PILE TESTING

OUTLINE

- Types of test
- Static tests & side effects of various test procedures
- Test interpretation
- Instrumented pile tests
- Dynamic load testing
- Statnamic testing
- Integrity testing

TEST CATEGORIES

- **Load Tests on Uninstrumented Piles**
  - Measure only load-settlement or deflection at pile head
- **Load Tests on Instrumented Piles**
  - Measure load or strain distribution as well as load – displacement
- **Non-Destructive tests**
  - Measure or deduce:
    - structural integrity
    - Pile head stiffness

LOADING TYPES

- Static
  - Conventional type
- Dynamic
  - Widely used now
- Intermediate ("Statnamic")
  - Recent development

STATIC LOAD TESTING PROCEDURES

- Maintained loading test
  - Standard approach

- Constant Rate of Penetration (CRP) test
  - Mainly for load capacity

LOAD APPLICATION & REACTION SYSTEMS

- Jacking against supports loaded with kentledge
- Jacking against reaction beam supported by anchor piles
- Jacking against reaction beam supported by ground anchors
- Using the **Osterberg Cell** – pre-installed flat jack near base of pile

LOAD APPLICATION AND REACTION SYSTEMS

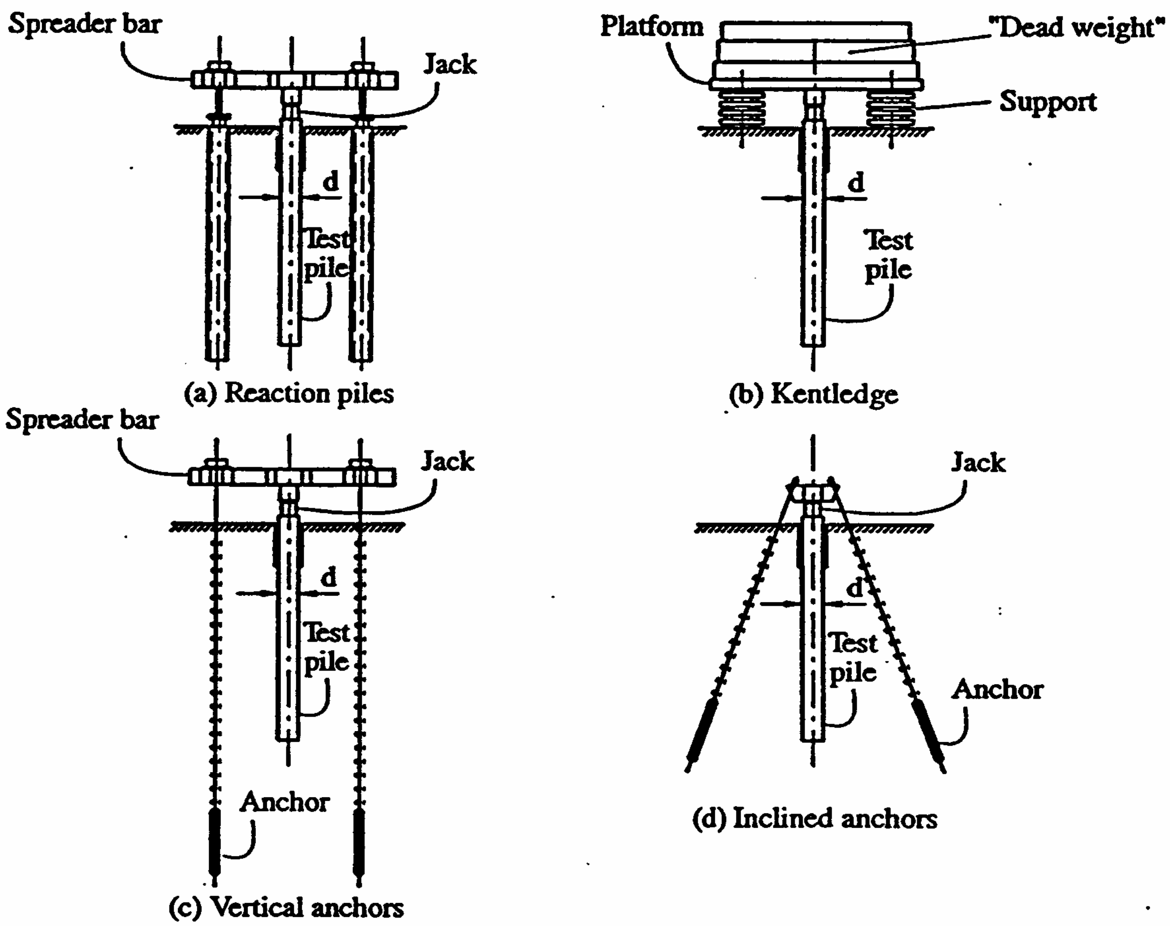
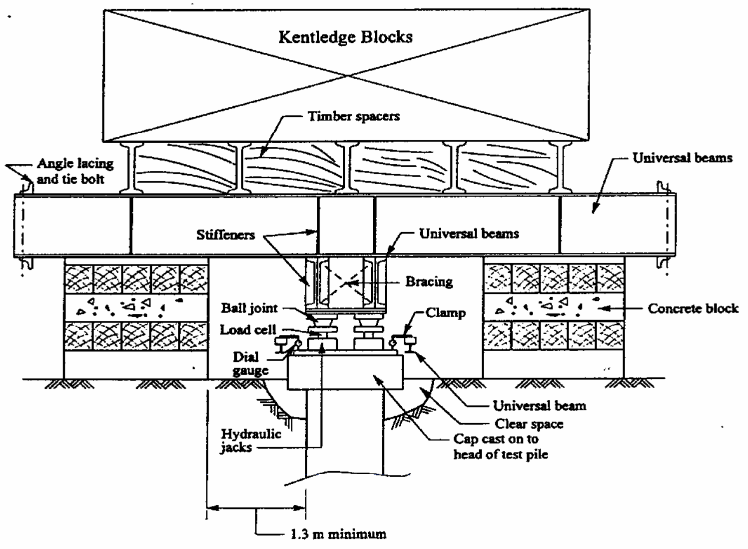


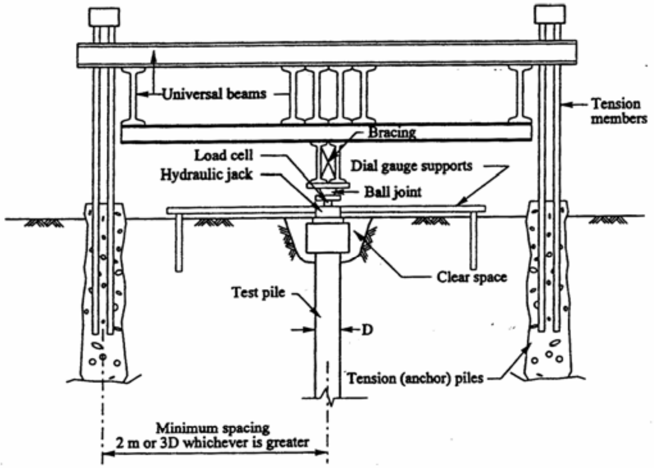
Fig. 1 Typical static pile load testing reaction systems

DETAILS OF REACTION SYSTEMS



Kentledge

Note : Figure based on Tomlinson (1994).



Anchor Piles

Note : Figure based on Tomlinson (1994).

3000t LOAD TEST WITH REACTION ANCHORS

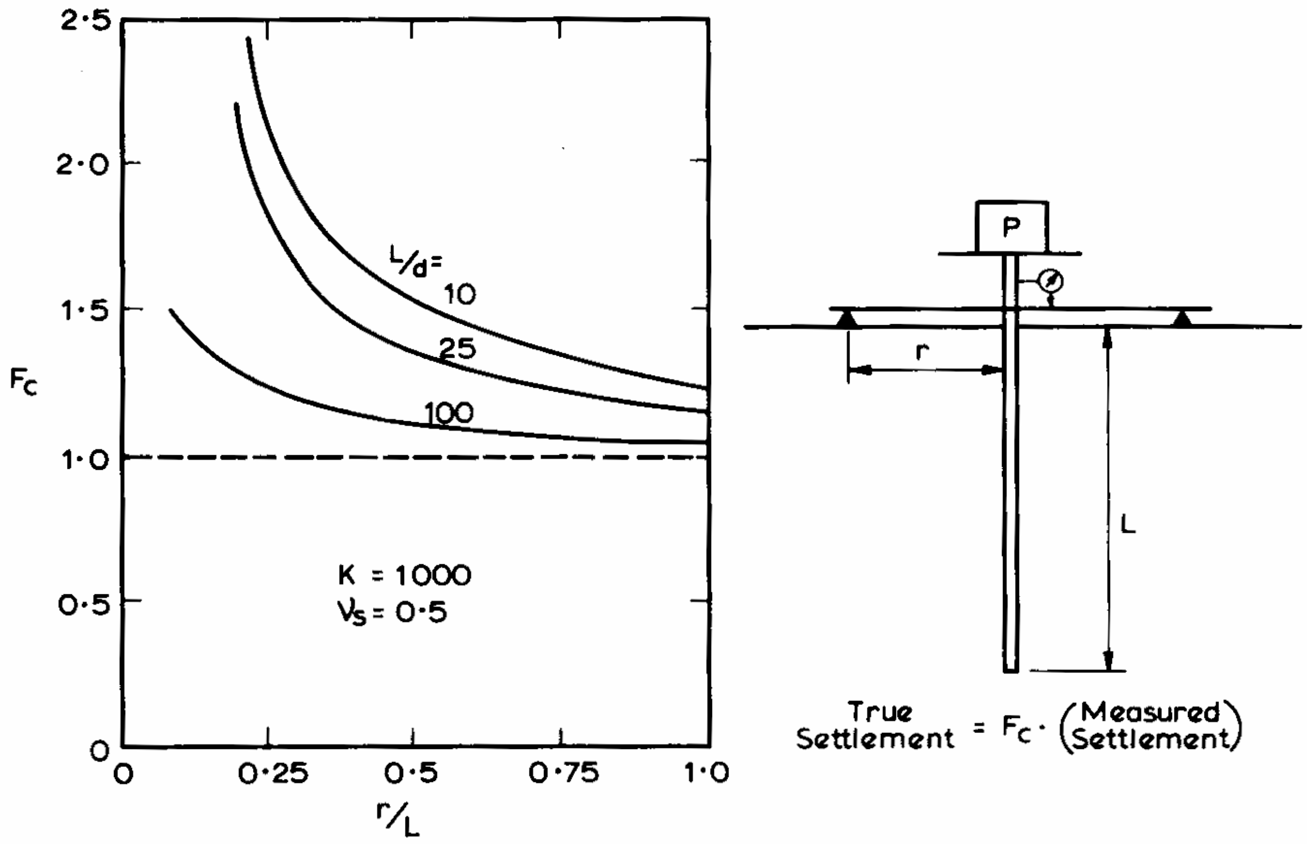
Emirates Project, Dubai

POSSIBLE INTERACTION EFFECTS IN PILE LOAD TESTS

- Movement of supports used for settlement, due to pile load
- Interaction between test pile and reaction piles
- Interaction between test pile & anchors
- Interaction between kentledge reactions and test pile (reactions vary with pile loading)

Can assess possible importance of some of these interaction effects from pile-soil-pile interaction analyses.

CORRECTION FOR SETTLEMENT BEAM MOVEMENTS DUE TO PILE LOAD



Correction factor F_c for floating pile in deep layer of soil.

True Settlement = F_c * Meaasured Settlement

CORRECTION TO MEASURED SETTLEMENTS DUE TO EFFECTS OF REACTION PILES

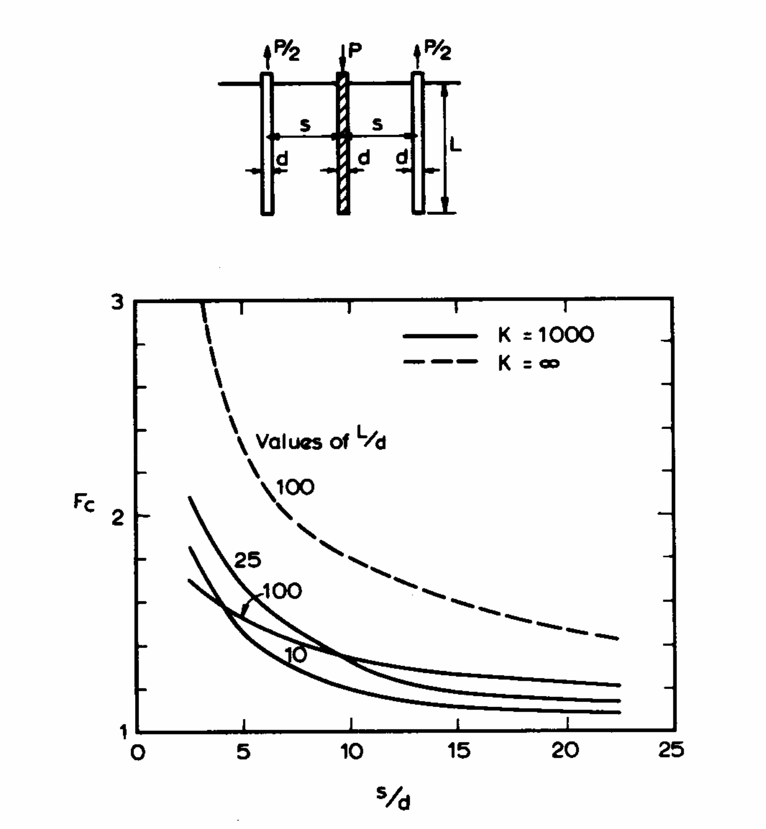


FIGURE 16.7 Correction factor F_c for floating pile in a deep layer jacked against two reaction piles.

Floating piles

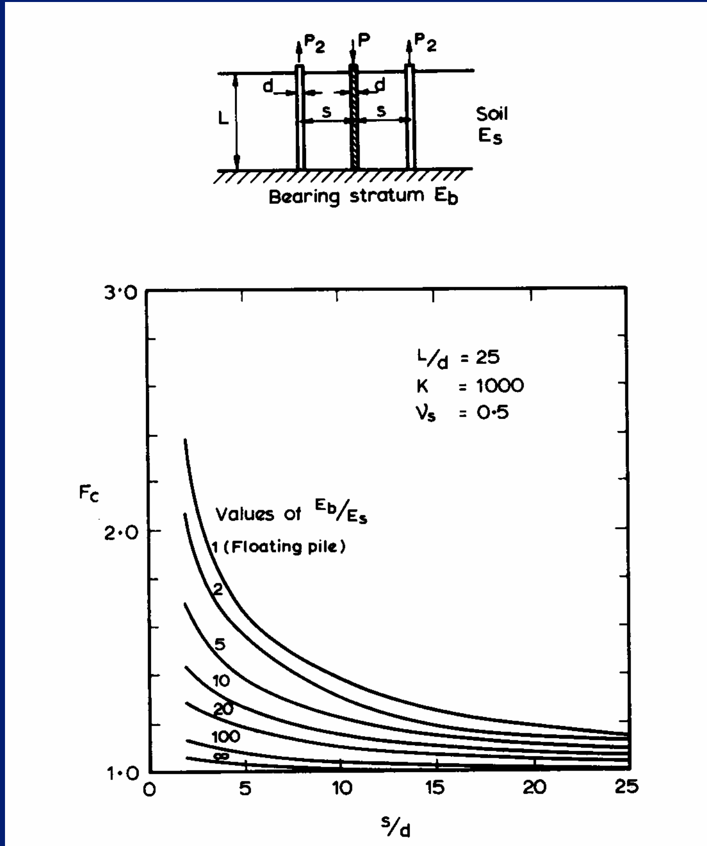


FIGURE 16.9 Correction factor F_c. Effect of bearing stratum for end-bearing pile jacked against two reaction piles.

