Imperial College – Structures Section

* = named in the FIF proposal

Imperial College London

STRUCTURAL ENGINEERING

Dr Leroy Gardner

Steel structures

Dr Robert Vollum

Concrete structures

Dr Ana Ruiz-Teran

Bridges

+ EXTREME LOADING

Prof Ahmed Elghazouli*

Earthquake, fire, blast

Dr Luke Louca

Blast

Dr Peter Stafford

Earthquake

STRUCTURAL MECHANICS

Prof Bassam Izzuddin*

Computational Mechanics

Dr Lorenzo Macorini

Computational Mechanics

Dr Ahmer Wadee

Structural stability

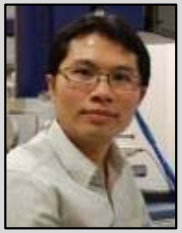
Dr Andew Phillips

Bio-mechanics

CONCRETE DURABILITY

Prof Nick Buenfeld*

Durability of concrete structures



Dr Hong Wong

Concrete microstructure

2 areas in which we would particularly like to contribute...

Imperial College London

Area	Main contacts:
1. RESPONSE UNDER EXTREME LOADING	
Measurements -	Prof Ahmed Elghazouli
Modelling -	Prof Bassam Izzuddin
2. DURABILITY OF CONCRETE STRUCTURES -	Prof Nick Buenfeld

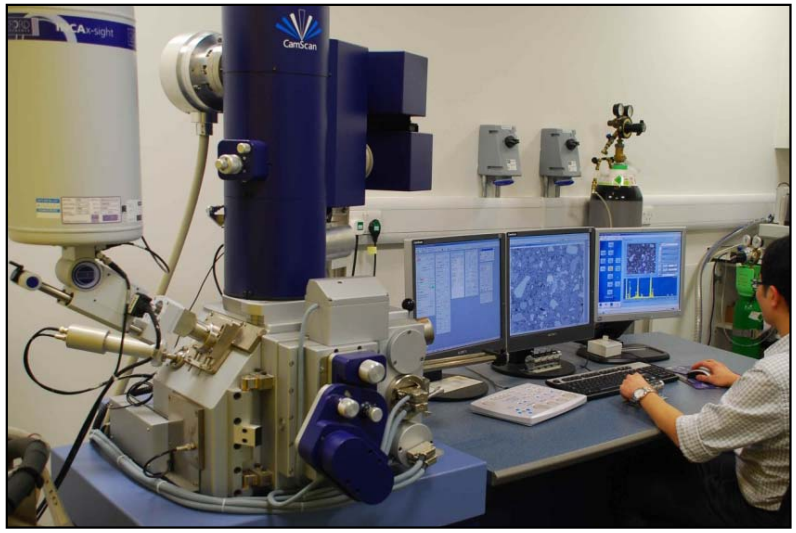
New Structures Laboratories

Imperial College London

Structural testing

Preparation Areas

Mechanical Workshops



Durability Labs

Structures Lab testing facilities

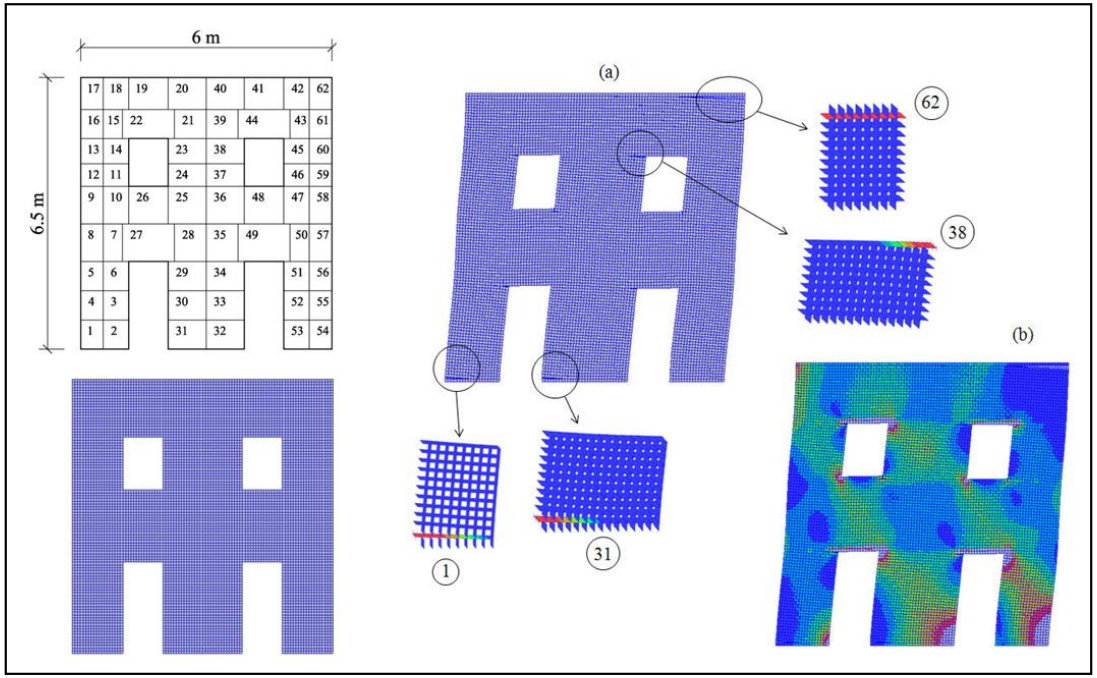
Imperial College London

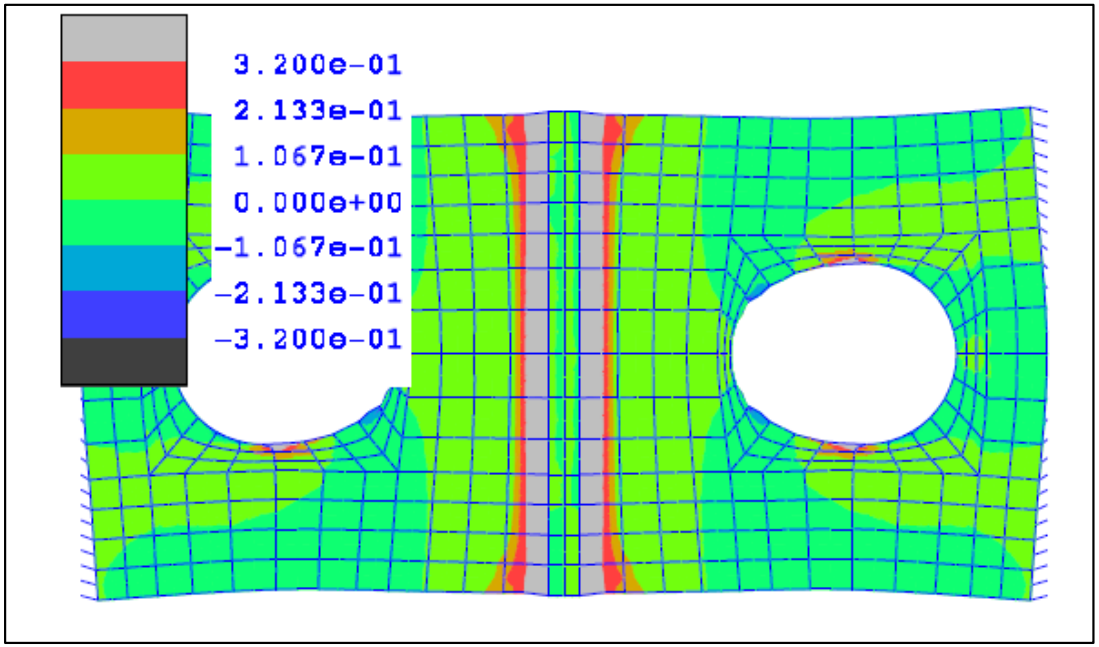
- Controlled-rate load testing up to 10MN.
- Bi-axial testing of material and structural specimens.
- Cylindrical triaxial testing of materials at up to 700 MPa radial stress.
- High rate testing of specimens by impact and rapid hydraulic systems.
- Cyclic/fatigue testing of components.
- Material creep testing.
- Fixing technology for concrete and masonry.
- Environmental specimen conditioning and elevated temperature testing.
- Range of instrumentation and data acquisition systems.

Computational Structural Mechanics

Imperial College London

- ***ADAPTIC***: advanced nonlinear analysis program developed at Imperial College over past 20 years
- Blast, fire, earthquake and extreme static loading
- Steel, reinforced concrete, composite and masonry structures
- Whole building response: frame, slabs, walls, connections,…
- Geometric and material nonlinearity
- Robust and efficient solution procedures
- Modelling of large scale structures using High Performance Computing (HPC)
- Coupled modelling of nonlinear soil-structure interaction

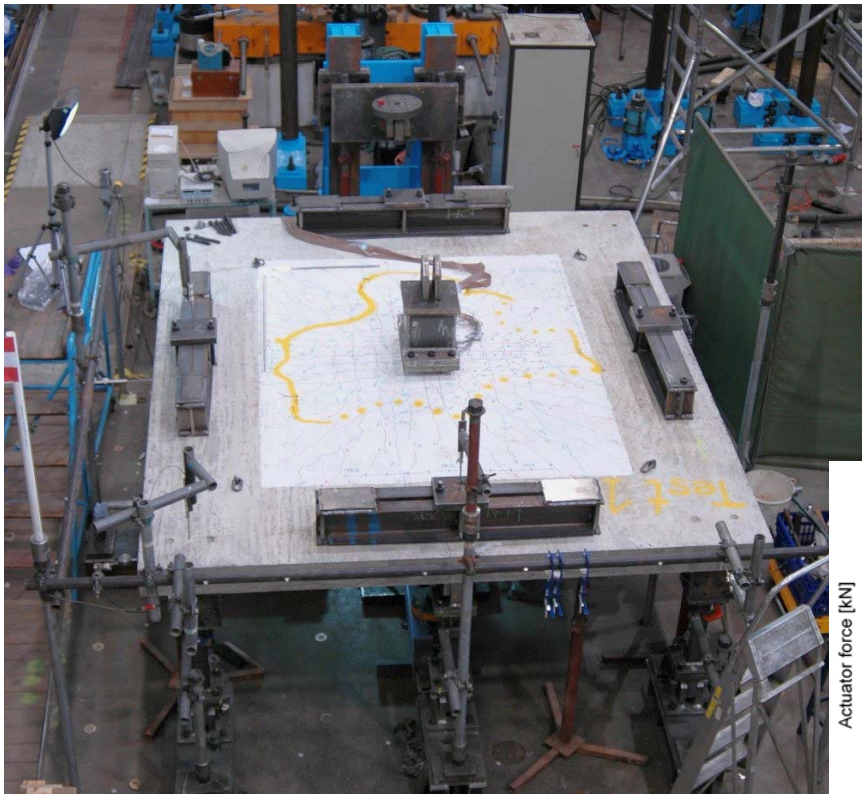


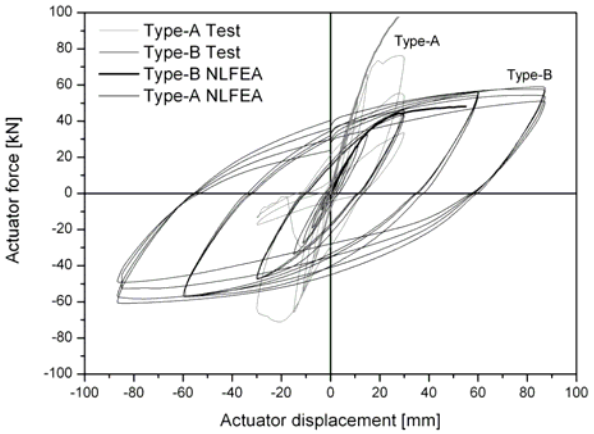


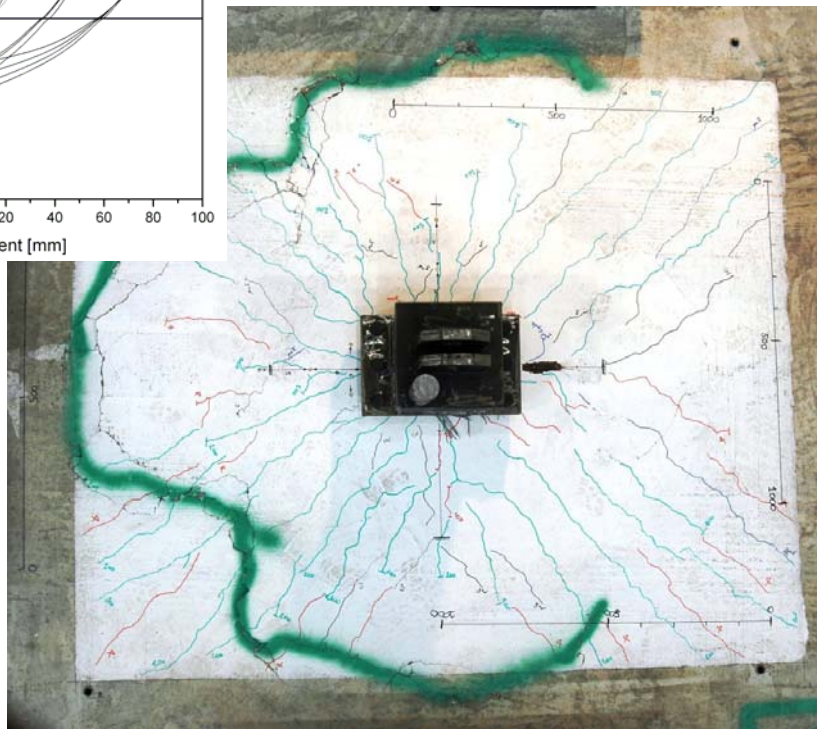
http://www.imperial.ac.uk/csm

Response under Extreme Loading - Earthquake

Imperial College London







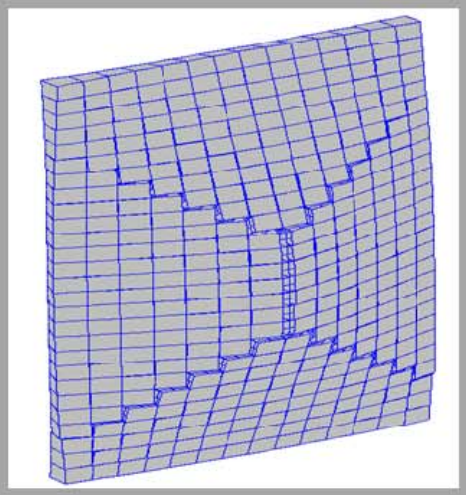
- Experimental, analytical and design on seismic response of structures
- Application to steel, concrete, composite, and masonry structures
- Significant involvement in professional activities - code development and consulting
- Recent/current research projects funded by: CEC/EU, EPSRC, manufacturers, insurers

