Imperial College London

Two UK Joint Industry Projects

Piles driven piles in chalk
Monopiles driven in sand & stiff clay

Richard Jardine

Chalk: Axial behaviour

Motivated by Offshore Wind Farms such as Wikinger, German Baltic

70 Turbines on jackets: 286 piles, 2.4 to 3.6m diameter

Static, cyclic & dynamic testing offshore

Supporting onshore research in UK

Innovate UK
Technology Strategy Board

Imperial College London

IBERDROLA

GCG

Research sites

Wikinger

- Offshore Germany, full scale, 40m water
- Static, cyclic & dynamic tests
- Low-Medium density chalk & glacial till

Wikinger OWF location

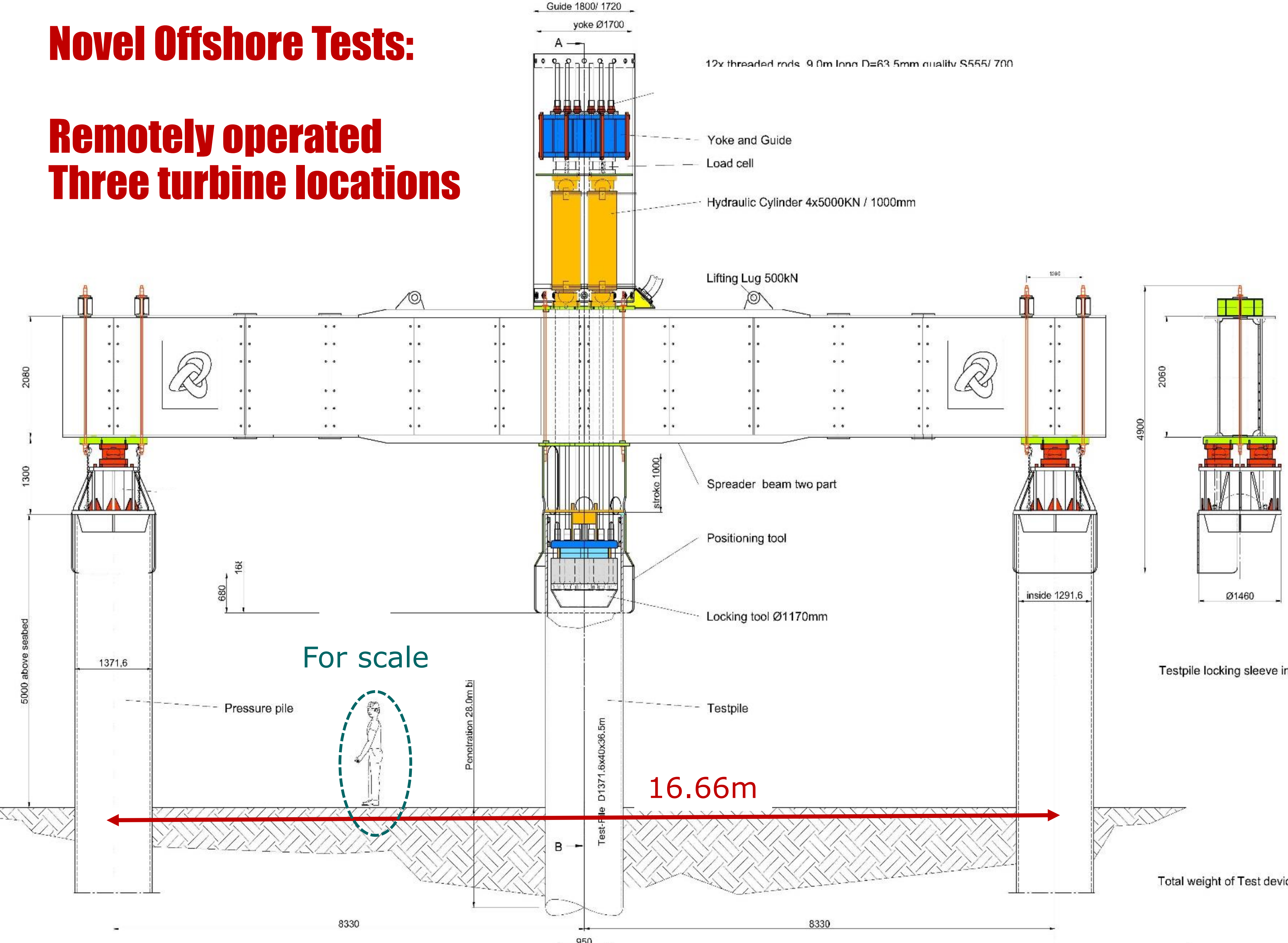
Kent

- Onshore, chalk quarry in SE England
- Reduced scale, more control
- Low-Medium density Chalk from surface