End Bearing Piles

MEASURED EFFECTS OF REACTION PILES ON TEST PILE BEHAVIOUR

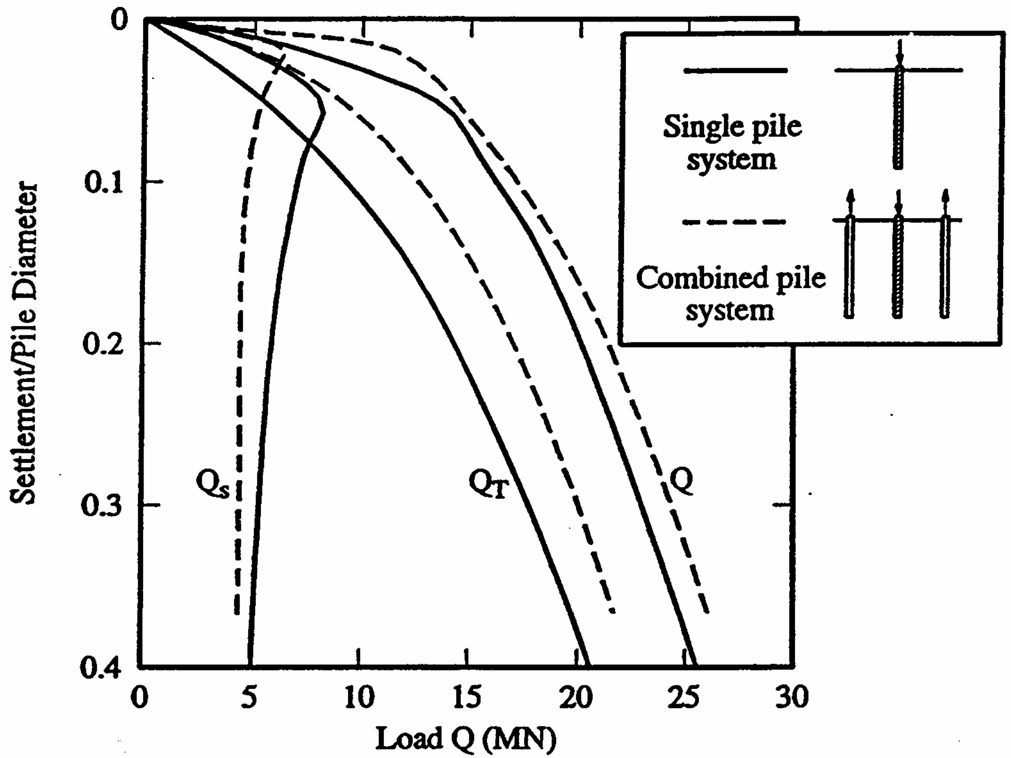


Fig. 4 Effect of interaction on development of total load, skin friction and tip resitance of tests piles observed from the combined pile system and from single pile system. (after Latotzke et al, 1997)

“SIDE EFFECTS” OF USING KENTLEDGE

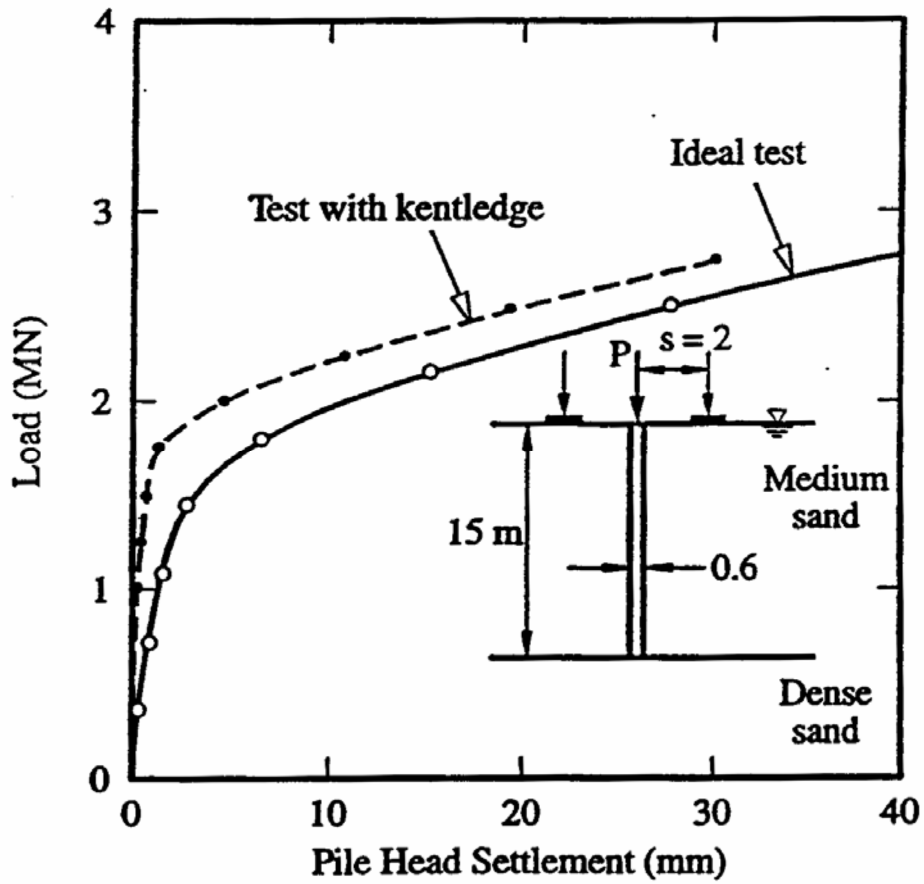


Fig. 2 Example of influence of kentledge on pile test in sand

CORRECTION TO MEASURED SETTLEMENTS DUE TO EFFECTS OF REACTION ANCHORS

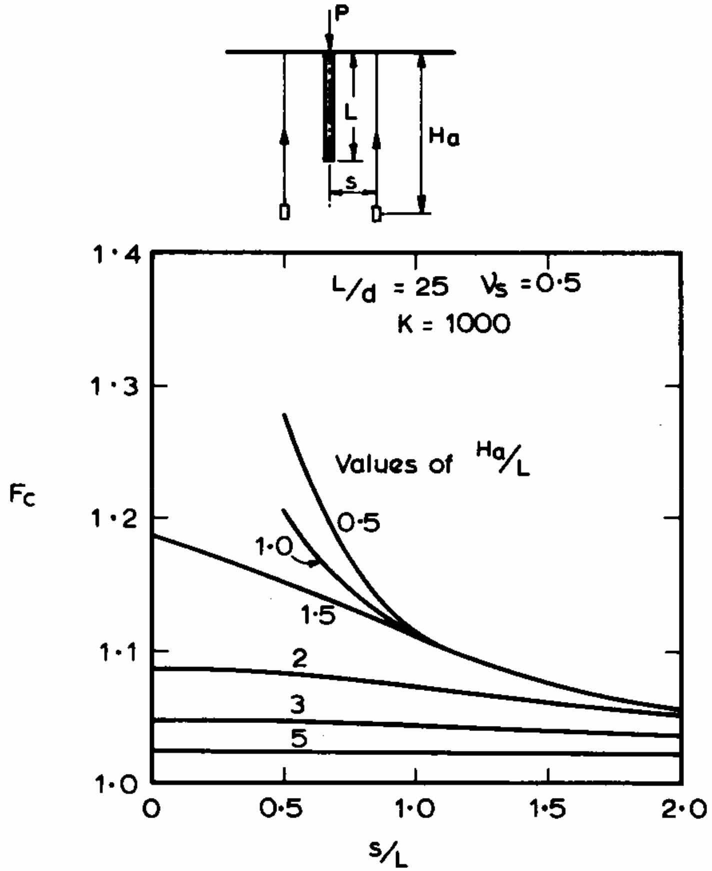


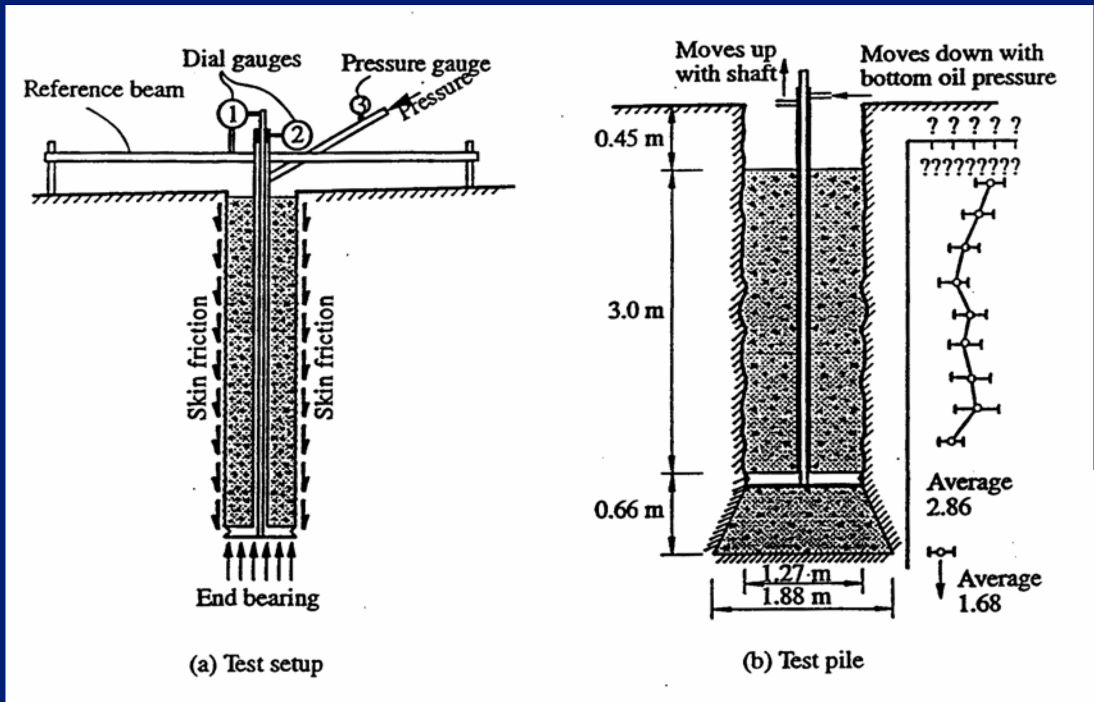
FIGURE 16.11 Correction factor F_c for floating pile in a deep layer jacked against ground anchors.

True Settlement =

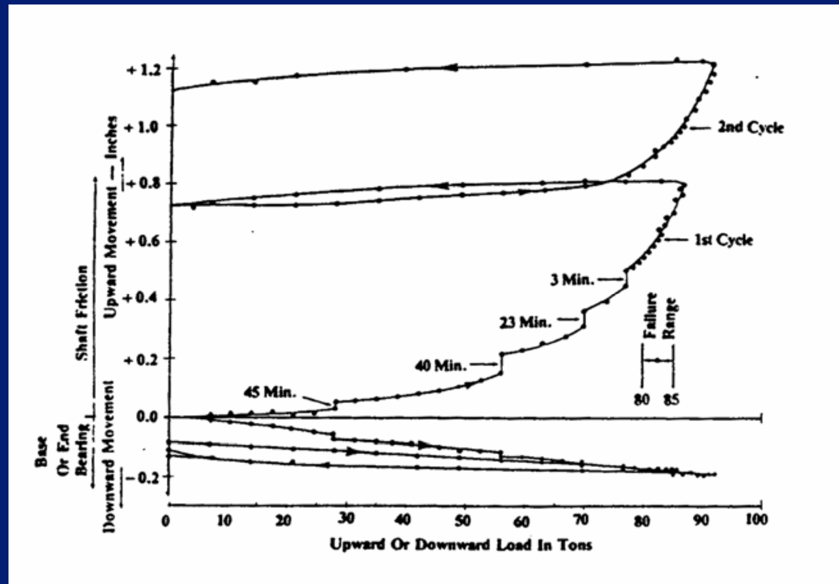
F_c * Meaasured

Settlement

THE OSTERBERG CELL

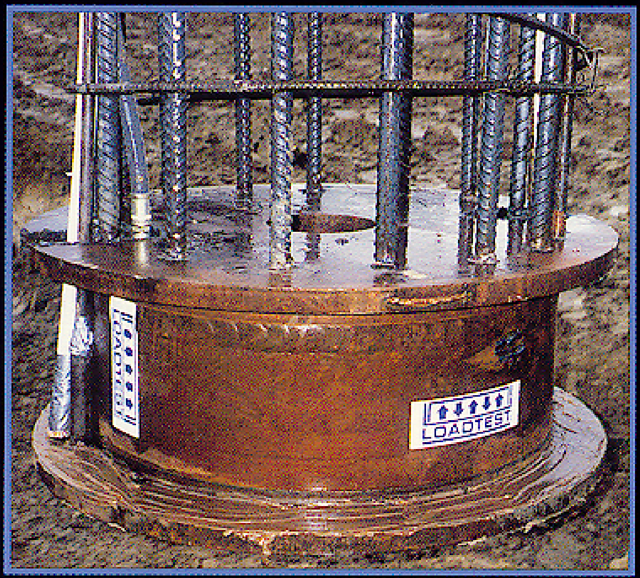


The Principle

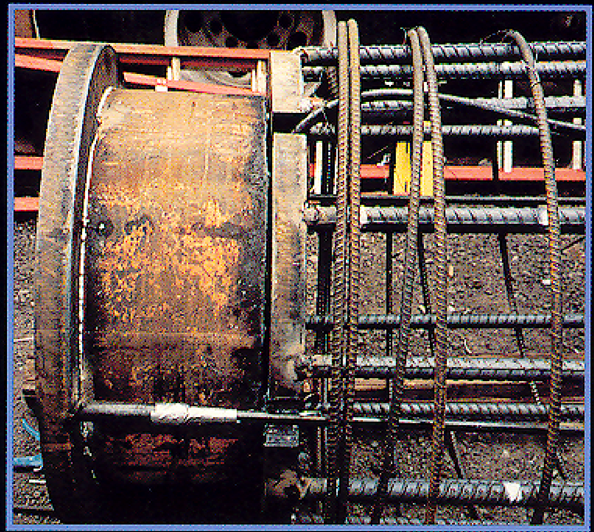


Shaft Load & Base Load vs Settlement Curves

THE OSTERBERG CELL



Close up of Osterberg cell prior to installation.



