The Role of Computer Modelling in the Design, Optimisation and Operation of CP systems

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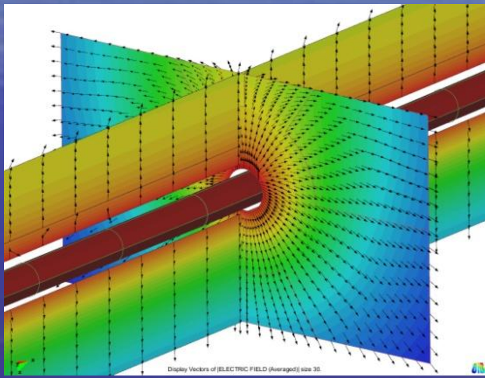
BEASY™

Introduction

- **Until computer-based mathematical simulation, achievement of required protection when designing a CP system relied on:**
  - **adherence to standards**
  - **skill and experience of the designer**
- **Computer simulation however now provides tools necessary to provide detailed *prediction* of protection levels**
  - **These tools can be used early in the design process, and can be used to optimise a design (whether SACP, ICCP, or a combined system)**
  - **Predictions can be used to help interpret data from surveys and monitoring**

Basis of mathematical modelling

- The simulation software determines:
  - Currents flowing through the electrolyte which may be seawater, ground, concrete
  - potential at any location in the electrolyte (eg survey positions, reference cell locations)
  - Potential and current density on the metal surfaces being protected
  - Magnitude of anode output
  - Anode remaining life
  - IR drop in long structures (pipelines, well casings etc)
  - Stray current or interference between different structures



Vectors showing current flow around an on-shore buried pipeline

Basis of mathematical modelling

- The software:
  - solves the Laplace equation in the electrolyte
  - Uses polarisation curves (long-term or potentio-dynamic) on metal surfaces
  - Solves circuit equations in the return-path
- By performing time stepping account can be taken of:
  - Effects of changing coating breakdown factor
  - Anode mass loss and corresponding change of anode size
- The software used in work reported in this paper is BEASY CP

Field surveys

- **Simulation results can be used to gain confidence in survey data, and to extrapolate survey data to all parts of a structure**

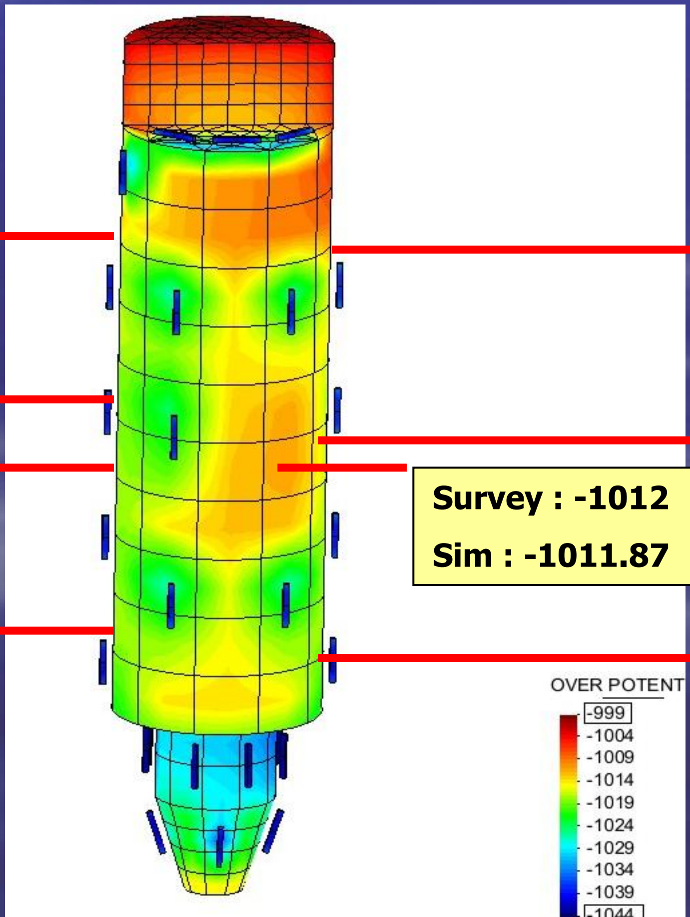
STARBOARD, closer to the FPSO

Survey : -1014
Sim. : -1015.80

Survey : -1011
Sim. : -1017.66

Survey : -1015
Sim,. : -1017.70

Survey : -1012
Sim,. : -1017.77



Survey : -1012
Sim : -1011.87

PORT

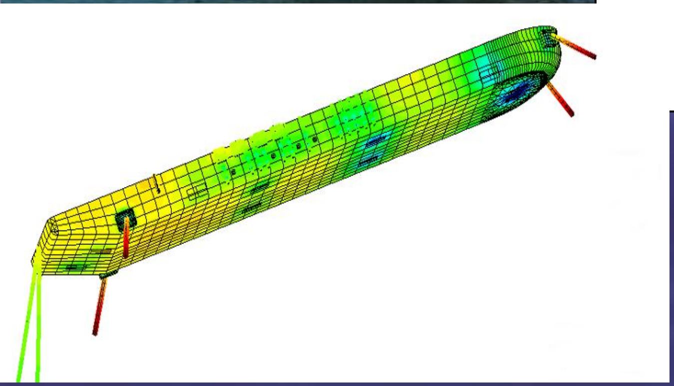
Survey : -1004
Sim. : -1010.60

Survey : -1014
Sim. : -1015.92

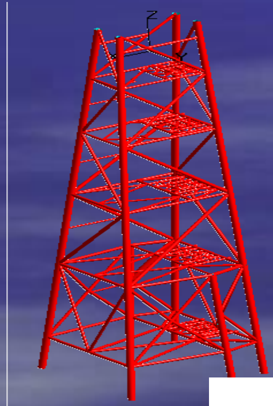
Survey : -1014
Sim. : -1018.32

Published data

- Extensive publications on simulation of CP systems in ships, offshore structures etc
  - where it has been used as an up-front design tool for optimisation of the CP system



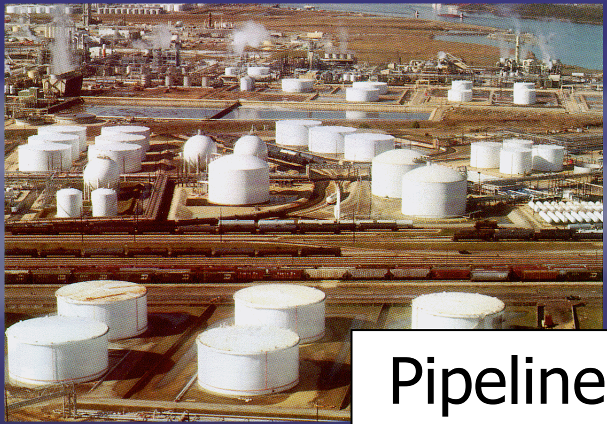
Ships/ FPSO's



Off-Shore Structures

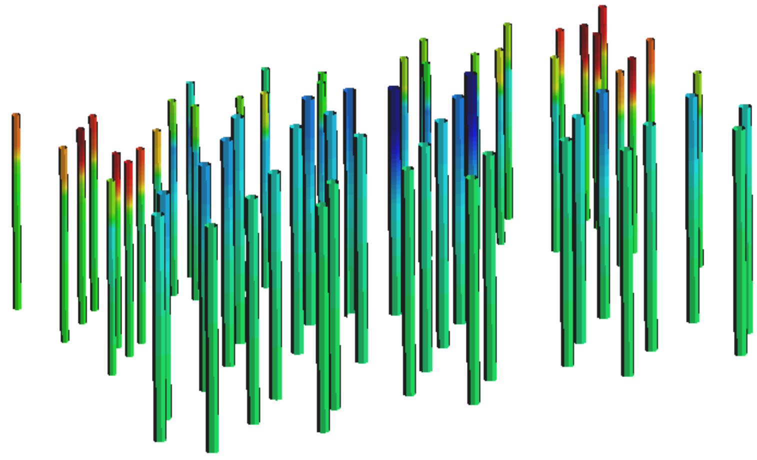
Verified methodology

- As acceptance of accuracy of the methodology has been established, the experience has been extended to other structures, such as:
  - Storage tanks
  - Pipelines
  - Reinforced concrete



Pipelines,Storage tanks, Jetties, Pilings

Protection potentials on reinforced concrete pilings



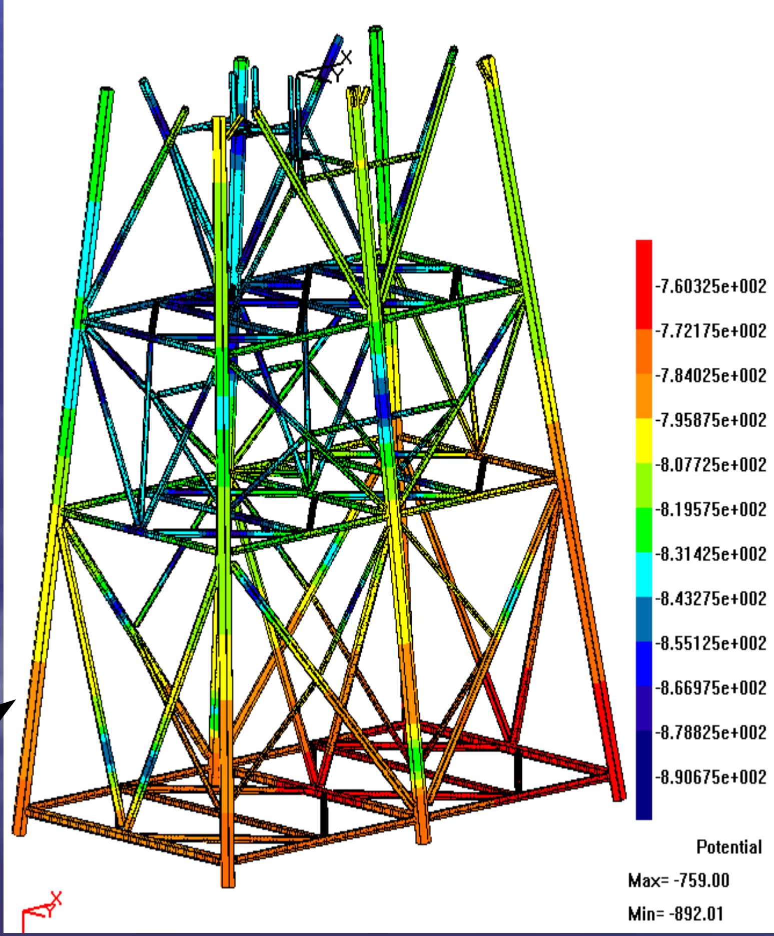
Asset operation and maintenance

- Simulation is developing as a means to support ongoing operation and maintenance of an asset
  - Repeated simulation each year with calibration to annual survey to establish ongoing state of the asset
  - Prediction of best time to install retrofit CP systems (based on prediction of when existing anodes will be consumed)
  - Design of optimised retrofit CP system
  - Investigation of changes to the environment (new tie-ins, crossings etc)