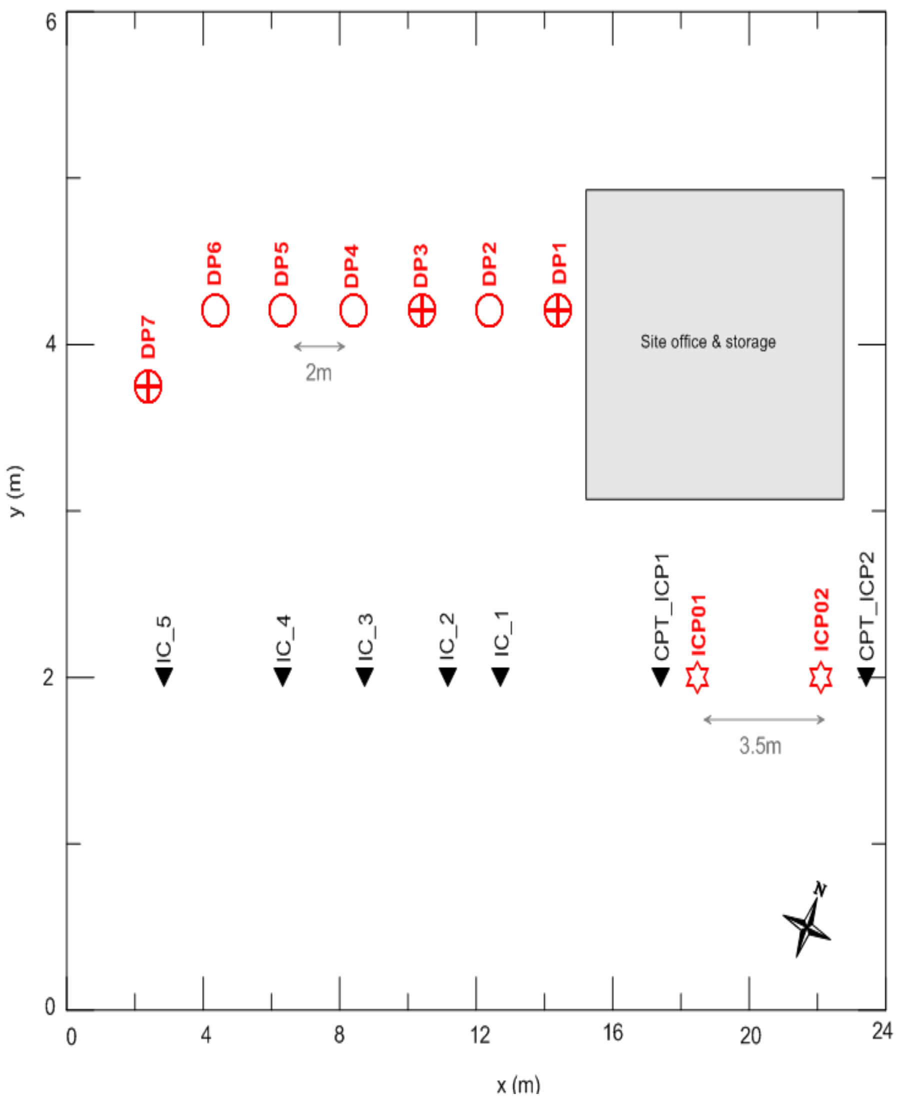
Kent test site

Novel Offshore Tests:

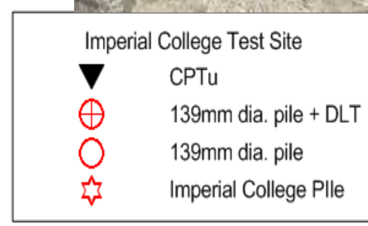
Remotely operated
Three turbine locations



Kent test site



Current site



Field testing:

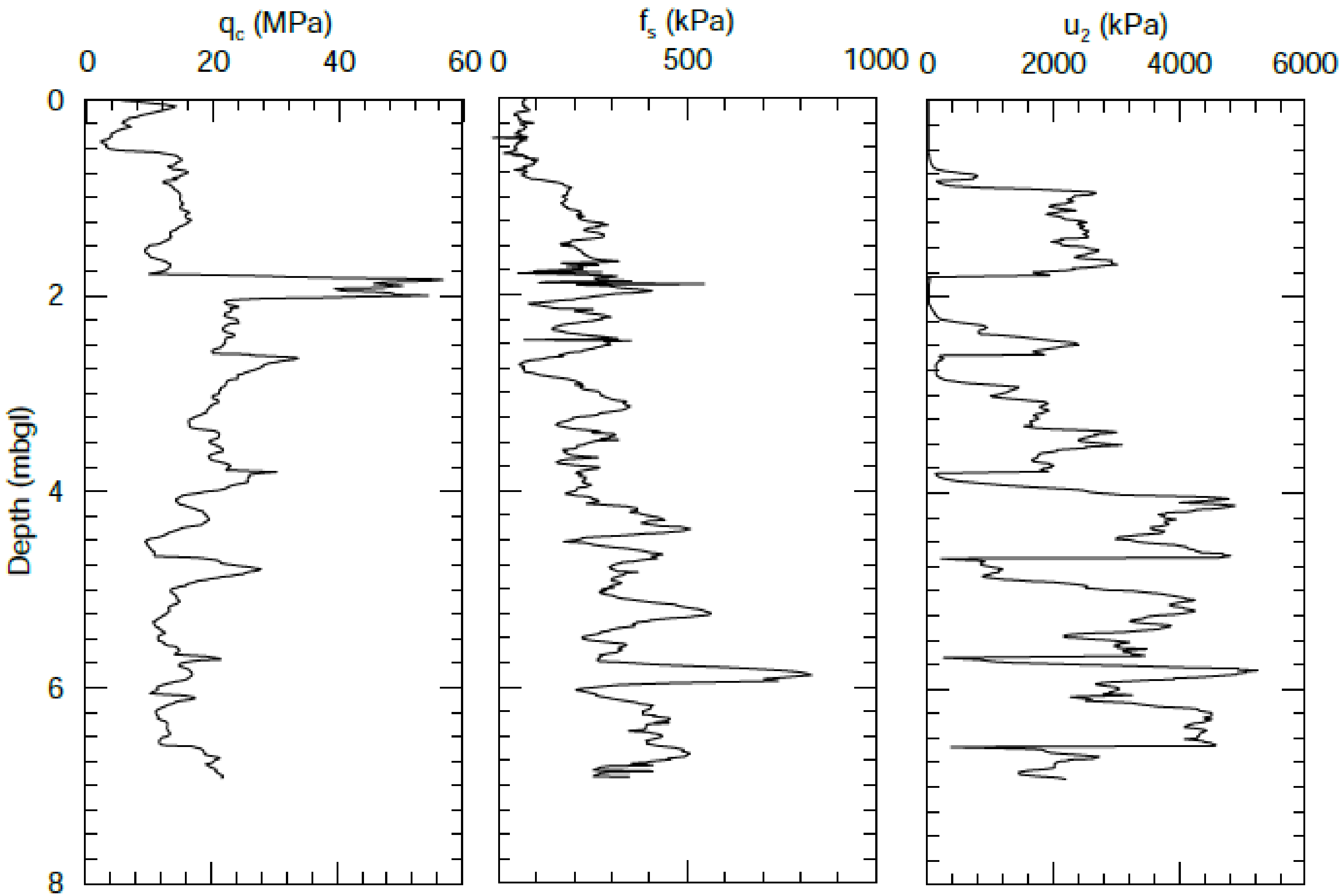
Driven piles, with dynamic monitoring

Plus highly instrumented ICP

And in-situ and laboratory testing

Kent site conditions

- CPTu trends, water table below investigation depth
- Saturated low to medium density chalk from surface



