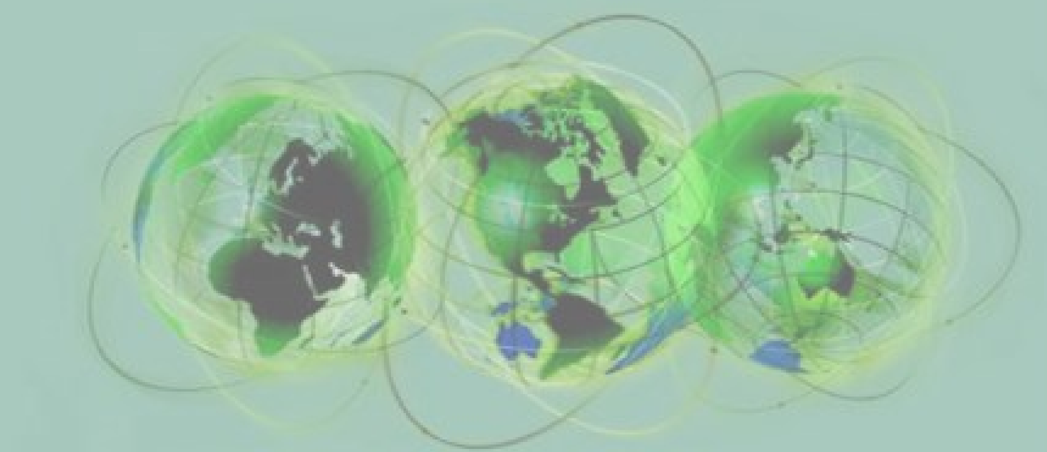

Introduction to the Design of Rock Socketed Piles

Dr Chris Haberfield

Lecture 1 Outline

- *Rock Socketed Piles*
- *Base resistance*
- *Shaft resistance*
- *Design for Serviceability*
- *Limit States*
- *Design for Construction*
- *Design/Construction system (GARSP)*
- *Major Projects*
- *Load Testing*
- *Summary*

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Acknowledgements

- Dr Julian Seidel
- Foundation QA Pty Ltd for use of Rocket
- Researchers at Monash University
- Dr Ben Collingwood and Wagstaff Piling Pty Ltd

Rock socketed piles :

- prominent foundation solution for large loads
- formed by drilling into rock and filling void with concrete (+ reinforcement)
- lengths >50m
  diameters up to 1.8 m
  (>3m elsewhere)
  SWL of up to 40 MN
  (100 MN elsewhere)

Bored piling rig with bucket auger

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Traditional design :

- Ultimate load based design

  $q_{ult} = A_b f_{bu} + A_s f_{su}$

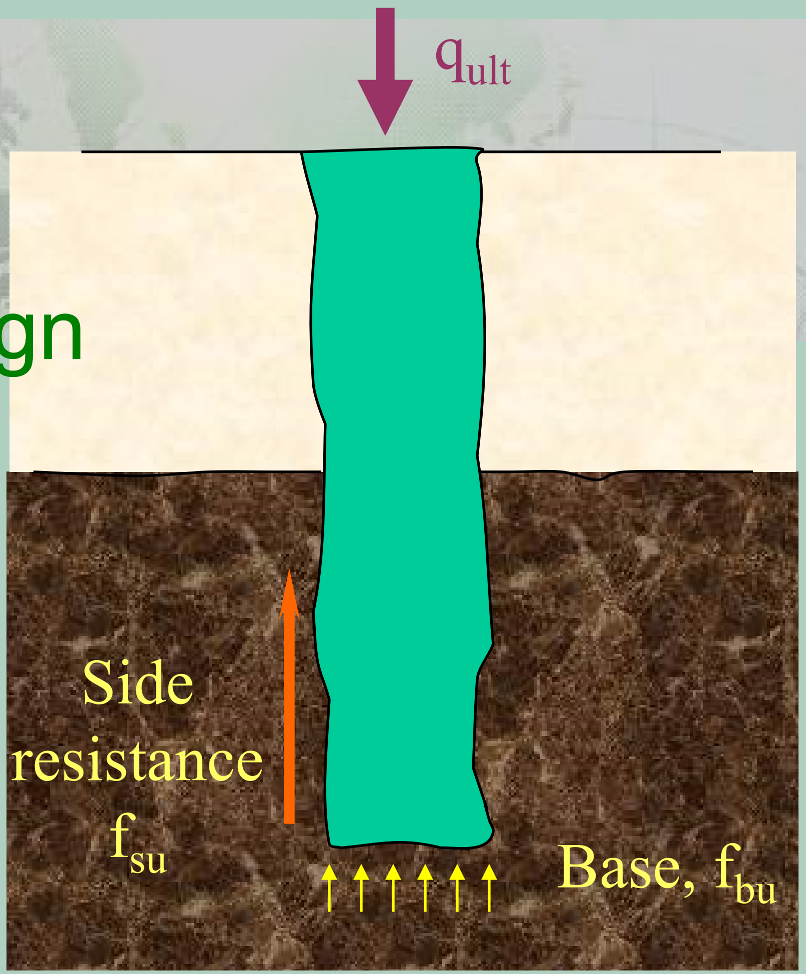
- Allowable loads

  $q_{allow} = 0.4(A_b f_{bu} + A_s f_{su})$

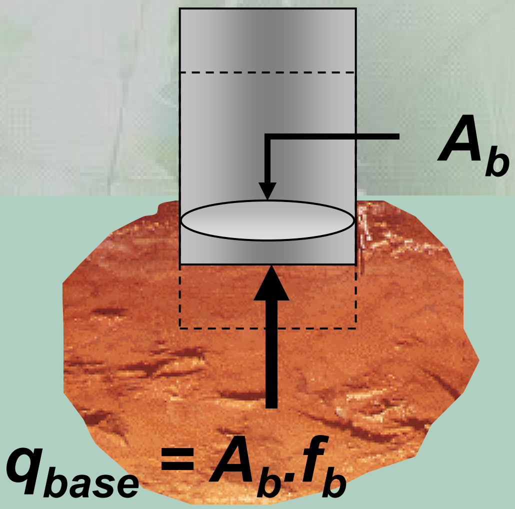
  $q_{allow} = 0.33 A_b f_{bu} + 0.5 A_s f_{su}$

- Settlement quoted (rarely calculated)

  <1% diameter (from experience)



Base resistance



Pre 1960 : Ultimate pile resistance dominated by base capacity

Ergo, ignore shaft resistance.

Spencer Street Bridge - Chapman (1929)

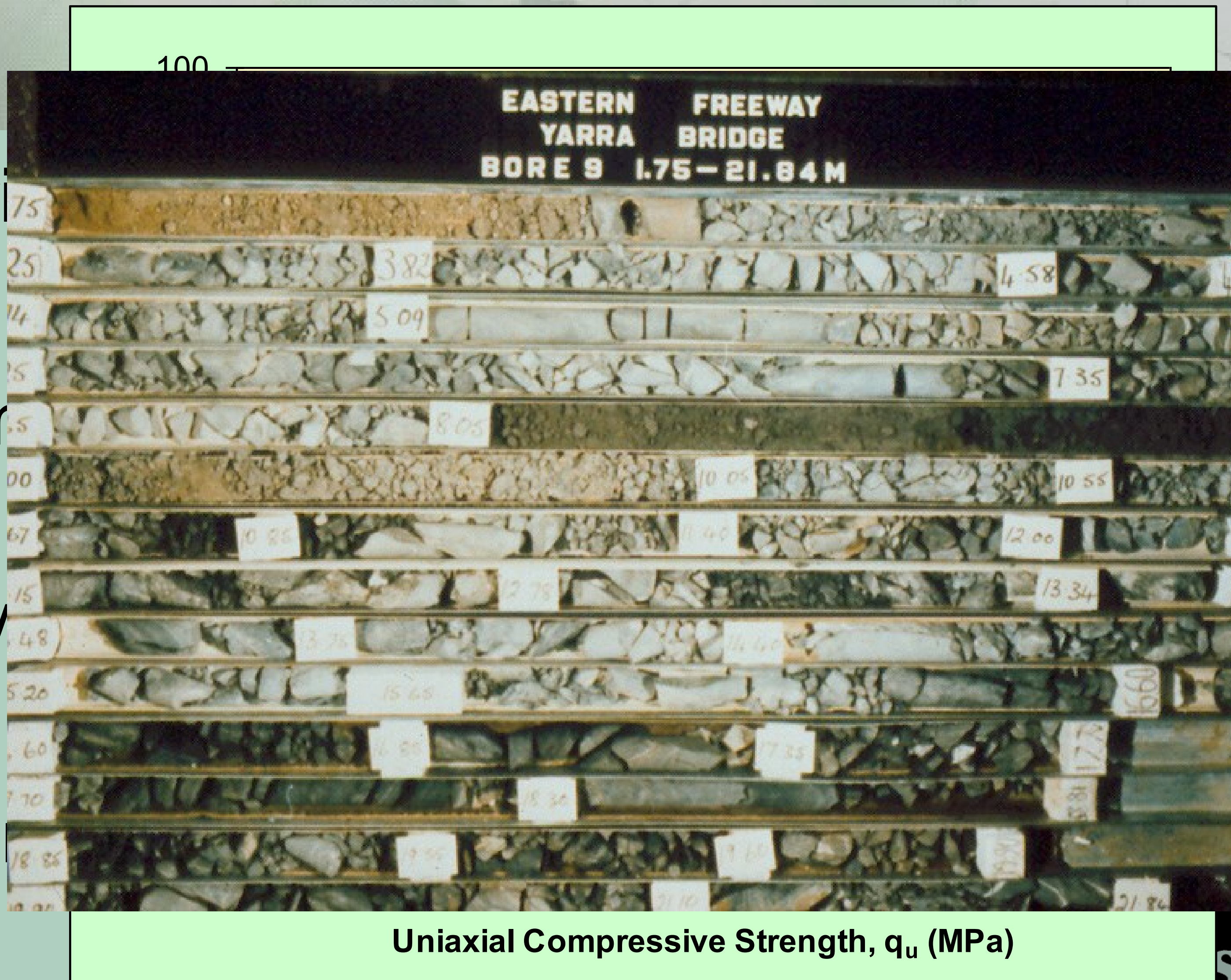
0.86 MPa <u>end bearing only</u>

King's Bridge - Wilson (1960)

