University of Edinburgh

Mike Forde,
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(Carillion Professor)

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Edinburgh Joint Research Institute:

Edinburgh Napier University

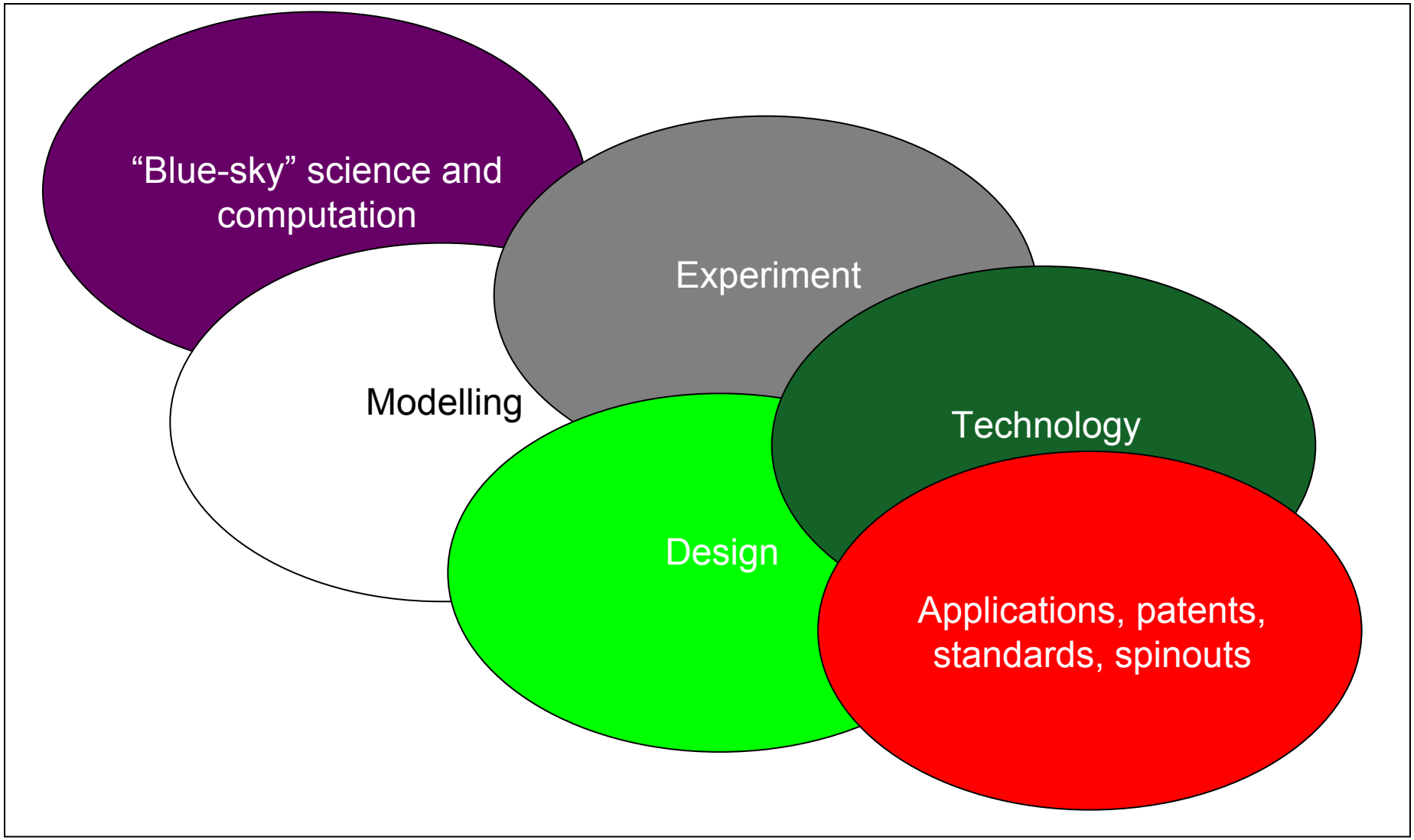
Heriot-Watt University

University of Edinburgh

University of Edinburgh – School of Engineering

Original separate Depts	RAE'2001	School of Engineering
Chemical Engineering	4	Institute for Digital Communications (IDCoM)
Civil Engineering	5	Institute for Energy Systems (IES)
Electrical Engineering	5*	**Institute for Infrastructure & Environment (IIE)**
Mechanical Engineering	4	Institute for Integrated Micro & Nano Systems (IMNS)
		Institute for Materials and Processes (IMP)

Research focus and drive



Institute for Infrastructure & Environment (IIE)

BRE Centre for Fire safety Engineering

Structural Mechanics Group - FEM

Particulate Materials Activity - DEM

Environmental Engineering Activity

NDT & Railway Engineering – FDTD & FEM – GprMax.org

Construction Management

Industry involvement & Sponsorship:

Arup/RAEng Senior Fellowship in Structures & Fire – Luke Bisby

BRE/RAEng Chair of Fire Safety Engineering – Jose Torero

Carillion Chair – Mike Forde

Edinburgh NDT Research Group

Faculty:

- Prof Mike Forde
- Dr Antonis Giannopoulos
- Prof Dave McCann *(Visiting Prof)*
- Dr Pankaj
- Dr Asif Usmani
- Dr Mike Hardy
- Prof Ian Main *(Geophysics)*
- Dr Nigel Davidson
- Sandy Batchelor
- Kevin Broughton
- Chris Burnside
- Peter Fenning
- Nyall McCavitt
- Prof Luigia Binda *(Poli di Milano)*
- Prof M Ohtsu & Prof M. Shigeishi *(Kumamoto University, Japan)*
- Ian Whyte

Grad Students:

- Dr Donald Armstrong
- Dr Farhad K Birjandi
- Dr HF "Cyril" Chan
- Dr Maxwell Clark
- Dr Camilla Colla
- Dr Sabrina Colombo
- David Connolly
- Dr Robert De Bold
- Dr Ria Diamanti
- Dr Francis Drossaert
- Dr Ian Fegen
- Gerry Gallagher (MSc)
- Pedro Gonzalez (MSc)
- Dr Michael Gordon
- Dr Julia Summers (nee Martin)
- Prof W John McCarter
- Dr Roberto Morelli
- Dr Ivo Padaratz
- Dr Scott Rodgers
- Prof Alan Sibbald
- Dr Craig Warren

Acknowledgements:

carillion

EPSRC

HIGHWAYS AGENCY

Network Rail

KUMAMOTO UNIVERSITY
2-39-1 KUROKAMI KUMAMOTO 860-8555 JAPAN
FAX 81-96-342-3110

HOLEQUEST LIMITED

GI

Caputh Bridge
Hawick Retaing Wall Lauder Bridge,
Middleton Bridge

Developing New Standards for NDT of Bridges

DESIGN MANUAL FOR ROADS AND BRIDGES BA 86/06

THE HIGHWAYS AGENCY

TRANSPORT SCOTLAND

WELSH ASSEMBLY GOVERNMENT
LLYWODRAETH CYNULLIAD CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

UK

Advice Notes on the Non-Destructive Testing of Highway Structures

Published 2006

Summary: These advice notes publicise the outcome of the latest research in NDT carried out by the Highways Agency. They do not endeavour to provide full details of techniques in common use, but the full range of available techniques is summarised. This Standard supersedes BA 86/04 and now includes Acoustic Emission (AE).

228298

Member Price $37.00
Convention Price $24.00

ACI 228.2R-98

USA +

Nondestructive Test Methods for Evaluation of Concrete in Structures

Reported by ACI Committee 228

Published 1998

Update: late 2011

american concrete institute
P.O. BOX 9094
FARMINGTON HILLS, MICHIGAN 48333-9094

Future Infrastructure needs to demonstrate:

Sustainability

Resilience

"*One Goal" of the FIF project:*

say ~30% reduction in construction costs

Predictable long-term life of the structure

Predictable cost expenditure over structure's life

- University of Edinburgh demonstrates:

- Sustainability, &
- Resilience
- in multiple environments

Trams bill four times that of similar projects in UK

DAMIEN HENDERSON TRANSPORT CORRESPONDENT

21 Sep 2011

EDINBURGH'S over-budget tram project is expected to cost nearly four times as much per mile of track than similar light rail projects elsewhere in the UK, a Government report has confirmed.

Figures published by the Department for Transport put the average cost of building tramways in urban conurbations at £25 million per mile, though this does not include Edinburgh, where costs have rocketed by £231m and the route has been curtailed due to a funding shortfall.

NOSE-TO-TAIL: Congestion caused by the closure of Princes Street for tram repairs was felt on George Street as traffic was diverted on to the thoroughfare.

Tools

TRANSPORT CORRESPONDI
HENDERSON'S TWEETS

damienhenderson: @davidfuzzyli
compliment! (Which is a bit worryir
Sep 21, 6:00 pm

damienhenderson: @ScotRail @
Victory for the rail anorak! ScotRai
munching QS tickets at Charing X
Sep 21, 3:23 pm

damienhenderson: @RoSPA You
long version of that? Sounds intere
Twitter) a bit too condensed!
Sep 21, 2:00 pm

Follow @DamienHenderson

Carrera and Cayenne			
One year renewal	One year stand-alone	Two years renewal	Two years stand-alone
£1,079	£1,158	£2,095.00	£2,174.00

Porsche Approved Warranty

The Porsche Approved Warranty is included on all Porsche Approved vehicles purchased through our Centres, for a minimum of one year. The Approved Warranty can also be purchased from our Centres to extend any existing Porsche Warranty, whether New or Approved. A Porsche Approved Warranty can be placed on any Porsche, subject to certain criteria, even if the car does not have an existing Porsche Warranty, this is referred to as a Stand-Alone Policy. Porsche Approved Warranties can be purchased in either one or two year packages.

The Porsche Approved Warranty also provides comprehensive bumper to bumper cover, but excludes wear and tear failures.