Asset operation and maintenance- Retrofit Design

- **If localized or more general loss of calcareous deposits occurs, any retrofit SACP system will need to be able to produce the higher currents required to regenerate the calcareous deposits**
- **It is therefore financially beneficial to carefully time the installation of a retrofit system to avoid loss of calcareous deposits**

Potentials if previous anodes are consumed and calcareous deposits maintained by them are lost



Asset operation and maintenance- Retrofit Design

- **It was decided that the retrofit system should be installed before the date when the previous system would expire**

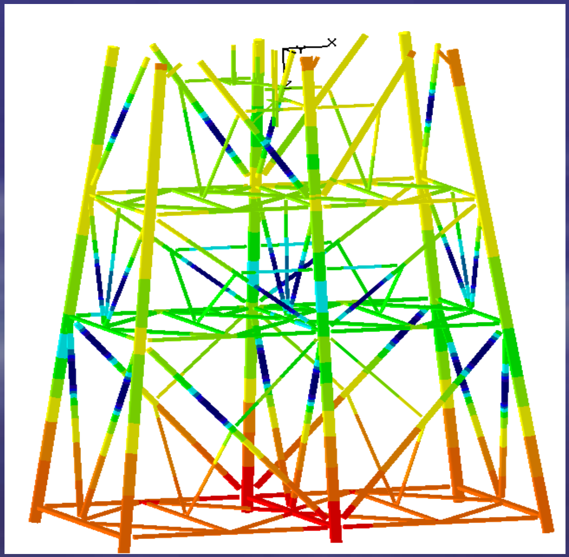
- **This meant that calcareous deposits produced by the previous system would still be in place, and *could* be used to reduce the anode mass required in the retrofit**

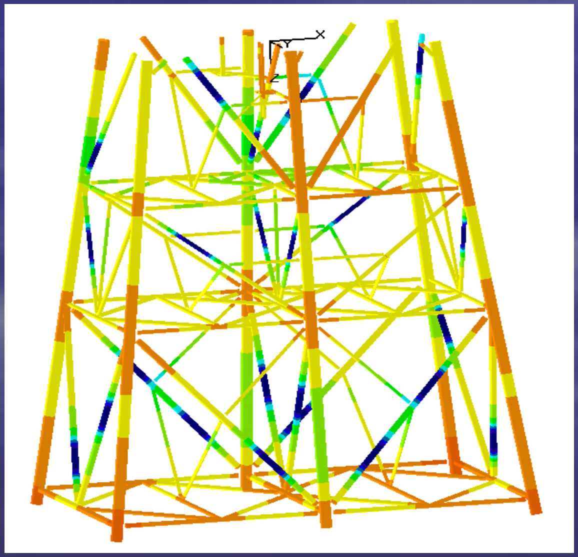
Retrofit optimisation

- An initial anode layout was designed, then:
  - Performance was assessed
  - The results were used to guide anode position (and number) changes for the next, improved, design
  - Three or four such iterations produced a design with much better uniformity of potential and anode life

Retrofit optimisation

- **Structure potentials for two of the designs tested show greater variation over the structure for an early design (left) than for a later design (right)**

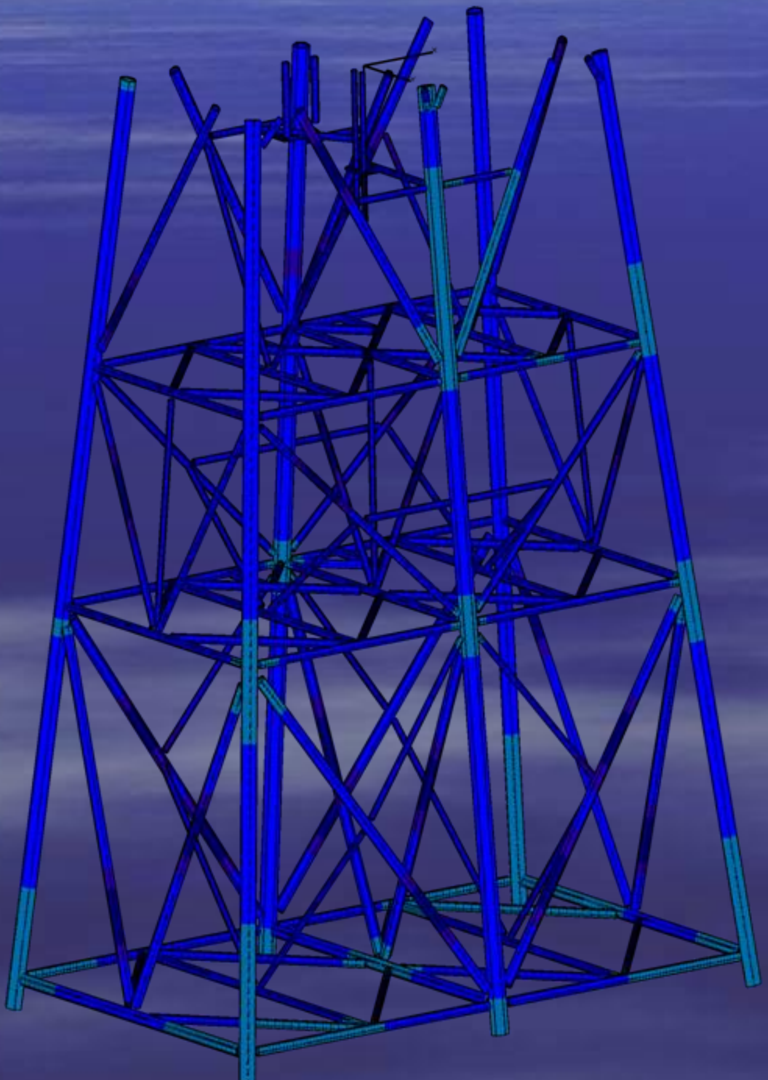




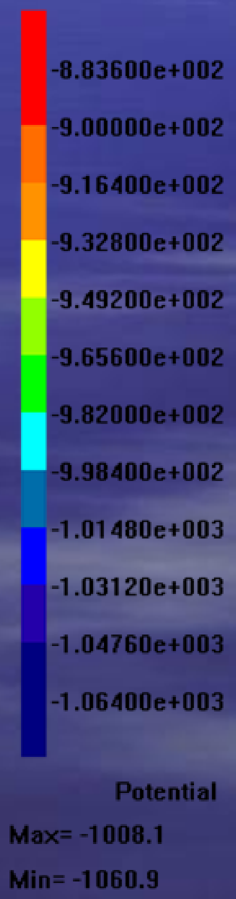
Retrofit optimisation

- Corresponding anode life projections made at end of life (after 15 years time stepping) showed:
  - Anode life ranged from 9 to 14 years (design with 50 anodes)
  - Anode life ranged from 8 to 10 years (design with 46 anodes)
- Data (remaining life/mass) is generated for each individual anode, and takes account of change of profile over time as it is consumed. Anodes reaching the defined utilisation factor are removed from the model.

