Some Geotechnical Observations for Deep Excavations in Weak Rock

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Scope

- Stratigraphy and Strength of Weak Rock Formations
  - Barziman Formation in Dubai
  - Dammam Formation in Doha
- In Situ Stress and Stiffness
- Ground Movement Prediction

Excavation Experiences

Name	Location	Type	Depth (m)	Rock Formations
Arabian Canal Trial Site – 2006 to 2009	Inland Dubai	2Mm^3 Open excavation	35	Gayathri and Barziman Formations (siliceous and carbonate type sandstones, siltstones, and mudstones)
Mall of Emirates – Current	Coastal Dubai	Barrette Foundations	10	Barziman / Gayathri Formation – Sandstone
Deep shaft – Current	Inland Abu Dhabi	Deep shaft	30	Fars Formation carbonate mudstones and gypsum.
Central Doha Sites – Current	Doha 1 Doha 2	Open excavation and D wall support	Currently 5 to 20	Dammam Formation Simisma limestone, Midra Shale, and Eocene - Rus Formation - chalky limestones and siltstones
New Doha International Airport – 2010 - 2011	Doha coast	Permanent D wall	20	Dammam Formation Simsima limestone, Midra Shale

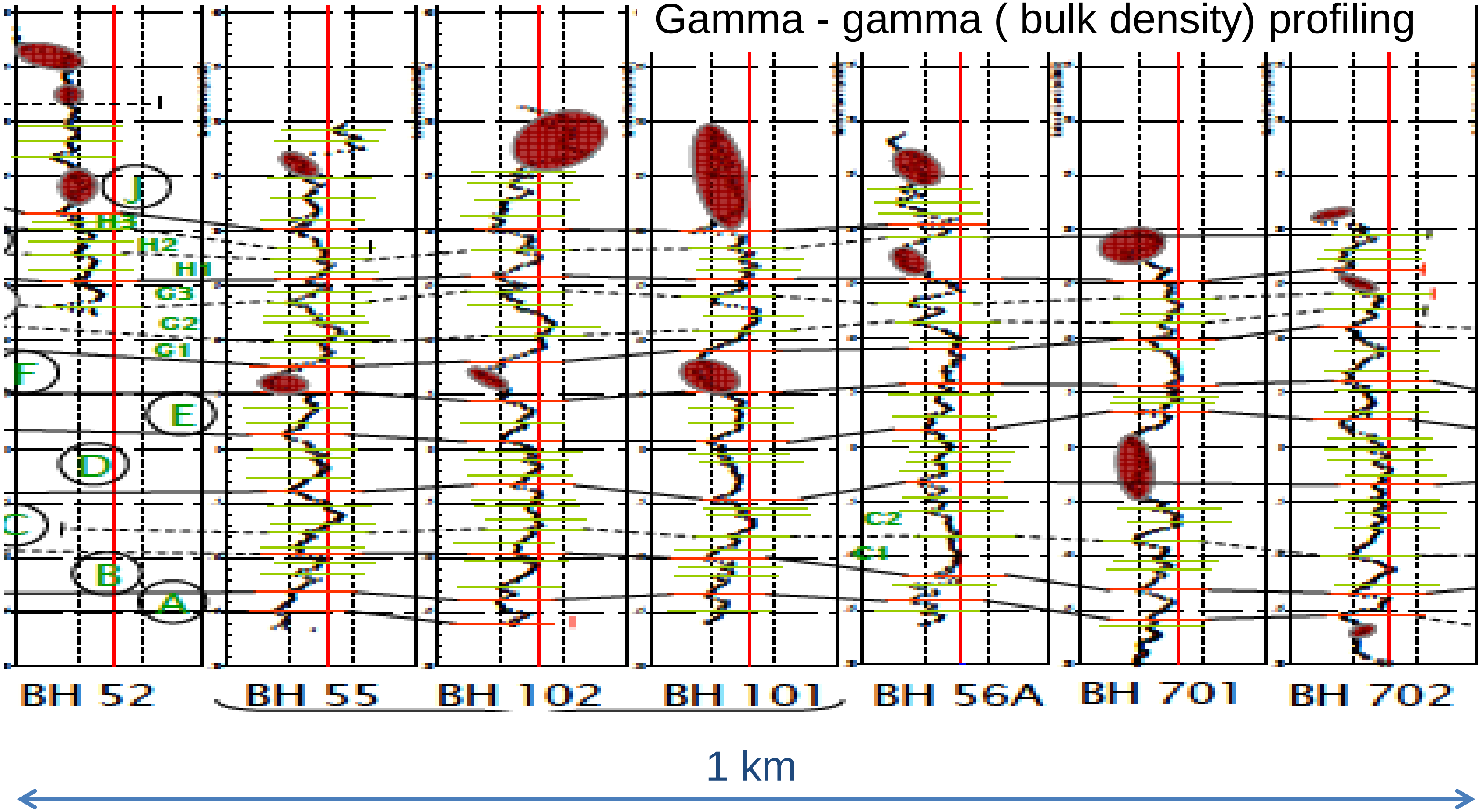
Key themes for deep foundation engineering

- Geological stratigraphy and strength stratigraphy
- *In situ* stress
- Rock stiffness
- Raft – pile interaction
- Ground movement prediction
- Groundwater is not covered in this presentation