Unless during the first 12 months post a new car delivery, acceptance of a car for a Porsche Approved Warranty requires a mandatory 111 point check. Also a car must meet the terms and conditions of the Approved Warranty and it can be purchased until your car is 9 years old or has covered 125,000 Miles (or 8 years for a 2 year policy).

Rolls-Royce

TotalCare®

TotalCare is a flexible approach to achieving an engine support service

TotalCare® is a flexible approach to achieving an engine support service that has the correct fit and scope of services to meet the operator's specific needs.

It provides a single source solution ensuring "peace of mind" for the lifetime of the engine, from the time the engine is delivered to the customer until the engine goes out of service. This is achieved through our sharing of knowledge, expertise and experience.

Through a partnership approach, TotalCare:

- aligns incentives and goals
- minimises financial and operational risk
- enables the operator to concentrate on core business
- improves residual value

TotalCare is a total support programme aligned to each customer's operation and paid against hours flown.

Total commercial visibility

Against an agreed cost per flying hour, TotalCare offers the opportunity to remove uncertainties from engine management and provides greater financial confidence from managing predictable costs.

Rolls-Royce wins $2.2bn TotalCare® deal from Emirates

Rolls-Royce, the global power systems company, has won a $2.2bn TotalCare® long term services contract from Emirates, covering Trent engines for 70 Airbus A350XWB aircraft. The agreement will bring the airline's Rolls-Royce powered fleet of 128 aircraft, in service and on order, under TotalCare® arrangements.

Tim Clark, President – Emirates Airline, said: "Emirates' 70 A350XWB aircraft on order will play an important role in our growth when they come online in the next few years. This TotalCare® contract with Rolls-Royce is an important step in ensuring our A350XWB engine life cycle costs are managed effectively and maintained to the highest standards. Already current users of TotalCare®, we look forward to maintaining this relationship with Rolls-Royce to drive additional operational improvements."

Mark King, Rolls-Royce, President – Civil Aerospace, said: "We are delighted to sign this contract with Emirates, a valued customer with three Trent engine family members already in service. With this contract all of Emirates' Rolls-Royce powered fleet are, or will be, supported by TotalCare® packages that add significant value and allow customers to optimise their operations."

TotalCare® long term service agreements, in place on 90 per cent of all Trent engines, are designed to minimise customer financial risk and enhance operational performance and reliability, allowing operators to concentrate on their core business.

The new TotalCare® contract for Trent XWB engines comes two months after Rolls-Royce won a $1.2bn TotalCare® contract for Trent 700 engines powering 27 Airbus A330s and Trent 800 engines powering 21 Boeing 777s.

Cabinet Office

Government Construction Strategy

Executive Summary

The right model for public sector construction procurement in the UK is one in which:

- clients issue a brief that concentrates on required performance and outcome; designers and constructors work together to develop an integrated solution that best meets the required outcome;
- contractors engage key members of their supply chain in the design process where their contribution creates value;
- value for money and competitive tension are maintained by effective price benchmarking and cost targeting, by knowing what projects should cost, rather than through lump sum tenders based on inadequate documentation;
- supply chains are, where the programme is suited, engaged on a serial order basis of sufficient scale and duration to incentivise research and innovation around a standardised (or mass customised) product;
- industry is provided with sufficient visibility of the forward programme to make informed choices (at its own risk) about where to invest in products, services, technology and skills; and
- there is an alignment of interest between those who design and construct a facility and those who subsequently occupy and manage it.

*

The BRE Centre *for* Fire Safety Engineering

Mitigating the risks of innovation in the built environment

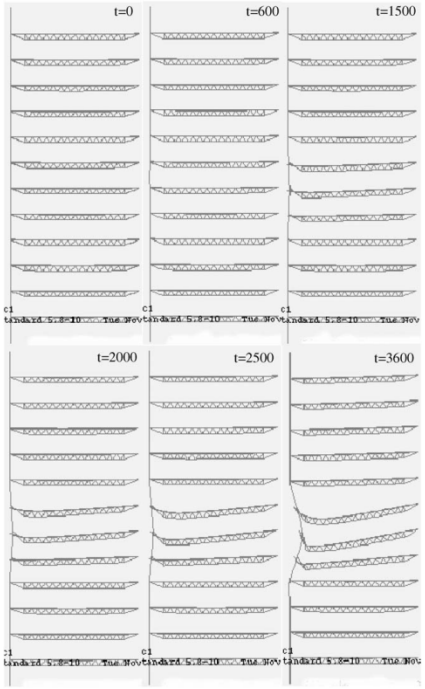
http://www.see.ed.ac.uk/fire/

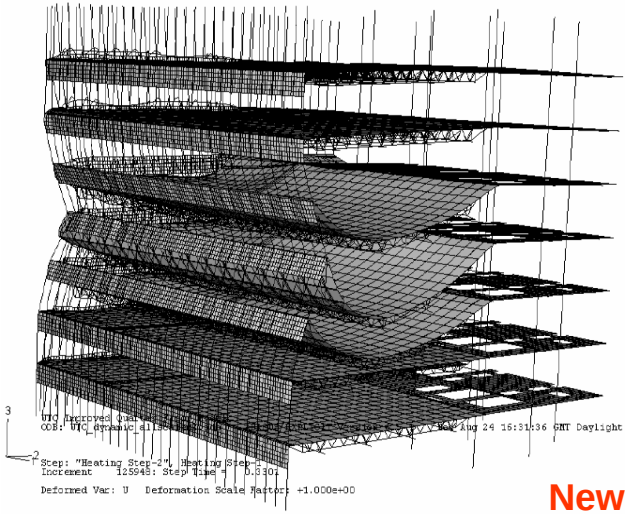
Also...

- **People:**
  - 6 PhD Research Associates
  - Full-time Technician
  - > 40 PhD Students
  - > 20 MEng Project Students
- **Laboratories:**
  - Fire Dynamics Lab
  - Fire & Materials Lab
  - Structures (& Fire) Lab
  - Access to the Building Research Establishment
- **External Relationships:**
  - In-house consultancy business
  - Links with Fire Brigades, Building Regs & Codes (internationally)
  - Strong academic/industry links (internationally)

Experimental Capabilities: Fire Lab

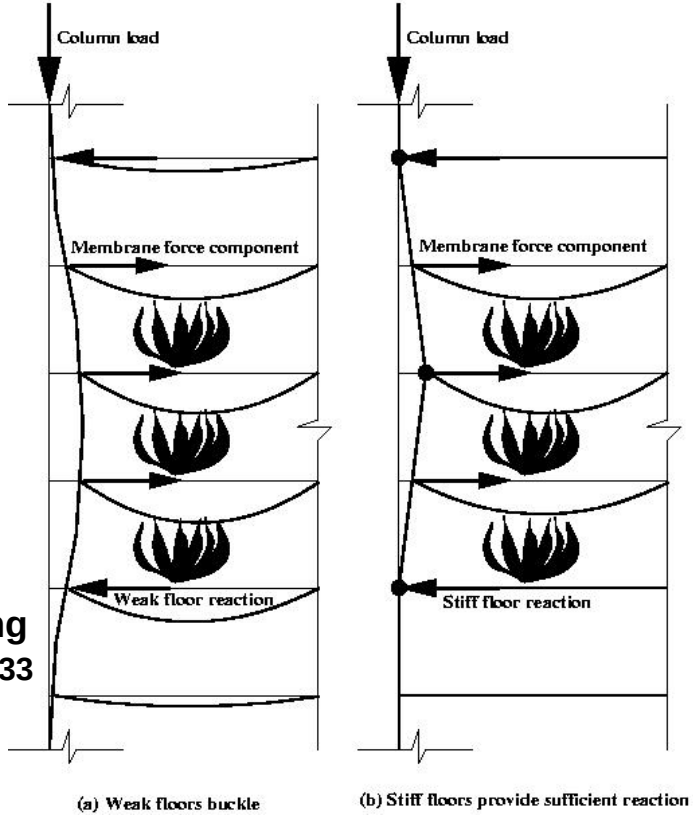
Tall buildings in fire





WTC towers collapse modelling
***Fire Safety Journal* 38 (2003) 501–533**

Lessons learnt….
***Int. J. of Steel Structures* 9 (2009) 17-28**



Weak floor collapse **Strong floor collapse**

Possible to design for multiple floor fires!

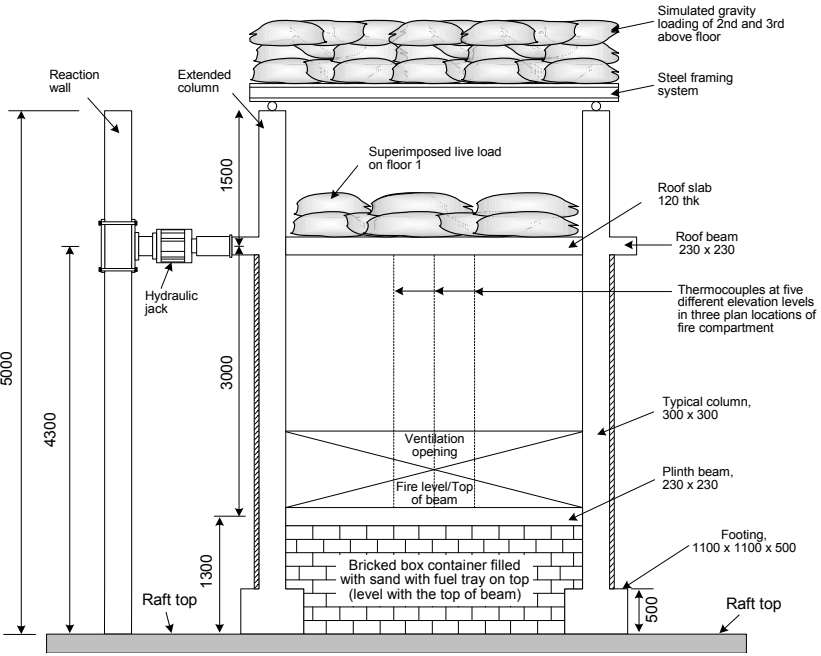
New grant: EPSRC EP/J001937/1
"Real fires for the safe design of tall buildings"
Nov 2011 - Nov 2014

