Site Investigation for Kingdom Tower

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Presentation Outline

- Introduction & Project Details
- Tall Buildings - Challenges
- Geotechnical Investigation & Testing
- Geology
- Field Testing Program
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  - Pressuremeter Testing
  - Down-hole Geophysics
- Laboratory Testing Program
  - Compressive Strength Testing
  - Consolidated-Drained Triaxial Compression Testing
- Conclusions & Comparison of Field & Laboratory Measurements

Kingdom Tower

Location:

Jeddah – Kingdom of Saudi Arabia

Developer:

Jeddah Economic Company (Kingdom Holding) – Emaar was client at time of study

Architect:

Adrian Smith + Gordon Gill Architecture
Dar Al Handasa (Architect of Record)

Geotechnical consultant:

Langan International

Structural Engineer:

Thornton Tomasetti

Contractor:

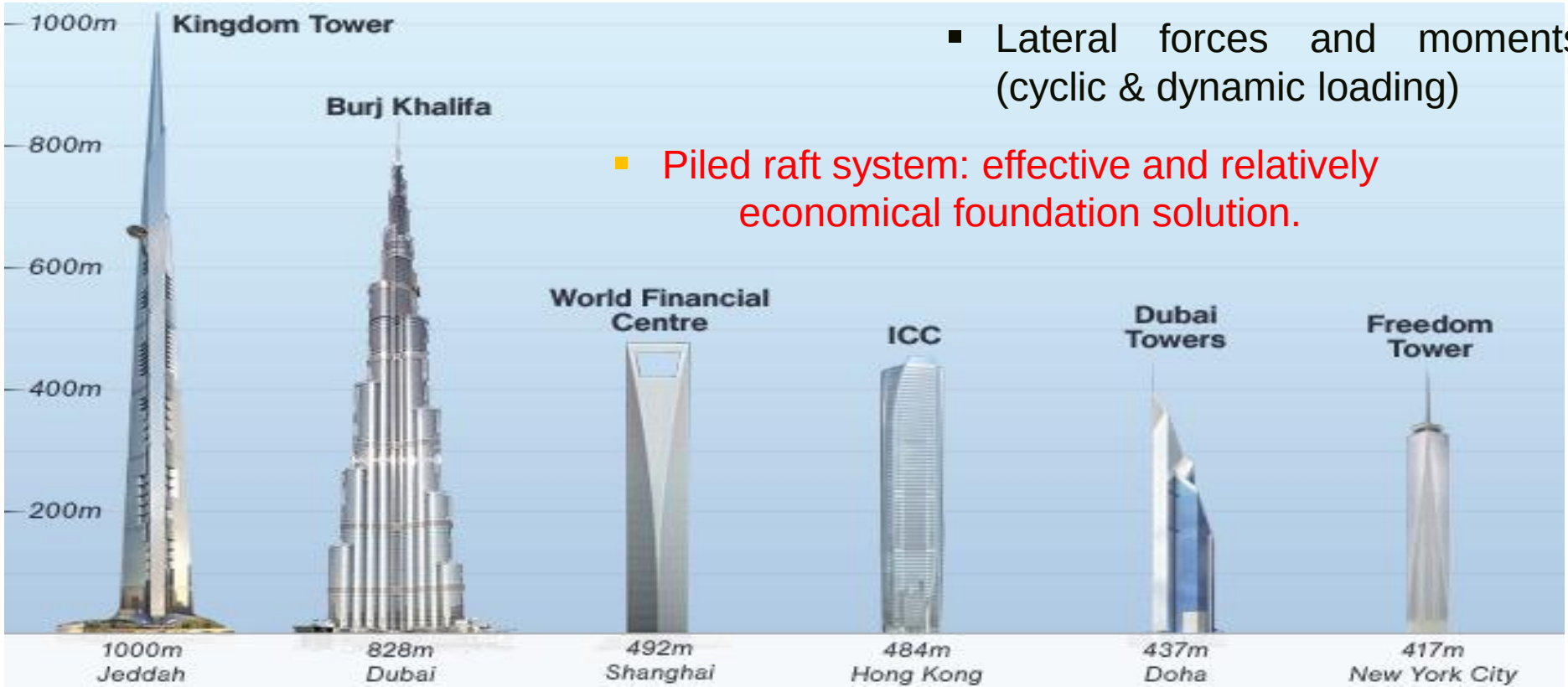
Saudi Bin Laden

Project description

Ultra-Tall Tower +1000m (167 floors)
Podium +4 levels of basements+ services

Tall Buildings-Geotechnical Challenges

- Remarkable increase in the rate of construction of tall buildings.
- Structural and geotechnical design challenges.
- Sophisticated and state-of-the art methods instead of traditional empirical methods.
- Rigorous process of foundation design.
- Nature of soil and rock deposits (Middle East).
- Characteristics that influence foundation design:
  - Weight
  - Differential settlement
  - Lateral forces and moments (cyclic & dynamic loading)