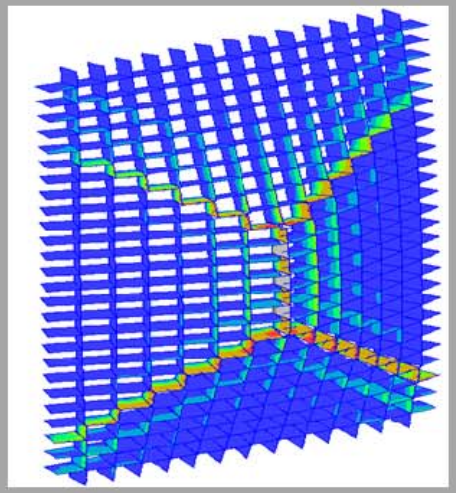
Response under Extreme Loading – Blast & Impact

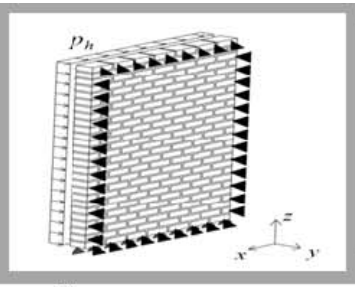
Imperial College London

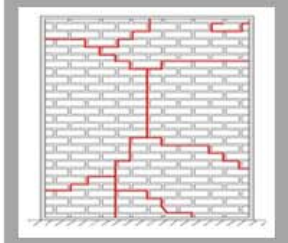
- Numerical & experimental assessment of structures
- Dedicated impact and triaxial testing facilities for high-rate loading
- Application to carbon/stainless steel, concrete, and polymeric composites
- Significant involvement in professional activities and forensic assessments
- Recent/current research projects funded by: EPSRC, CEC/EU, HSE, QinetiQ, Shell, US Naval Academy

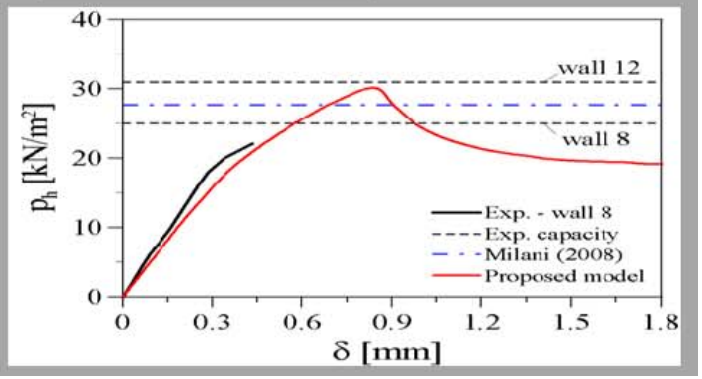
Assessment of blast-damage in buildings







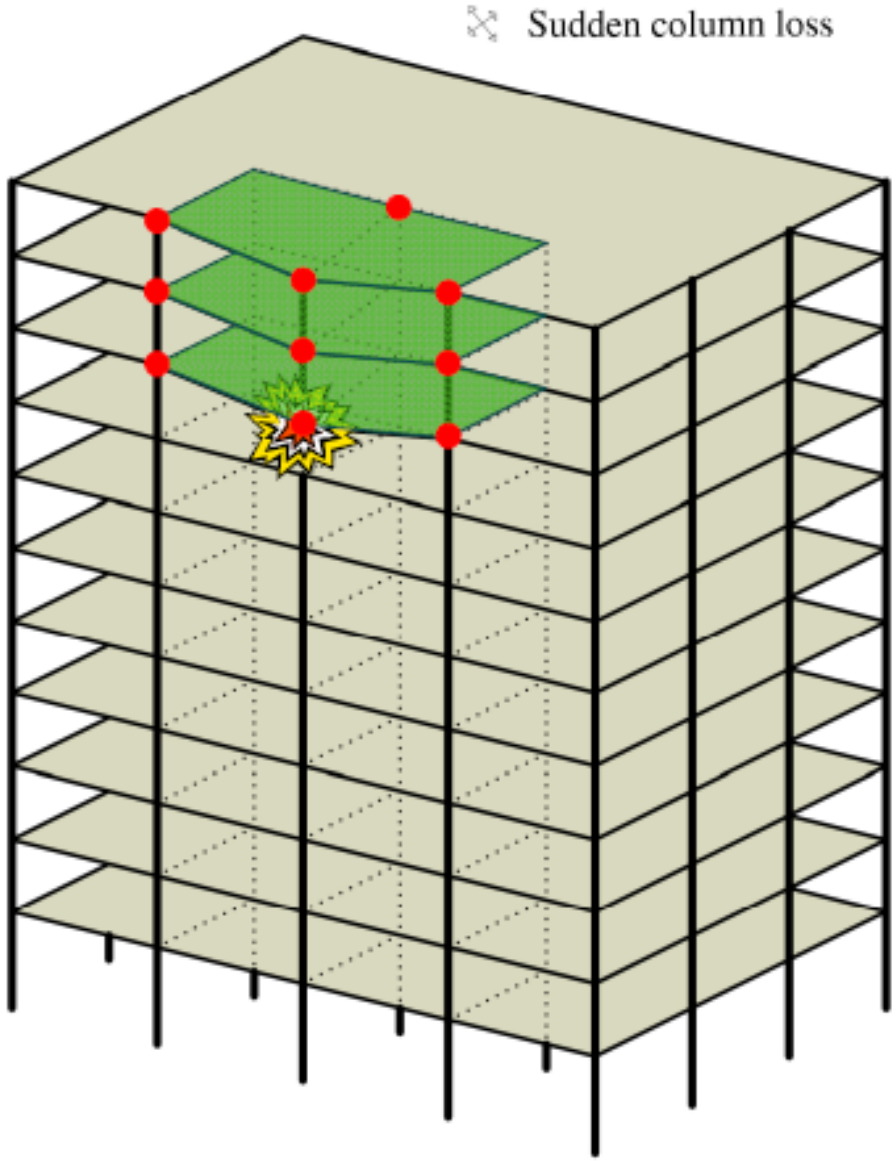




Response under Extreme Loading - Robustness

Imperial College London

- Progressive collapse assessment of multi-storey buildings
- Development of detailed numerical simulation models
- New design-oriented models suitable for use in practice
- Assessment of column-removal and floor-on-floor collapse scenarios
- Complementary experimental studies on members and connections, with focus on quantifying failure
- Recent/current research projects with funding from: CEC/EU, US Homeland Security, Arup, TataSteel, others



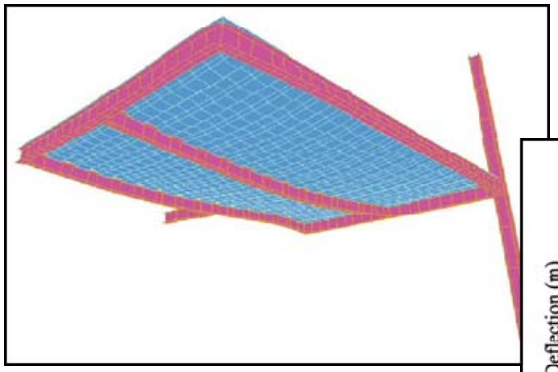
Column-removal and floor-on-floor scenarios

Response under Extreme Loading - Fire

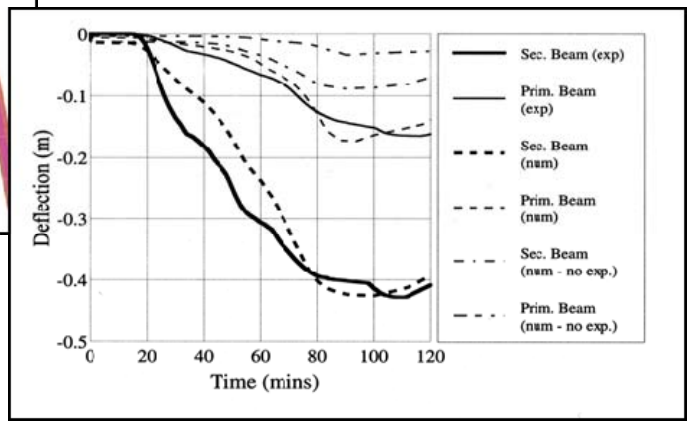
Imperial College London

- Numerical and design assessments of whole steel, concrete and composite building under fire conditions
- Complementary experimental work on components and materials, with focus on failure criteria
- Application to multi-storey buildings, car-parks and off-shore structures
- Significant involvement in leading and concerted UK research including Cardington and follow-up activities
- Recent/current research projects with funding from: EPSRC, CEC/EU, BRE, SCI, industry-other