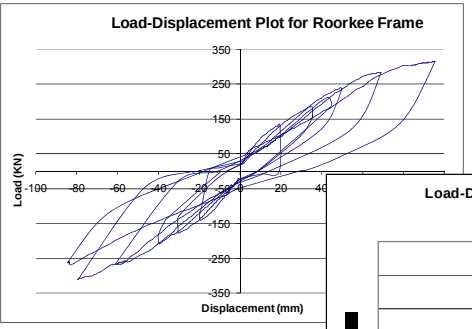
First ever full-scale fire testing of damaged RC frames subjected to fire

UoE-IIT Roorkee (India) project funding by UKIERI

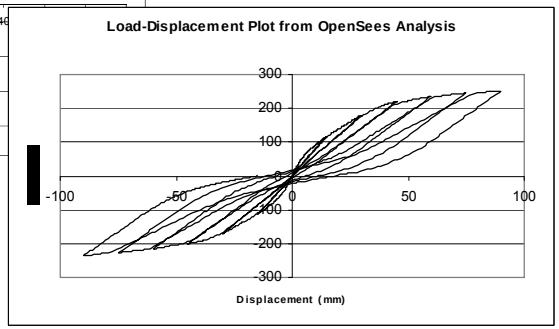
Accepted for publication, *ICE Structures and Buildings*

Frame geometry and loading

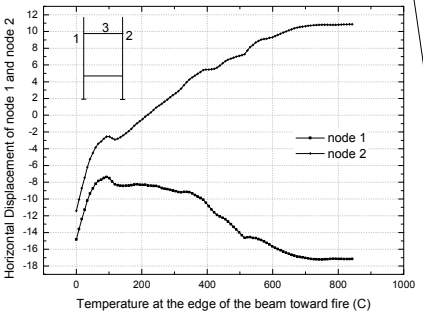




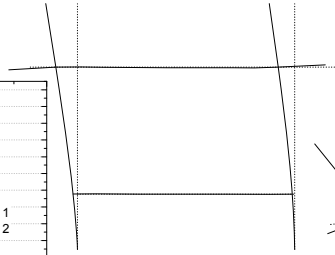
Load-disp during cyclic loading to simulate seismic damage



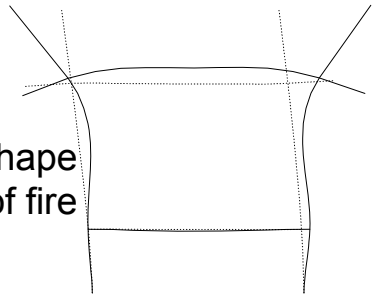
OpenSees Simulation of cyclic loading



Tempr-disp during fire from simulation

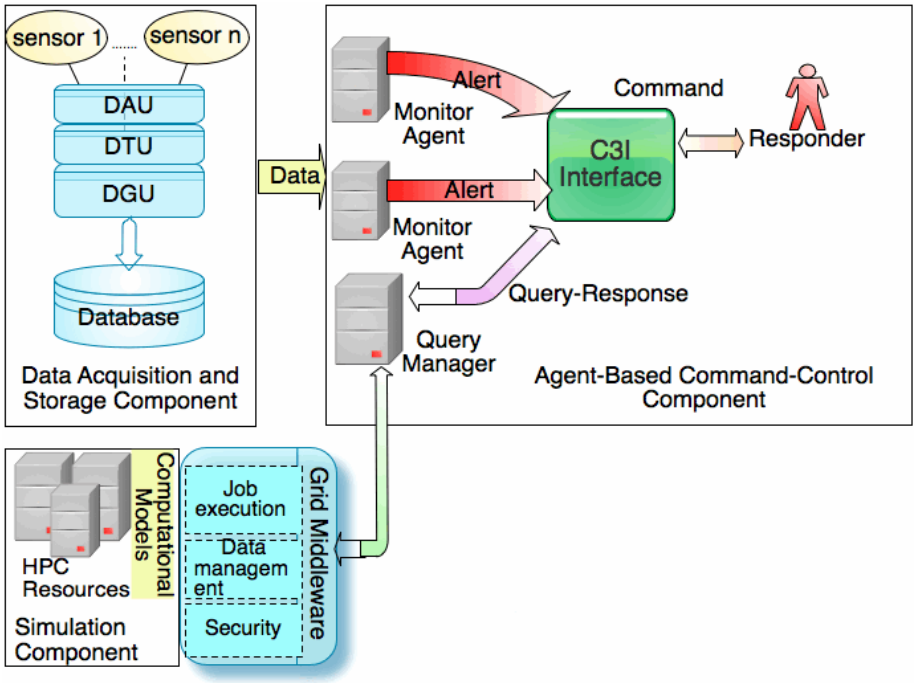


Displaced shape at end of cyclic loading



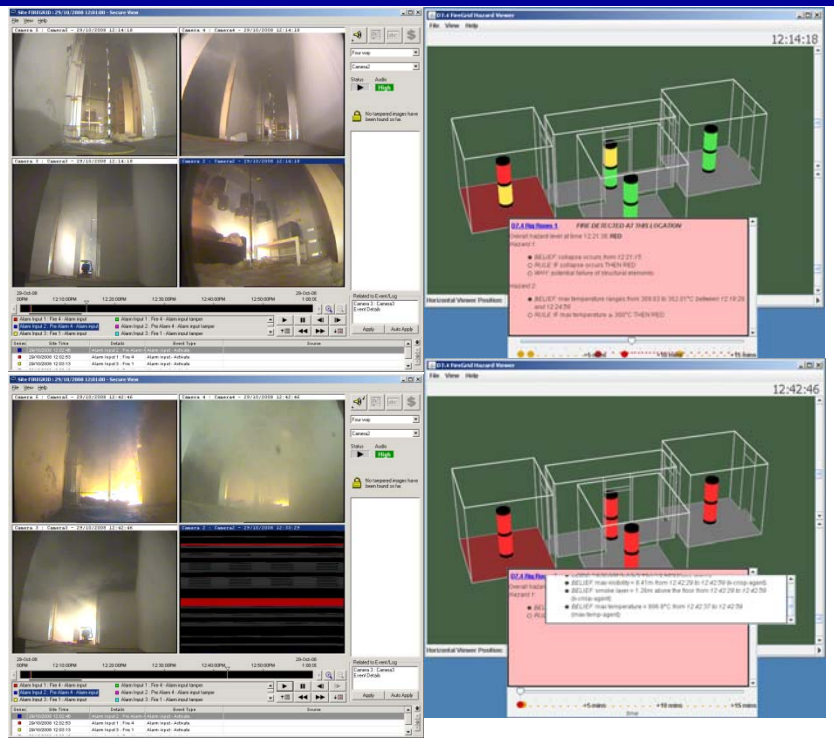
Displaced shape (x20) at end of fire

FireGrid for real-time sensor-assisted fire emergency response, (*spin-off project: energy efficiency in modular buildings*)



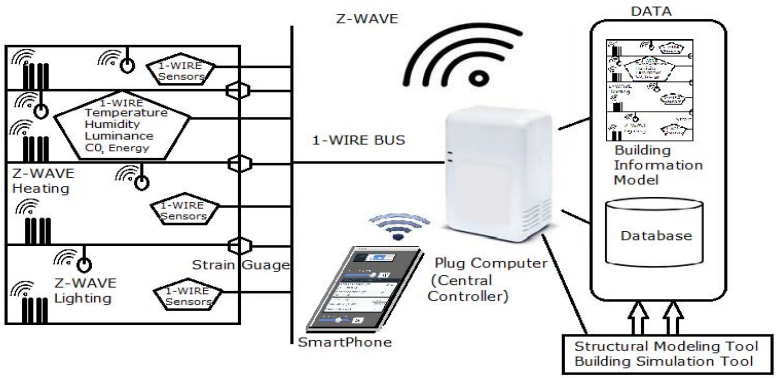
System architecture

***J. Parallel Distrib. Comput.* 70 (2010) 1128–1141**

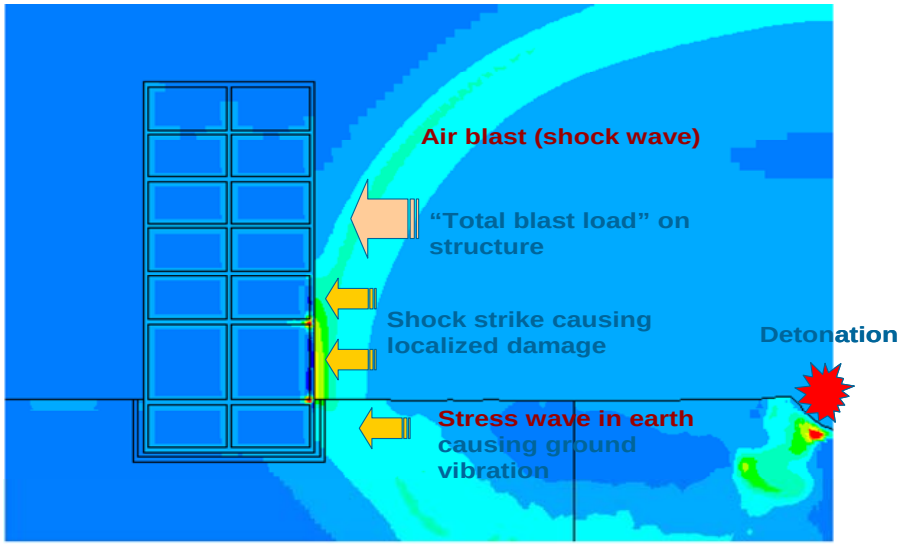


Visuals of system and real fire from project demo

Integrated energy efficiency and intelligence + structural monitoring in modular buildings