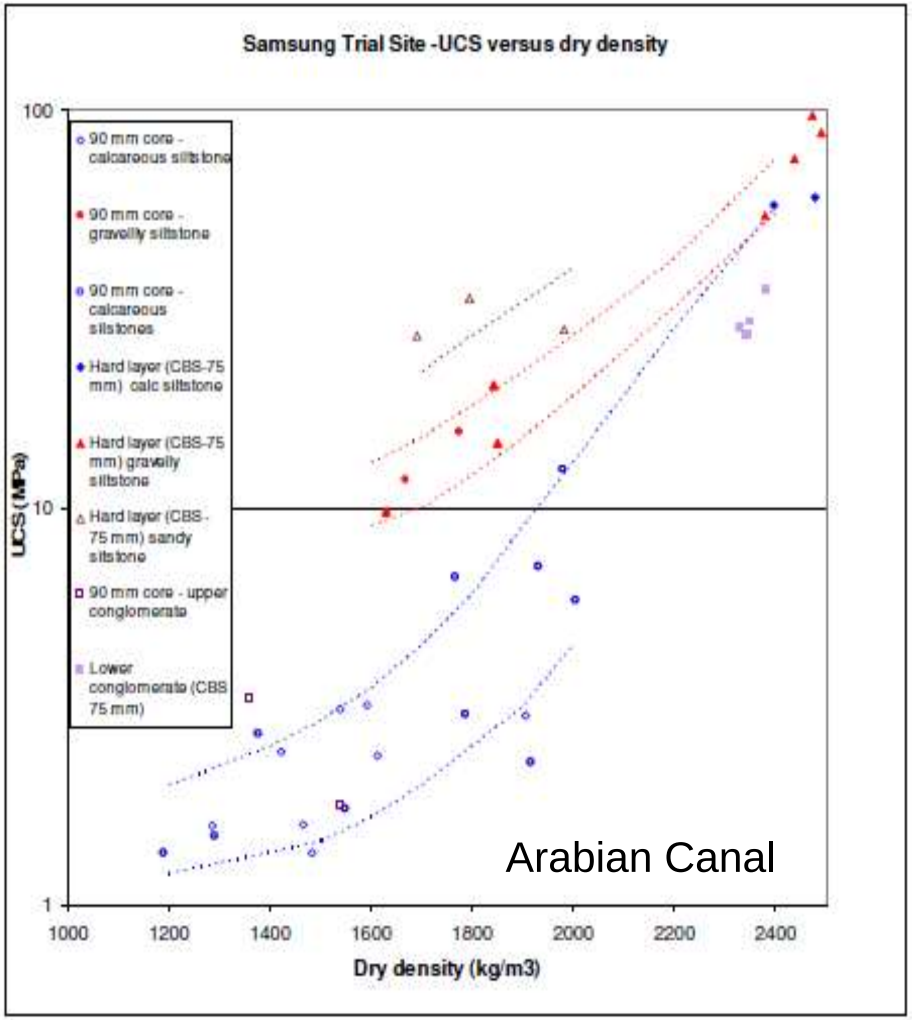
Stratigraphy

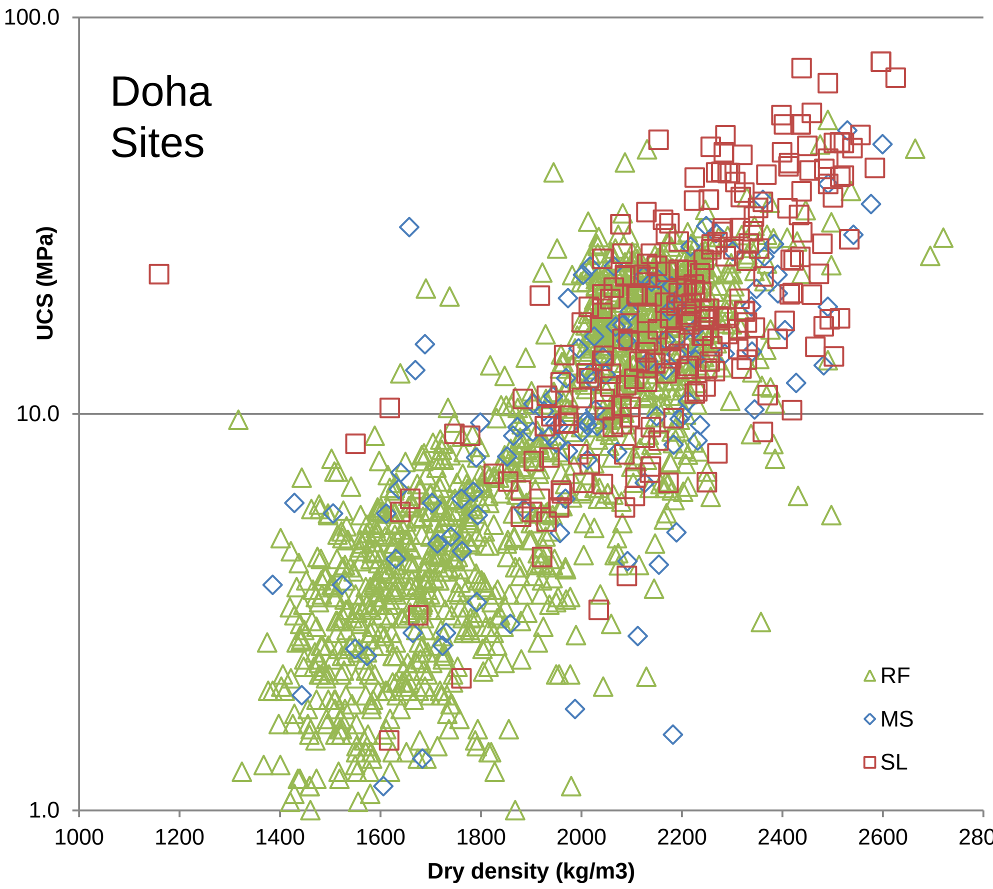
Geological Stratigraphy – Arabian Canal

Gamma - gamma (bulk density) profiling



Rock Strength and Dry Density

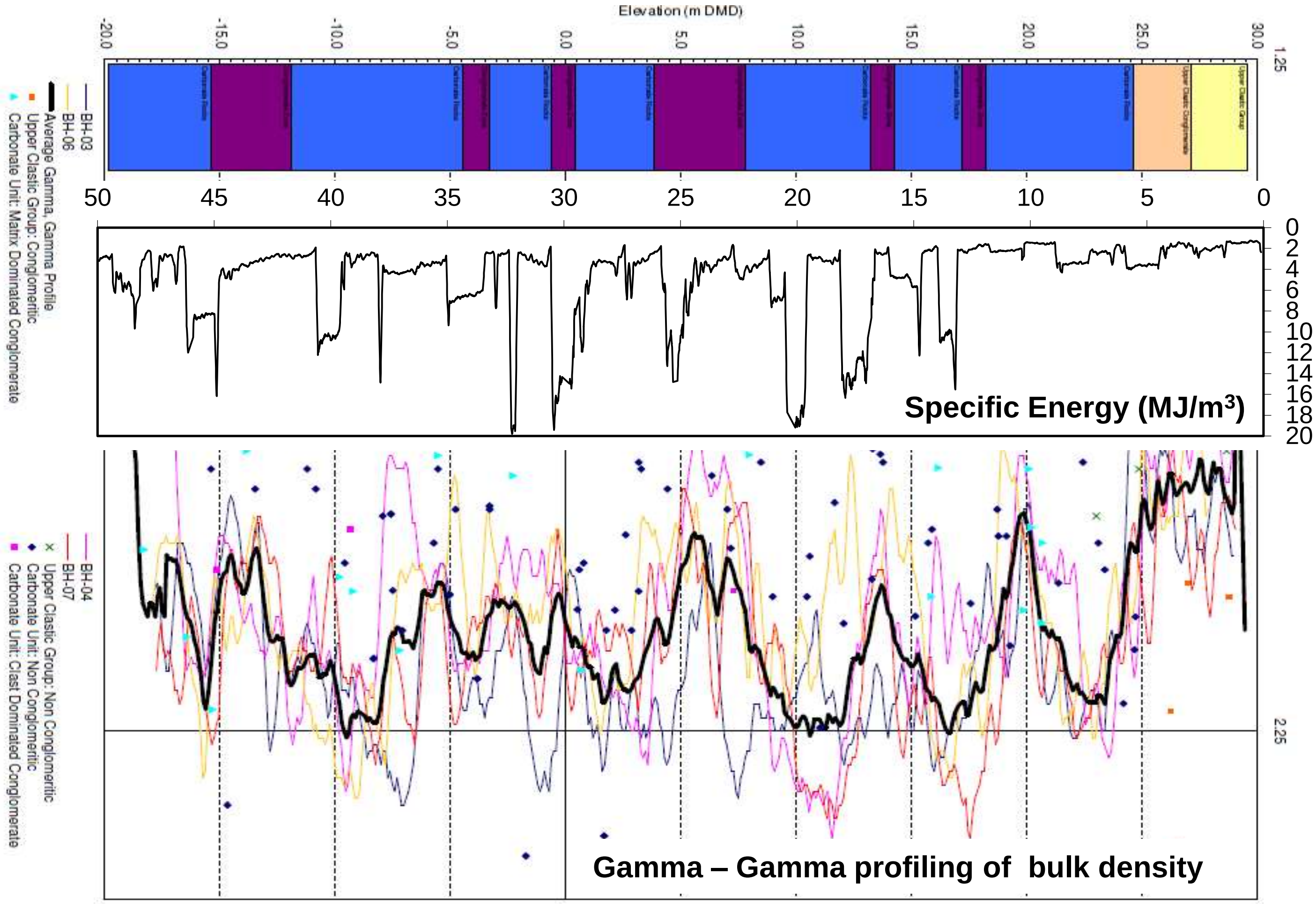




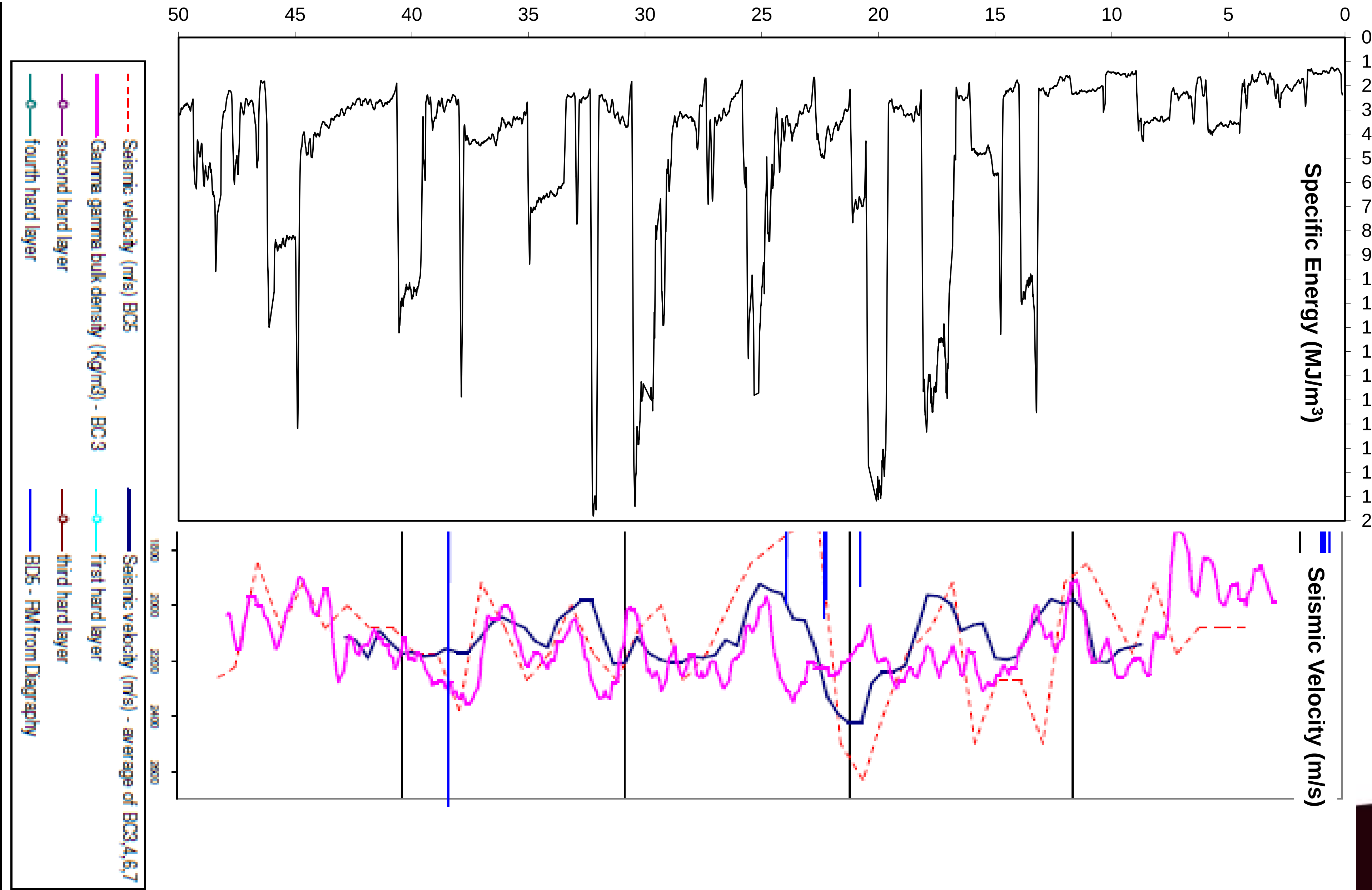
Rock Strength from Instrumented Drilling

- Origins in Offshore oil drilling – check on efficiency of drilling operations relative to rock strength
- Specific Energy = work done to drill unit volume of rock (MJ/m^3 or MNm/m^3) – Teale 1965
- Monitor bit pull down pressure, rate of penetration, applied torque, and rpm
- Good summary of technique by Okuchaba – MSc dissertation, Texas A and M University, 2008
- SE = (vertical work + rotational work + hammer work)/unit volume
- SE approximately equates to Unconfined Compressive Strength

