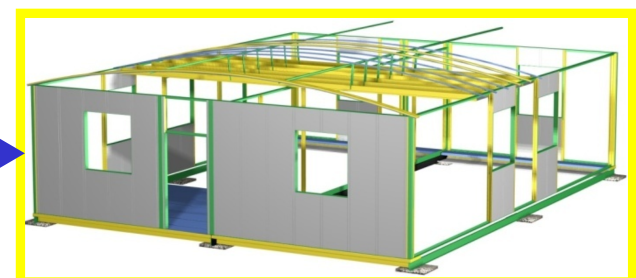
Research Methodology: Combination of full-sized physical testing and analytical and computational (FEA) analysis

Deliverables and Impact: Information for the preparation of safety critical design ‘rules’ and provisions in standards and or codes of practice



Family of ‘Startlink’ shapes

TSB Project for a Code level 6 house



WARWICK

J. T. Mottram 2011

Professor Toby Mottram, DSc, CEng, FIStructE

Warwick University, 1987-:

- **Materials and structures teaching**
  - Steel Structures
  - Forensic Engineering
- **Civil Research Group**
  - newer construction materials
  - structural analysis

Institution of Structural Engineers, member 1994-:

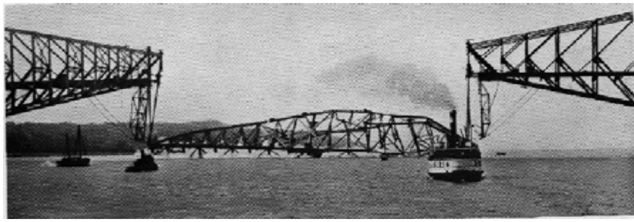
- Branch Committee,1995 –
- Journal Editorial Board 2006 –

Eurocodes, 2011-: CEN/TC 250 WG 4 FRP Eurocode

LIMESNET, 2011-12: Member in ESPRC Network for *Low Impact Materials and innovative Engineering Solutions for the built environment*

NGCC: Convening steering group preparing publication for *Guidance for the Design of FRP Bridges*

EPSRC 2010-2014: Connections and Joints for Buildings and Bridges of Fibre Reinforced Polymer



2nd Quebec bridge, 1916

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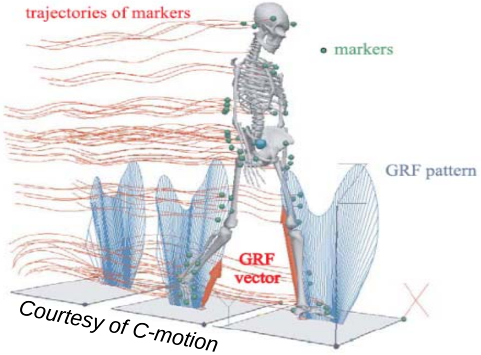
Sustainability and vibration serviceability

Aims:
-To design "vibration-free" structures
-To enhance human well being in built environment
-To achieve non-conservative material saving designs

If to translate this to structures dynamically excited and occupied by people, we have to know more about…

Dynamics of light slender structures

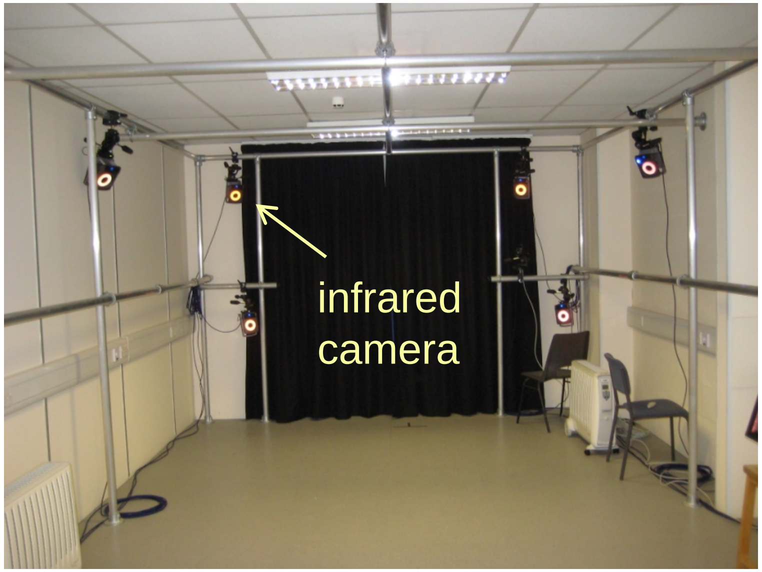
Dynamics of humans



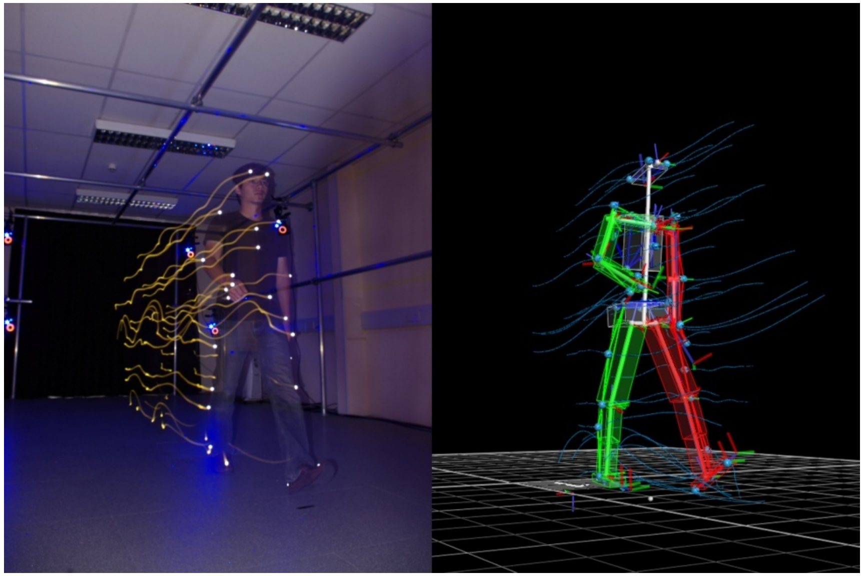
Human interaction with and perception of structures

Learning about kinematics and kinetics of human actions

Gait Lab facility



Tracking and modelling human body



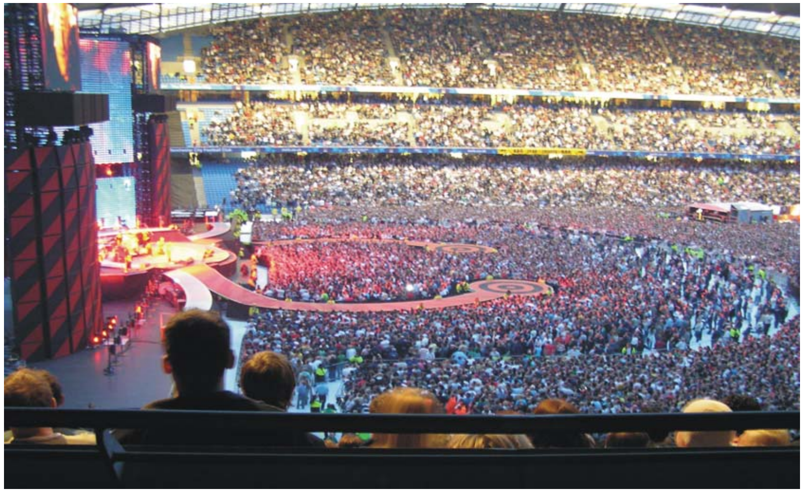
Human body has capacity to both attenuate and amplify structural vibrations.

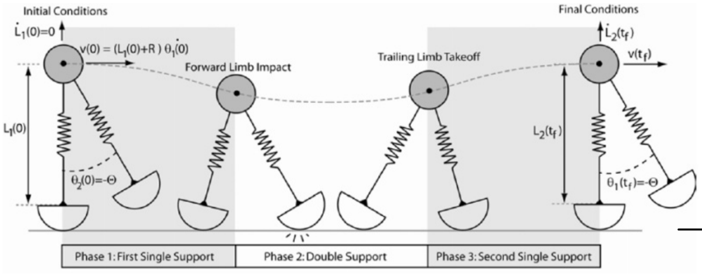
Understanding conditions leading to the two situations on as-built structures will lead to better controlled and high-quality infrastructure.