Resilience of structures under extreme conditions

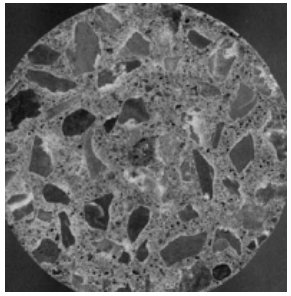


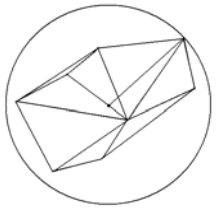
Large scale analysis on comprehensive effects of shock and blast

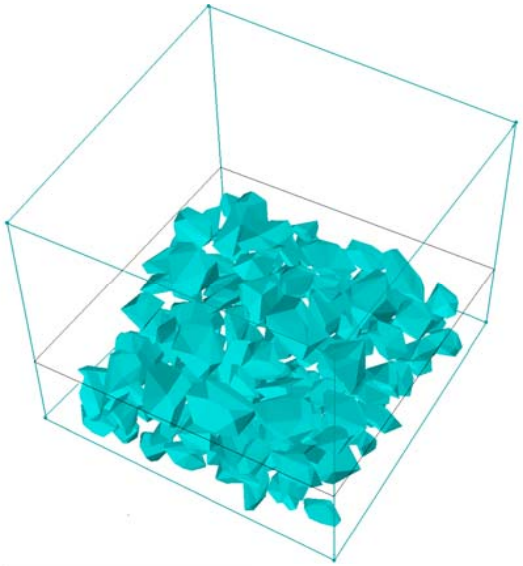
Real fire behaviour and effects on structures

- Behaviour of structures/materials under extreme conditions, especially fire / blast / /seismic/ – computational and experimental
- Failure mechanisms under such conditions, both locally and globally
- Resilience through material and local enhancement (e.g., through optimisation of material composition with micro-mesoscale analysis)
- Resilience through enhancing robustness of system – ongoing development of new metric for robustness assessment of structural systems

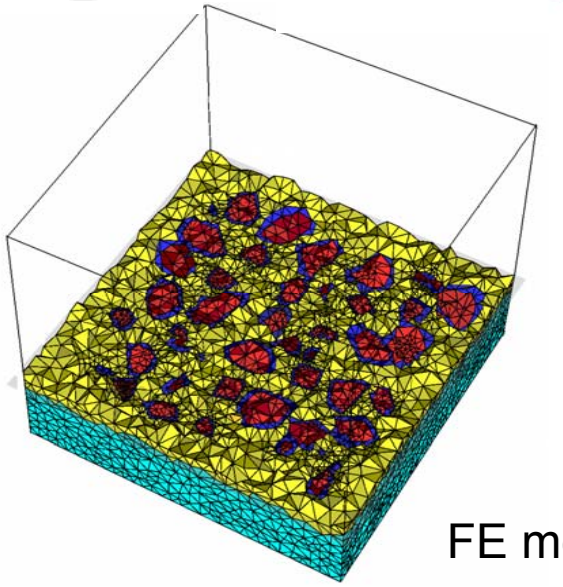
Resilience of structures under extreme conditions







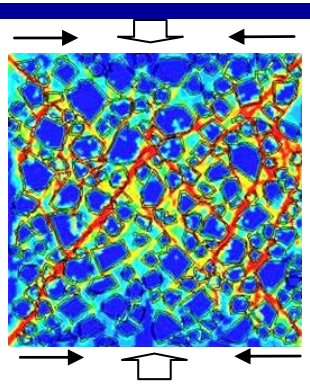
3D random meso-structure



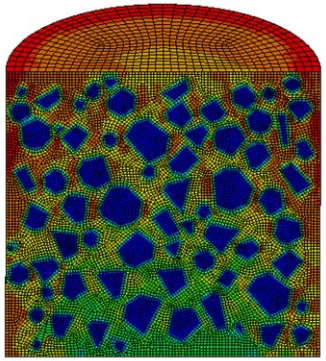
FE mesh

- High fidelity micro-meso scale analysis of cementituous materials (3D random particles in finite elements: unique at UoE)
- Optimisation of material composition for best resilience under specific conditions e.g. dynamic / elevated temperature
- Assessment and optimal design of composites made of recycled materials
- Extension to multi-scale modelling for analysis of environmental effects concerning durability and degradation
- Well-suited also for investigation of effective repairing/retrofitting, as well as effective monitoring and NDT techniques

Resilience of structures under extreme conditions

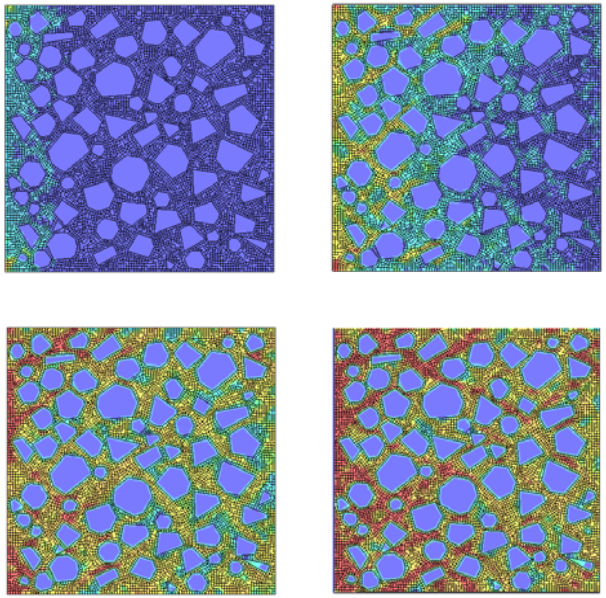


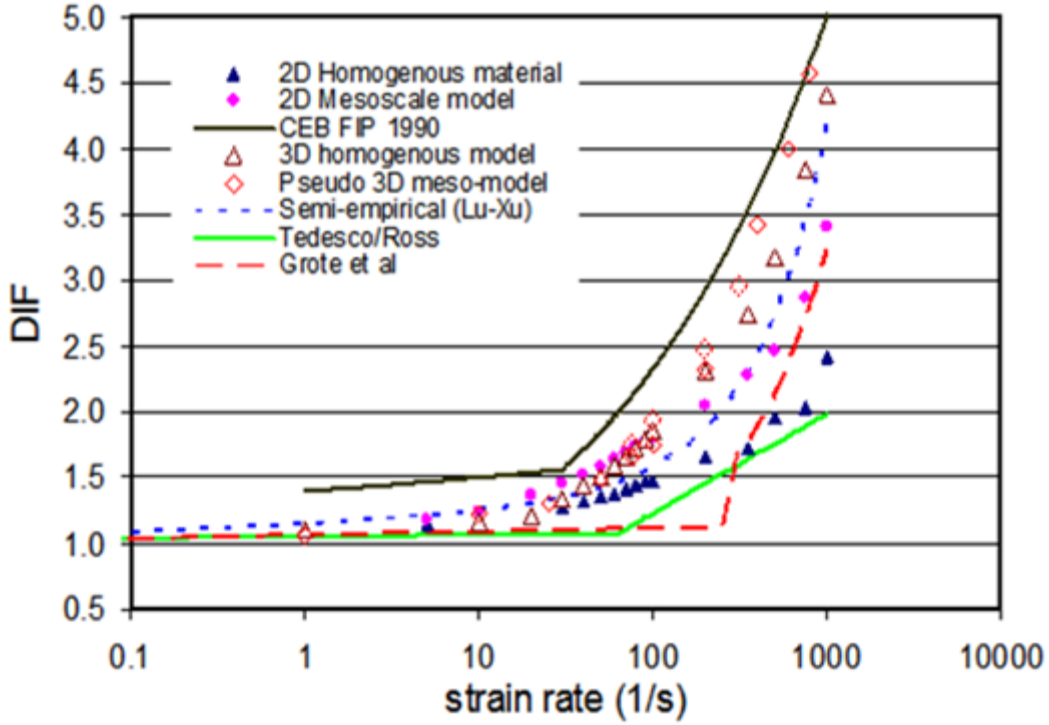
Static



Dynamic

- Example application: dynamic strain rate effects on behaviour of brittle composites





Predicting the life of bridge cable stays

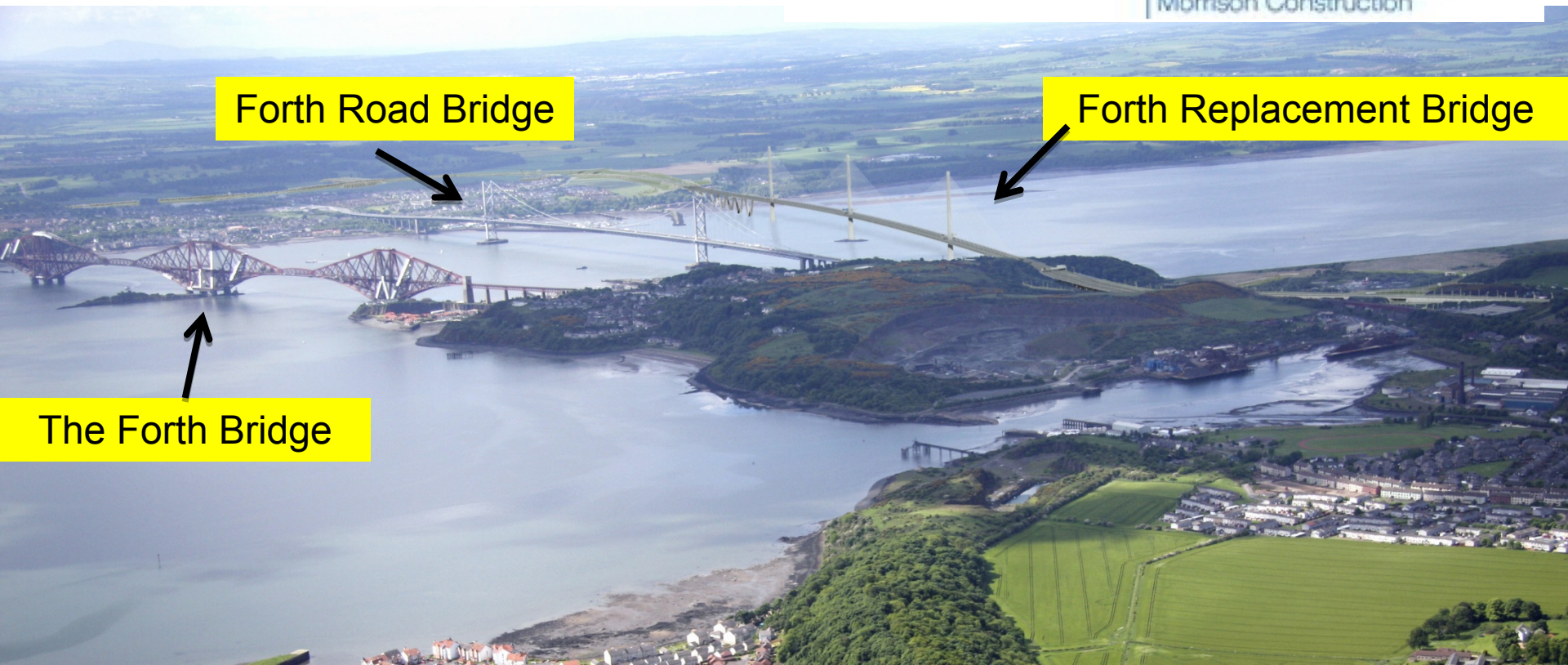
Acoustic Emission Relaxation Ratio:

Achieves

Sustainability & Resilience

Forth Crossing Bridge Constructors

HOCHTIEF Solutions
American Bridge International
DRAGADOS
Morrison Construction



Corrosion of stay cables

- poses a serious problem for cable stayed bridges.
- Stay cables - sheathing opposed to wrapping wires, & paste layer typically used to protect suspension cables.
- Cracked sheathing develops a humid microclimate - leads to fast deterioration of the high strength steel wires.

Collaborations:

Forth Crossing Bridge Constructors

Bridge Technology Consulting, New York, NY, USA

Professor Masayasu Ohtsu, Kumamoto University, Japan

Cracked sheathing on Luling Bridge in Louisiana, USA

- cable stayed bridge opened to traffic in October 1983.
- stays' protective 1⁄4-inch to 1-inch thick, high-density polyethylene sheathing has deteriorated leading to the corrosion of wires.
- In 2008, in Louisiana - most economical solution - replace all 72 stay cables.
- $30-million project to replace cables

Köhlbrand Bridge, Hamburg, Germany

- Opened in 1974; 88 locked coil ropes made of bright wires (non-galvanized), due to fear of hydrogen embrittlement.
- two years in service, during a 1976 inspection 25 broken wires detected, 22 of which were found at the lower cable anchorages - a significant contribution of deicing salt.
- Eventually, all cables had to be replaced.

Maracaibo Bridge, Venezuela

- opened to traffic in 1962. The bridge across the Lake of Maracaibo, Venezuela,
- Main span supported with 16 locked coil ropes.
- Between 1974 & 1978, several broken wires were detected.
- In-depth inspection at the end of 1978 showed more than 500 broken wires.
- In early 1979, three ropes had completely severed. Bridge was re-cabled

Gutenberg-Ritcher formula can be modified as:

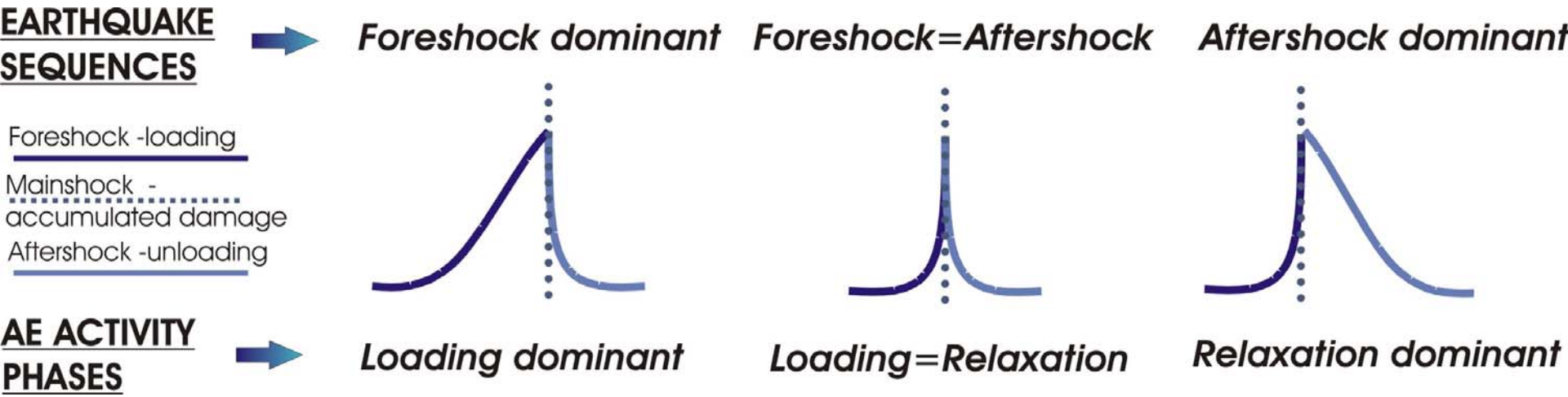
$$\log_{10} N = a - b' A_{dB}$$

where A_{dB} is the peak-amplitude of the AE events in decibels:

$$A_{dB} = 10 \log_{10} A_{max}^2 = 20 \log_{10} A_{max}$$

b-value	*Cracking process*
$1.0 \leq b - value < 1.2$	Implies that the channel is very near to a large crack; i.e. macrocracks forming
$1.2 < b - value \leq 1.7$	Uniformly distributed cracking; i.e. macrocracks are constant
$b - value > 1.7$	Microcracks are dominant or macrocracks are opening

"Relaxation Ratio"



$$\textit{RELAXATION RATIO} = \frac{\text{Average energy during unloading phase}}{\text{Average energy during loading phase}}$$

Collaboration:

Prof Masayasu Ohtsu, Kumamoto University, Japan

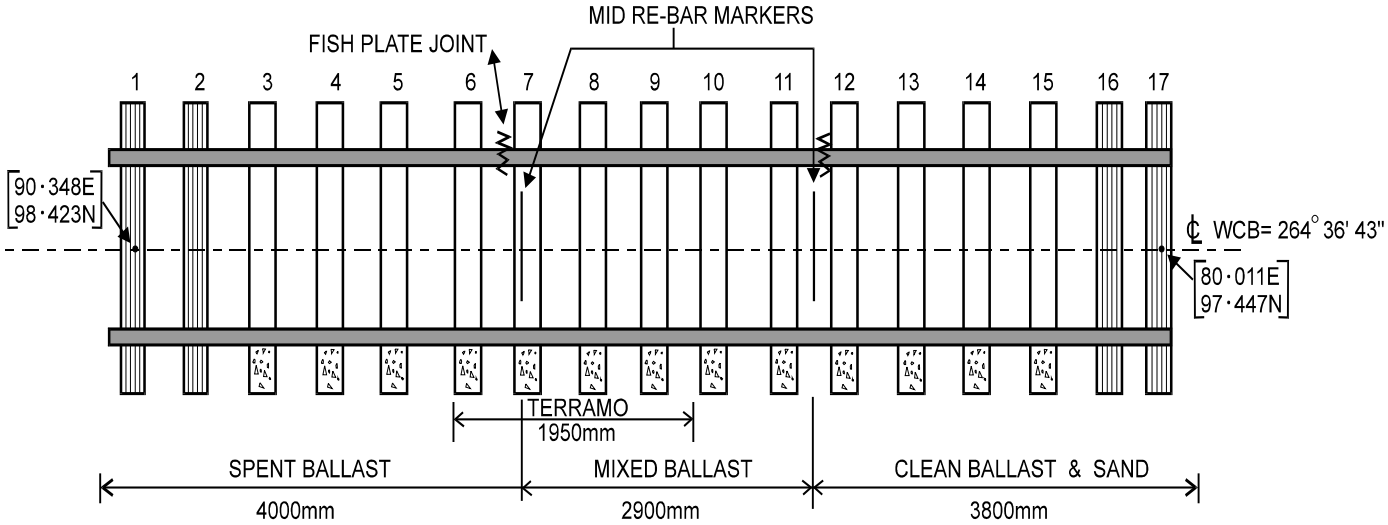
Key AE Conclusions

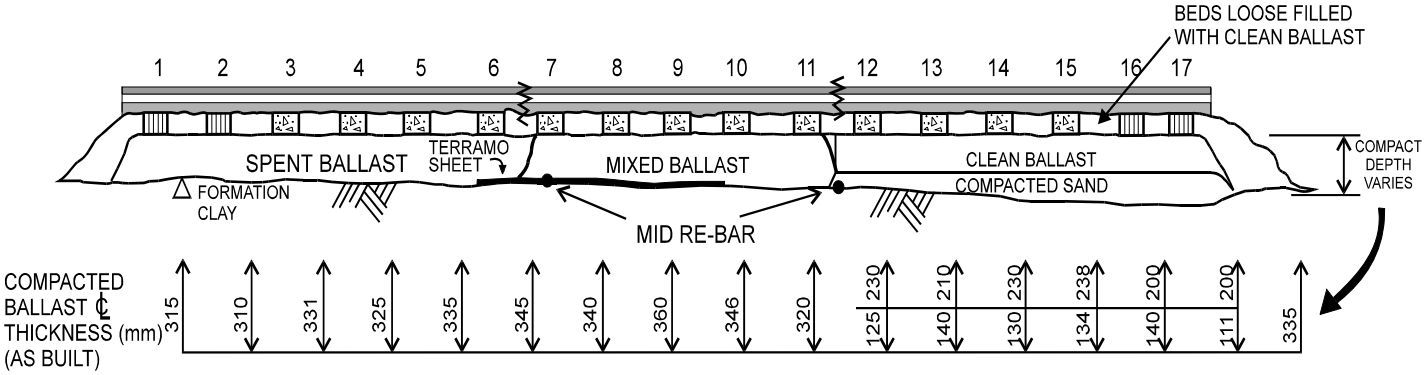
- *RELAXATION RATIO =*

  $$\frac{\text{average energy during unloading phase}}{\text{average energy during loading phase}}$$