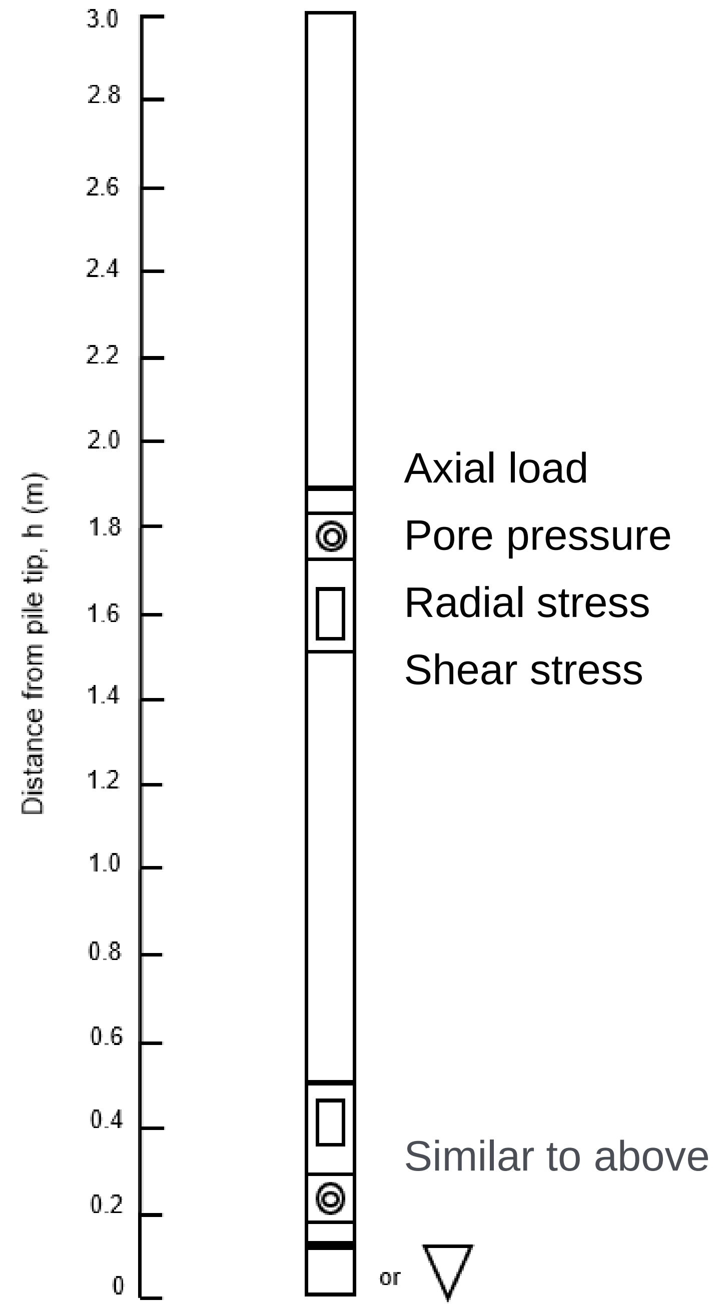
CPTu IC_05

Driven piles: 2015-15

- 140mm dia. tubular steel piles
- Dynamic driving monitoring
- Ageing study: tests on **fresh** piles at four ages
- Cyclic investigation: **fresh** piles at $\approx$ 250 day age

ICP tests 2015-2016

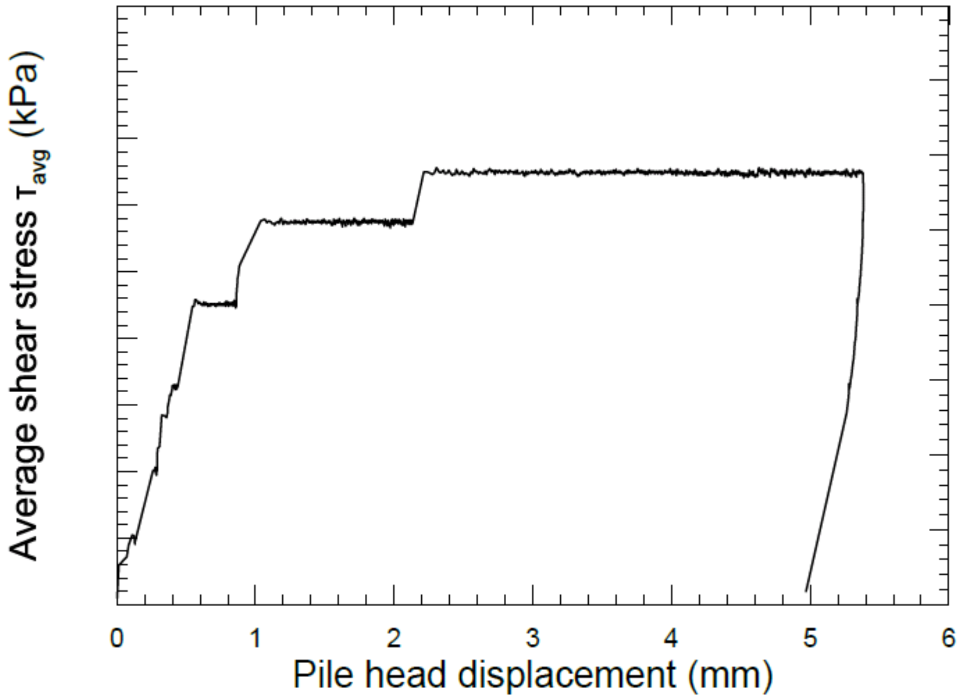
- Complement driven piles
- 102mm dia. jacked closed-ended
- Local radial and shear shaft stresses, pore water pressures & axial loads
- Local effective stress paths during installation, long term equalisation & loading
- Collaboration with Barry Lehane (UWA)



