LECTURE SERIES AND WORKSHOPS ON GEOTECHNICAL ENGINEERING IN PRACTICE

Centre for Infrastructure Engineering and Management and Griffith School of Engineering
Griffith University Gold Coast campus

PDA Testing Overview

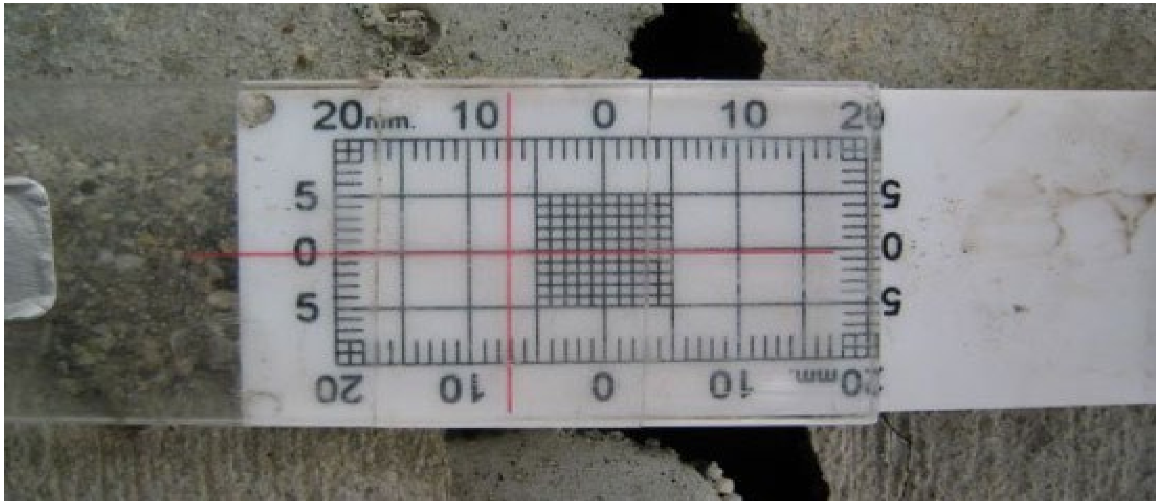
Presenter: Dr Julian Seidel

Foundation System

- collection of individual elements
- performance as a whole
- redundancy

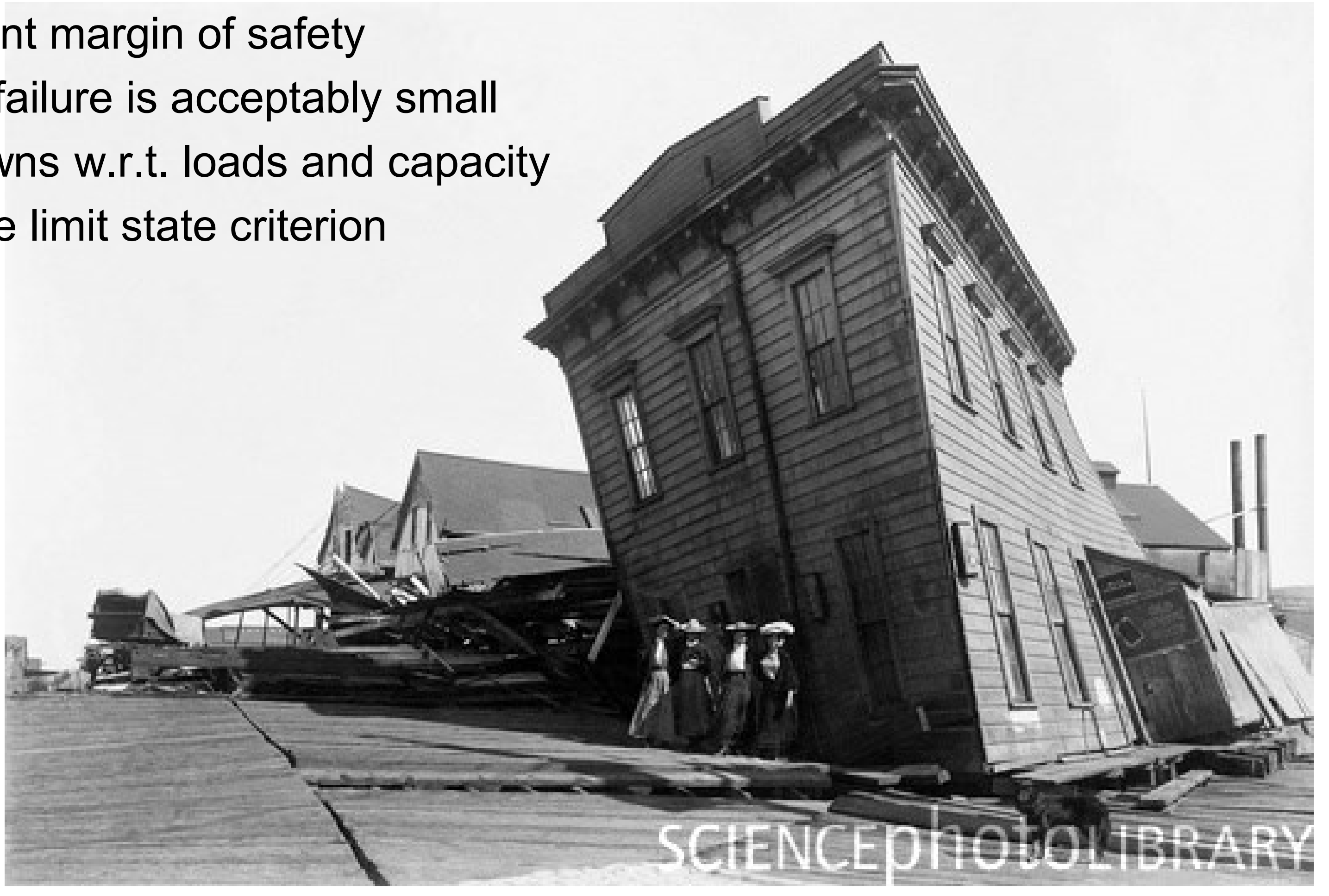
Adequacy

- "fit for purpose"
- does not interfere with the function of the structure
- serviceability criterion



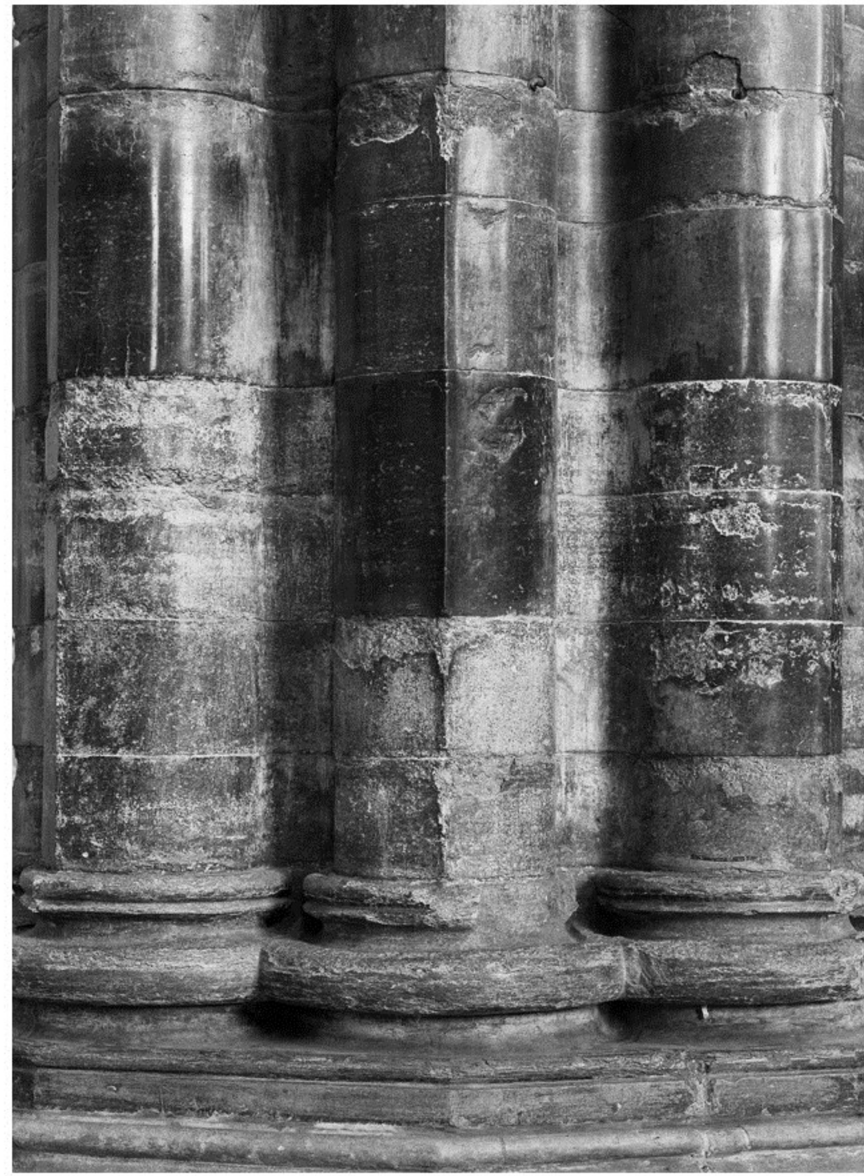
Safety

- sufficient margin of safety
- risk of failure is acceptably small
- unknowns w.r.t. loads and capacity
- ultimate limit state criterion



Efficiency

- only be as large or as deep or as expensive as it needs to be
- lowest cost solution that still meets Adequacy and Safety
- skill of Engineer to find balance



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Geotechnical Design

Foundation design is an inherently complex hence flawed and risky procedure. It is much more uncertain than structural design.

Site investigation : MUCH TOO limited! (<0.002%)

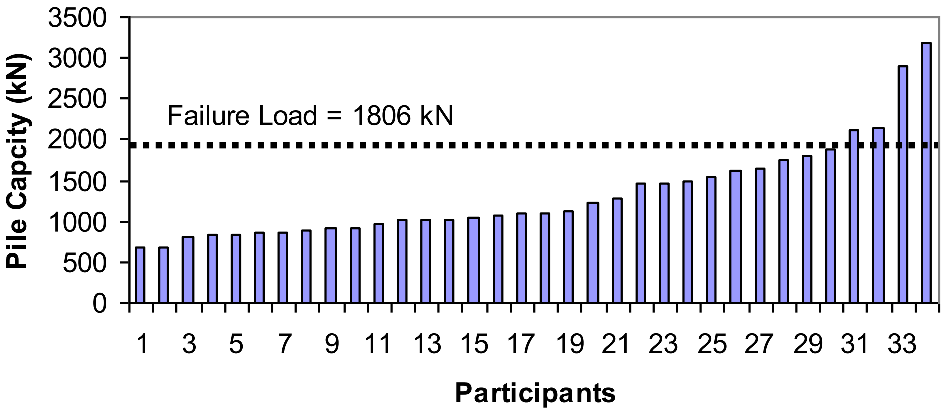
Effects of construction technique

Site variability

Design parameters : representative?

Design method : applicable?

Foundation Design



Geotechnical Verification

Design should continue to be refined through the installation process to reduce risk. Very strong need for testing cf structures.

Need to test complete system in-situ

Site testing : (should be) extensive (statistical)

Design parameters : as installed

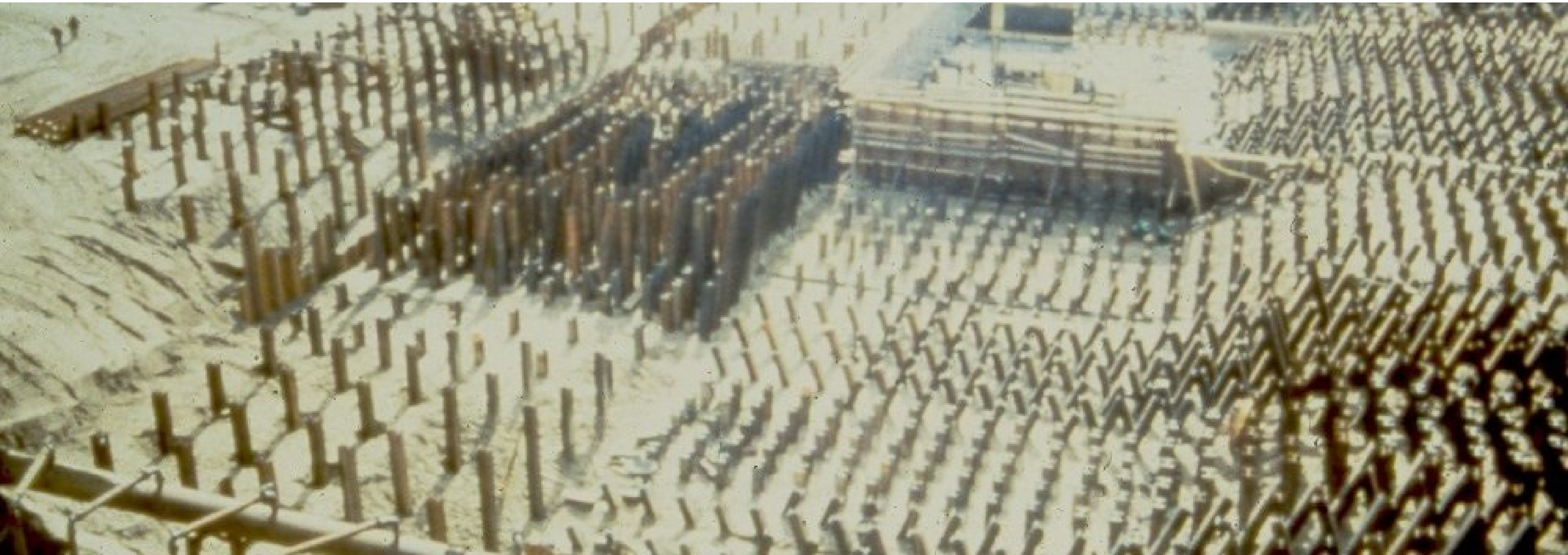
Design method : direct

Foundation Design

Feedback to next design

How can we assess the safety and adequacy of the foundation system?

- Quality construction
- Testing of Representative Piles
- Methods for Extrapolating Representative to Represented Piles



Quality construction

- Experienced contractor with qualified engineers and supervisors
- Effective and meaningful quality systems
- Rational and appropriate criteria for pile acceptance

Testing of Representative Piles

- Appropriate Test Methods
- Sufficient Tests
- Reliable Test Evaluation

Methods for Extrapolating Representative to Represented Piles

- Linkage to construction parameters
- Rational and defensible methods for inferring capacity of untested piles

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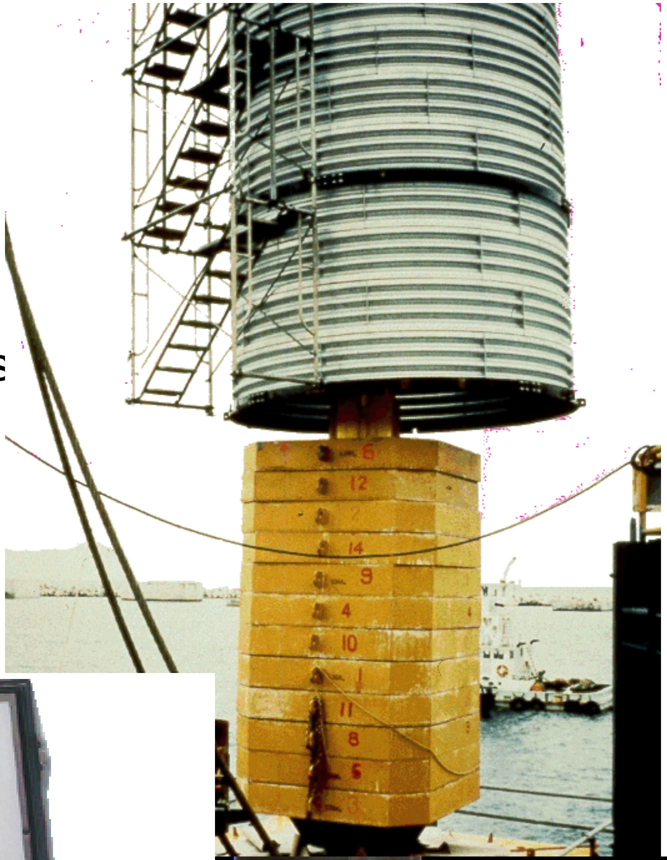
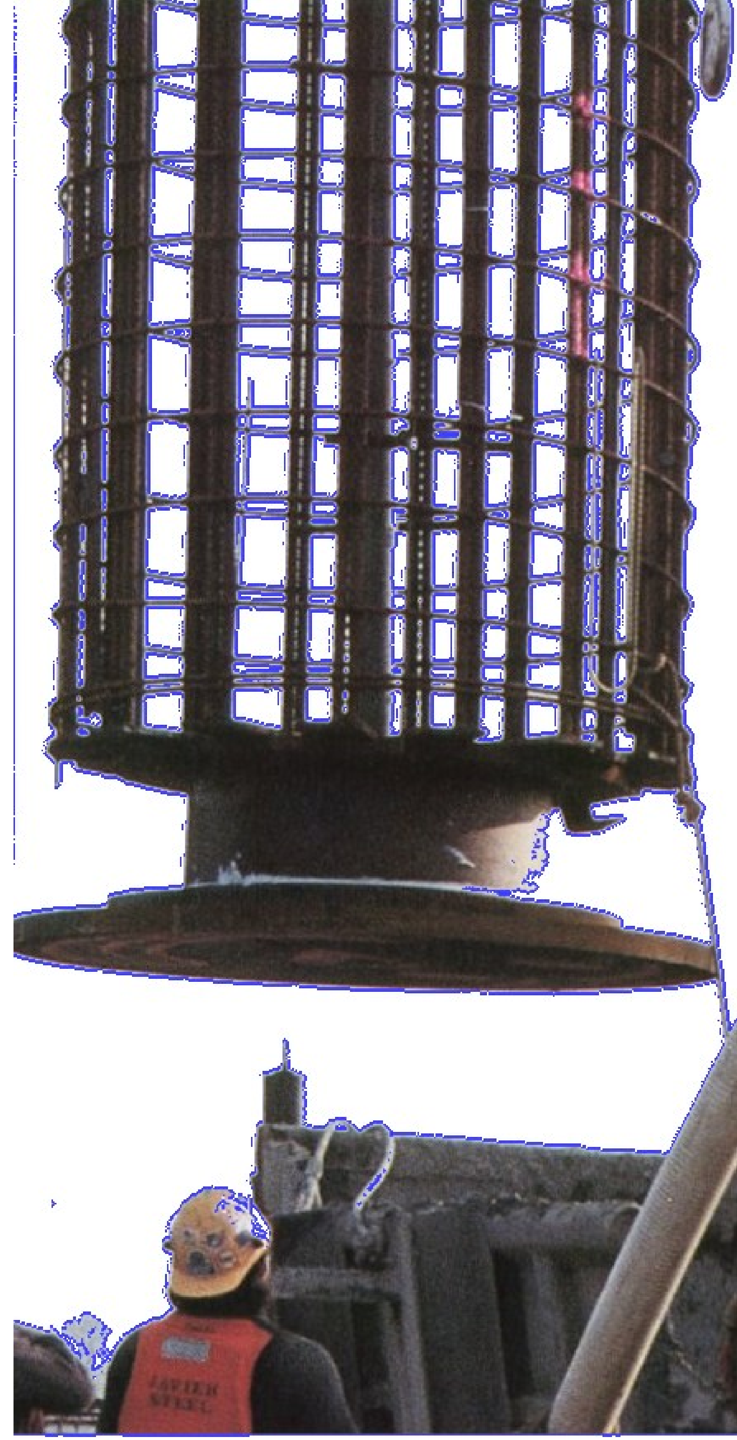
Appropriate Test Methods

- Static Load Tests
- Rapid Load Tests
- Dynamic Load Tests
- Use in isolation or combination aware of benefits and limitations



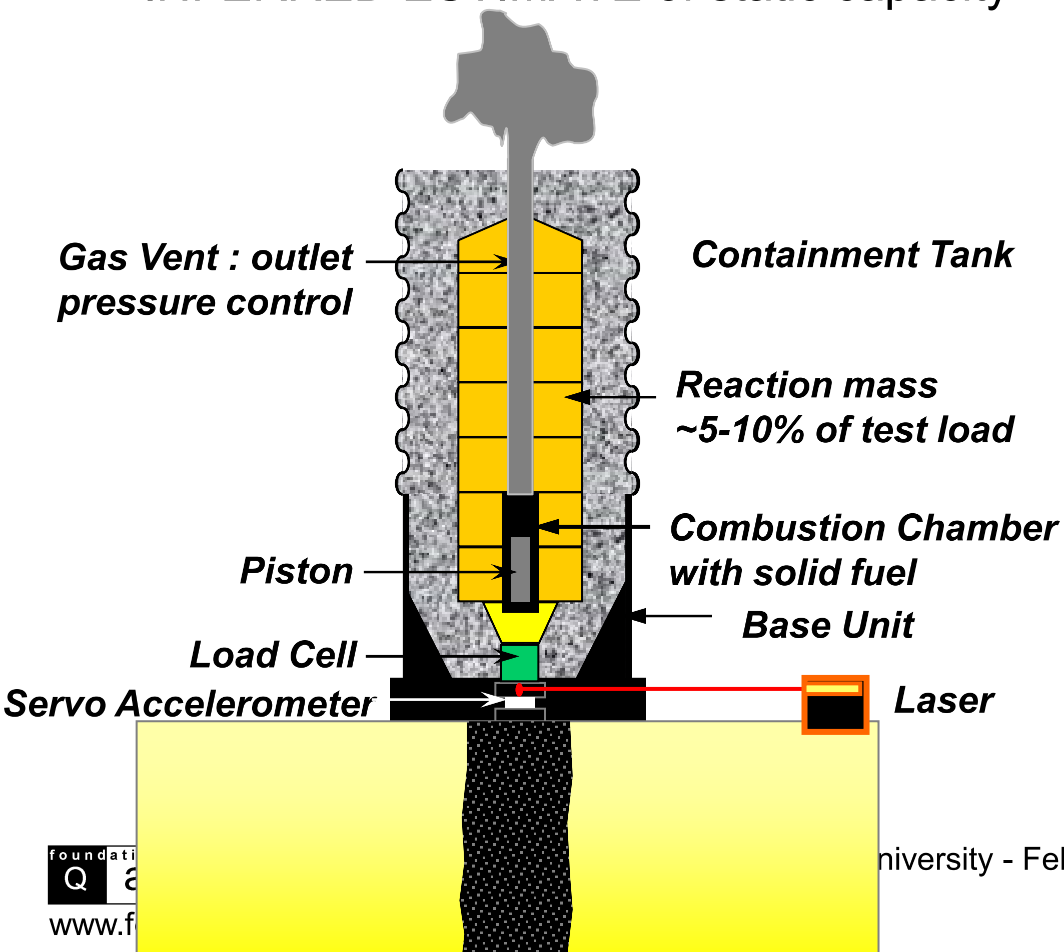
Static Load Tests

- Conventional (top-down)
- Osterberg (bottom-up)
- DIRECT measurement of static capacity



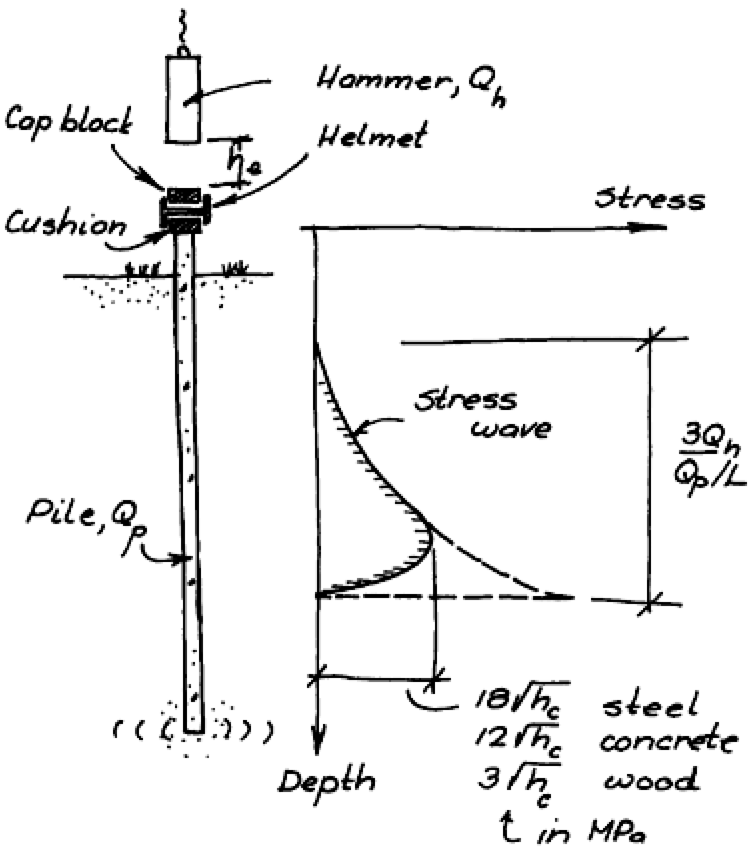
Rapid Load Tests

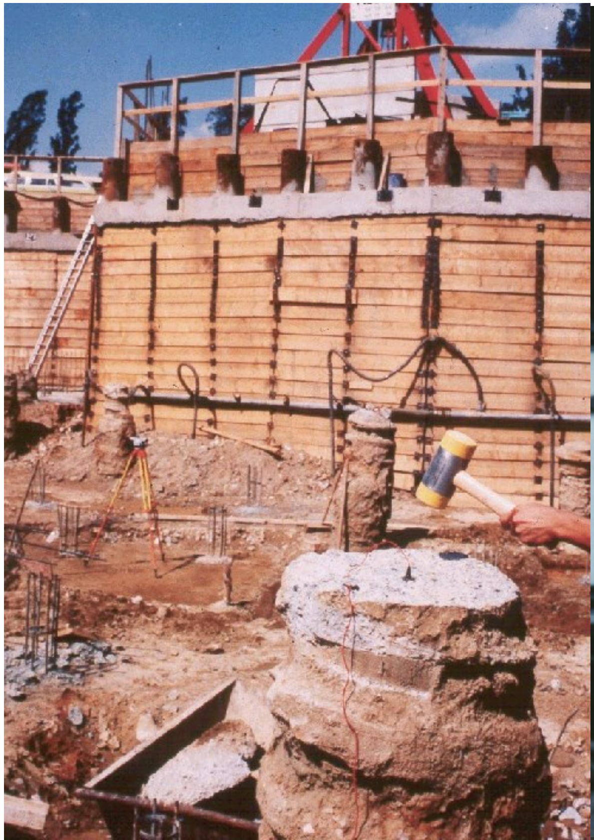
- Statnamic
- Pseudo-static / Fundex PLT
- INFERRED ESTIMATE of static capacity



Dynamic Load Tests

- Low strain (integrity only) tests
- High strain dynamic pile tests
- INFERRED ESTIMATE of static capacity





Difficulties in Establishing Foundation Adequacy and Safety

- Small percentage of piles tested
- Time-dependent capacity changes
- Inference of untested pile capacities
- Variable ground conditions
- Installation effects on stress regime
- Friction fatigue and other poorly understood effects
- Poor information on resistance distribution
- Residual stresses for driven piles
- Downdrag
- Testing to proof not ultimate
- Rate-dependence of capacity
- Need to consider group effects
- Subsequent changes to ground or water levels
- Measurement errors
- Inaccurate analysis of indirect test methods
- Knowledge of true load effects

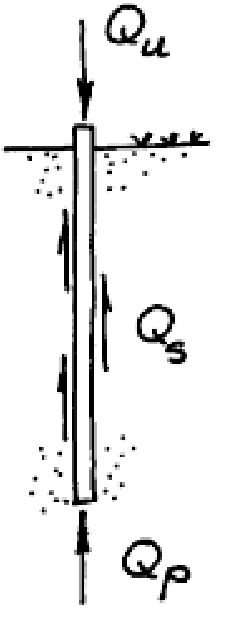
Difficulties in Establishing Static Load Capacity

- Can address some but not all of these issues
- Engineers not scientists
- Apply experience, logic, problem-solving

Pile-soil Interaction

What happens and when ?