0.4 to 2.0 MPa <u>end bearing only</u>

Base resistance

- Histori
- Goodr
- Soil M
- Willia



Shaft resistance

Freeman et al., (1972) suggest *allowable* values:

Type of Rock	*Allowable* skin friction for rock sockets	
	tons / ft^2	kPa
Manhatten schist	12.5	1300
Black Utica shale (Montreal)	10.5	1100
Black Billings shale (Ottawa)	10.5	1100
Dundas shale (Toronto)	10.5	1100
Limestone (Chicago)	16.0	1700

Shaft resistance

Tomlinson, (1977) suggests *ultimate* values:

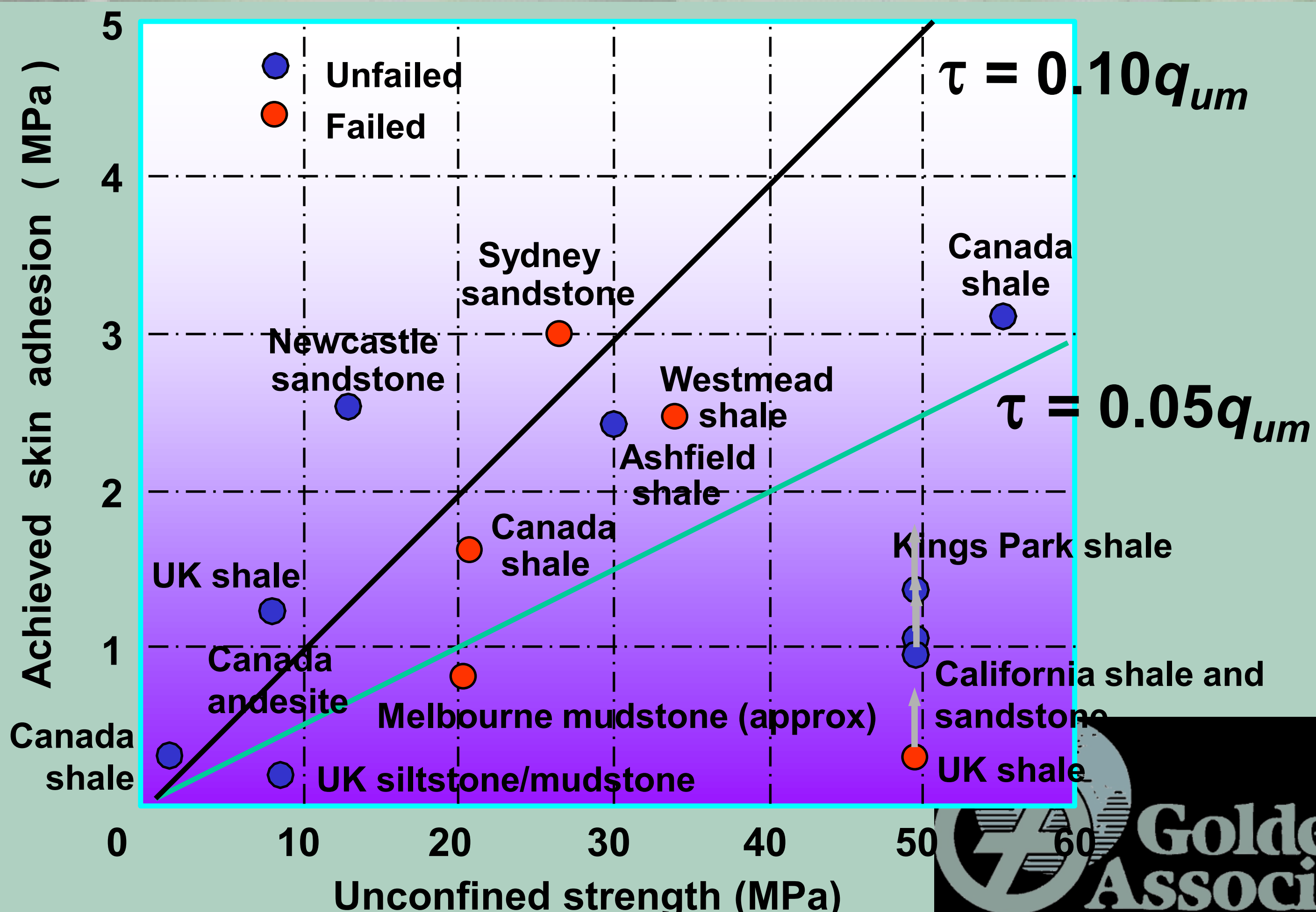
Type of Rock	*Ultimate* skin friction for rock sockets	
	tons / ft^2	kPa
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Billings shale (Canada)	28	3000
Mudstone (weak)	1.1 - 1.7	120 - 190

Develop a design methodology

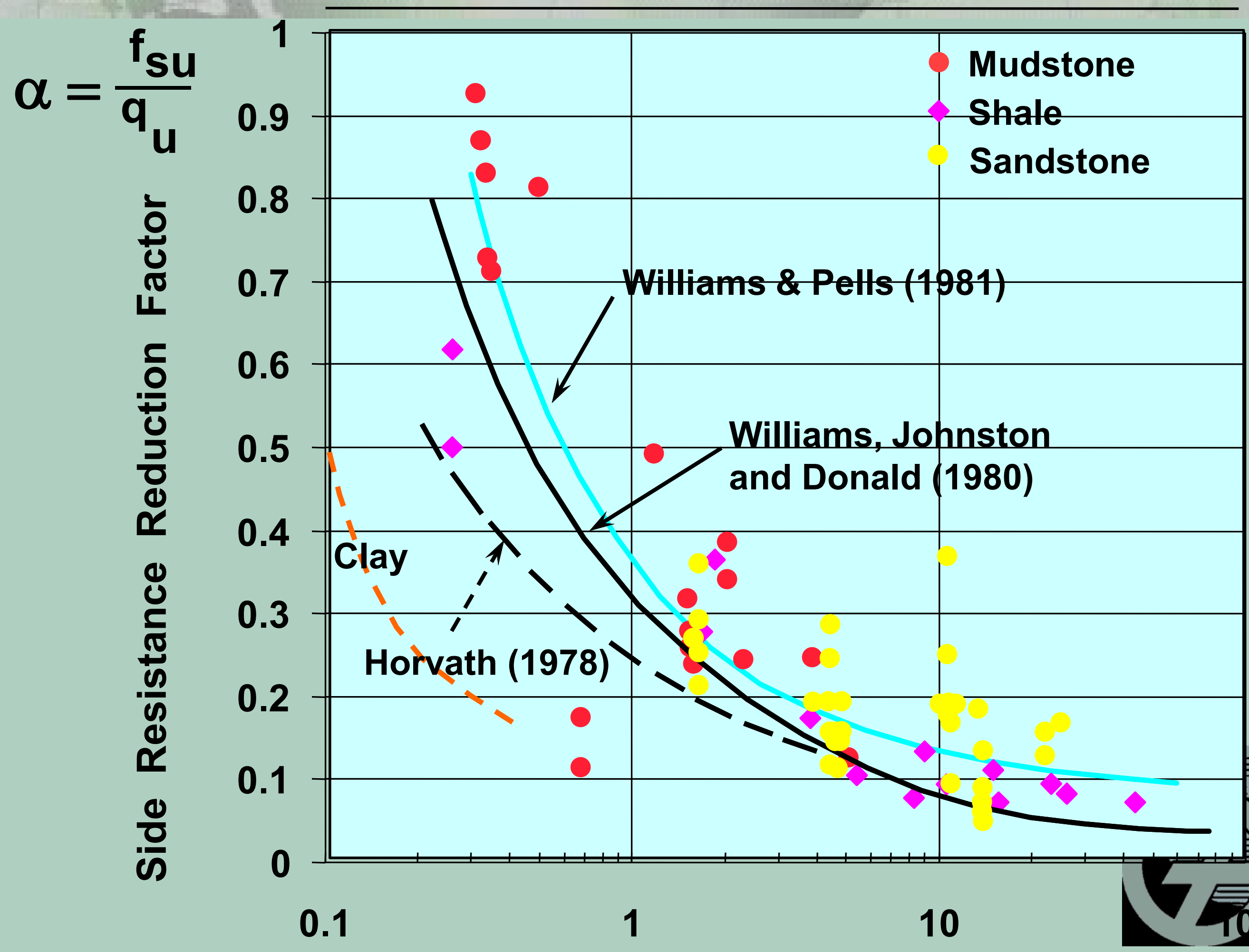
e.g. relate f_{su} empirically to rock strength q_u or with socket roughness or some other parameter