Osterberg cell, bearing plates and steel casings attached to reinforcing steel cage.

Installation of Osterberg cell into test shaft.

THE OSTERBERG CELL- "SIDE EFFECTS" DUE TO INTERACTION

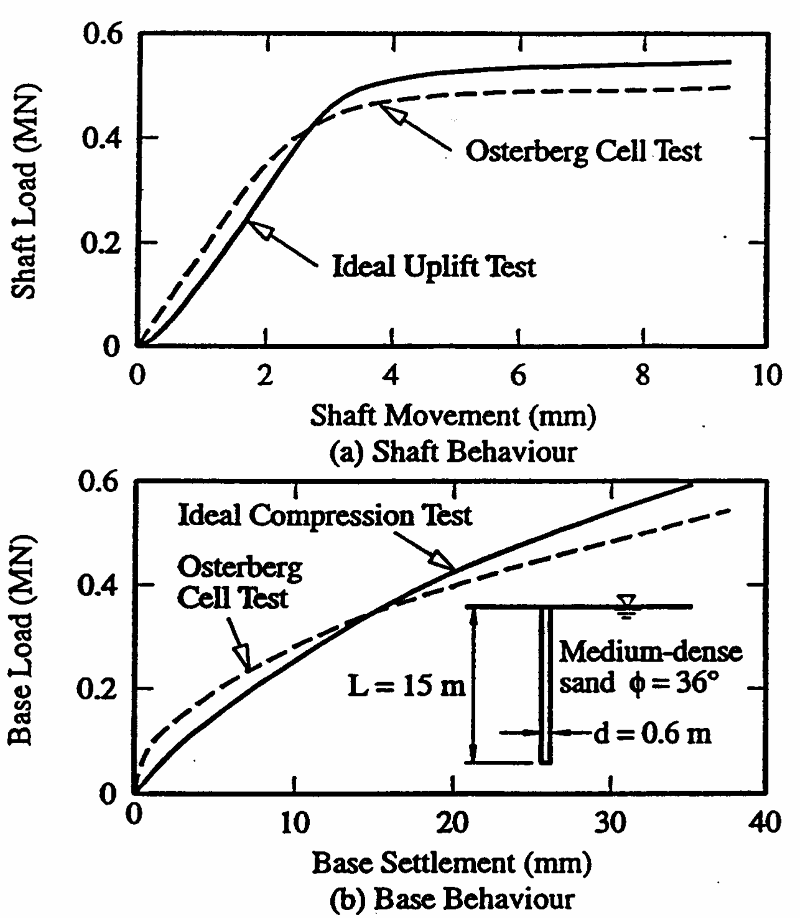
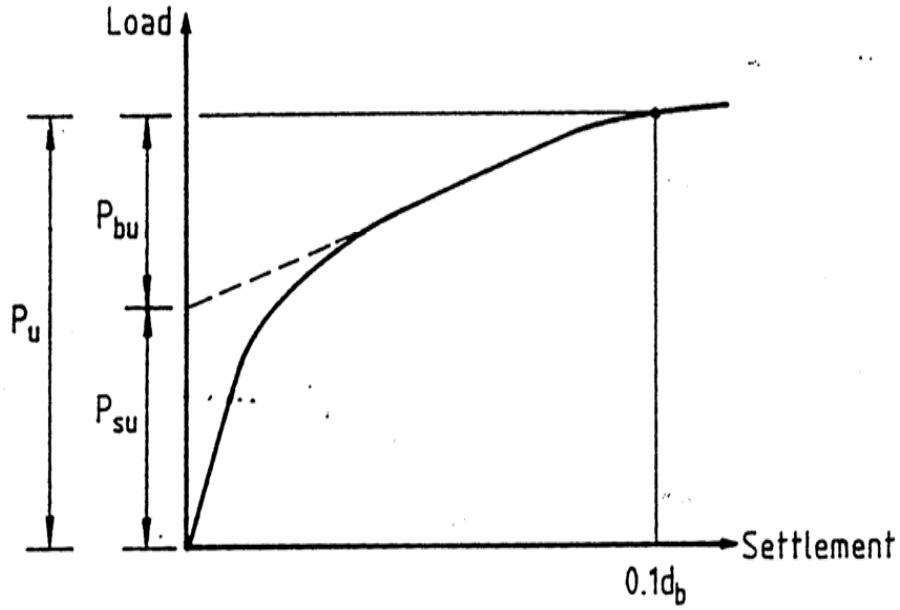


Fig. 9 Theoretical comparison between ideal tests and Osterberg cell test for pile in sand

INTERPRETATION OF UNINSTRUMENTED PILE TEST RESULTS

ULTIMATE LOAD

- Open to much debate.
- Many methods suggested
- Simplest & defensible approach is to adopt load at which head settlement is 10% of pile base diameter (Terzaghi)

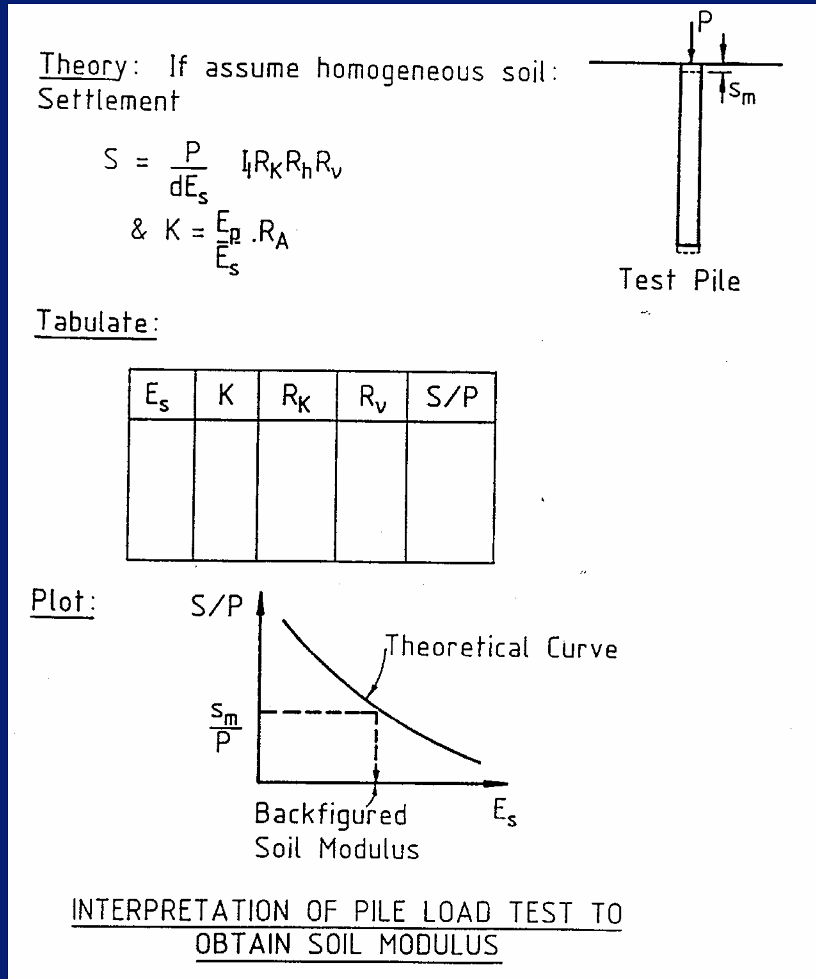


Suggested Interpretation for Ultimate Load

INTERPRETATION OF UNINSTRUMENTED PILE TEST RESULTS

SETTLEMENT

- Use measured settlement at working load with settlement theory to backfigure average soil modulus
- Need to make appropriate assumptions about distributions of soil modulus with depth along shaft and below base.



INSTRUMENTED PILE TESTS

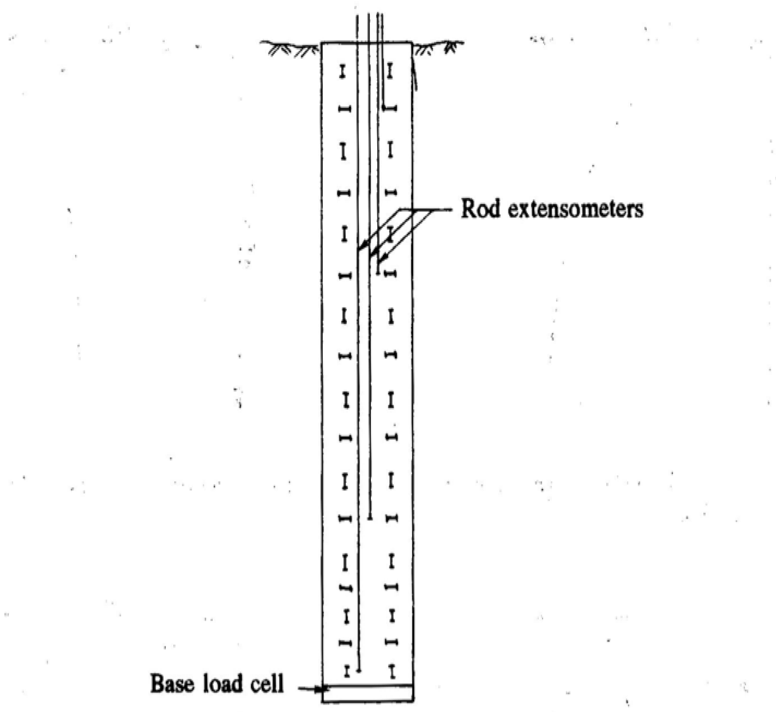
INSTRUMENTATION METHODS

- “tell-tale” strain rods
- Strain gauges –
  - on reinforcement
  - In tube within pile
- Load cells

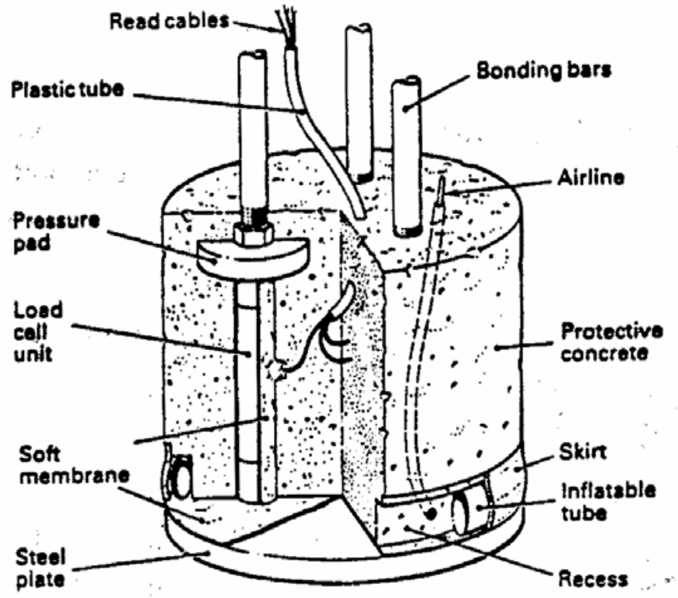
ADVANTAGES

- Enables distribution of skin friction & base load to be evaluated
- Can measure residual loads
- May provide check of structural integrity of pile

TYPICAL INSTRUMENTATION DETAILS



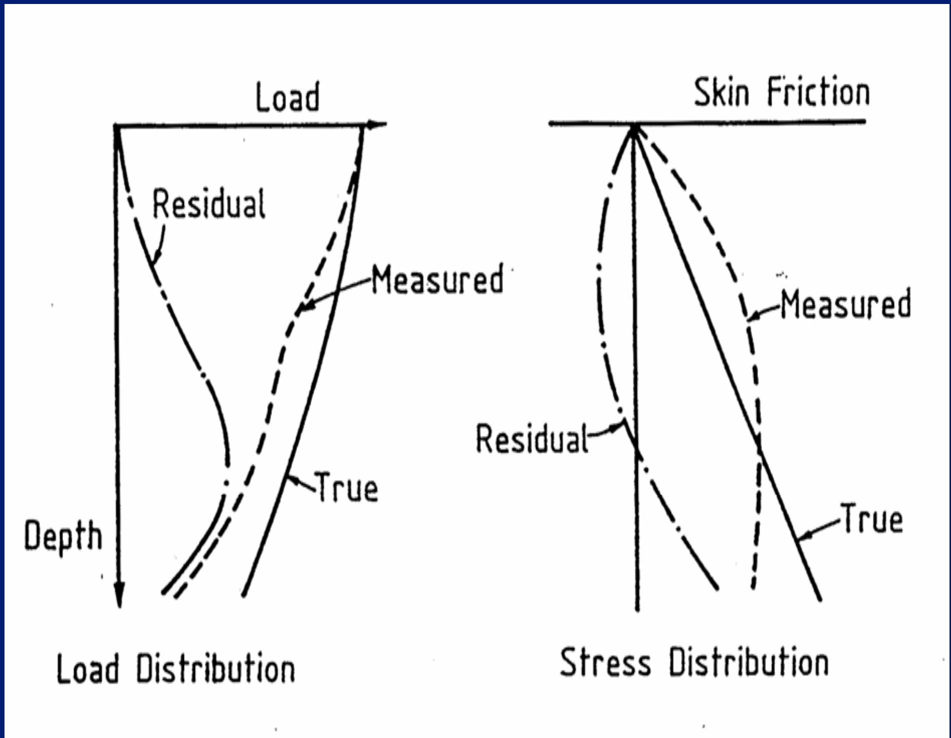
(a) Typical Instrumentation Scheme



Price & Wardle's (1983) type

(b) Details of Typical Base Load Cell

EFFECTS OF RESIDUAL LOADS



- Ignoring residual stresses can lead to mis-interpretation of shaft and base loads
- Can under-estimate base load & over-estimate shaft load
- Pile stiffness (load/settlement) can also be affected by residual settlement – can be appear to be greater than it is.
- SO, need to measure or estimate residual stresses.

DYNAMIC LOAD TESTING

- HIGH – STRAIN TESTS
  - Static load capacity
  - Load-settlement characteristics
  - Load distribution along pile
  - Structural integrity of pile
- LOW-STRAIN TESTS
  - Structural integrity of pile
  - “Small strain” stiffness of pile head (?)