- Relaxation ratio became > 1 when approx 45% of ultimate bending load was reached
- **Predict failure load of RC beams by multiplying load at Relaxation Ratio of 1 - by a factor of 2.2**
- **Limitations: Loading rate & concrete mix?**

Simplified Railroad Test Rig: General Arrangement

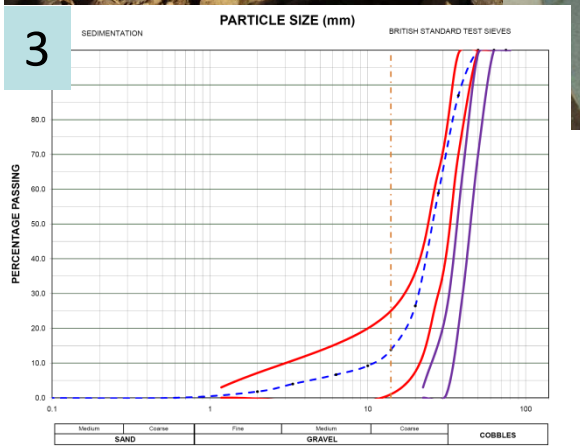




Edinburgh Rail Trackbed Test Rig

Particle Size Distribution Results-2009

1	0.90%	Clean
2	1.05%	Moderately Clean
3	0.77%	Clean
4	0.84%	Clean
5	1.37%	Moderately Clean
6	0.79%	Clean
7	3.00%	Moderately Clean
8	4.80%	Moderately Clean
9	7.12%	Moderately Clean
10	7.20%	Moderately Clean
11	0.99%	Clean
12	13.79%	Moderately Fouled
13	17.45%	Moderately Fouled
14	10.79%	Moderately Fouled
15	11.70%	Moderately Fouled
16	20.47%	Fouled



1. Ballast samples collected
2. Shaker distributed particles in sieves
3. PSD charts produced and analysed

Radar Data Collection

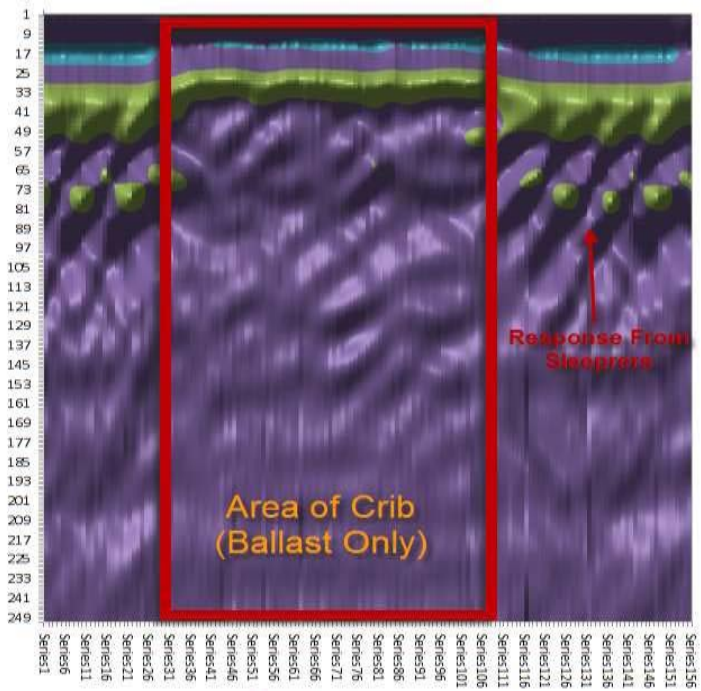
- Data collected - 500MHz, 900MHz, 1.0GHz, 1.6GHz, 2.6GHz antennas
- Deterioration based on wave scattering
- Compared with particle size distribution analysis of cribs
- Each antenna - scanned the length of the track in both orientations.

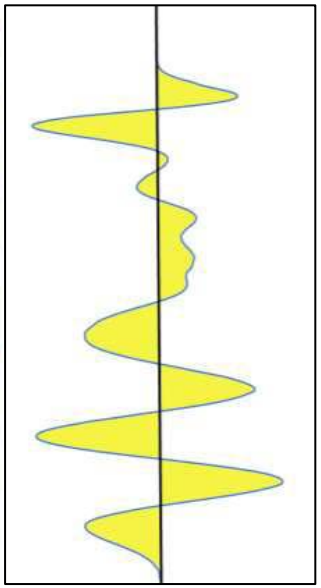
Diagram of Scanning Procedure

Photo of Scanning in Progress

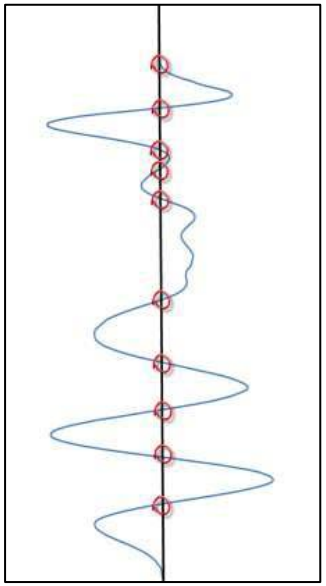
Metrics to Determine Scattering

- Length of track scanned - data for each crib isolated.
- 3 metrics developed to numerically analyse crib radar data:
  - Calculation of area of each individual radar scan
  - Calculation of number of times each individual radar scan X-es axis
  - Calculation of number of inflection points on each individual radar scan