Building response under compartment fires



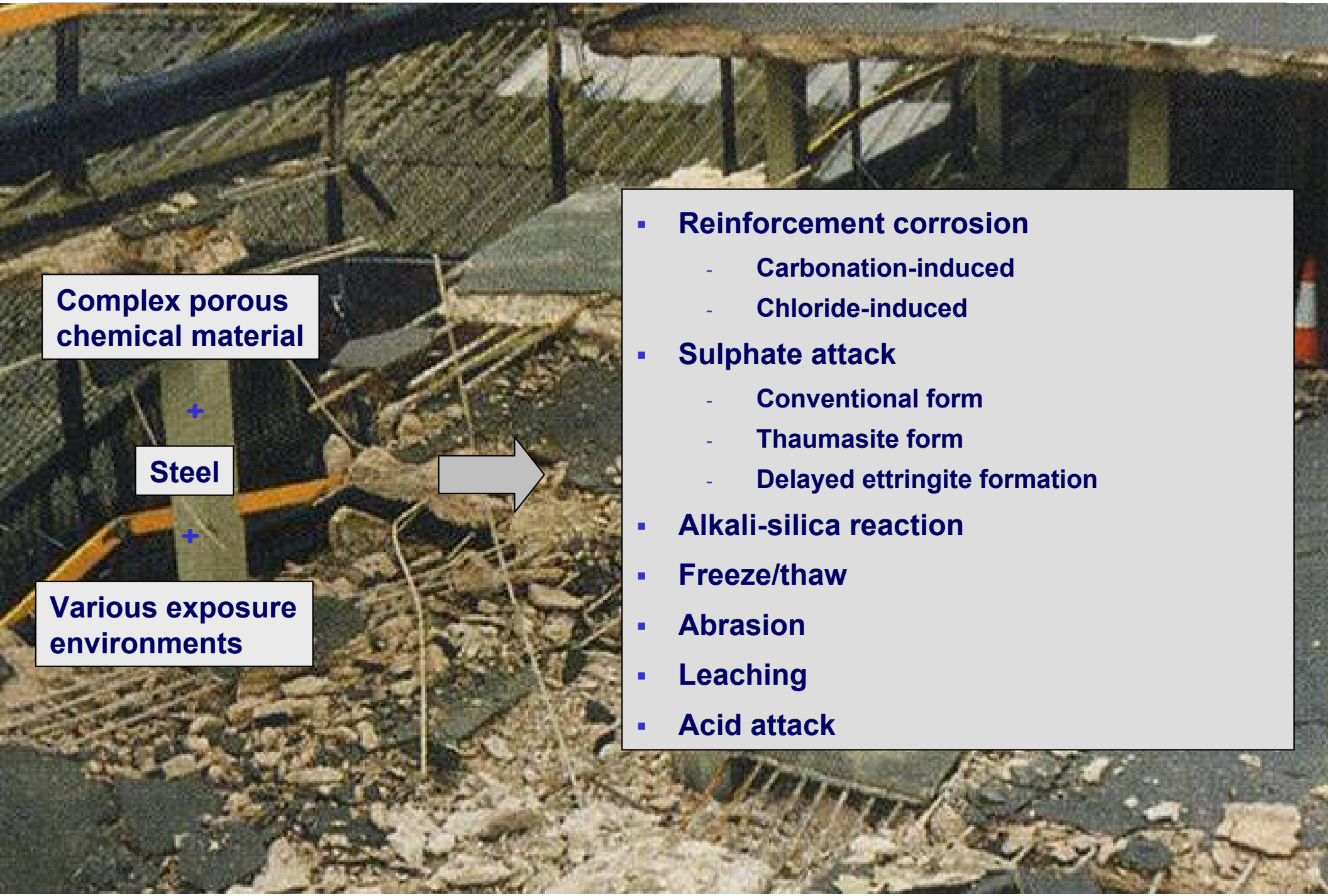
Composite ribbed floor slab under fire



Material and component testing

Durability of Concrete Structures - Deterioration mechanisms

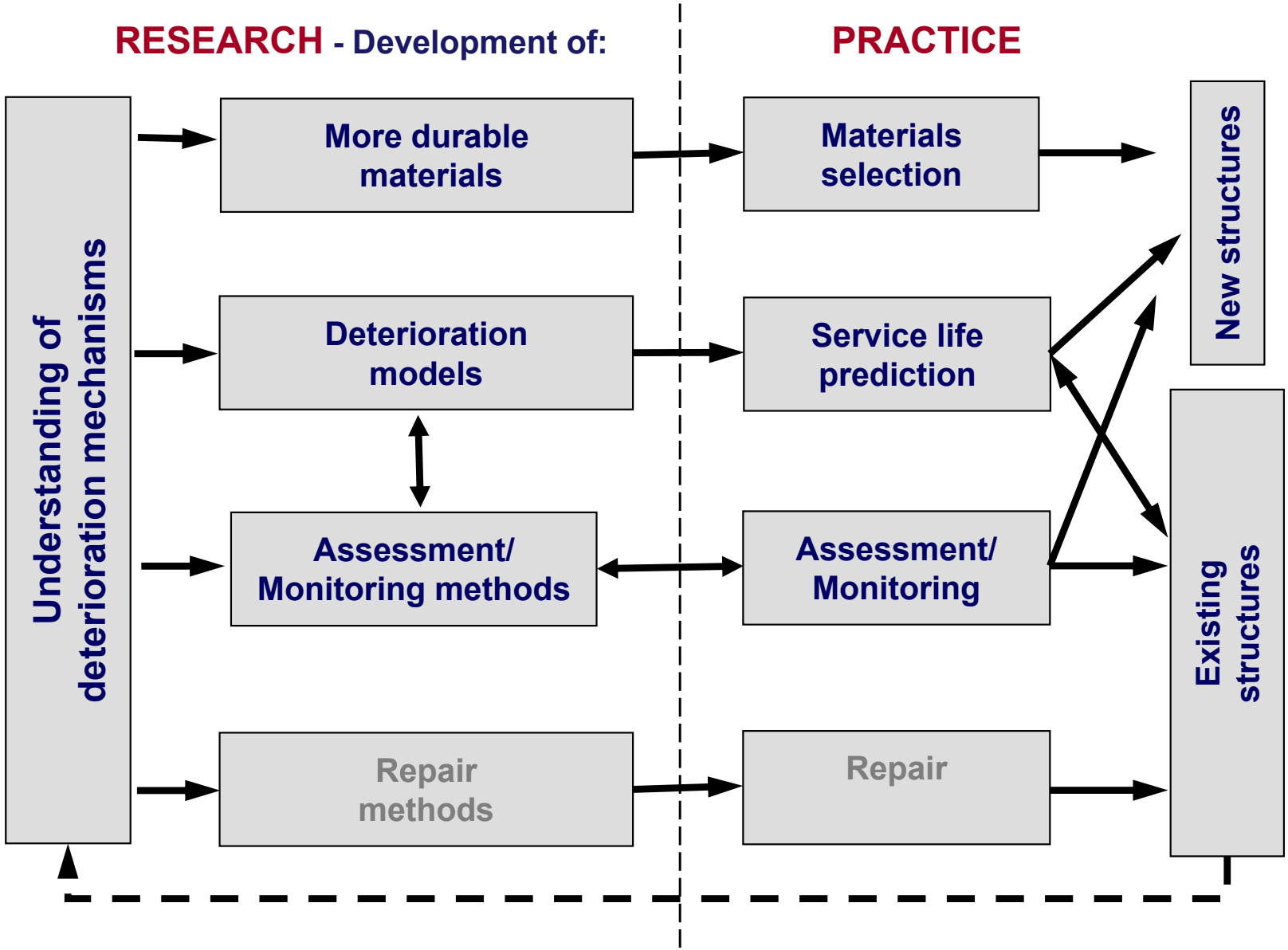
Imperial College London



- **Reinforcement corrosion**
  - Carbonation-induced
  - Chloride-induced
- **Sulphate attack**
  - Conventional form
  - Thaumasite form
  - Delayed ettringite formation
- **Alkali-silica reaction**
- **Freeze/thaw**
- **Abrasion**
- **Leaching**
- **Acid attack**

Concrete Durability Group: Areas of interest

Imperial College London

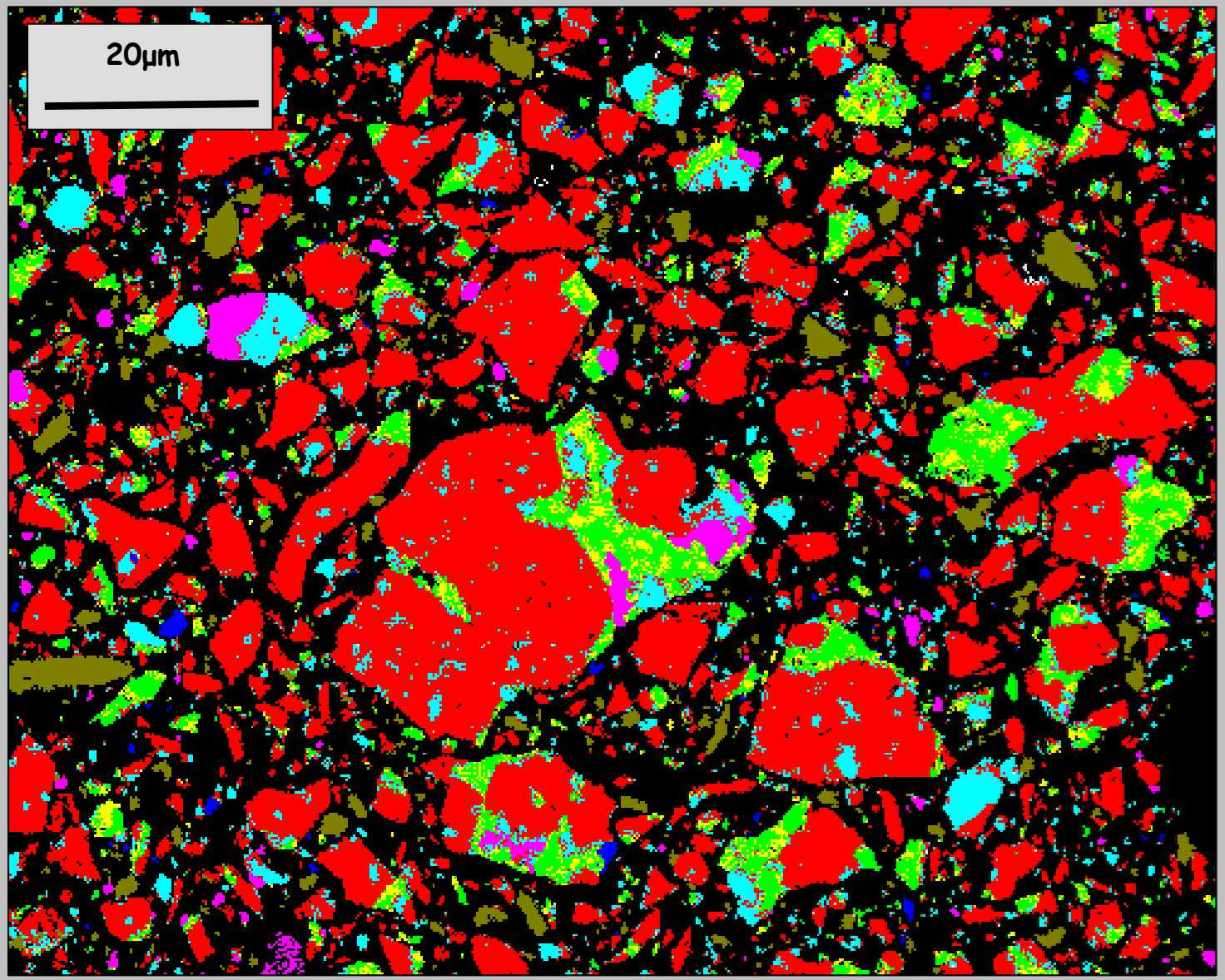


21 EPSRC research projects including 2 Platform Grants

Other projects funded by CEC, DTI, DoT, CIRIA, Lafarge, LUL, ….