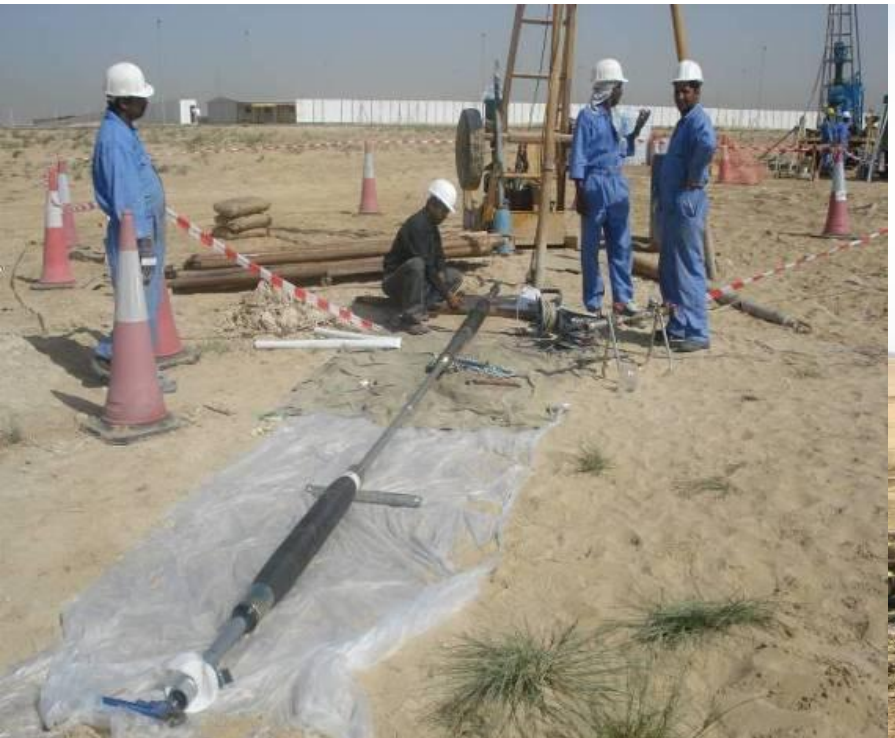
- Piled raft system: effective and relatively economical foundation solution.

Drilling & Sampling

- 3 phases: 81 boreholes (~20m - 200m).
- Rotary drilling using mud/water flush.
- Disturbed, undisturbed & split spoon samples.
- SPT in soil; continuous coring in rock.
- Conventional\wireline & double\triple core barrels.
- Coring systems: PWF, PQ/PQ3, HQ/HQ3 & T2-76.

Field Testing & Instrumentation

- Standard penetration test (SPT).
- Permeability (packer) testing (total 40 test).
- Pressuremeter testing (total 232 test).
- Geophysical Survey Down-hole test (total 3 tests down to 180m).
- Installation of standpipe piezometers (total 16).