Modelling human-structure dynamic system

Traffic on footbridges

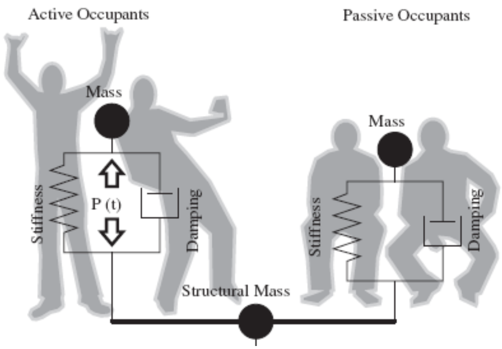
Spectators on grandstands



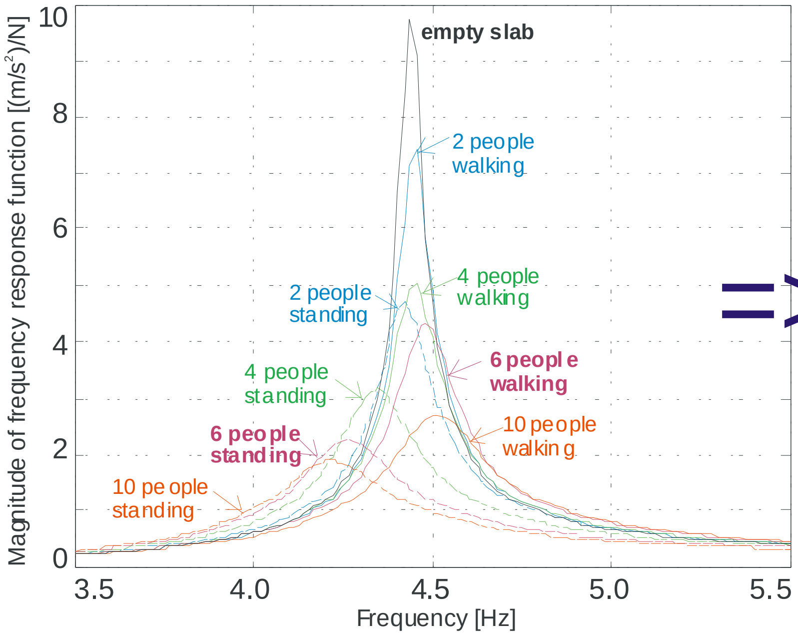


y(t)

Wobbly surface



Example: dynamics of human-slab structure system



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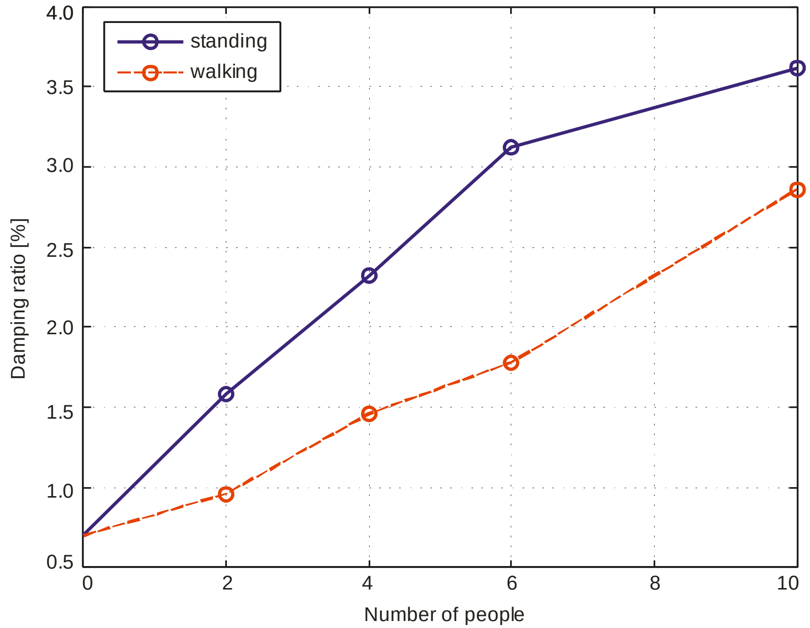
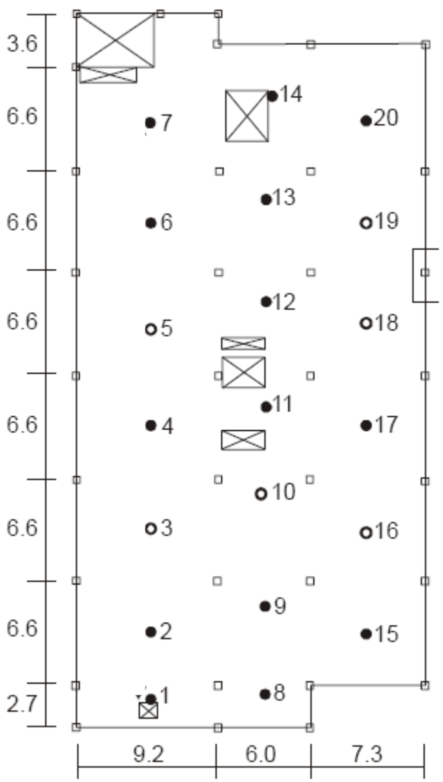


Six people standing on slab

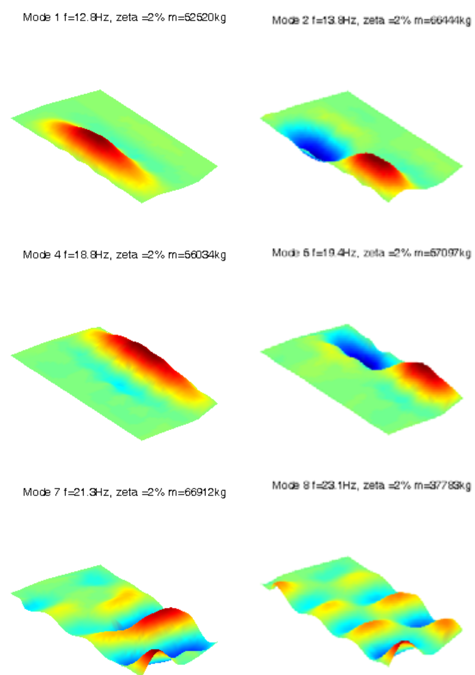
Six people walking on slab

System damping increased with increasing number of people present (even when people were walking)

Example: optimising vibration performance

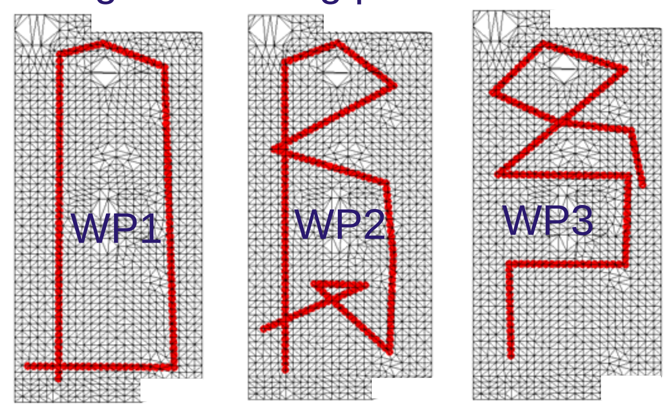


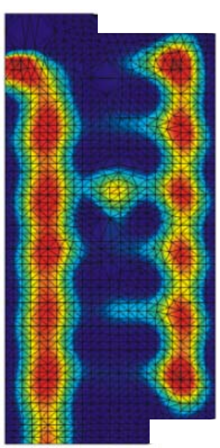
Floor



Some vibration modes

Design of walking paths





Vibration response for walking along WP1

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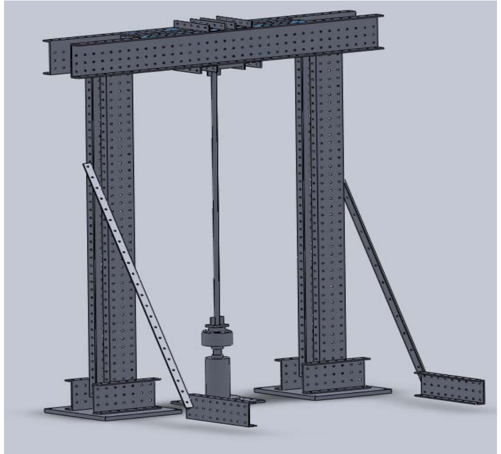
Concrete-filled tubular brace under cyclic loading

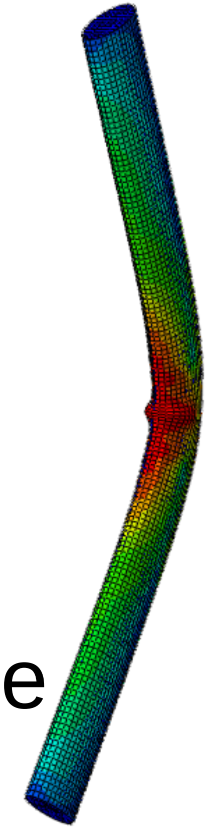
- **Funded by**
  - TATA steel



- **Objective**
  - Investigation into energy dissipation performance of concrete-filled tubular braces under cyclic loading