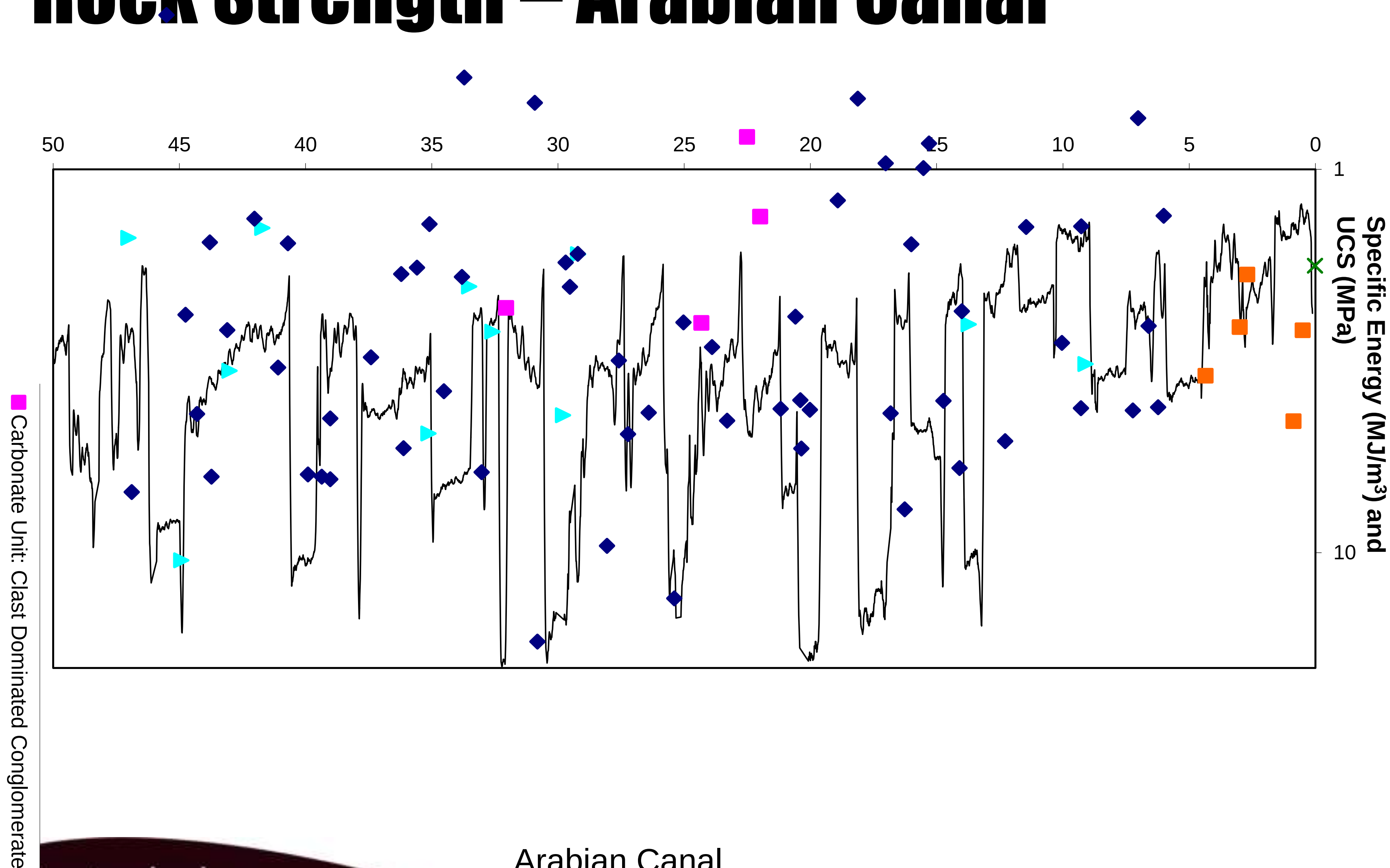
Cyclic Parameters - Arabian Canal (1)



Cyclic Parameters - Arabian Canal (2)