Q. Faced with such discrepancy what do we adopt?

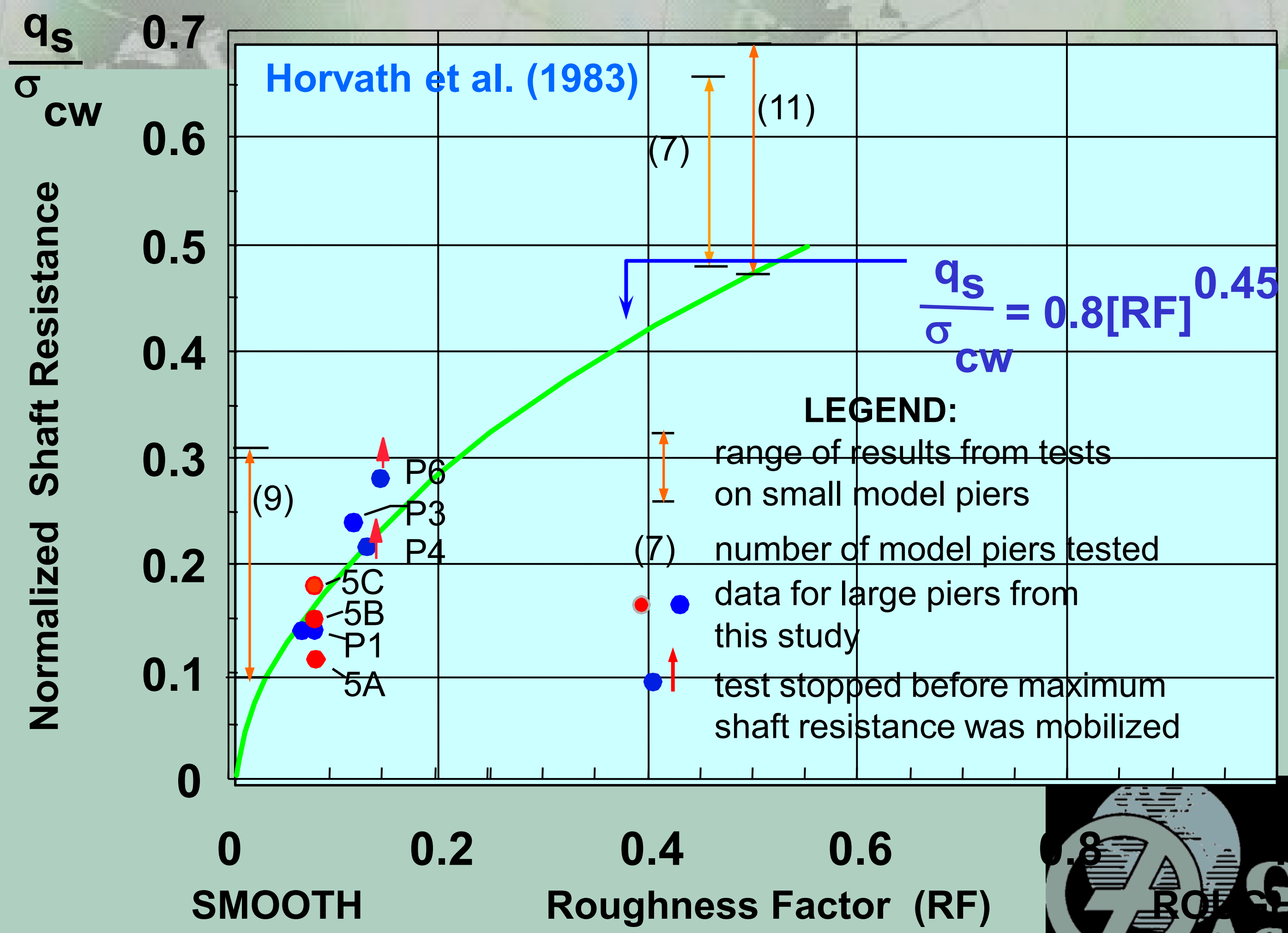
Shaft resistance - mid 1970's



For weaker rocks, adhesion values are much higher than suggested by analogy with clays



Is the higher α for sockets due to roughness?



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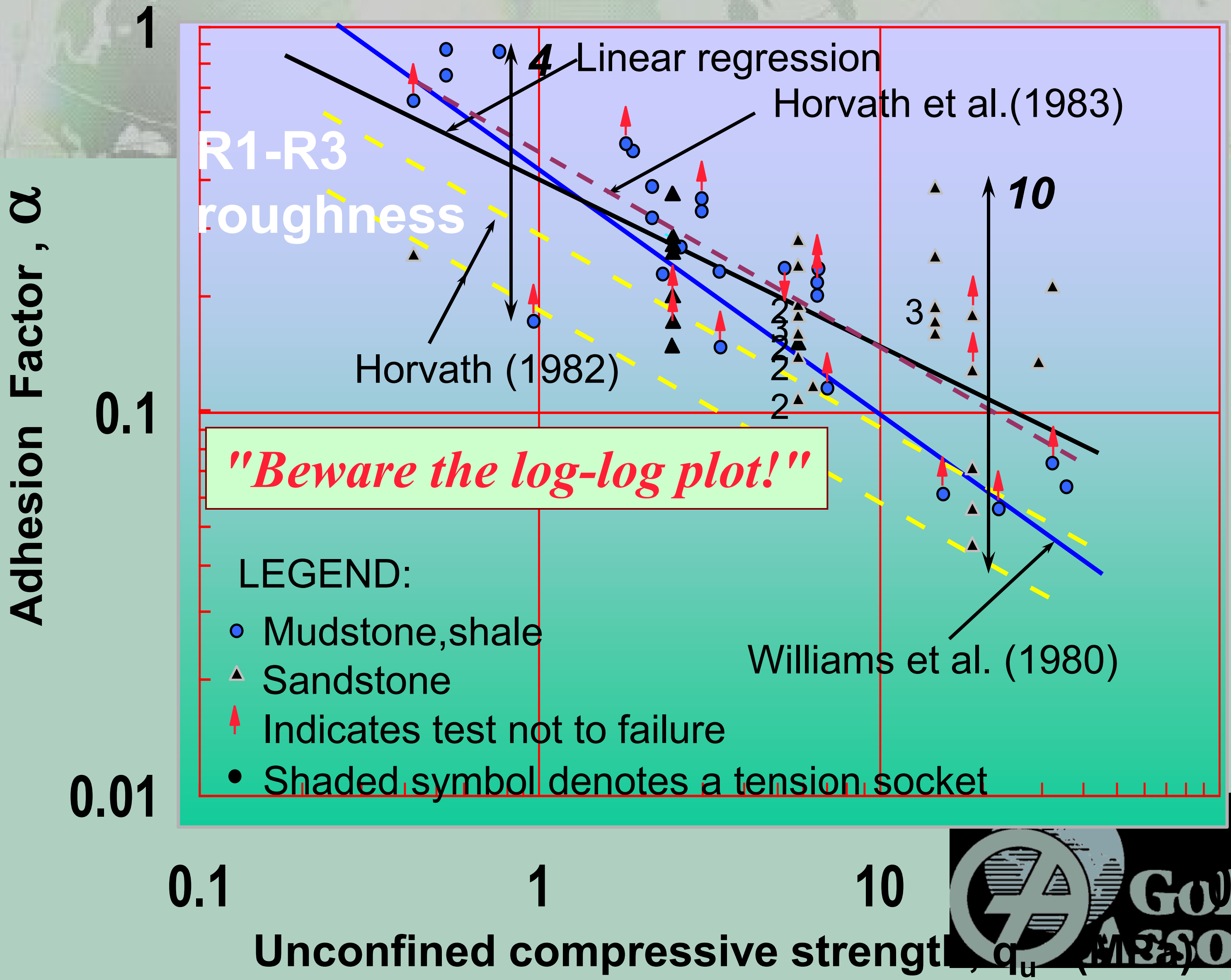
Early roughness scales

Pells et al. (1980) also proposed a set of roughness scales based on small diameter model piles in Sydney Sandstone :-

Roughness Class	*Description*
R1	*Straight, smooth-sided socket, grooves or indentations less than 1mm deep*
R2	*Grooves of depth 1 - 4mm, width greater than 2mm, at spacing 50mm to 200mm.*
R3	*Grooves of depth 4 - 10mm, width greater than 2mm, at spacing 50mm to 200mm.*
R4	*Grooves or undulations of depth > 10mm, width > 10mm at spacing 50mm to 200mm.*

Does this form of roughness description capture the roughness that is important ?

Empirical charts (Rowe & Armitage)



Theoretical Models

- Numerous models proposed (analytical, FE (elastic, elasto-plastic, softening and hardening, non-linear, wear theory etc), curve fitting)
- Results of analyses highly dependent on constitutive laws assumed for the interface (and input parameters)

Rowe & Armitage (1984)

"the use of empirical correlations would be more appropriate given the predictions depend heavily on input parameters which are difficult to obtain with sufficient reliability"

But empirical correlations ….

Large variation in base and side resistances

- f_{bu} (1.5 q_u to > 10 q_u)
- f_{su} (0.1 q_u to 1 q_u)

So what does the designer do when faced with such such variation ?