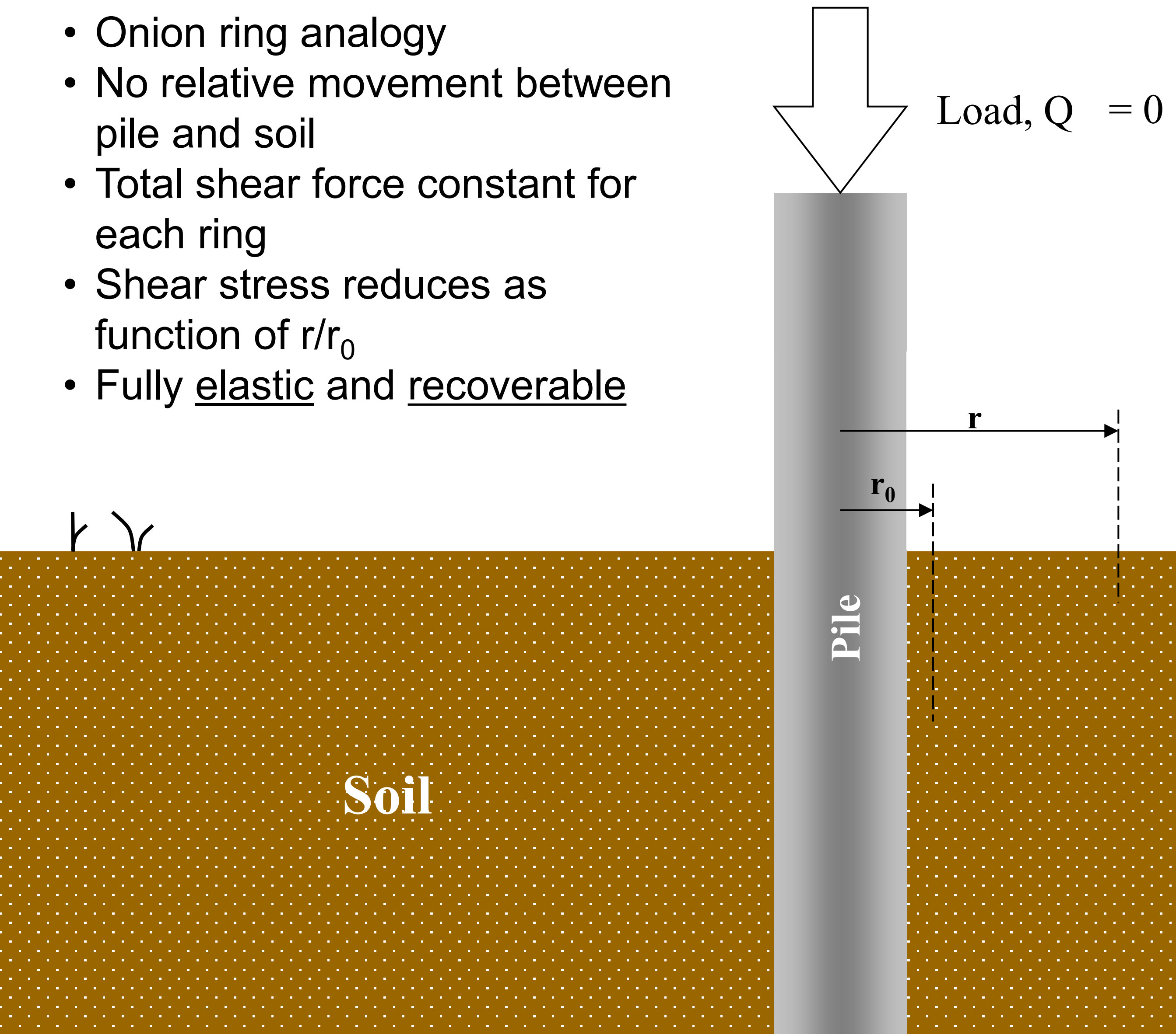
- Initial Elastic Phase
- Mobilization of Shaft Resistance
- Mobilization of End Bearing

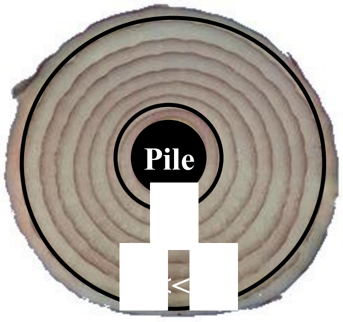


Initial Elastic Phase

Replay

- Onion ring analogy
- No relative movement between pile and soil
- Total shear force constant for each ring
- Shear stress reduces as function of r/r_0
- Fully <u>elastic</u> and <u>recoverable</u>

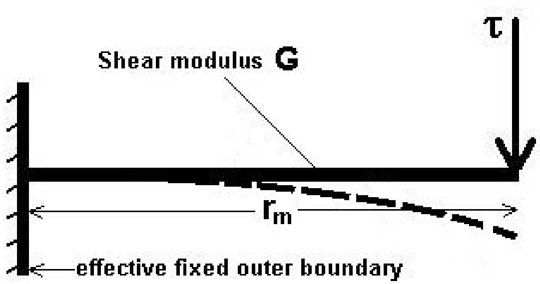


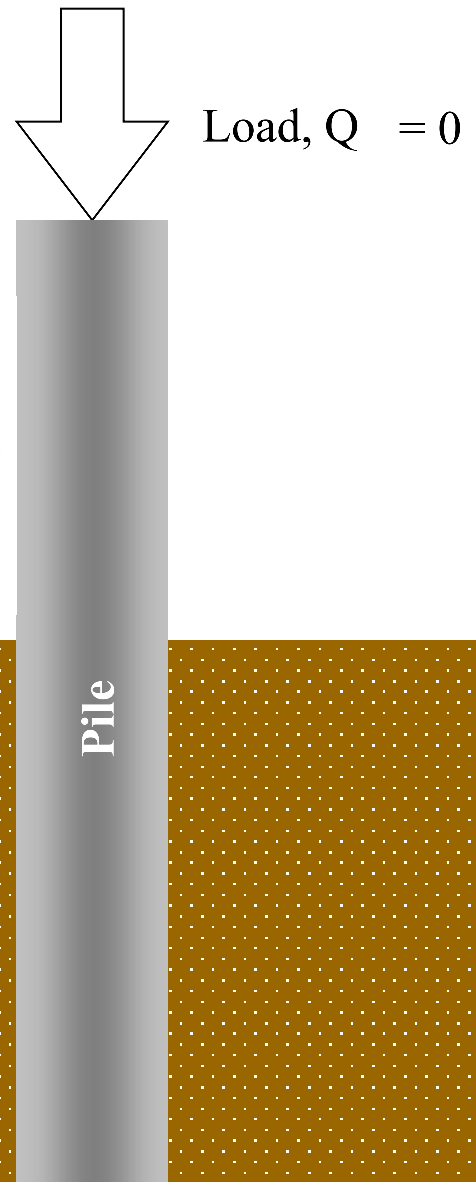


Initial Elastic Phase

Replay

- Cantilever / membrane analogy
- No relative movement between pile and soil
- Fully <u>elastic</u> and <u>recoverable</u>

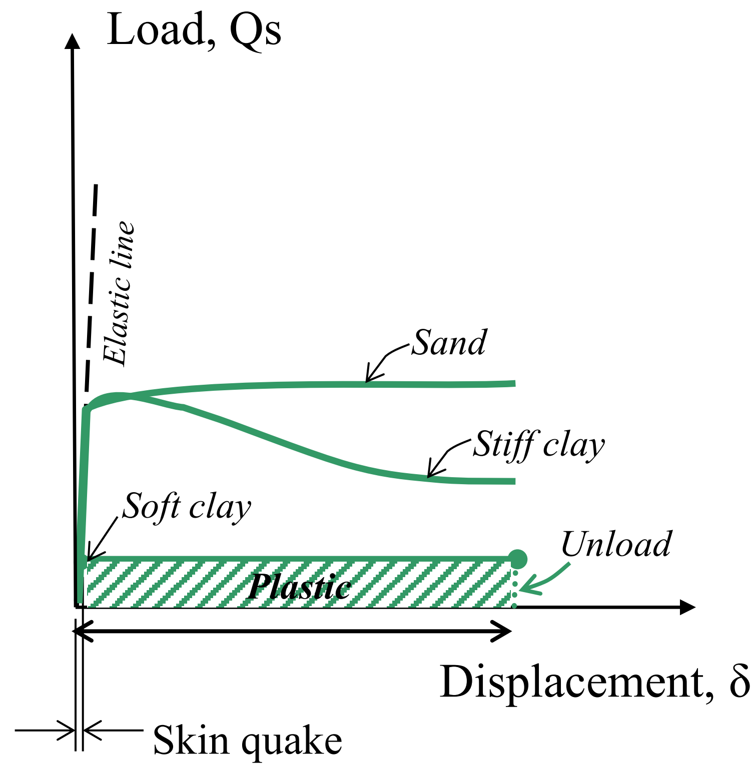




Mobilization of Shaft Resistance

Replay

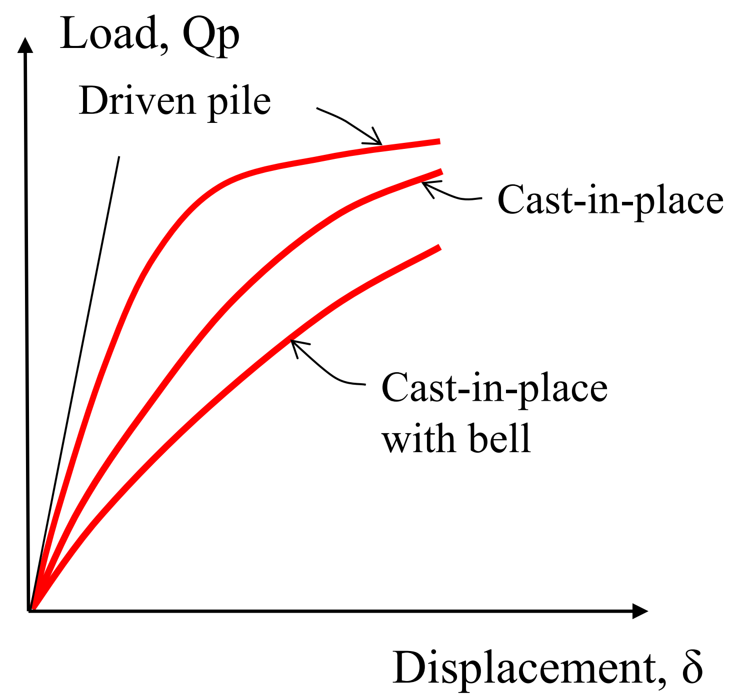
- Shaft resistance is relatively STIFF
- Initially ELASTIC and RECOVERABLE
- At about 2.5mm or 0.1" reaches shear limit
- Limiting distance called SKIN QUAKE
- Once skin quake is reached resistance is constant (PLASTIC and NON-RECOVERABLE)
- Shaft resistance is well approximated by a LINEAR ELASTO-PLASTIC model (i.e. Sand, Stiff clay, Soft clay)



Mobilization of End Bearing

Replay

- Last component of resistance to be developed
- Highly non-linear and hence poorly approximated by LINEAR ELASTO-PLASTIC model
- Generated by bearing failure
- Driven piles : 5-10% of diameter, Drilled piles : 10-20% of pile diameter - hence relatively SOFT

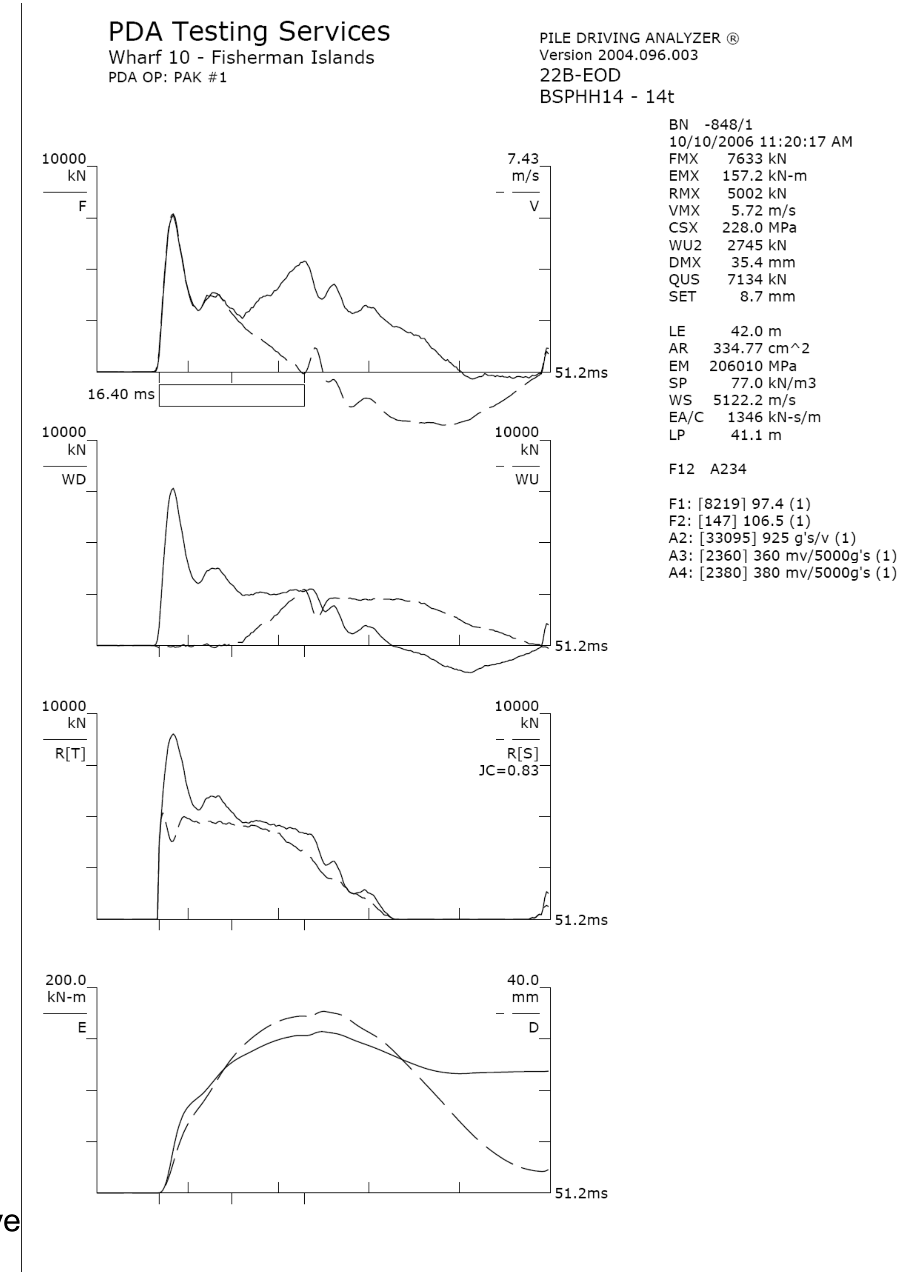


Standard 4-graph output

PDA Standard graphical outputs are:

- F and VZ vs time
- WD and WU vs time
- RT and RS vs time
- E and D vs time

Black Box



Analyzing a Static Load-Movement Test Response

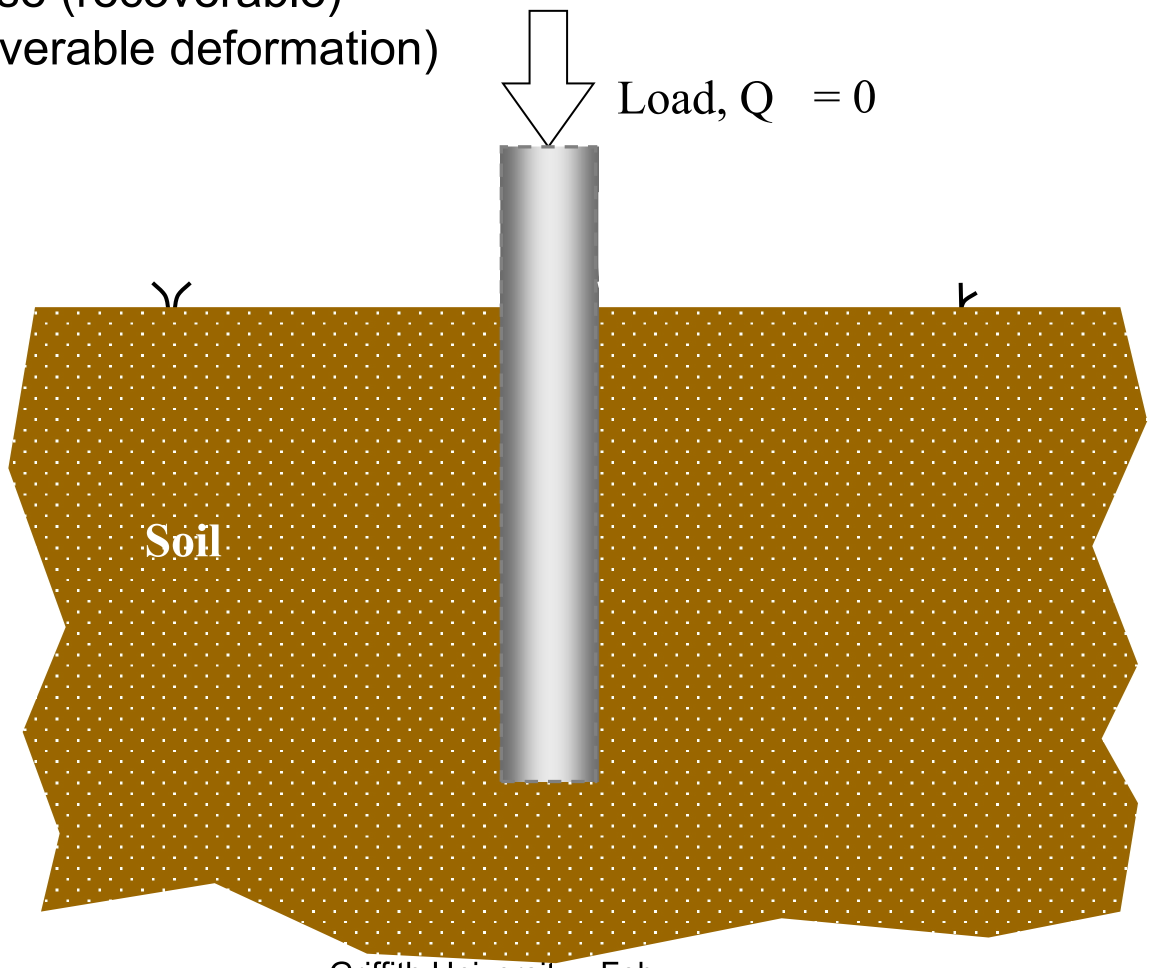
- Loading and Unloading phases
- The load-step or load-time domain
- The movement-step or movement-time domain
- Plastic Movement - Set Equivalency
- Set vs Mobilized Capacity
- Energy-Movement Relationship
- Energy-Load Step Relationship
- Multi-cycle Load-Movement Response
- Multi-cycle Movement-Time Response

EQUIVALECY BETWEEN ALL STATIC AND DYNAMIC TESTING CONCEPTS

Static Load-Movement Test Response

Replay

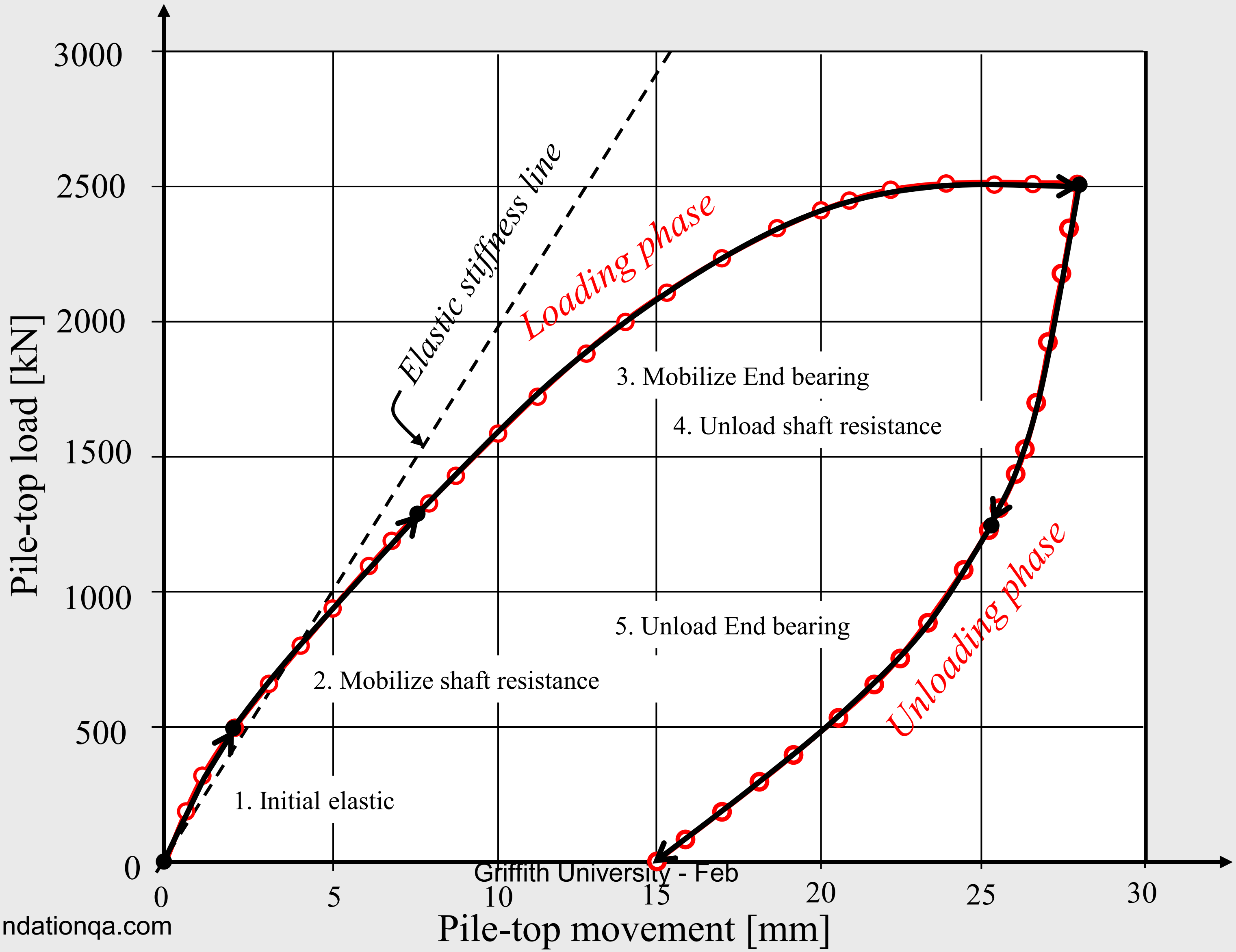
- Initial elastic phase (recoverable)
- Plastic (non recoverable deformation)
- Unloading phase



Loading and Unloading phases

Replay

- Static load-movement response

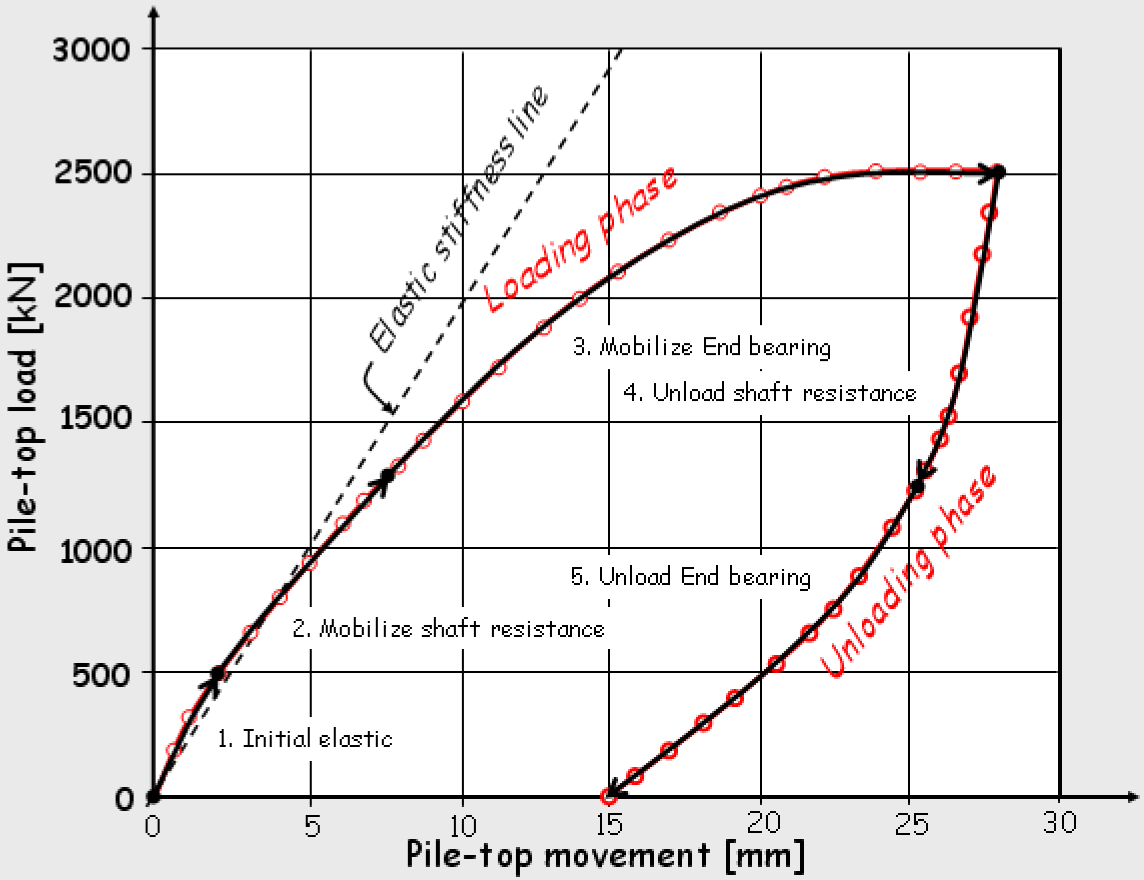


Loading and Unloading phases

- Static load-movement response

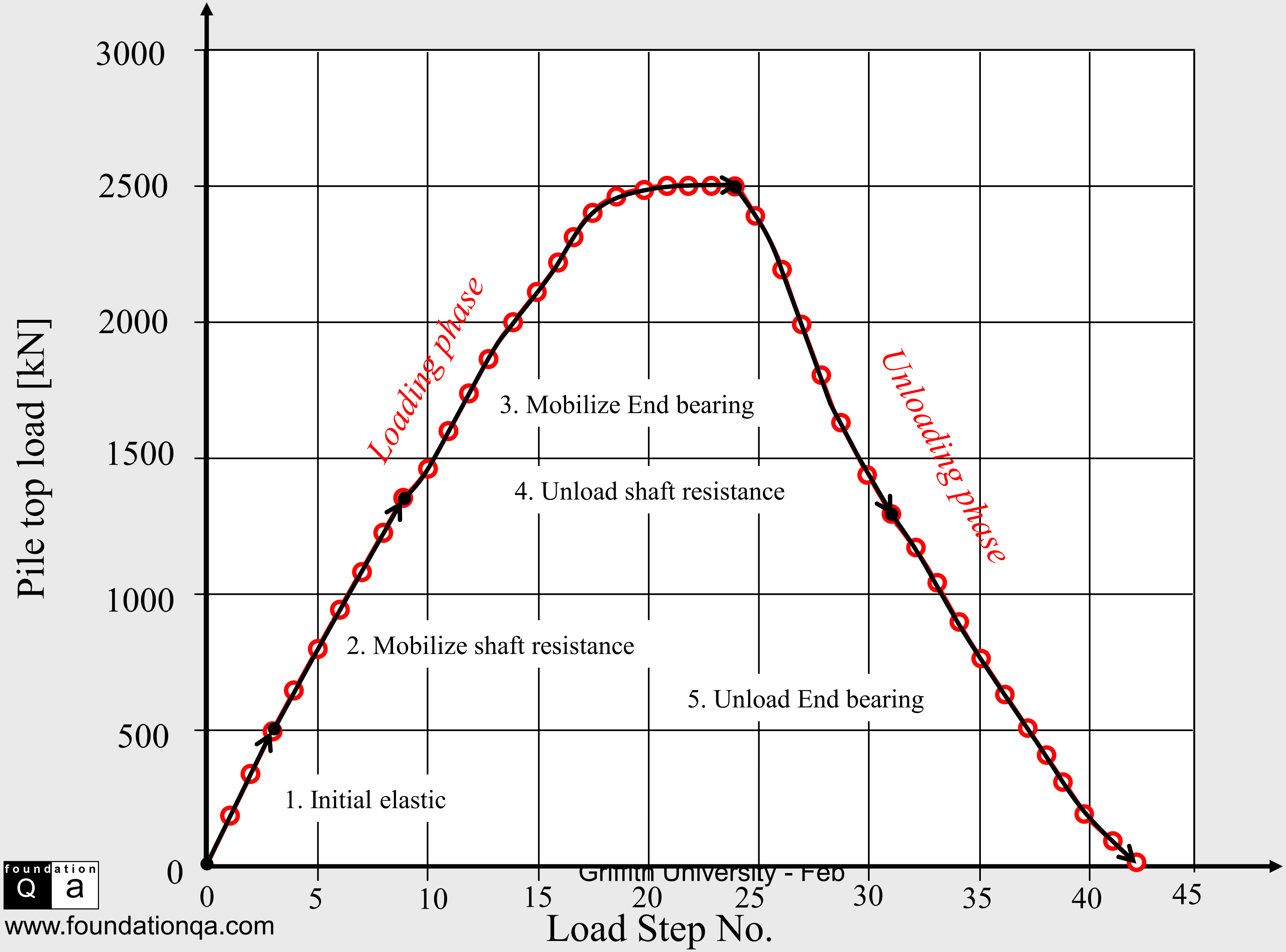
Key points are:

- The load - movement domain is the conventional representation
- Pile moves down as load is increased
- Shaft is loaded first, followed by end bearing
- Pile partially rebounds as load is released
- Shaft unloads first, followed by end bearing
- Note unloading is an inverted mirror image of the loading phase



The load-step or load-time domain

- Static load-time step response



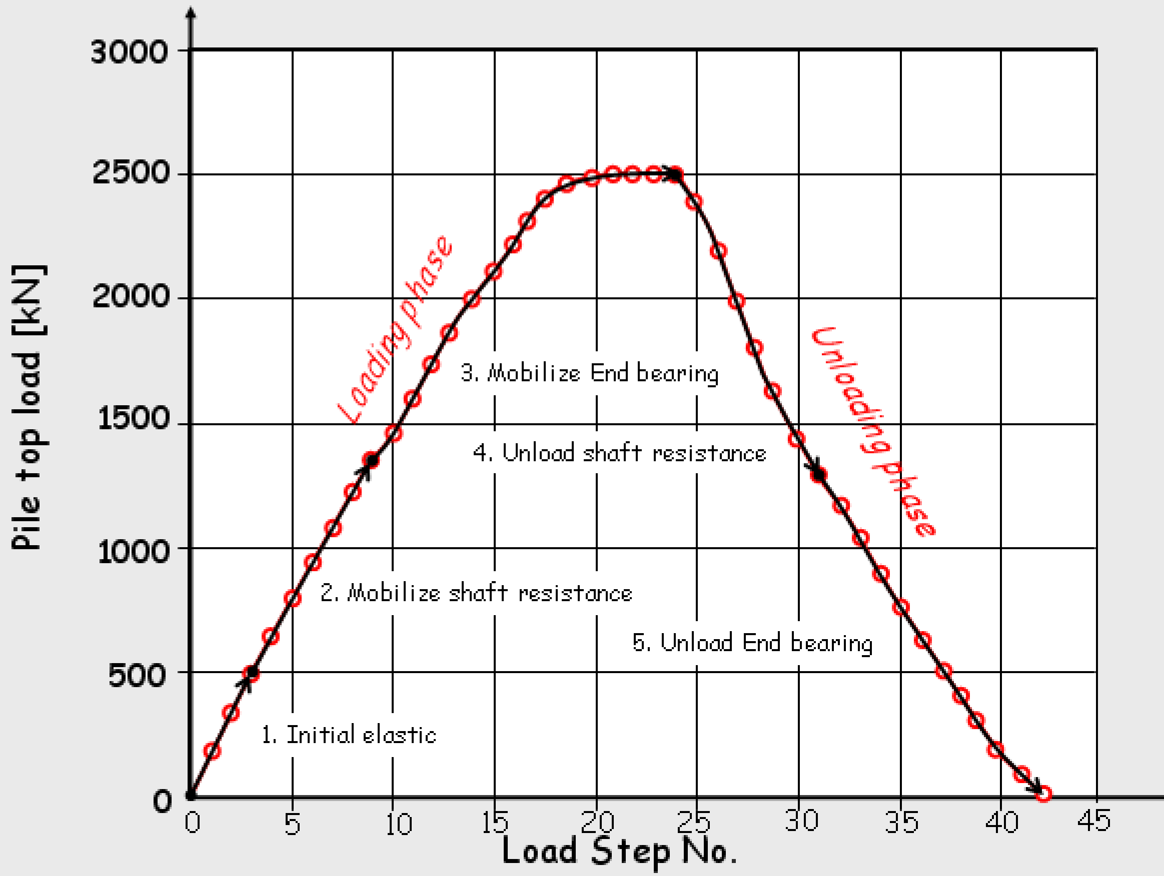
Replay

The load-step or load-time domain

- Static load-time step response

Key points are:

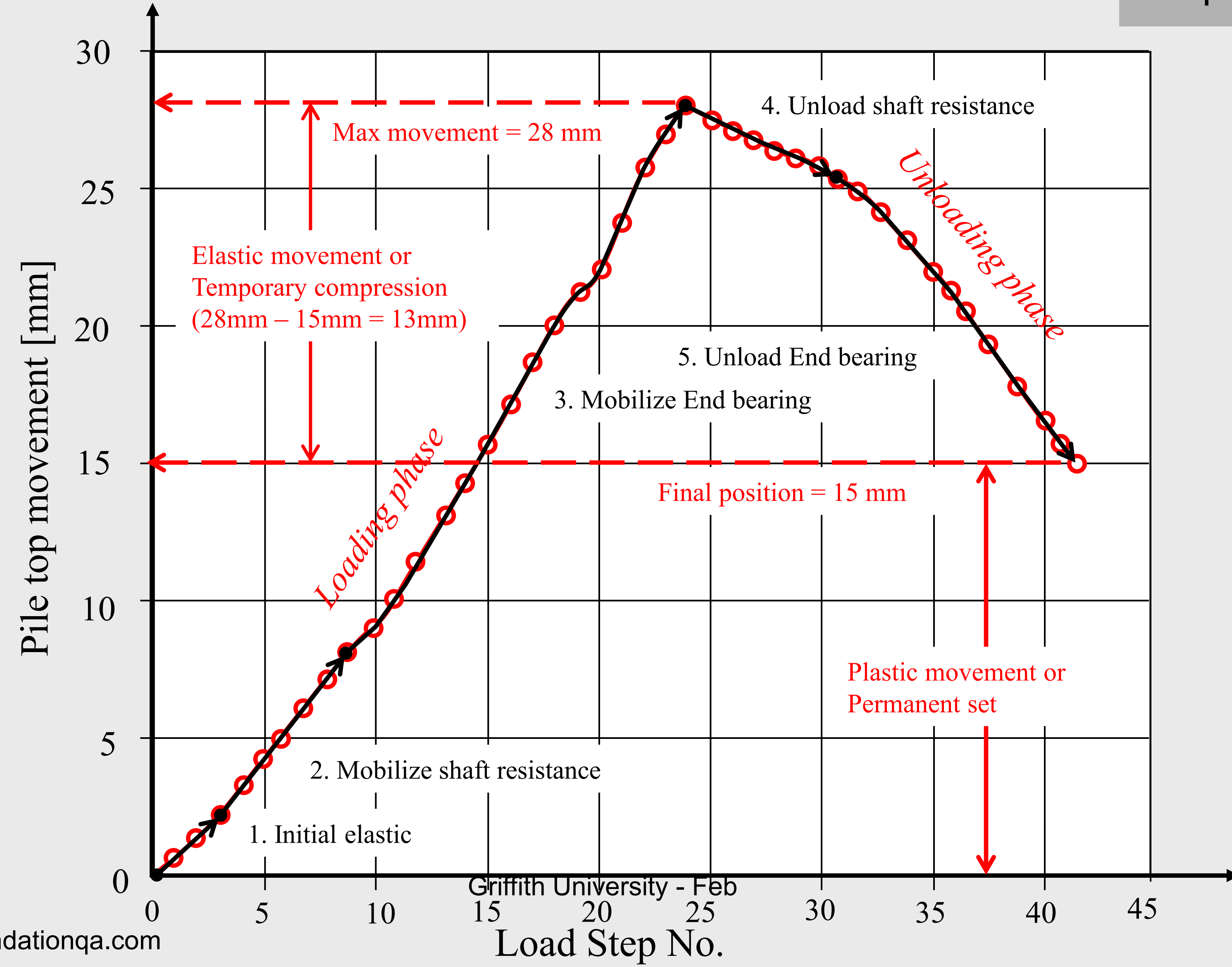
- An uncommon view of the same data
- Load is now plotted against sequential load-steps
- = time steps for constant time intervals
- if time steps unequal, longer hold periods will be stretched
- as time progresses, the mobilized resistance increases to a peak and then decays over the complete test event



The movement-step or movement-time domain

- Static movement-time step response

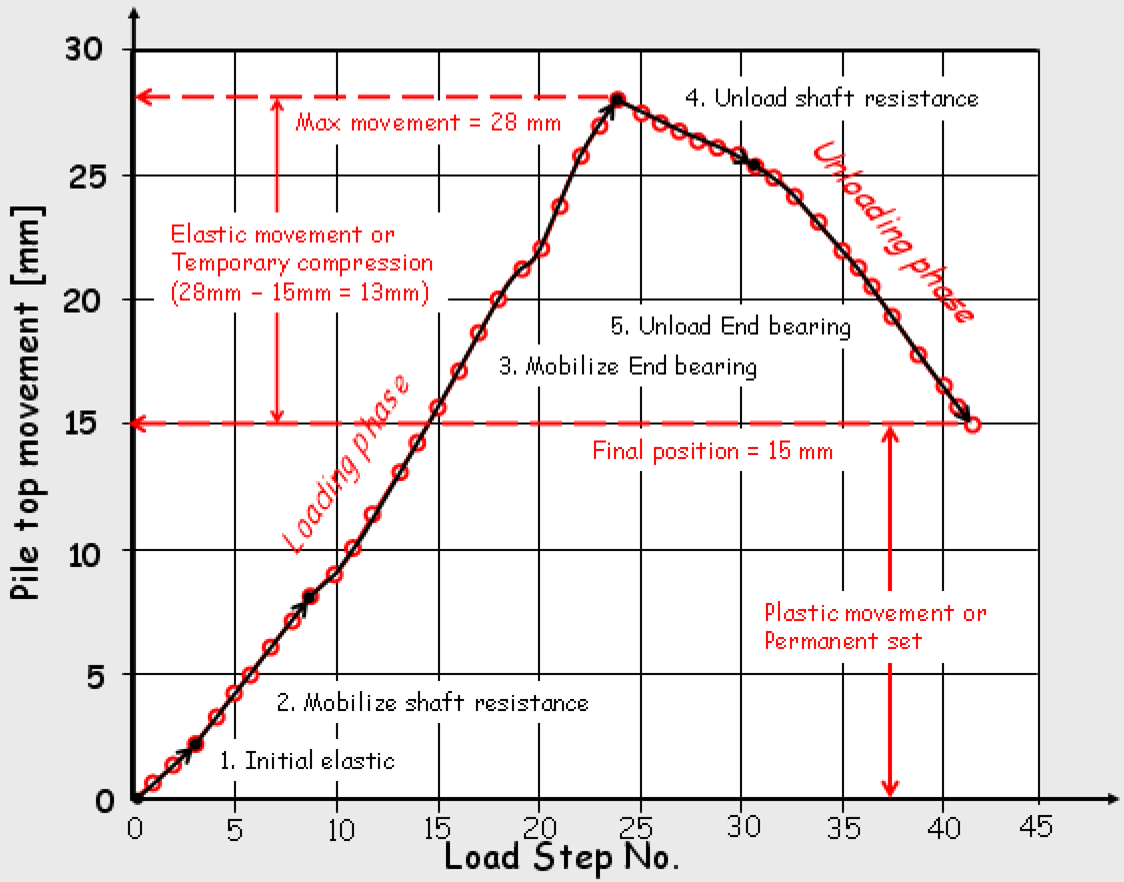
Replay



The movement-step or movement-time domain

Key points are:

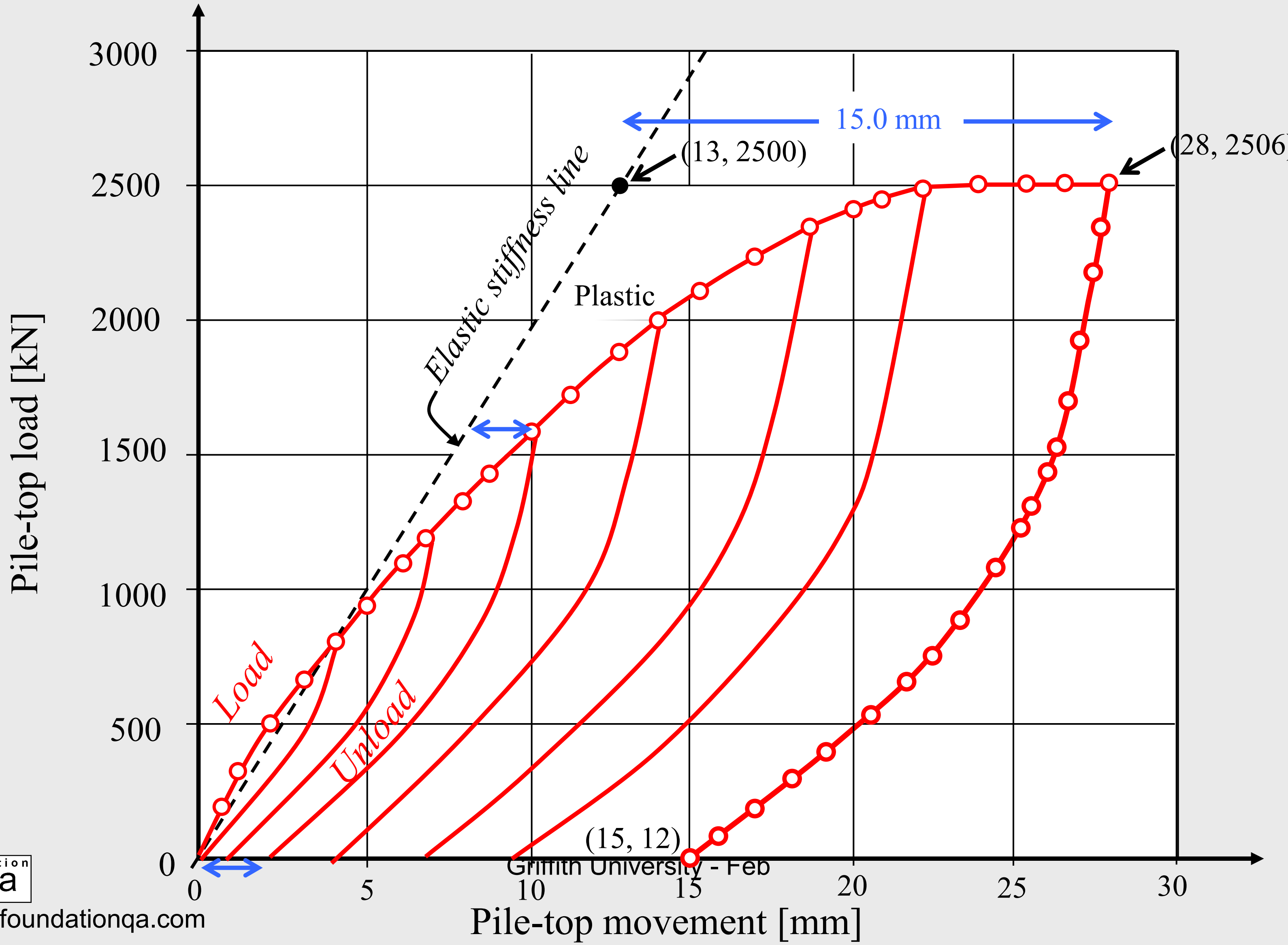
- Using the same data (Pile 415 – Cycle 1)
- Movement is now plotted against sequential load-steps or time-steps
- Pile is first pushed into the ground and then rebounds
- Pile-top movement reaches a maximum 28mm and net movement at end of test is 15mm
- Plastic, unrecoverable movement or SET is 15mm
- Elastic, recoverable movement or TEMPORARY COMPRESSION is 13mm
- This is exactly analogous to SET and TC for pile driving



Plastic Movement - Set Equivalency

Replay

- Static load-movement response

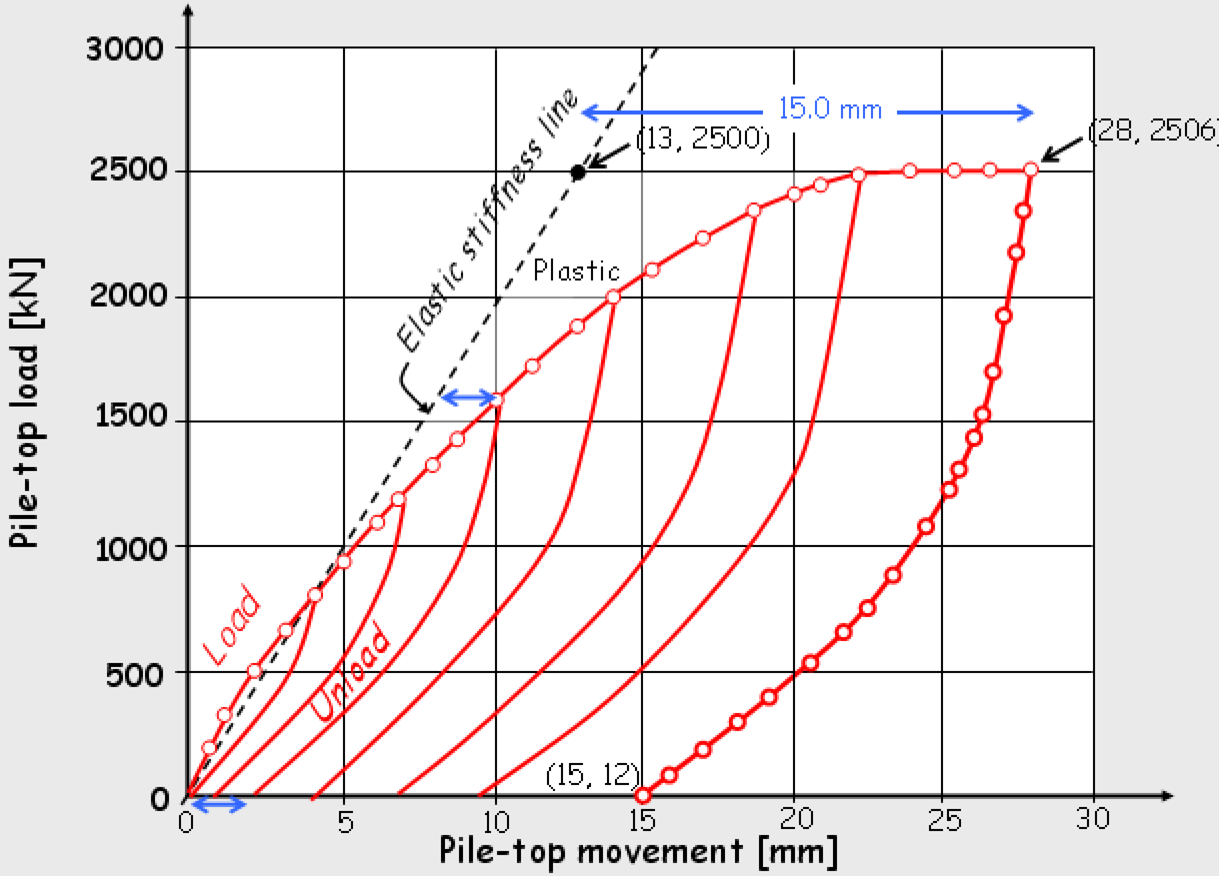


Plastic Movement - Set Equivalency

- Static load-movement response

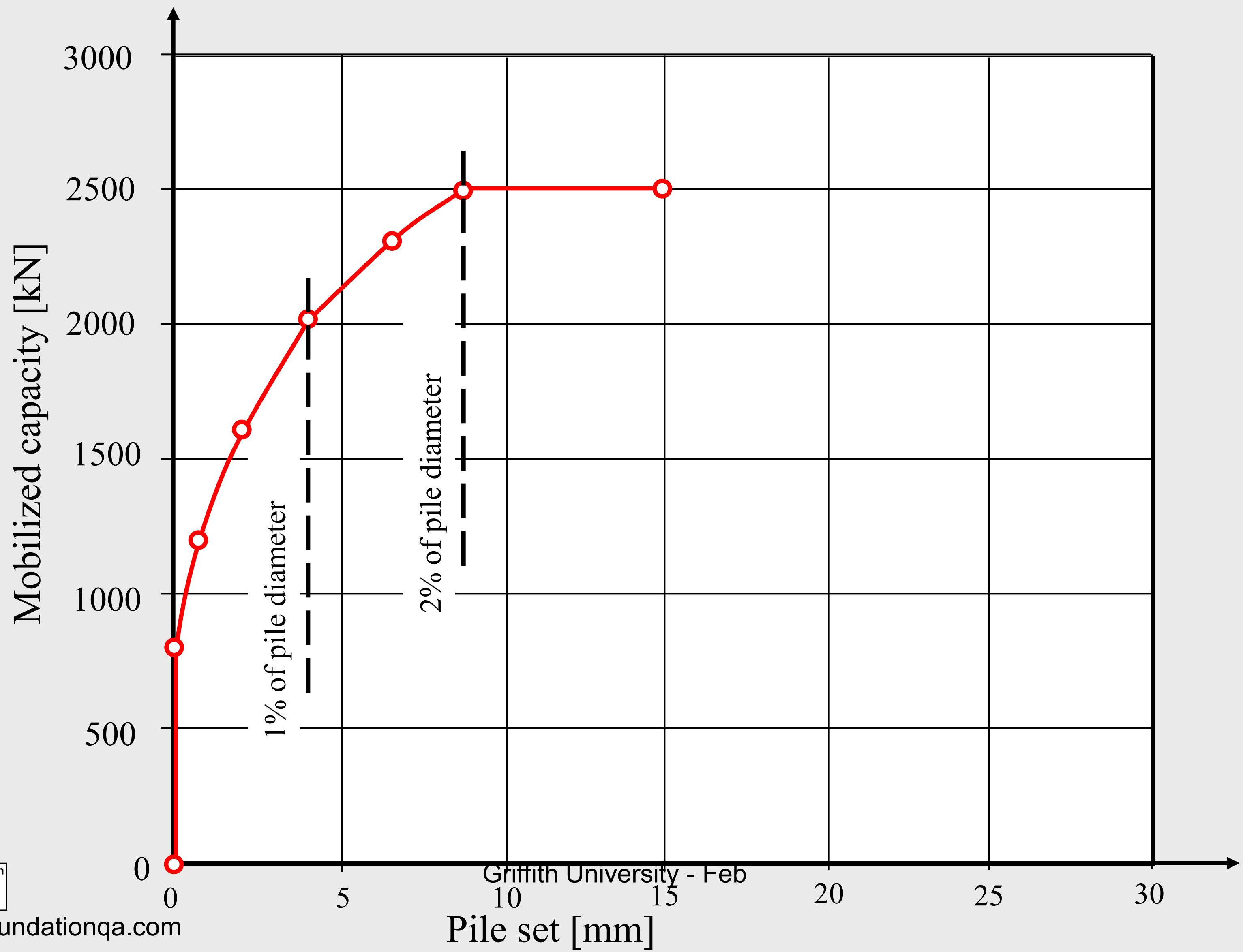
Key points are:

- The amount of plastic movement at any load level is the movement additional to the elastic line
- Plastic movement during loading and set on unloading are equivalent
- Plastic movement increases with increasing load



Set vs Mobilized Capacity

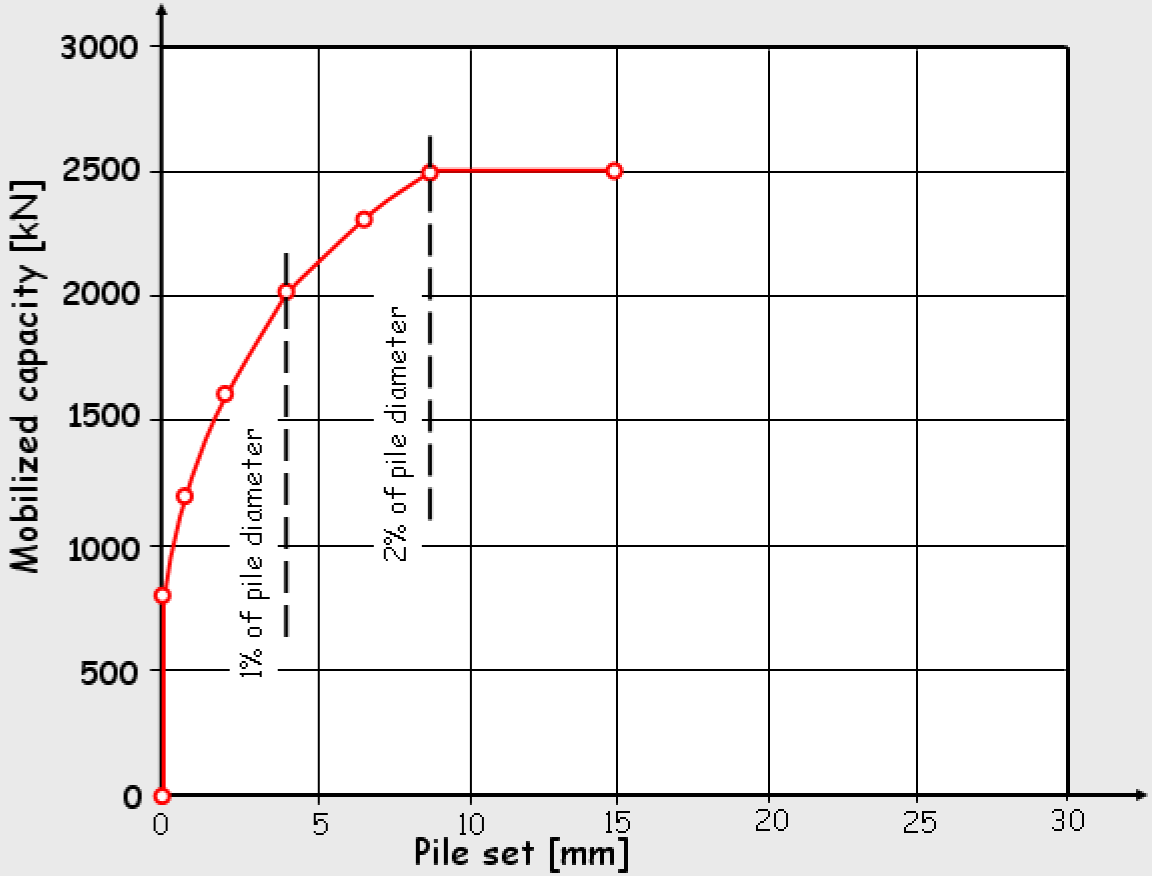
Replay



Set vs Mobilized Capacity

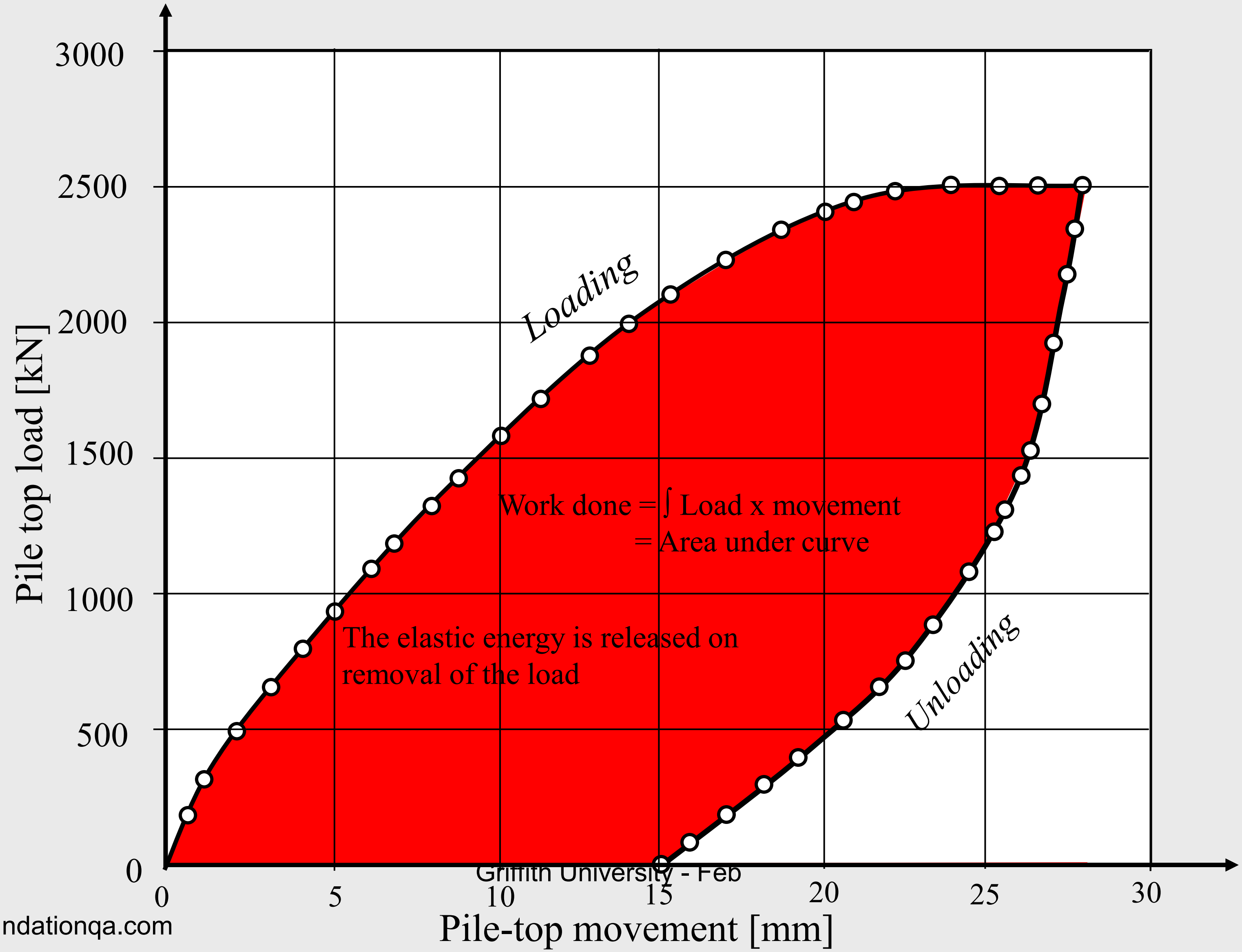
Key points are:

- Final set is therefore an indicator of the proximity to ultimate pile capacity
- At low or small set, mobilized capacity is a small percentage of available capacity
- At a permanent SET of 1% of pile diameter, 80% of the capacity has been mobilized
- Ultimate capacity is achieved at a permanent SET of 2% of pile diameter



Energy-Movement Relationship

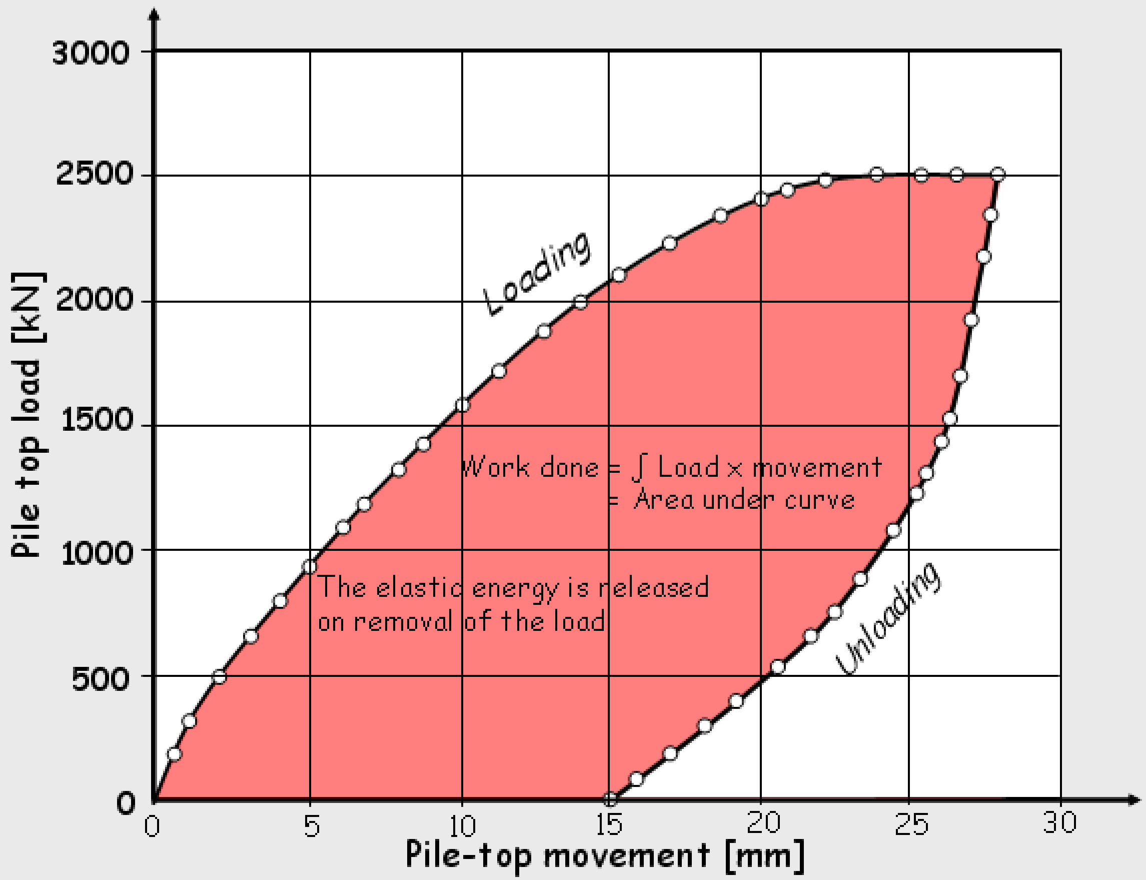
Replay



Energy-Movement Relationship

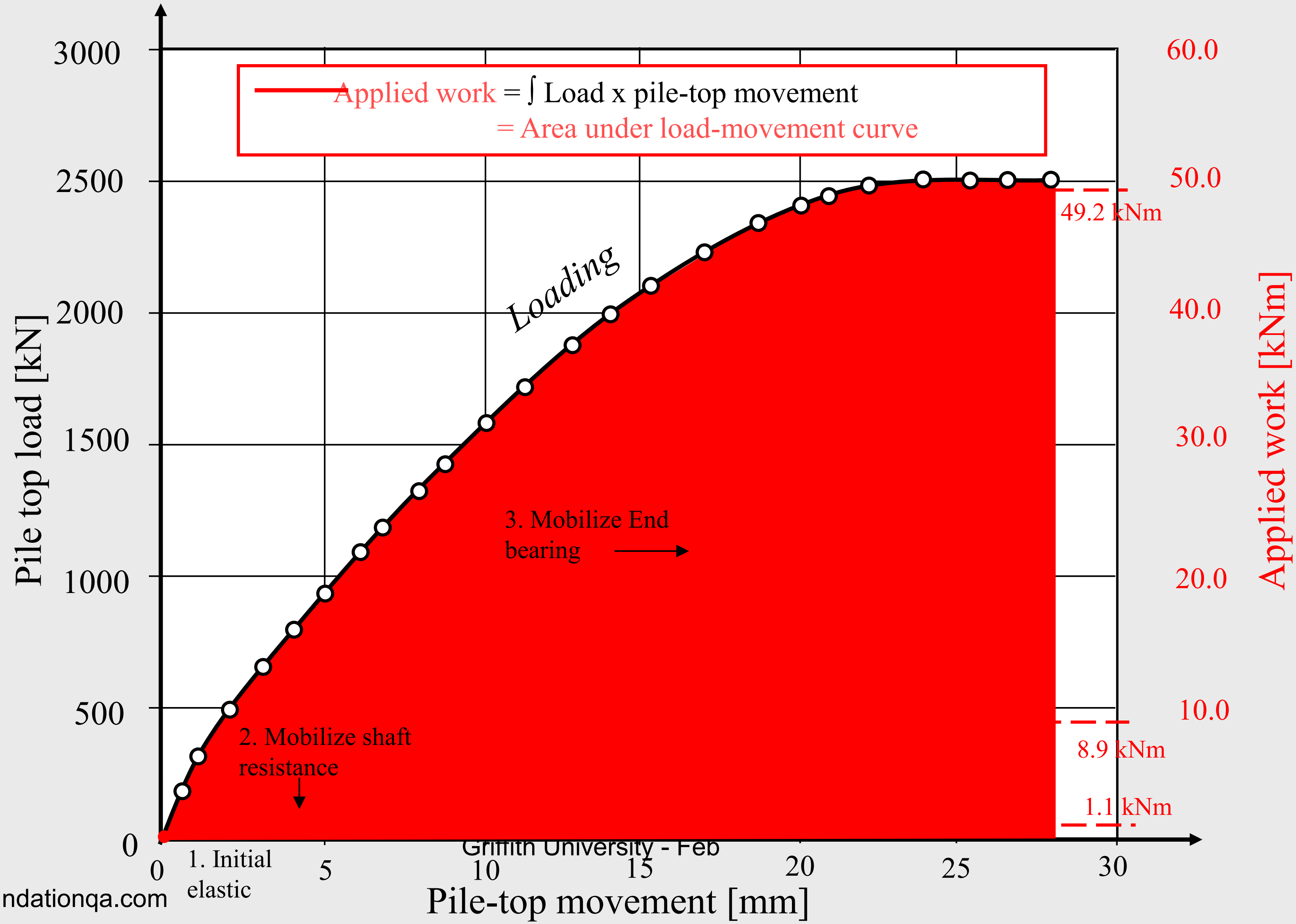
Key points are:

- Energy = Work = Integral (Force x Distance) or (Load x top movement)
- Energy includes recoverable elastic strain energy and unrecoverable plastic failure energy



Energy-Movement Relationship

- Energy-movement response (Loading phase)



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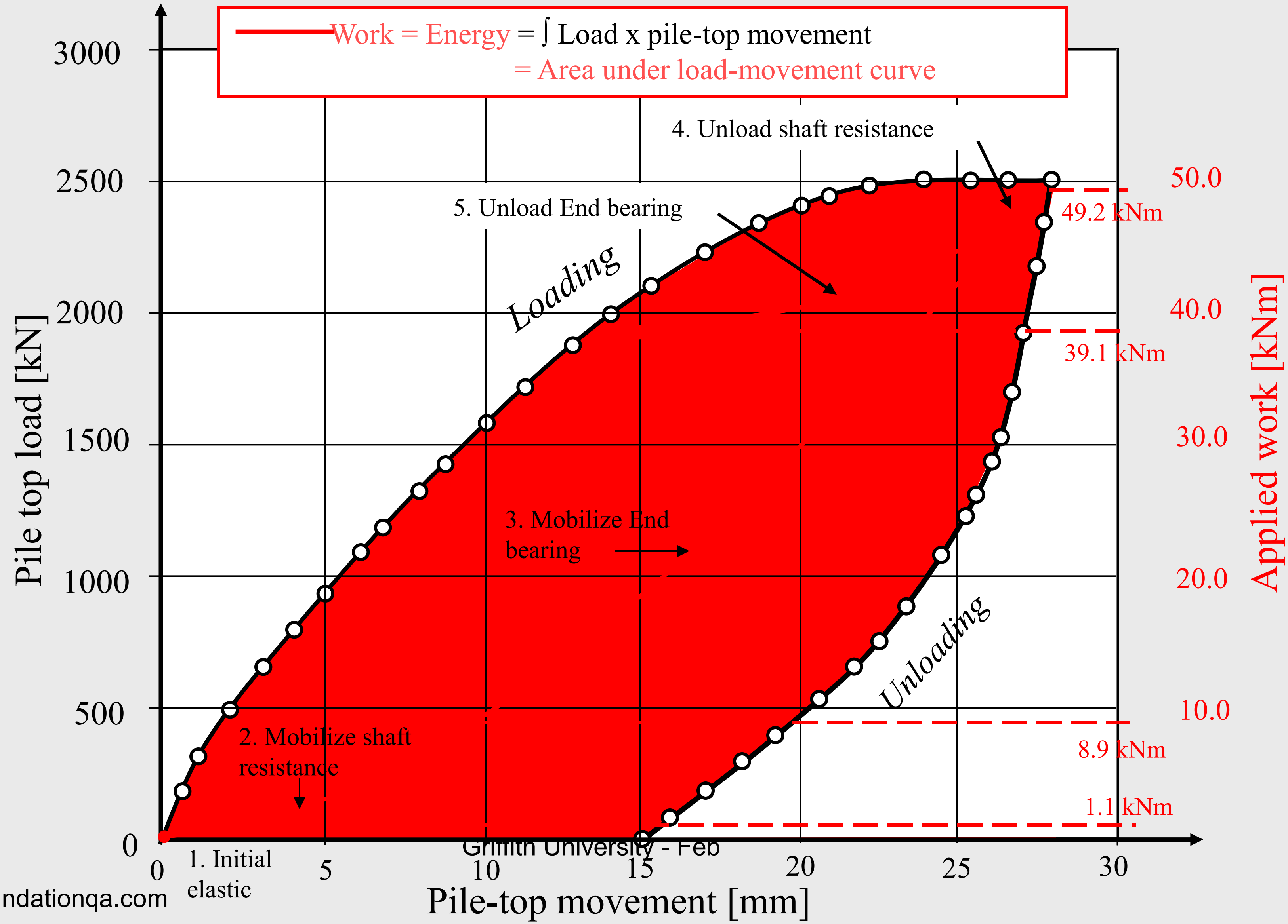
Energy-Movement Relationship

- Energy-movement response (Loading & Unloading phases)



Replay

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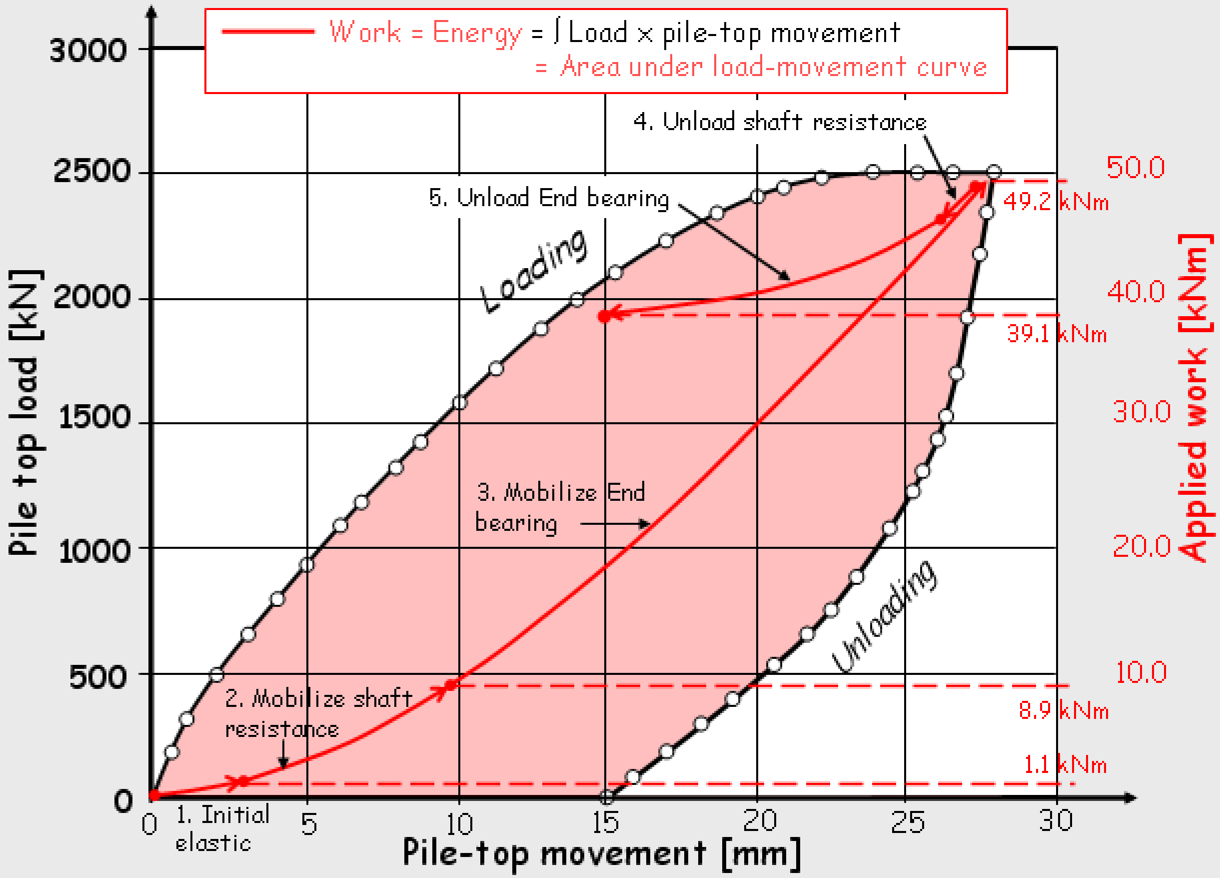
Energy-Movement Relationship

- Energy-movement response (Loading & Unloading phases)

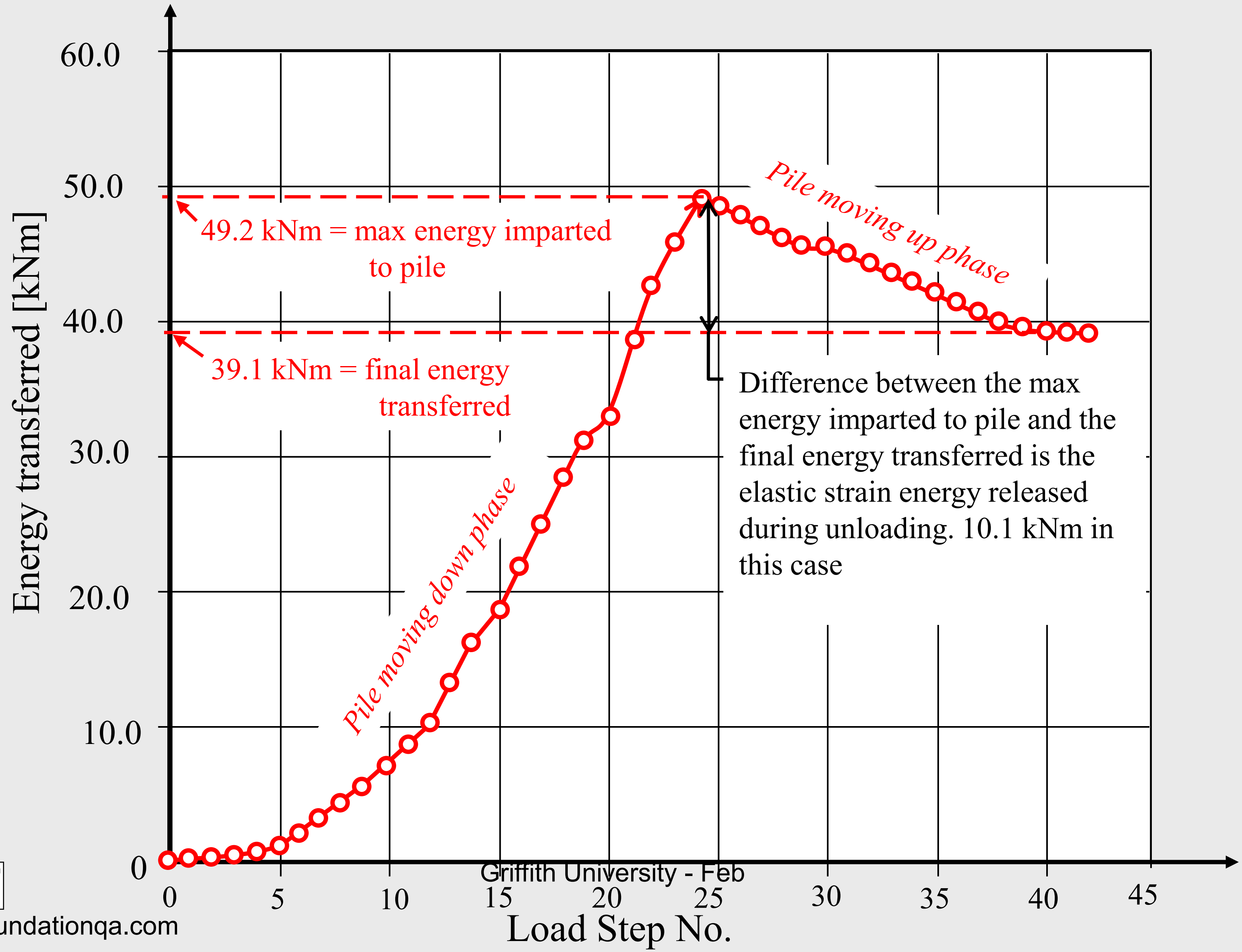
In the example presented:

- Only 8.9kNm (18%) is used to mobilize the shaft resistance
- 40.3kNm (82%) is used to mobilize the end bearing
- 10kNm is recovered during unloading (rebound)



Energy-Load Step Relationship

- Energy-time step response



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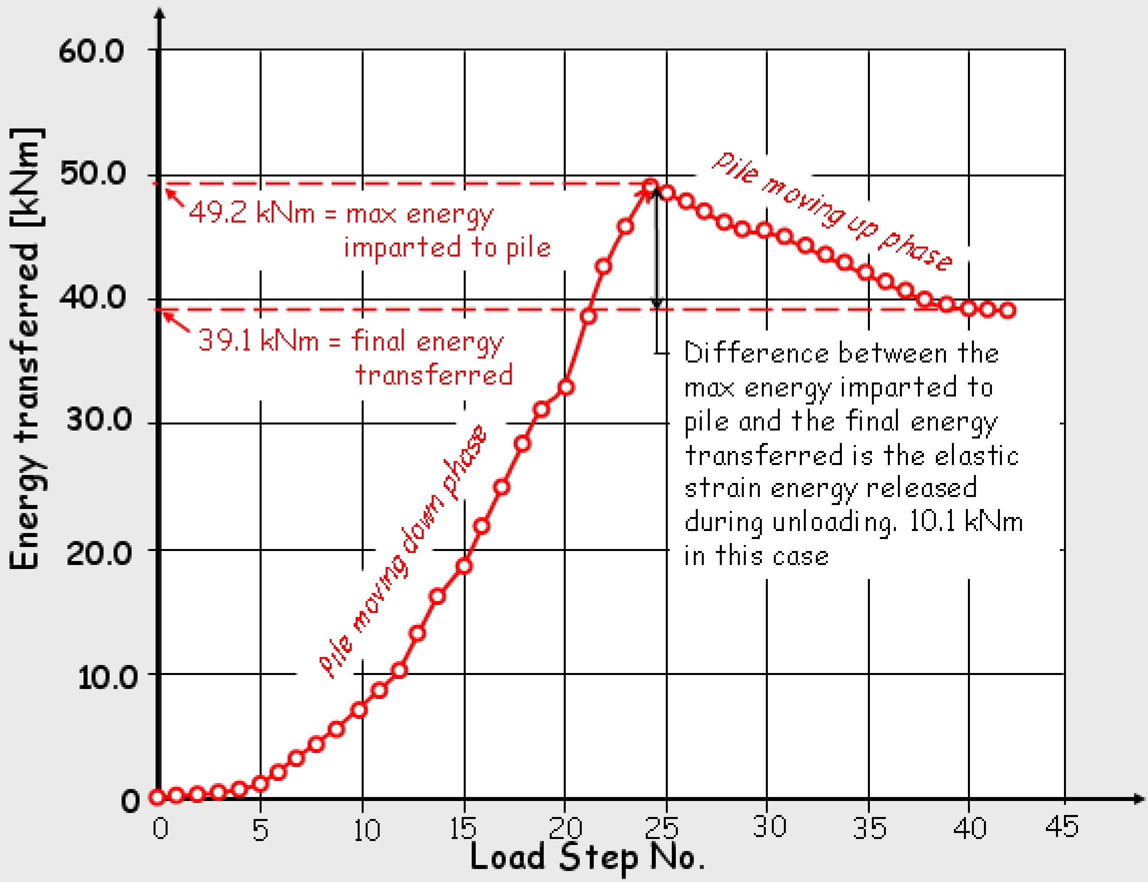
Energy-Load Step Relationship

- Energy-time step response

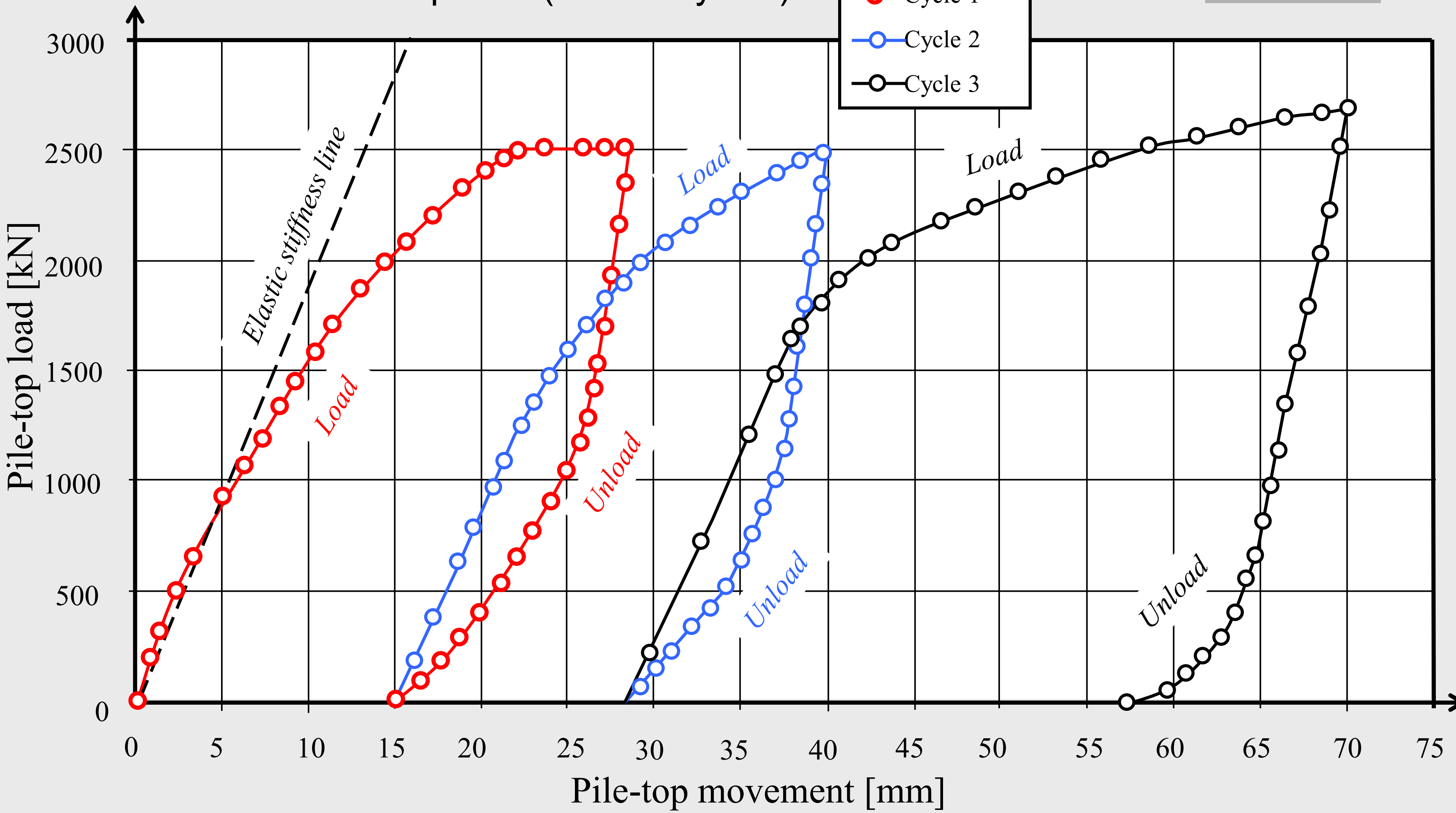
In the example presented:

- Maximum energy (EMX) is 49.2kNm
- Final energy (EFN) is 39.1kNm
- 10.1 kNm of elastic strain energy returns to jack
- Energy goes INTO pile when pile moves DOWN
- Energy is released from pile when pile moves UP



Multi-cycle Load-Movement Response

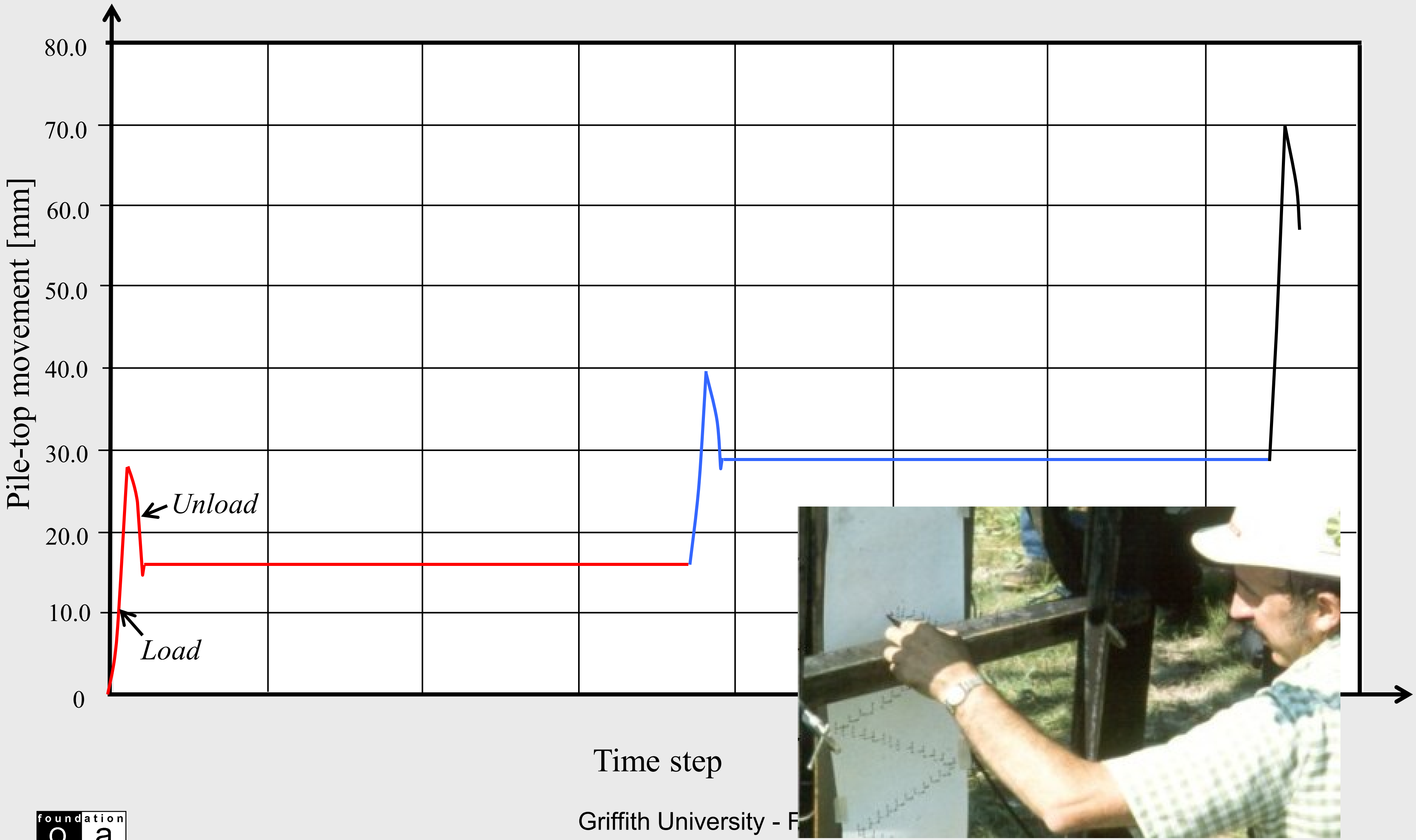
- Load-movement response (3 load cycles)



Replay

Multi-cycle Movement-Time Response

- Movement-time step response (Cycles 1 – 3)



Static-Dynamic Equivalency

- Shaft resistance loads before end-bearing
- Also shaft resistance unloads before end-bearing
- Mobilized resistance increases to a maximum and then reduces
- Initially elastic, with plastic movement mostly related to end bearing
- Shaft resistance needs little energy to mobilize; end bearing requires much more
- Energy goes into pile as it is pushed down; the elastic portion is returned as the pile rebounds
- Static load tests exhibit a set and temporary compression just like pile driving
- The amount of set indicates how close the test was taken to ultimate capacity

So what could be wrong with static testing?