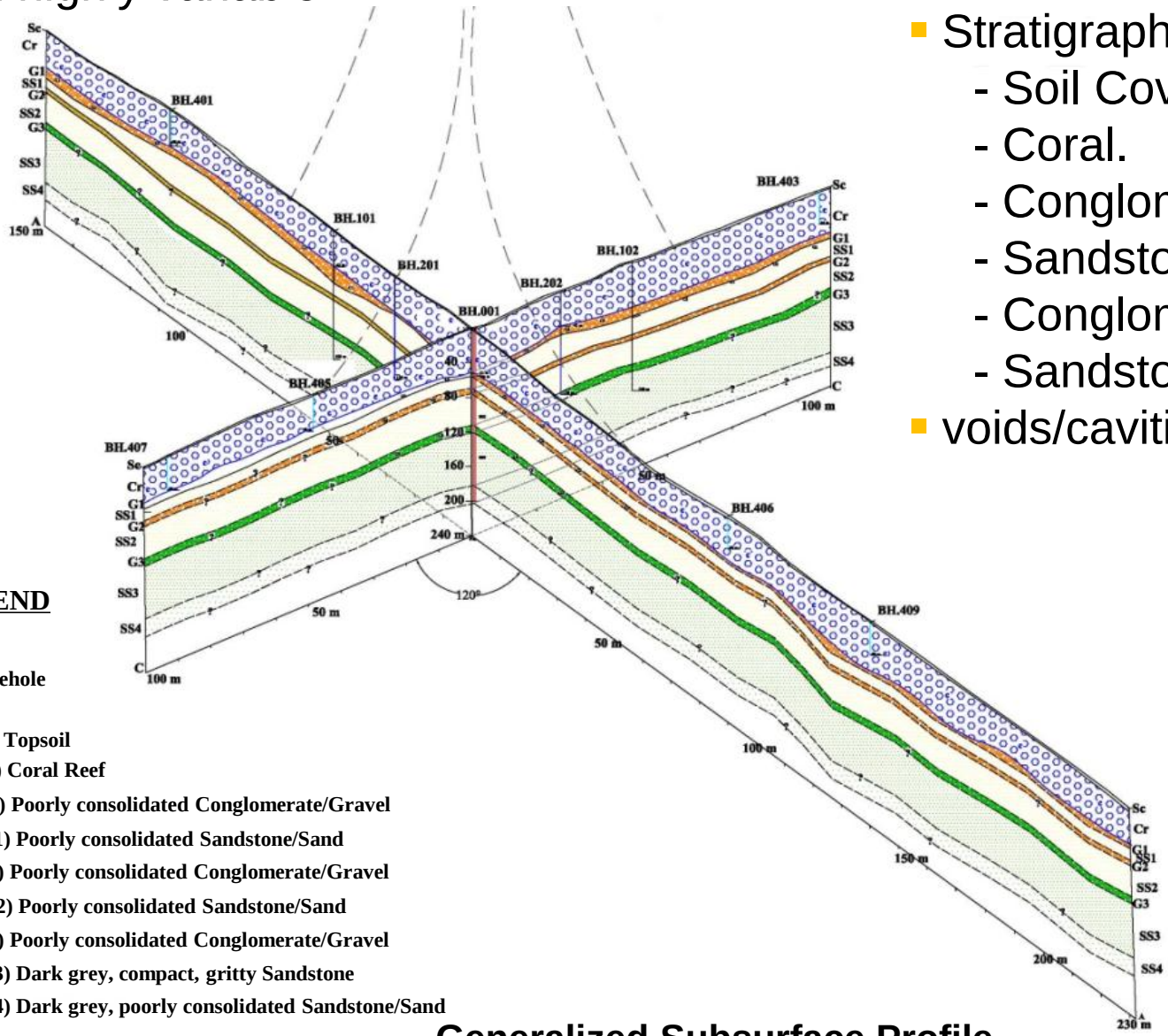
Laboratory Testing

- Classification & index testing.
- Strength testing (instrumented USC; point load).
- Advanced tests (CD triaxial with volume change measurements and repetitive cyclic tests) – Surrey Lab.
- Chemical testing.

Geology and Site Conditions

Horizontally stratified profile of marine sediments which are complex and highly variable.

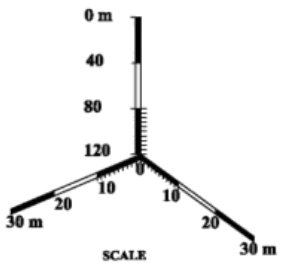
- Stratigraphy:
  - Soil Cover.
  - Coral.
  - Conglomerate/Gravel.
  - Sandstone/Sand.
  - Conglomerate/Gravel.
  - Sandstone.
- voids/cavities in S.st (~173m).



LEGEND

BH403 — Borehole

- (Sc) Topsoil
- (Cr) Coral Reef
- (G1) Poorly consolidated Conglomerate/Gravel
- (SS1) Poorly consolidated Sandstone/Sand
- (G2) Poorly consolidated Conglomerate/Gravel
- (SS2) Poorly consolidated Sandstone/Sand
- (G3) Poorly consolidated Conglomerate/Gravel
- (SS3) Dark grey, compact, gritty Sandstone
- (SS4) Dark grey, poorly consolidated Sandstone/Sand



Generalized Subsurface Profile

Subsurface Stratigraphy

Coral Reef (15.2m-20.0m)

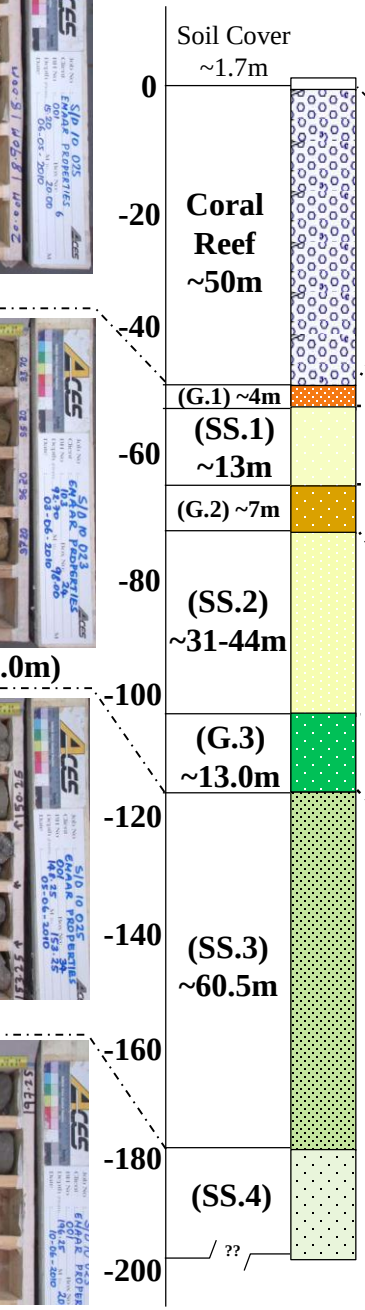
Soft Sandstone/Sand (92.7m-98.0m)

Sandstone (148.25m-153.25m)

Fine grained Sandstone (196.25m-200m)

Gravel (53.13m-56.92m)

Conglomerate (63.0m-67.0m)



Fossiliferous silty sand with many fragments of broken shells, corals.