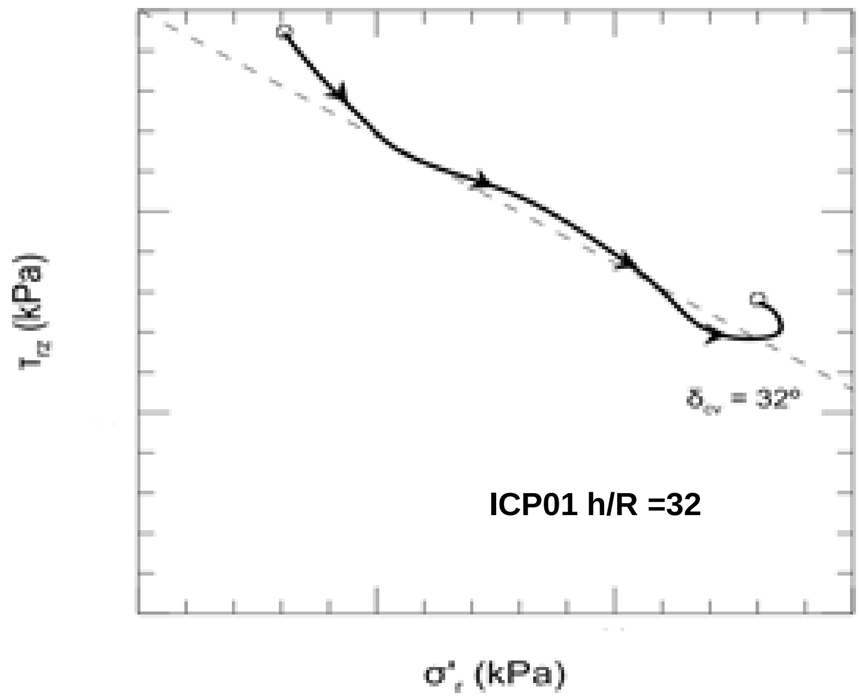
ICP configuration

Example ICP results – load testing

Staged maintained loading



Local effective stress path

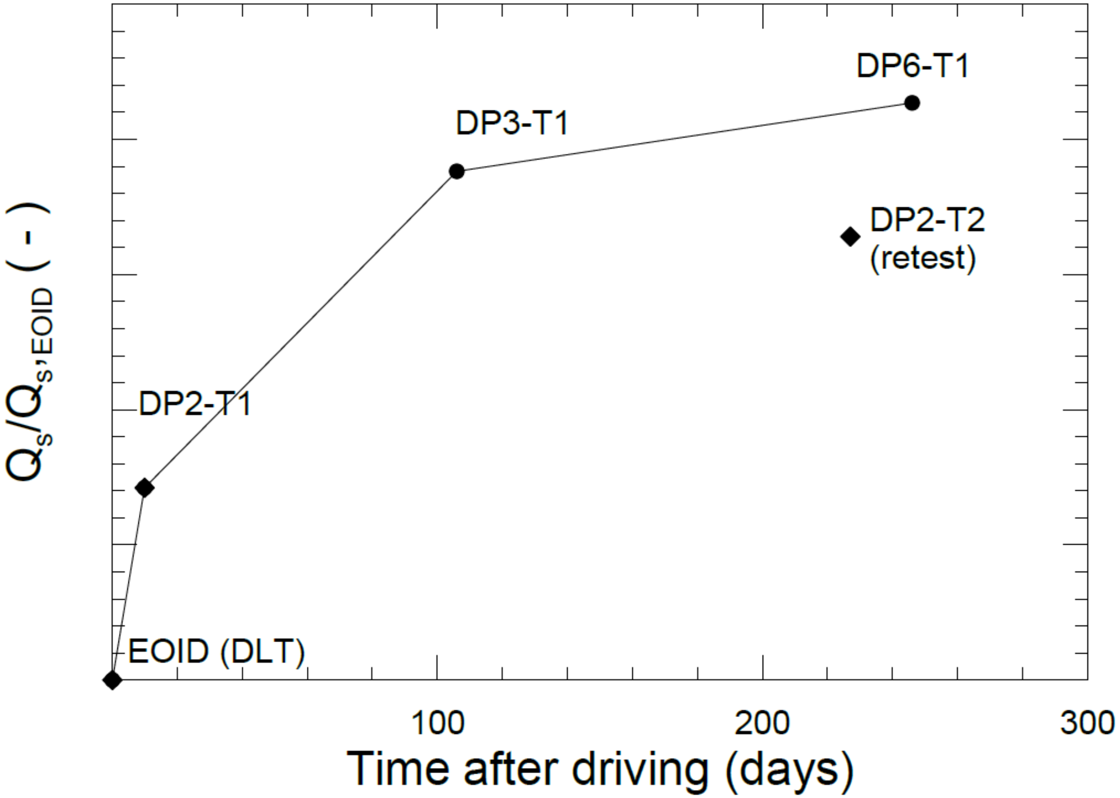


Effective stress paths defined during static & cyclic loading

Constrained dilation on loading to failure

Response to cyclic loading also established

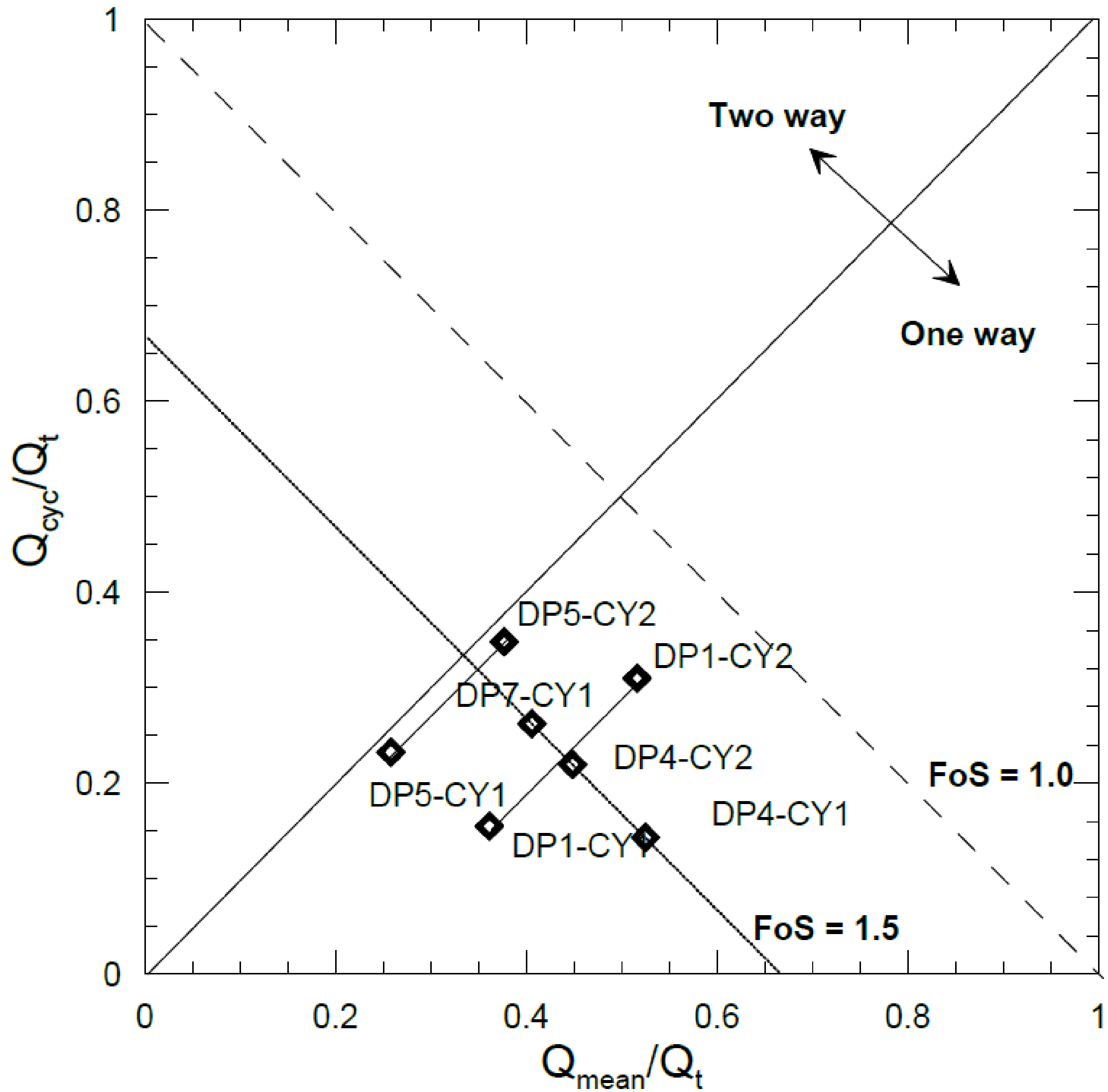
Driven piles: static tests on ‘fresh’ driven piles