PRINCIPLES OF DYNAMIC LOAD TESTING – HIGH STRAIN

1. Force (F) & velocity (v) caused by stress wave related as:

   F = v.EA/c

2. This holds until reflected wave arrives at pile head
3. Resistance effects cause force to increase relative to velocity
4. Difference between force & velocity vs time plots gives indication of soil resistance & distribution.
5. Can deduce static load capacity & load-settlement curve, using trial & error fitting (CAPWAP)

THE CAPWAP METHOD

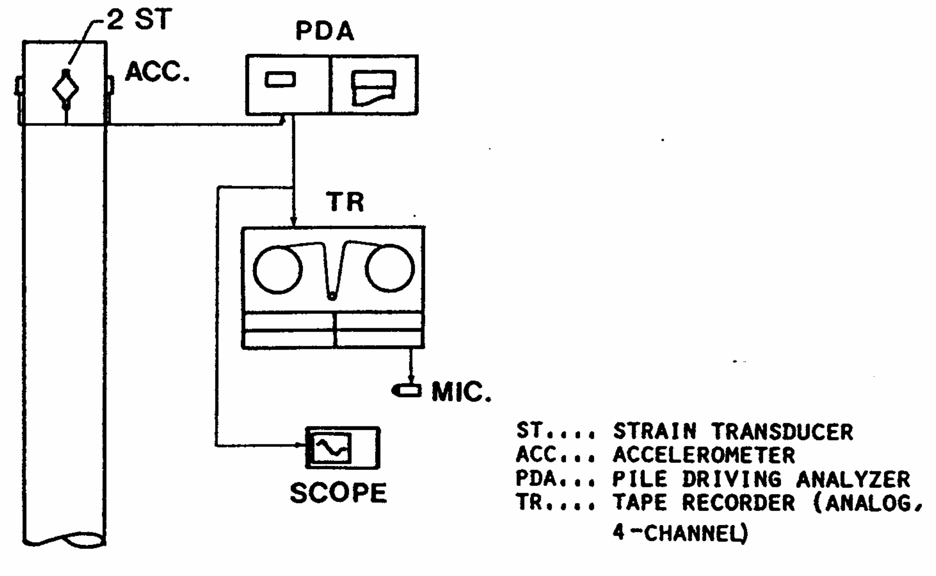
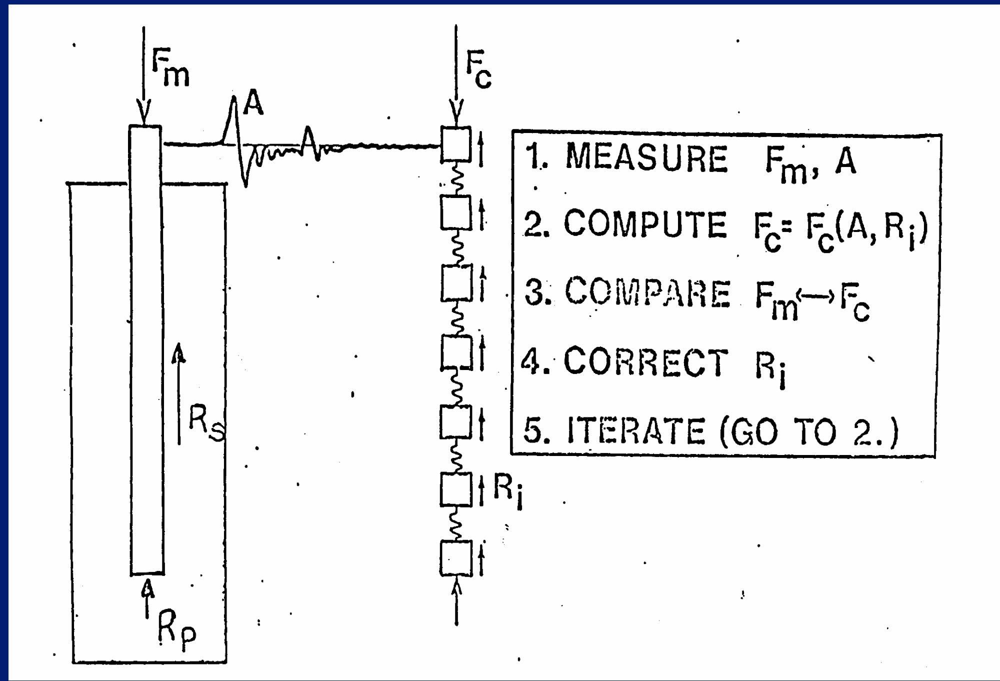


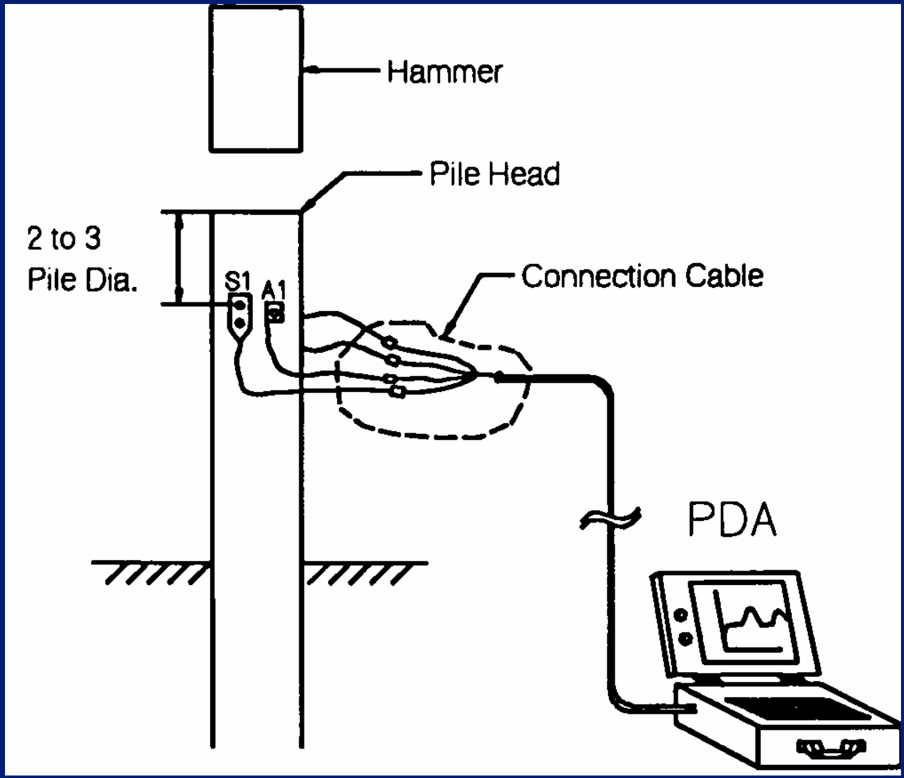
FIGURE 1: SCHEMATIC OF INSTRUMENTATION



The equipment (original)

The fitting process

THE CAPWAP METHOD



The instrumentation setup

The equipment ("black box")

THE CAPWAP METHOD

The equipment (gauges installed on pile)

THE CAPWAP METHOD

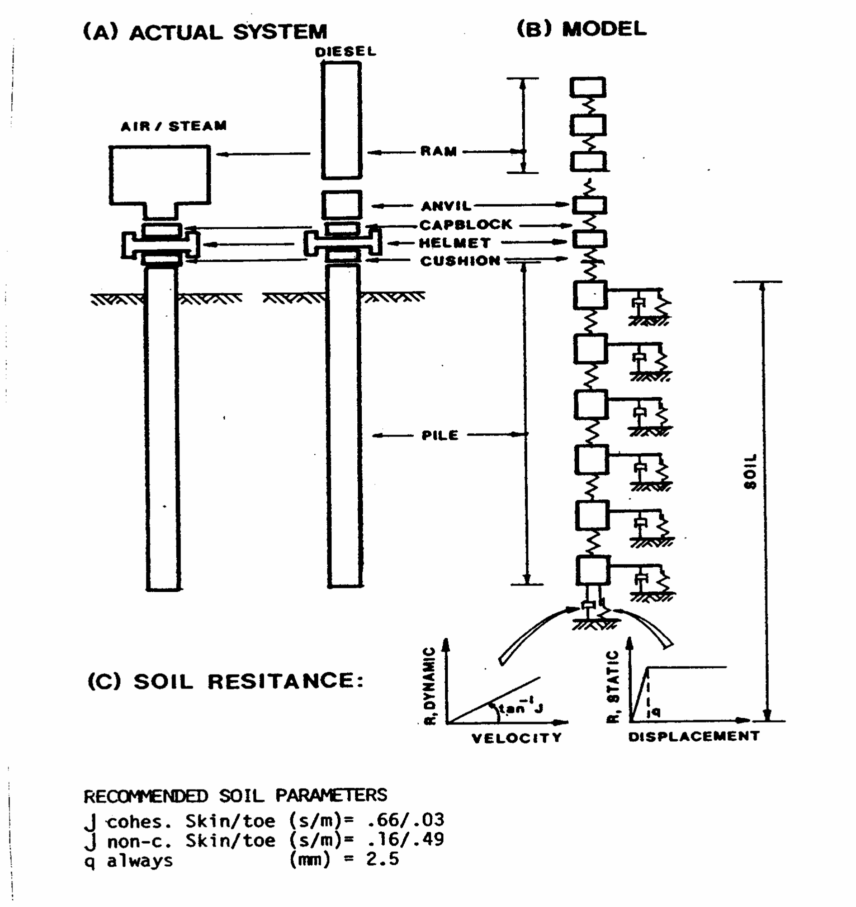
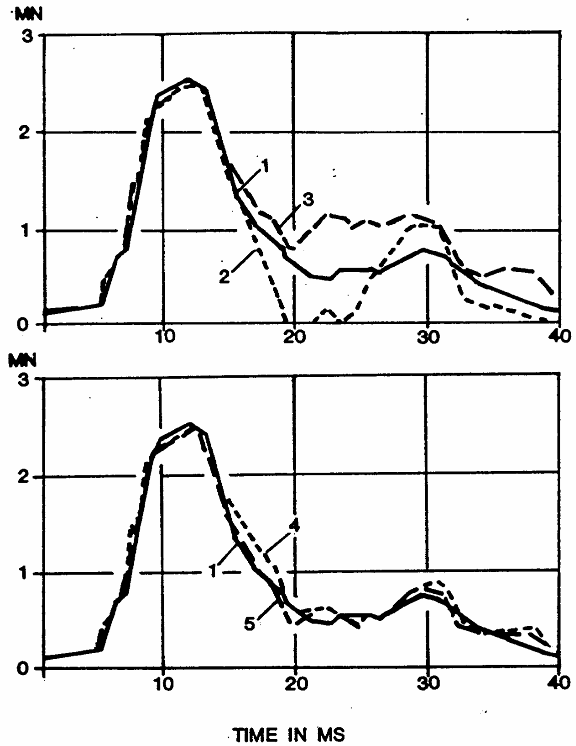


Figure 5: Hammer-Pile-Soil Model of Wave Equation

- Wave equation analysis model used to carry out calculations
- Vary quake, damping, static soil resistances until obtain fit between theoretical and measured behaviour at pile head

THE CAPWAP METHOD

PILE FORCE MATCHES FOR 4 DIFFERENT PARAMETER SETS



1: MEASURED FORCE CURVE
2: LOW DAMPING
3: HIGH STATIC RESISTANCE
4: HIGH SKIN FRICTION, LOW END BEARING
5: FINAL SOLUTION

FIGURE 4: PILE TOP FORCE MATCHES FOR FOUR DIFFERENT SETS OF SOIL RESISTANCE PARAMETERS. FOR FURTHER DETAILS SEE TABLE 2.

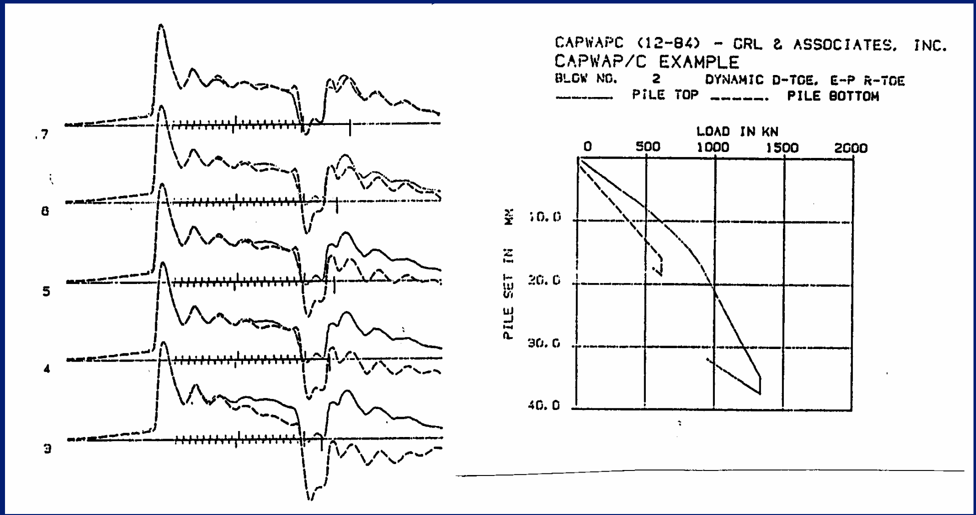
Table 2: CAPWAP Trial Run Parameters

Run Identif.	Ultimate Capacity Skin MN	Toe MN	Total MN	Case Damping Skin	Toe	Quake Skin mm	Toe mm
Low Damping	1.36	.42	1.78	.35	.10	3.6	4.1
High Static	1.72	.53	2.25	.55	.20	3.6	4.1
High Skin	1.65	.13	1.78	.55	.20	3.6	4.1
Final	1.36	.42	1.78	.55	.20	3.6	4.1

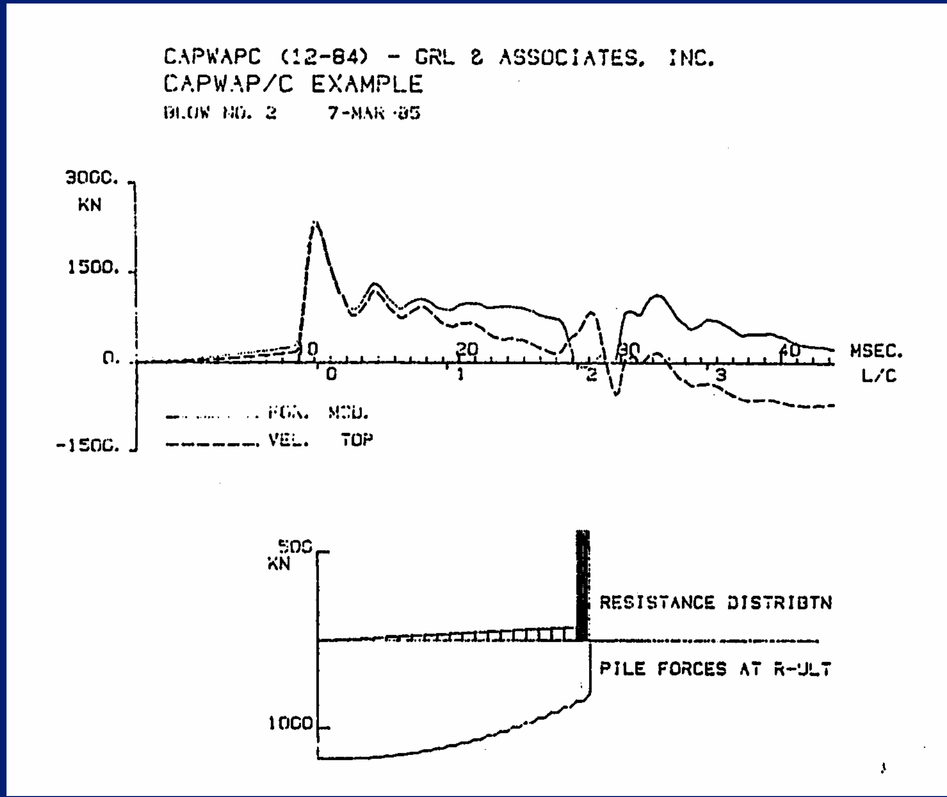
Details of analysis parameters

THE CAPWAP METHOD

TYPICAL RESULTS



Successive matches.
Deduced static load-settlement
Curves for top & base of pile.