Concrete is chemically complex

Imperial College London

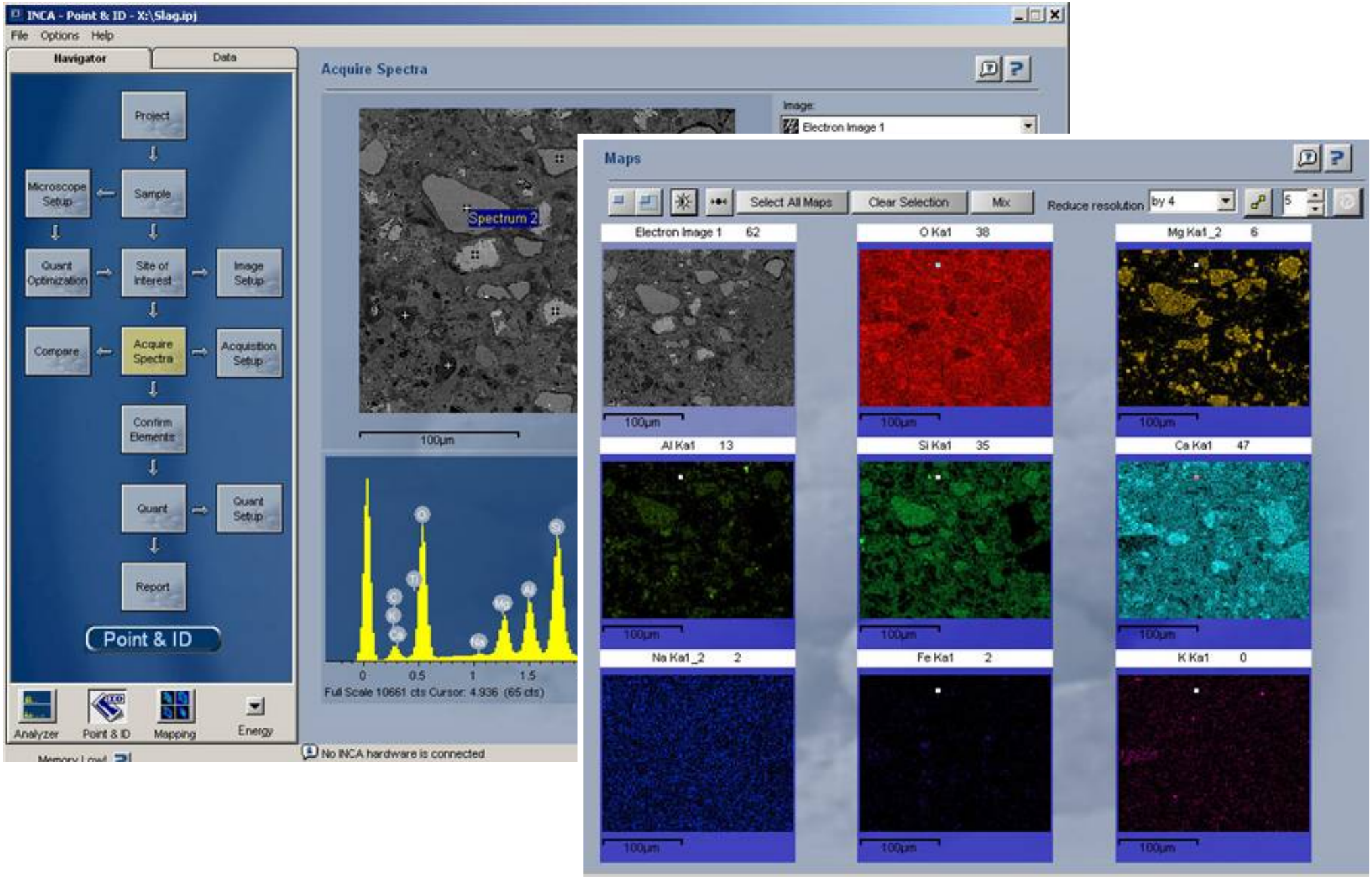


- C_3S
- C_2S
- C_3A
- C_4AF
- Gypsum
- Free lime
- Mg-Ca phase

NIST VCCT Lab: x-ray microanalysis of cement embedded in resin

Elemental composition - EDS & μ-XRF

Imperial College London



Rebar corrosion

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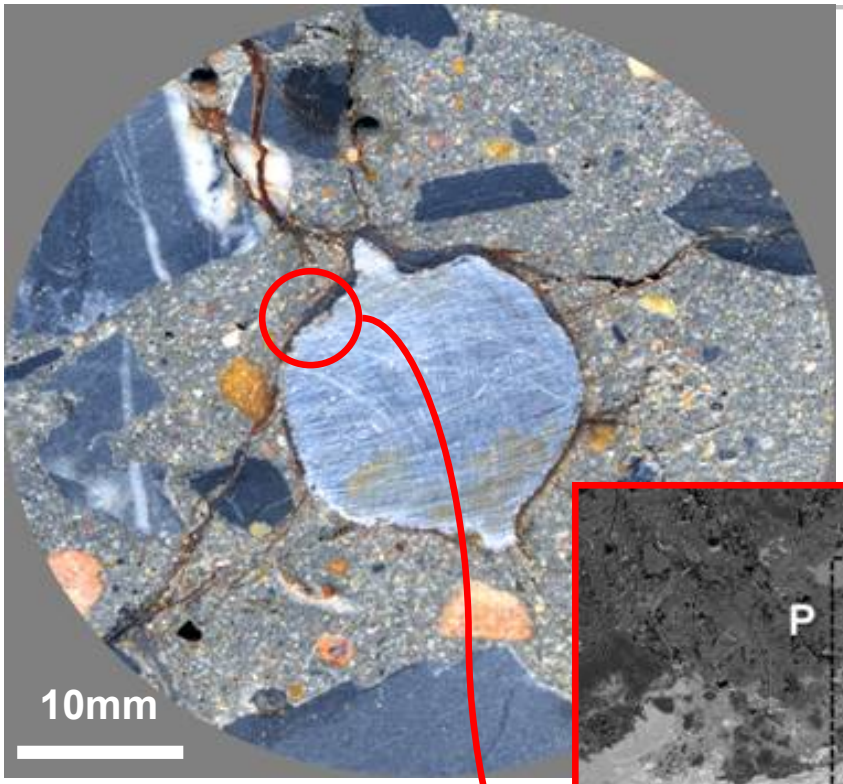
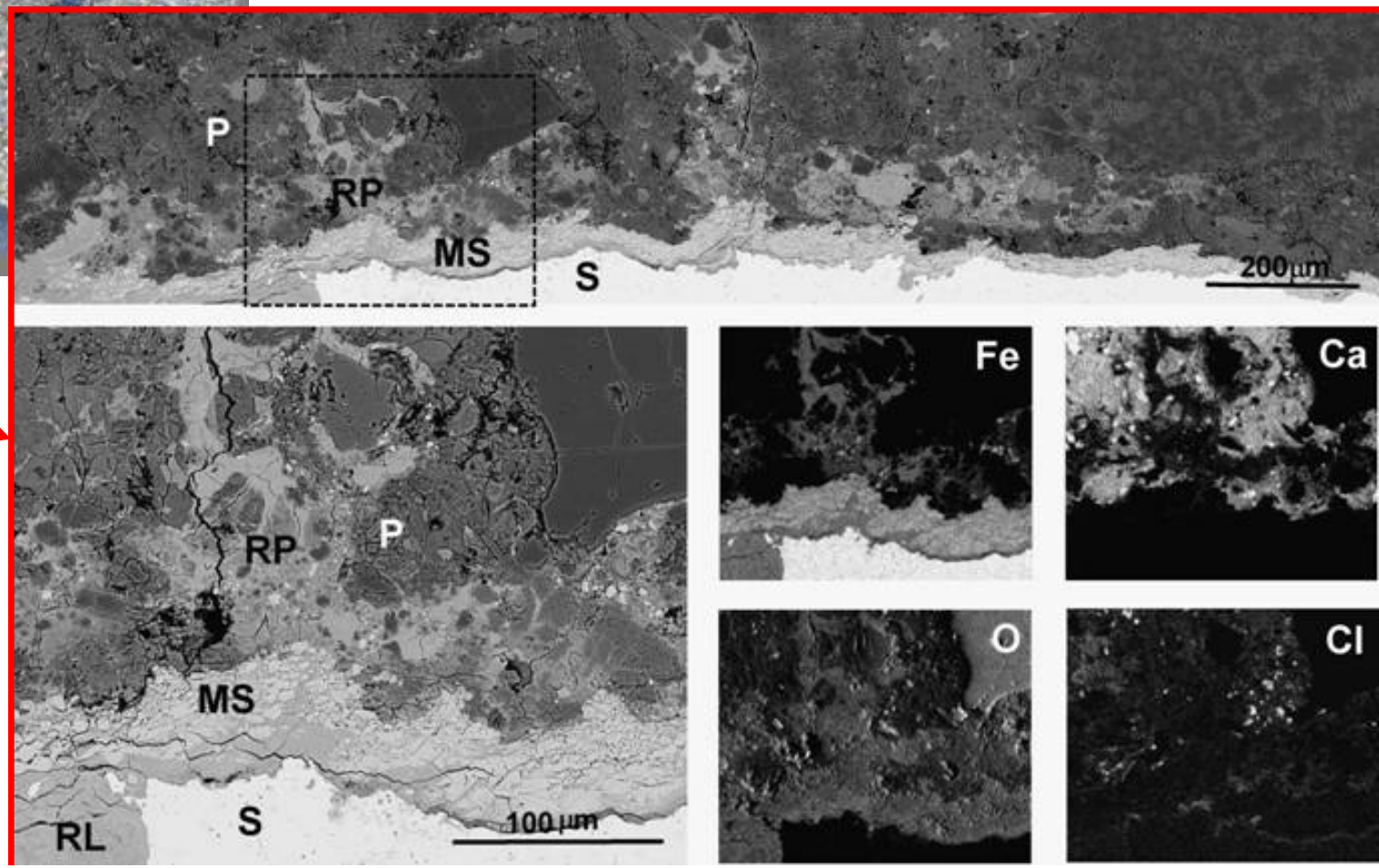
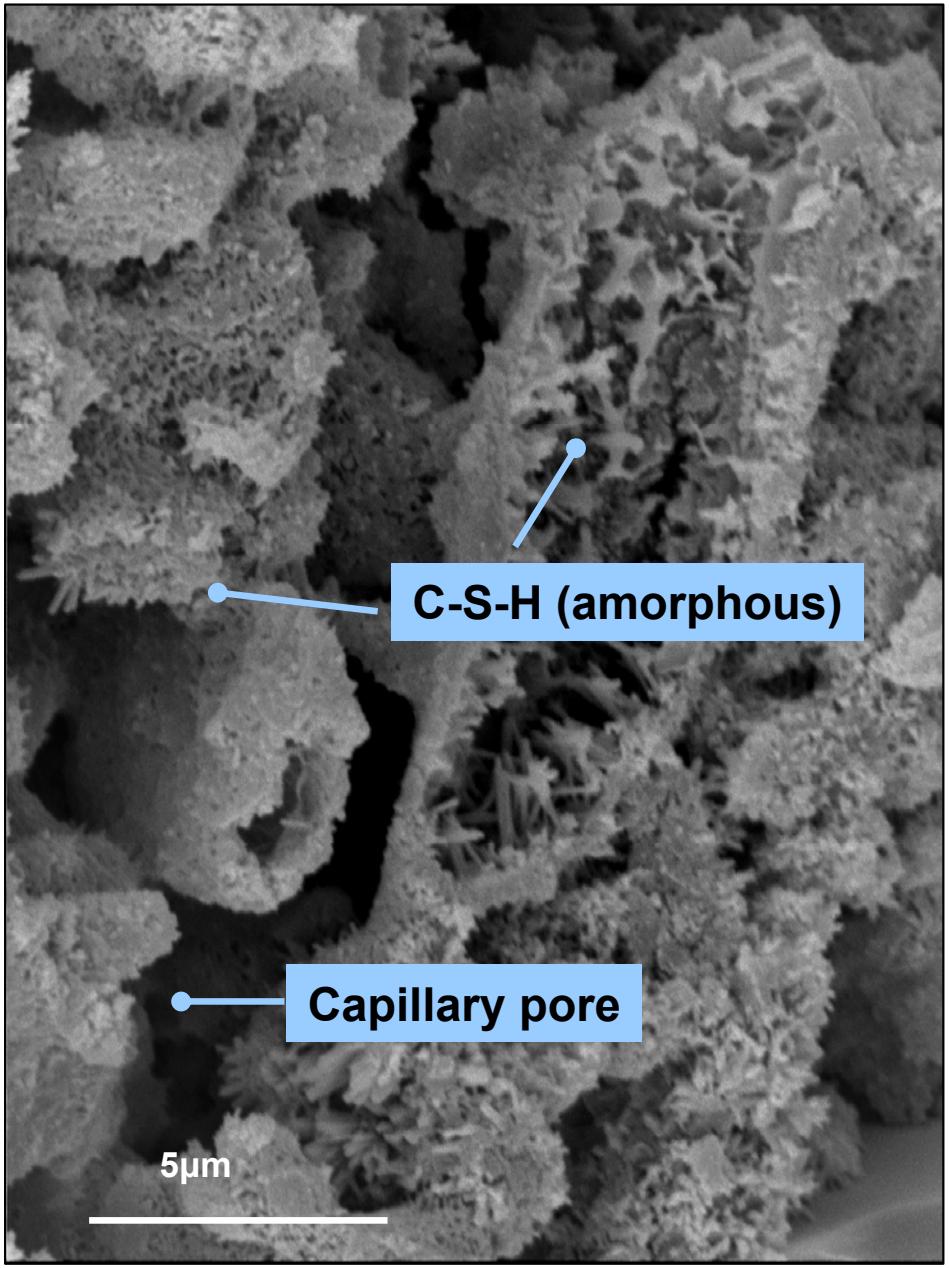
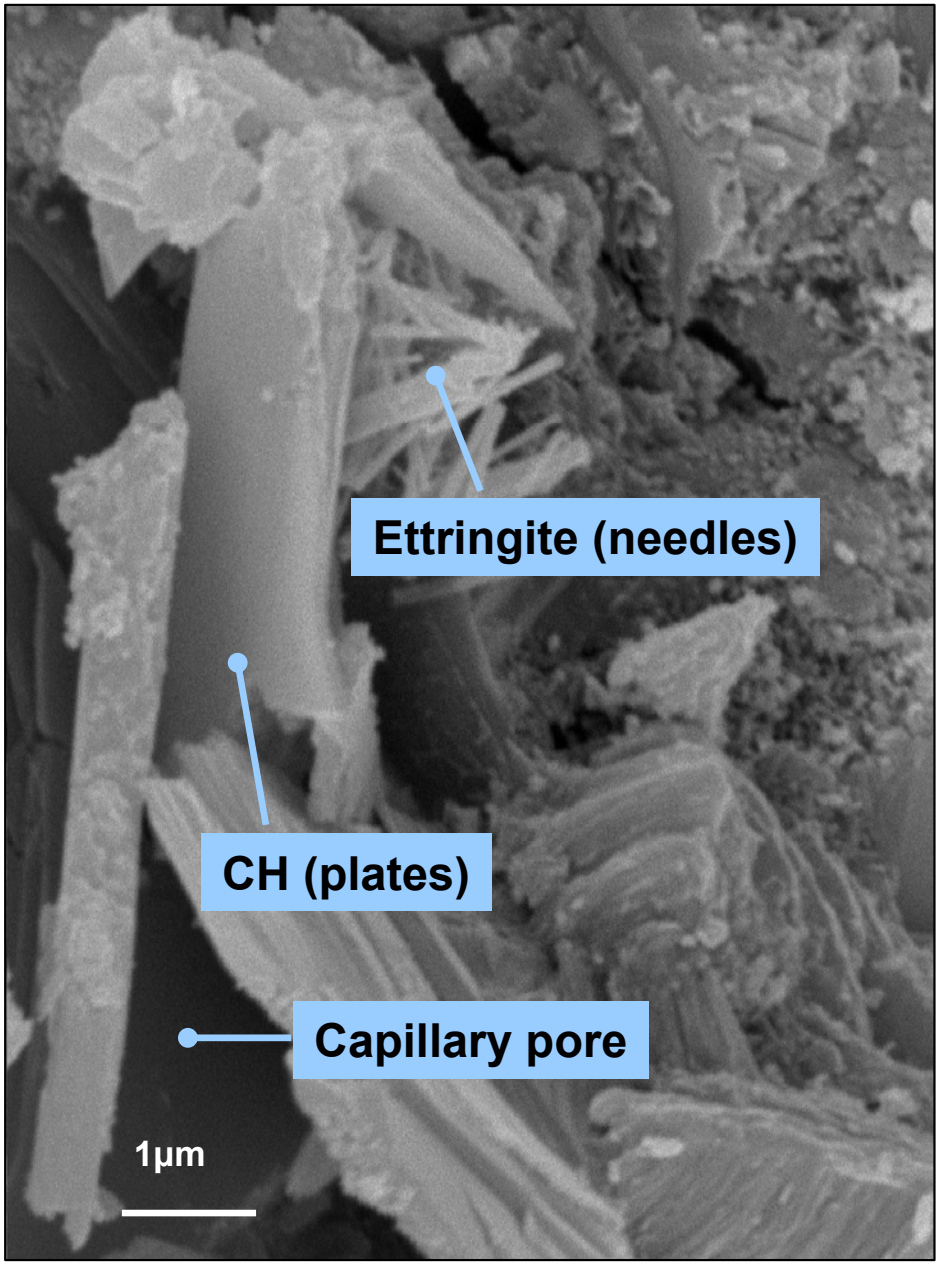