Concrete-filled tubular brace under cyclic loading

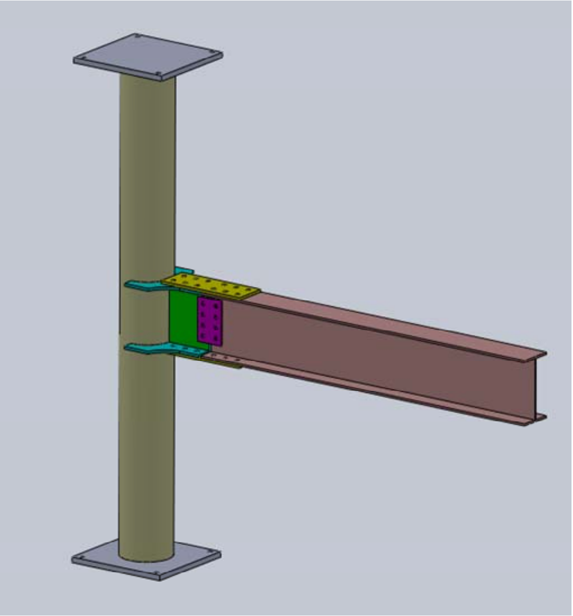
- **Methodology**
  - o Full scale experimental tests
  - o Finite element simulations



- **Target**
  - o Generation of hysteretic performance data

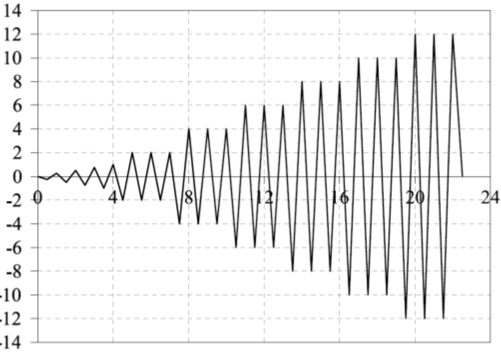
Connection between tubular column and I-beam

- **Funded by**
  - Engineering Physical Sciences Research Council
- **Supporters**
  - TATA Steel, Arup, Steel Construction Institute



Connection between tubular column and I-beam

- **Methodology**
  - Full scale experimental tests
  - Finite element simulations



- **Target**
  - Generation of hysteretic performance data for semi-rigid connections

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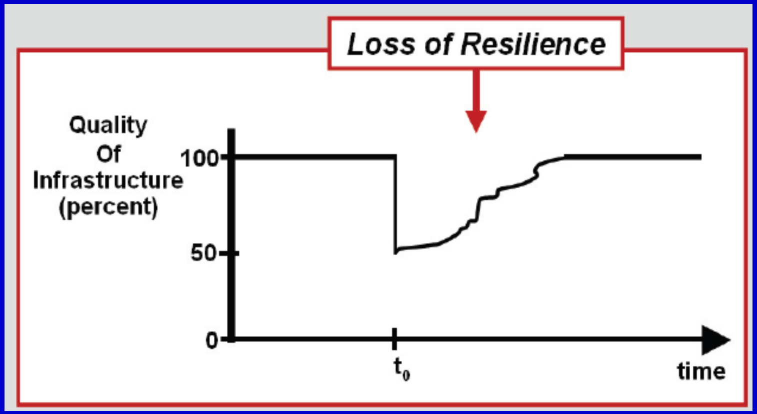
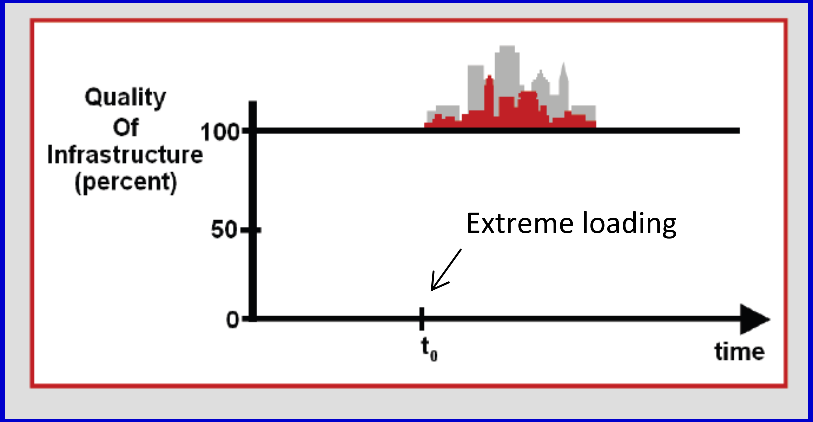
Resilient Structures Lab

Dr. Theodore Karavasilis



VS.



OUR RESEARCH EMPHASIZES ON THE DEVELOPMENT OF STRUCTURAL SYSTEMS WITH AN INHERENT POTENTIAL TO PROVIDE ROBUSTNESS AND RAPIDITY

Robustness: Resistance

Rapidity: Speed with which occupation, use, service, etc.. are restored after severe loading conditions

Resilient Structures Lab

Dr. Theodore Karavasilis

Ultimate goal:

•Elimination of the socio-economical risks related to extreme loading conditions (earthquakes, windstorms, blast)

Research on:

•Minimal-damage structures under extreme loads

•Structures which can be easily repaired without loss of use or occupation

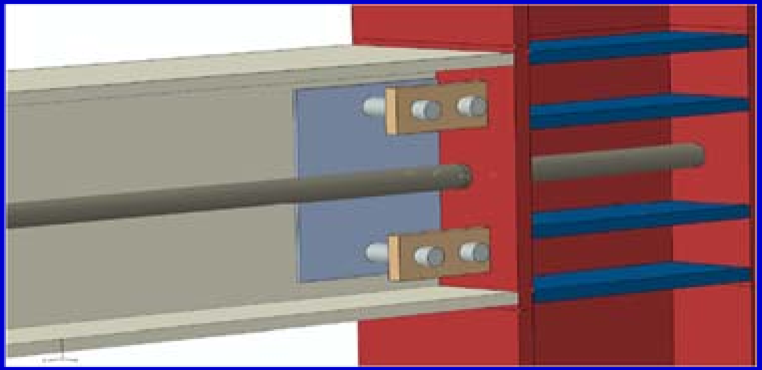
•Advanced solutions for retrofitting existing infrastructure economically and time efficiently

Consider:

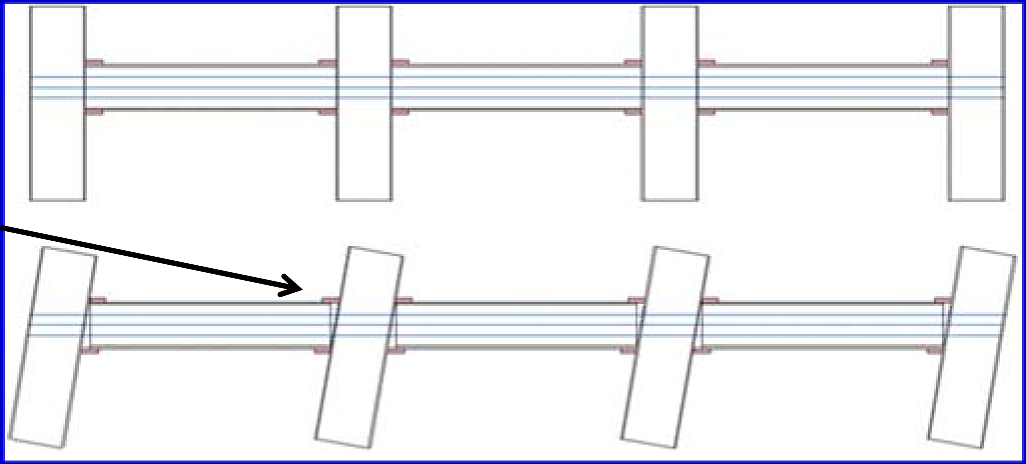
•Leaner construction

•Reduction of steel weight

1. Resilient damage-free self-centering steel MRFs



Gap opening in the beam-column interface



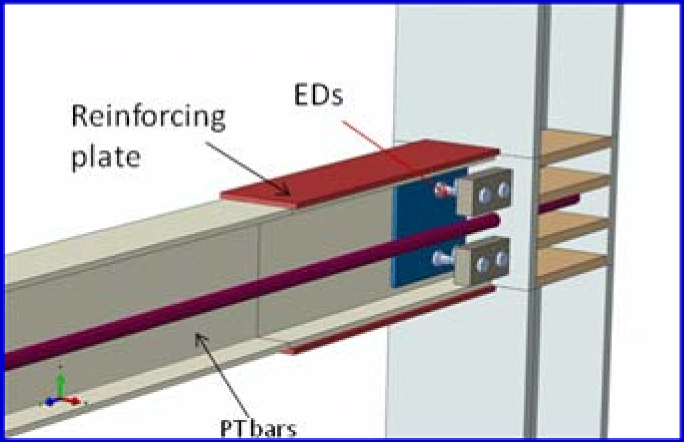
Initial

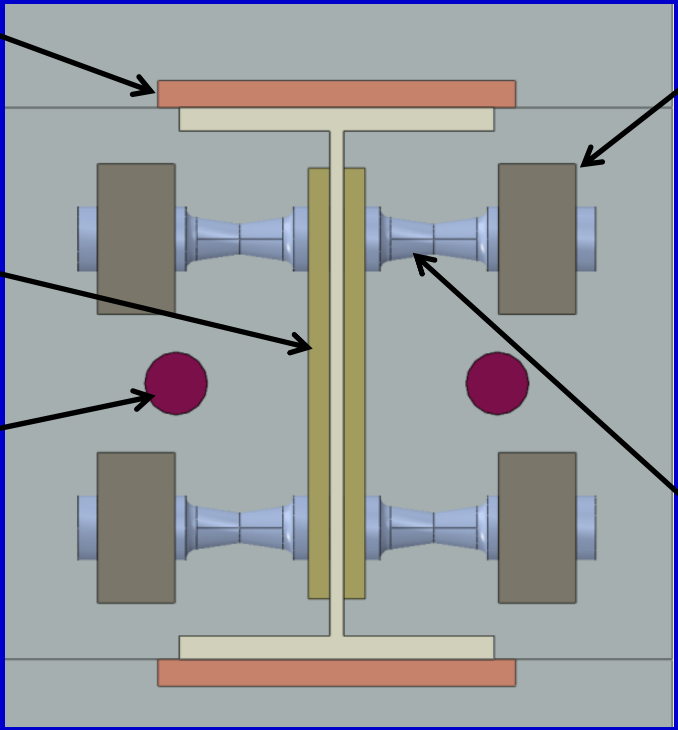
Deformed

Resilient Structures Lab

Dr. Theodore Karavasilis

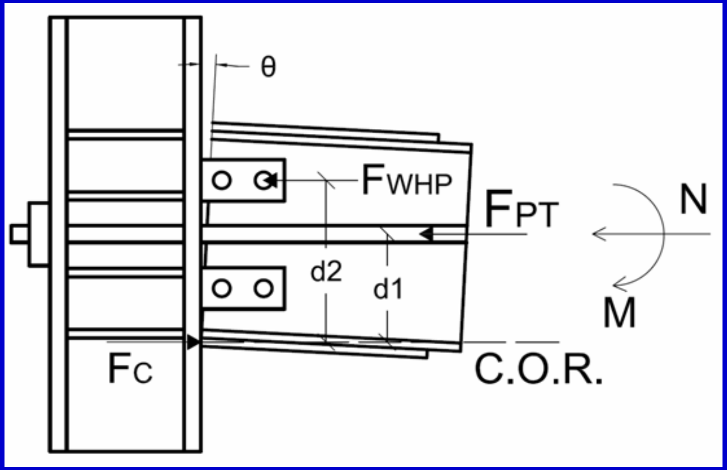
Recently developed innovative steel post-tensioned connection

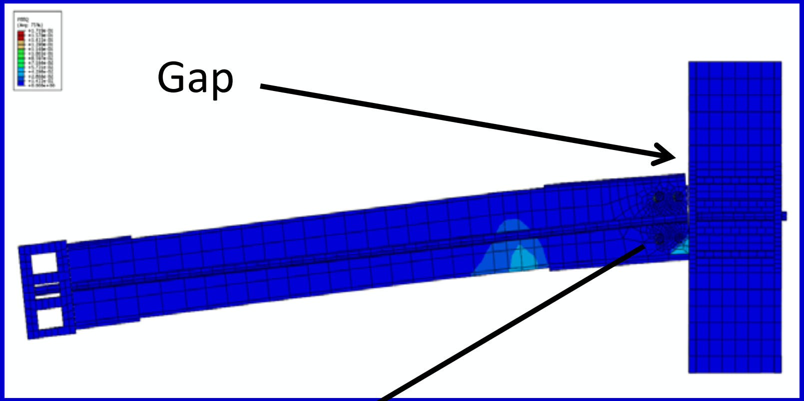


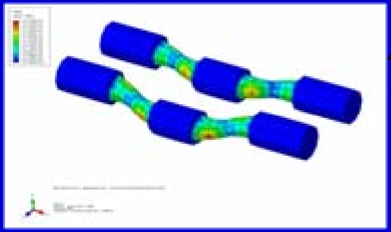


Design concept

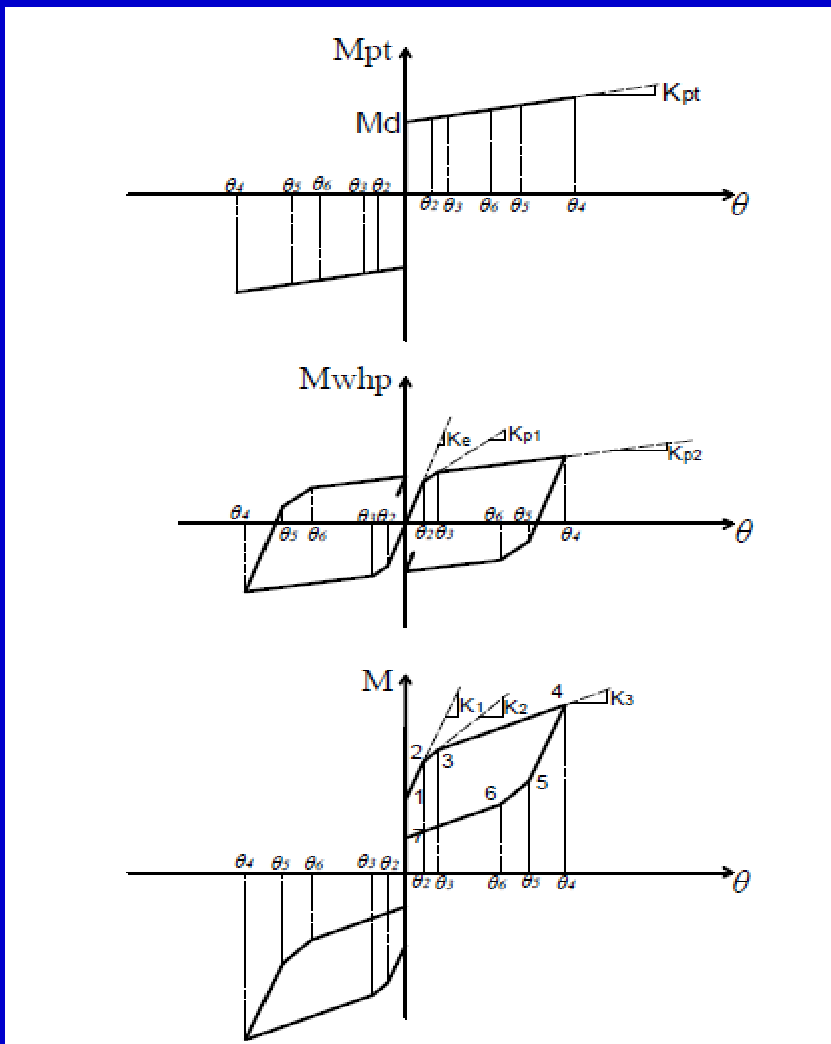
- Gaps open and close in the beam-column interface
- Post-tensioned high strength steel bars clamp the beam to the column and provide self-centering capability
- Energy dissipation elements (WHPs) which are activated when gaps open and can be very easily replaced without bolting or welding







How it works…

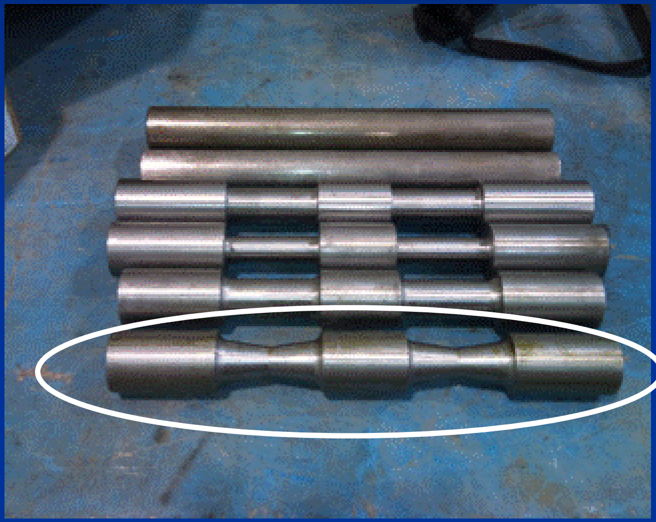


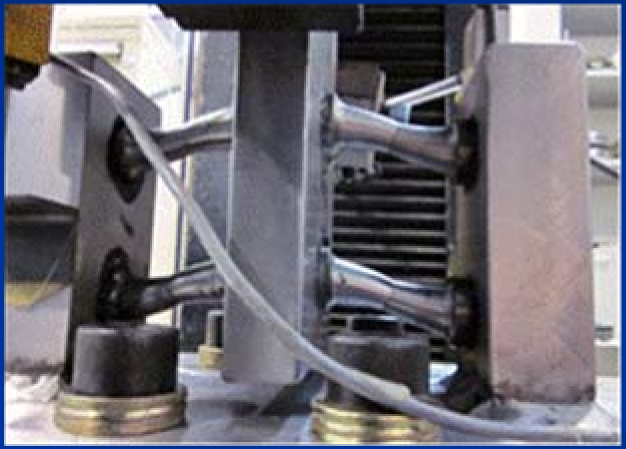
Contribution of post-tensioned bars

Contribution of WHPs

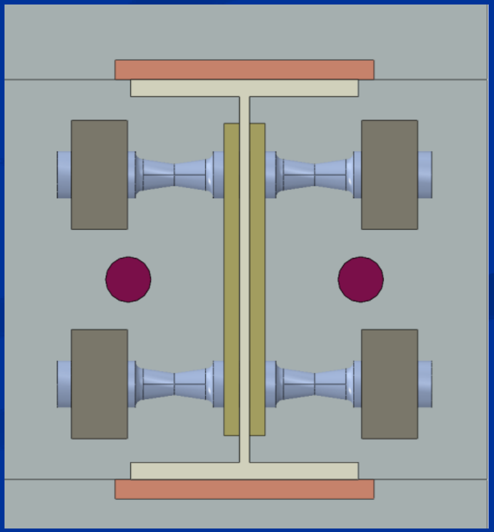
Total connection moment-rotation behaviour