Force & velocity traces.
Deduced pile force distribution.

Coffey Geosciences

THE CAPWAP METHOD

CONSISTENCY OF INTERPRETATION (Goble, 1994)

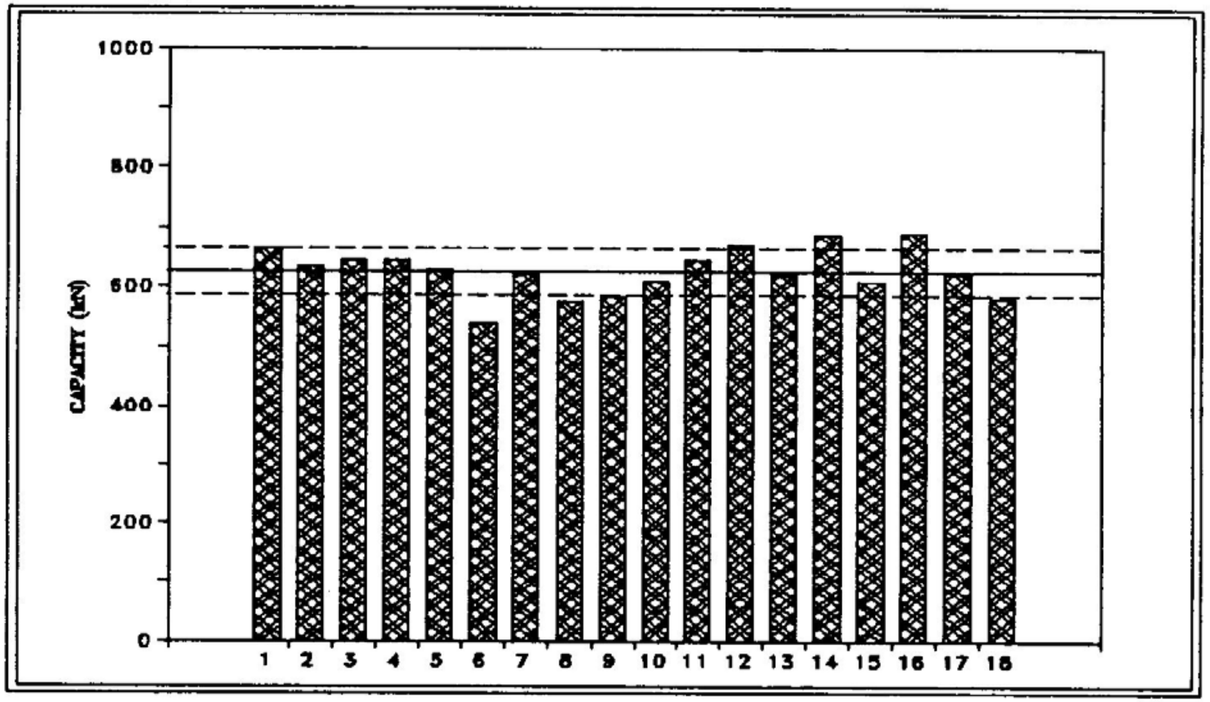
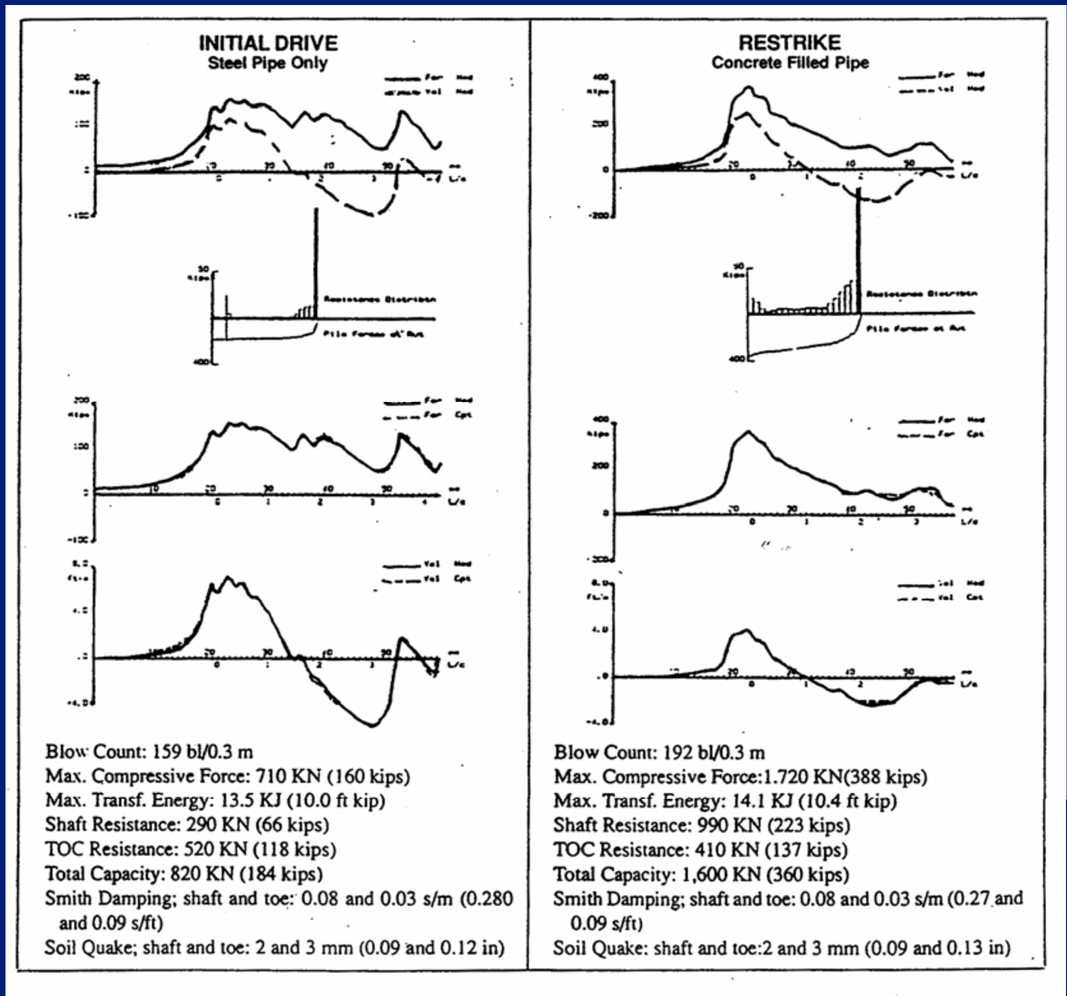


Figure 6: CAPWAP Result Obtained by 18 Operators from a Particular Measurement

INITIAL DRIVE vs RESTRIKE BEHAVIOUR



Larger shaft & total resistances after re-strike.

Restrike results generally closer to static load test results

INITIAL DRIVE vs RESTRIKE BEHAVIOUR

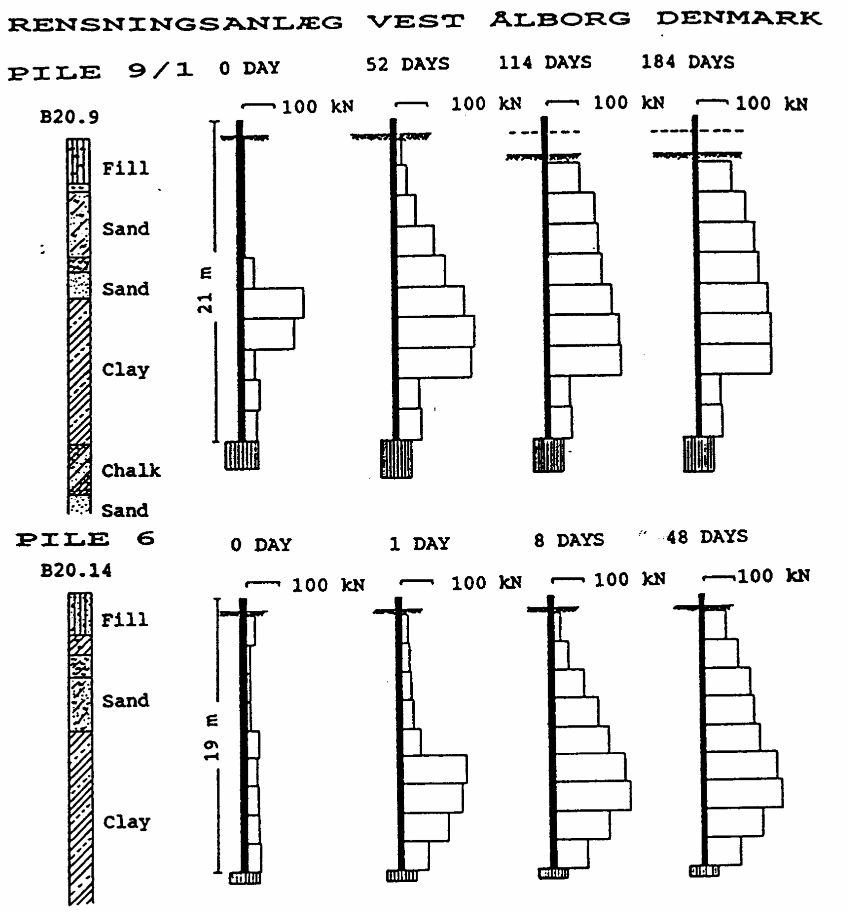


Figure 1: Distribution of shaft and toe resistance from CAPWAP analysis at driving and restriking.

Larger shaft & total resistances after re-strike.

COMPARISONS BETWEEN STATIC & DYNAMIC TESTS

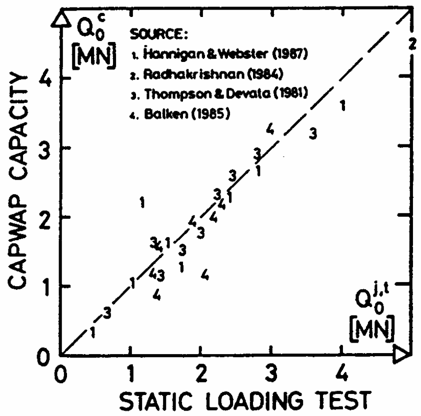


Figure 8: Bearing capacities calculated by CAPWAP analyses against static loading tests (e.g. 3 denotes one point from source 3).

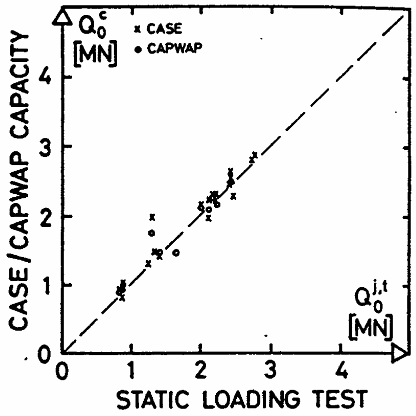


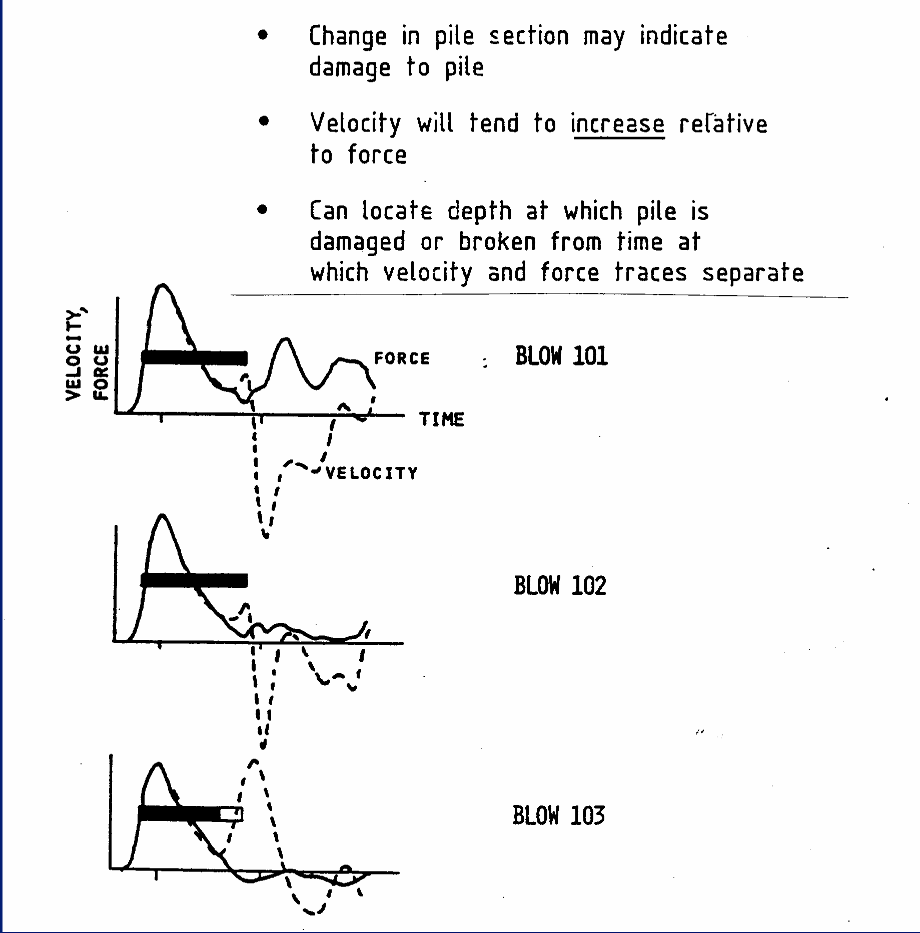
Figure 9: Bearing capacities from Case formula or CAPWAP analysis against static loading tests (from Skov, 1988).

Table 3: Standard deviation for stress-wave method.