Very weak to weak, buff white, unweathered to partly weathered, intermittently fractured, porous and vuggy Coral.

Gravel in fine to medium sand matrix with local inter-layers of reddish brown siltstone.

Poorly consolidated Sands with gravel and local patches/pockets of consolidated sand.

Gravel to sand with gravel; with thin (10-30cm) interlayers of poorly consolidated sand.

Poorly consolidated, Sandstone/Sand with interlayers of Gravels/Conglomerates of ~ 1m thickness.

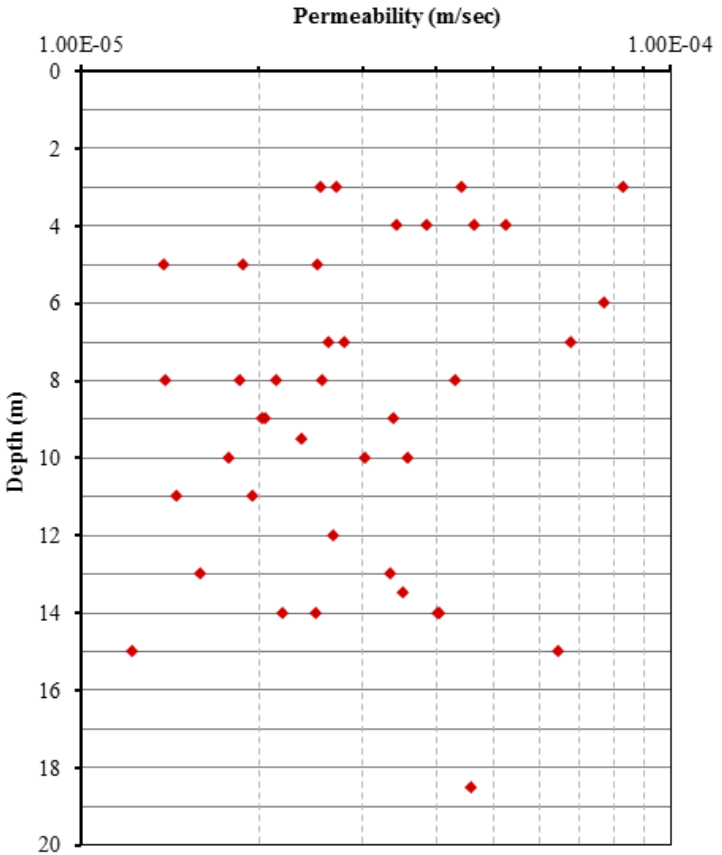
Gravel/Conglomerate with interbeds of hard, slightly weathered gritty Sandstone of 1-4m thickness.

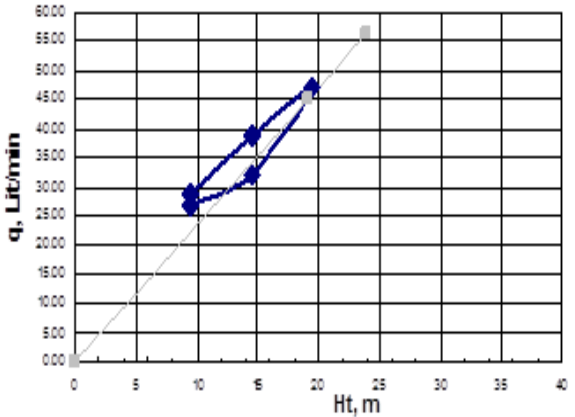
Greenish grey coarse, gritty Sandstone with Coral fragments.

Dark grey to greenish grey, poorly consolidated, fine grained Sandstones/Sand.

Permeability Packer Tests - BS 5930-1999

- 40 double packer tests.
- Various depths (~3.0-18.5m)
- Tests carried out in Coral Layer.
- Permeability 1.23×10^{-5} to 8.38×10^{-5} m/s.