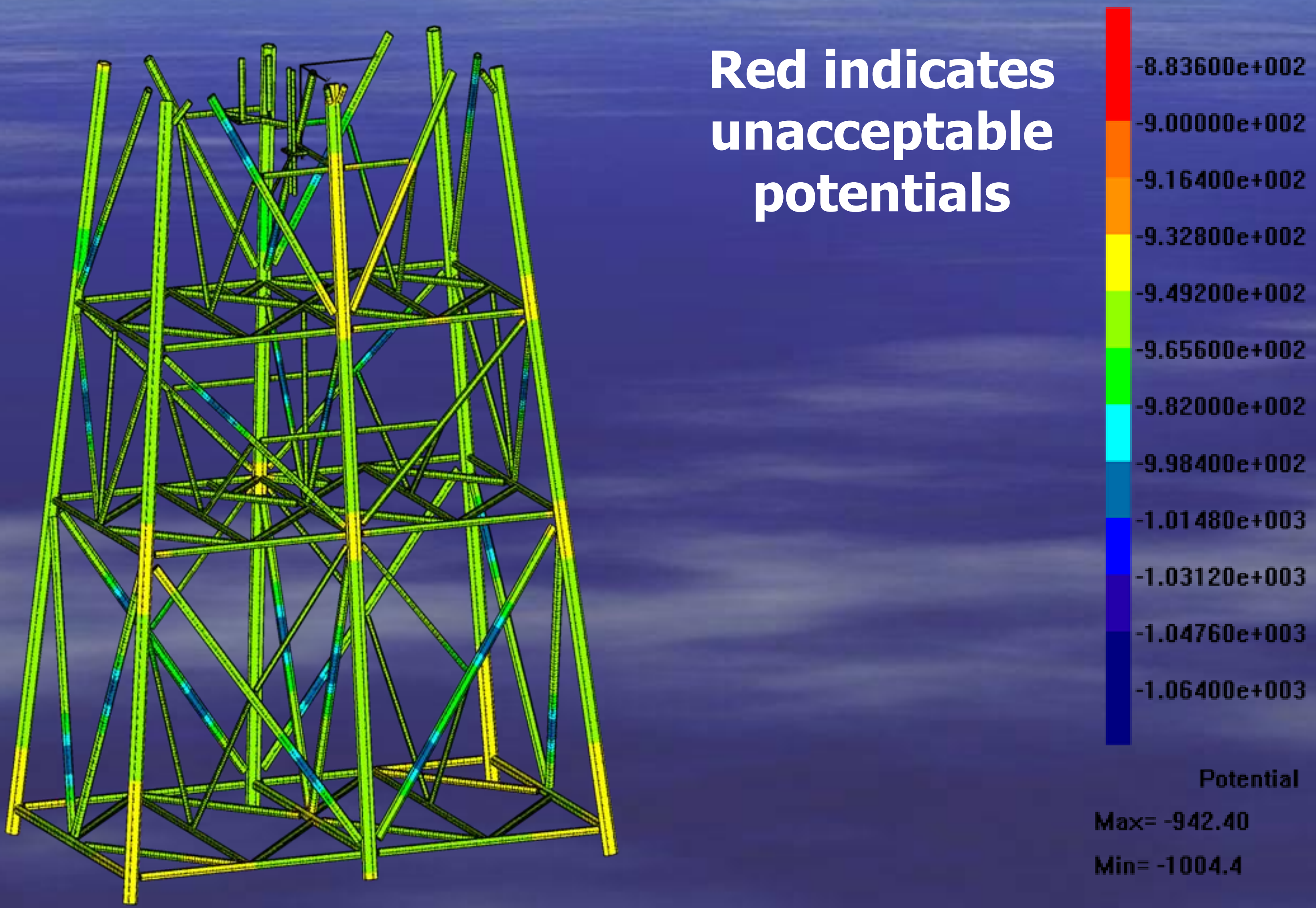
New Retrofit: After Installation



Blue indicates acceptable potentials



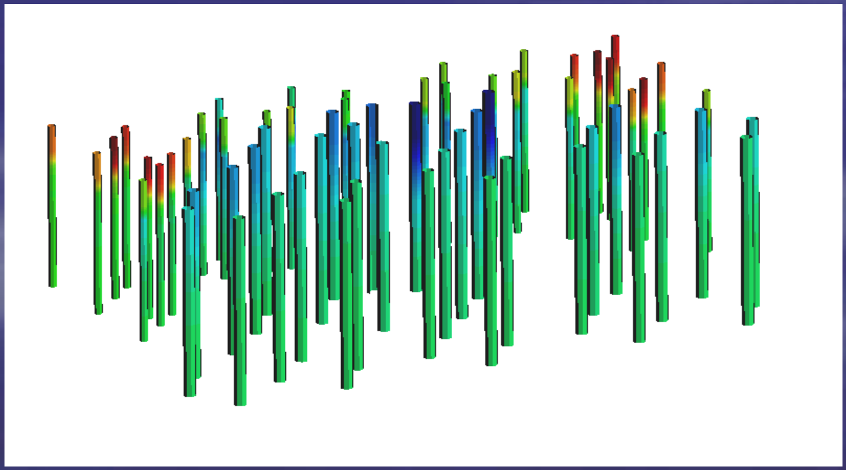
New Retrofit: After 15 Years



Red indicates unacceptable potentials

CP of steel in concrete

- CP systems for reinforced concrete, or steel piles coated in concrete, can be optimised using simulation
  - Design of an ICCP system applied to piles was optimised to control protection potentials

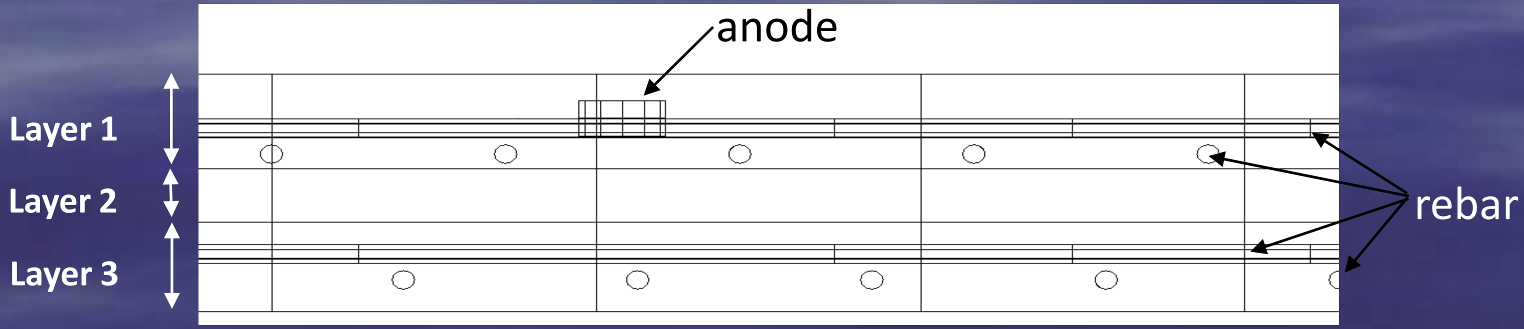


CP of steel in concrete

- Retrofit CP systems to protect steel in concrete can be assessed and optimised
  - On a global scale (complete structures)
  - At a local scale (including individual reinforcement bars)

CP of steel in concrete – local scale

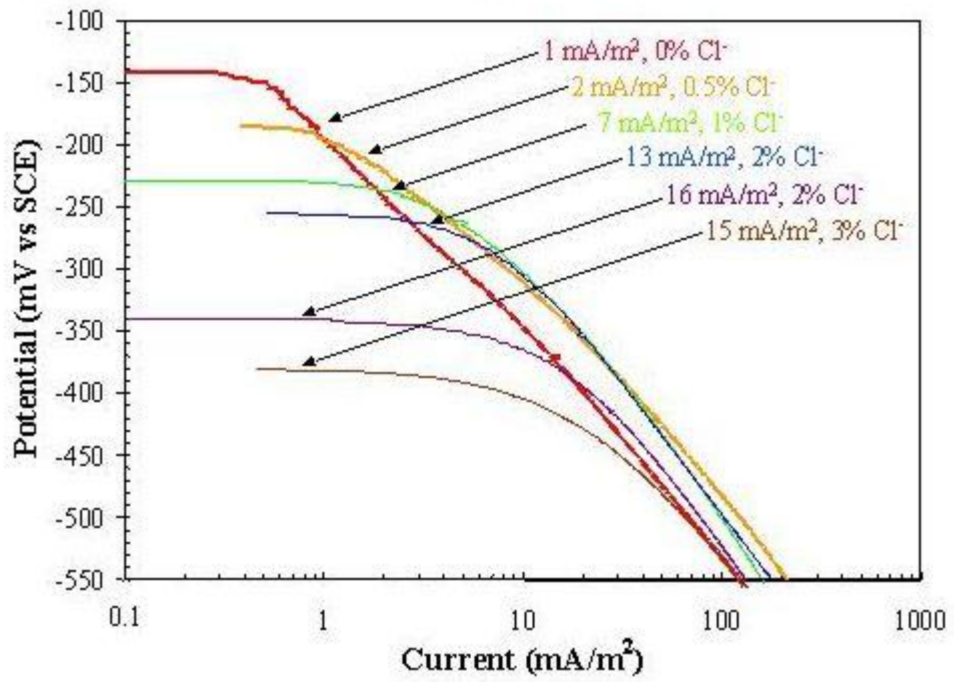
- **Investigation of potential distribution around single discrete anodes**



CP of steel in concrete – local scale

- **Various polarisation curves for reinforcement bars in different conditions**

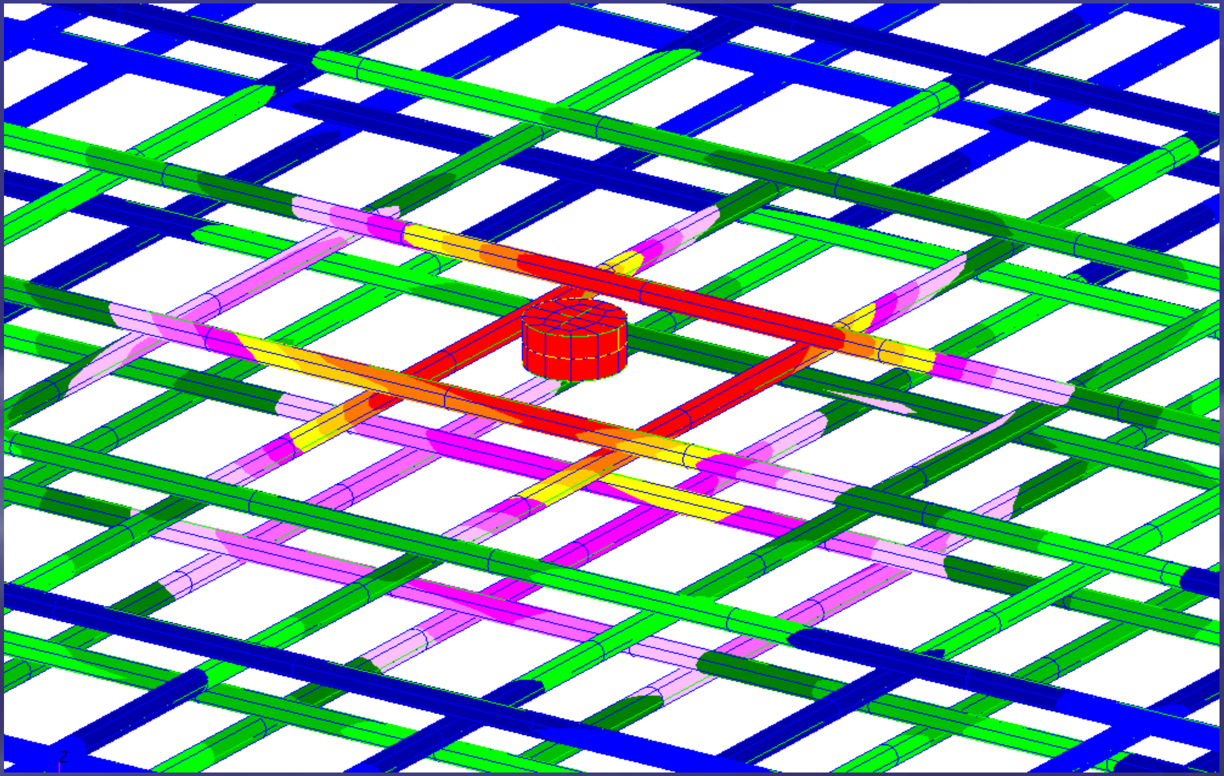
Fig. 8. Cathodic polarisation curves determined on steel in concrete exhibiting a range of initial corrosion rates resulting from variations in chloride content.