Method	Standard deviation s_1 (ln μ)	Standard deviation s (ln μ)	Number of piles	Source
Case	0.12	(0.14)	97	Goble et al. (1981)
		0.11	19	Skov (1988)
		0.14	14	Present Investigation
Capwap	0.13	(0.16)	17	Goble et al. (1981)
		0.22	26	Different sources (see Fig. 8)
		0.10	10	Skov (1988)
		0.13	14	Present Investigation

In many cases, dynamic test results are within 15-20% of static values.

INDICATIONS OF PILE DAMAGE / FRACTURE



- Analyzer wave traces for 3 successive blows
- Pile is broken during Blow 103
- Velocity increases relative to force at location of break, and the traces separate

STATNAMIC TESTING

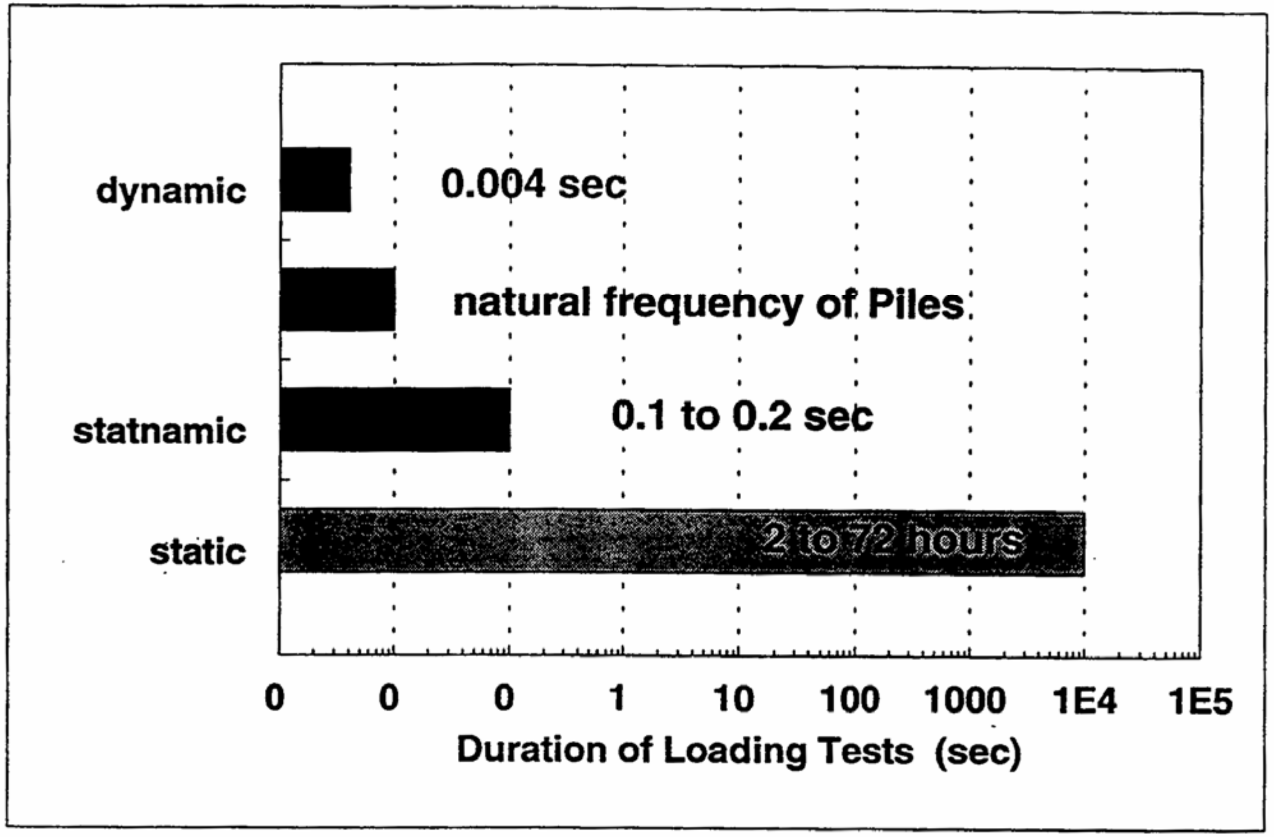
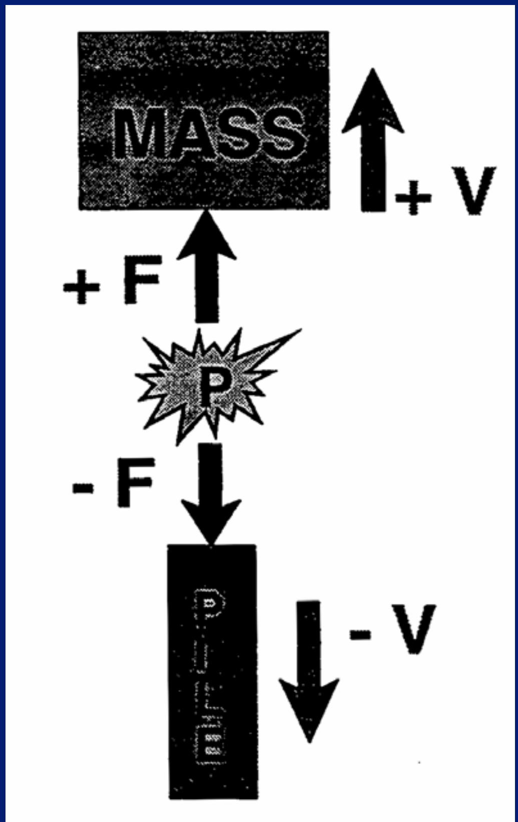
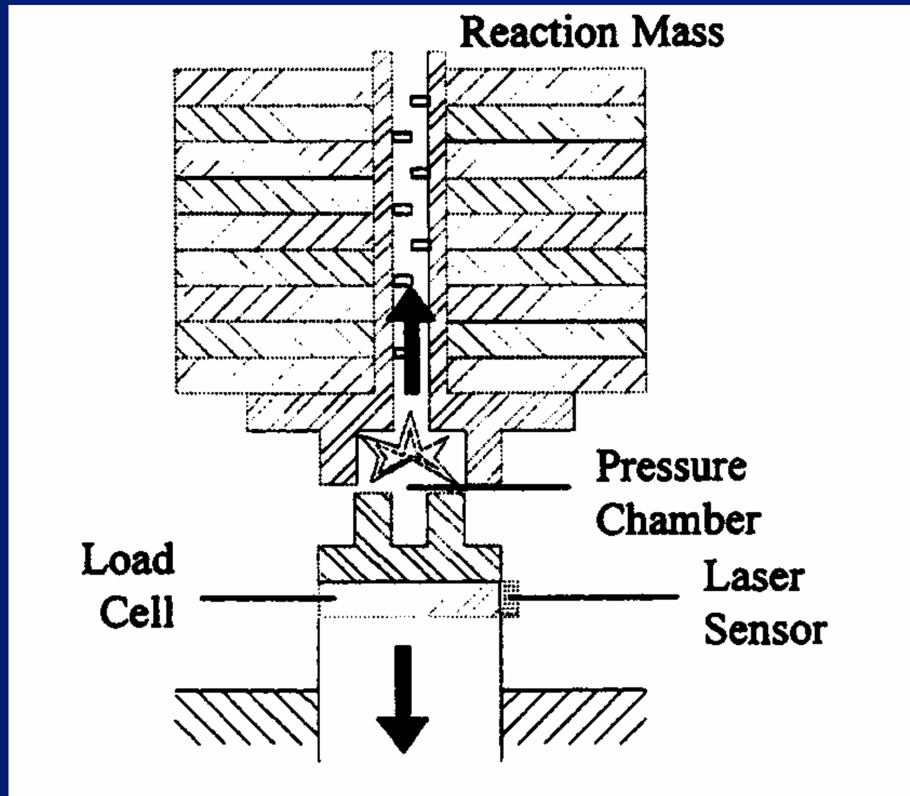