- Time consuming
- Expensive
- Limited number - not statistically significant
- Effectiveness as evaluating FOUNDATION SYSTEM
- There is no direct link to installa parameters
- No guidance on construction cc
- Only broad indication of resista distribution

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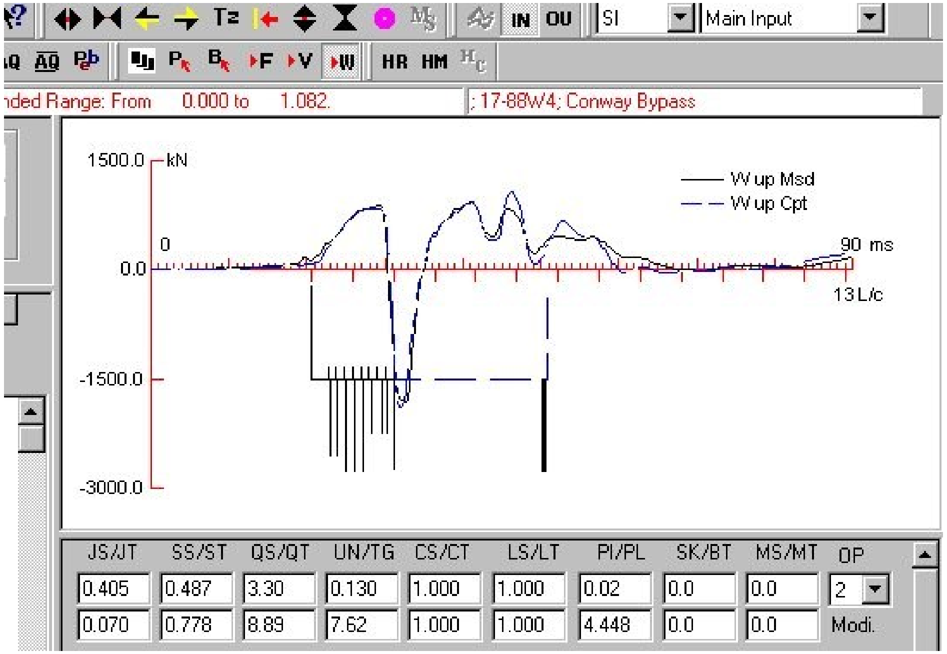
Potential benefits of PDA testing

- Other alternatives not considered here
- Much more rapid
- Much cheaper
- More bang for same bucks - i.e. test a statistically significant number of piles
- Test during installation to provide a DIRECT relationship with installation parameters
- Test after installation to evaluate capacity changes (set-up or relaxation)
- Construction control parameters (sets, drop heights etc.)
- More detailed evaluation of resistance distribution

Fundamental limitations of PDA testing

- The test method is INDIRECT. Static capacity is INFERRED, not directly MEASURED.
- Quality of inference depends on the applicability of the mathematical model to the particular pile and soil conditions.
- Quality of advice MAY also depend on the skill and knowledge of the tester and analyser - this can vary tremendously.



Force vs Resistance

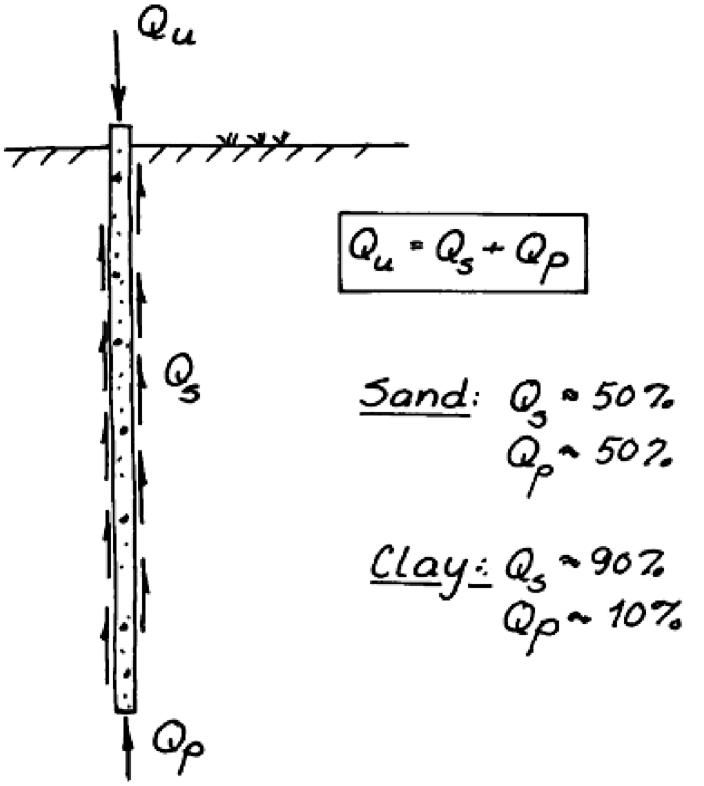
- FORCE = INPUT
- DISPLACEMENT = RESPONSE
- RESISTANCE derived
- Static FORCE results in static equilibrium and RESISTANCE is therefore easily derived
- Dynamic FORCE input causes a motion response and the STATIC RESISTANCE cannot be determined directly
- PDA and Hiley

Applying the Force – Static testing

- FORCE applied through jack
- FORCE measured by manometer (up to 25% error)
- or FORCE measured by load cell (very small error)
- Displacement response measured by dial gauges, transducers or precise level.

Static FORCE - RESISTANCE Equilibrium

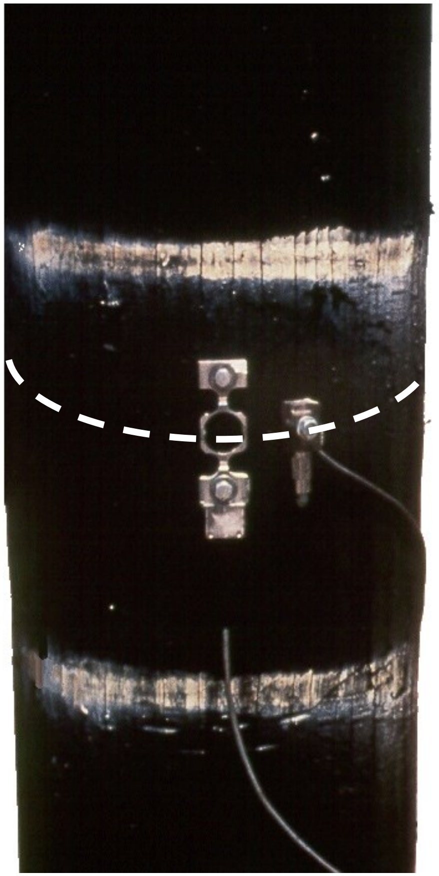
- At each stage of static test, applied load and MOBILIZED resistance are exactly in equilibrium
- Mobilized resistance increases to a peak and then unloads to zero.
- For our purposes, pile is STATIC
- Actually test is QUASI-STATIC because movement occurs.

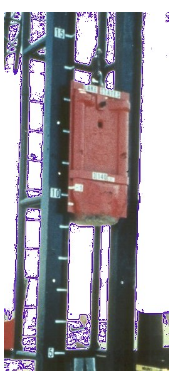


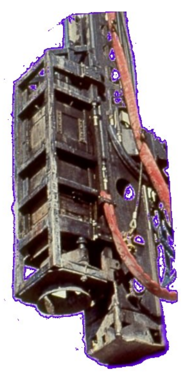
After Broms, B.B. Foundation Engineering. www.geoforum.com

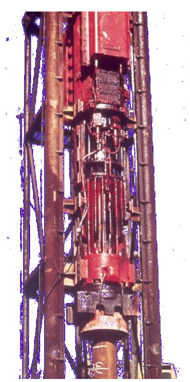
Applying the Force - Dynamic

- FORCE applied by hammer impact
- STRAIN measured by strain transducers (up to 3% error)
- Multiply STRAIN by pile cross-sectional AREA and MODULUS of elasticity at gages to compute equiv FORCE
- VELOCITY response measured by accelerometers and integrated



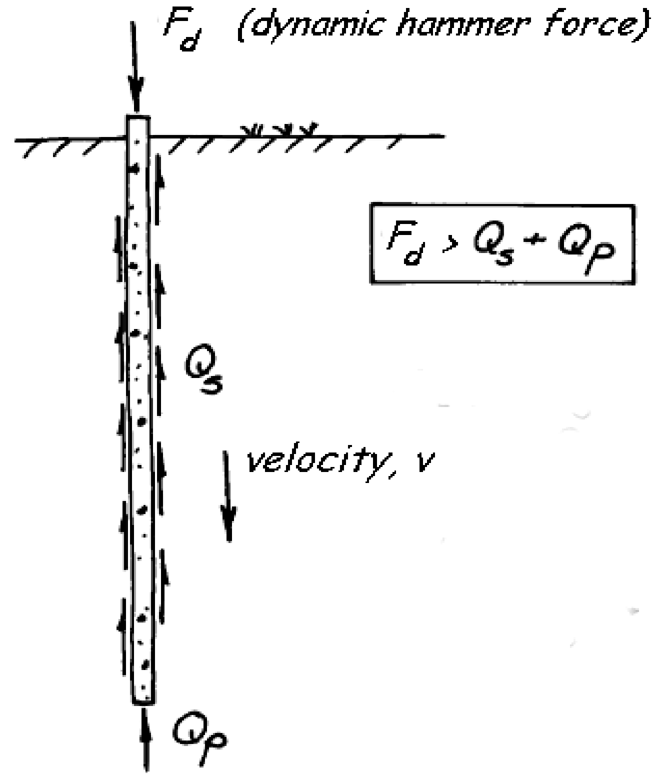






Dynamic FORCE-RESISTANCE Inequilibrium

- Applied force is related to hammer and pile properties and effectively INDEPENDENT of the available resistance
- if Fd >> R, pile moves down with velocity v - called 'pile driving'
- if Fd << R, pile 'refuses'
- Refusal is a RELATIVE term



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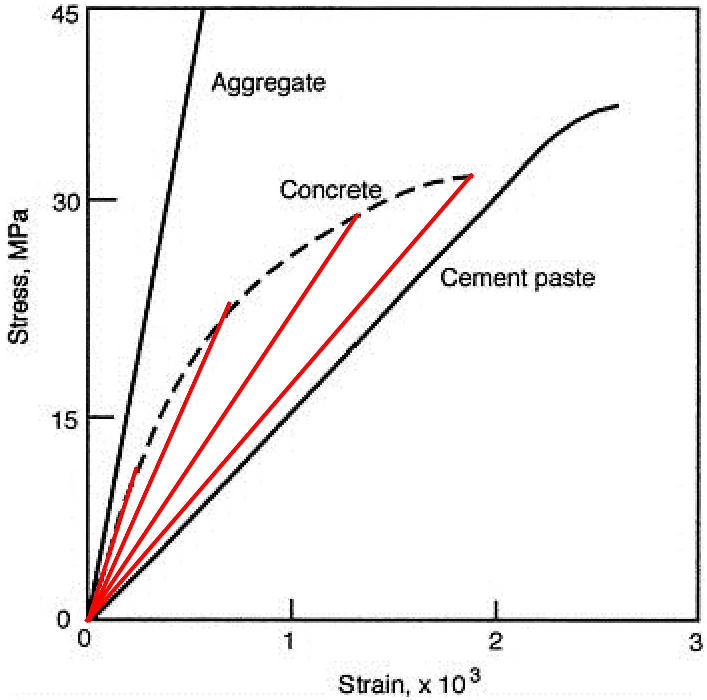
Converting Dynamic STRAIN to FORCE

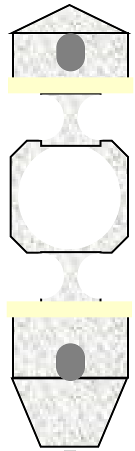
- Cross-sectional AREA at transducers typically known
- MODULUS FIXED for Steel (206MPa or 30ksi)
- MODULUS VARIABLE for Concrete, Grout and Timber
- Function of strength, constituents, age, strain level (non-linear)
- Modulus MAY be independently assessed from WAVESPEED or principle of PROPORTIONALITY
- AN error in MODULUS will lead to errors in interpreted FORCE, ENERGY, RESISTANCE and DISTRIBUTION
- The validity of the MODULUS should be reviewed to ensure it is within reasonable limits



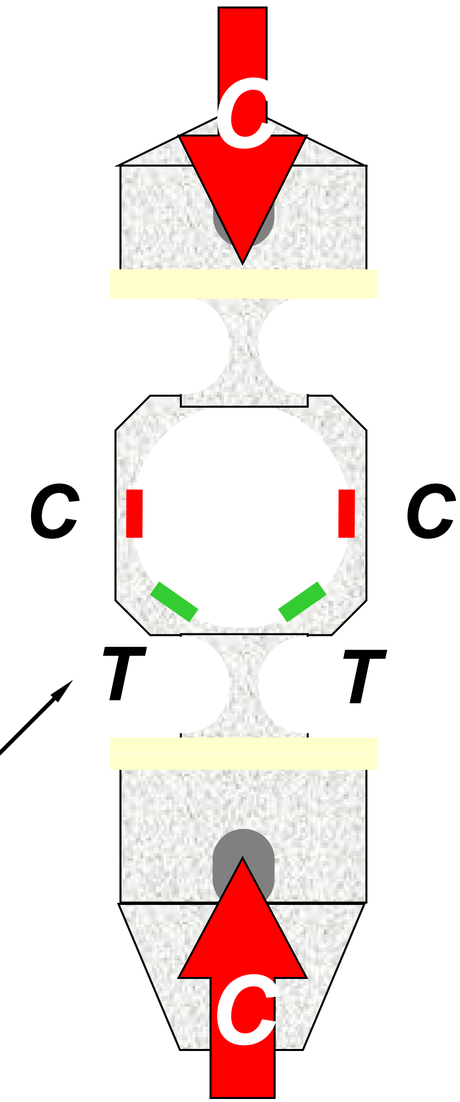
Measuring the dynamic strain

- Measuring AVERAGE section strain
- Strain transducer principles
- 2 and 4 strain transducers

Strain Transducer



$$F = sA = e\,EA$$



Strain Transducer

Resistance strain gauges connected in Wheatstone bridge configuration

Bending effects at the pile top

- Bending stresses are local stresses which can be induced by incorrect hammer-pile alignment and are **superimposed** on average section stresses
  - **the hammer may hit the pile off-centre**
  - **the pile leads may not direct the hammer parallel to the pile axis**

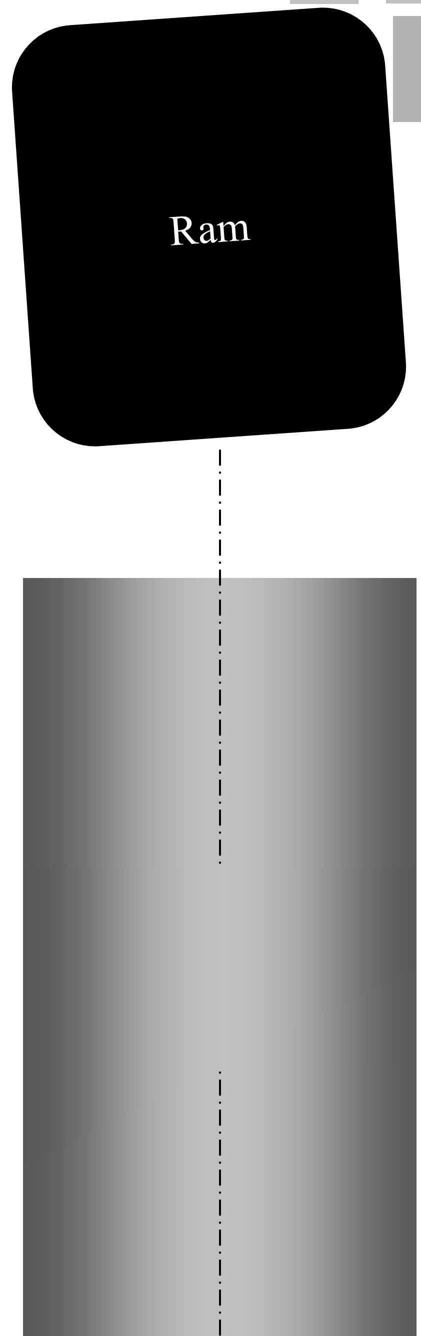
- High localised stresses should be minimized by good driving practice
- They are compensated for however by measuring the average section strain:

- $\varepsilon av = (\varepsilon_1 + \varepsilon_2)/2$, or

- $\varepsilon_{av} = (\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4)/4$

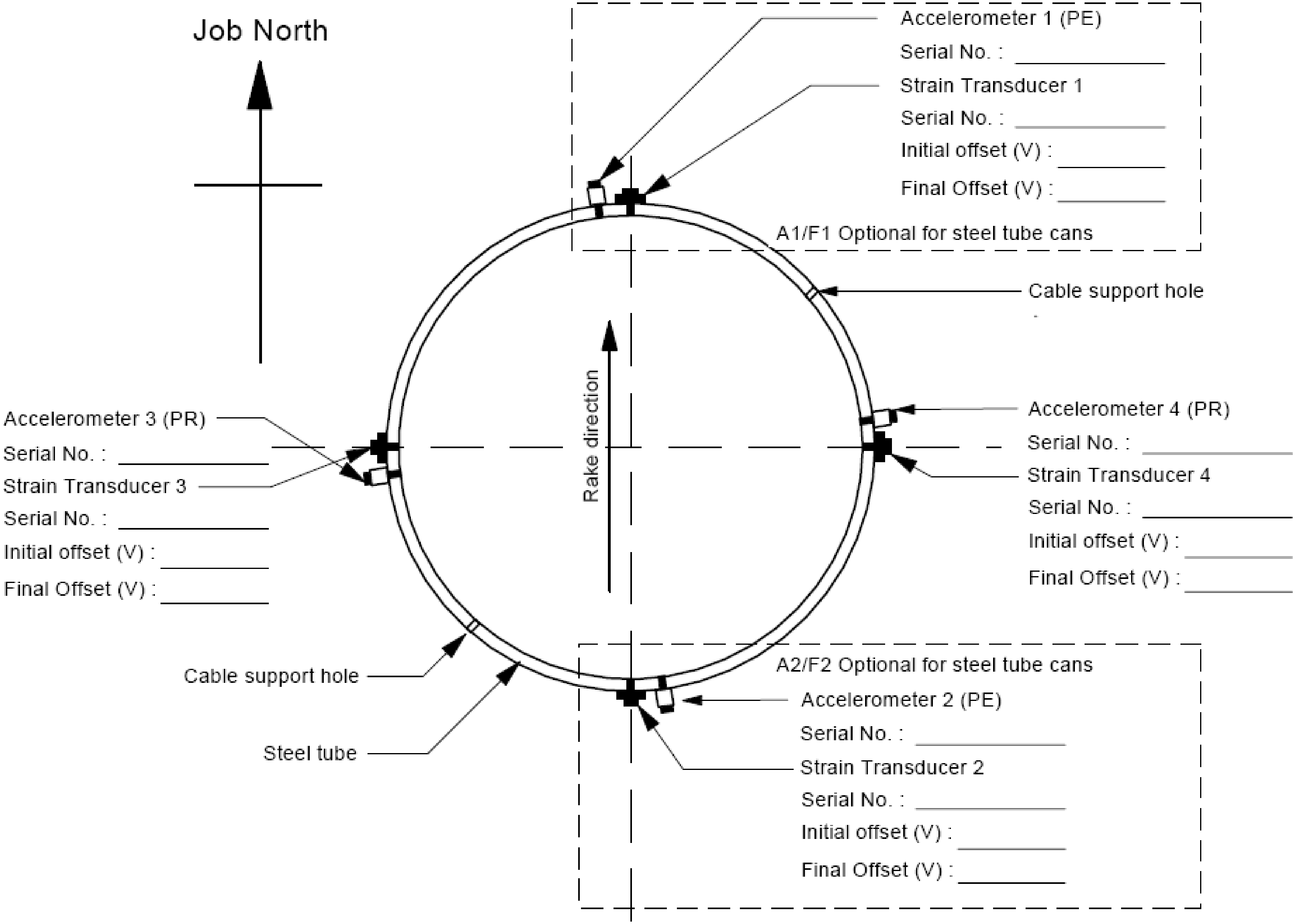
- Average section Force, $F = \varepsilon_{av} AE$

Replay



Measuring the dynamic strain

- Schematic showing transducer attachment to a steel pipe pile



Measuring average section strain

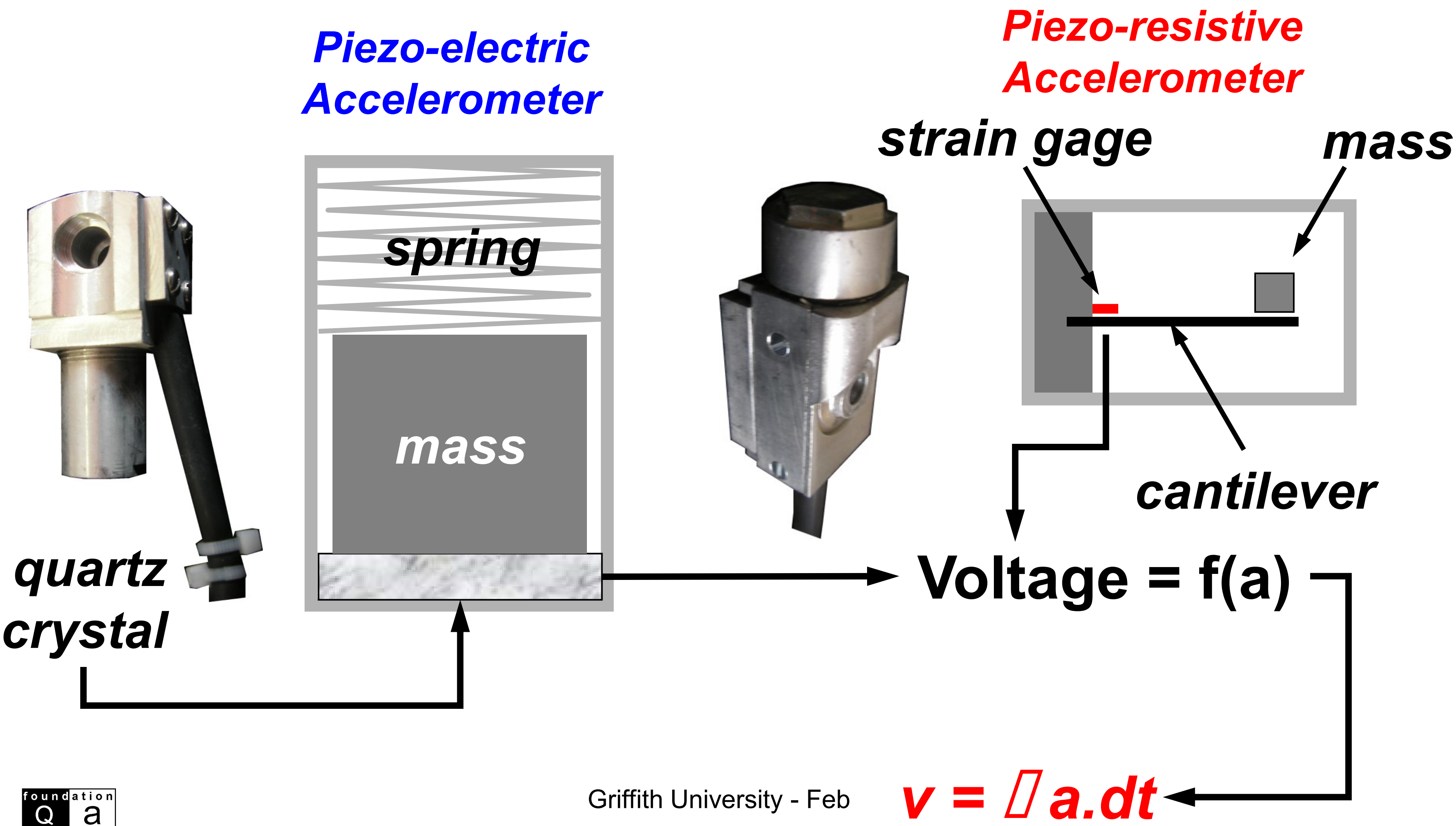
- A MINIMUM of two (2) strain transducers are required to determine the average section stress in most cases.

- **It is recommended that four (4) strain transducers be used when testing**
  - Large piles
  - Spiral welded pipe piles
  - Cast-in-situ piles
  - Timber piles
  - Any pile for which uplift capacity is to be estimated

- It is recommended that transducers are attached a distance of at least 1.5 times the pile width below the pile top. A distance of two (2) pile widths or more is preferable where possible.

- CHECK! – FORCE at start of record and end of record is stable and zero (or at least oscillates about zero line).

Accelerometers



Computing average section velocity

- Velocity is obtained by integrating the measured acceleration w.r.t time.
- v_1 , v_2 ,... v_n = individual calculated velocities at an arbitrary time, t
- 2 accelerometers used : $V_{av} = (v_1 + v_2)/2$
- 4 accelerometers used : $V_{av} = (v_1 + v_2 + v_3 + v_4)/4$

- Accelerometers measure body motion and are relatively insensitive to bending
- 2 reliably functioning accelerometers are usually sufficient
- 4 accelerometers provides redundancy and is preferred for larger piles esp.