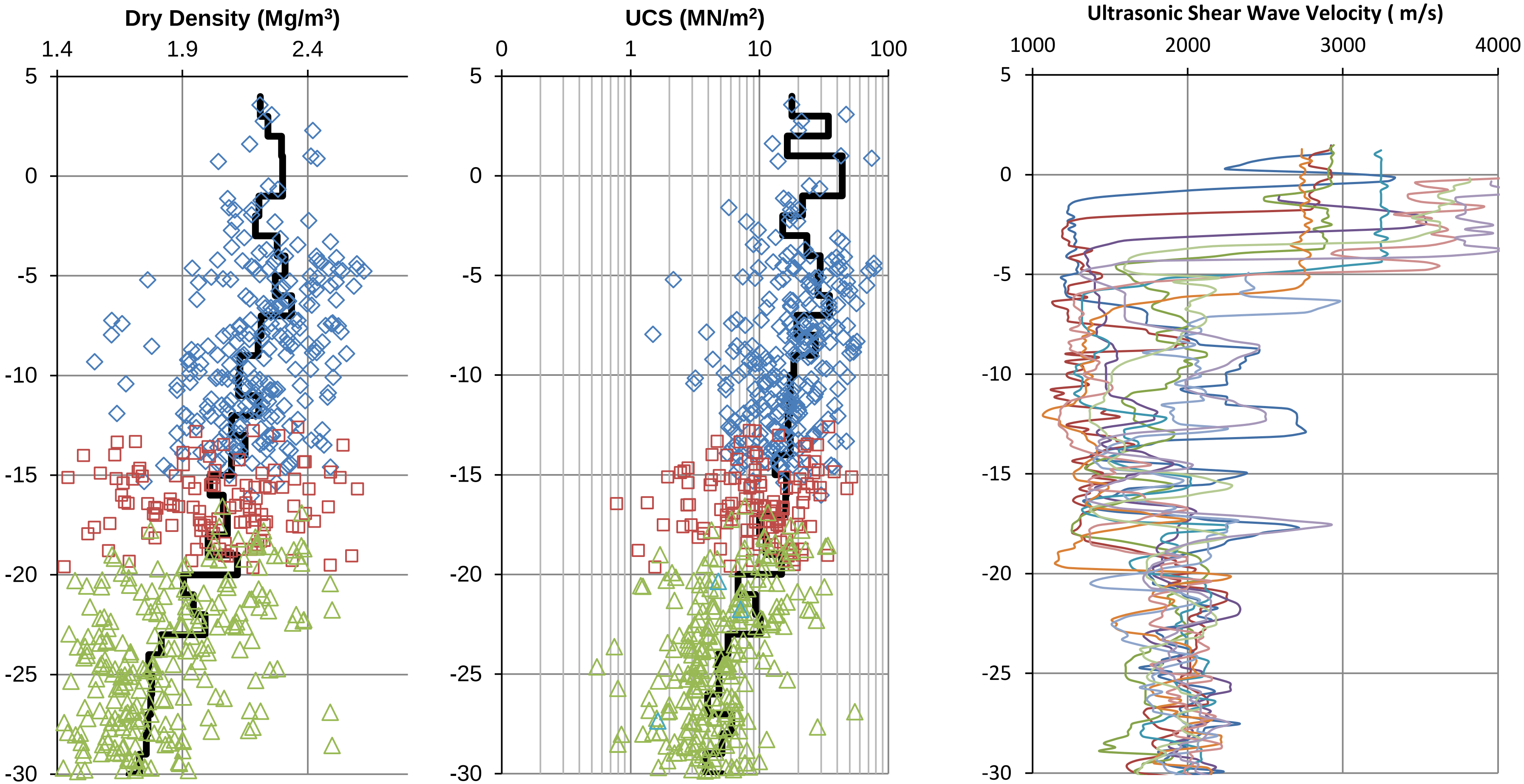


Rock Strength – Arabian Canal

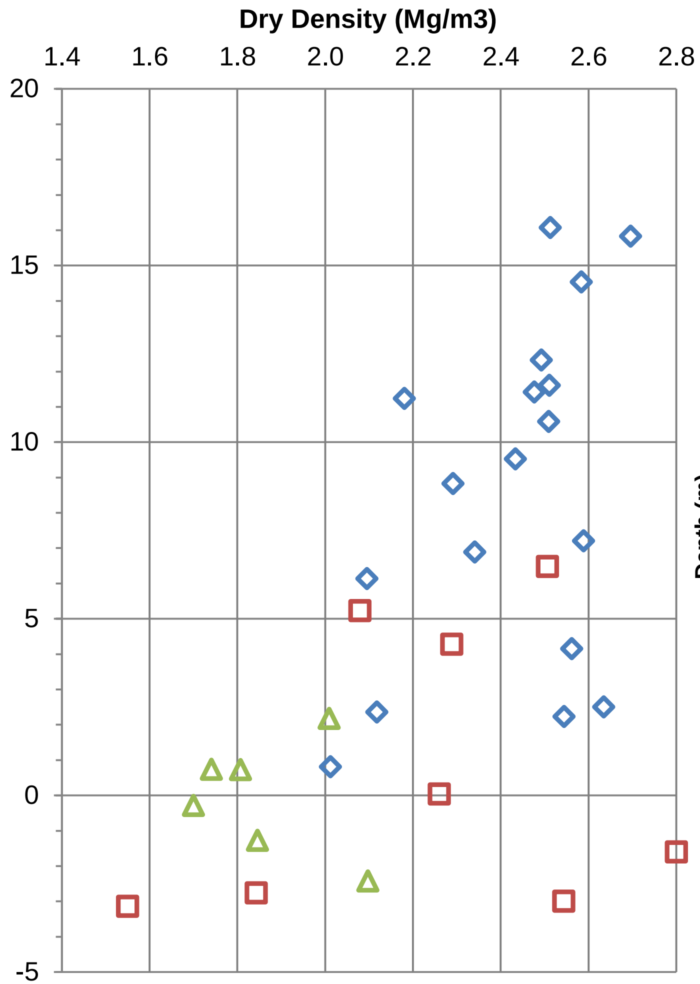


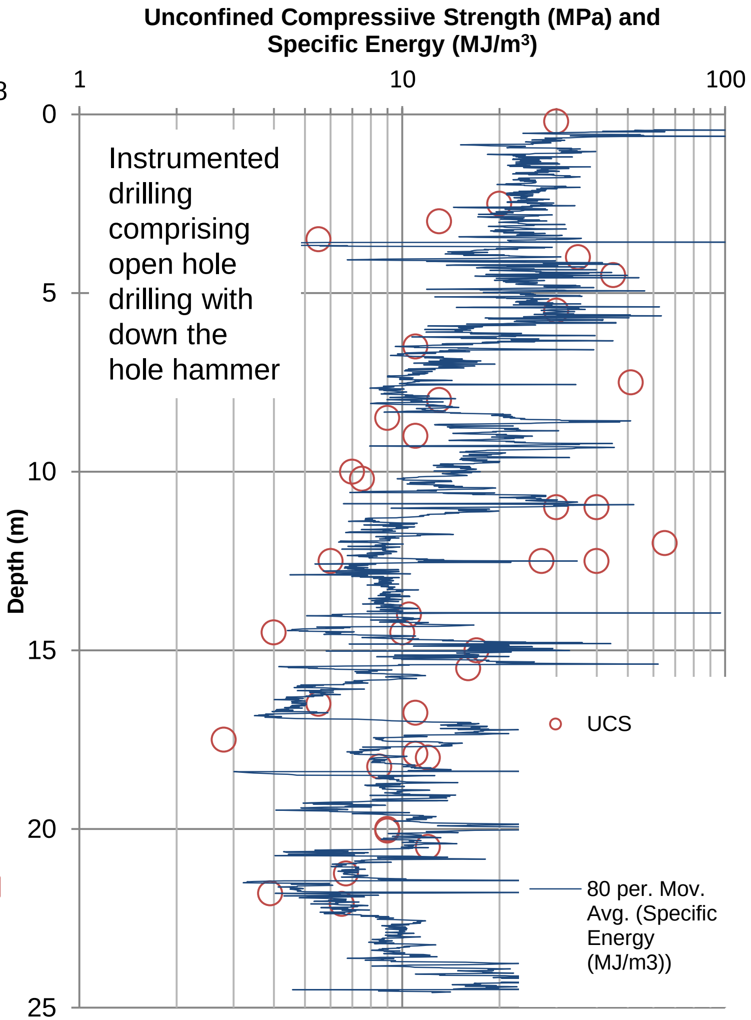
Arabian Canal

Cyclic Parameters - Doha 1 ?



Cyclic Parameters – Doha 2?



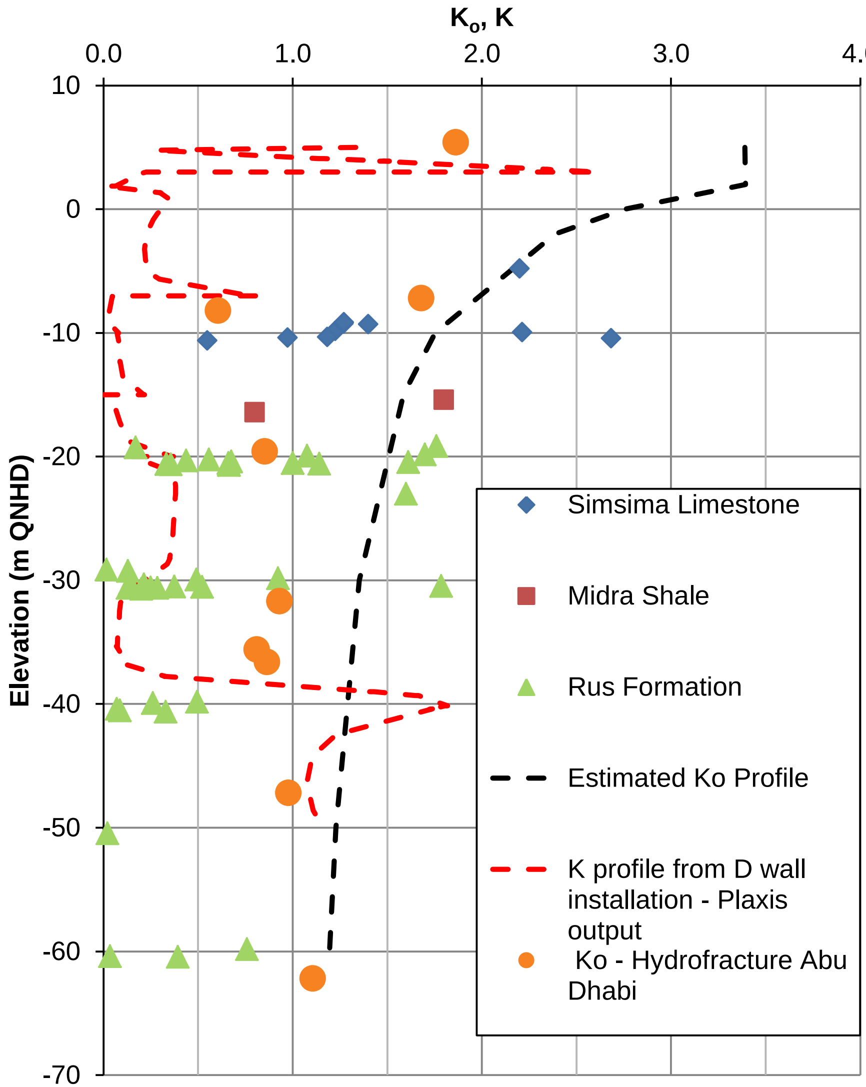


In situ stress

Elevated Ko from:

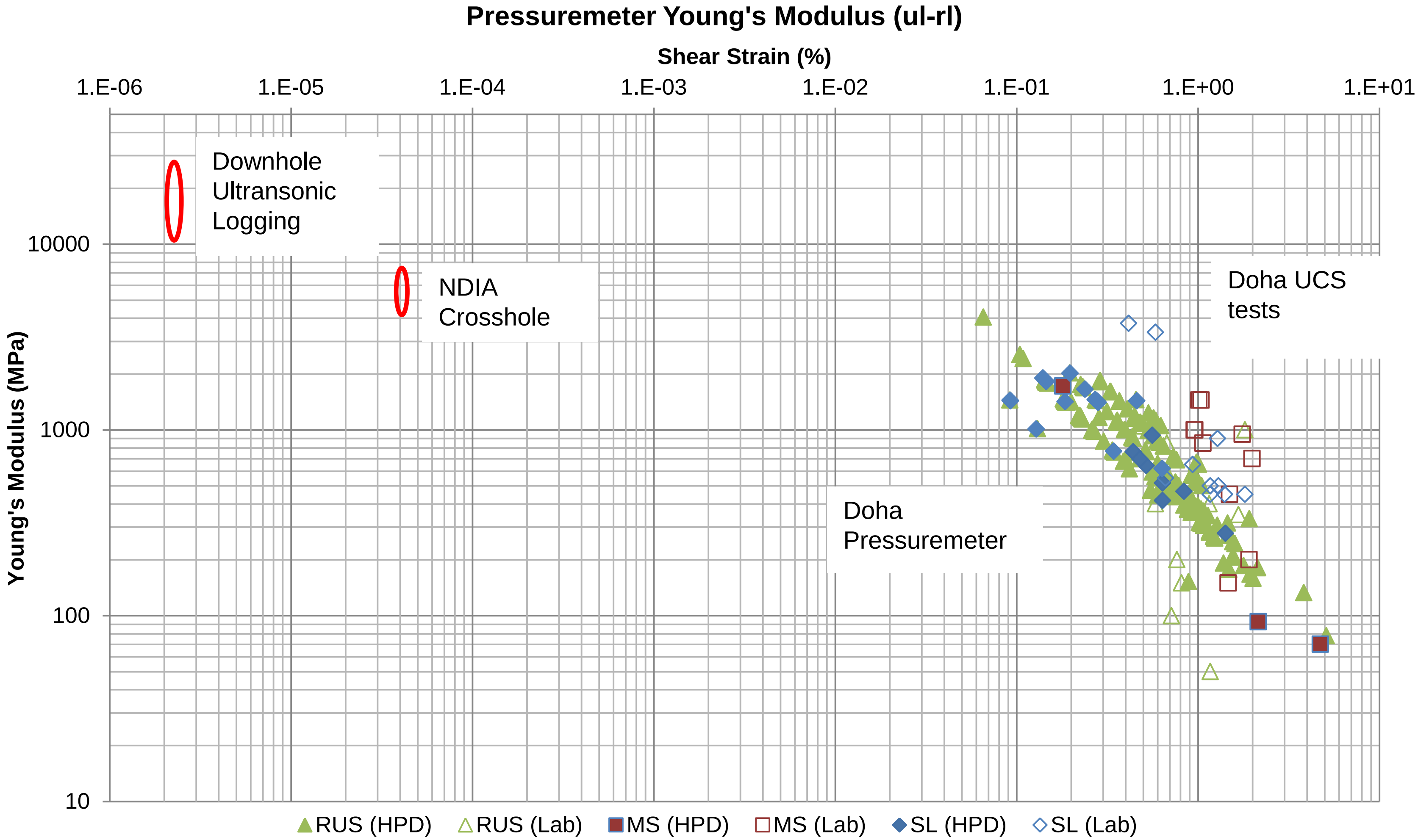
- Overburden removal
- Sea level fluctuations
- Urban groundwater level rise
- Tectonic stress