Concrete is physically complex

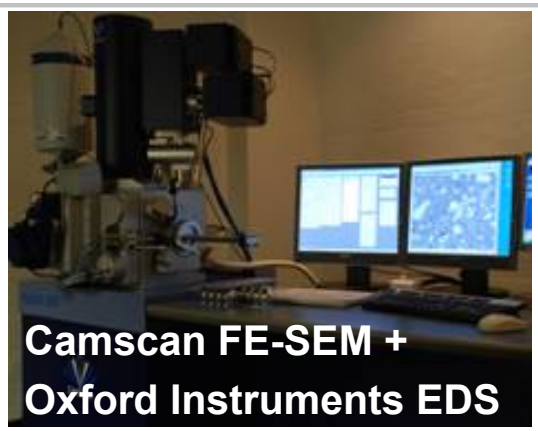
Imperial College London

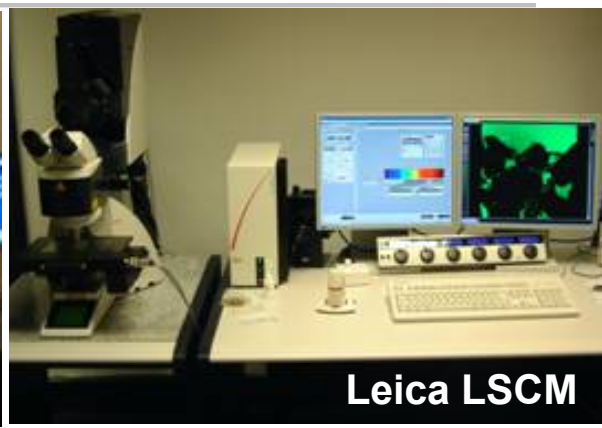


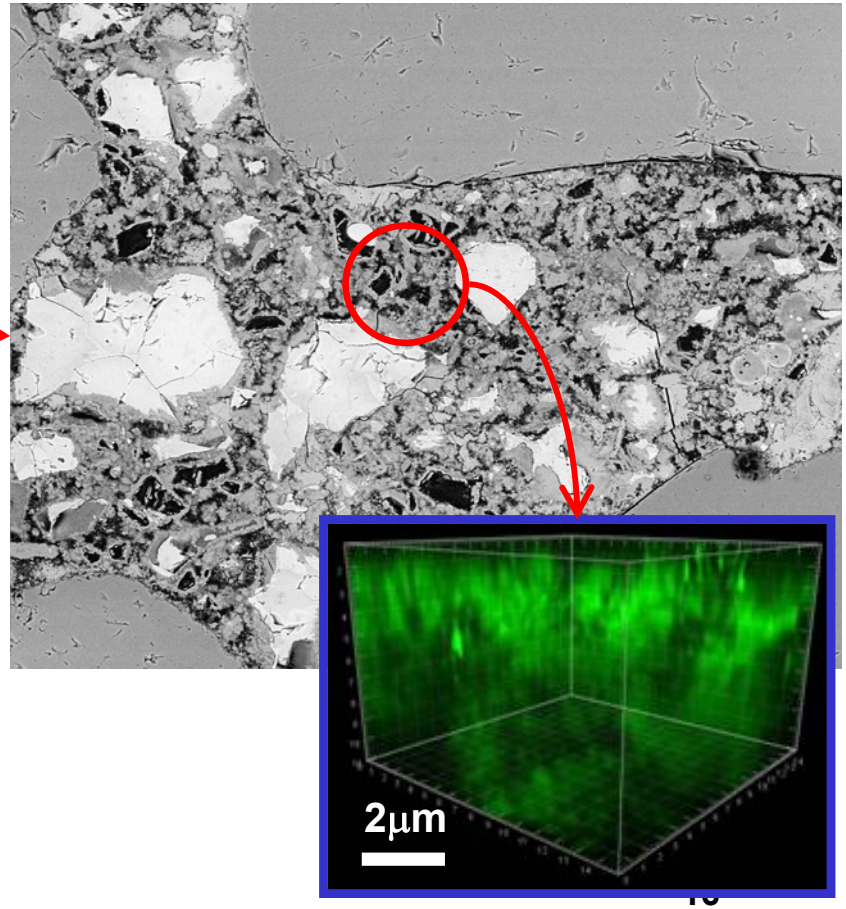


Imaging at different length scales

Imperial College London

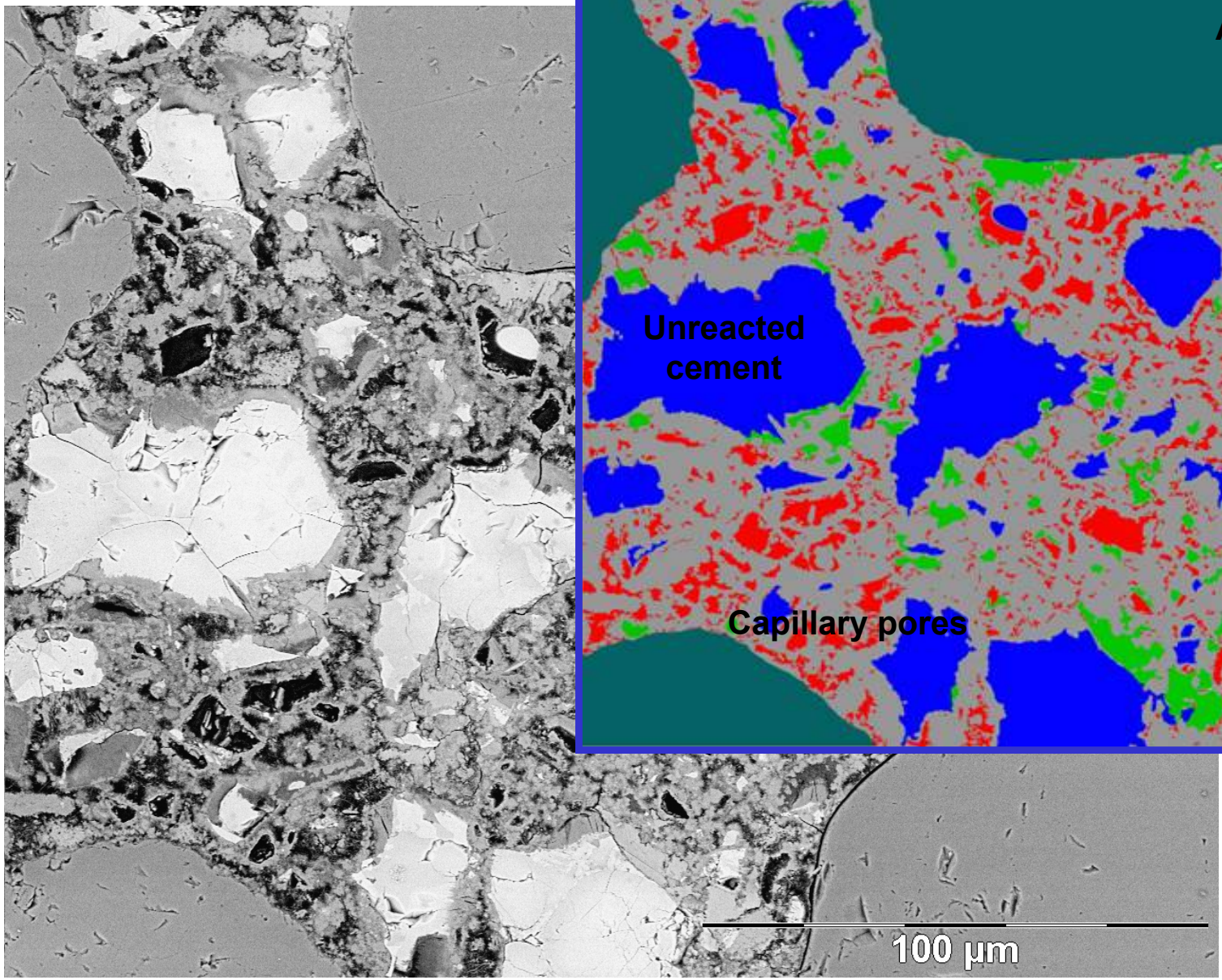






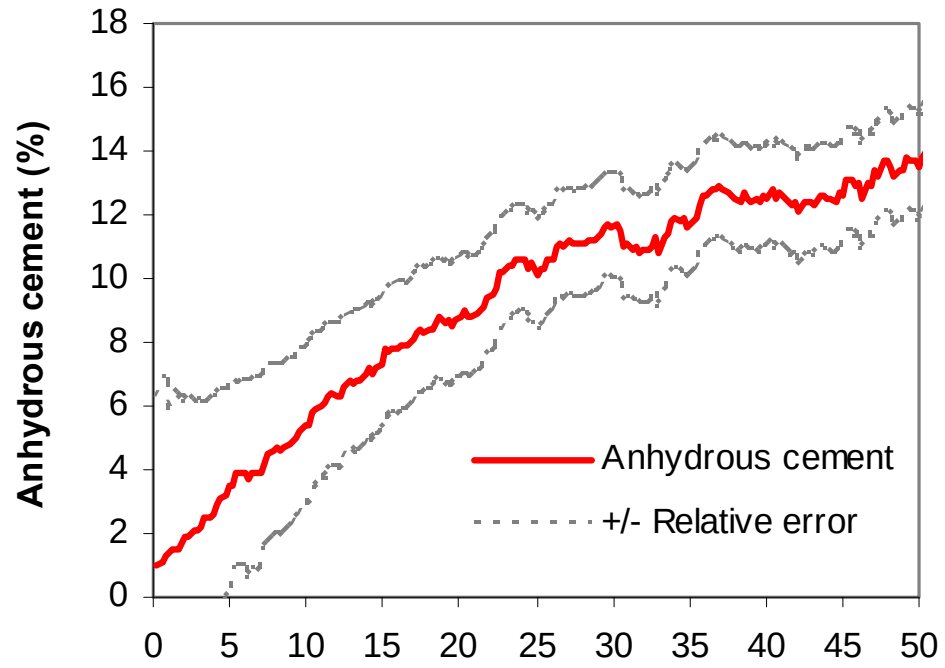
BSE imaging & phase segmentation

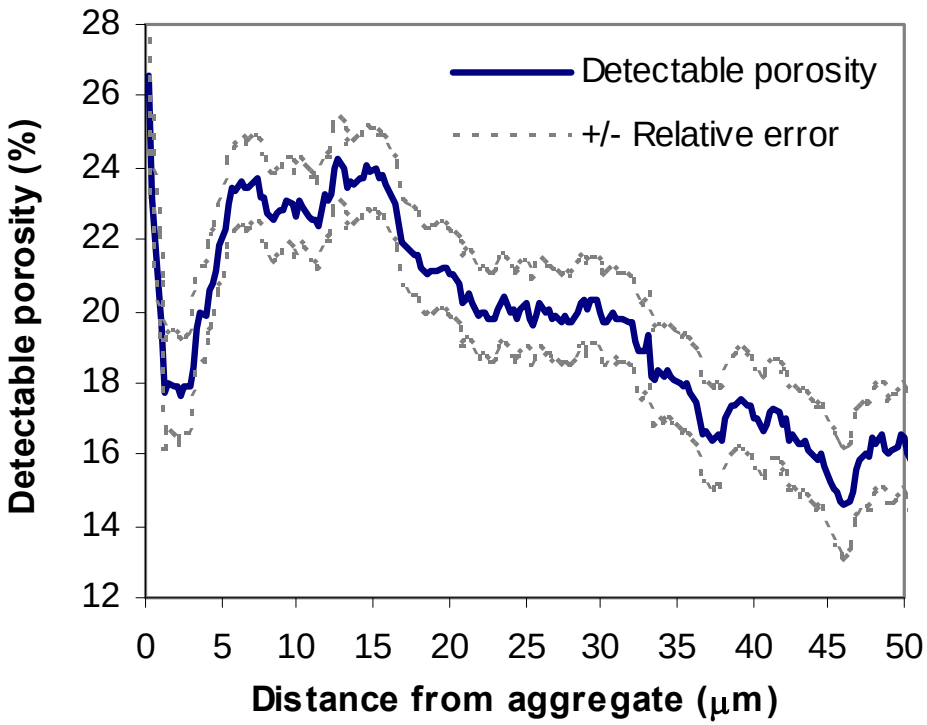
Imperial College London

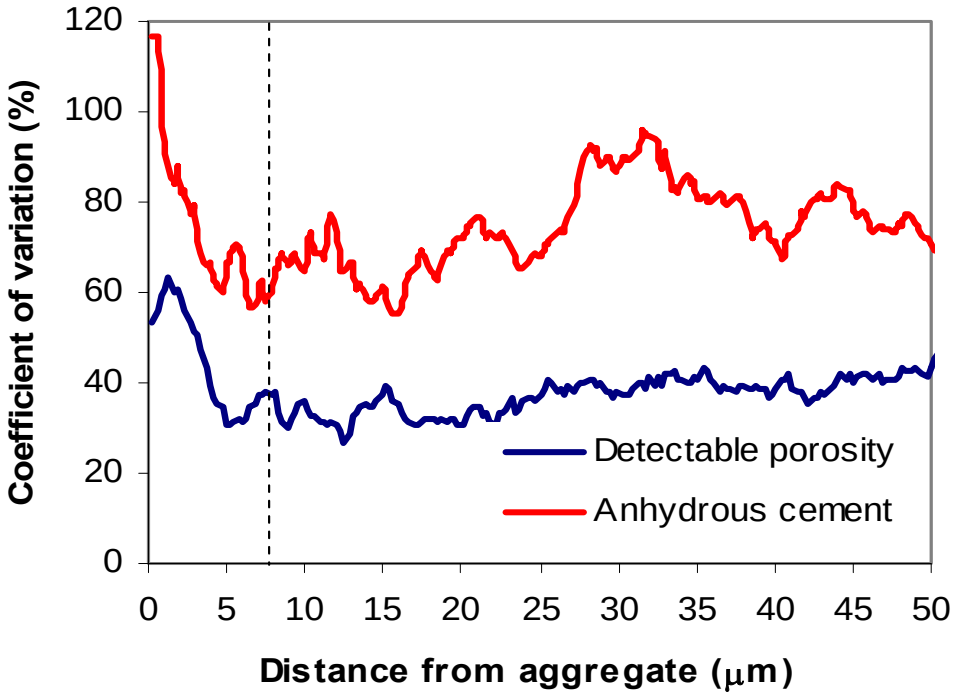


Aggregate-paste interface (ITZ)

Imperial College London







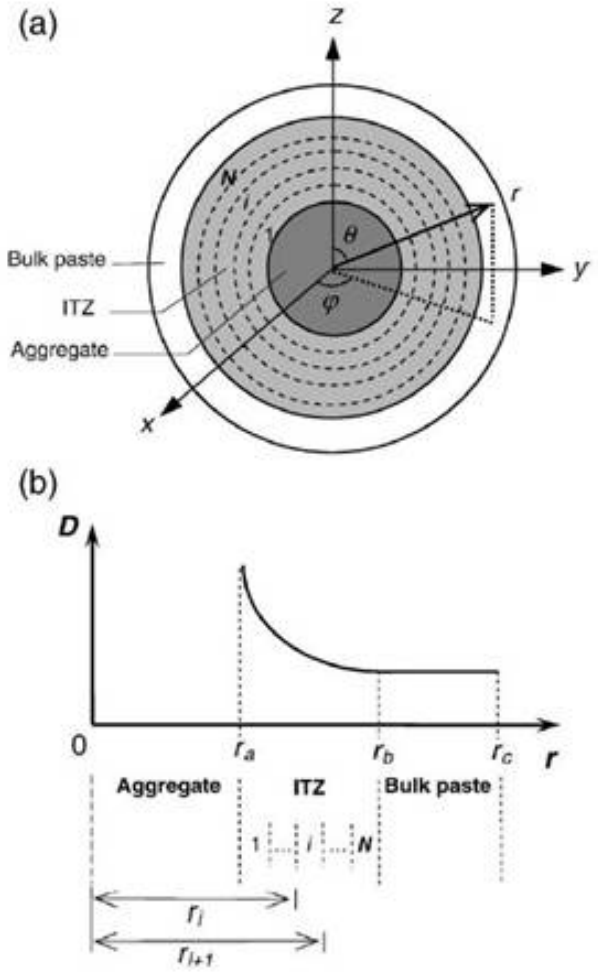
Distribution of porosity and unreacted cement from the ITZ. Note the dense zone at < 5μm from the aggregate surface. Values are the average of 30 frames