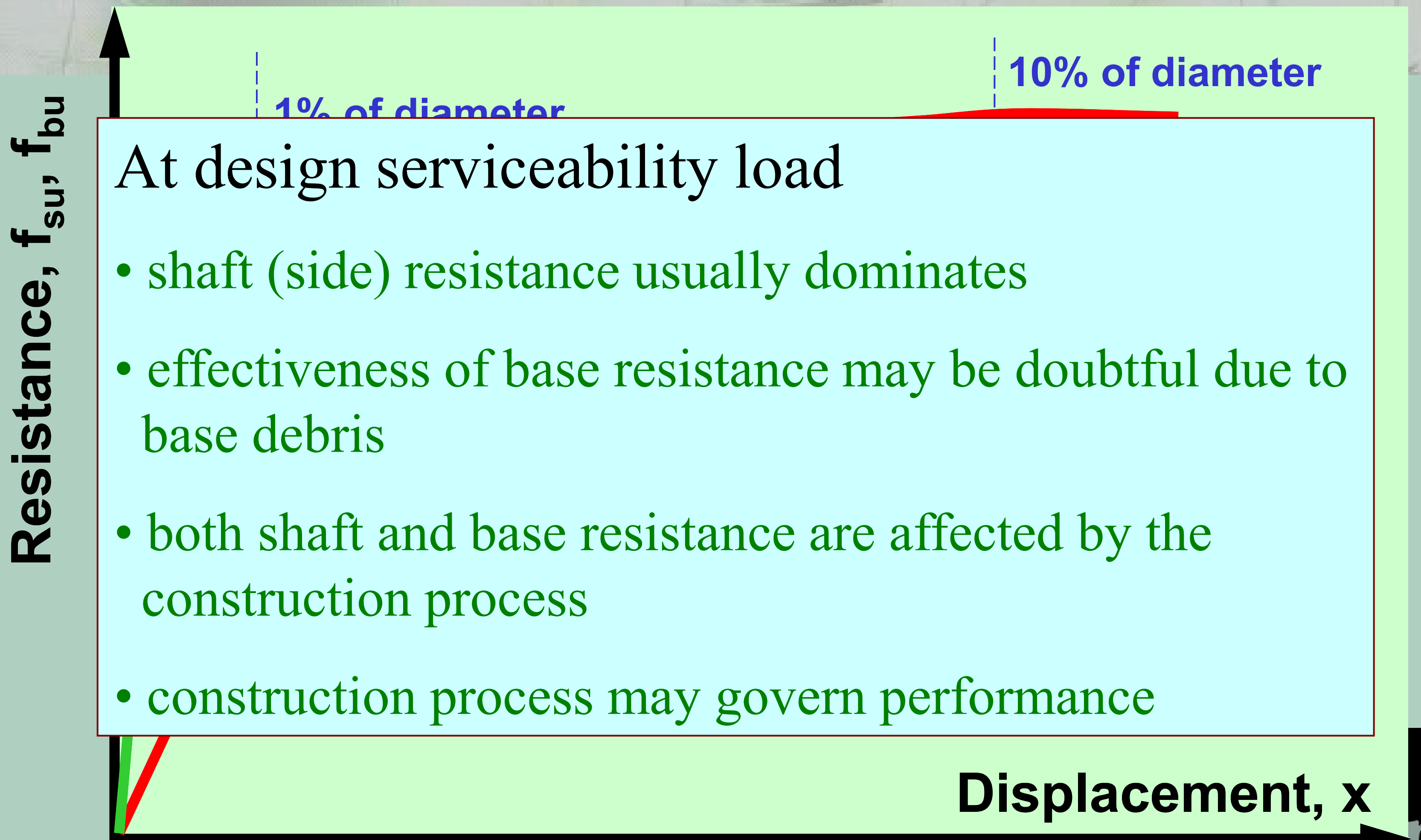
Adopts a conservative approach

e.g. $f_{ba} = f_{bu}/3 = 0.5\ q_u$

$f_{sa} = f_{su}/2 = 0.05\ q_u$

→ Inefficient sockets

Also … Serviceability (not ultimate load) is critical



At design serviceability load

- shaft (side) resistance usually dominates
- effectiveness of base resistance may be doubtful due to base debris
- both shaft and base resistance are affected by the construction process
- construction process may govern performance

So…How do we make our sockets more efficient while controlling risk ?

Some suggestions

1. design for serviceability – noting that shaft resistance (usually) dominates at serviceability loads
   - use research results to assess impact of rock properties and construction techniques on the rate of mobilisation and magnitude of socket resistance
   - improve our site investigation and testing to achieve more accurate design parameters
2. design for construction
   - observe socket construction so we know what is actually there
   - adopt a flexible design process to account for variations observed during construction
   - insist on good construction practices

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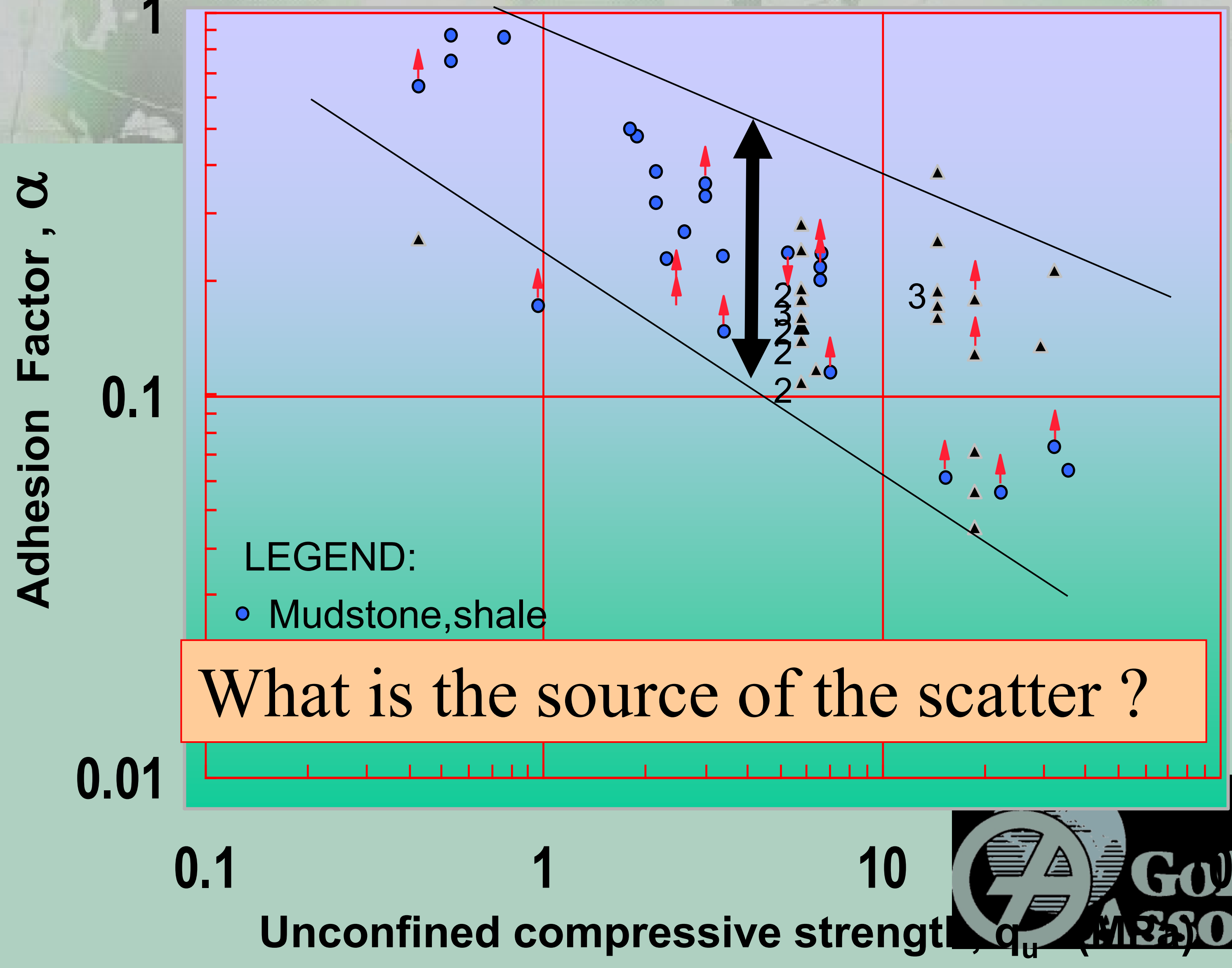
Design for serviceability…..

- Understand what effects shaft resistance
- Reasonably estimate shaft resistance performance from basic rock parameters (e.g. Young's modulus, strength) and pile geometry (socket diameter and roughness) and knowledge of construction practices
- Reasonably estimate base resistance performance from basic rock parameters (e.g. Young's modulus, strength) and pile geometry (socket diameter) and knowledge of construction practices (base cleaning)

Understanding Shaft Resistance



What is the source of the scatter ?

Parameters affecting Shaft Resistance

Rock

Are their models we can use to predict these effects ?

What engineering properties are required ?