- Accelerations are as much as 500 – 700g!

Errors in the dynamic velocity

- Repetitive high shocks can cause accelerometers to malfunction, especially in steel-steel impacts
- Rapid acceleration reversals
- Accelerometer alignment non-axial
- Sensitivity of instrument that has to measure up to 700g

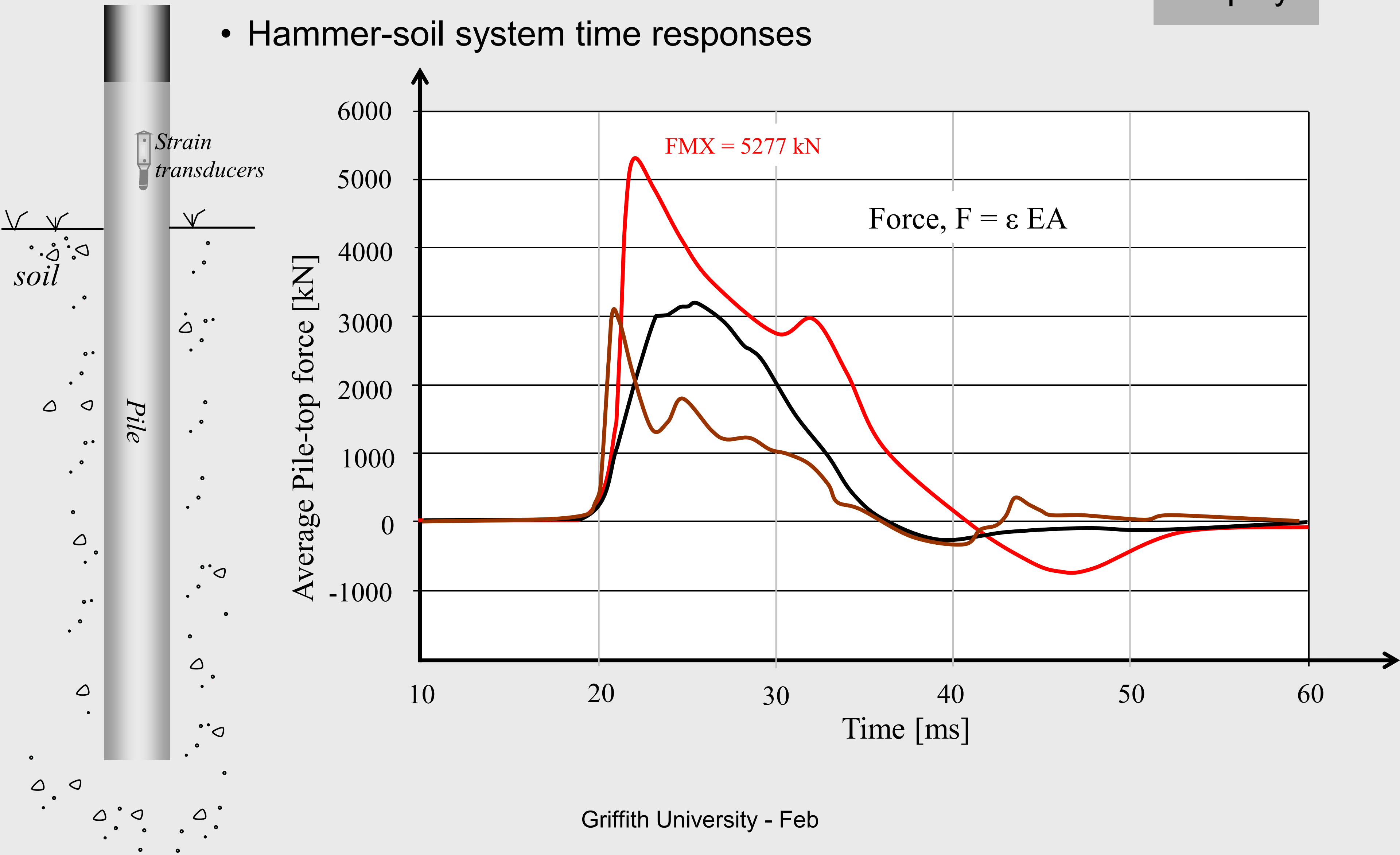
- PDA "corrects" acceleration record by imposing a zero velocity boundary condition at the end of the measurement period – generally satisfactory result.

- CHECK! – velocity at start of record and end of record is stable and zero (or at least oscillates about zero line).

Dynamic Force -Time Responses

Replay

- Hammer-soil system time responses

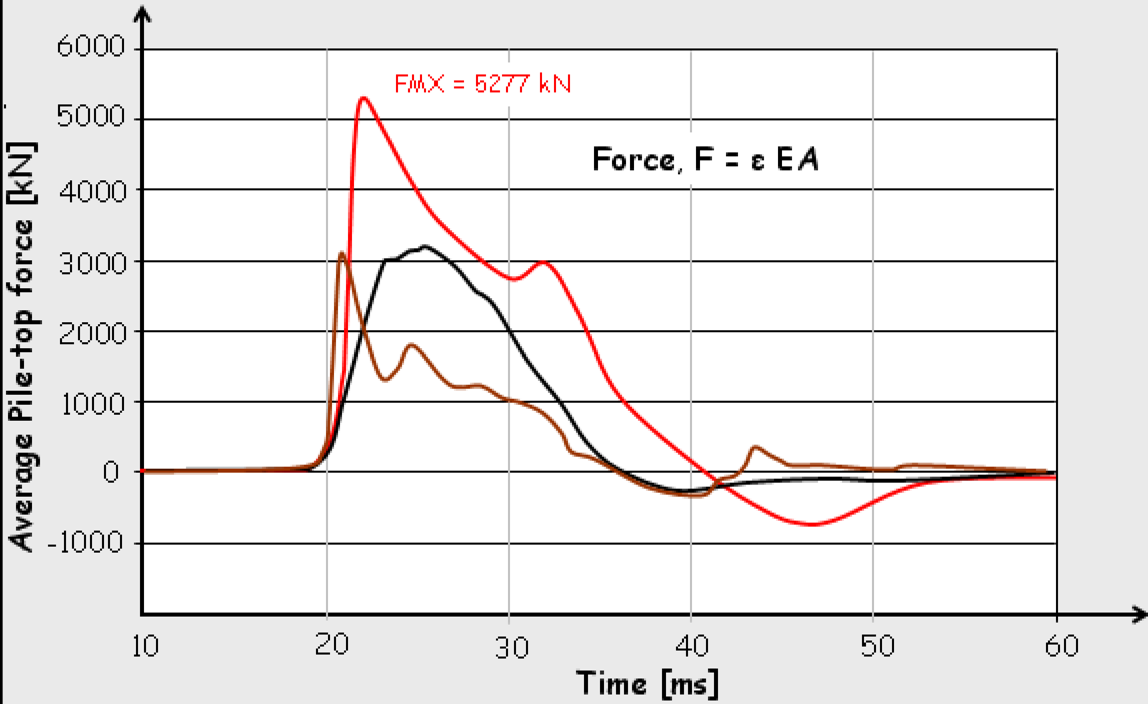


Dynamic Force-Time Responses

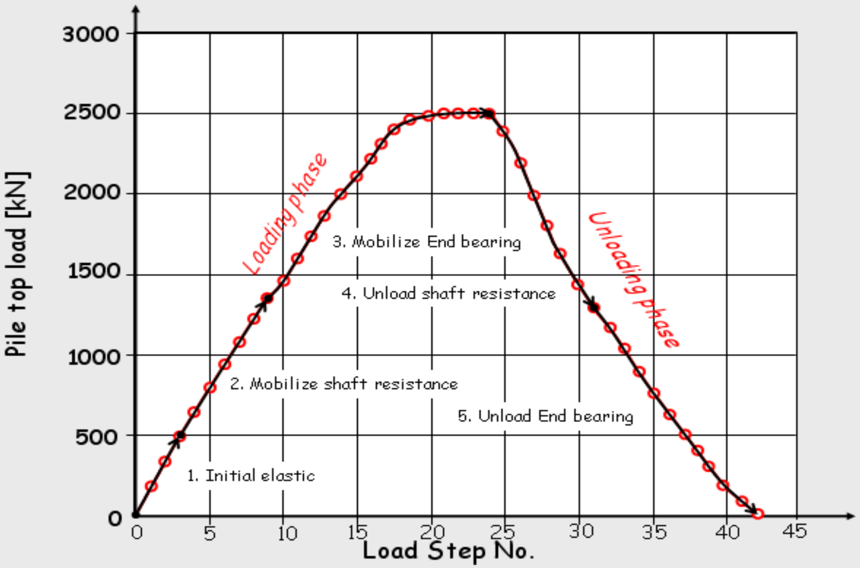
- Hammer input-time response

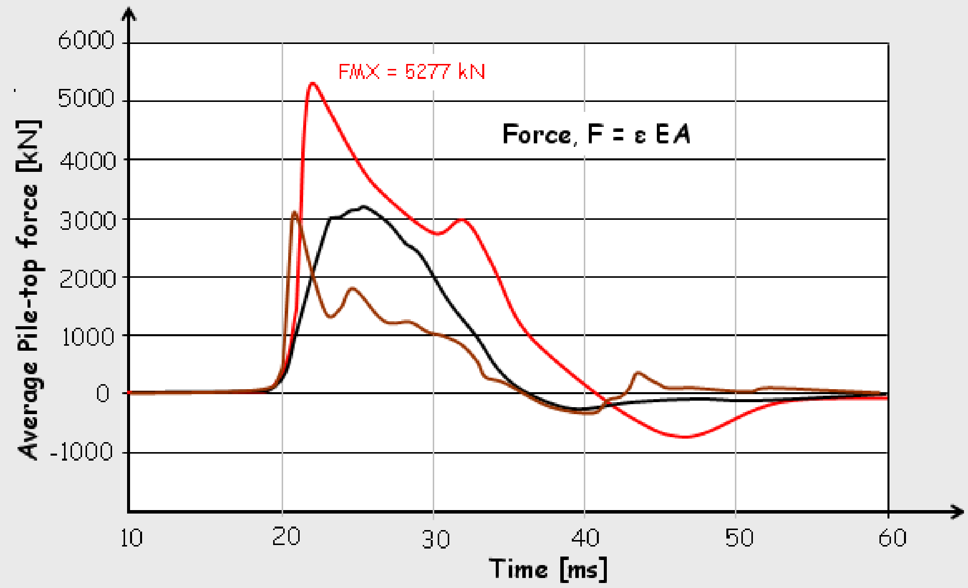
Key points are:

- Force rises quickly to peak (FMX) and then decays (exponentially) to zero with main impact completed in 5 to 10ms
- Similar to static test : 0 - peak - 0
- Shape and peak affected by type of hammer, cushion properties, pile material and geometry
- Heavy hammers on small piles: long push
- Light hammers on large piles: "bounce"
- Predict impact form in advance using GRLWEAP



Static and Dynamic Force Responses

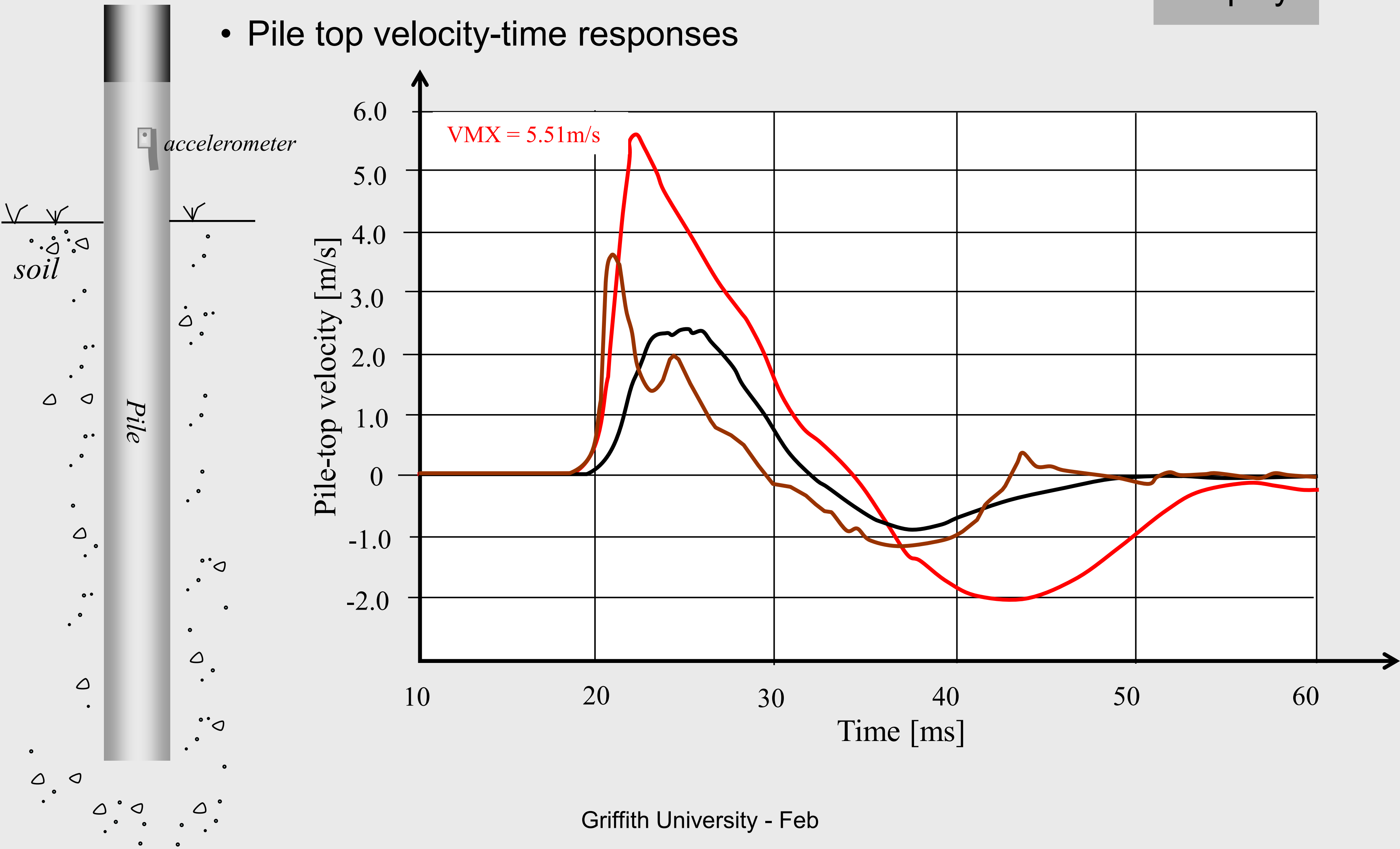




Dynamic Velocity – Time Responses

Replay

- Pile top velocity-time responses

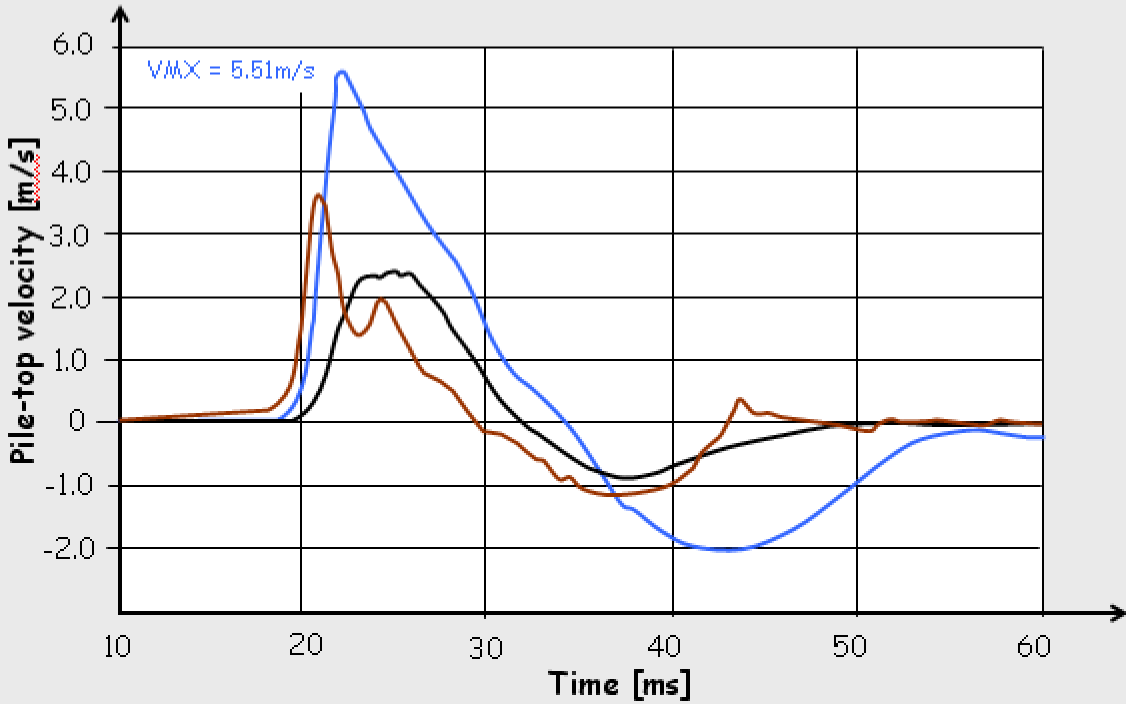


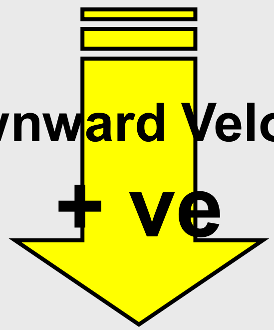
Dynamic Velocity-Time Responses

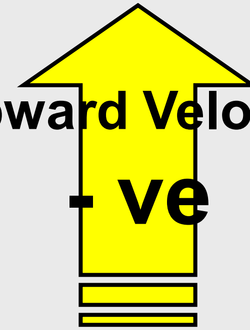
- Pile top velocity-time responses

Key points are:

- Velocity response initially similar to Force response
- Reaches peak (VMX), then starts to decay
- But rather than returning to zero, goes negative before returning to zero
- Positive velocity = downward movement; negative velocity = rebound (upward movement)







Computing pile displacement

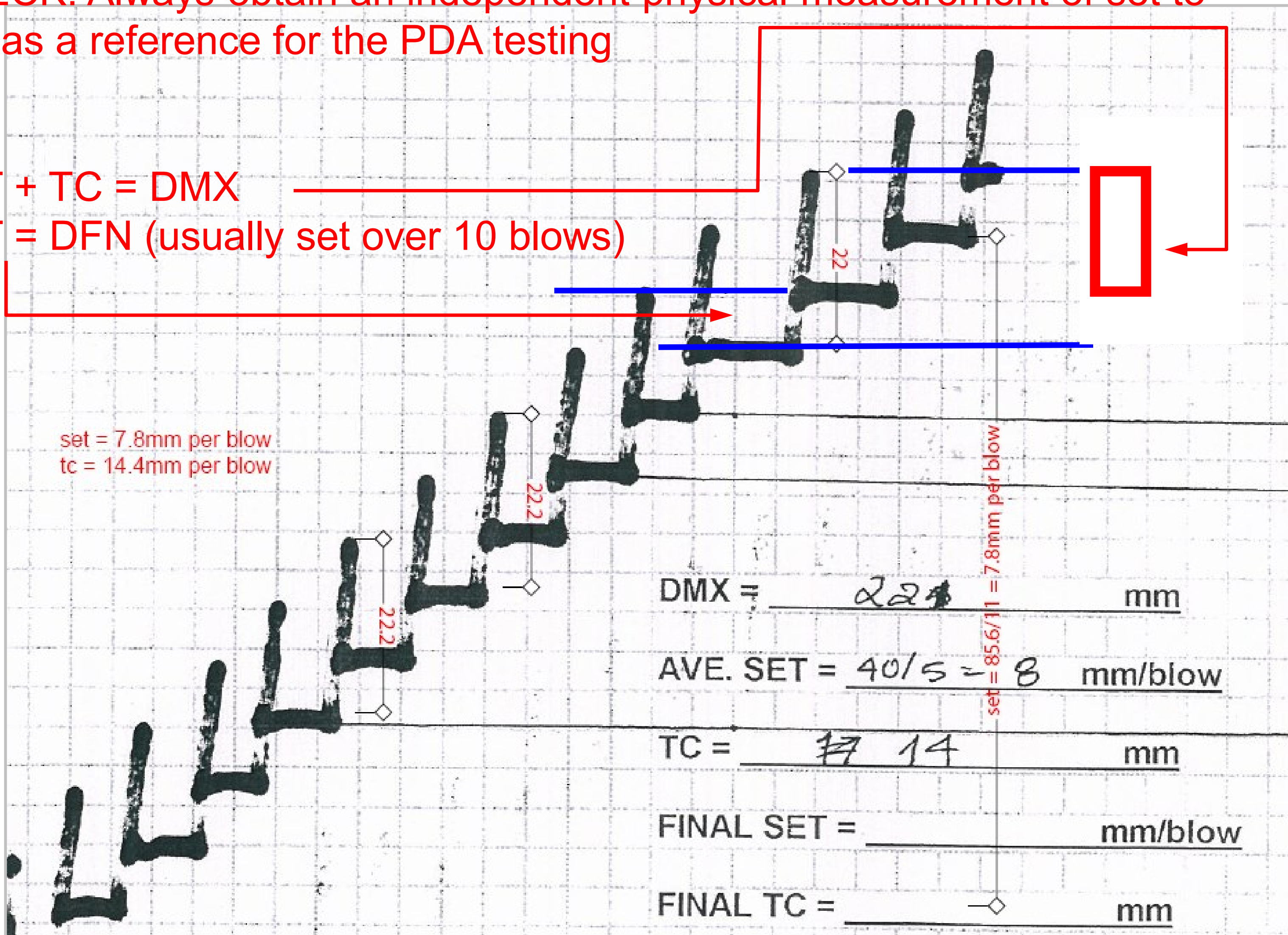
- Accelerometer is integrated once for velocity
- Double-integrated for displacement
- Integration errors - small for small time intervals, substantial for large time intervals
- Maximum displacement (DMX) occurs soon after impact, and hence is quite reliable
- Final displacement (DFN) occurs after a (relatively) long time, and cannot therefore be assumed reliable

Set card – a physical reference

CHECK! Always obtain an independent physical measurement of set to use as a reference for the PDA testing

SET + TC = DMX

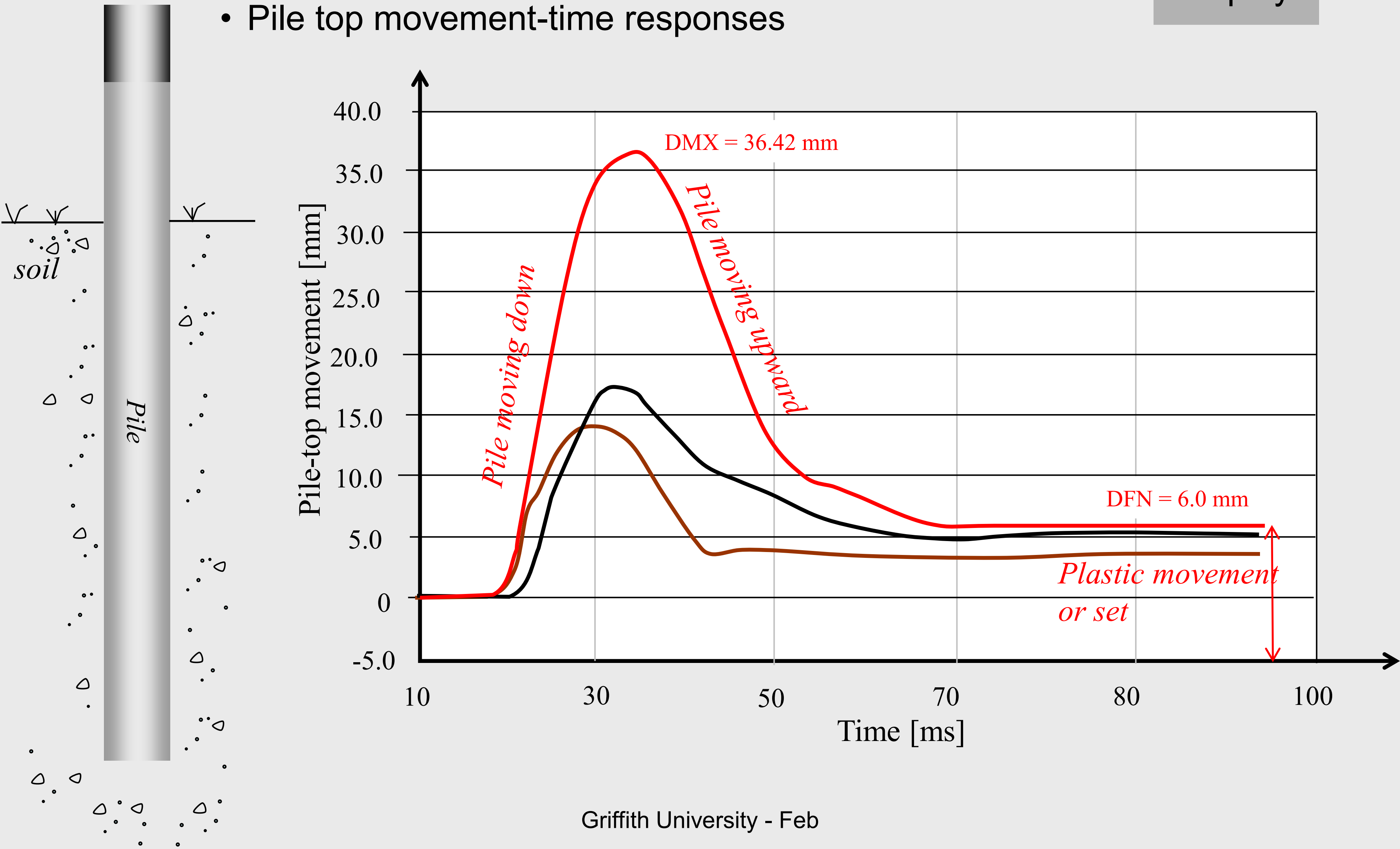
SET = DFN (usually set over 10 blows)