High variability of the measured porosity and unreacted cement, particularly at < 5μm from the aggregate surface.

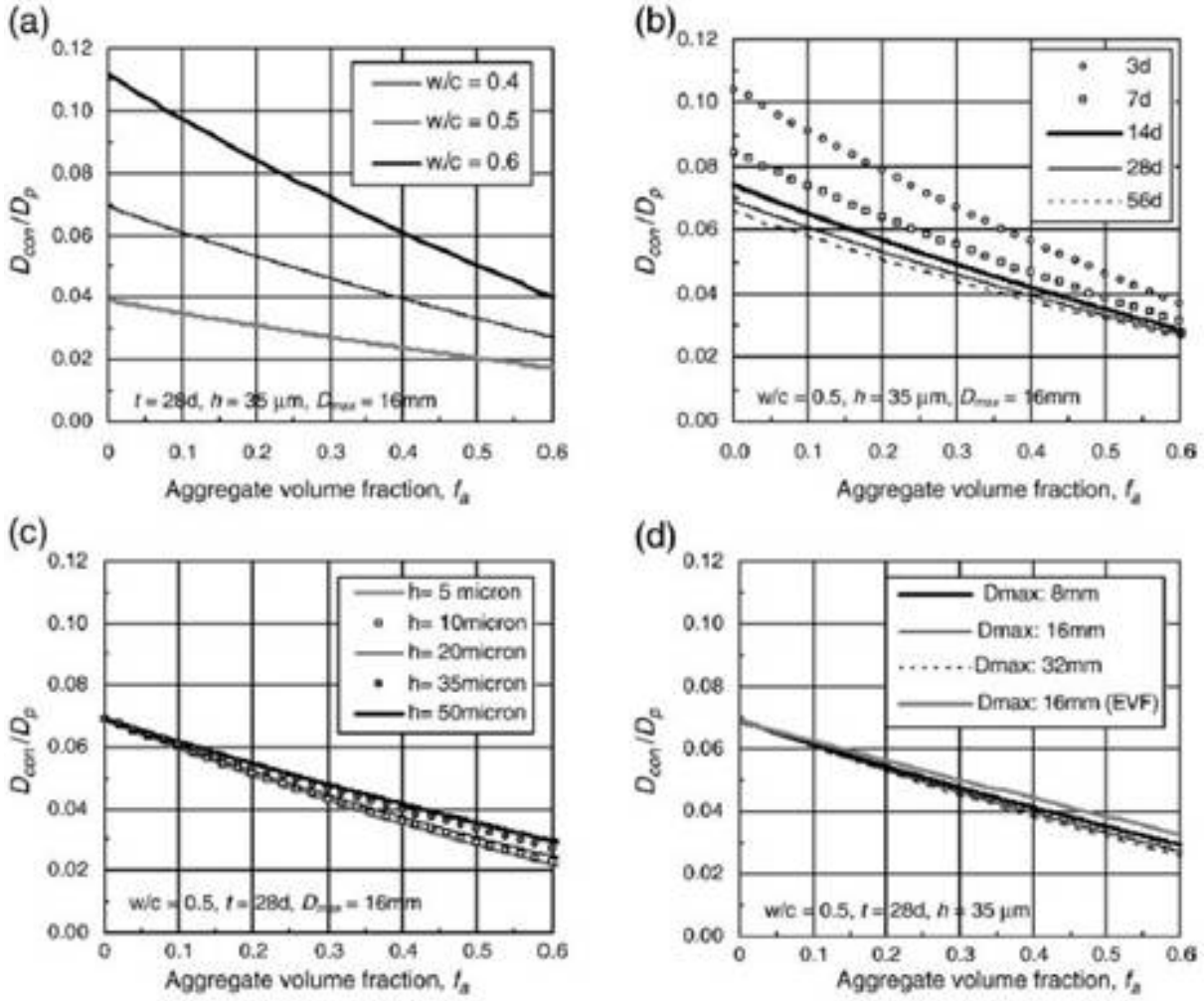
Modelling – Influence of ITZ on chloride diffusivity

Imperial College London

With Prof. J.J. Zheng (Zhejiang University, China)



3-phase composite model

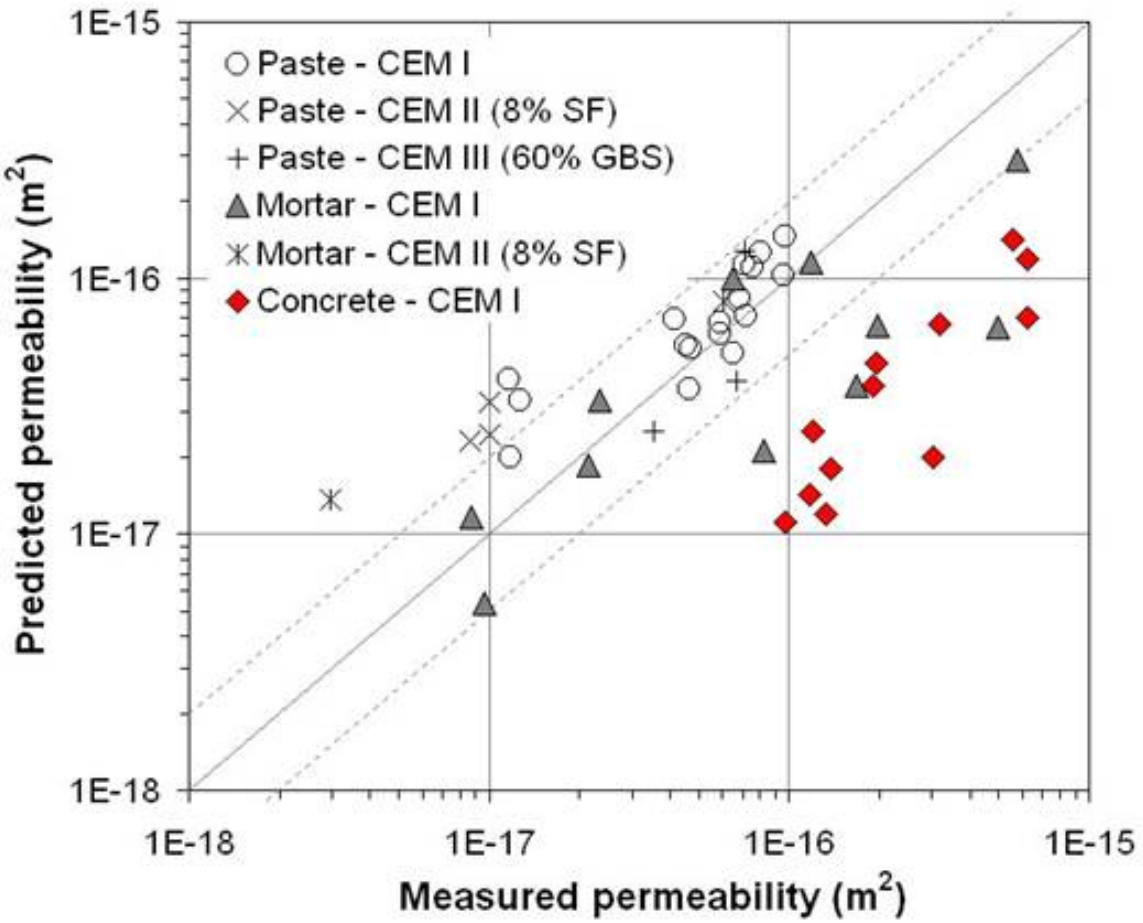


Effect of w/c ratio, curing age, ITZ width & max aggregate size on simulated diffusivity

J.J. Zheng, H.S. Wong, N.R. Buenfeld (2009), Assessing the influence of ITZ on the steady-state chloride diffusivity of cement-based materials using a numerical model, *Cem. Concr. Res.*, 39, 805-813.