- Rate of set up reduces with time, approximately log-linear trend
  - Previously tested piles follow different trend
- Field and laboratory study of impact on chalk around piles

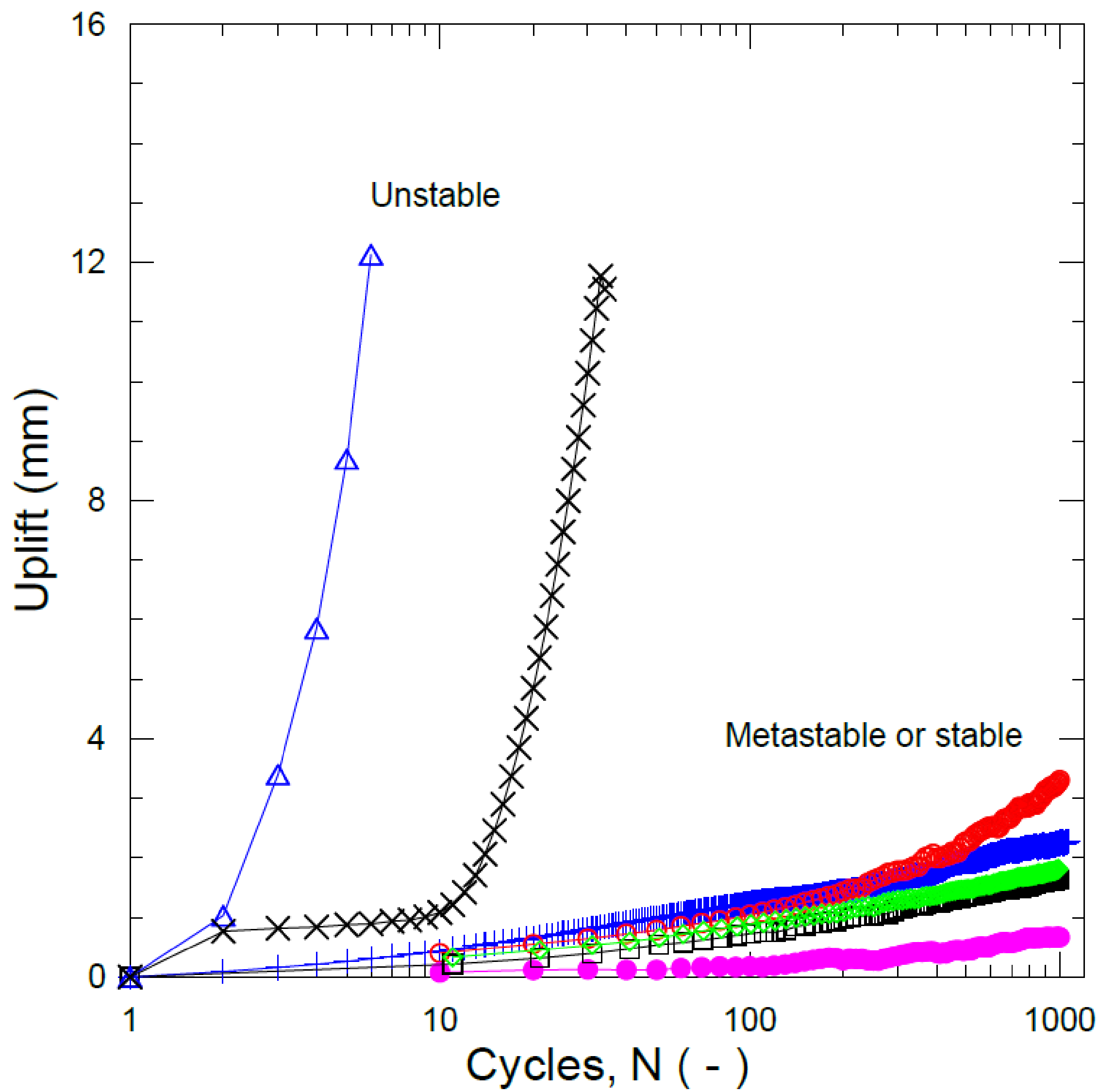
Cyclic tests on driven piles in Kent

- First: static reference test
- Q_t tension capacity pre-cycling
- 7 cyclic tests on 4 piles ≈ 250 days post driving
- Load controlled, 20s period
- Up to 1000 one-way cycles



Cyclic tests: driven piles in Kent

- Unstable, metastable & fully stable responses observed
- Static reference test after each cyclic failure
- Not unduly sensitive to cycling after ageing
- Larger scale, instrumented tests under two-way conditions: ALPACA JIP proposal



Summary: Chalk JIP

- Offshore: dynamic, static & cyclic tests

  Onshore: static & cyclic tests on driven piles and ICPs

  All testing completed 2016

  Improving design for axially loaded driven piles

- Papers in 2017: SUT OSIG, Geotechnique, & Can. Geot. Journ.