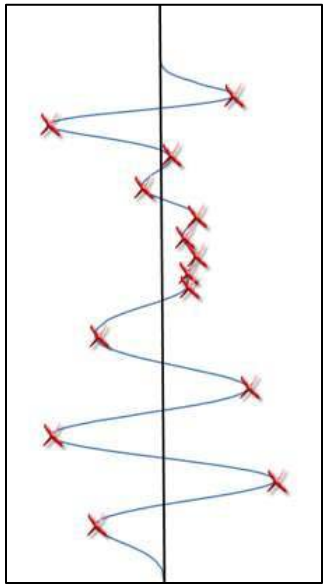




Typical Area Of Scan



Typical Axis Crossings

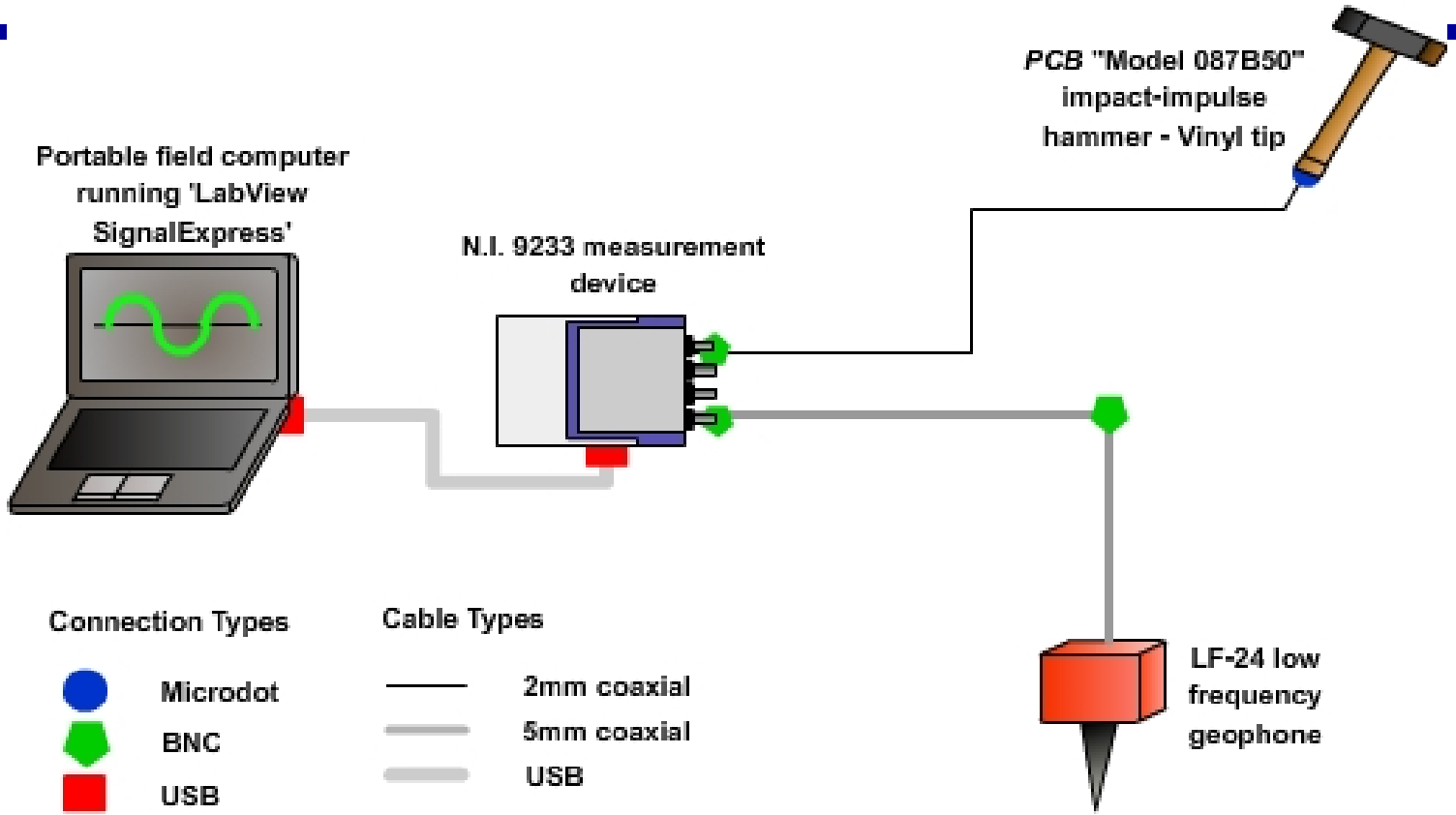


Typical Inflection Points

Fouling index correlation factors for full-time range scattering analysis

Antenna	Orien.	Scan Area			Axis Crossings			Inflection Points		
		Full Range	Com. Range	Prop. Range	Full Range	Com. Range	Prop. Range	Full Range	Com. Range	Prop. Range
500 MHz	Perp.	0.809	0.019	0.499	0.286	-0.356	0.378	0.462	0.616	0.619
	Paral.	0.924	0.566	0.816	0.295	0.674	0.613	0.034	0.133	0.213
900 MHz	Perp.	0.740	0.569	0.502	-0.599	-0.157	-0.074	-0.719	-0.488	-0.392
	Paral.	0.756	0.634	0.648	-0.439	0.076	0.041	-0.802	-0.289	-0.340
1.0 GHz	Perp.	0.436	0.519	0.519	-0.336	0.072	0.149	-0.481	-0.296	-0.423
	Paral.	0.678	0.641	0.679	-0.061	0.504	0.234	-0.340	-0.006	-0.057
1.6 GHz	Perp.	-0.185	-0.228	-0.257	-0.327	-0.388	0.180	-0.251	-0.079	0.448
	Paral.	0.545	0.672	0.676	-0.274	-0.466	-0.551	-0.221	-0.306	0.136
2.6 GHz	Perp.	0.282	0.111	0.722	-0.120	0.065	0.000	-0.647	-0.683	-0.563
	Paral.	0.326	0.342	0.301	-0.306	-0.140	0.000	-0.687	-0.721	0.035

Experimental Setups



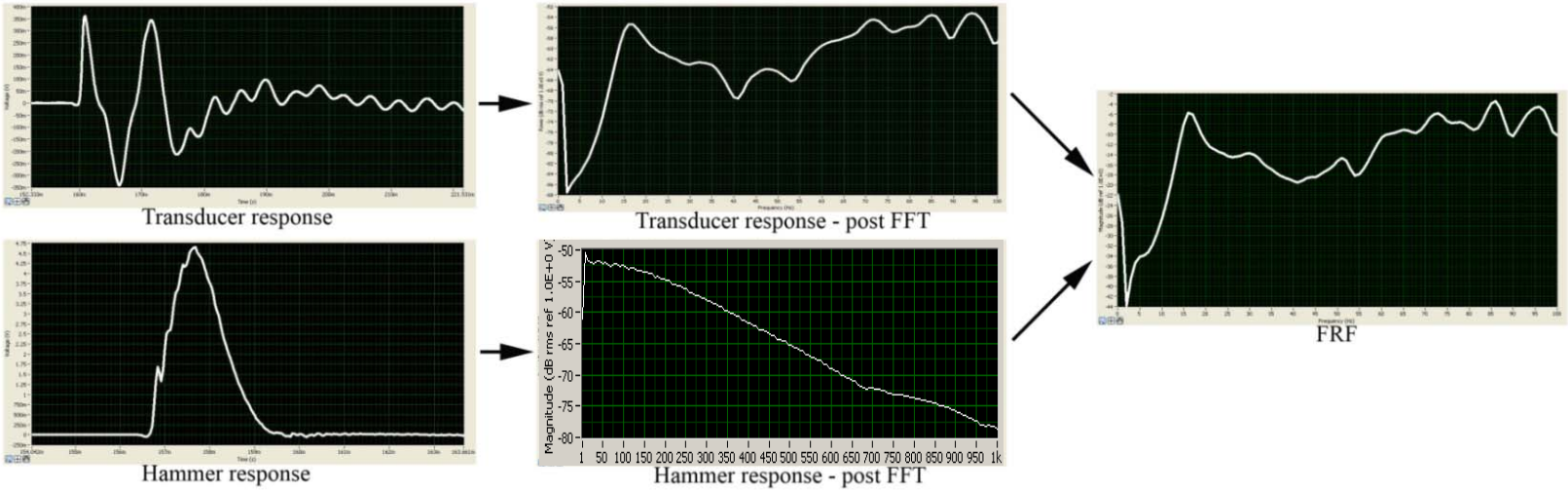
- Hammer imparted force onto various parts of railtrack structure
- Geophone measured response

Setup 1	Ballast impacted	Ballast measured
Setup 2	Ballast impacted	Tie measured
Setup 3	Ballast impacted	Rail measured
Setup 4	Rail impacted	Ballast measured
Setup 5	Tie impacted	Ballast measured

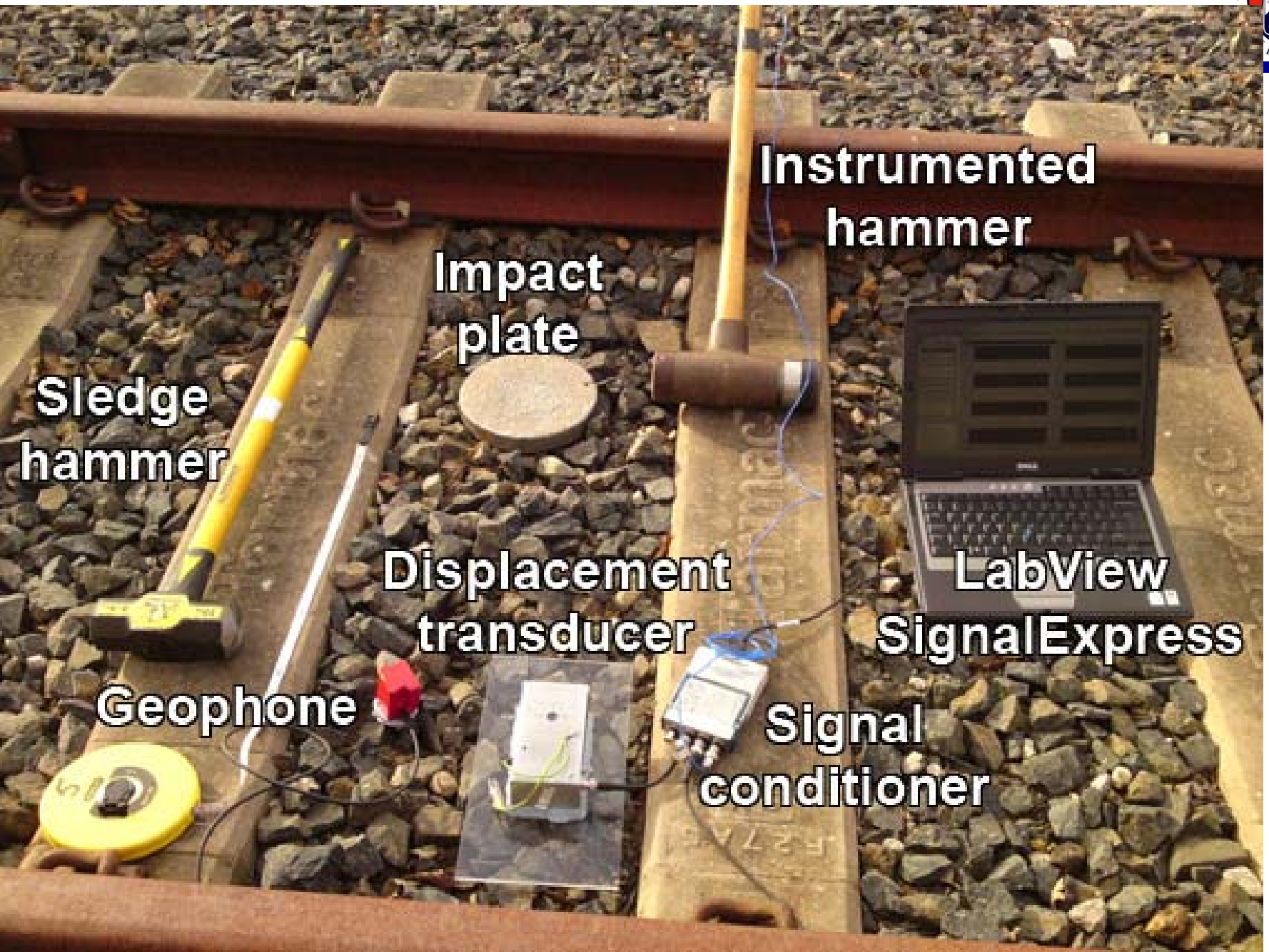
Impulse or Frequency Response Function - FRF