Data extracted from the paper: Cathodic protection of steel in concrete
[G. K. Glass*, A. M. Hassanein# and N. R. Buenfeld
Department of Civil and Environmental Engineering, Imperial College, London, SW7 2BU]

CP of steel in concrete – local scale

- **Potentials shown on individual reinforcement bars**

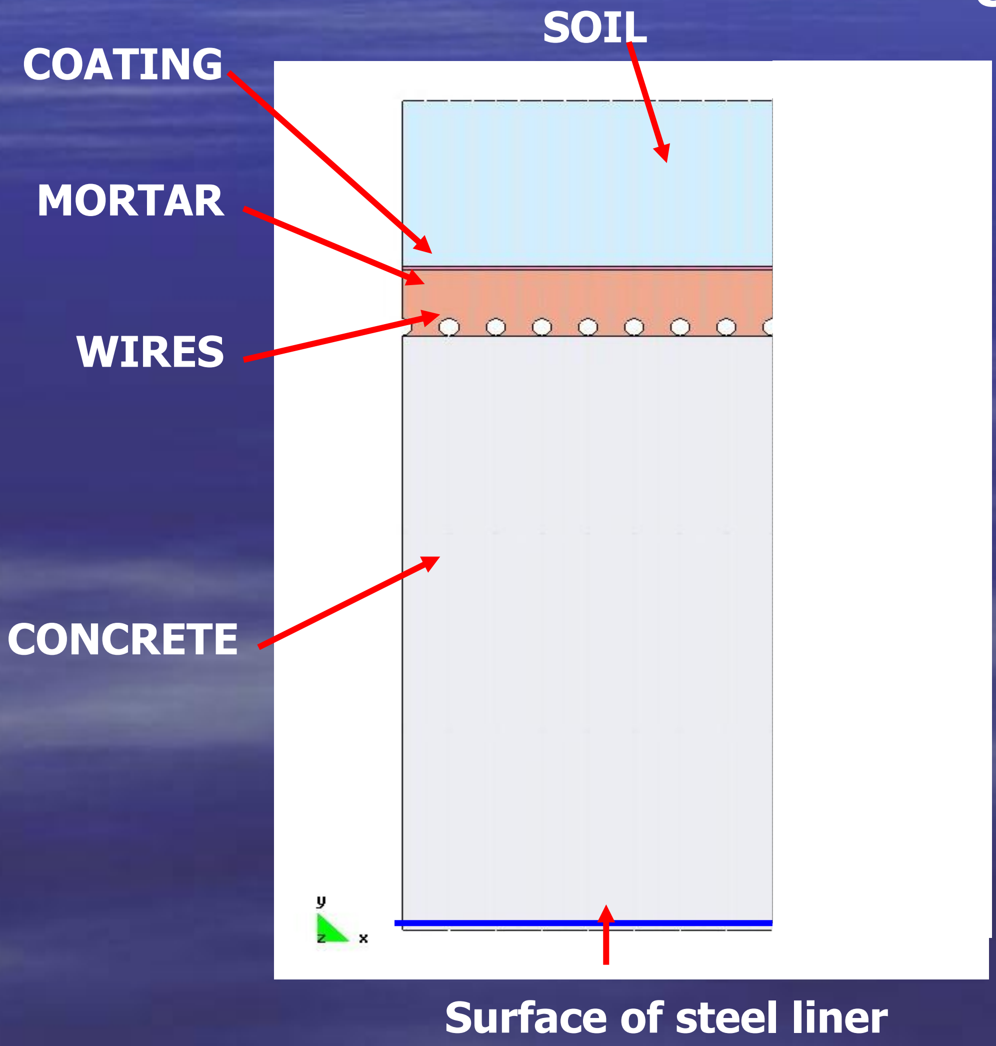


CP of steel in concrete – global scale

- It is not feasible to include individual reinforcement bars in a large scale structure (100 metres or more)
- Instead:
  - A local model is used to determine properties which can be assigned to the surface of the concrete. This model includes:
    - Embedded steel
    - Rebars/wires
    - Concrete/mortar
    - Any coating on the surface of the mortar/concrete
  - The properties so-determined are then applied to surfaces in the large-scale model of the complete structure

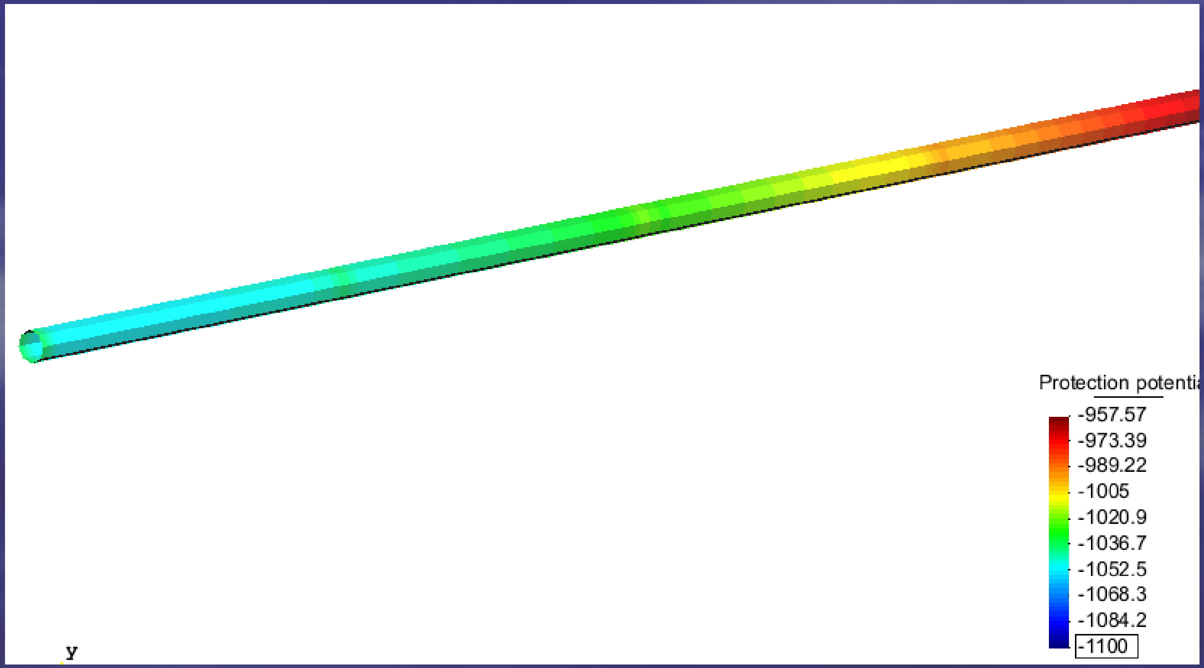
CP of steel in concrete – global scale

- For a PCCP structure the local investigation used:



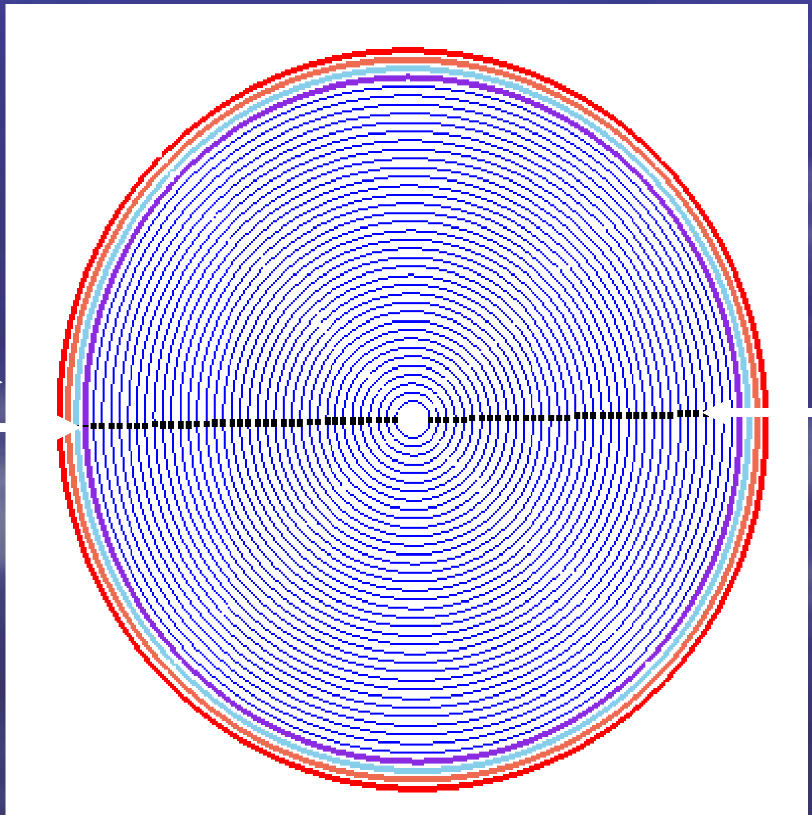
CP of steel in concrete – global scale

- The PCCP structure was protected by a CP system with linear anodes arranged along the length of the PCCP, but connected only periodically to the pipe
  - Potentials on the PCCP surface can be converted into protection potentials on steel surfaces embedded in concrete/mortar