Lecture 2 - this afternoon

- socket cleanliness
- concrete pour
- contractor experience and expertise

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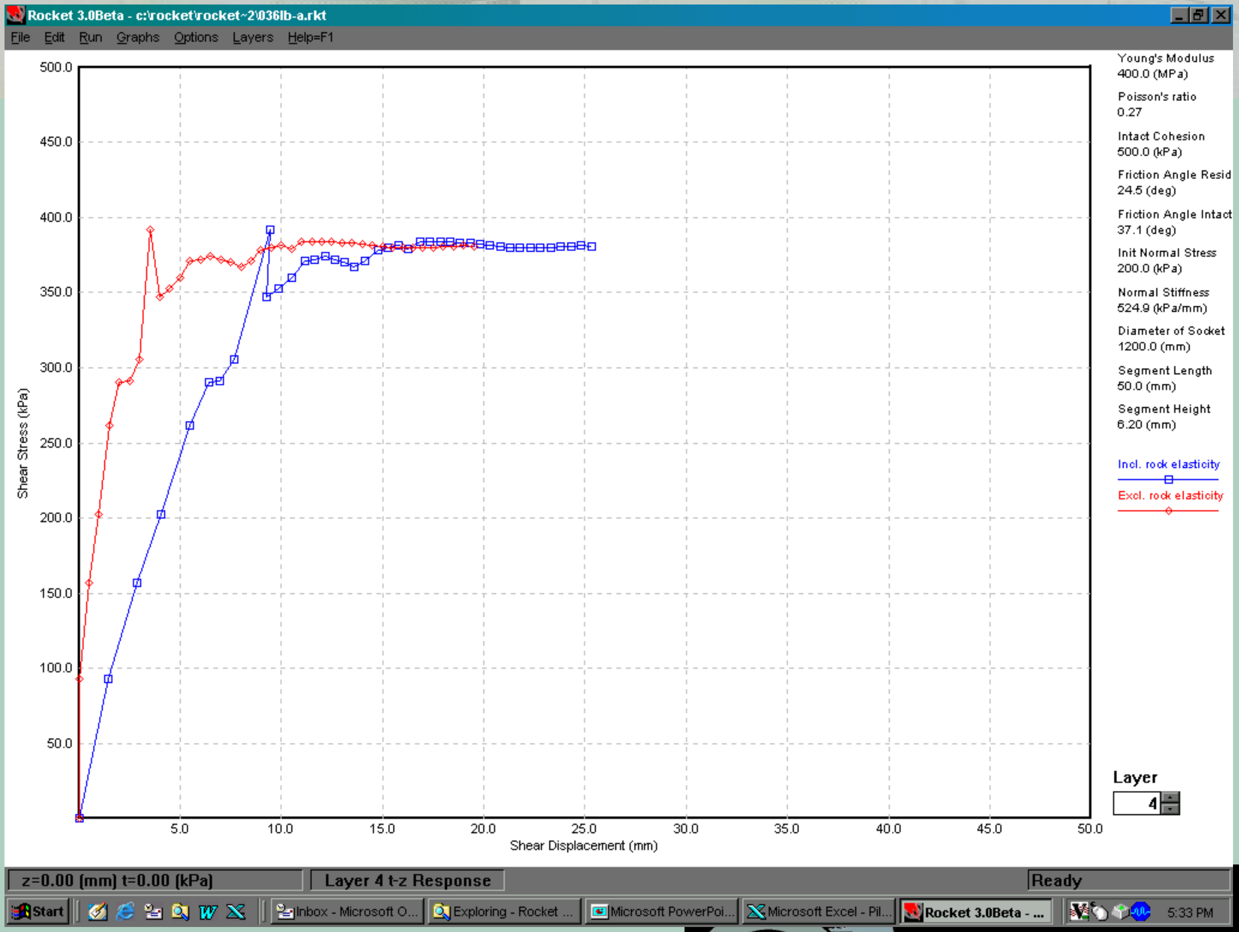
Estimating Design Pile Performance

If we are to design for serviceability, we need to be able to quantify :

- Mobilisation of shaft resistance
- Mobilisation of base resistance
- Distribution between shaft and base

Estimating Pile Shaft Performance

- Subsurface stratigraphy for each pile
- Shear stress vs displacement curve (T – z) for concrete/rock interface along socket



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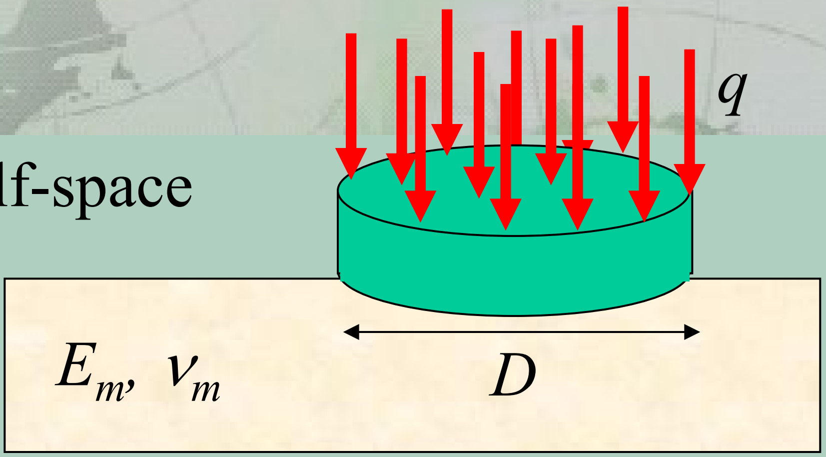
Estimating Pile Base Performance

Use rigid circular footing on a half-space

$$\rho = \frac{\pi D}{4}\left(1 - \nu_m^2\right)\frac{q}{E_m}$$

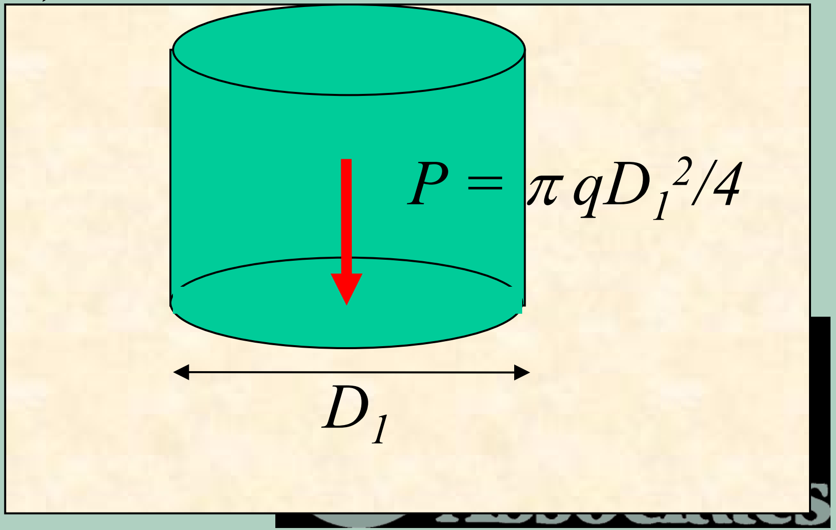


For design assume 50% of base (why ?)

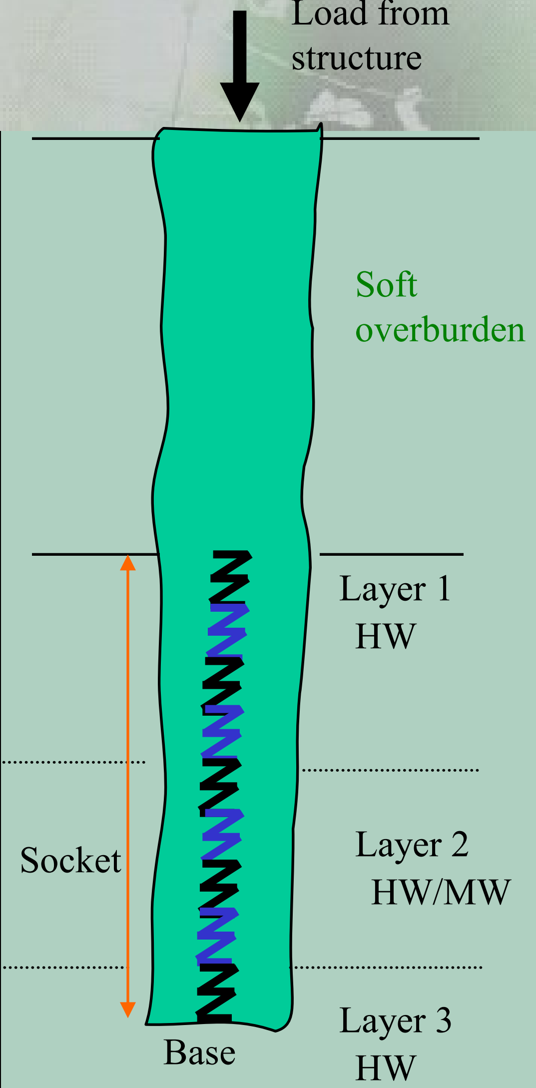
(D_1 = 0.707D)

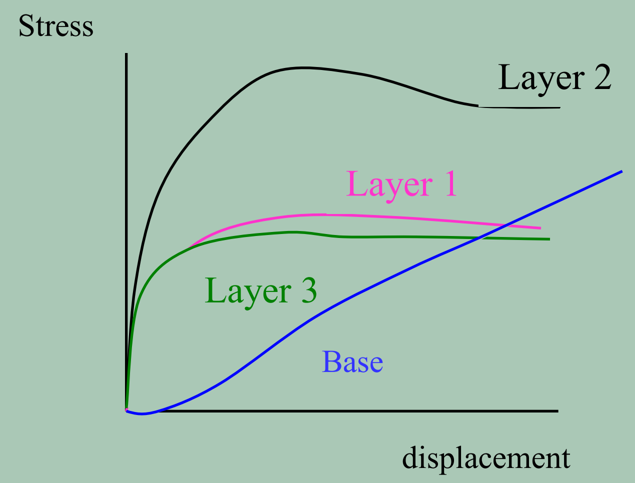
$$\rho = \lambda P$$

$$\lambda = \frac{1.414\left(1 - \nu_m^2\right)}{E_m D}$$



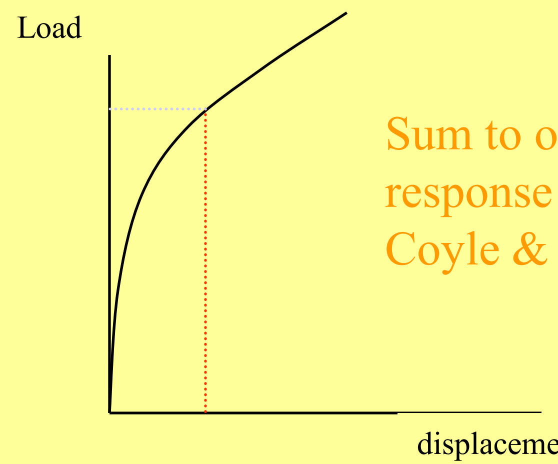
Combining Shaft and Base (interaction)