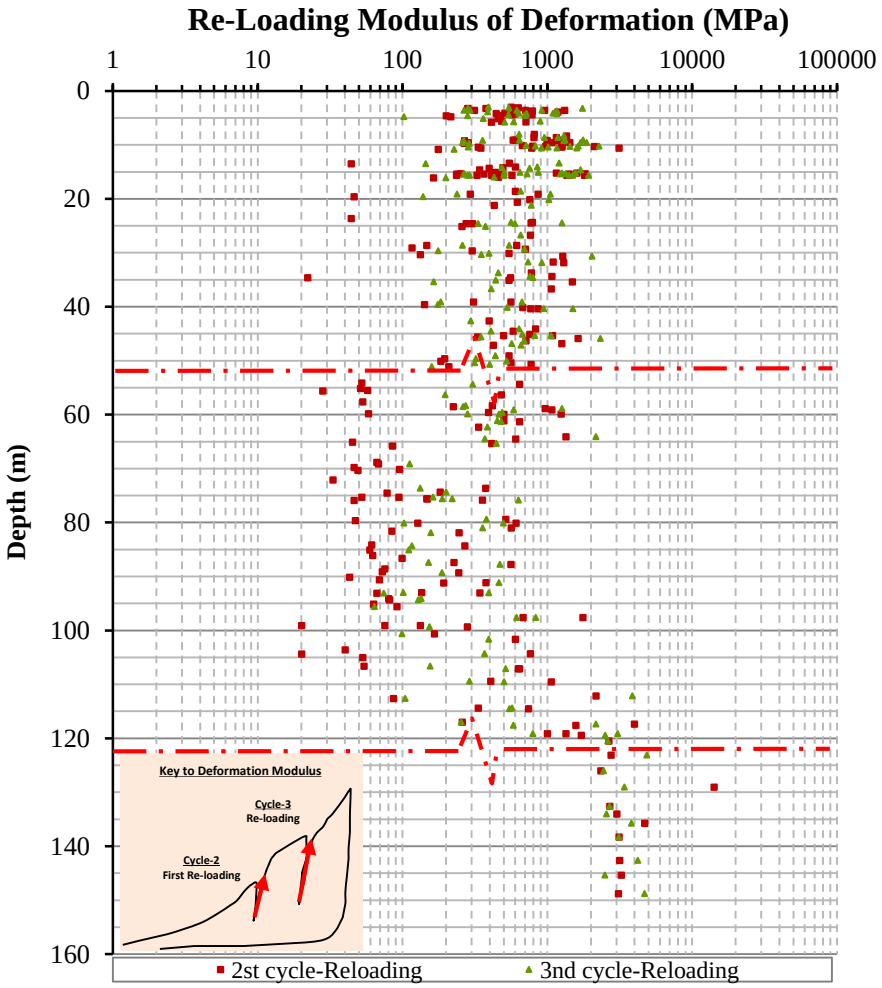


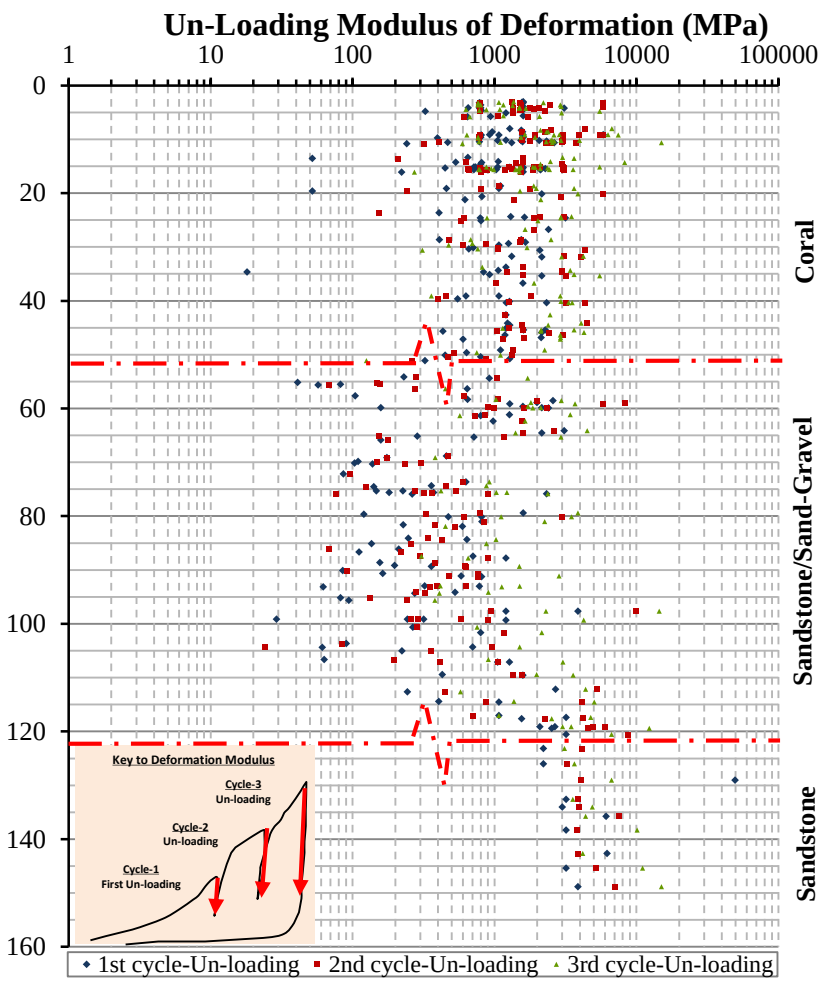


Pressuremeter Tests - ASTM D 4719

- High Pressure Dilatometer (HPD) tests in Coral and Sandstone/Sand.
- Total 232 tests at various depths ~3.0m-149m below ground level.
- Calibration ~ pressure & volume.
- Test section drilled/prepared using T2-76 core barrel.