Figure 1. Duration of Loading Tests

STATNAMIC TESTING

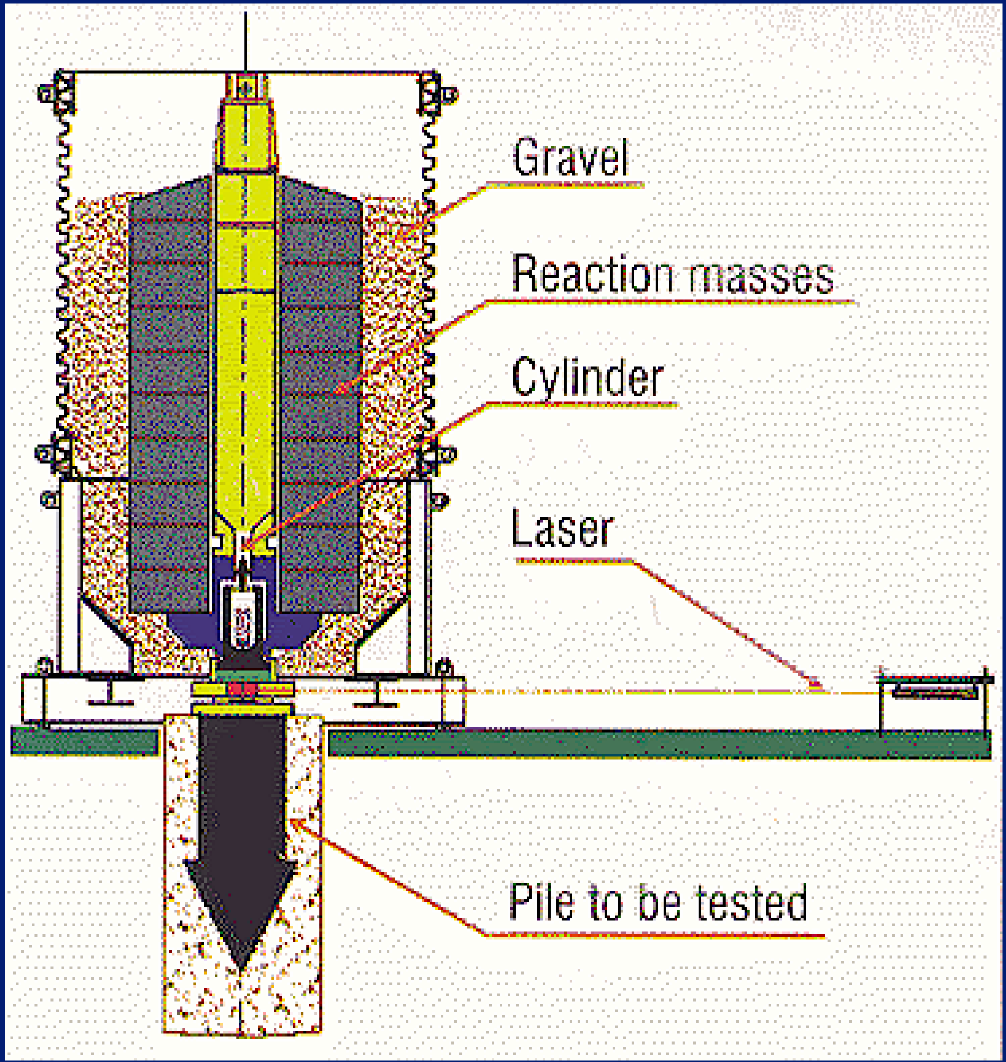


Statnamic loading event

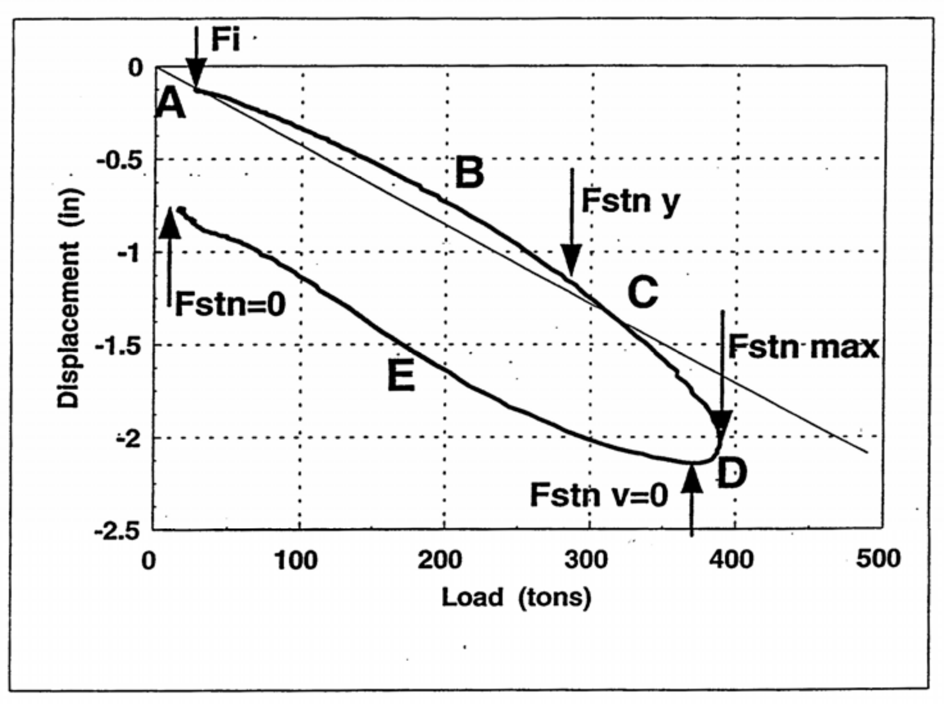


Statnamic loading principle

STATNAMIC TESTING
TEST SETUP

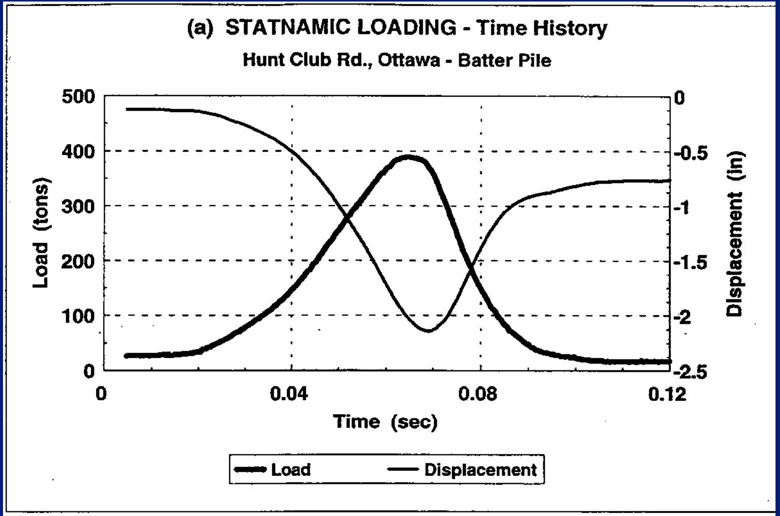


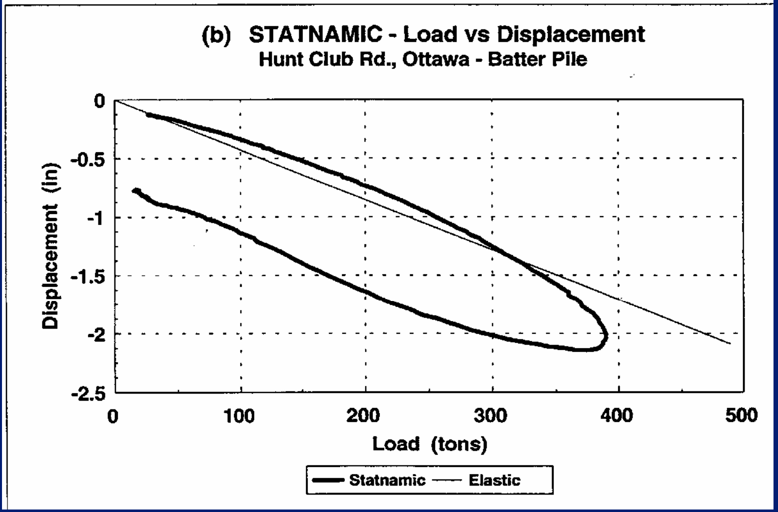
AREAS OF STATNAMIC LOAD-DISPLACEMENT CURVE

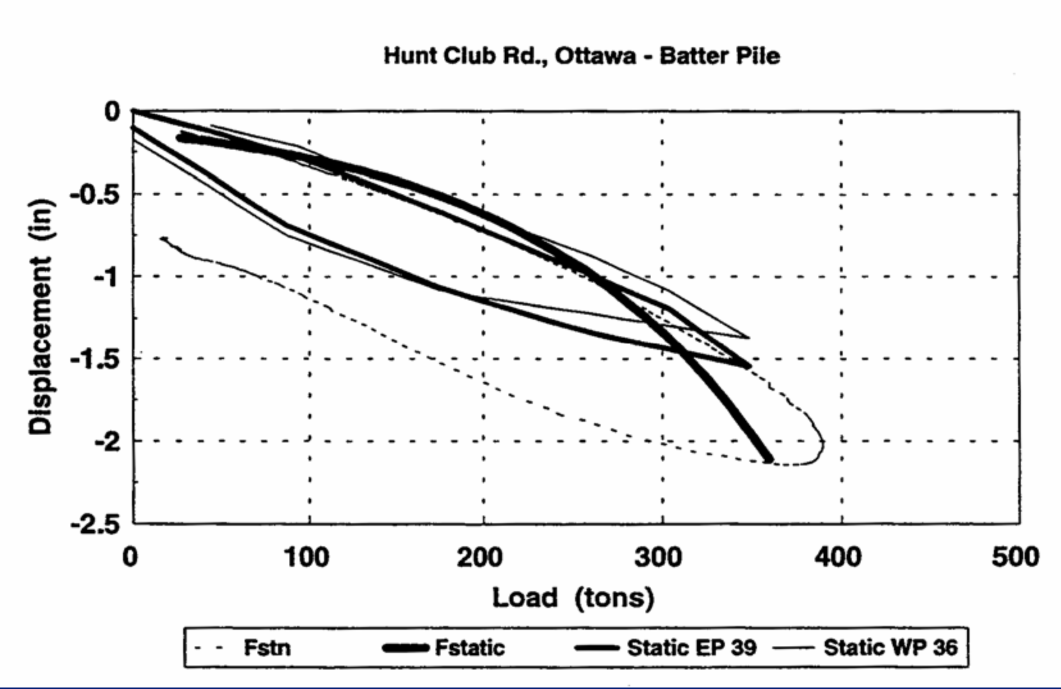


- **OA** – reaction mass placed
- **AB** – Elastic behaviour
- **BC** – Non-linear behaviour, ultimate strength of soil reached
- **CD** – Velocity increases rapidly when load reaches & exceeds Fstny. Max. load reached at Fstnmax
- **DE** – Load decreases, but pile continues to move down (inertia).
- When pile velocity=0, applied Statnamic load = static load.
- Pile rebounds beyond that point.

STATNAMIC LOAD TEST RESULTS



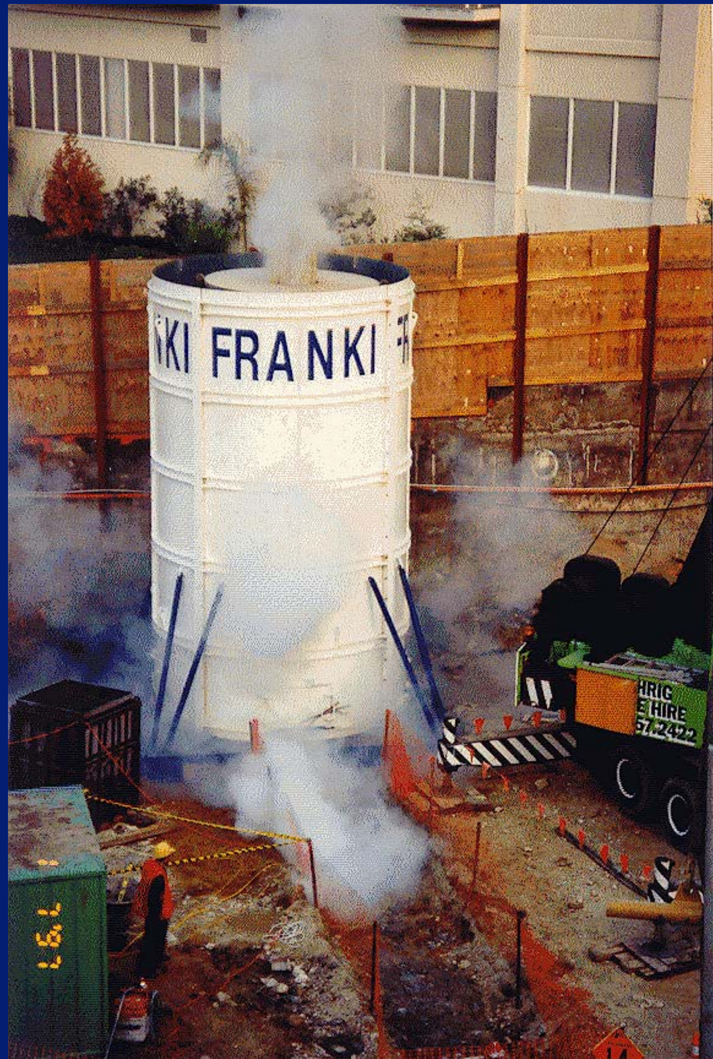




Good agreement between Statnamic & Static loading test load-settlement curves.

STATNAMIC TEST IN MELBOURNE

COFFEY



COMPARISONS BETWEEN STATNAMIC & OSTERBERG TESTS

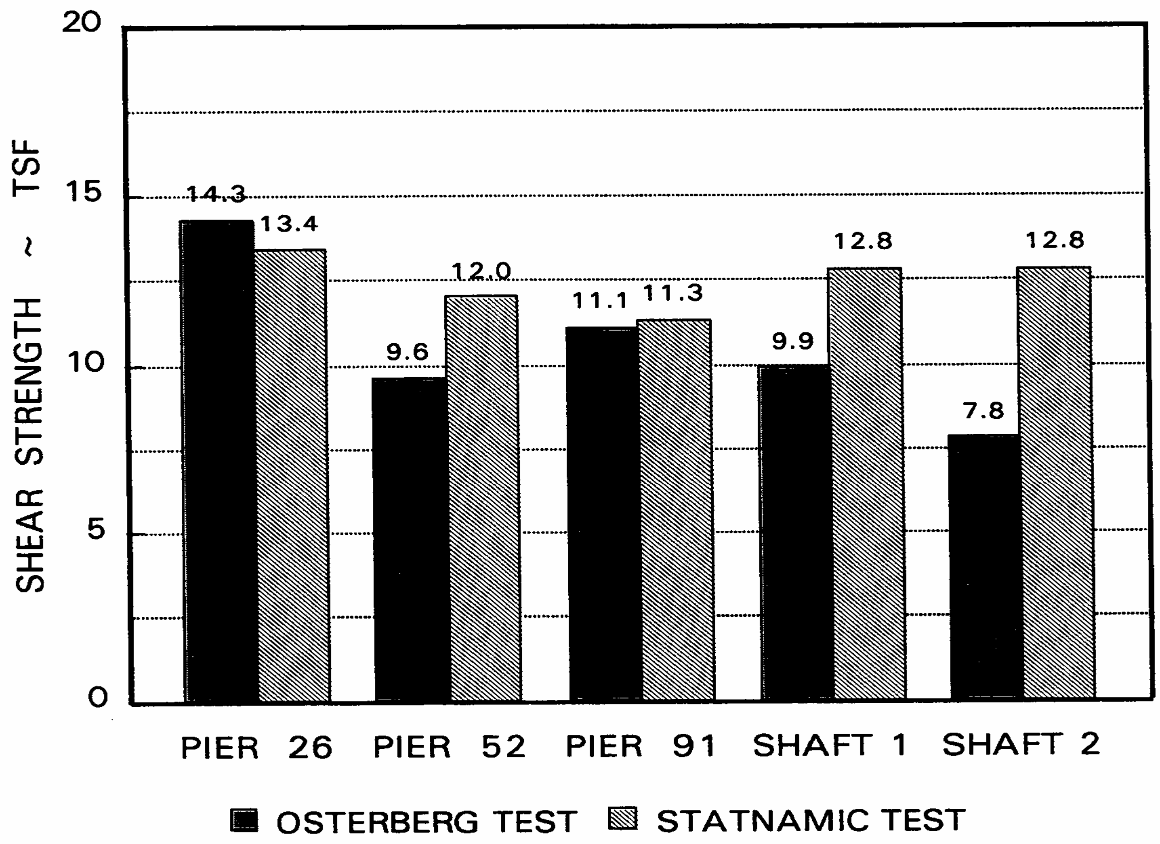


Figure 18. Summary of Osterberg and Statnamic Shear Strength Comparisons for Gandy and Victory Bridge Sites.

Bored piles in Florida limestone

NON-DESTRUCTIVE TESTING OF BORED PILES

- Drilling cores
- Shaft compression test
- Radiometric logging
- Sonic logging
- Vibration testing
- Sonic integrity testing.

These are mainly **STRUCTURAL INTEGRITY** tests, and need to be pre-planned (except for sonic integrity & vibration testing).

CROSS-HOLE SONIC LOGGING

CROSS-HOLE SONIC LOGGING

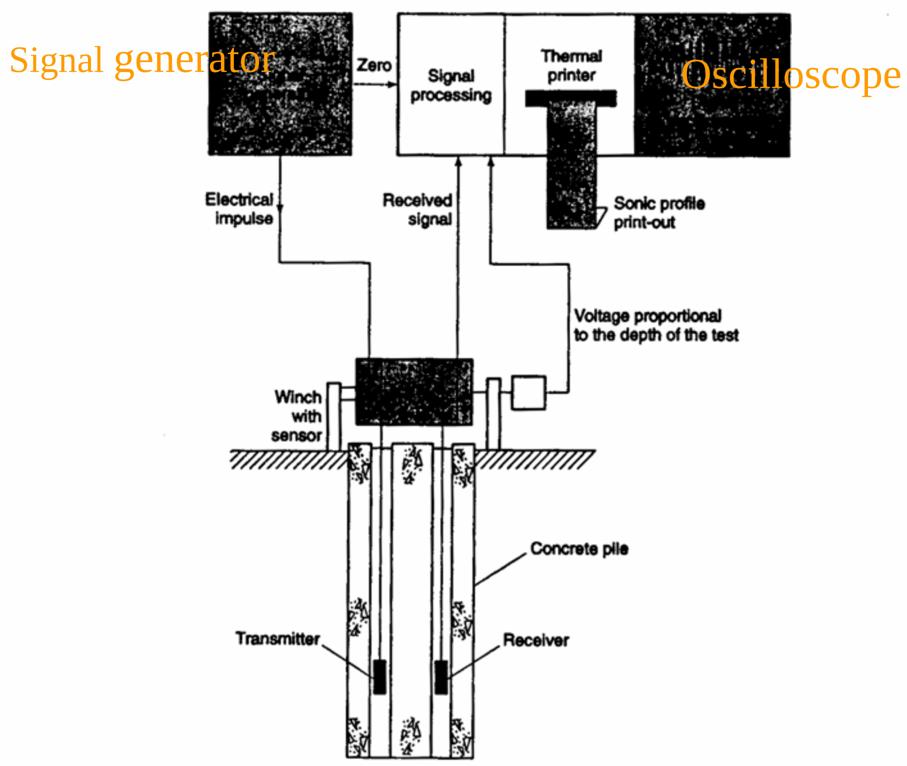


Figure 6.2 Elements of a cross-hole sonic logging system (after Stain and Williams, 1991)

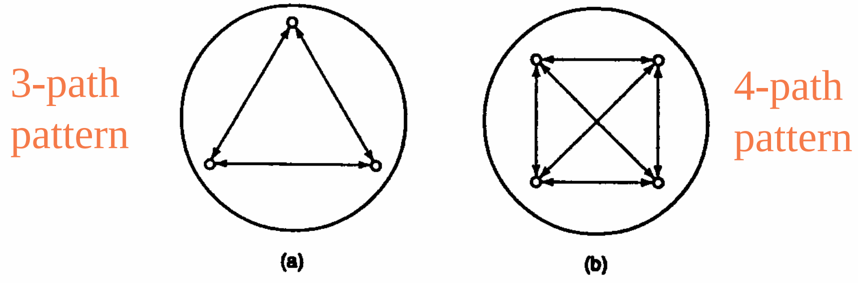


Figure 6.3 Typical tube layouts for sonic logging (a) with 3 tubes (3 paths); (b) with 4 tubes (6 paths)