Tank base protected by ICCP

- The ICCP system is based on concentric rings of anode ribbons
  - Feeder cables were attached to both ends of each half-ring



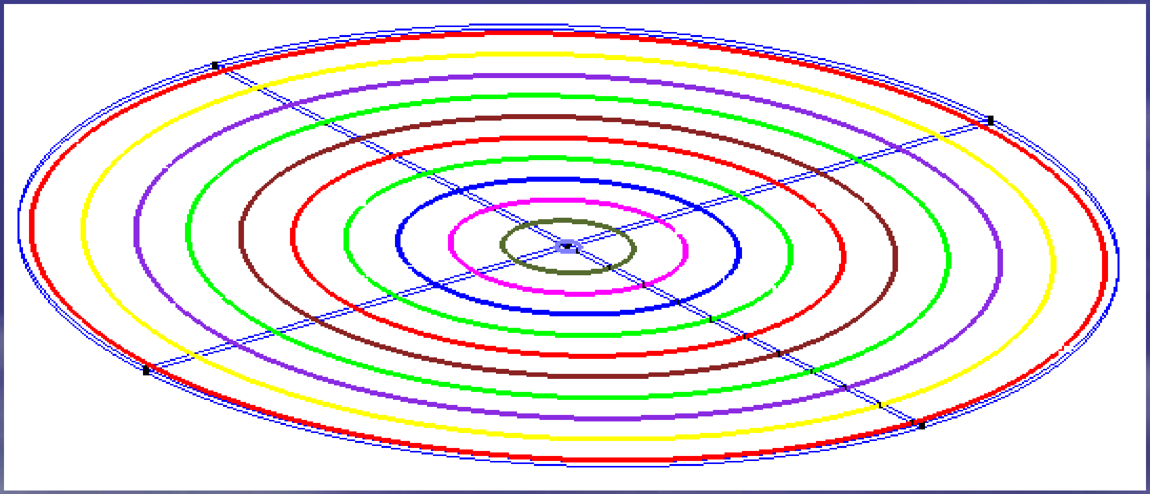
CONNECTION POINTS shown as black dots

Tank base protected by ICCP

- The circular tank base has diameter 42 metres, and sits on a 23 cm thick layer of sand below which there is a membrane
- The ribbon anodes:
  - have small cross-section, so large IR drops occur along them in the return path
  - are MMO coated titanium
  - are located 0.06m above the membrane
  - have cross-section 6.35mm by 0.635mm

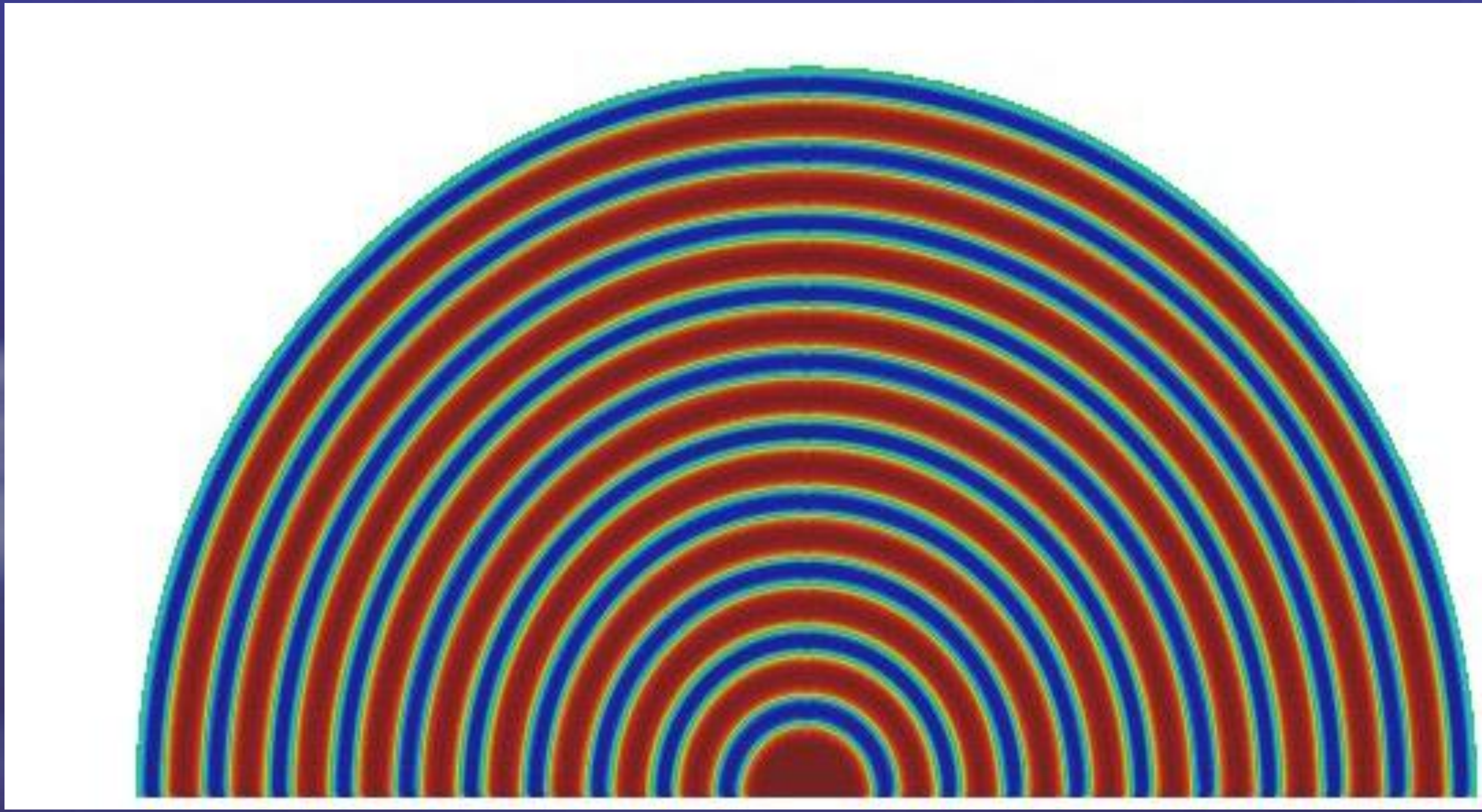
Tank base ICCP system optimisation

- Design 1 has 2 metres separation between ribbons



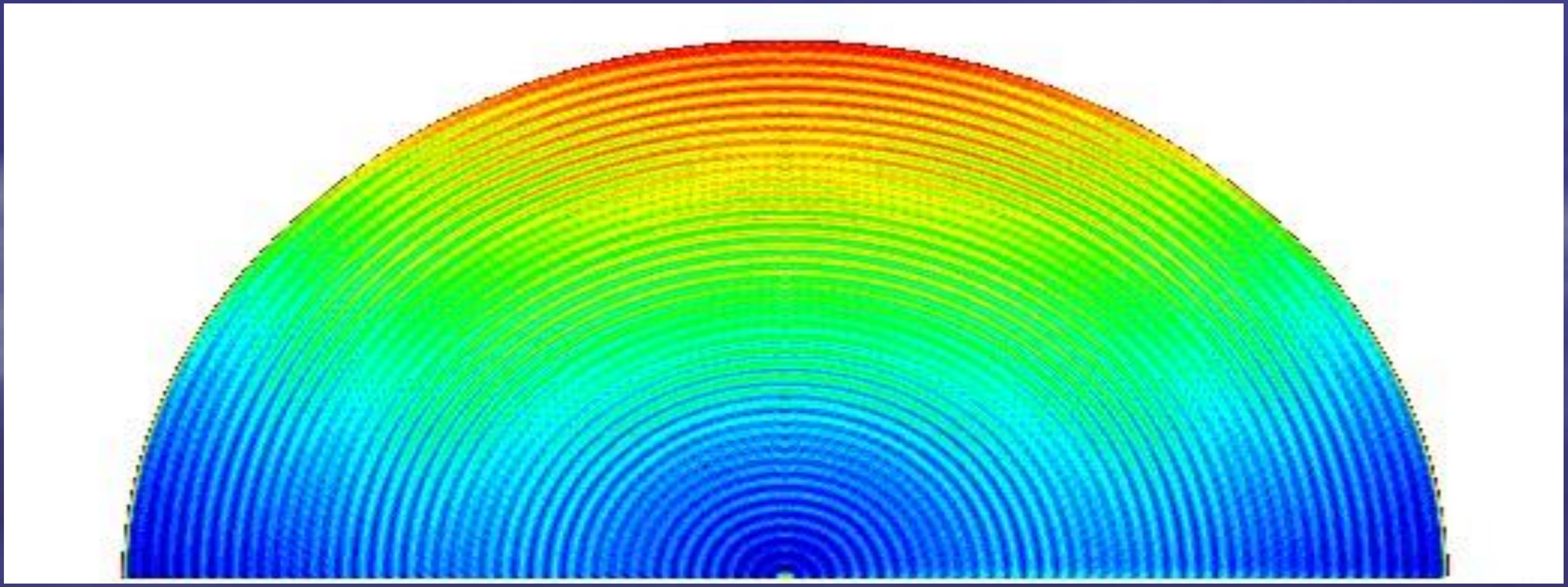
Tank base ICCP system optimisation

- Potentials on the tank base are not within the target range, even with maximum TRU output