Mainly to obtain modulus: $G = \frac{1}{2} \times (dp/d\varepsilon_c)$; $E = 2G(1+v)$



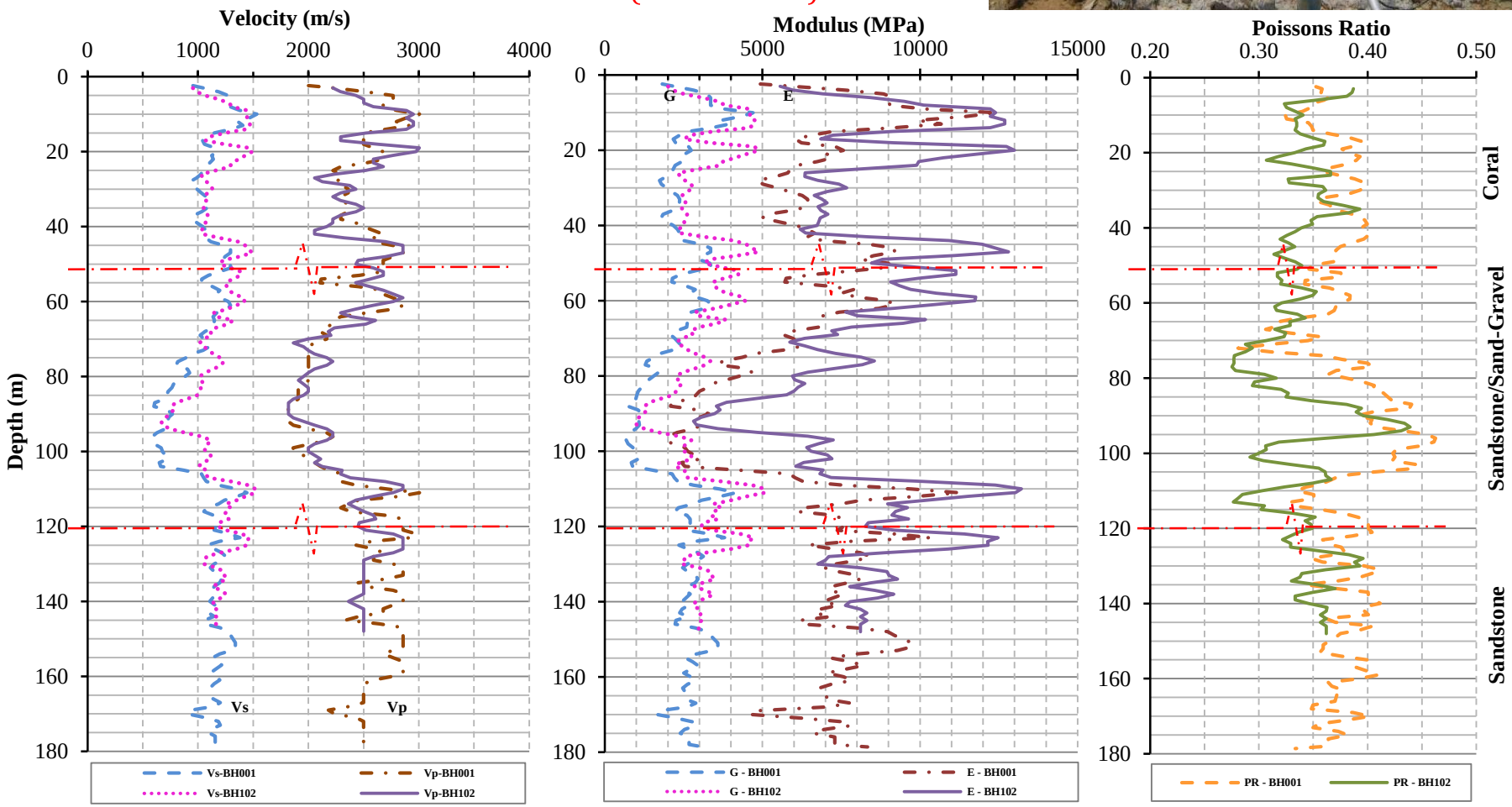


Down-Hole Geophysics

- PS suspension carried out to acquire P-S wave velocities to derive dynamic soil properties (E, G, v).
- Density estimated from lab tests.
- Borehole cased, grouted & filled w/ water.

$$G = \rho V_s^2 \quad , \quad G = \frac{E}{2(1+v)} \quad , \quad v = \frac{(V_p/V_s)^2}{2\left\{(V_p/V_s)^2 - 1\right\}}$$