Web Hourglass Pins (WHPs)





Hourglass shape to provide enhanced:
1)energy dissipation capacity
2)fracture capacity
3)hysteresis without pinching



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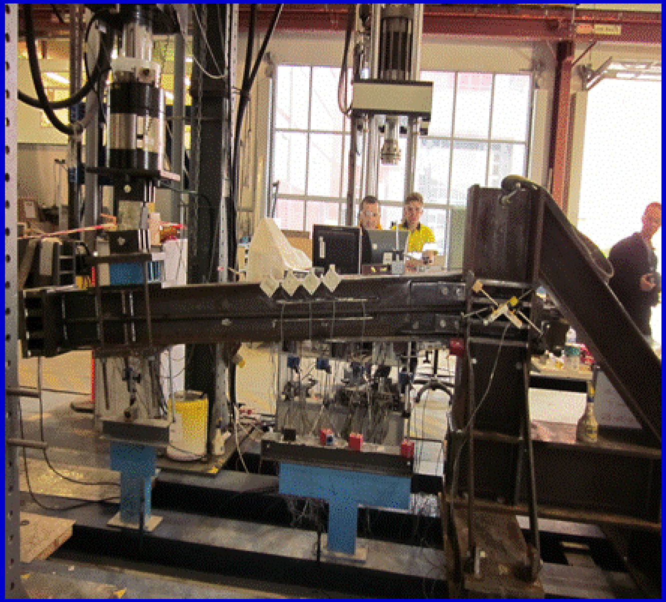
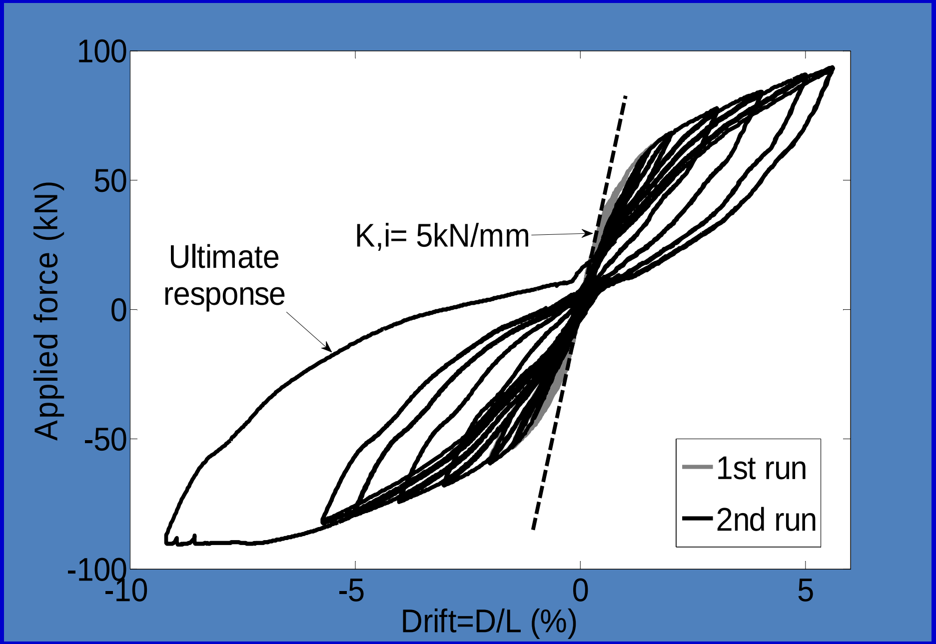
Large-scale experimental validation of connection behaviour

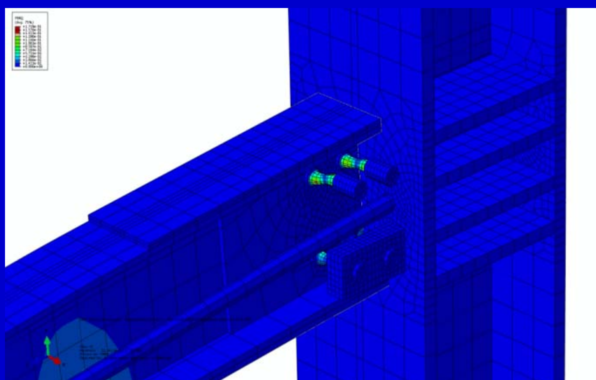




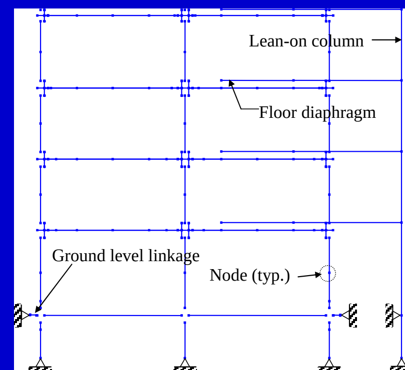
- Beam and column damage-free for drift ≤ 5%
- Elimination of residual drift
- Sequence of tests along with replacing damaged WHPs :robust non-disruptive reparability
- Reduced site construction (easy erection process, less welding and bolting)
- Can be applied to retrofit of existing structures