Tank base ICCP system optimisation

- A revised design using 41 anode rings was assessed
- There was significant variation on the tank base, but potentials are within the target range

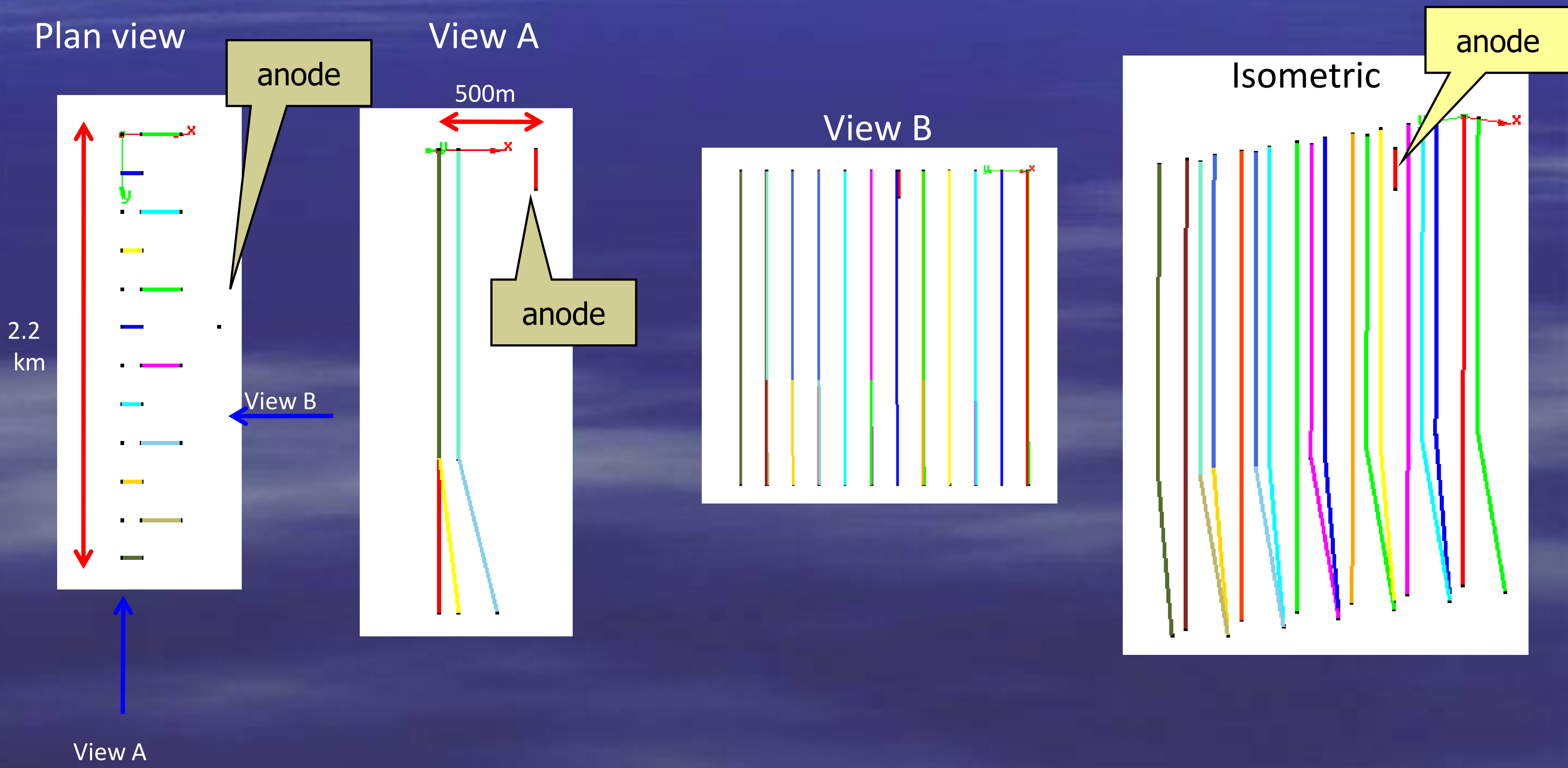


Deep well casings

- Protection of deep well casings is made difficult by:
  - Significant IR drop along the well casing
  - Layers of ground which have relatively high/low resistivity
  - The need to place anodes at or close to the seabed or ground surface
- Simulation allows these influences to be investigated

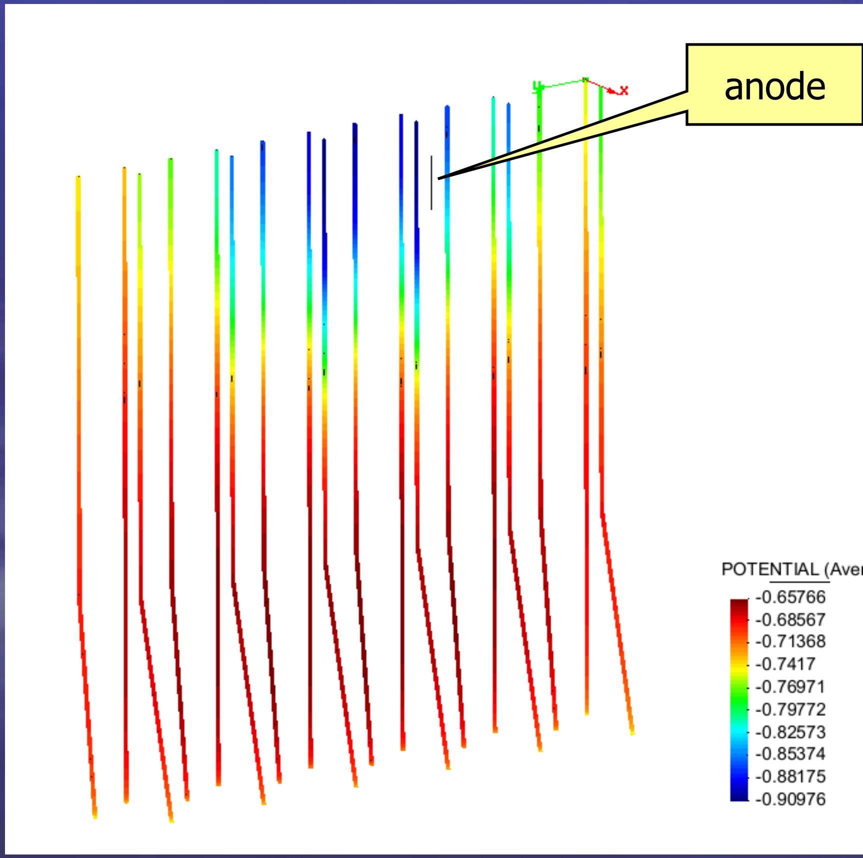
Effect of multiple wells

- We first investigate an array of wells in two rows, with a single anode ground bed
- Here the ground is assumed to be homogeneous



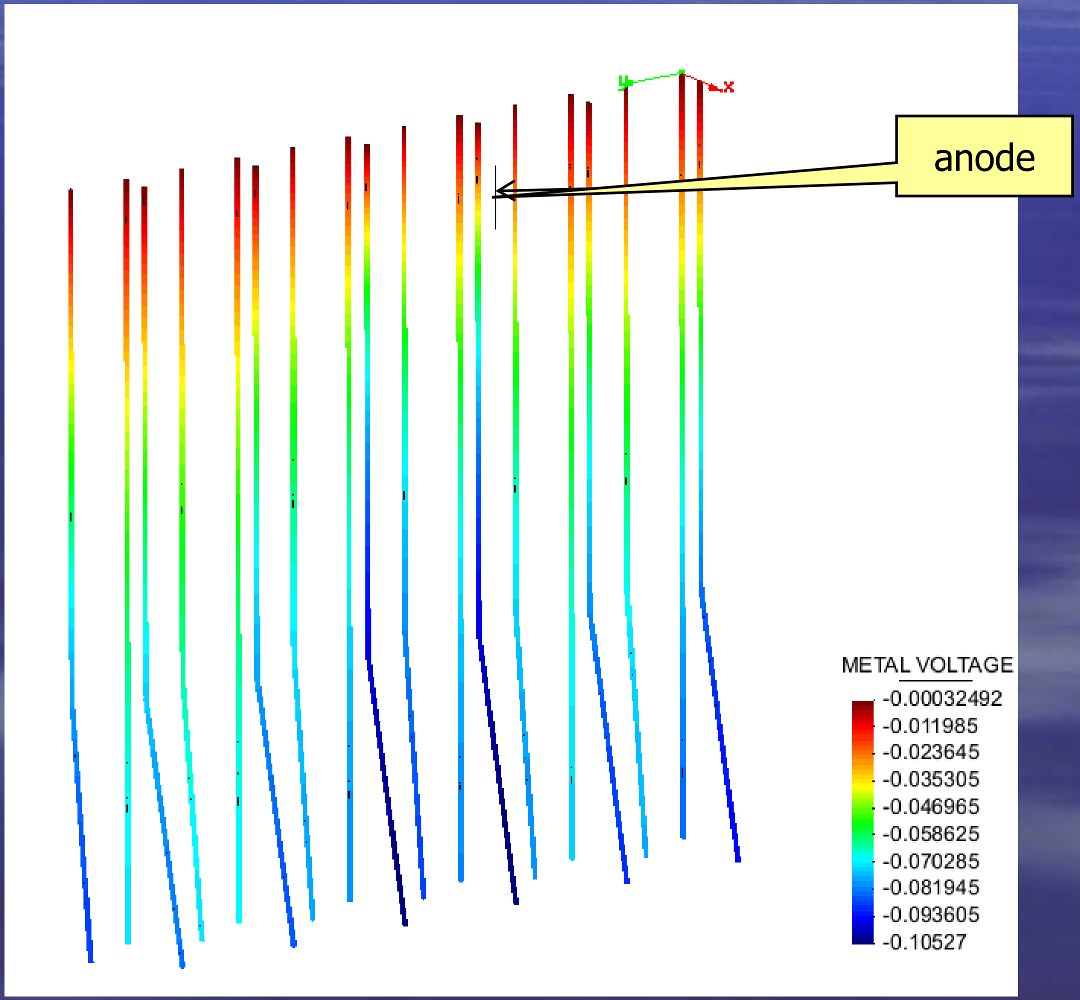
Potentials on the well casings

- Most negative potential is at the top of the well casings which are closest to the anode
- Significant negative potentials extend to greater depth down the wells in the row closer to the ground bed
- The well furthest from the anode (shown on the left) is better protected than the well next to it, because it receives “end-effect” current