Results of Down-Hole PS Suspension

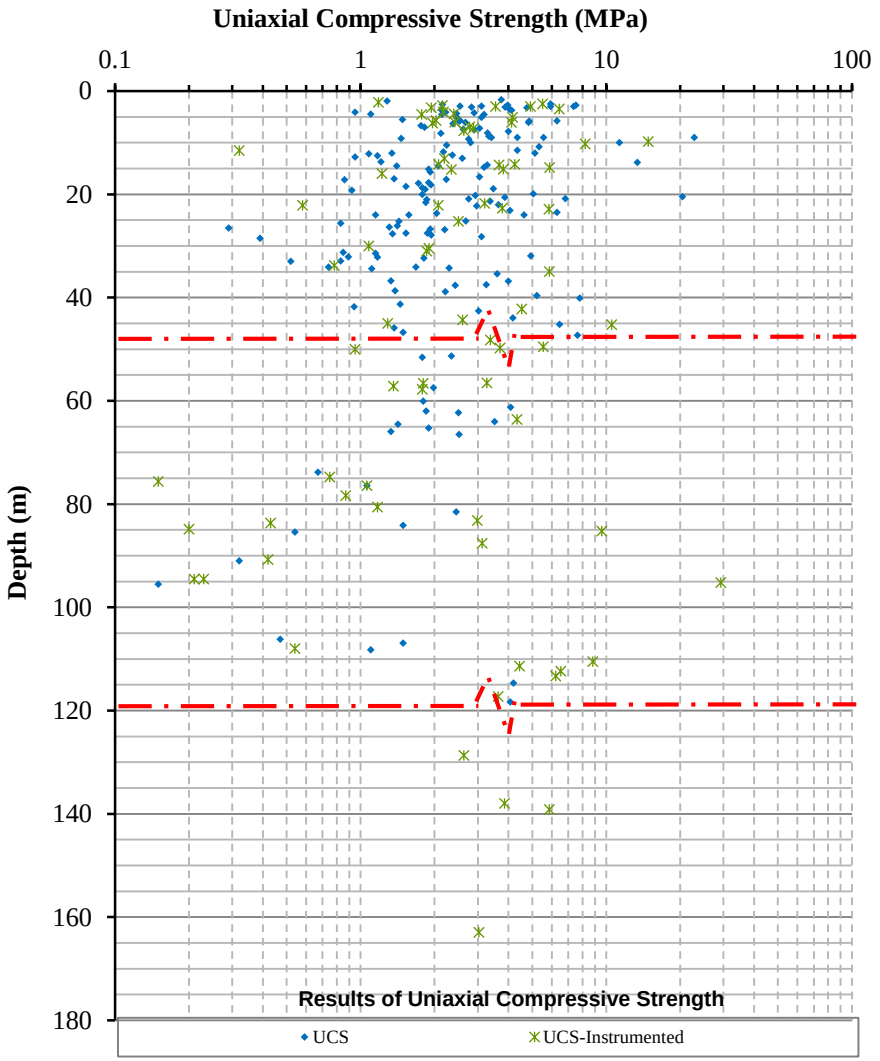


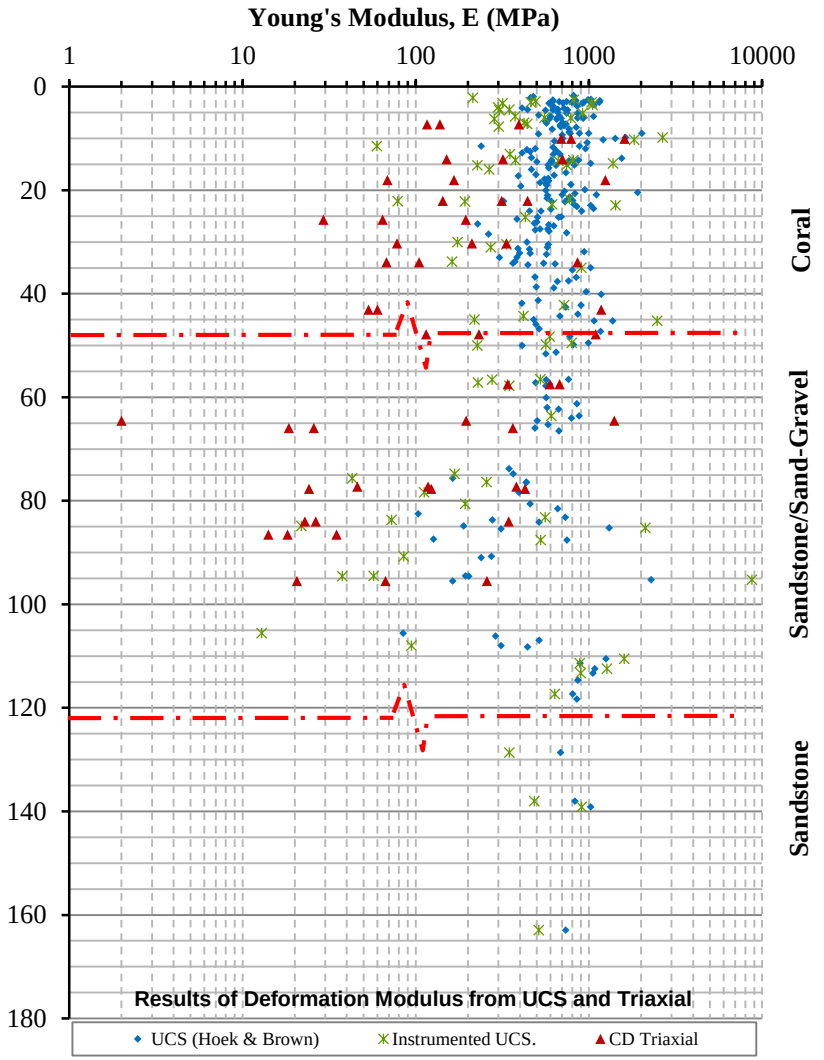
Compressive Strength

- Empirical relationships to estimate deformation modulus from uniaxial compressive strength.
- Hoek & Brown (1997)

$$E_m(GPa) = \sqrt{\frac{UCS\ (MPa)}{100}}\, 10^{\left(\frac{GSI-10}{40}\right)}$$