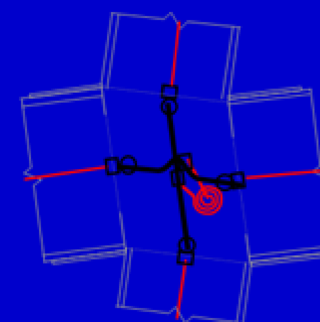
Currently we are working on…

FEM models

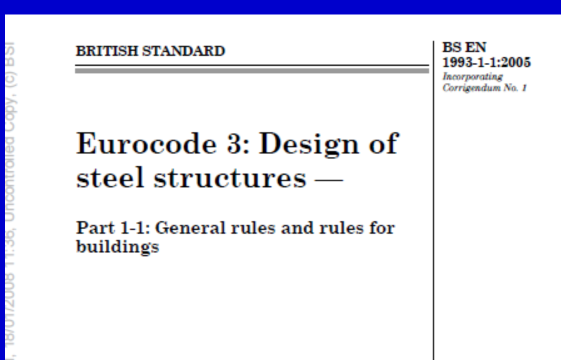


Models for global analysis of post-tensioned frames





Design methodologies for post-tensioned frames in the framework of Eurocodes

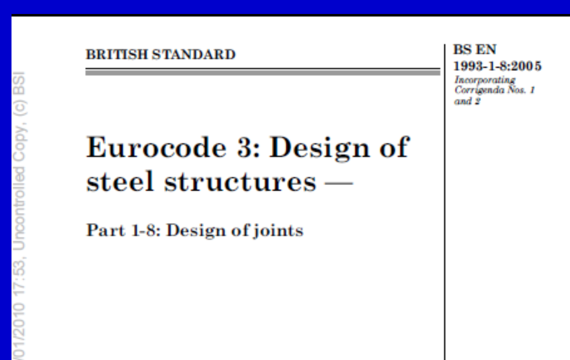


BRITISH STANDARD

BS EN 1993-1-1:2005
Incorporating Corrigendum No. 1

Eurocode 3: Design of steel structures —

Part 1-1: General rules and rules for buildings

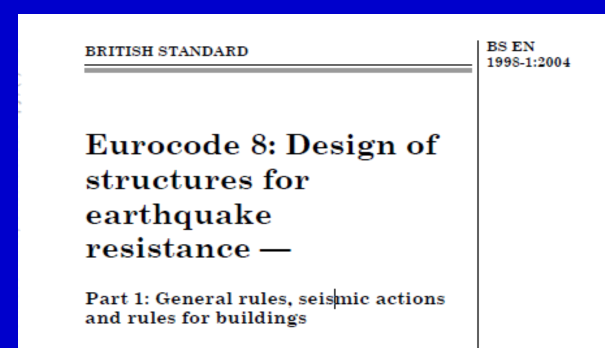


BRITISH STANDARD

BS EN 1993-1-8:2005
Incorporating Corrigenda Nos. 1 and 2

Eurocode 3: Design of steel structures —

Part 1-8: Design of joints



BRITISH STANDARD

BS EN 1998-1:2004

Eurocode 8: Design of structures for earthquake resistance —

Part 1: General rules, seismic actions and rules for buildings

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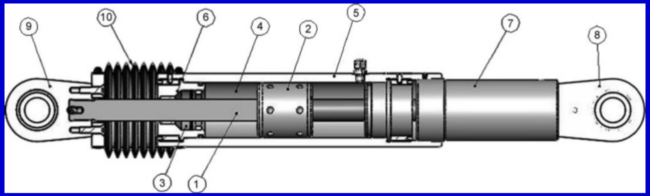
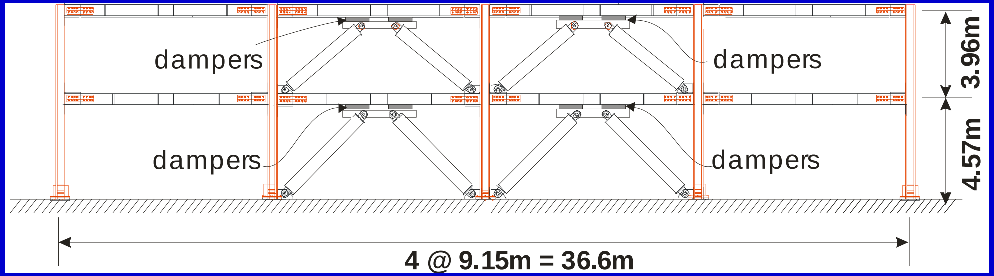
2. Resilient minimal-damage structures equipped with rate-dependent passive dampers

Fluid viscous dampers



Elastomeric dampers



- **Structural and non-structural damage control**
- **Steel weight reduction (up to 40%)**
- **Retrofit of existing structures**
- **Effective for multi-hazard mitigation (blast, windstorms, earthquakes)**

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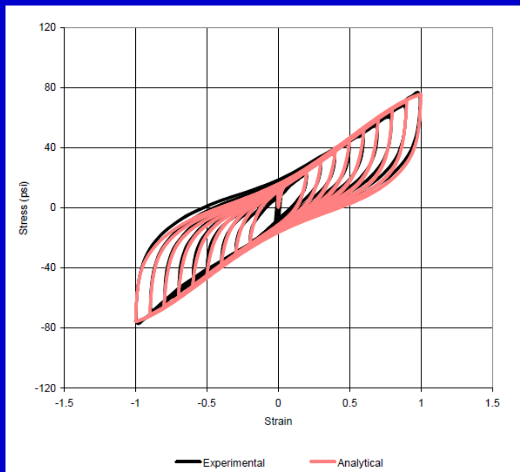
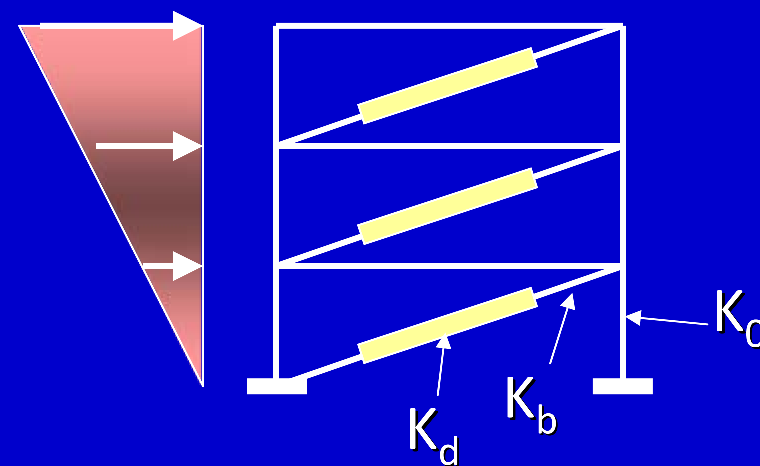
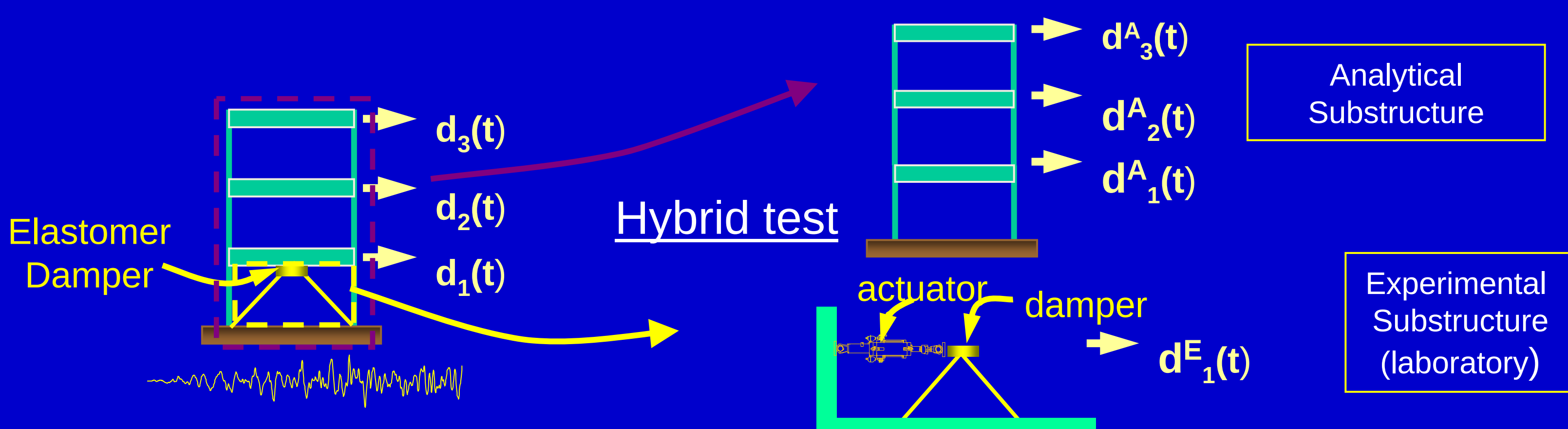
Advanced models for rate-dependent materials (e.g., elastomers)



Practical design procedures for structures with rate-dependent passive dampers



Tools for real-time hybrid testing



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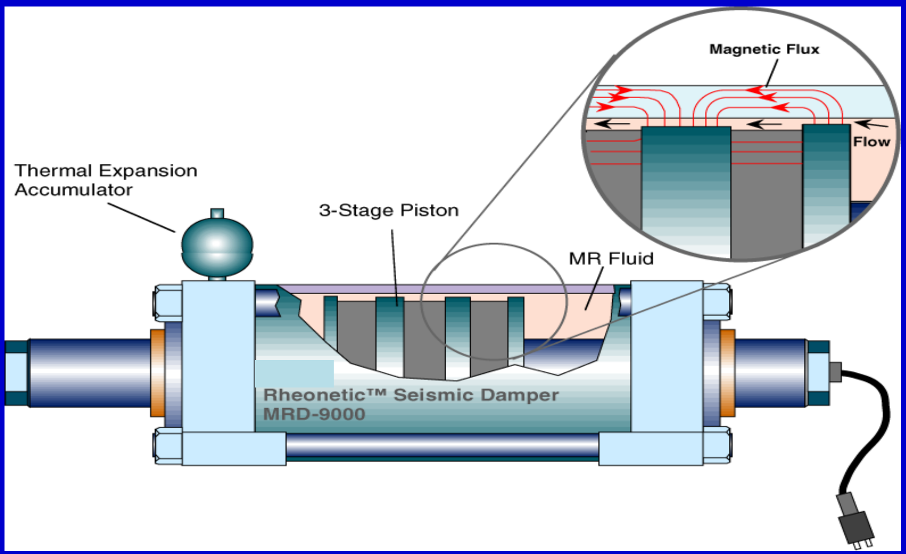
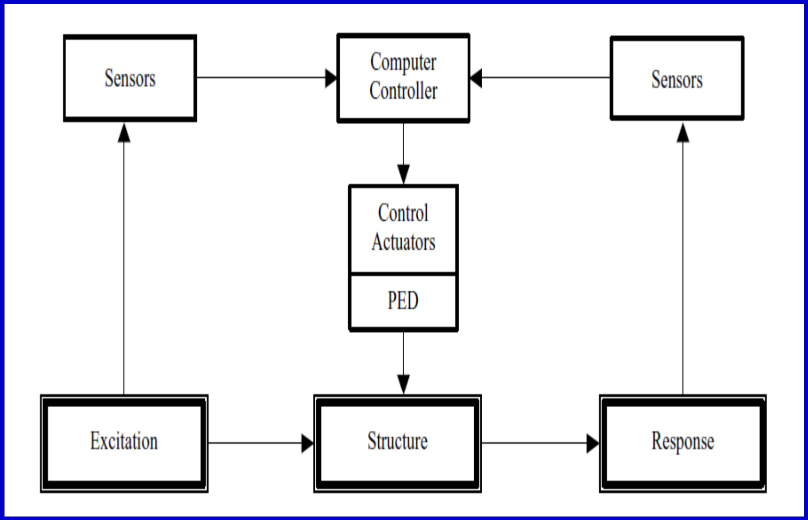
3. Extension of service life of bridges using semi-active control