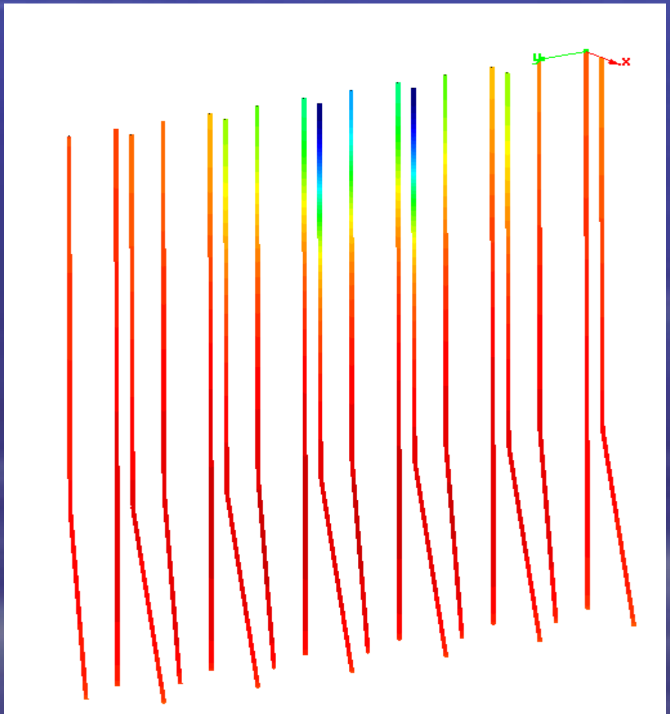
IR drop along the well casings

- This contour plot of metal voltage shows that greatest IR drop occurs in the wells nearest to the anode (because these wells receive more current)



Current density on the deep well casings

- Blue shows biggest current density

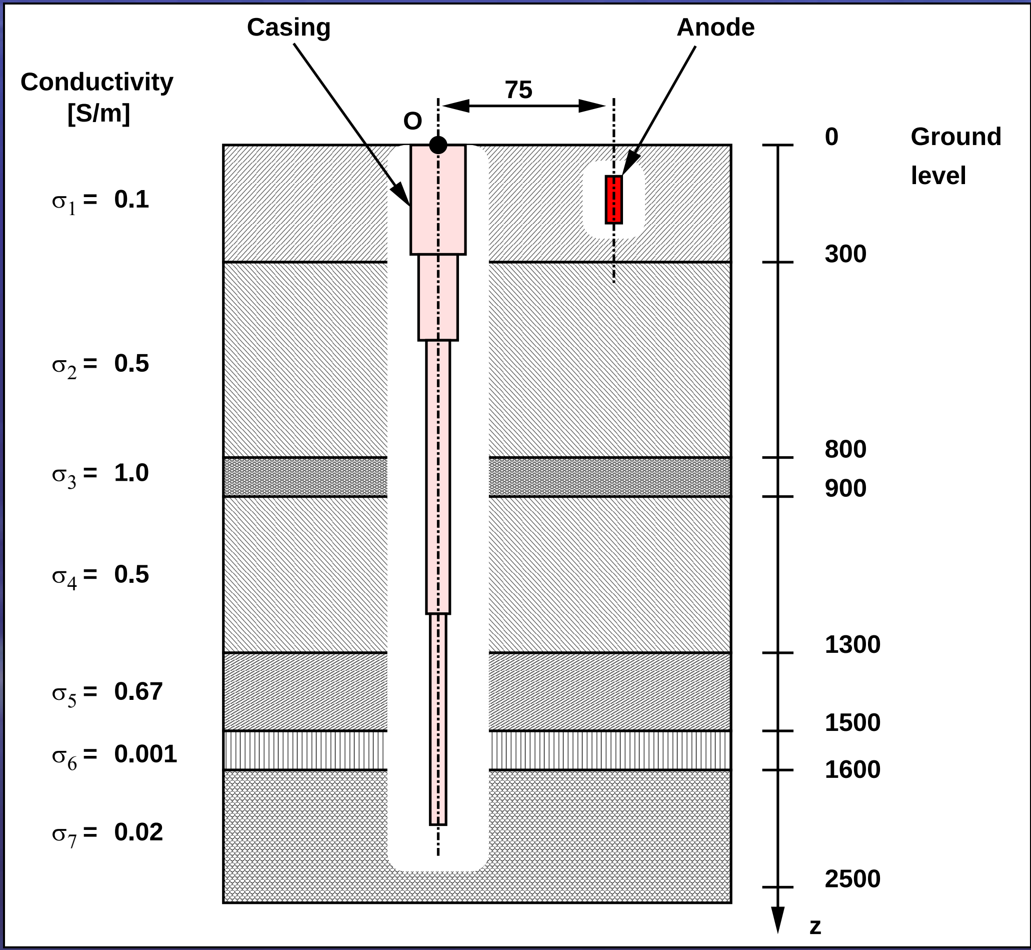


Anodes protecting arrays of deep well casings

- **Conclusion:**
- **The complex geometry of *arrays* of well casings has a significant effect on achieved protection potential**
  - **Simulation is essential for understanding and control of protection potentials**

Deep well casings in layered ground

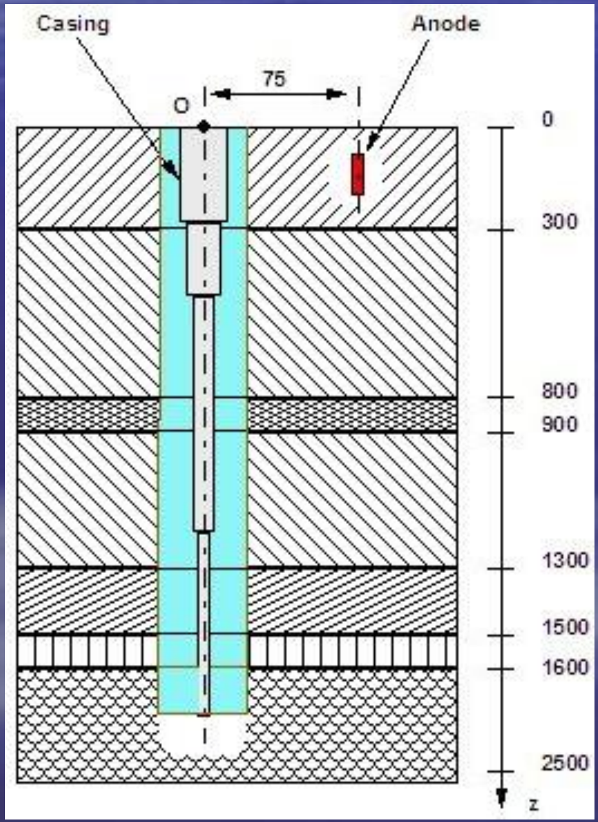
- When multiple ground layers are present, the situation is also complex
- Here we investigate a single vertical well casing
- The anode output is fixed at 10 Amps*



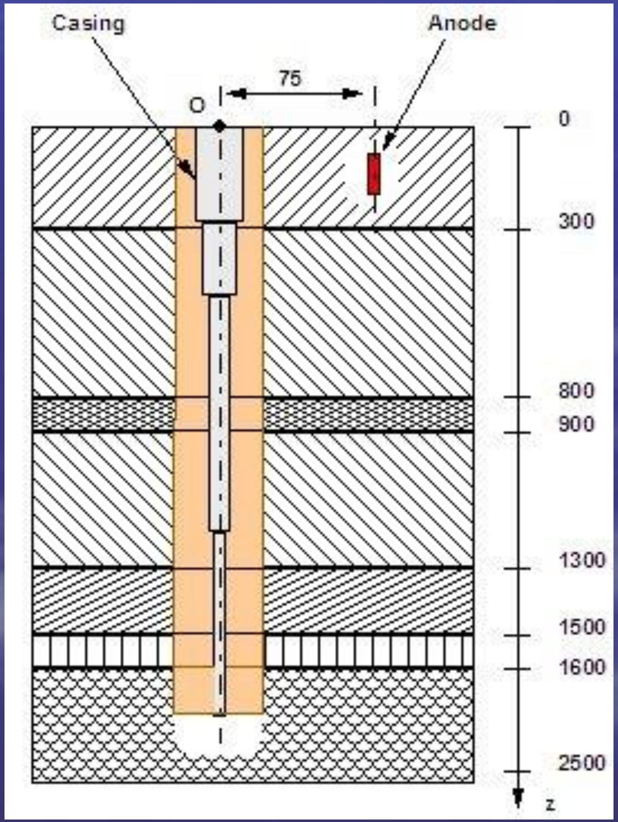
* A thorough investigation using BEASY was reported by Roche, Vittonato and Jebara in "Cathodic Protection Modeling of Deep Well Casing by 3D software Simulation: Comparison with E-LogI and CPET Data", NACE Corrosion 2008 Conference, Paper number 08273