- Further work, including lateral loading? In progress, ALPACA proposal- learning from PISA 1 & PISA 2 monopile projects

PISA JIP

Discretionary Project Steering Committee

CARBON TRUST, DONG energy, IBERDROLA, RWE, SSE, Statoil, Statkraft, VATTENFALL

Non OWA Partners

ALSTOM, EDF energies nouvelles, Van Oord

Project Partner Technical Experts

Academic Work Group

Principal Investigator: Professor Byron Byrne
Professor Guy Houlsby, Dr Harvey Burd, Dr Chris Martin
Dr Ross McAdam

Imperial College London

Professor Richard Jardine
Professor David Potts
Professor Lidija Zdravkovic
Dr David Taborda

UCD Dublin

Dr Ken Gavin,
Dr Paul Doherty
Dr David Igoe

Lead Partner

DONG energy

Project Manager:
Jesper Skov Gretlund

Technical Manager:
Miguel Pacheco Andrade

Independent Technical Review Panel

NTNU
Chairman: Professor Gudmund Eiksund

DNV
Liv Hamre

GD Consult
Dr Fabian Kirsch

GL Garrad Hassan
Tim Camp

BAM Bundesanstalt für Materialforschung und -prüfung
Professor Werner Rucker

Assisting Consultants

ORDTEK – UXO Consultant

bre – Testing Assistance

ATKINS – Testing Management

GCG – Advanced Numerical Modelling

PARSONS BRINCKERHOFF – Structural Designer and SI Supervision

Testing Contractors

ESG Environmental Scientifics Group – Principal Testing Contractor

NLMK DanSteel A/S – Steel Supplier

BLADT INDUSTRIES – Pile Fabricator

marmota geotechnical experts fiber-optic monitoring – Fibre Optic Supplier

dcp DAWSON CONSTRUCTION PLANT LTD – Pile Installation

SANGWIN – Site Preparation

GEOLABS – Laboratory Testing

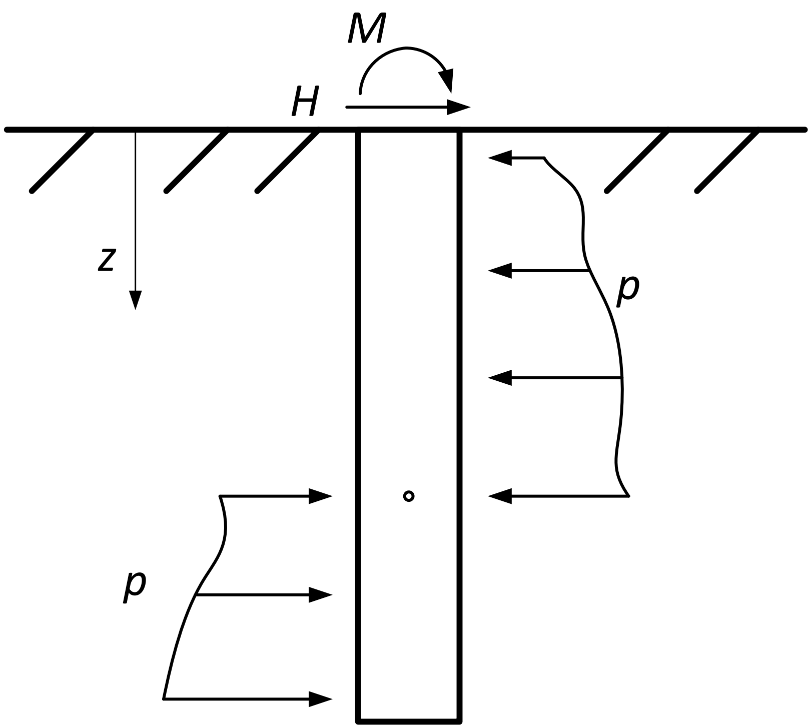
IN SITU SITE INVESTIGATION – CPT Investigation

CONCEPT – Site Investigation

PISA

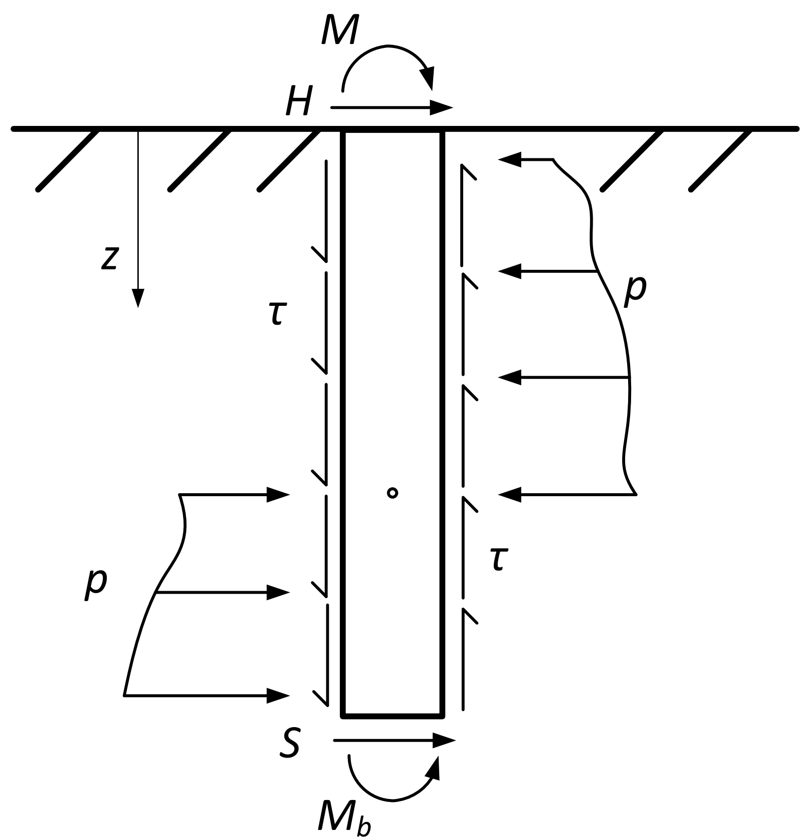
PISA: new design from analysis, advanced SI & field tests