Calculate response for each layer (plus base)

Divide socket into discrete elements



Sum to obtain full pile response curve (reverse Coyle & Reese)

Limit State Design

- Don’t apply reduction factors to basic input properties (why not ?)
- Apply reduction factors to calculated response
- Check code requirements

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Reduction Factor : Serviceability Limit State

For Service

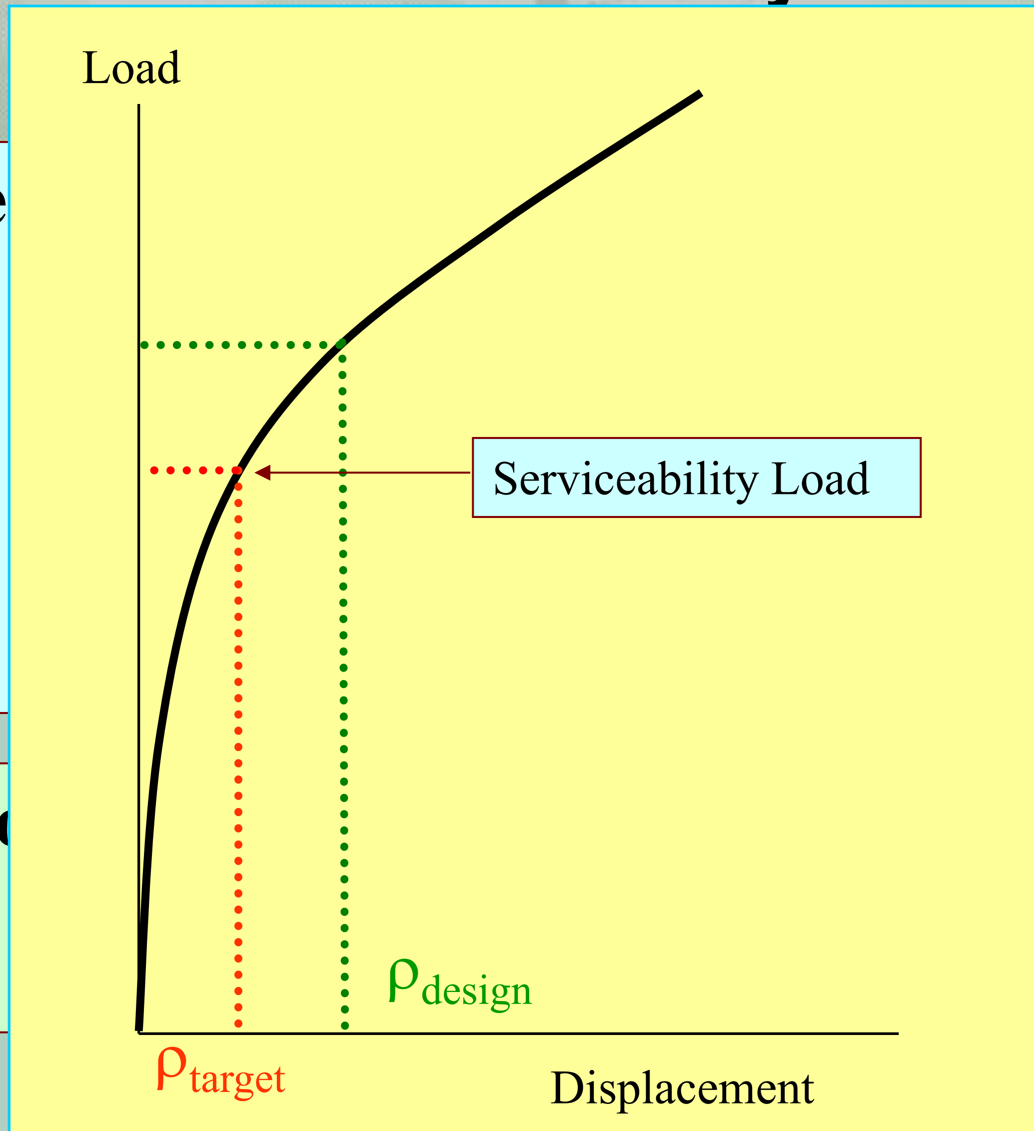
$\phi > 0.667$ ng)

$\phi = 0.667$

$\phi = 0.5$ ecific data)

$\phi = ?$ roach)

Target T ysis



Reduction Factor : Ultimate Limit State

For Ultimate Load :

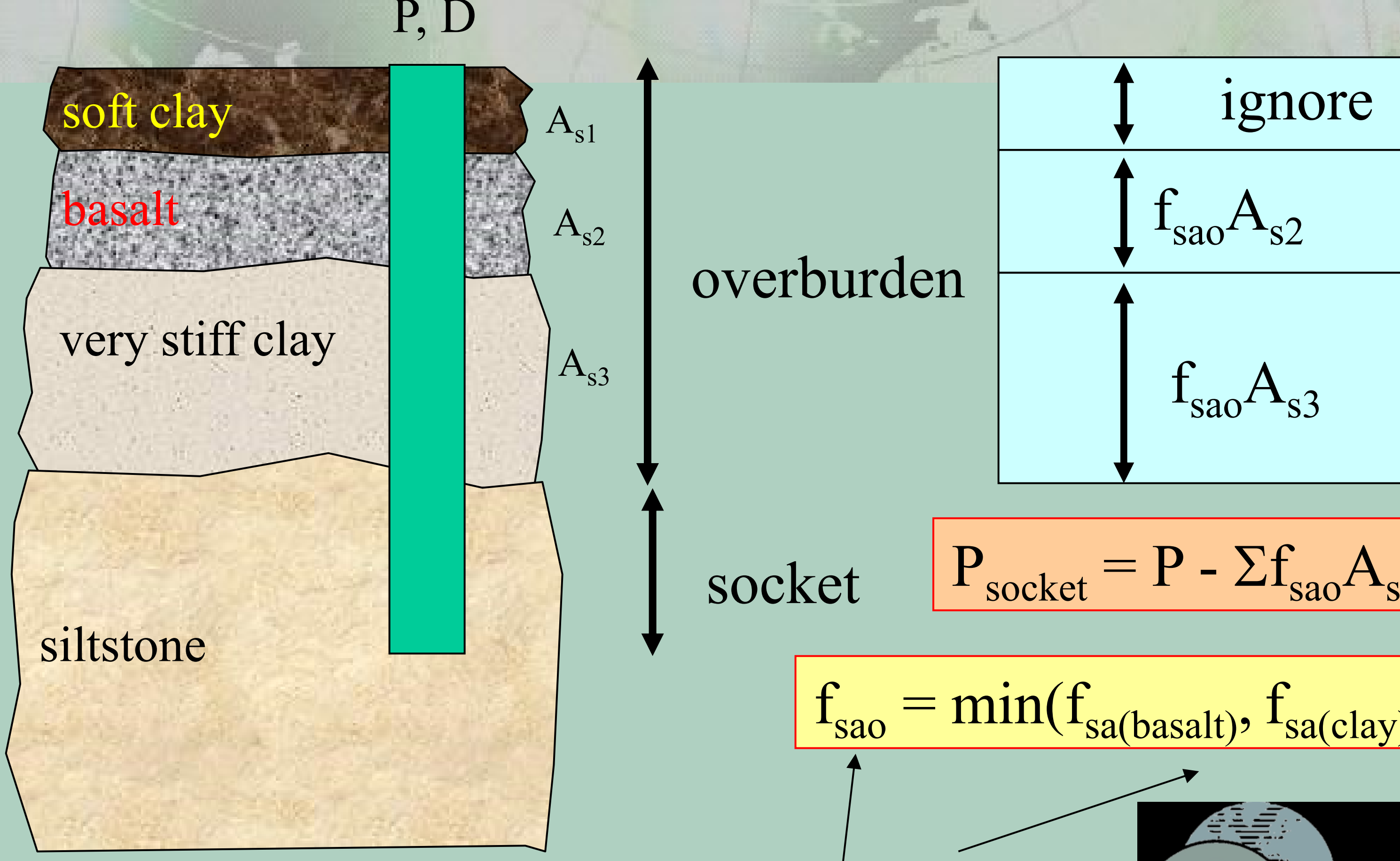
$\phi = 0.7$ to 0.95	shaft
$\phi = 0.55$ to 0.7	overburden
$\phi = 0.55$ to 0.7	base (max. 5 q_u)
$\phi = 0.45$ to 0.55	total (socket + base)

- consider carrying working load on shaft only. Use base for safety margin (why ?)
- for tension – may be requirement for additional 0.8 reduction factor (why ?)
- for tension check cone pull-out (isolated and group)
- concrete strength often governs (geotechnical strength > concrete strength) due to serviceability requirements.

Some Common Circumstances

- How is layered overburden handled ?
- What about compressible layer beneath pile toe ?