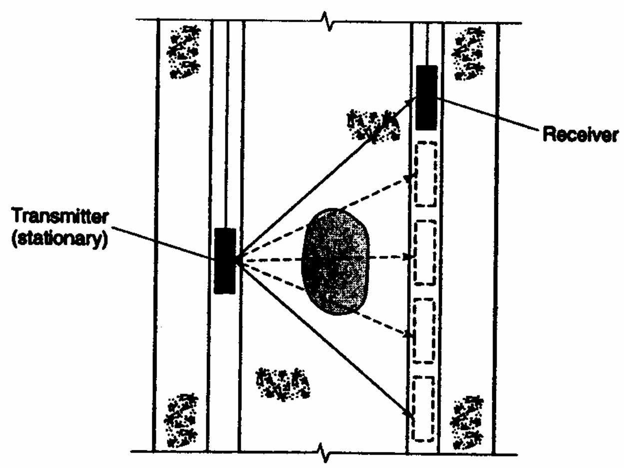
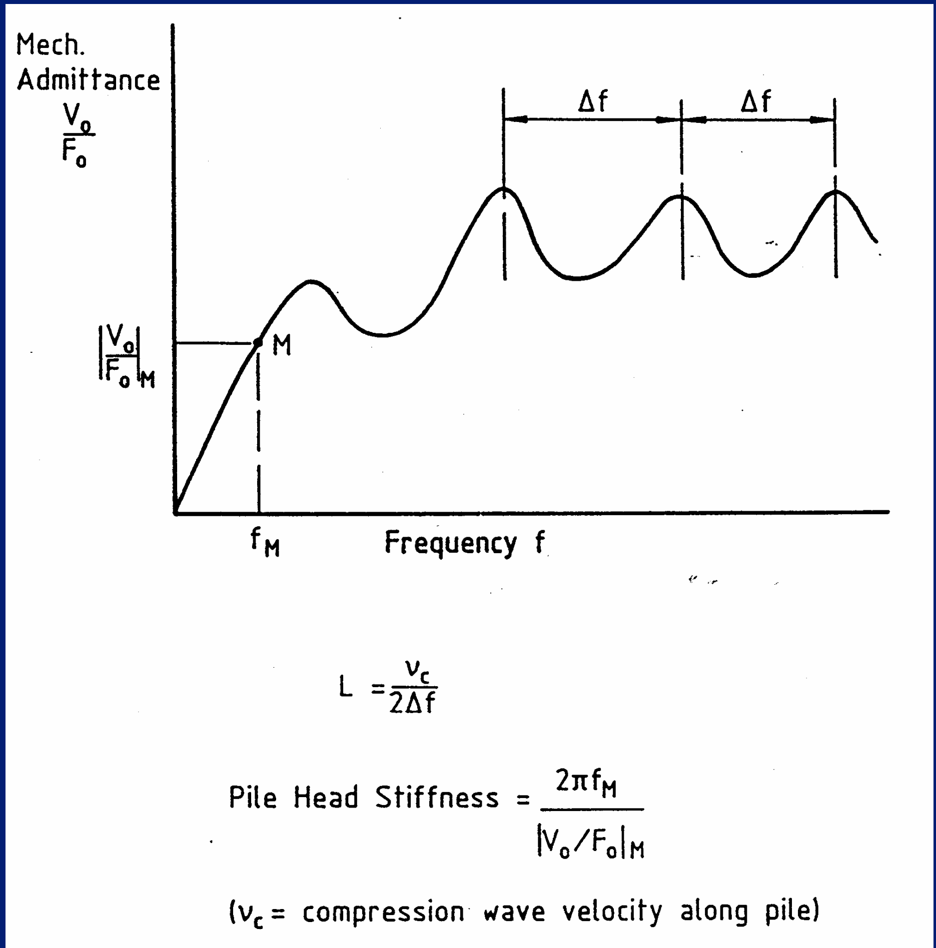


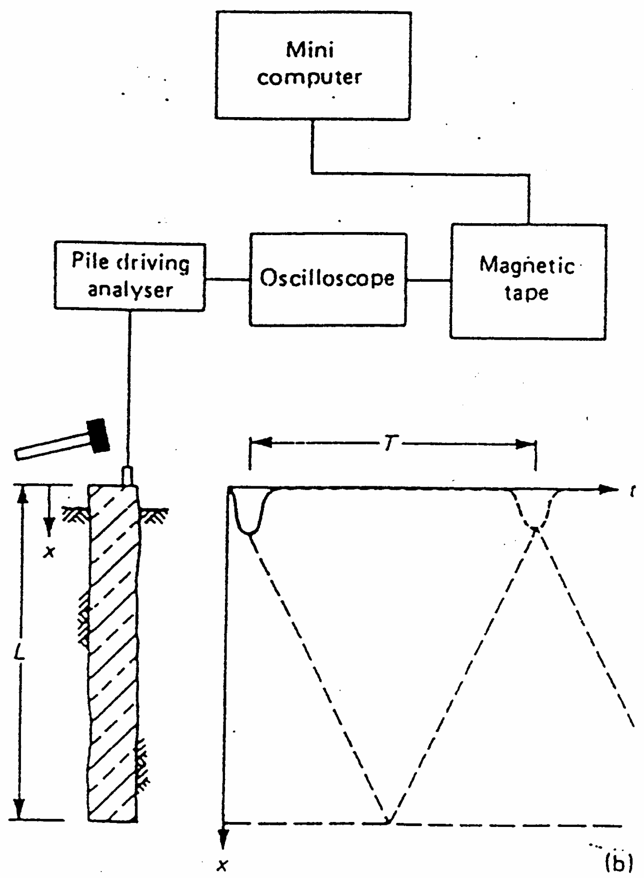
Figure 6.6 Use of fan-shaped test lines for investigating extent/shape of feature

PRINCIPLE OF VIBRATION TESTING



- Can detect possible defects via inferred L value (if inferred L< actual L)
- Can estimate small-strain pile head stiffness

SONIC INTEGRITY TESTING



Low strain integrity testing
(a) Test set-up;
(b) Wave propagation

- Based on analysis of reflections from changes of impedance along pile
- Pile Impedance is:

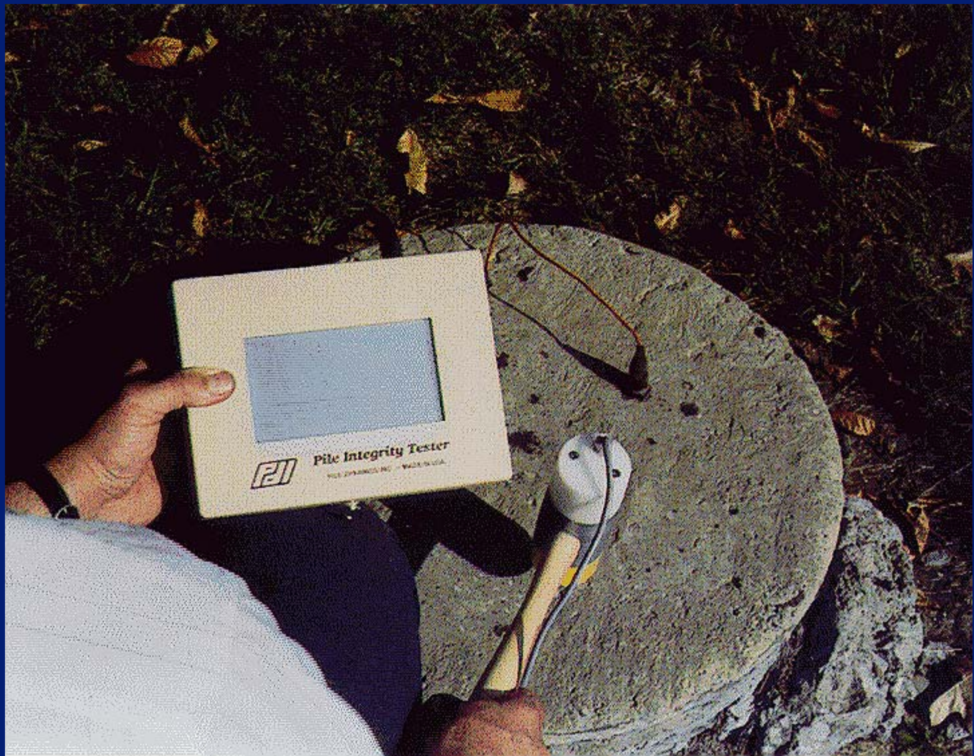
$Z = A(E\rho)^{0.5}$

where A = X-sect. Area

E = Young's modulus of pile

ρ = pile material density

SONIC INTEGRITY TESTING



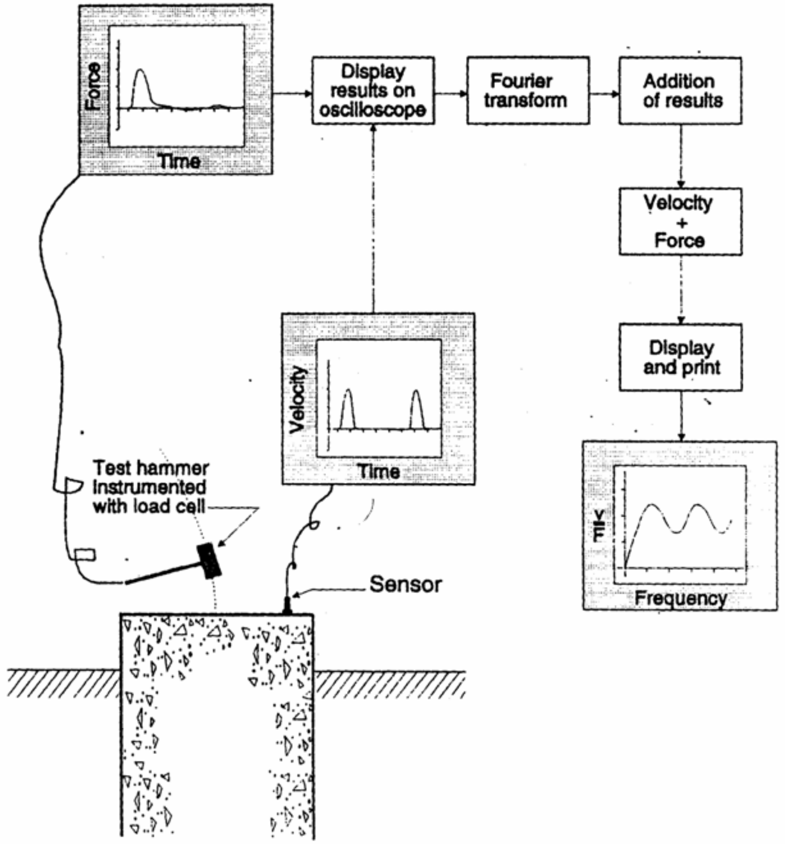
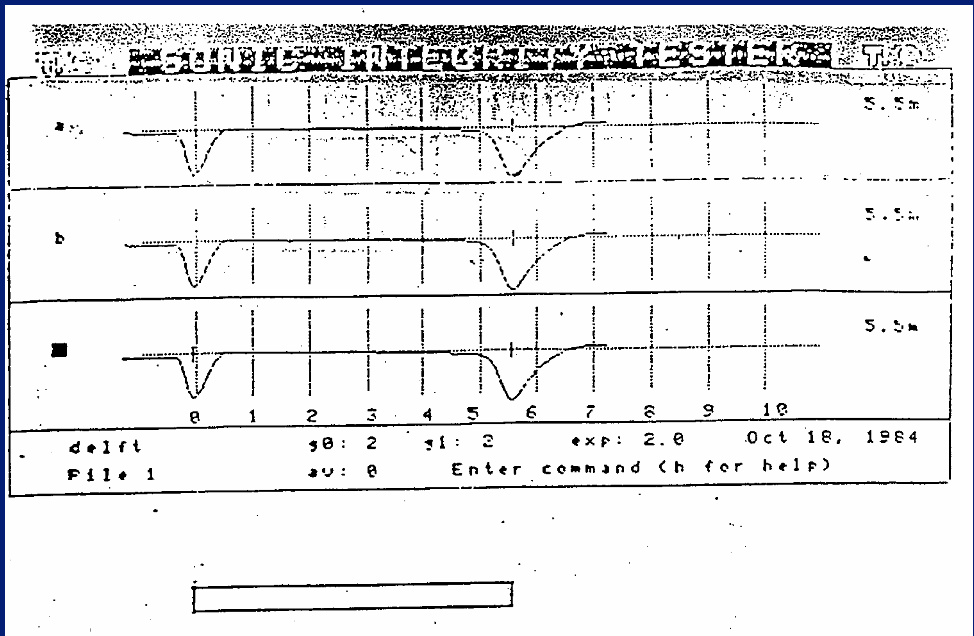


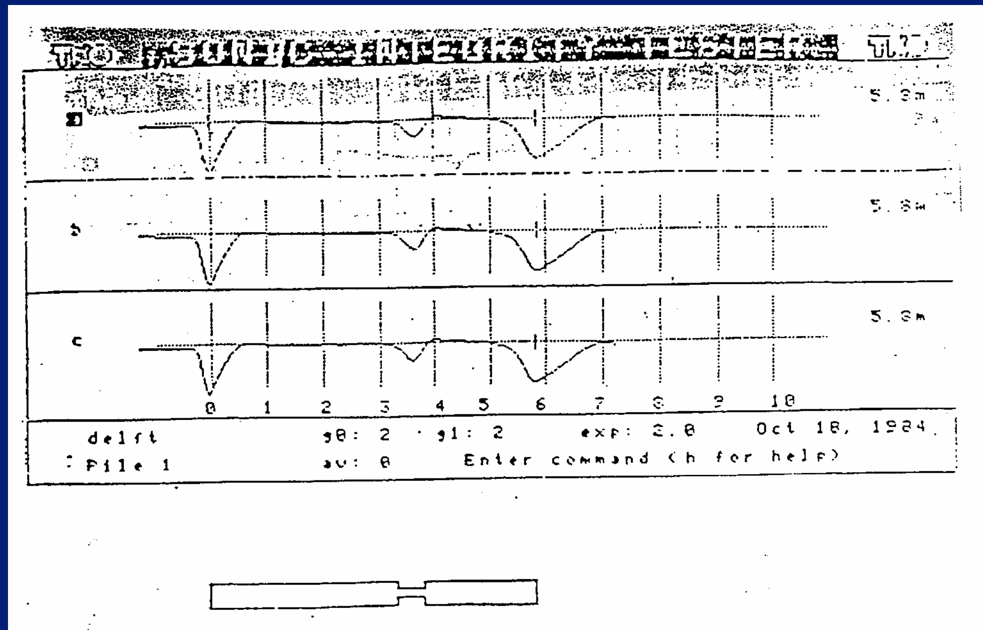
Figure 5.16 *Elements of a typical transient frequency-response test (after Stain, 1982)*

SONIC INTEGRITY TESTING
CAUSES OF REFLECTIONS

- Pile toe
- Inclusions
- Cracks
- Pile joints
- Dimensional changes
- Variations in concrete quality
- Variations in soil stiffness
- Changes in skin friction
- Reinforcement overlapping (heavy reinforcement)

SONIC INTEGRITY TESTING
SOUND & DEFECTIVE PILES





Sound pile –
no premature reflections

Defective pile – reflection
above pile toe

LOW STRAIN SONIC INTEGRITY TESTING

ADVANTAGES

- Quick inspection method for major defects. Can test 50-200 piles /day
- No preparation needed, except trimming back
- Early discovery of defects; need only 5 days curing for bored piles
- Considerable experience accumulated.

LIMITATIONS

- No quantitative information on load capacity
- No information on minor defects (local loss of cover, small inclusions or gaps)
- No indication of debris at base
- No length indication when pile is very long or damping too high
- Over-emphasis of cracks when small cracks cover whole cross-section