Significant Ko reduction due to D Wall installation $K_{NDIA} = 0.36$

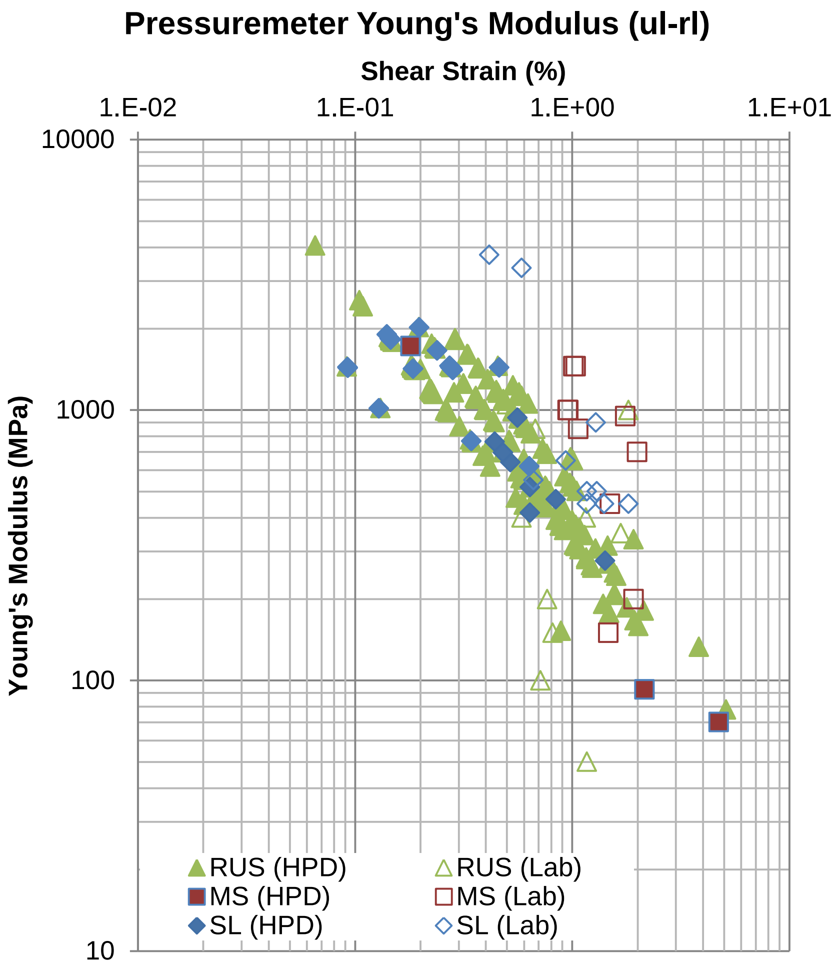


Doha and Abu Dhabi

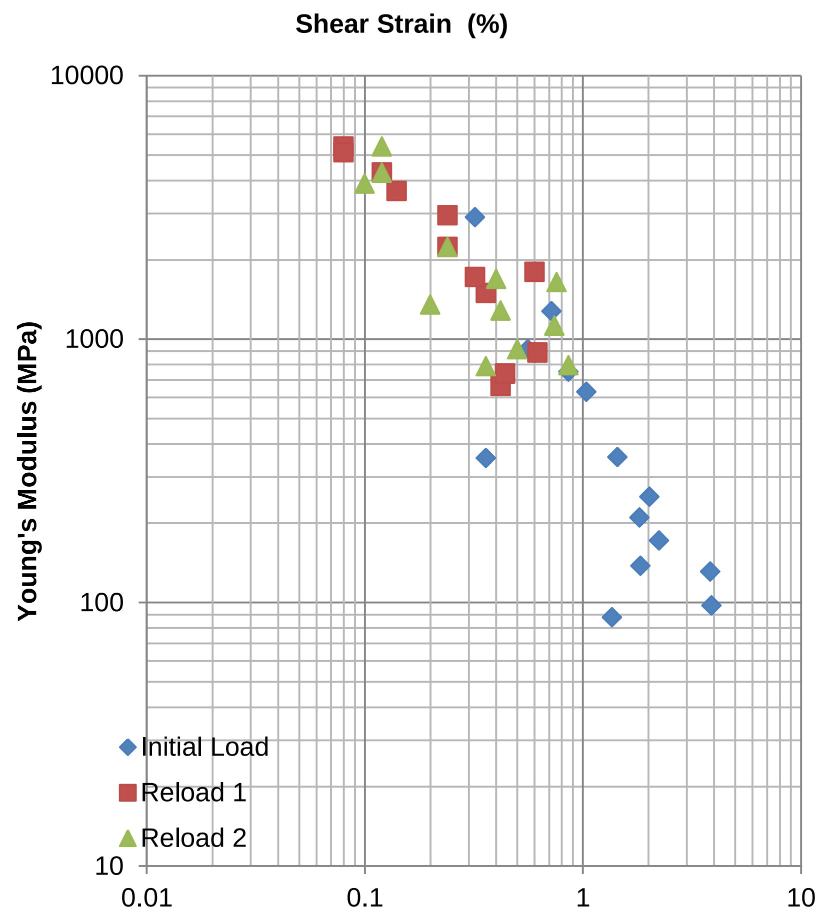
In situ horizontal stiffness – Doha 1



In situ horizontal stiffness – Doha 1



Doha 1



MOE

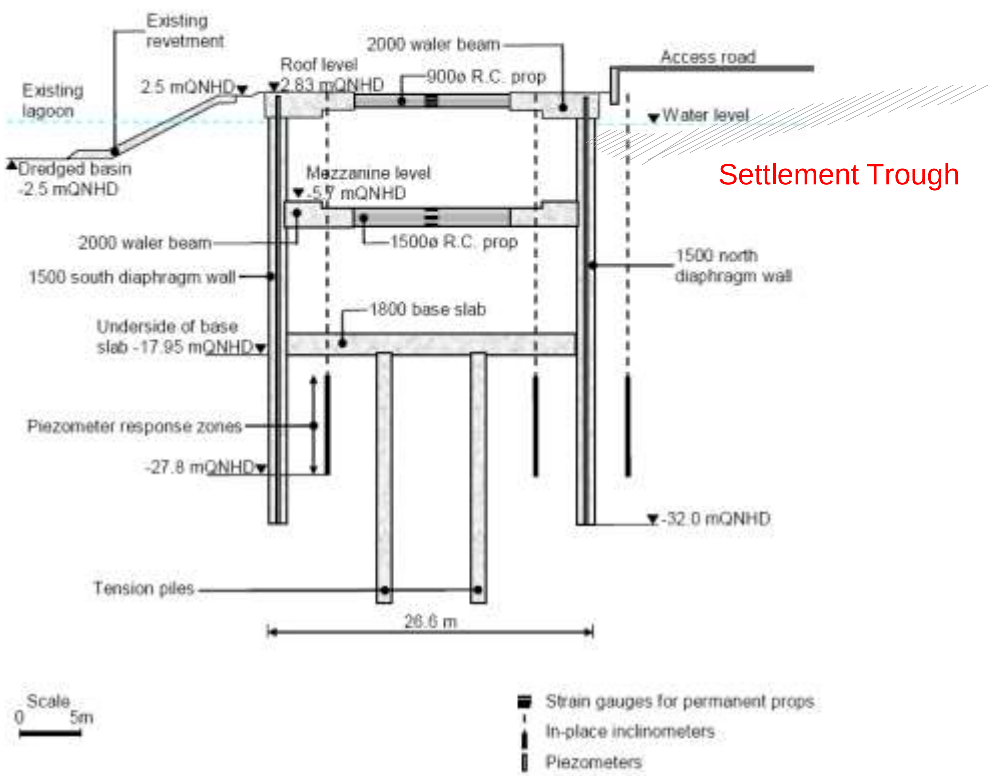
Raft – Pile Load Interaction

Doha 2 Site: 2 m thick raft underpinned by 1.5 m diameter piles on 6 m x 9 m grid carrying compression load within SF capacity of piles

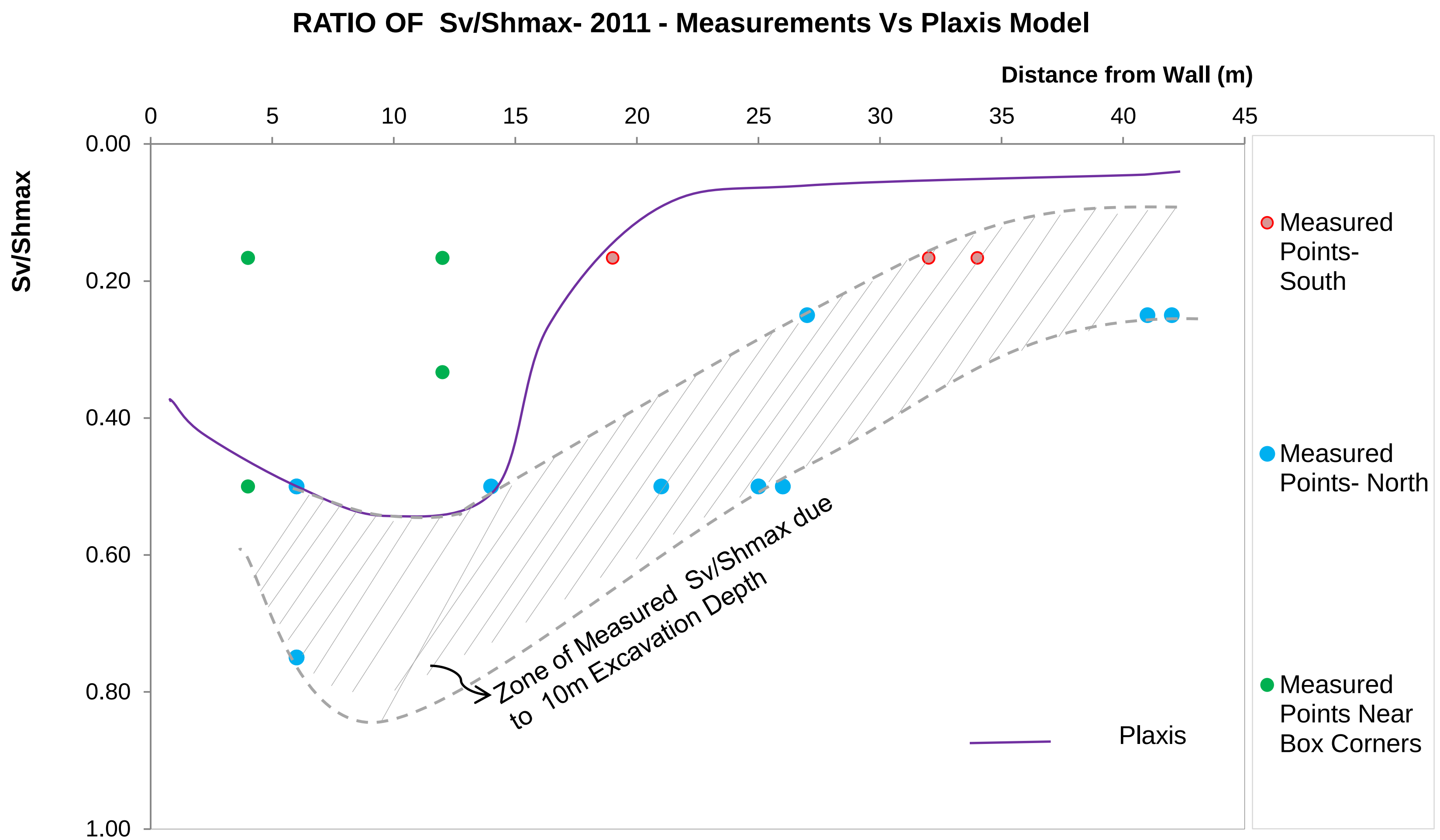
Rock Stiffness (GPa)	Pile Stiffness (GPa)	% Load Share	
		Rock	Piles
5	30 to 50	90	10
1	30 to 50	70	30
0.5	30	50	50