Modelling permeability using Effective Medium Approximation

Imperial College London



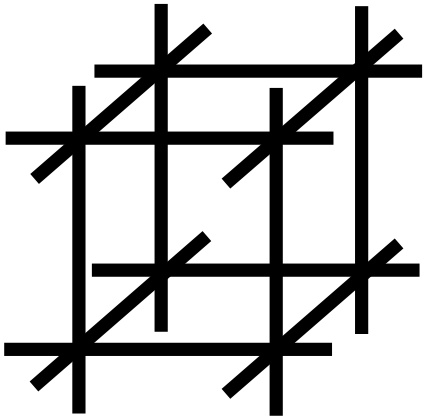
Approach:

- Assume cubic lattice arrangement
- Measure pore size distribution from images
- Stereological factors to account for the random angle between image plane and pore axis
- Constriction factors to account for variation in cross-sectional area along the pore length
- Hydraulic conductance from measured pore area and perimeter, using hydraulic radius approximation
- Effective pore conductance from Kirkpatrick's EMA

$$k = \frac{NC_{eff}}{1.47A_{tot}}$$

$$C_i = \frac{A_i^3}{2\Gamma_i^2} \times 0.375 \times 0.44$$

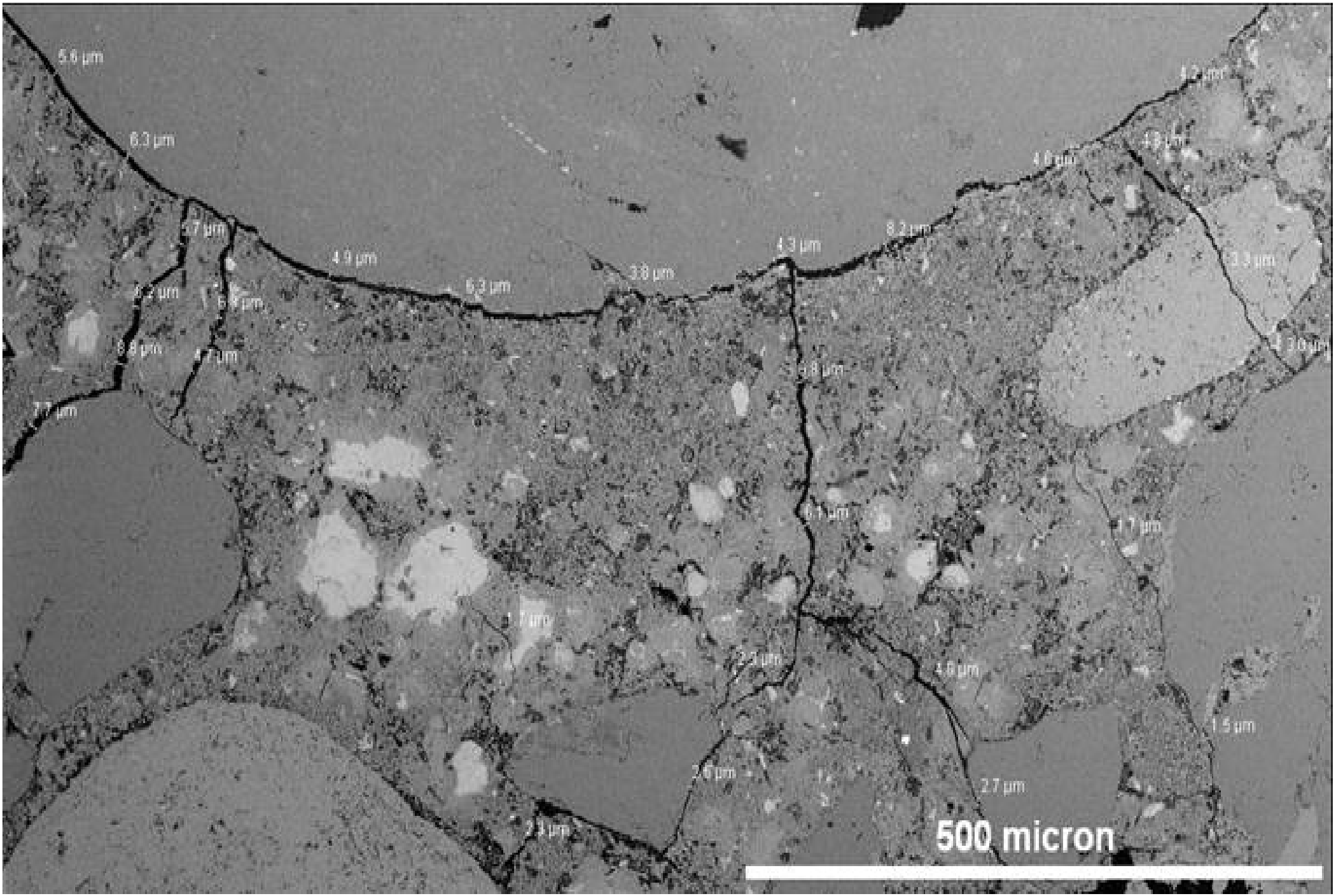
$$f(C_{eff}) = \sum_{i=1}^{n} \frac{C_{eff} - C_i}{[(z/2)-1]C_{eff} + C_i} = 0$$



H.S Wong, R.W. Zimmerman, N.R. Buenfeld (2011), Estimating the permeability of cement pastes and mortars using image analysis and effective medium theory, *Cem. Concr. Res*. (Accepted)

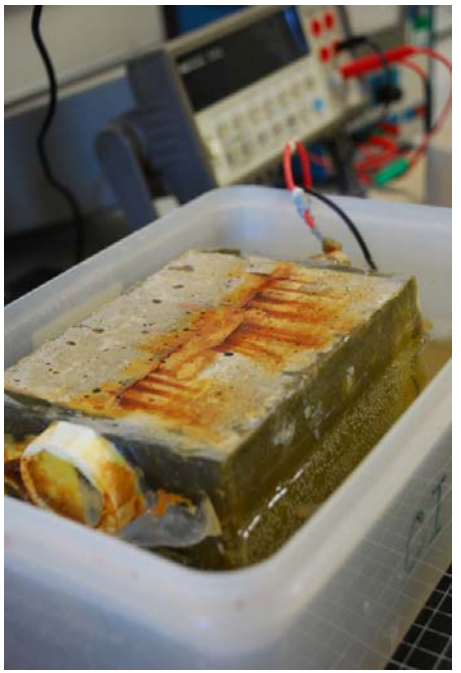
Micro-cracking

Imperial College London



Transport measurements

Imperial College London



Laboratory-based JLE tunnel simulation

Imperial College London

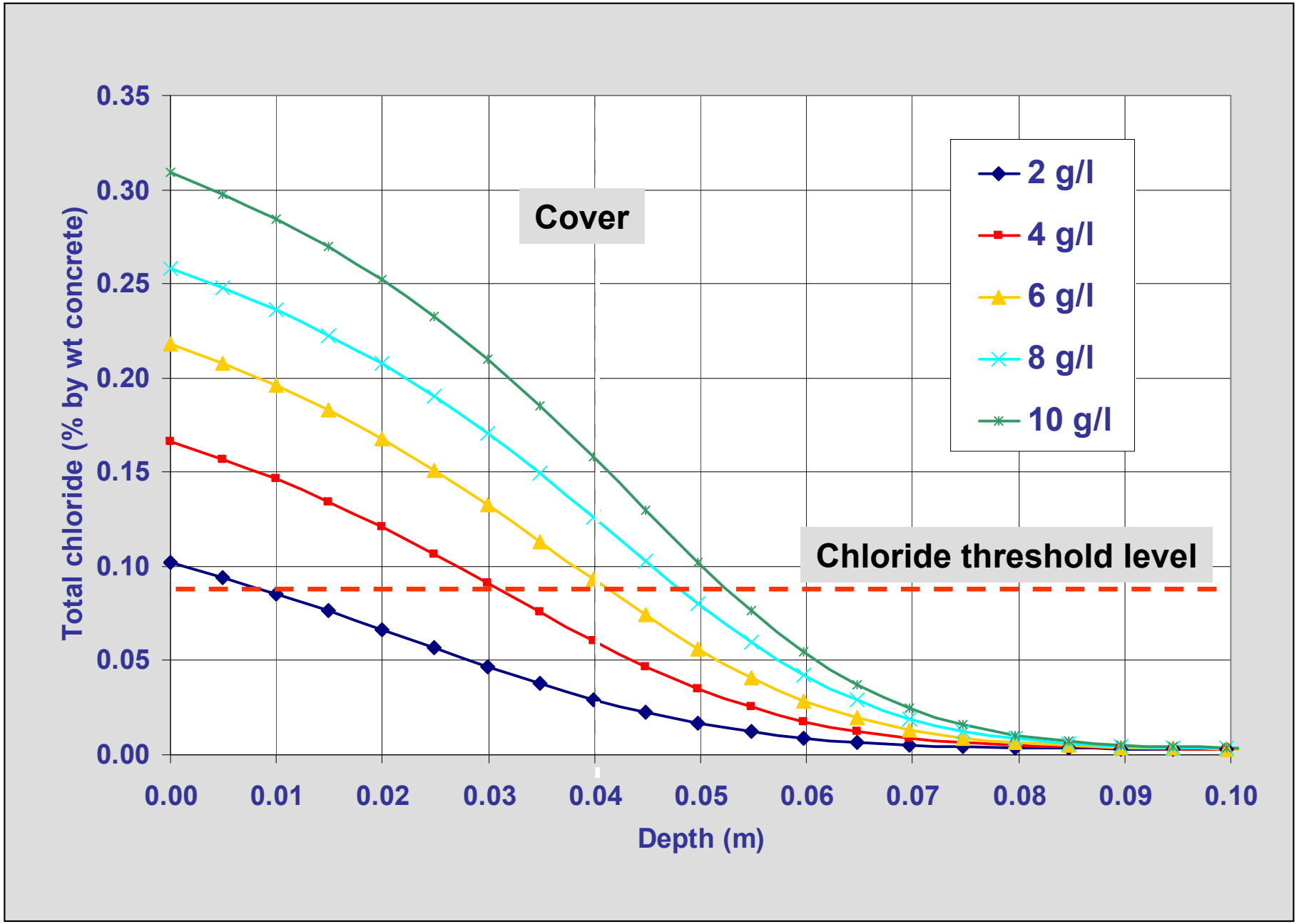
JLE concrete core:
100mm dia.
250mm long
0.34 w/b
30% pfa

Simulated groundwater:
3.5 g/l Cl
30m head

35% RH

Effect of Cl concentration on predicted (120 years) profiles

Imperial College London



Jubilee Line Extension

Imperial College London

Project

Jubilee Line Extension

Client

London Underground Ltd

Activity

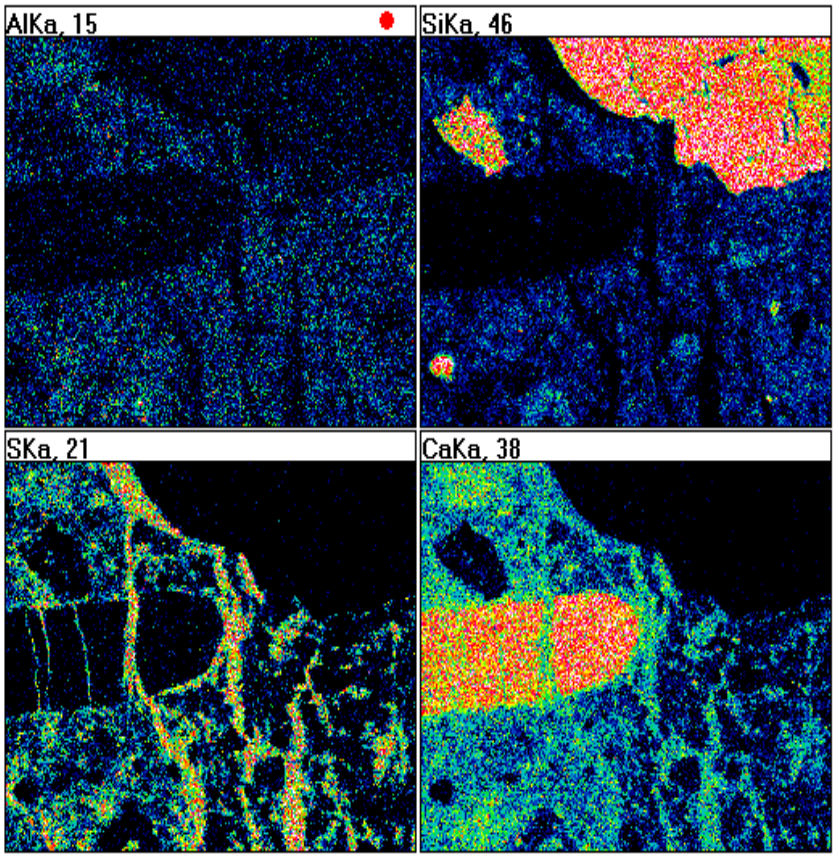
1) Development of service life model

2) Long-term lab tests to calibrate model.

3) Outline design of monitoring system.

Victoria Line tunnels

Imperial College London



Project

Assessment of Victoria Line Tunnels.