Layered Overburden

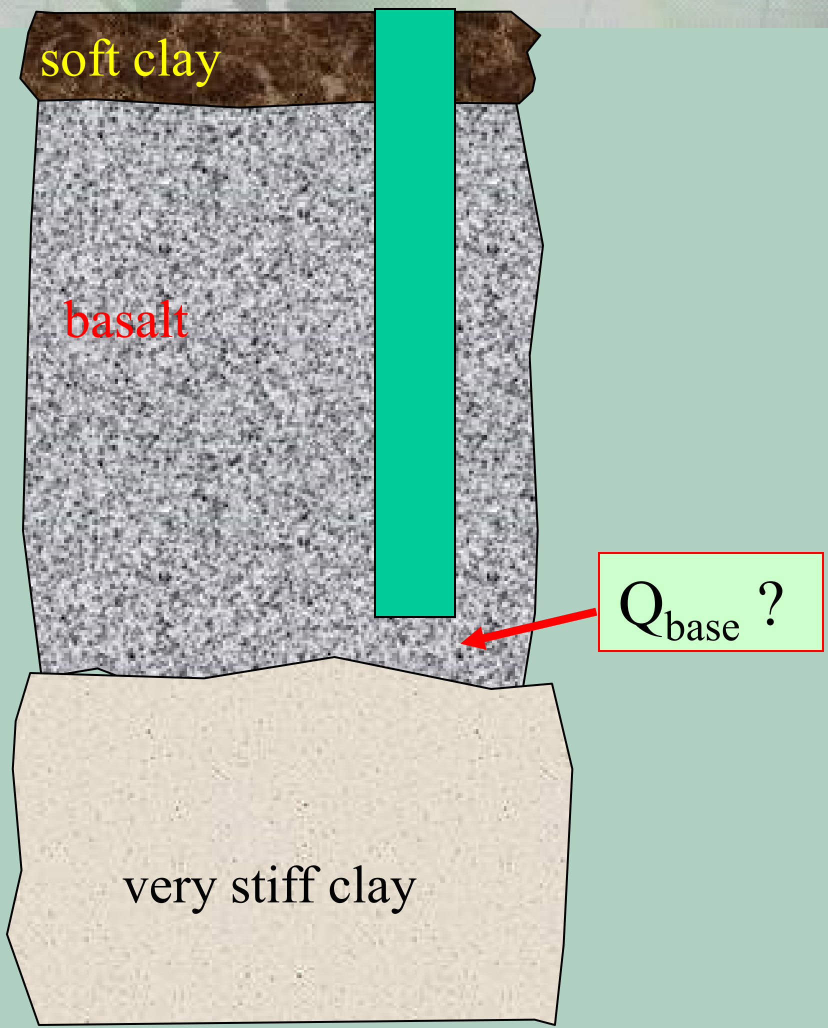


$$P_{socket} = P - \Sigma f_{sao} A_s$$

$$f_{sao} = \min(f_{sa(basalt)}, f_{sa(clay)}, \ldots.)$$

allowable

Compressible base



What f_{bu} should we adopt ?

The value for the clay.

What about settlement ?

Group response.

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Design for construction…..

- Design for what is there and how the piles are constructed
- Confirm design assumptions

Design Process - GARSP

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GARSP

Three stage process :

- Site Investigation Stage
- Design Stage
- Construction Stage

Stage 1 : Site Investigation

- sufficient boreholes to assess variation across site and with depth
- insitu testing
  - pressuremeter tests every 2m to 3m
- laboratory testing
  - moisture contents at 1m intervals
  - UCS tests at pressuremeter test locations
  - point load index tests (for stronger rocks only)
  - CNS direct shear tests
  - (keep core moist and tests ASAP)

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Stage 2 : Preliminary Analysis and Design

1. Assess stratigraphy (subsurface model)
2. Preliminary sizing for costing (Rocket analyses)
3. Develop design charts for field sizing of sockets
4. Assess global settlements (differential and total)

Stage 3. During construction

- fully brief field staff
- observe and log drill cuttings as socket is drilled.
- assess socket length based on field observations and design charts
- insist on socket roughening and cleaning (why ?). May require special tools
- check consistency of logging (with water content testing if appropriate)
- run occasional check analyses on design pile performance

Some Major Projects

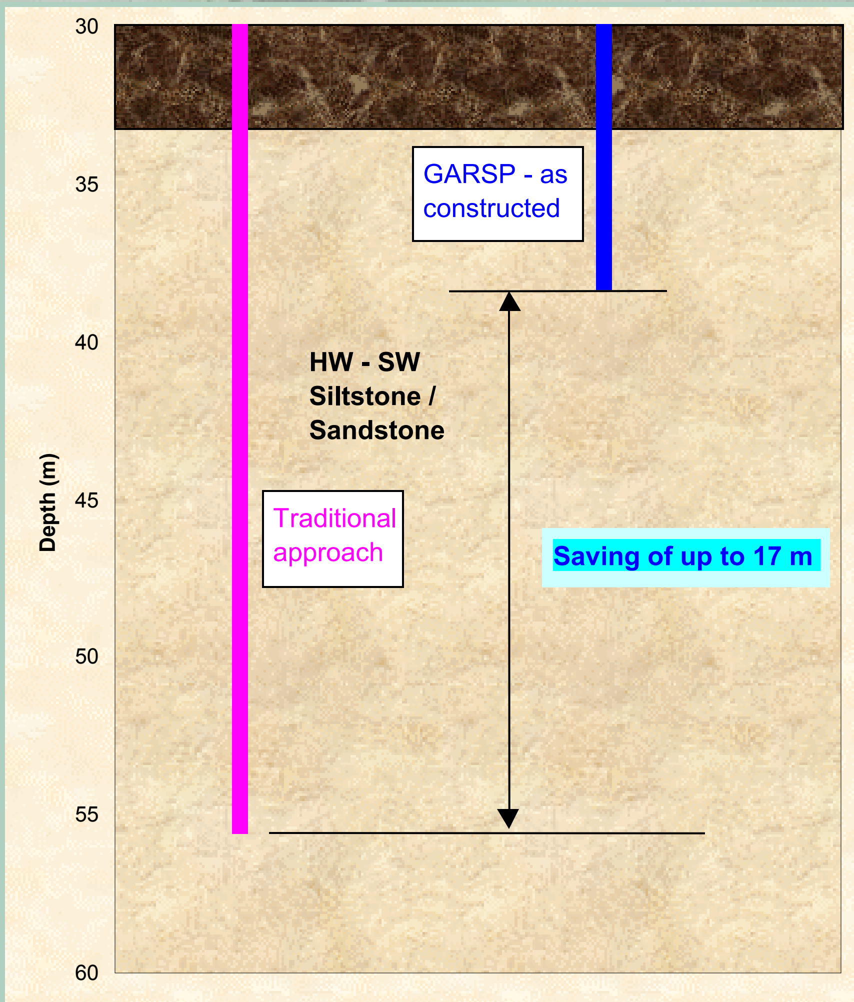
- Freshwater Place
- Royal Domain Tower
- MCG Northern Stand Redevelopment 2002-2005
- Spencer St Redevelopment
- Many others

Freshwater Place

- 30 m overburden over HW to SW siltstone (variable)
- ~ 70 x 1.2 m diameter piles (plus others)
- serviceability loads of 17 MN to 30 MN
- design top-of-socket settlement : 1 % diameter

Freshwater Place

1.2 m diameter pile, serviceability load = 27 MN



Overall

- **Estimated Savings**
  - 900 m in socket length
  - 1000 m^3 of concrete
  - 1500 m^3 reduction in spoil
  - 40 days of construction time
- **Additional Cost**
  - $20k in site investigation and design
  - minimal $ in construction sup[illegible]ision

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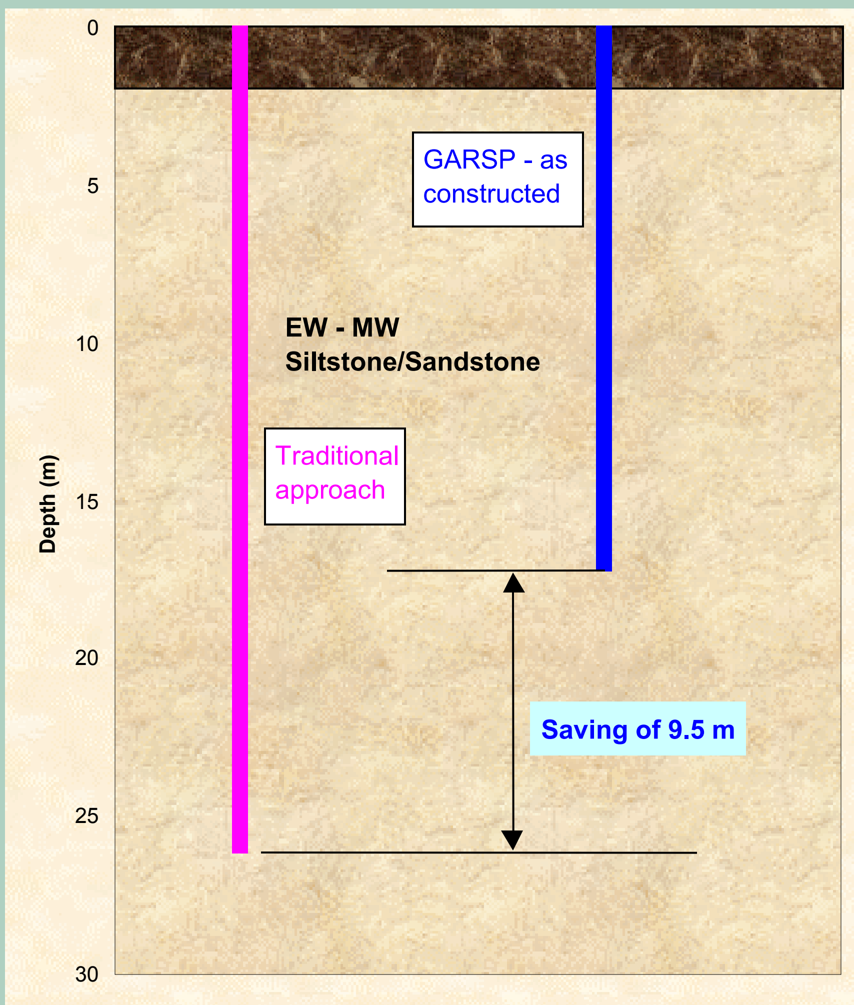
Royal Domain Tower