Dynamic Movement – Time Responses

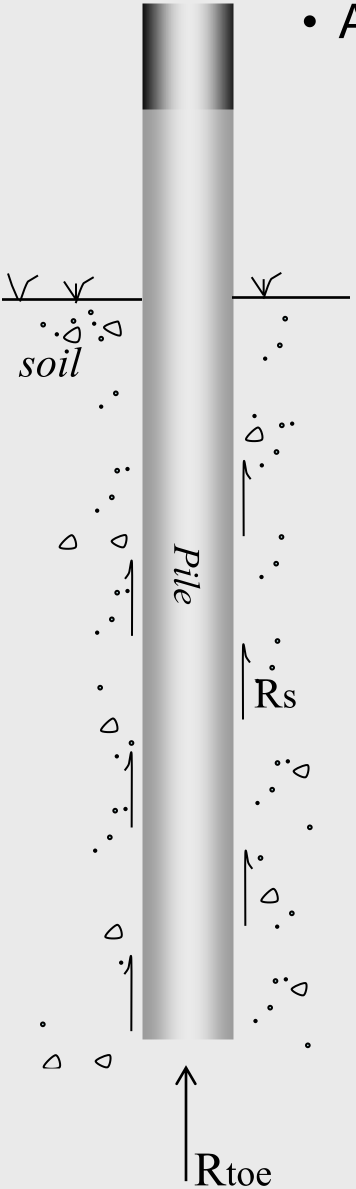
Replay

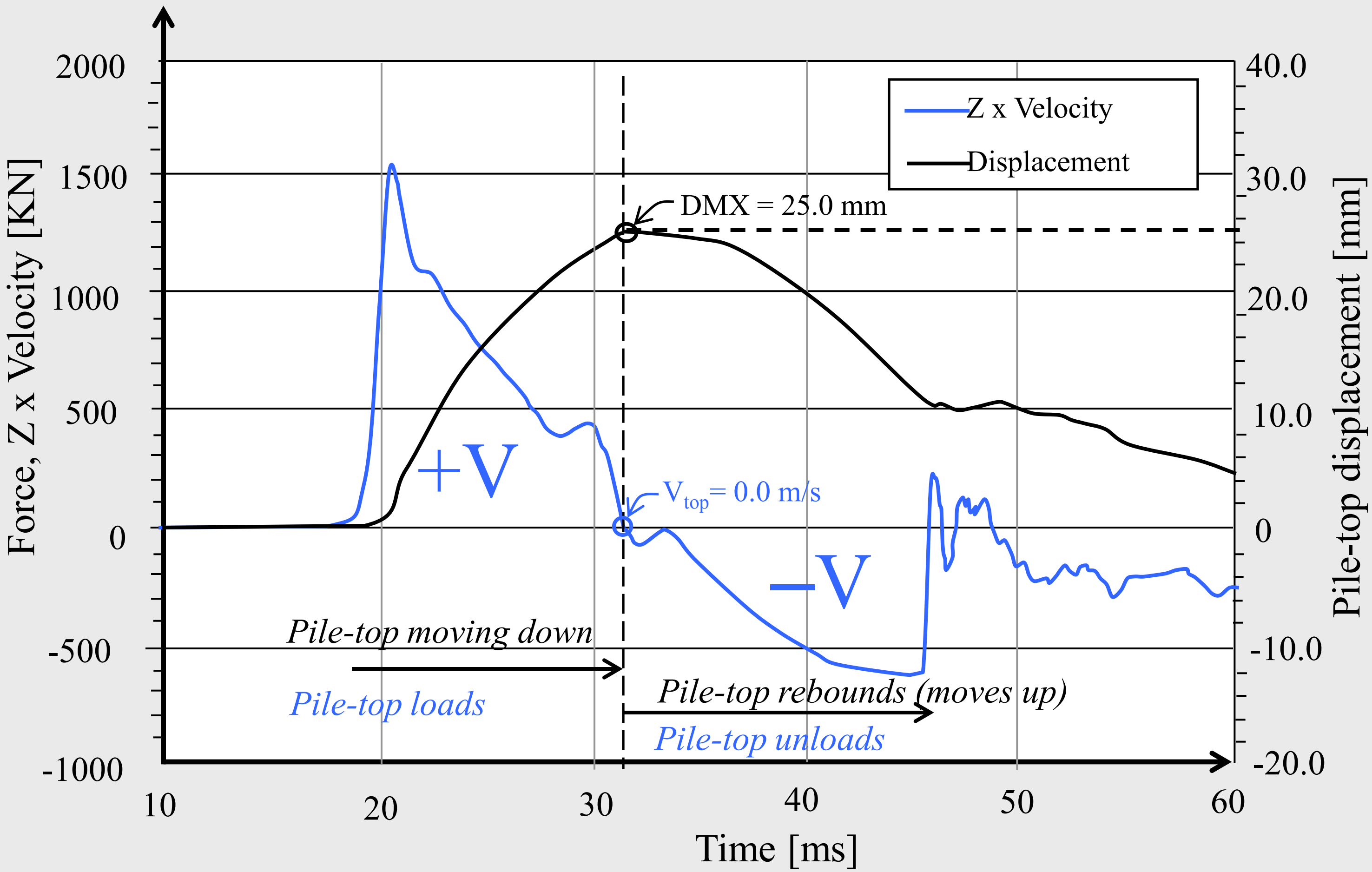
- Pile top movement-time responses



Loading and unloading

- At time, t ≈ 31.5 ms $V_{top} = 0$



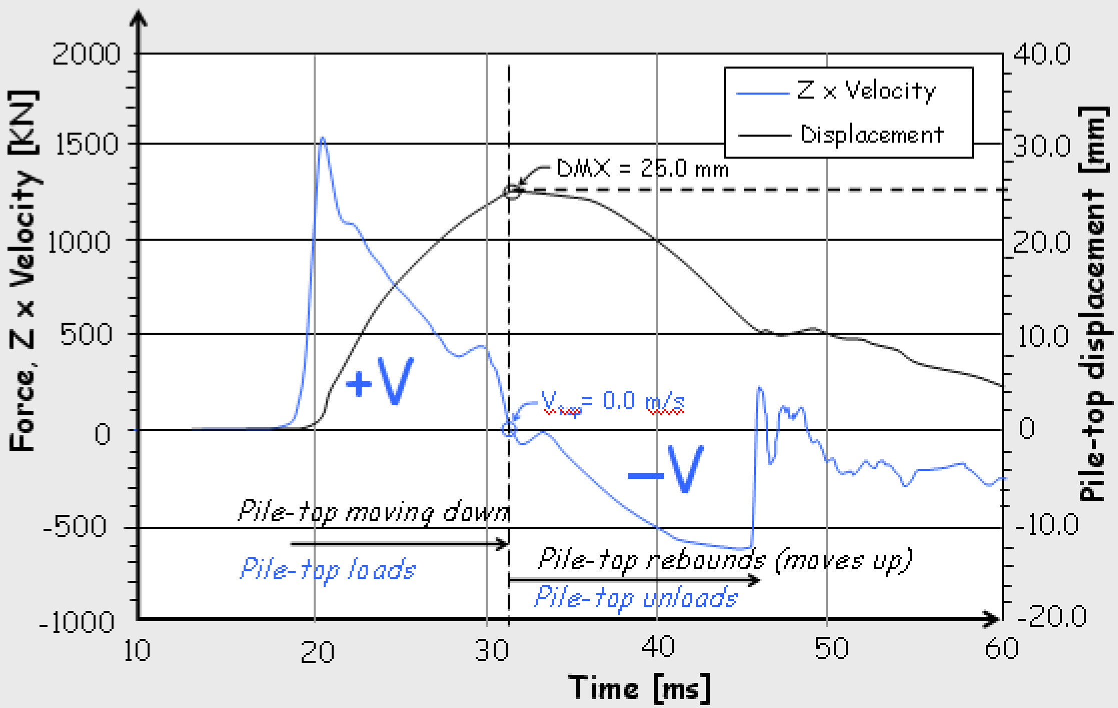


Replay

Loading and Unloading

Key points are:

- Pile-top moves down while V is positive and reaches DMX when V=0 (pile-top comes to rest)
- Pile top resistance is mobilized (loads) until V=0
- Pile-top rebounds when V is negative
- Pile-top resistance sheds (unloads) when V is negative

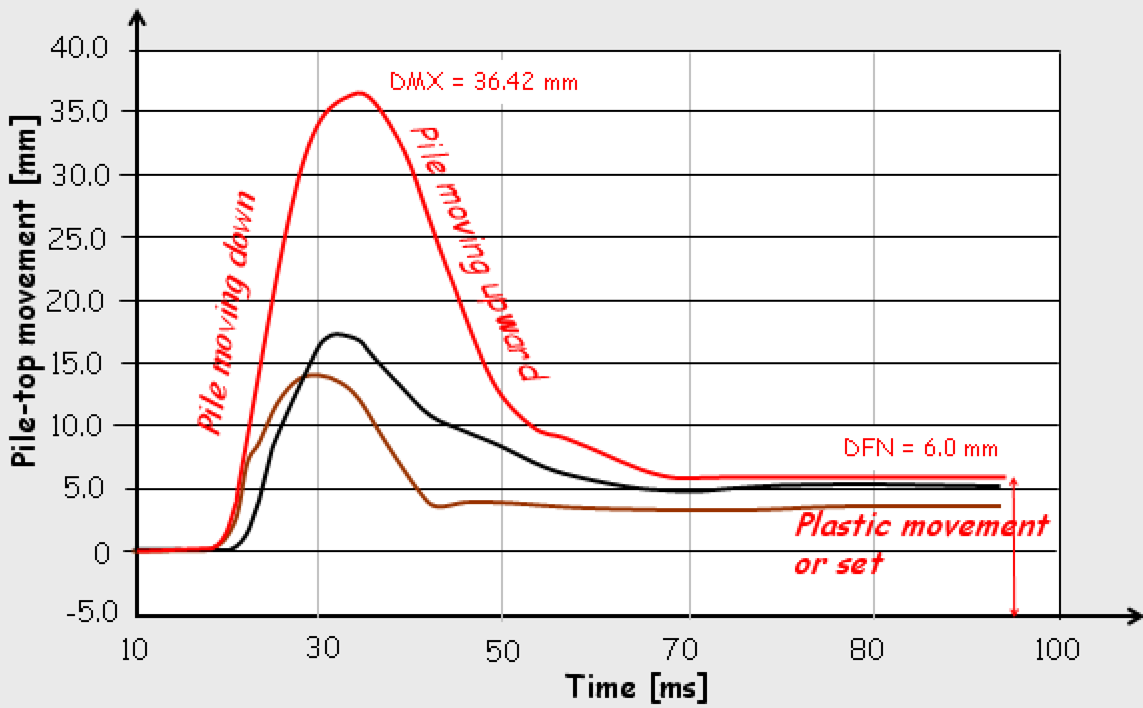


Dynamic Movement-Time Responses

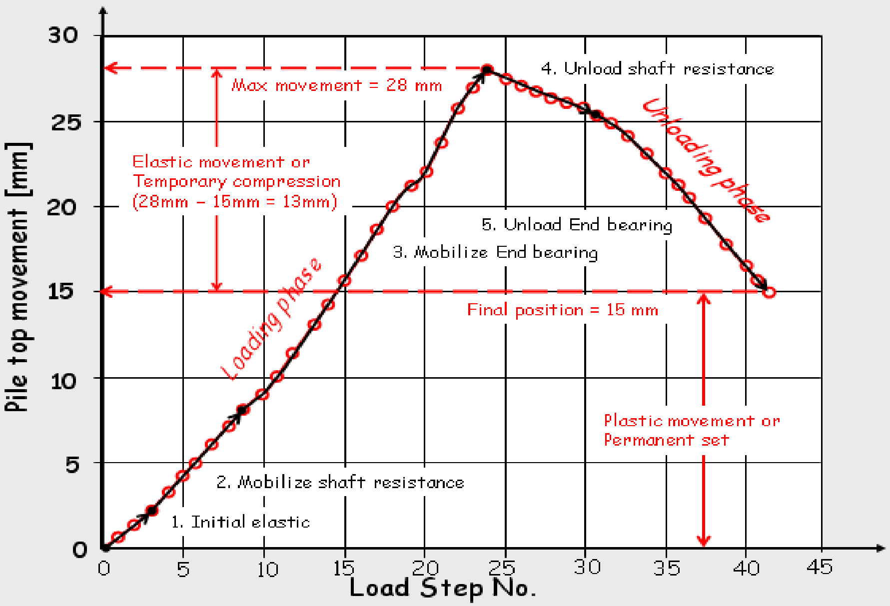
- Pile top movement-time responses

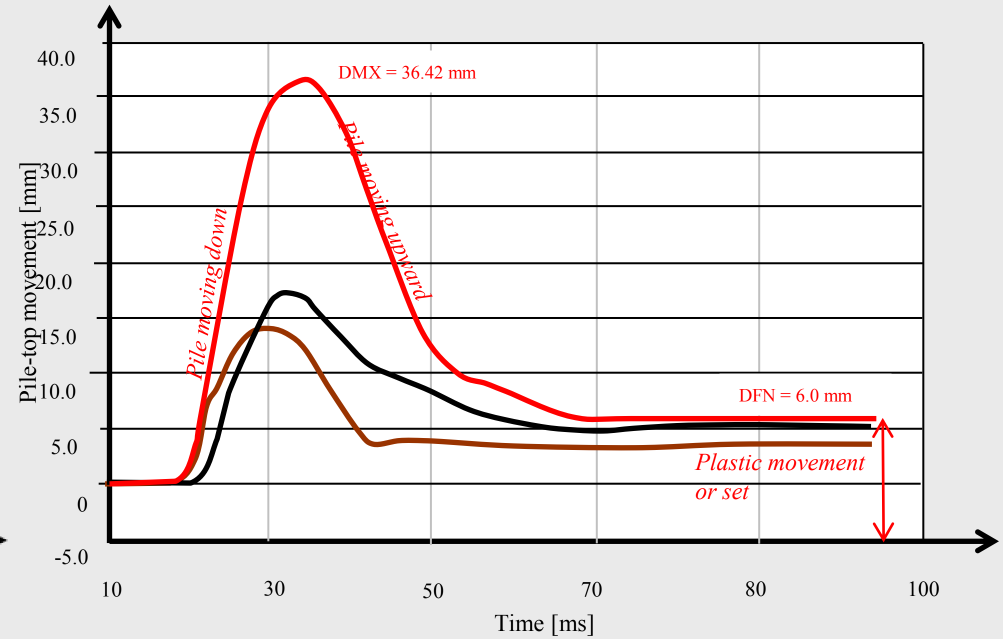
Key points are:

- Displacement response determined by integration of velocity
- Displacement reaches a maximum (DMX), then rebounds to final (DFN)
- DFN = SET
- TC (Rebound) = DMX – DFN
- Progressive loading as pile moves DOWN, progressive unloading as pile rebounds UP



Static and Dynamic Movement Responses





- Note similar form to static load test movement-time step response
- If the displacement responses are similar, the equivalent 'velocity' responses must also be similar
- Dynamic velocity is the derivative of the computed pile-top displacement
- The static test is really quasi-static, and the 'velocity' corresponds to rate of movement per load- or time-step

Animations

•Animations of free-end and fixed-end piles


1.exe


4.exe


5.exe

Wavespeed, ‘c’

- Dynamic events travel at the speed of sound in the material
- Wavespeed = c (celerity)

$$c = \sqrt{(E / \rho)}$$

- Steel - E (206,000 MPa) and ρ (7.85 t/m3) fixed : c (5120 m/s) fixed

- Concrete - E is a function of age, constituent properties, strain level, ρ varies but over a small range : c varies 3200 m/s to 4400 m/s

- Timber - E and ρ vary considerably for species, age etc, so c also varies widely

Hooke's Law - Equivalency

- Hooke's Law and Static Loading :
  - **Stress, σ = strain, ε x modulus of elasticity, E**
  - F/A = d/L x E
  - F = d EA/L

- Hooke's Law and Dynamic Loading :
  - **Stress, σ = strain, ε x modulus of elasticity, E**
  - F/A = v/c x E
  - F = v EA/c or F = v Z

Z = pile impedance = EA/c

Force/Velocity Proportionality

$$F = v\,Z$$

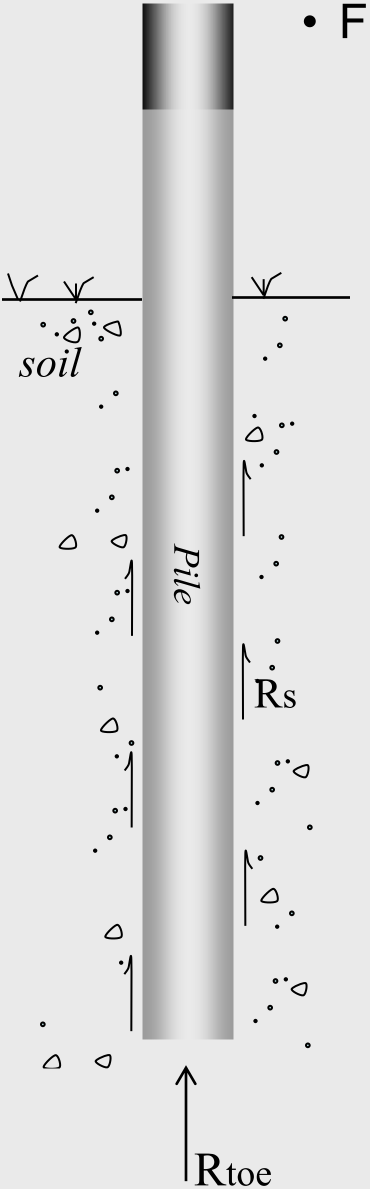
- Force and Velocity of any SINGLE wave travelling in a pile will be proportional
- Initially only a single wave travels from the hammer down the pile
- Therefore F = v.Z at the start, and until the first soil or pile reflections return to the pile-top

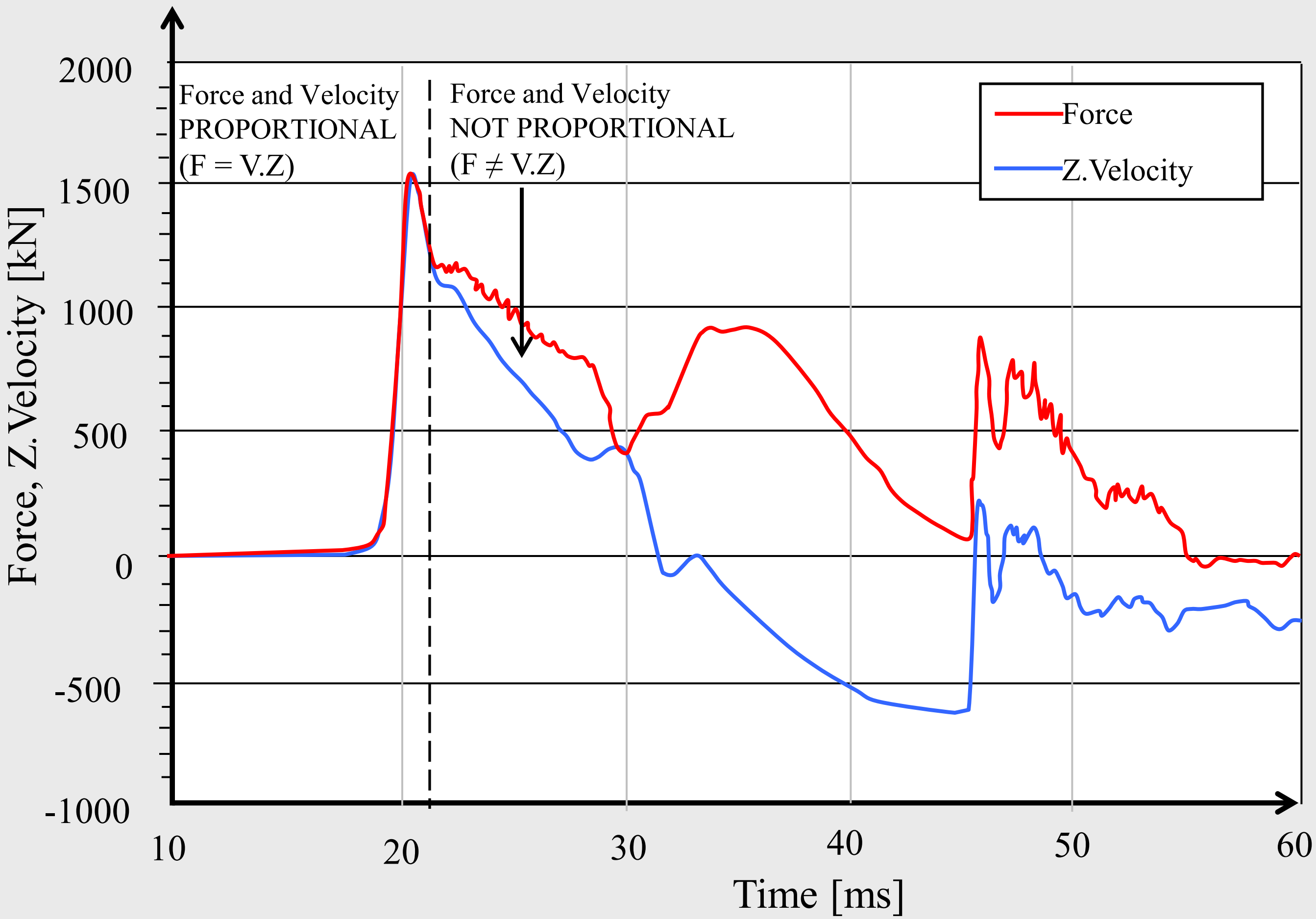
- This concept allows us to compute Z (EA/c) and hence pile modulus, E, from the relationship between F and v at the start of the impact.

Force/Velocity Proportionality

Replay

- From time, t ≈ 21.5 ms F ≠ v.Z





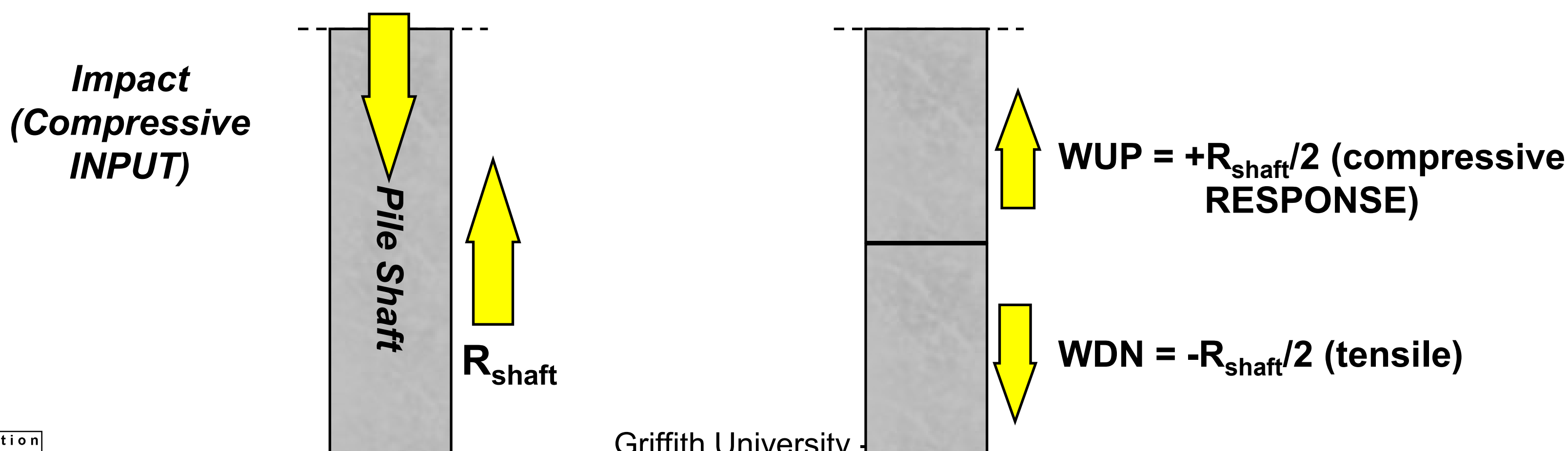
Reflected Waves - Shaft

- Waves travel both UP and DOWN the pile

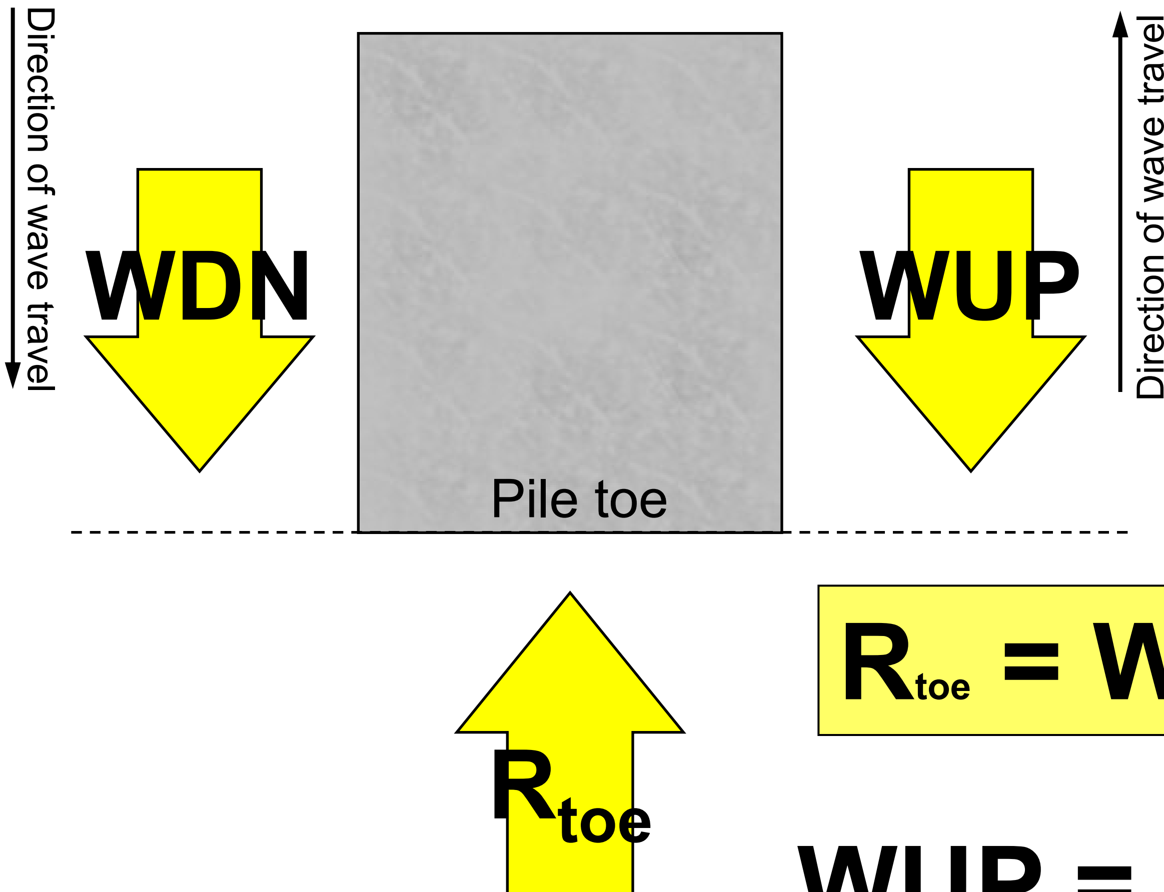
- The waves travelling DOWN are from the hammer – they are the INPUT
- The waves travelling UP are from the soil – they are the RESPONSE

- We are most interested in the SOIL response and hence UPWARD wave

- A soil resistance on the shaft of R_{shaft} will send back a reflection of $R_{shaft}/2$



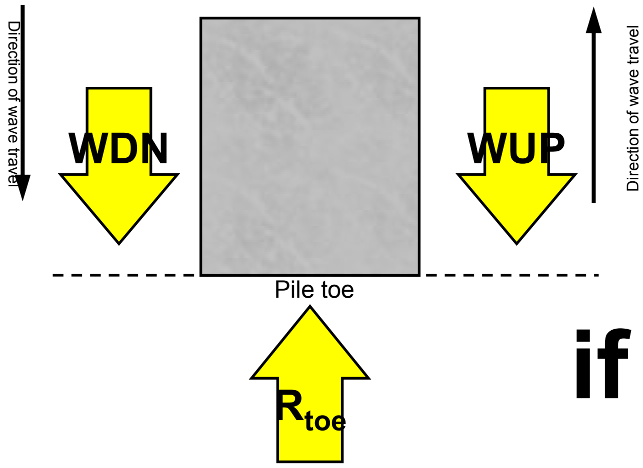
Reflected Waves - General Toe Response



$$R_{toe} = WDN + WUP$$

$$WUP = R_{toe} - WDN$$

Toe Response – Special cases



$$R_{toe} = WDN + WUP$$

$$\text{if } R_{toe} = 0 : \quad WUP = -WDN$$

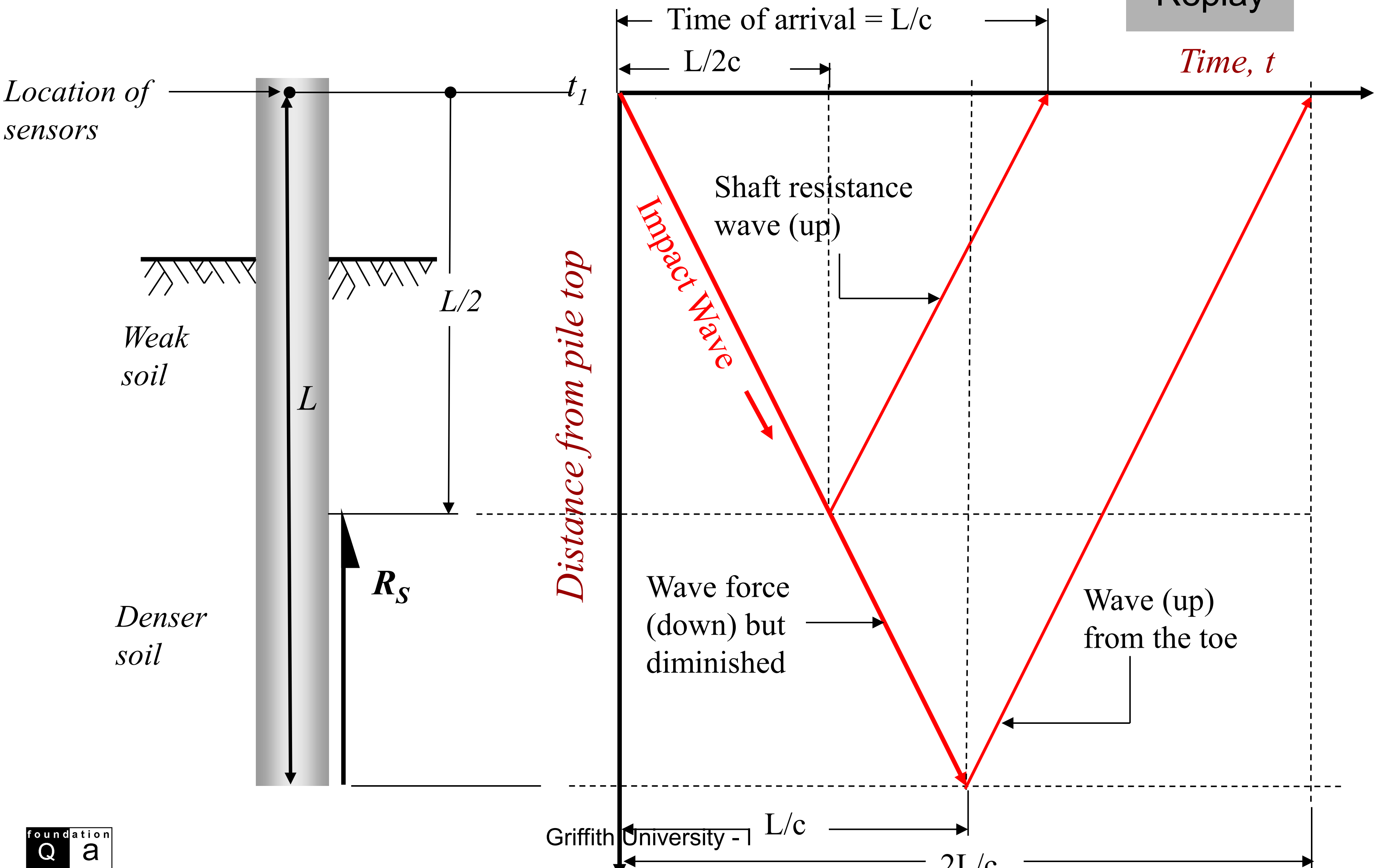
$$\text{if } R_{toe} = WDN : \quad WUP = 0$$

$$\text{if } R_{toe} = 2WDN : \quad WUP = WDN$$

As WDN is always compressive, reflection from toe can vary over full spectrum from full TENSION to full COMPRESSION depending on RELATIVE magnitudes of incoming wave and available toe resistance.