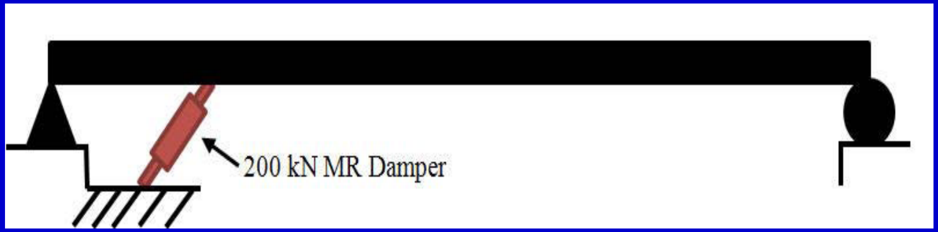
MR Damper



Integration of structural dynamics, structural design, control theory and sensors



MR damper controlled highway bridge



Extend service life under heavy traffic loading (economically and time efficiently)

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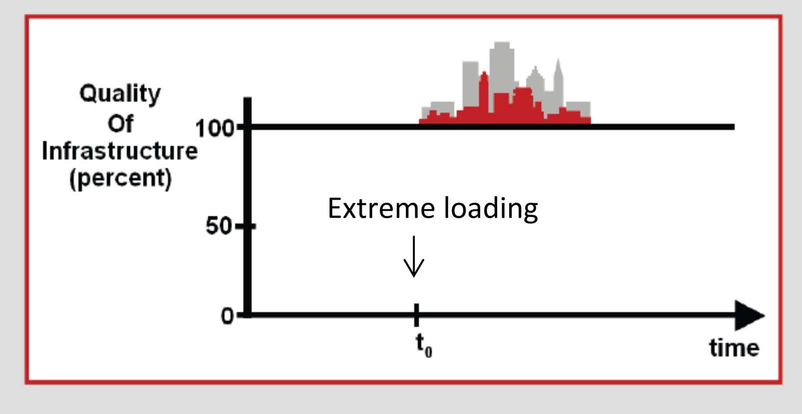
CONSTITUTIVE MODELS AND GLOBAL RESPONSE SIMULATIONS

DESIGN USING INNOVATIVE STRUCTURAL DETAILS AND SMART MATERIALS

STRUCTURAL COMPONENT AND HYBRID TESTING

RESILIENT DAMAGE-FREE STRUCTURAL SYSTEMS



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Sustainability & climate change

Dr Stefano Utili, Associate Professor at University of Warwick, Civil Group (geotechnical engineering)

Research on flood defence embankments:

1. Long term monitoring of the performance of flood defence embankments subject to progressive deterioration due to climatic effects (research funded by the Scottish Executive and Institution of Civil Engineers)
2. Determination of geotechnical expressions for ultimate limit states of flood defence embankments (funded within EU FP6 Floodsite, EPSRC FRMRC consortium, Environment Agency)

Embankments are an essential infrastructure for the defence from flooding and canalisation of water flow. They are becoming increasingly important due to climate change and renewed emphasis on sustainable development.

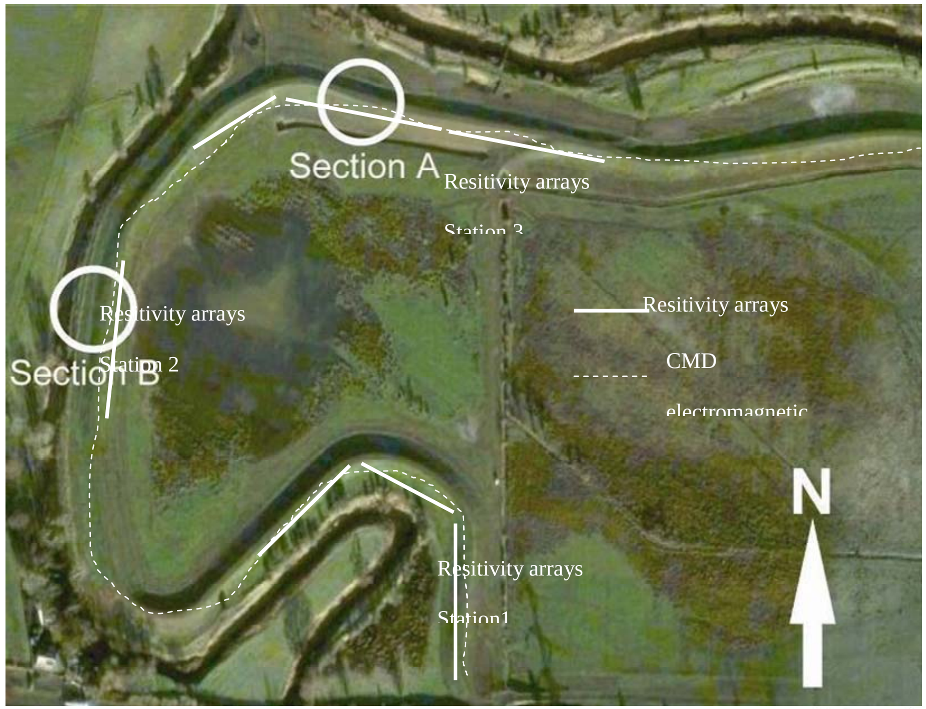
- Every year the UK alone spends £450 million on the maintenance and construction of new flood defence embankments.

  In Europe an area as big as 40.000 km square housing 16 million people is flood prone.

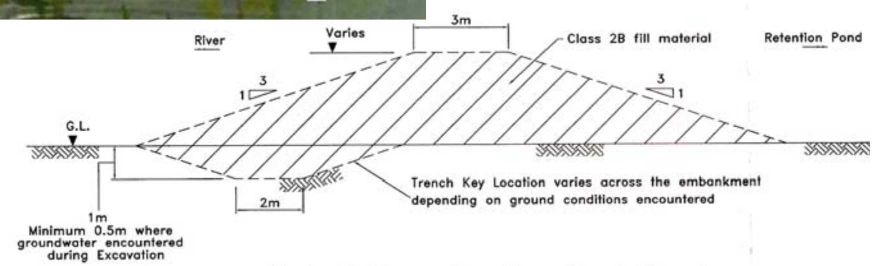
  Hurricane Katrina (2005) is an example of what happens when flood defence embankments fail.

1 Long term monitoring of the performance of flood defence embankments

Clay embankments are subject to desiccation fissuring/cracking. The presence of cracks in the embankment body may cause failure of the embankment for a hydraulic load significantly lower than the design one.



Embankment made of glacial till along the river Irvine, Galston (Scotland)