- 40 level tower
- EW to MW siltstone from surface - deep weathering profile
- dykes
- ~ 85 piles : 0.75 m to 1.5 m diameter
- serviceability loads of 5 MN to 15 MN
- design pile head settlement : 1 % diameter

Royal Domain Tower

1.2 m diameter pile, serviceability load = 15.3 MN



Overall

- **Estimated Savings**
  - 950 m in socket length
  - 950 m^3 of concrete
  - 1400 m^3 reduction in spoil
  - 42 days of construction time
- **Additional Cost**
  - $10k in site investigation and design
  - minimal $ in supervision

MCG NORTHERN STAND REDEVELOPMENT

MCG Northern Stand Redevelopment

- 300 No. load bearing foundation and retention piles:
  - 600 mm diameter to 1,800 mm diameter, up to around 25 m depth.
  - Pile loadings varied significantly with up to 30 MN axial loading,
  - Piles socketed into siltstone bedrock at depths ranging from ground level to 20m.

WAGSTAFF PILING

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MCG NORTHERN STAND REDEVELOPMENT

MCG Northern Stand Redevelopment

- Limited geotechnical investigation prior to the commencement the works due to the presence of an existing grandstand.
- Piling works became an ongoing site investigation
- Works complicated by the presence of badly decomposed and unpredictable igneous dykes and ancient riverbed alignment bisecting the site

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MCG Northern Stand Redevelopment

- Preliminary design of rock socketed piles based on available geotechnical data, but all sockets logged and final design lengths assessed using GARSP.
- The flexibility of GARSP enabled socket design to be adjusted on-site based on the conditions encountered, and allowed socket lengths to be optimised during the course of drilling.
- Despite the lack of preliminary site investigation, significant cost and time savings were able to be delivered. (Possible as siltstone properties were well understood)

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Spencer St Redevelopment

- 250 No. bored piles of 600 mm to 1,500 mm diameter across an extremely large site (around 75,000 m2)
- Pile founding materials:
  - Shallow weathered basalt (5m to 12m depth)
  - Dense Sands (~20m depth)
  - Siltstone Bedrock (30m+ depth)
- Stringent differential settlement criteria

SPENCER ST REDEVELOPMENT

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SPENCER ST REDEVELOPMENT

Spencer St Redevelopment

- Operational train station:
  - platforms were progressively closed and occupied for fixed durations
- Site investigation limited.
- Construction occupations varied from months to as little as 1-2 days
- Much of the works was completed on weekends and night shifts.

Spencer St Redevelopment

- Essential that pile design could be adjusted on-site during drilling
- Fixed occupation times and the high cost of mobilising piling equipment to poorly accessible locations required 'on the spot solutions'
- Design efficiencies and flexibility delivered by GARSP were invaluable in successful delivery
- Savings estimated to be in the order of hundreds of thousands of dollars and tens of week

Benefits

- Design system results in reduction in pile length leading to:
  - Savings in construction time
  - Savings in materials
  - Reduction in spoil
  - Cost savings
- On-site presence during pile installation provides...
  - Confirmation of design assumptions
  - Better control of risks due to unexpected or variable ground conditions and construction probl
  - Real time pile design and on-site design a

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Rational Design/Construction System

Socketed piled design/construction system successfully used on several projects. The process

- Requires detailed site investigation
- Uses state of the art analysis methods
- Designs for serviceability
- Requires site presence
- Design done in real time based on actual conditions and allows optimisation of socket dimensions
- Manages risk (e.g dykes)
- Design considers construction practice
- Promotes good construction practice
- Leads to increased Confidence + Savings

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Pile Load Testing

- of trial pile
  - Valuable
  - May allo
  - Can be u
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- of working
  - Static loa
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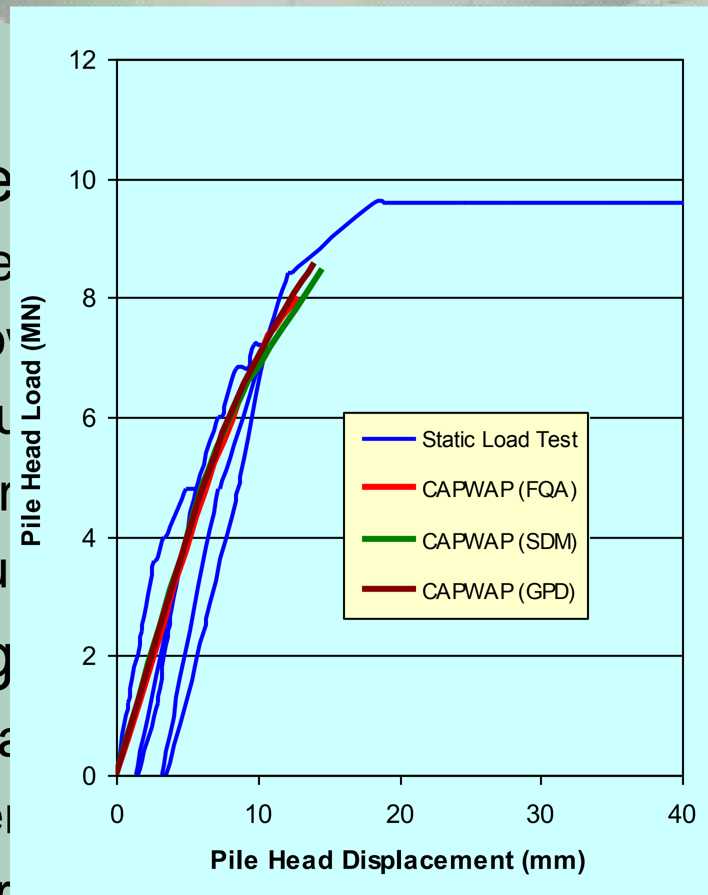
  - Integrity testing – crosshole sonic and PI



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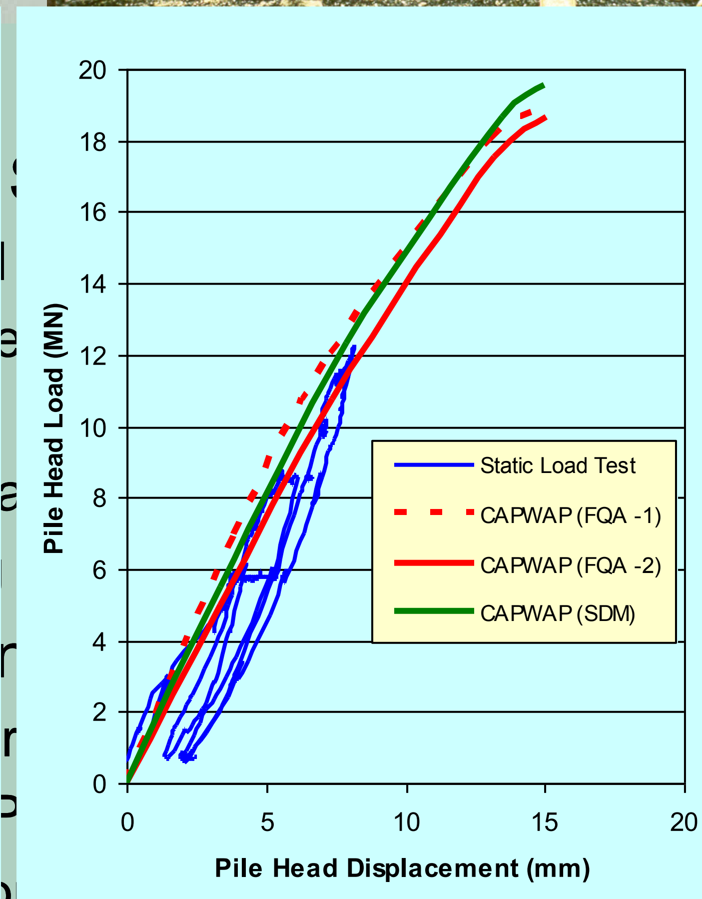

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Summary

- Shaft resistance usually dominates at serviceability load
- Design on shaft resistance, use base for safety (unless short)
- Construction effects dominate performance
- Design should consider construction effects and practices
- Use of empirical correlations requires greater conservatism
- Significant benefits from detailed ground investigation and rational approach to design and construction
- Design for serviceability, check ultimate
- Load testing of trial piles should be considered for design and construction (especially in new ground)
- Proof testing of piles by PDA/CAPWAP

This Afternoon

- Understanding shaft resistance
- Laboratory testing of interface response
- Roughness
- Parameters that influence performance
- Pile Load tests - validation

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