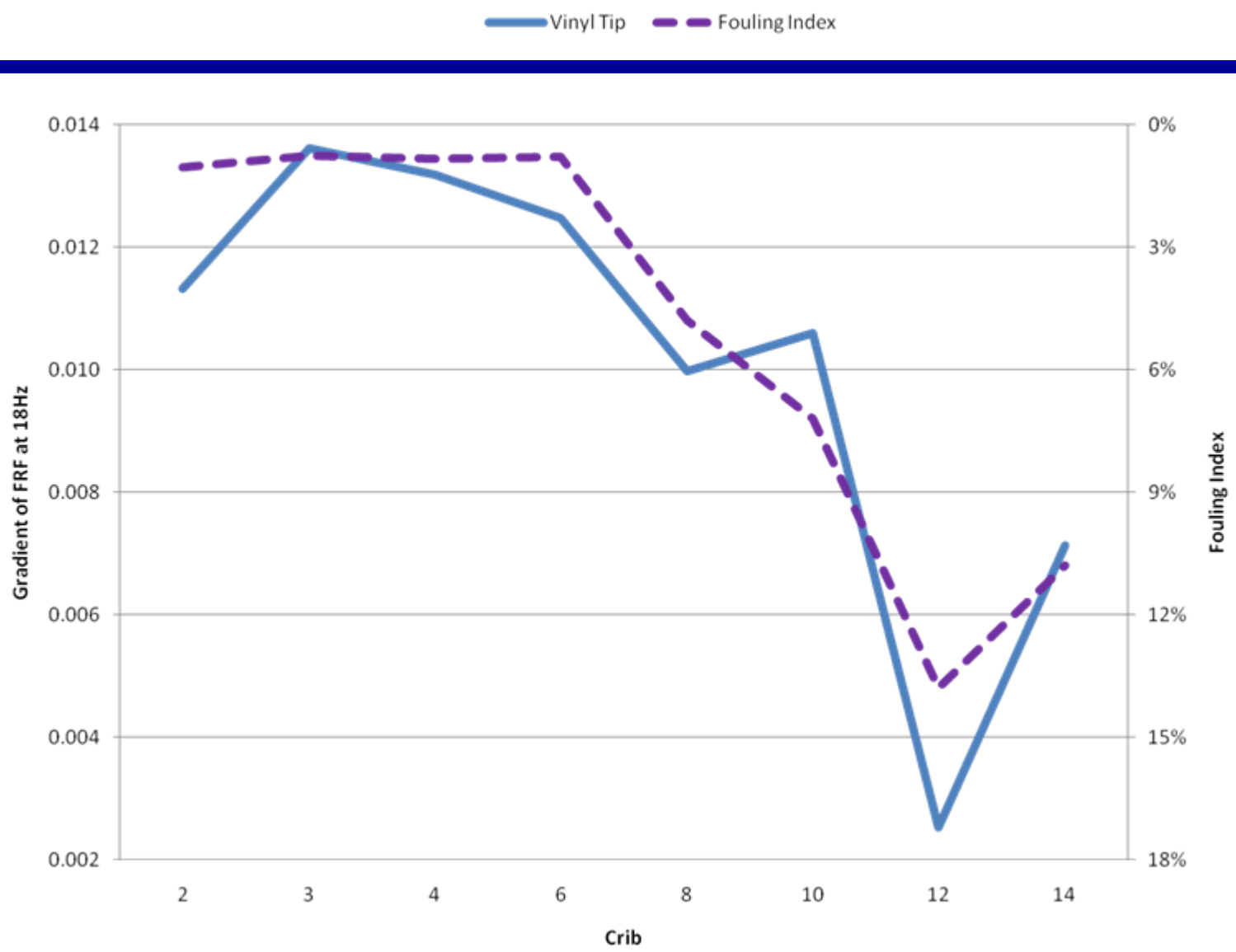
- Impulse or Frequency Response Function (FRF) can determine structural properties – known as Impulse Response
- FRF normalises the effects of magnitude and type of loading
- Thus, low frequency content can be related to track stiffness

$$\text{FRF} = \frac{\text{auto spectrum of geophone response}}{\text{auto spectrum of hammer impact}}$$



Impulse Response





Hit ballast, measure ballast 18Hz gradient results

Railway Enginering

- Design Guidelines of High Speed Rail
- GPR & Impulse Response correlated to ballast Fouling Index
- More cost effective – non-invasive quantification of ballast
- Better targeted maintenance & lower cost

Collaborations: Heriot Watt University, Edinburgh

Network Rail, RSSB, AECOM, Holequest, Carillion, Balfour Beatty, XiTrack

EPSRC: EP/H029397/1

Development of Design Guidelines for High-speed Railway Track Including Critical Track Velocities and Track Mitigation Strategies

April 2010 – March 2013

Process Modelling

- The stochastic nature of construction means non-deterministic techniques are needed for planning, estimating & control
- Previously, simulation & regression analysis have been used successfully
- More sophisticated methods are now employed with very good results:
  - Neural Networks
  - Case based reasoning
  - Hybrids

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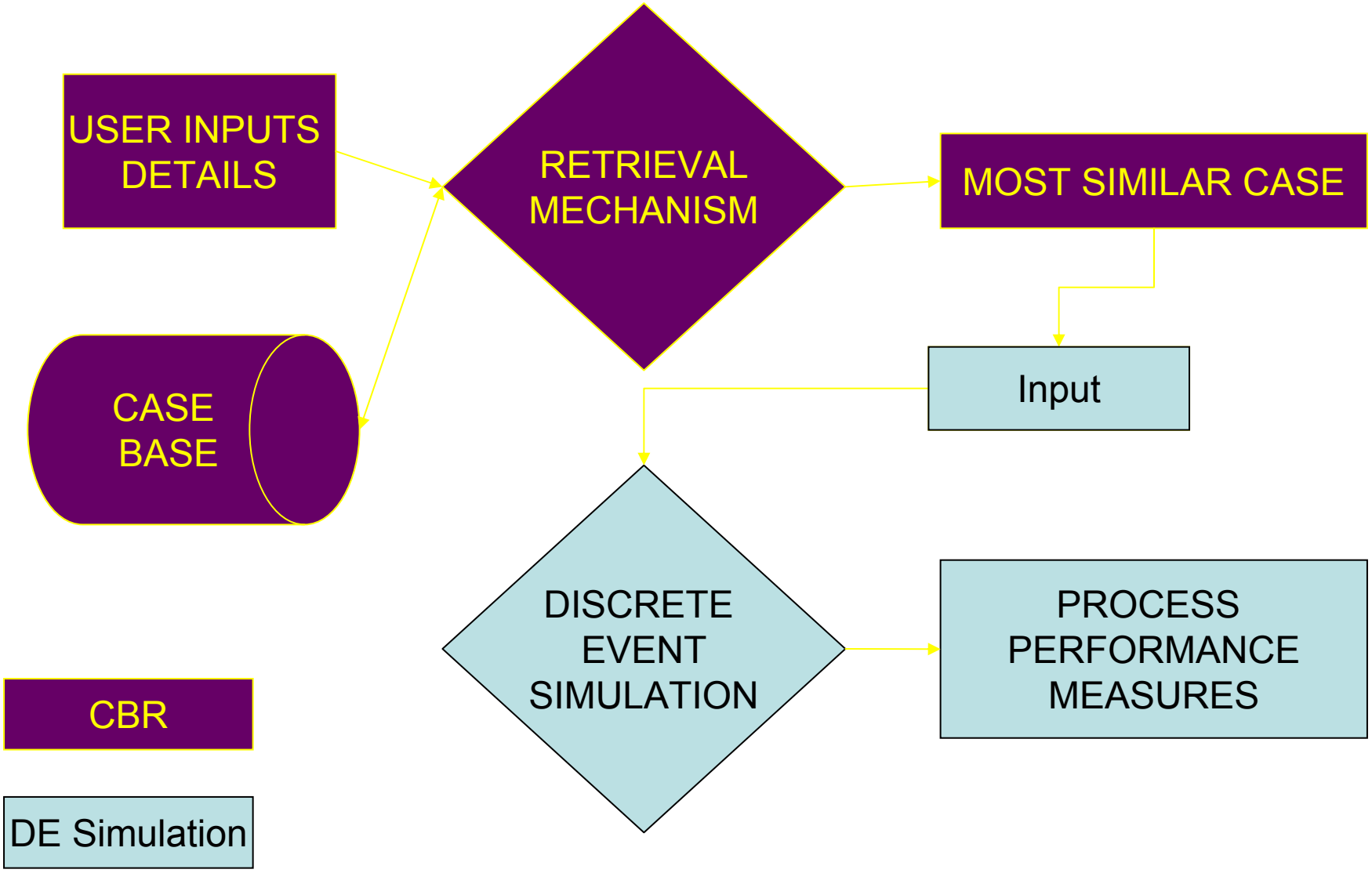
Case Based Reasoning (CBR) + Simulation Hybrid



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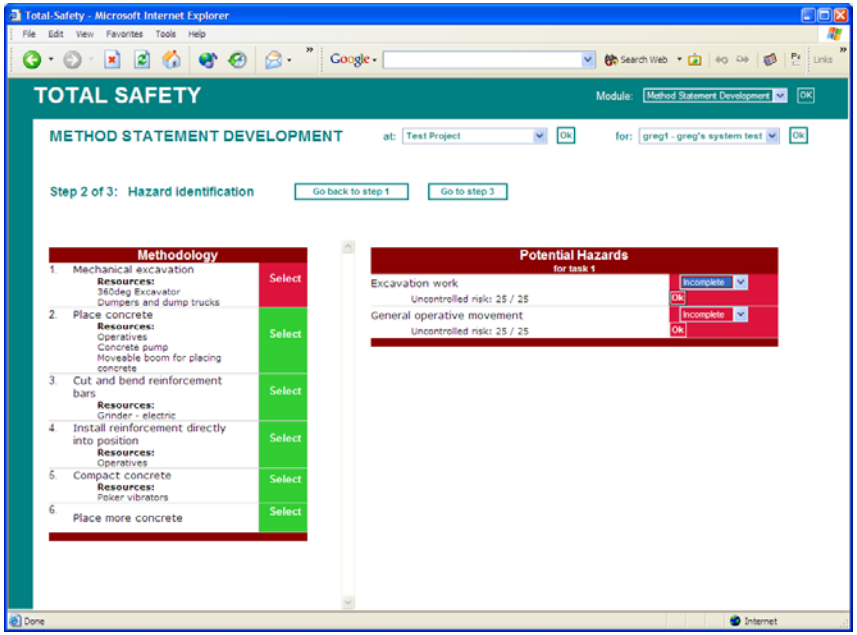
Safety risk management systems



- web enabled central database system
- allows company wide knowledge to be implemented on each project
- tackles the continuing problem of construction fatalities
- Knowledge ‘search’ enhanced through use of case-based reasoning

FIF - Conclusions

- More informed analysis & design
- Lower initial construction cost
- Lower lifetime cost
- Better infrastructure utilisation

Mike Forde

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