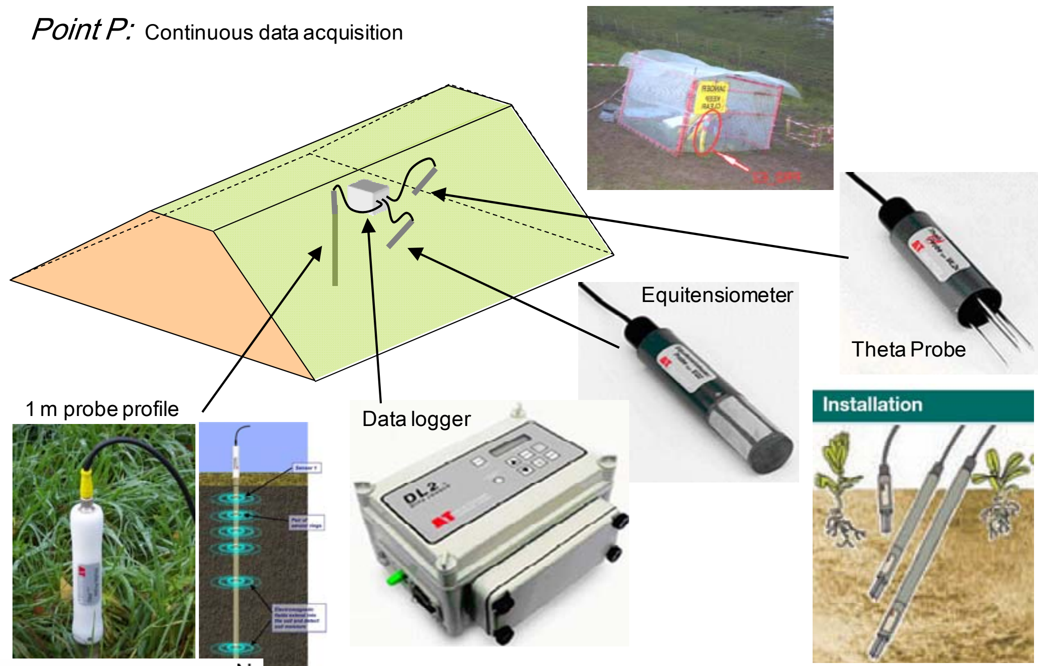


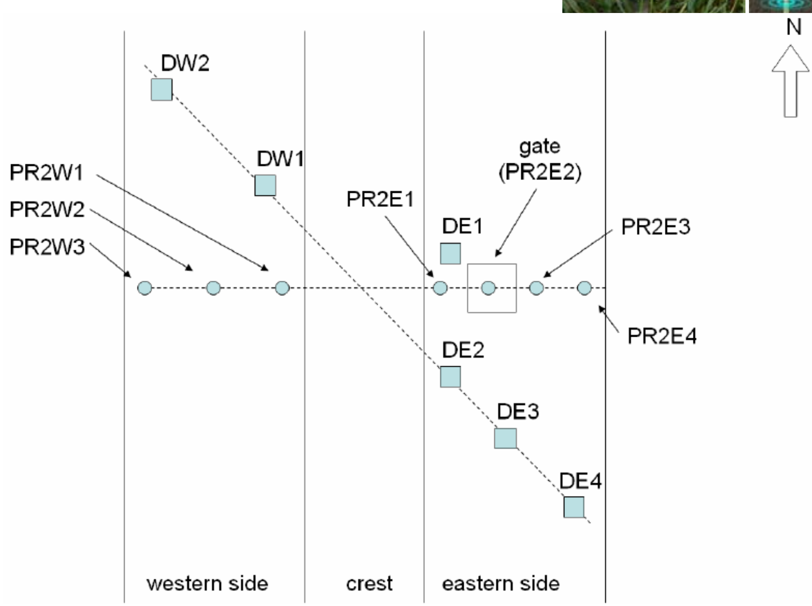
Typical Cross Section 1 of Flood Embankment

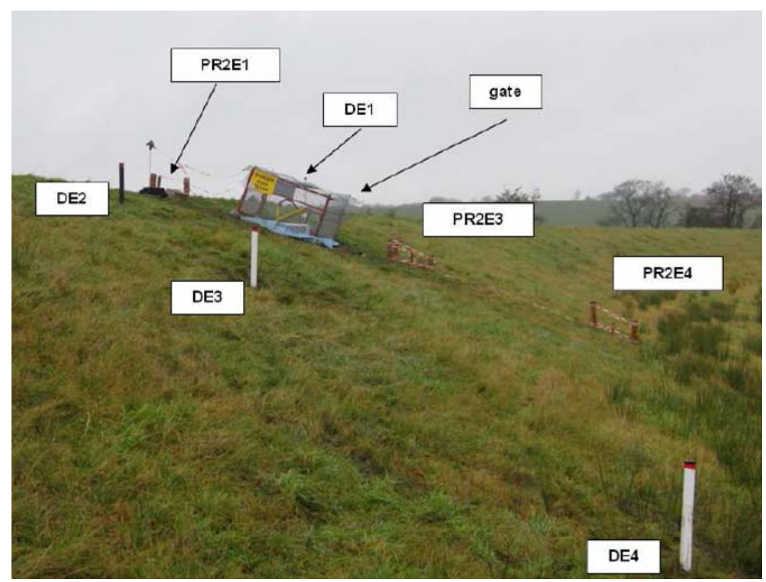
Scale 1:100

1 Long term monitoring of the performance of flood defence embankments

Data from a suite of geotechnical tools have been crossed with geophysical readings (resistivity array and CMD conductivity) to work out the water content function w=w(x,y,z,t) for the entire embankment







1 Long term monitoring of the performance of flood defence embankments

Achieved goals

- A link between water content and fine fissuring / cracking has been established
- The health of embankment has been related to its water content

2 Determination of geotechnical expressions for ultimate limit states of embankments subject to flooding

In recent years I pursued two research lines:

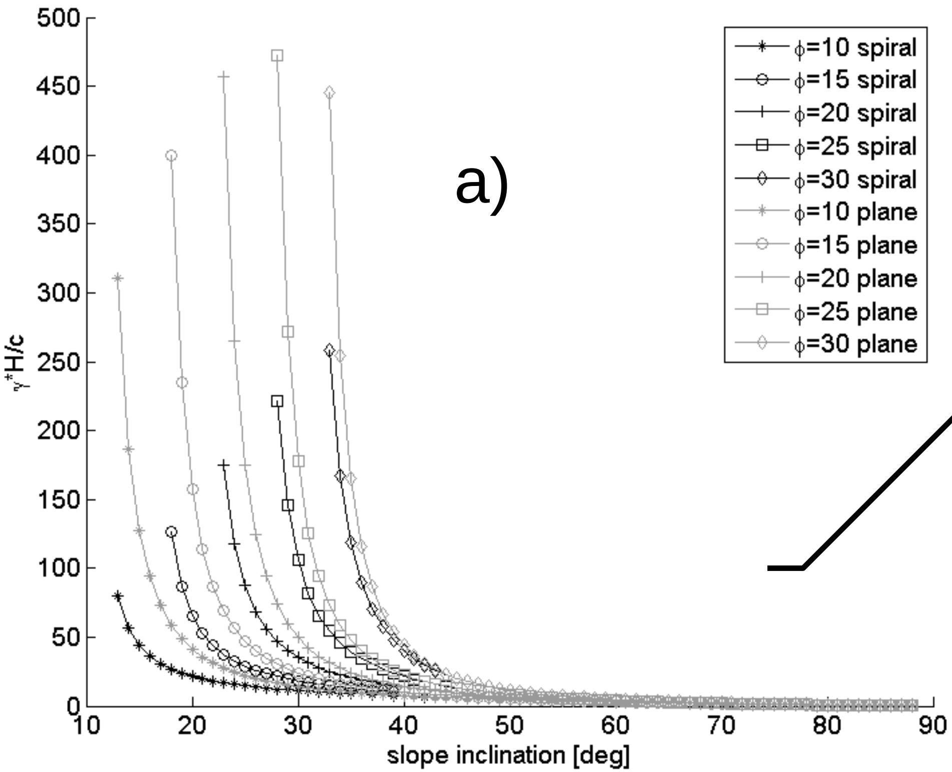
1. Influence of tension cracks (dry or filled with water) on embankment stability
2. Determination of suitable geotechnical expressions for the following failure mechanisms: fine fissuring and overtopping. This research was funded by EU FP6 Floodsite, the EPSRC FRMRC consortium and the Environment Agency.

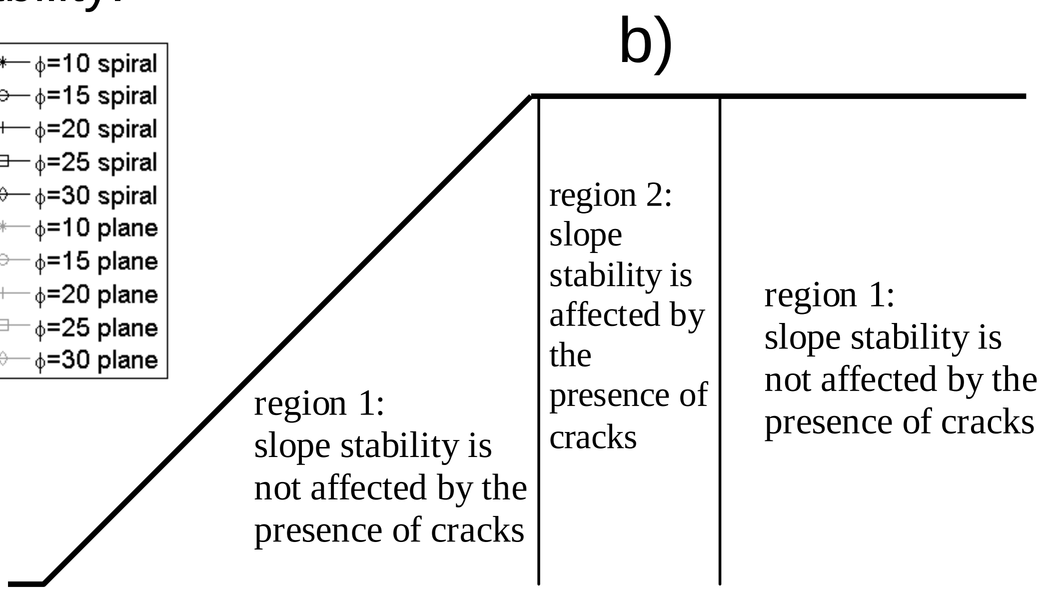
2 Influence of tension cracks on embankment stability

An analytical expression was achieved by means of the Limit Analysis upper bound method which provides:

a) the limit load for any tension crack length and hydraulic condition (water level);

b) regions of the embankment where the presence of cracks does not affect the embankment stability.





After (Utili S. On the stability of slopes with tension cracks by limit analysis. *Geotechnique)*

Thank you!

THE UNIVERSITY OF WARWICK