Ground Movement Prediction (1)

- Lack of case history data for comparable rock types
- NDIA station box – 1.5 m wide diaphragm wall, L= 25 m, D = 20 within Simsima Limestone.
- Propped top down construction
- Initial settlement from diaphragm wall installation of up to 6 mm (4 m offset from walls).
- Settlement behaviour behind D wall is trough like.
- PLAXIS back analysis – linear isotropic stiffness models do not work.
- Link ground movement to lateral wall movement

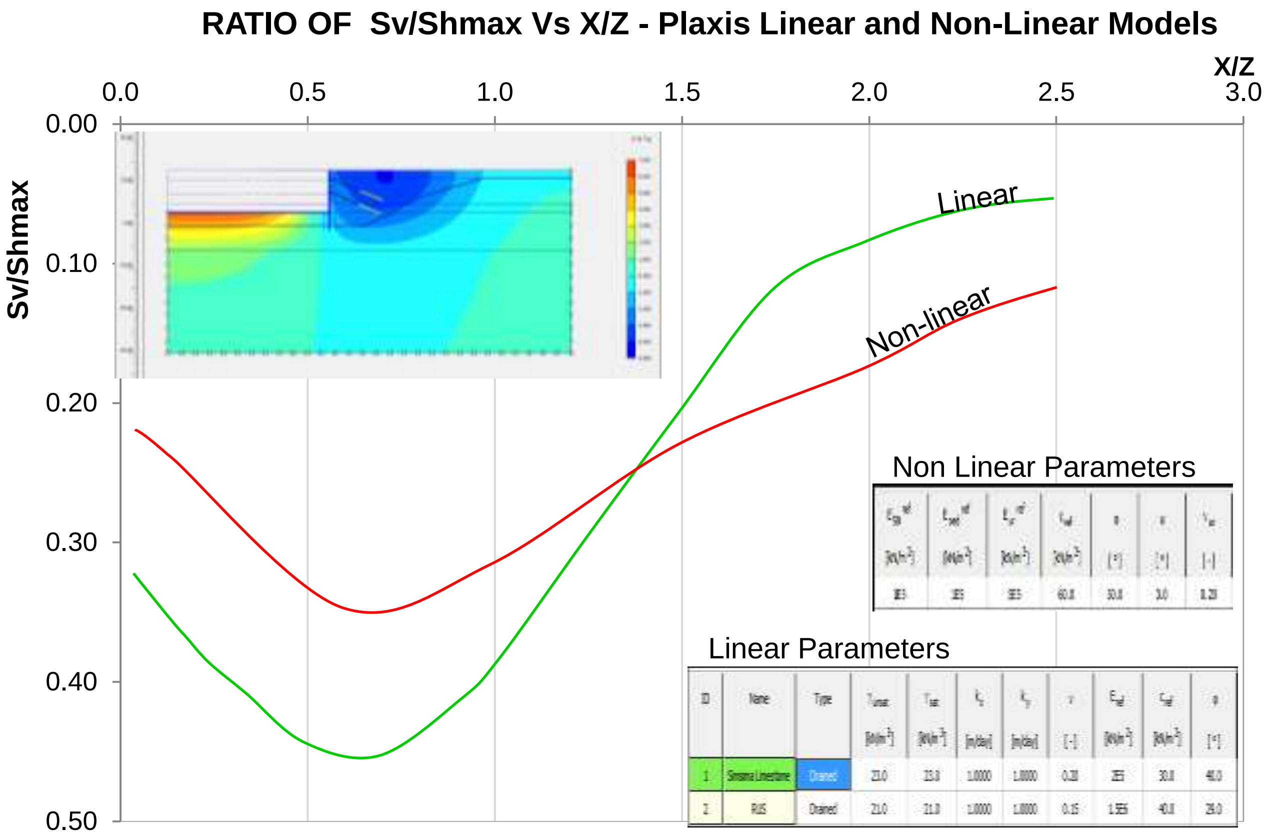


Ground Movement Prediction (2)



New Doha International Airport

Ground Movement Prediction (3)



Non Linear Parameters

E_{50}^{ref} [kN/m²]	E_{oed}^{ref} [kN/m²]	E_{ur}^{ref} [kN/m²]	c_{ref} [kN/m²]	φ [°]	ψ [°]	ν_{ur} [-]
3E5	3E5	9E5	60.0	30.0	3.0	0.20

Linear Parameters

ID	Name	Type	γ_{unsat} [kN/m³]	γ_{sat} [kN/m³]	k_x [m/day]	k_y [m/day]	ν [-]	E_{ref} [kN/m²]	c_{ref} [kN/m²]	φ [°]
1	Simsima Limestone	Drained	21.0	23.0	1.0000	1.0000	0.20	3E5	30.0	40.0
2	RUS	Drained	21.0	21.0	1.0000	1.0000	0.15	1.5E5	40.0	28.0

Simple Comparison Model

Findings

- Stratigraphy is important but strength stratigraphy may not match. Expect cyclic variation in density, strength and stiffness with depth.

- Adopt wider use of instrumented drilling as a strength profiling tool – may prove important for anchored wall design. Increased value for money and reduced turnaround time for SI.

- Expect strength to correlate closely with in situ dry density and specific energy– profile density by down-hole geophysical methods and determine m/c profile carefully.

- Expect elevated Ko values but also large reductions in Ko due to installation effects.

- Expect non linear stiffness behaviour - an important aspect in resolving pile – raft load share interaction. Design territory will be very small strain in the foundations.

- Wall / behind wall movement predictions require non linear elastic models and/or an empirical basis of trough settlement form linked to wall lateral displacement.

Ground Movement Prediction (4)