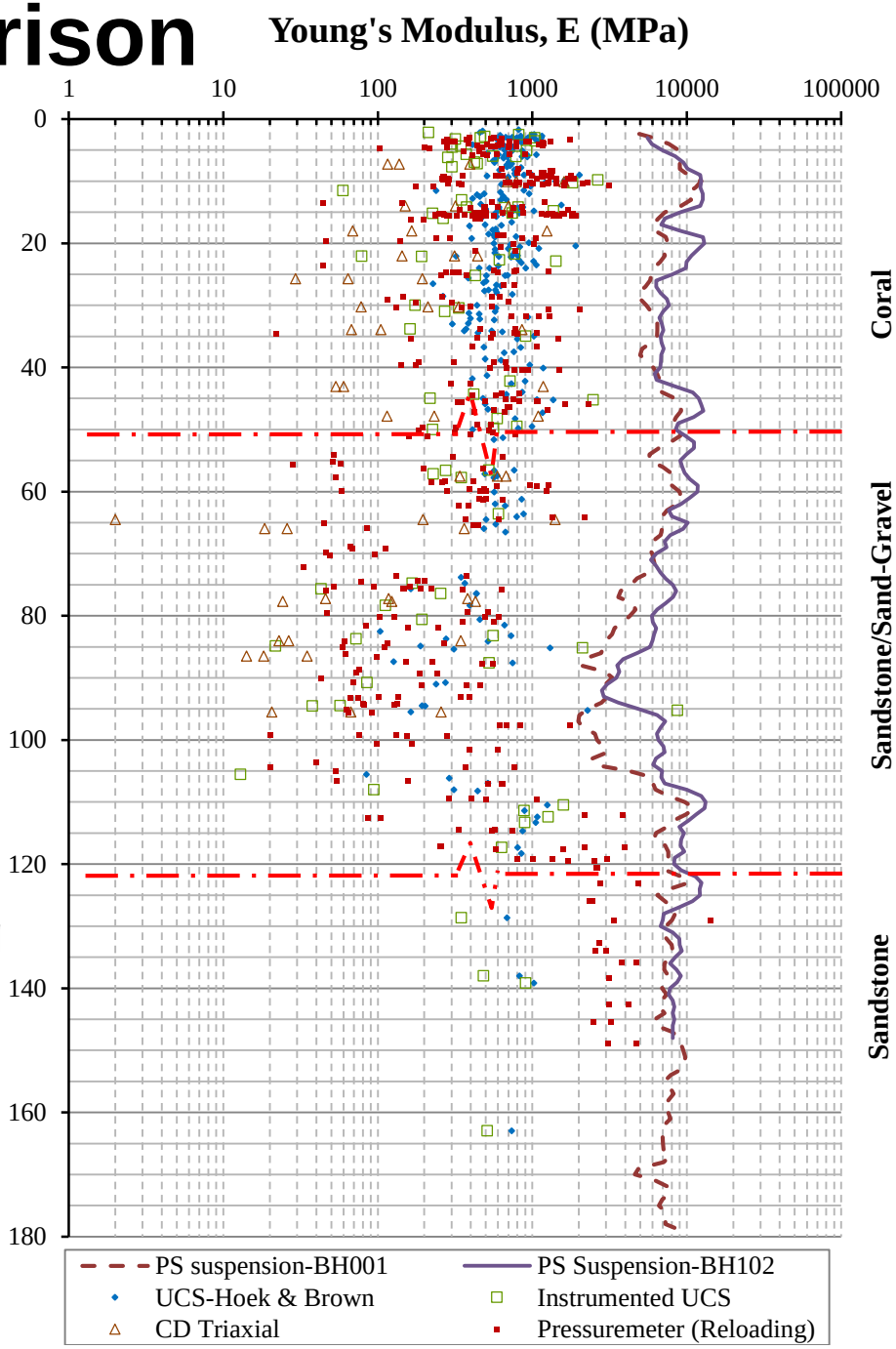
- Direct measurements of the intact Young's Modulus from the instrumented UCS.
- Consolidated-Drained Triaxial Compression Test (Surrey Lab)





Conclusions & Comparison

- The subsurface conditions at the Kingdom Tower site are quite complex and highly variable.
- The sound rock line is estimated in the underlying Sandstone layer at depth of 122m below ground level.
- Stiffness from the pressuremeter (reload cycle) compared relatively well with those obtained from the UCS and triaxial tests.
- The stiffness from the seismic testing were about 6-10 times those of the pressuremeter and UCS tests.
- Factors affecting stiffness include strain level, joint structure, disturbance, etc.



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