Conventional



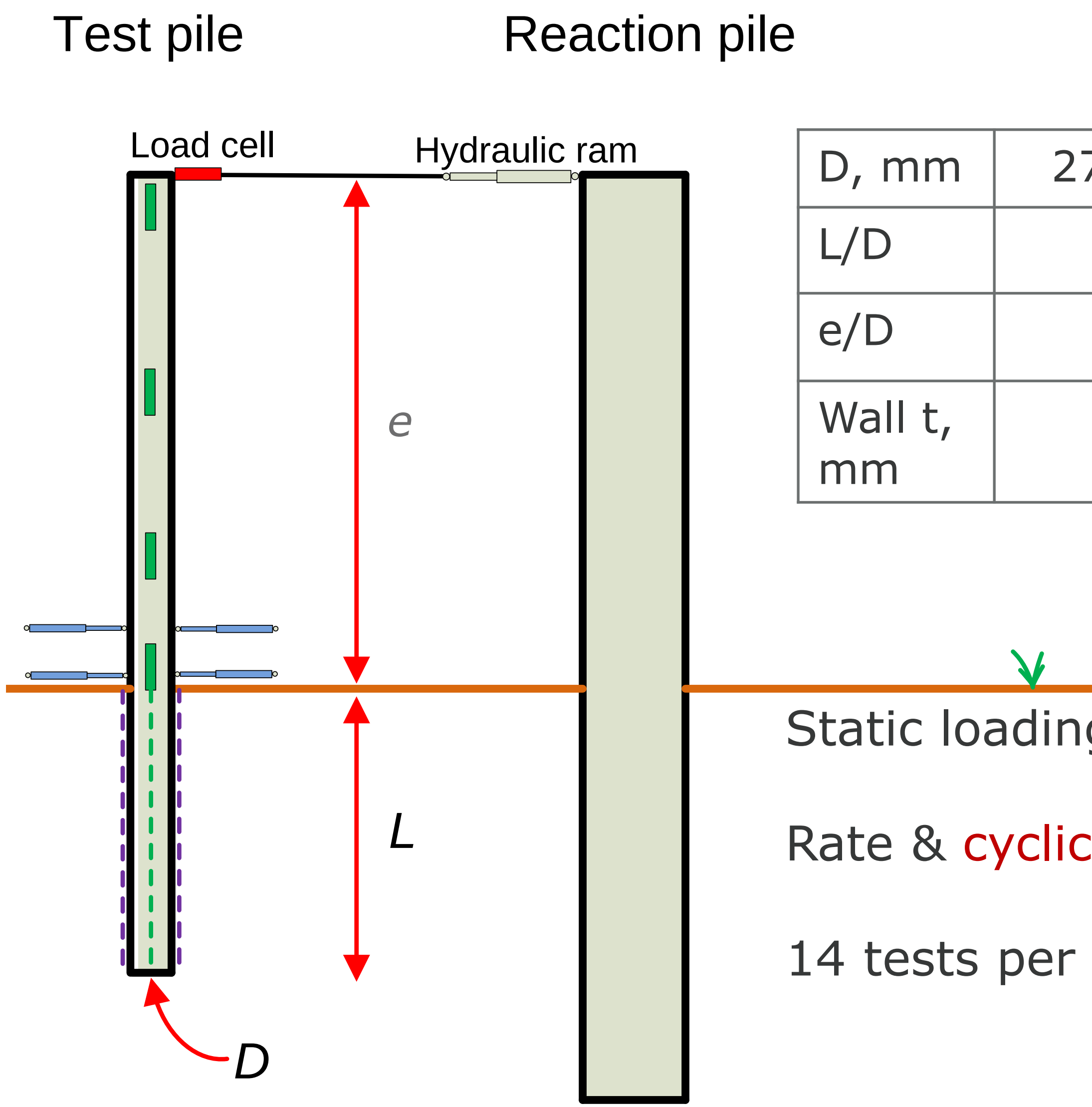
Only lateral p-y 'springs'
Little scope to capture detailed soil properties

PISA



Four sets of 'springs', check by 28 instrumented driven steel piles Dunkerque & Cowden test sites

PISA JIP: combined lateral & moment loading of low L/D monopiles: Dunkerque sand & Cowden glacial till



Inclinometers

Displacements

Fibre-optic & foil strain gauges

VW piezometers

D, mm	273, 762, 2000
L/D	3 to 10
e/D	5 to 18
Wall t, mm	7 to 25

Static loading to failure

Rate & cyclic tests

14 tests per site

Comprehensive CPTu & seismic in-situ testing

3-D ICFEP analysis to derive non-linear 'spring' curves
Calibrated to advanced lab tests at Imperial College