Different assumed well cementation

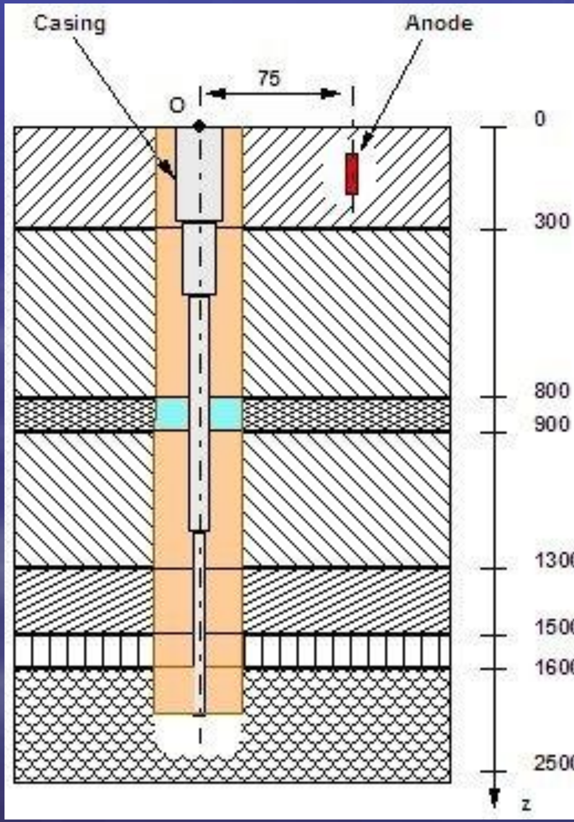
WET



DRY



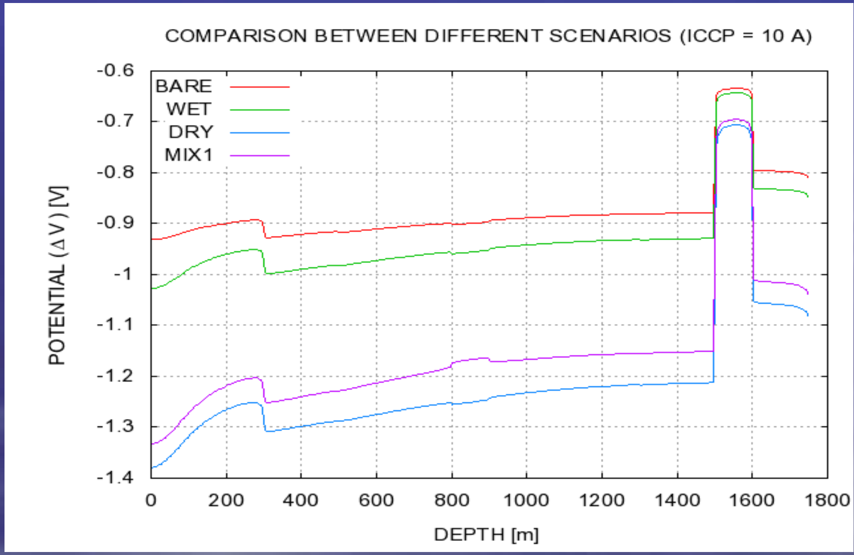
MIXED



Sketches are not to scale

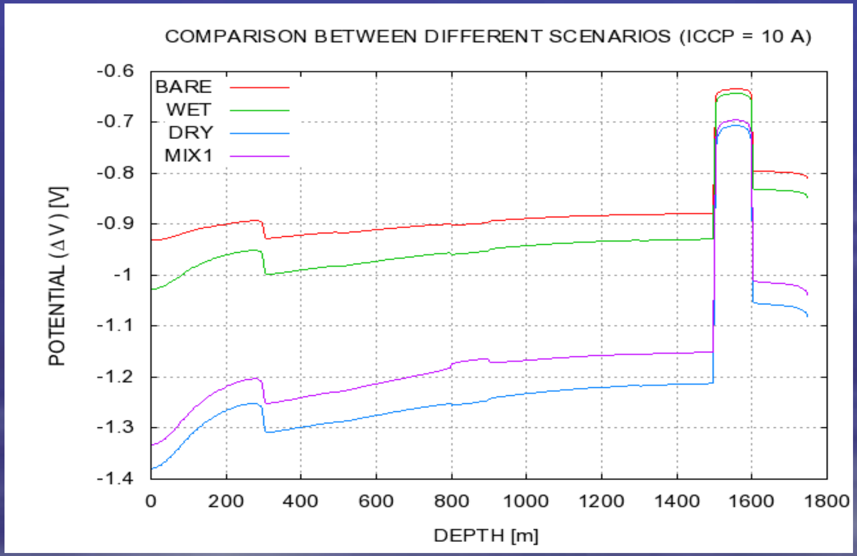
Potential on the well casing

- **The IR drop per metre length of the casing is biggest at the top where current along the casing is greatest**
- **Protection potential changes rapidly at layer boundaries where resistivity changes significantly**



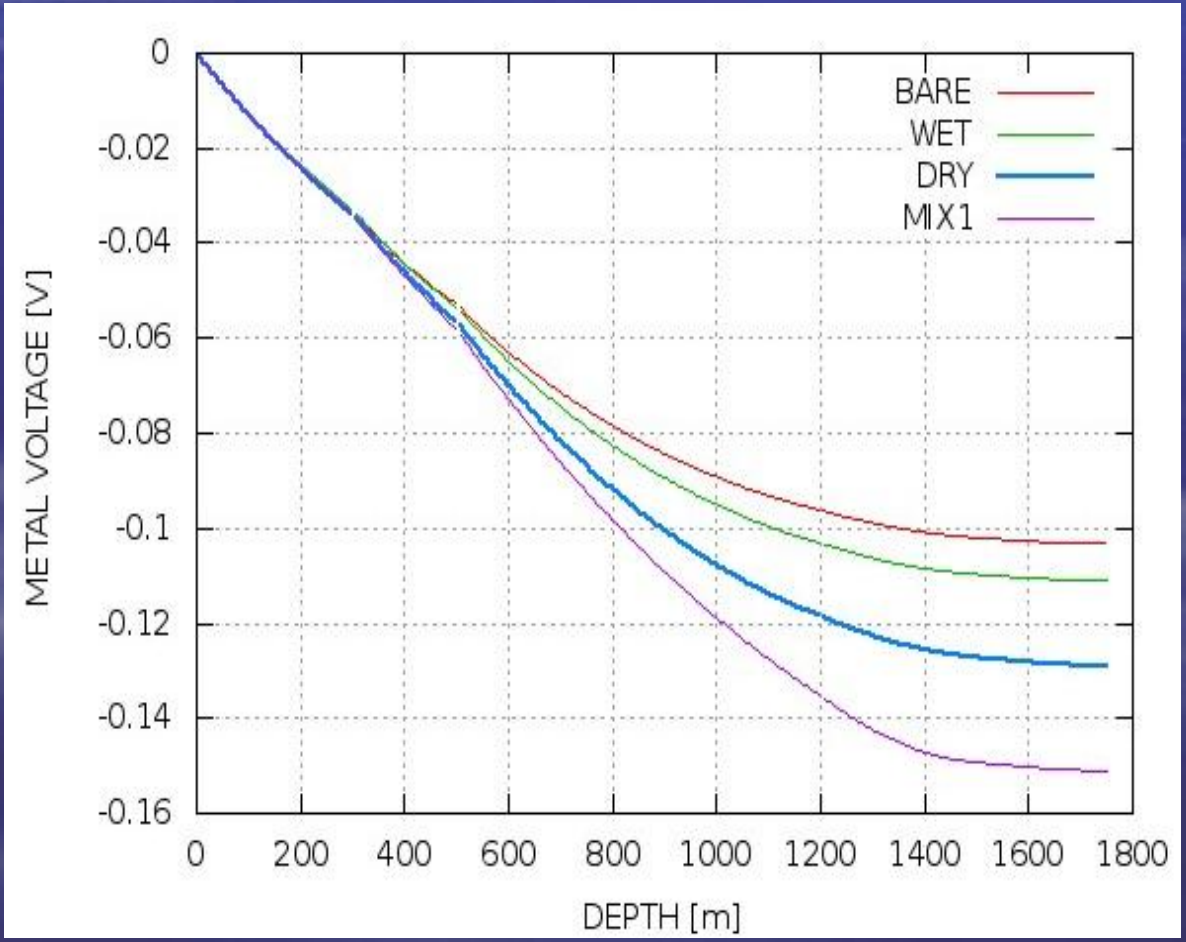
Potential on the well casing

- There is a ~300mV difference between the “Dry” and the “Wet” cement condition over the majority of the casing
- In the layer just above 1600m depth, where the conductivity is very low (ie resistivity is very high), it is not easy to produce a potential shift
- The layer below however receives current which has travelled vertically through the resistive layer and then horizontally to reach the casing



IR drop along the casing

- IR drop along the casing is 150 mV for the "MIX1" state of cementing



Conclusions

- This paper has shown:
  - how computer modelling simulation techniques can be applied to the Design, Optimisation and Operation of CP systems
  - That the situations to which simulation can be applied include jacket structures, reinforced concrete structures, ships/FPSOs, pipelines, storage tank bases, deep well casings, etc
  - That simulation can be used with sacrificial systems, ICCP systems
  - That CP simulation has a beneficial role to play in asset management

Conclusions

- The key demonstrated benefits are:
  - Retrofit requirement can be successfully reduced. Hence, significant cost savings achievable
  - Better CP current distribution can be obtained despite reduction of number of anodes by better strategic anode positioning
  - Assured targeted life extension of the CP system
  - Optimized future CP survey frequency is possible. Hence, costs of needless future surveys can be saved
  - Improved planning of retrofits and surveys
  - Clearly these techniques are of interest to practical CP design for achieving optimization and cost saving