Client

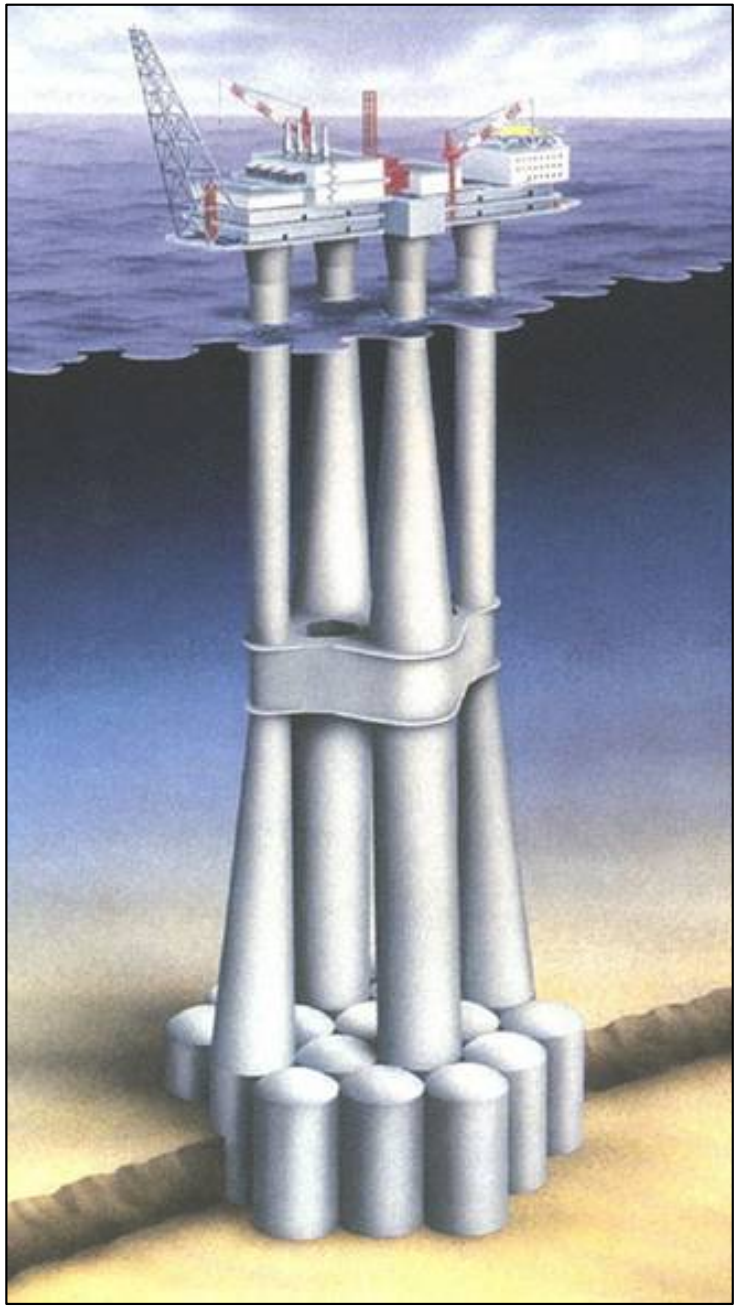
London Underground Ltd

Activity

Assessment of condition and remaining life of Victoria Line tunnels.

Troll Offshore Platform

Imperial College London



Project

Troll Offshore Platform (Norway)

Client

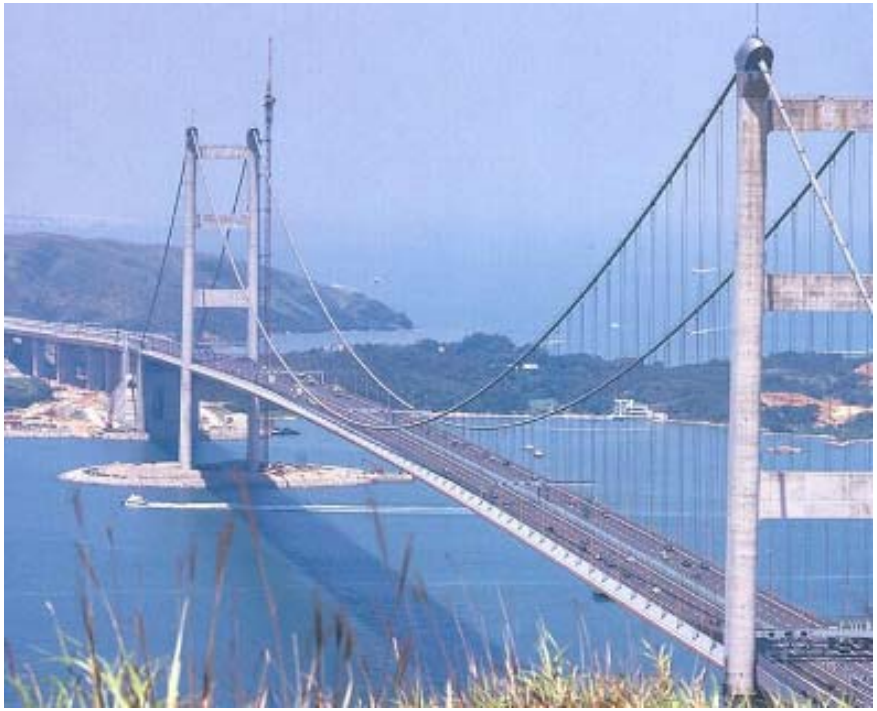
Norwegian Contractors

Activity

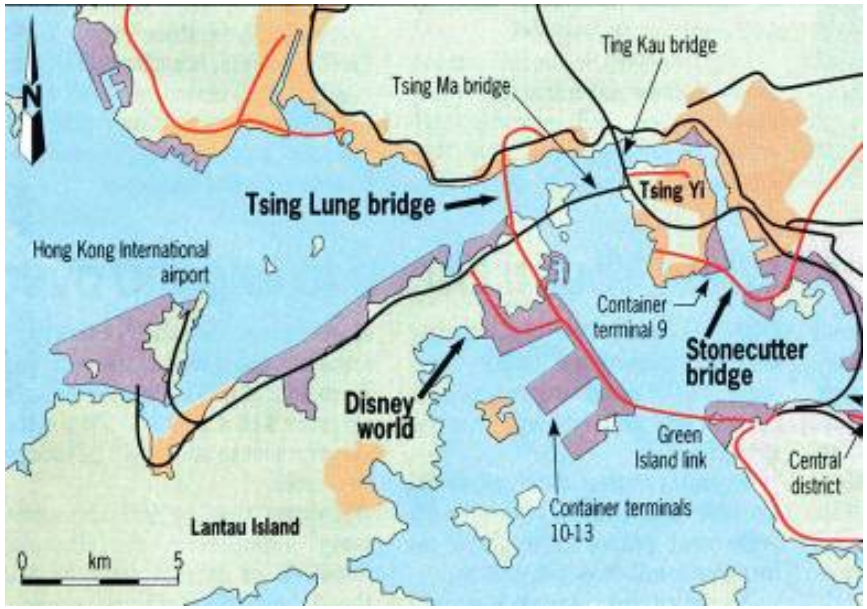
Theoretical investigation of influence of sea-water flow through cracks on stability of platform.

Large bridges in Hong Kong

Imperial College London



Project
Tsing Ma Bridge
Client
Hong Kong Government
Activity
Expert witness in £70m litigation concerning "Impossibility" of concrete specification for durability.



Project
Tsing Lung Bridge
Client
Maunsell Asia
Activity
Guidance re. design for durability.

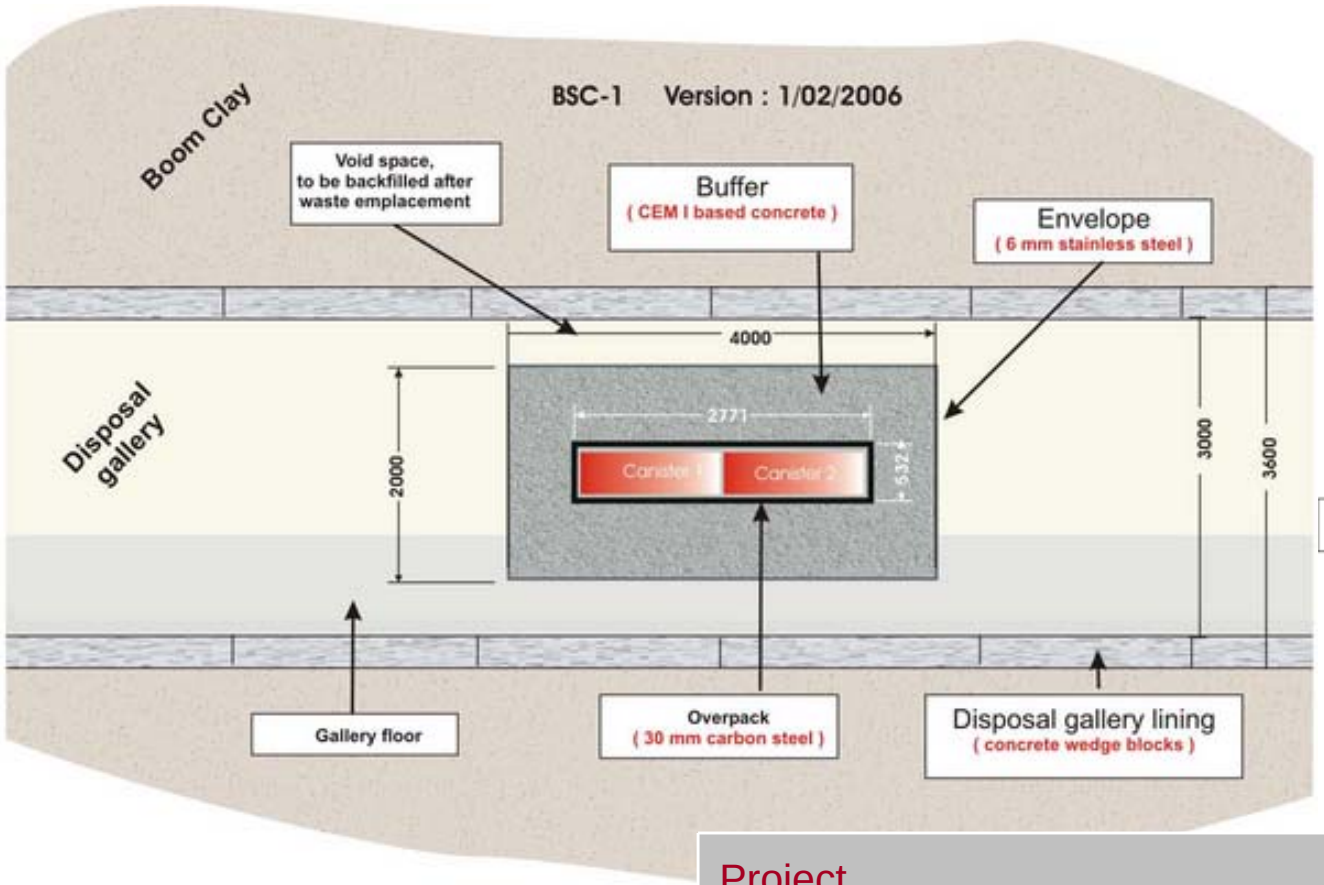
New Los Angeles Cathedral

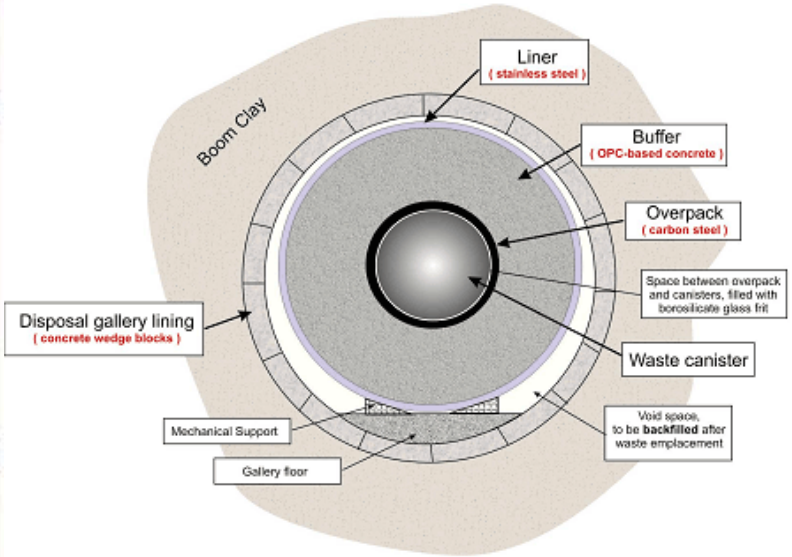
Imperial College London

Project **New Los Angeles Cathedral**
Client **Leo A. Daly (Architects)**
Activity **Guidance re. achieving 400 year life.**

ONDRAF NIRAS Supercontainer

Imperial College London





Project

Supercontainer

Client

ONDRAF NIRAS

Activity

Guidance re. specification and behaviour of Buffer (concrete), Backfill and Gallery lining.

Hinkley Point EPRs

Imperial College London

Project

European Pressurised Reactors - Hinkley Point

Client

EDF & AMEC

Activity

Guidance on specification of concrete for reactor containment, shield and raft

Great Manmade River (Libya)

Imperial College London

Project

Great Man-made River (Libya)

Client

ANC

Activity

Guidance re. increasing durability without reducing production.

Techniques available within Concrete Durability Group

Imperial College London

MAIN PURPOSE	FACILITY/TECHNIQUE
Specimen manufacture	Concrete technology lab with mixers, curing chambers, standard fresh and hardened concrete test methods.
Specimen exposure	Tanks and chambers to simulate various exposure environments
To help understand deterioration processes	Field emission SEM with X-ray micro-analysis
	Optical microscopy including Confocal microscopy
	Micro X-Ray fluorescence
	Mercury Intrusion Porosimetry
To quantify the rate of deterioration	Transport measurements including gas and water permeability; gas, water and ion diffusivity,
	Electrochemical monitoring including AC impedance spectroscopy
To model deterioration	FD/FE modelling
	Neural network analysis (to utilise site data)

2 areas in which we would particularly like to contribute...

Imperial College London

Area	Main contacts:
1. RESPONSE UNDER EXTREME LOADING	
Measurements -	Prof Ahmed Elghazouli
Modelling -	Prof Bassam Izzuddin
2. DURABILITY OF CONCRETE STRUCTURES -	Prof Nick Buenfeld

But we are open to other suggestions