Dunkerque: dense marine sand

Two PhD testing programmes: stress path & HCA experiments

Cowden: Humberside

Sandy glacial till with stones & fissures

HCA 'specimen sculpting' aided by CT scanning

Laboartory research by Ushev & Liu

38 & 100mm D triaxial tests

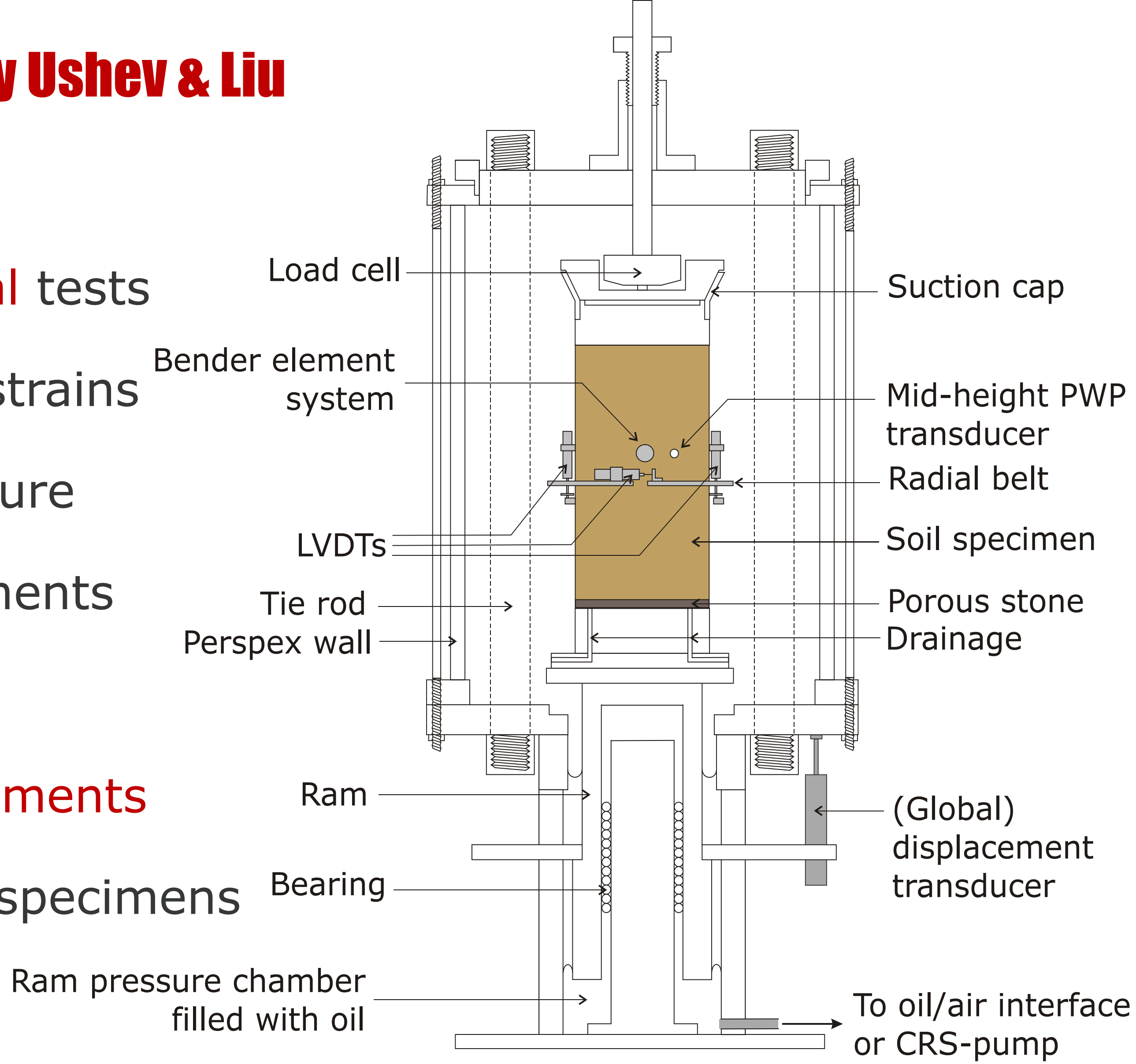
High-resolution local strains

Mid-height pore pressure

Dual-axis bender elements

72mm OD HCA experiments

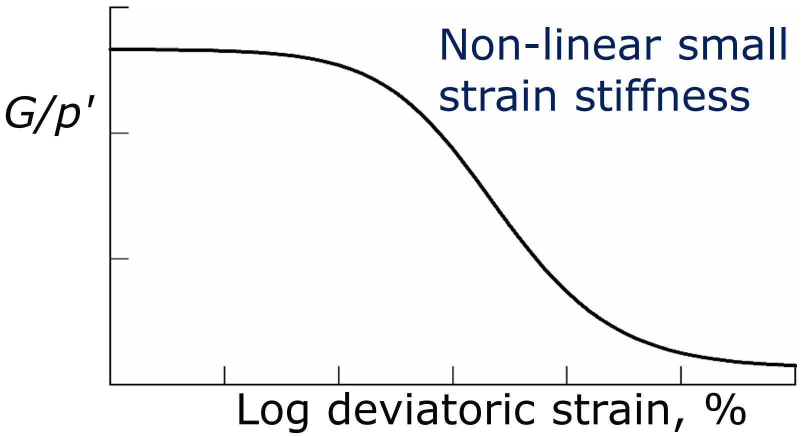
Cowden: lathe & drill specimens

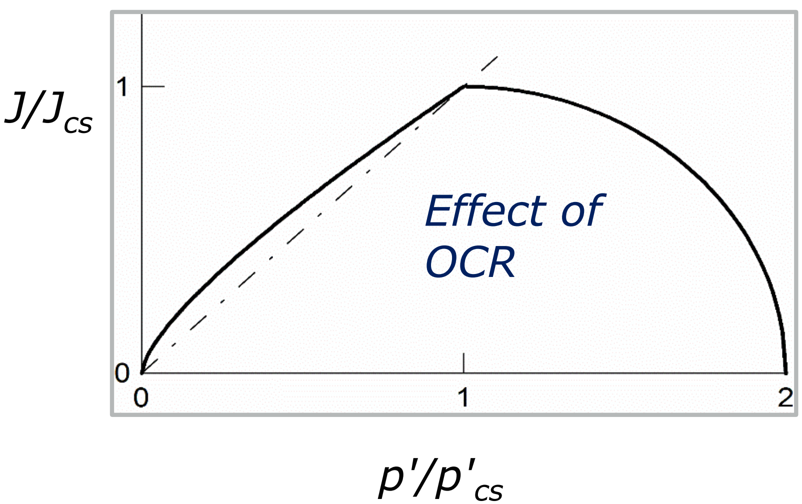


Compressibility, non-linear stiffness & shear strength
Anisotropy, strain rate & cyclic dependency

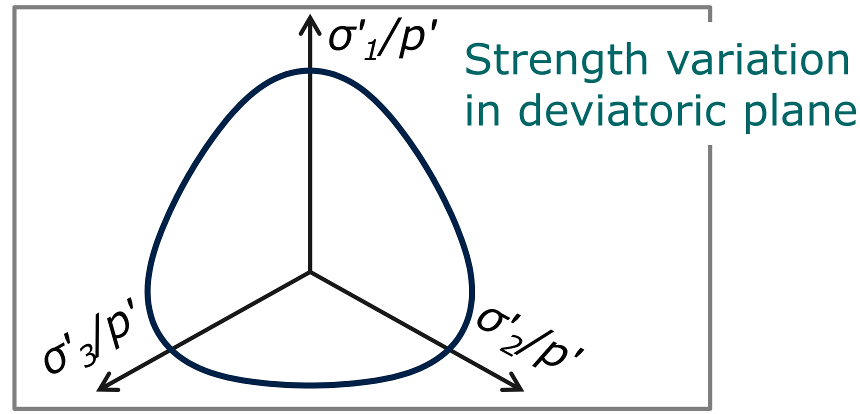
3-D ICFEP soil models
Calibrated to laboratory & in-situ tests

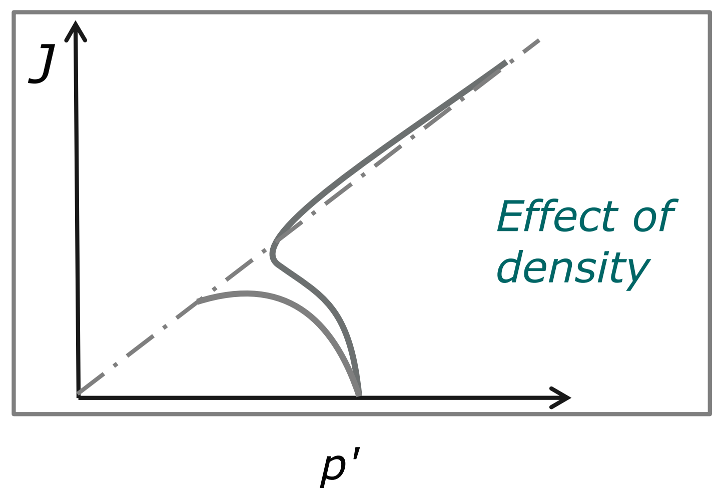
Cowden: expanded Mod. Cam Clay





Dunkerque: Bounding Surface Plasticity





Zdravković, Taborda, Potts, Jardine, Sideri, Schroeder, Byrne, McAdam, Burd, Houlsby, Martin, Gavin, Doherty, Igoe, Muir Wood, Kallehave & Skov Gretlund 2015

2m diameter monopiles under cyclic loading at Dunkerque

Summary for PISA: lateral and moment loading

- Improving design for monopiles; static response with cyclic testing
- Extensive analysis & field testing supported by laboratory testing
- New static design approach in use, papers in 2017; SUT OSIG Keynote & Journal submissions
- PISA 2 project: wider spread of soil conditions, including layering
- Cyclic design: new research