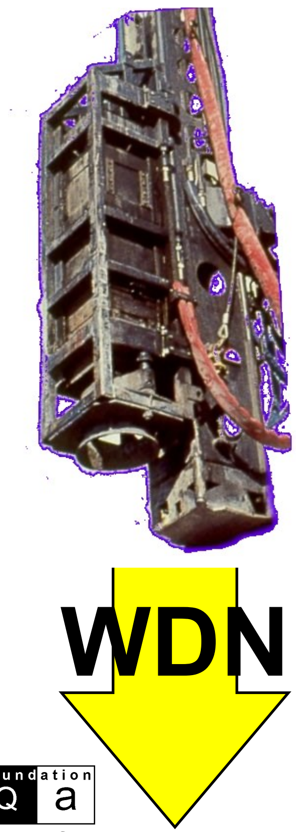
Wavespeed

Replay



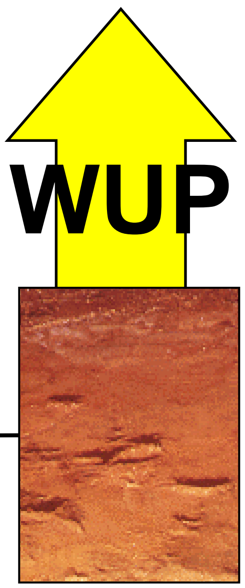
Reflected Waves

- We are most interested in the SOIL response and hence UPWARD wave
- By measuring FORCE and VELOCITY at one point we are able to separate the two wave components by a simple mathematical transformation. Hence :



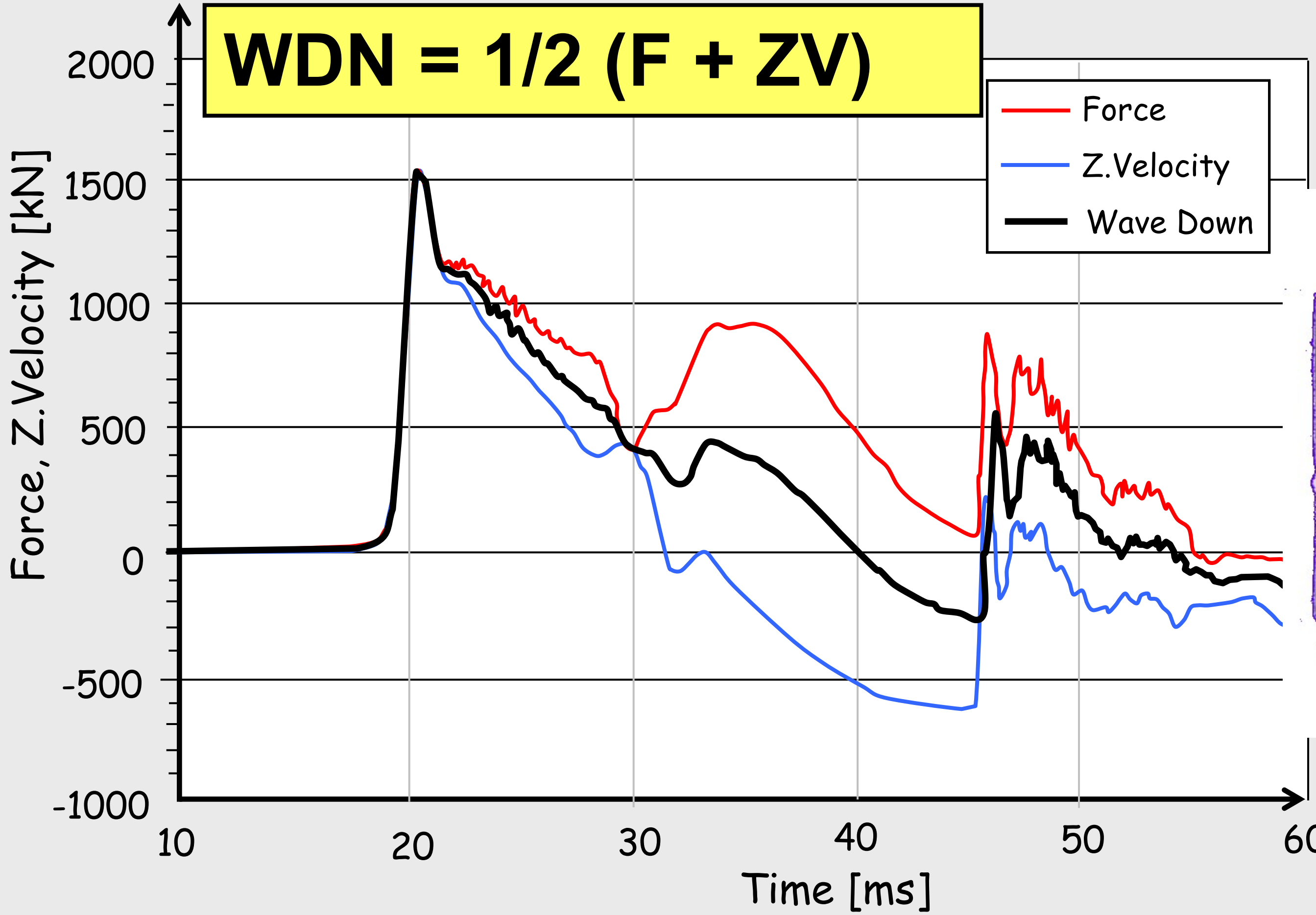
WDN = 1/2 (F + ZV)

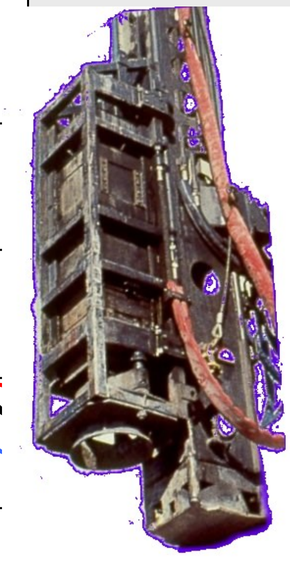
WUP = 1/2 (F – ZV)



F,VZ and WDN Equivalency

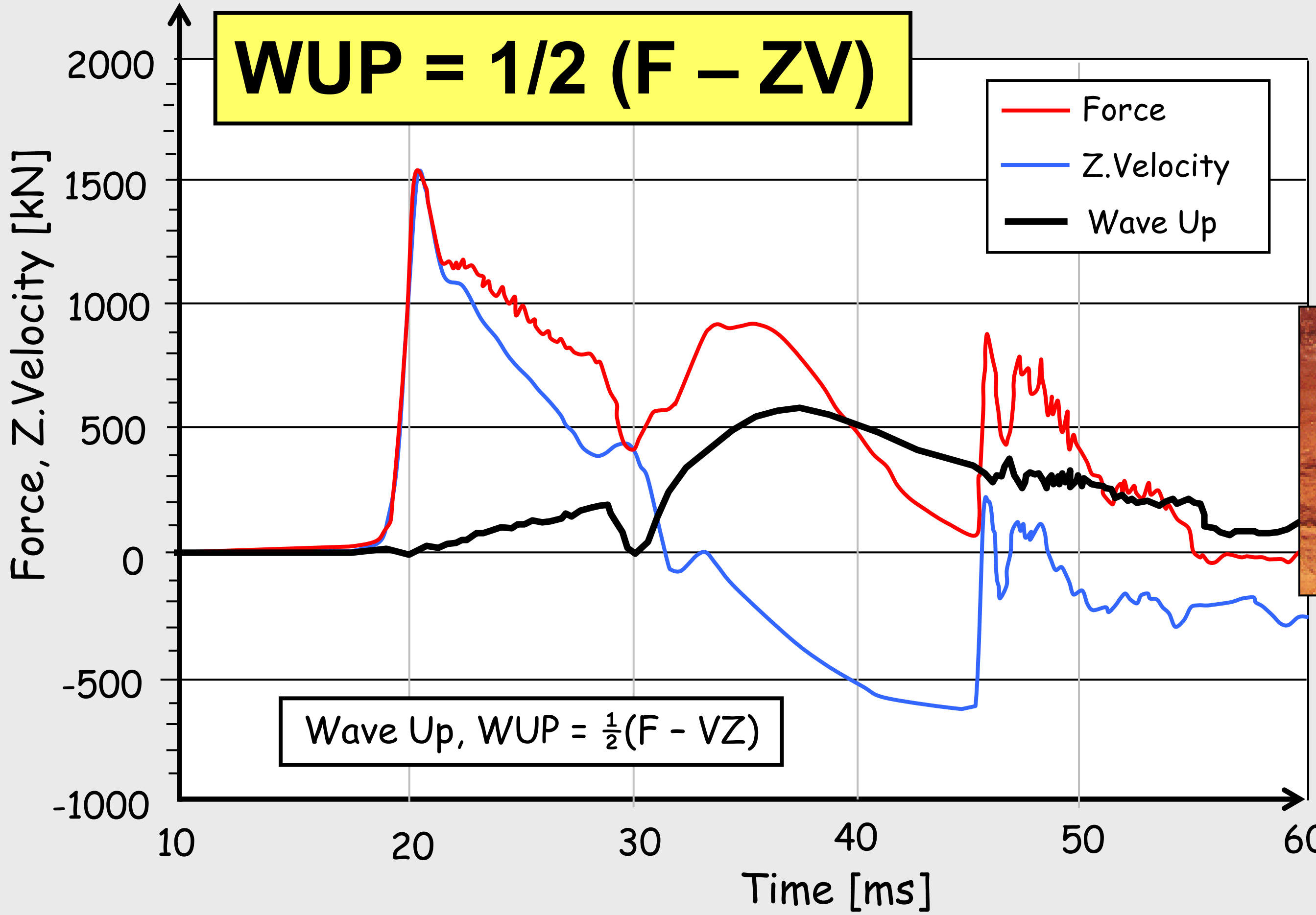
Replay

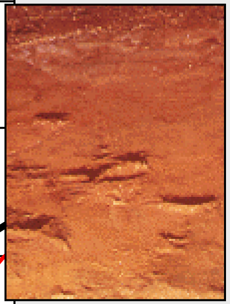




F,VZ and WUP Equivalency

Replay



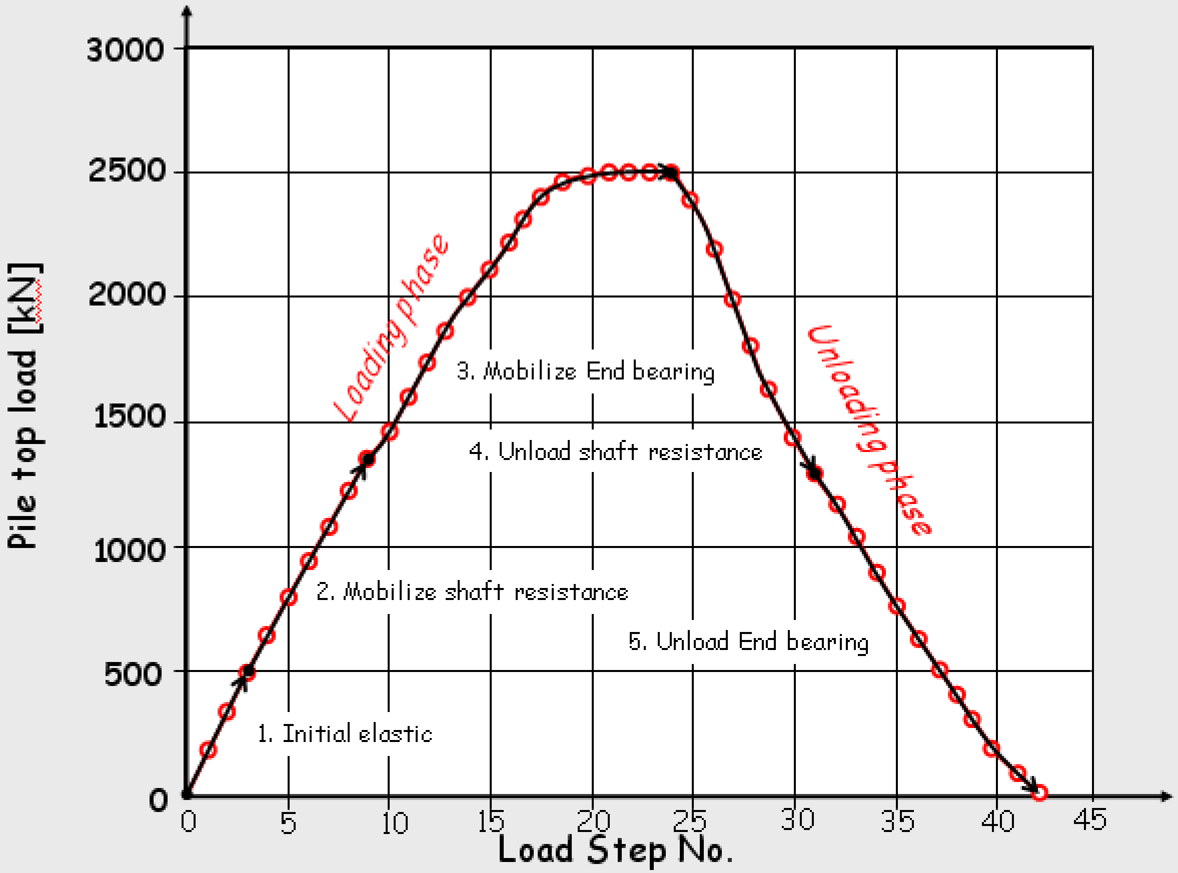


<u>The Wave Up curve is the most important of all dynamic testing curves</u>

Progressive Loading – Static case

Key points are:

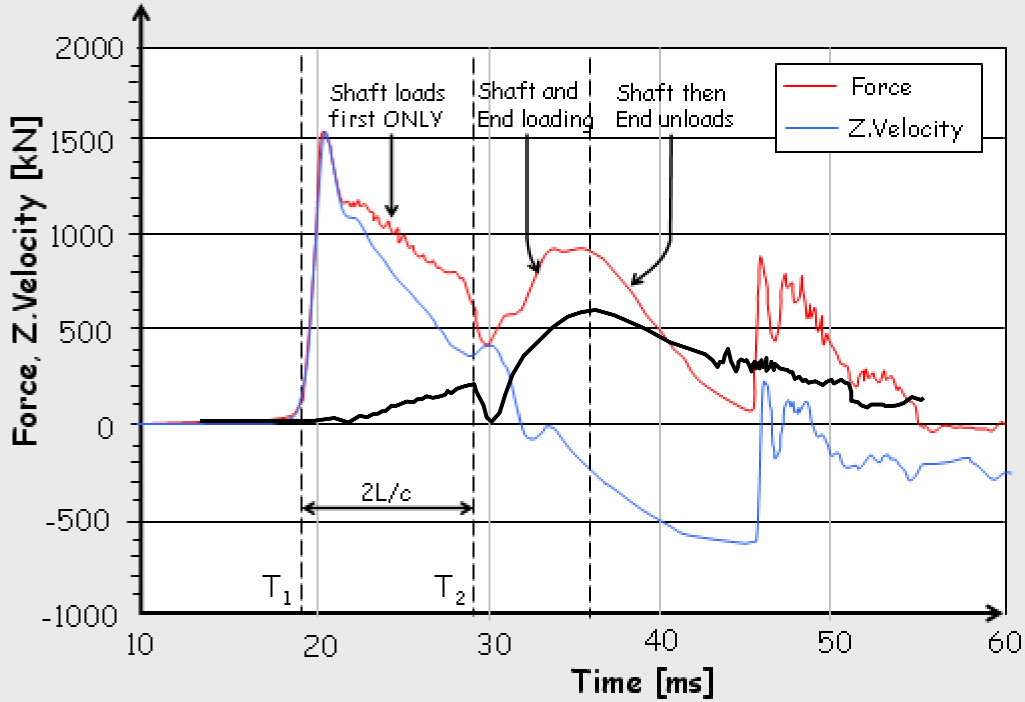
- Shaft loads first (top to bottom)
- End bearing loads last
- Significant overlap and separation often unclear
- Shaft resistance unloads first (top to bottom)
- End bearing unloads last



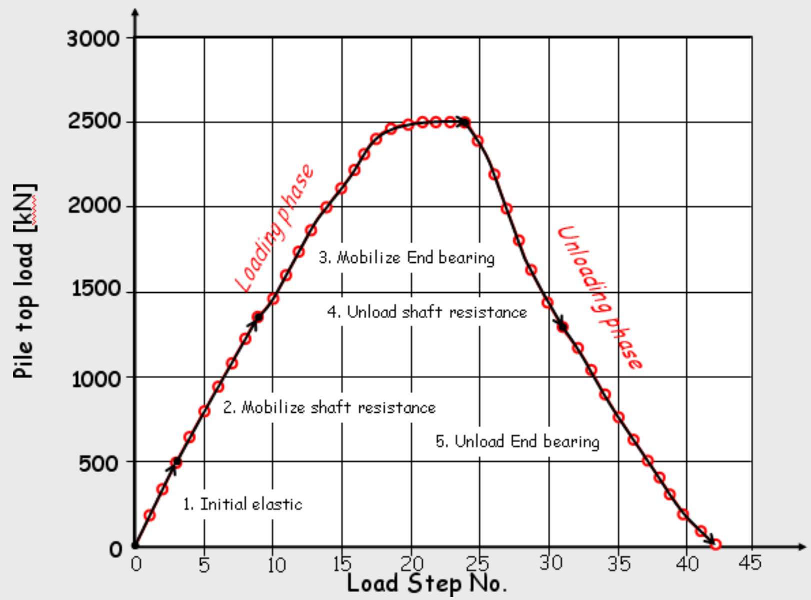
Progressive Loading Dynamic

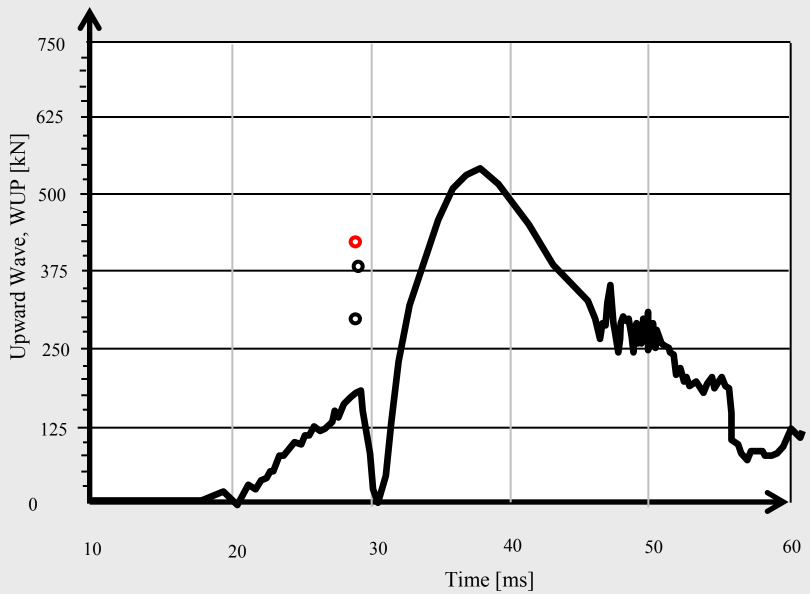
Key points are:

- Resistance only loads on arrival of wave front
- Shaft loads first (top to bottom)
- End bearing loads last
- Overlap depends on sharpness of blow, separation more distinct than for static
- Shaft resistance unloads first (top to bottom)
- End bearing unloads last



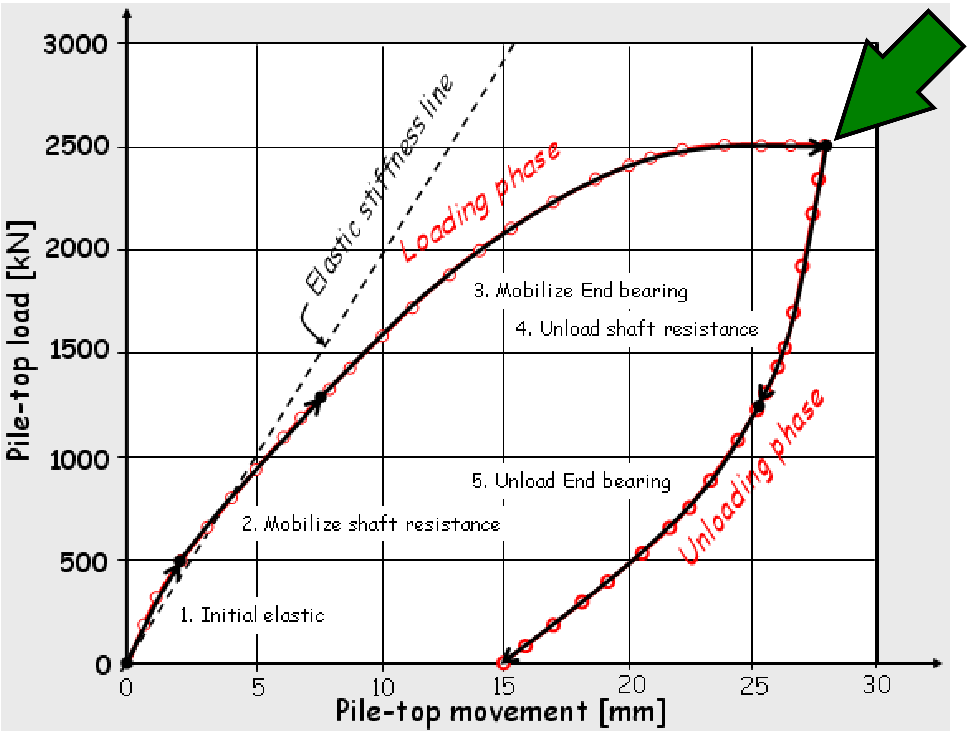
Static Resistance and WUP Equivalency

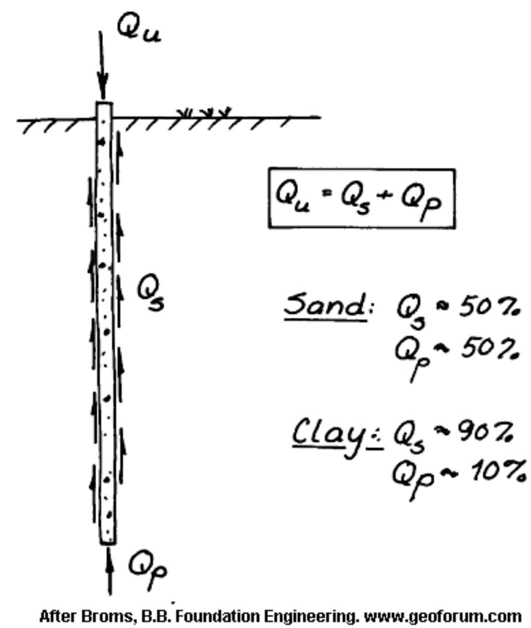




Note : Resistance ≈ 2 x WUP

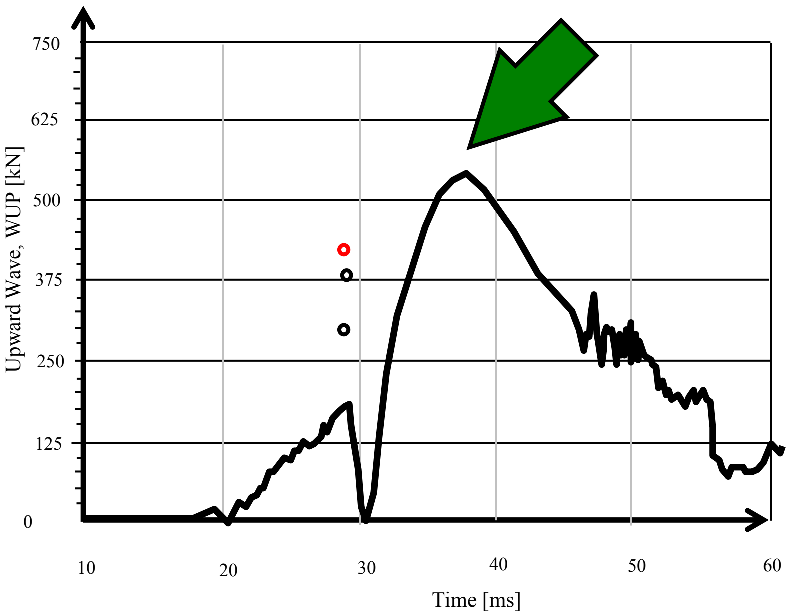
Maximum Resistance – Static Test

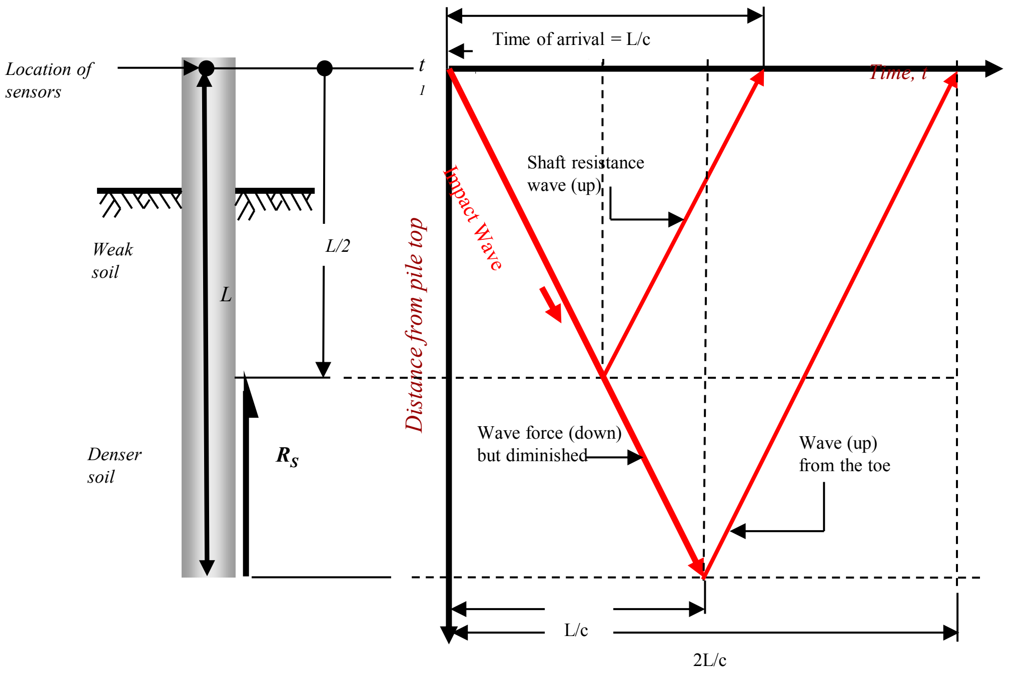




- In a static test, the maximum resistance is mobilized just prior to rebound or unloading
- All shaft and all toe resistance has been 'ENGAGED' or MOBILIZED
- Resistance = Applied Load (Static Equilibrium) : $Q_u = Q_s + Q_p$

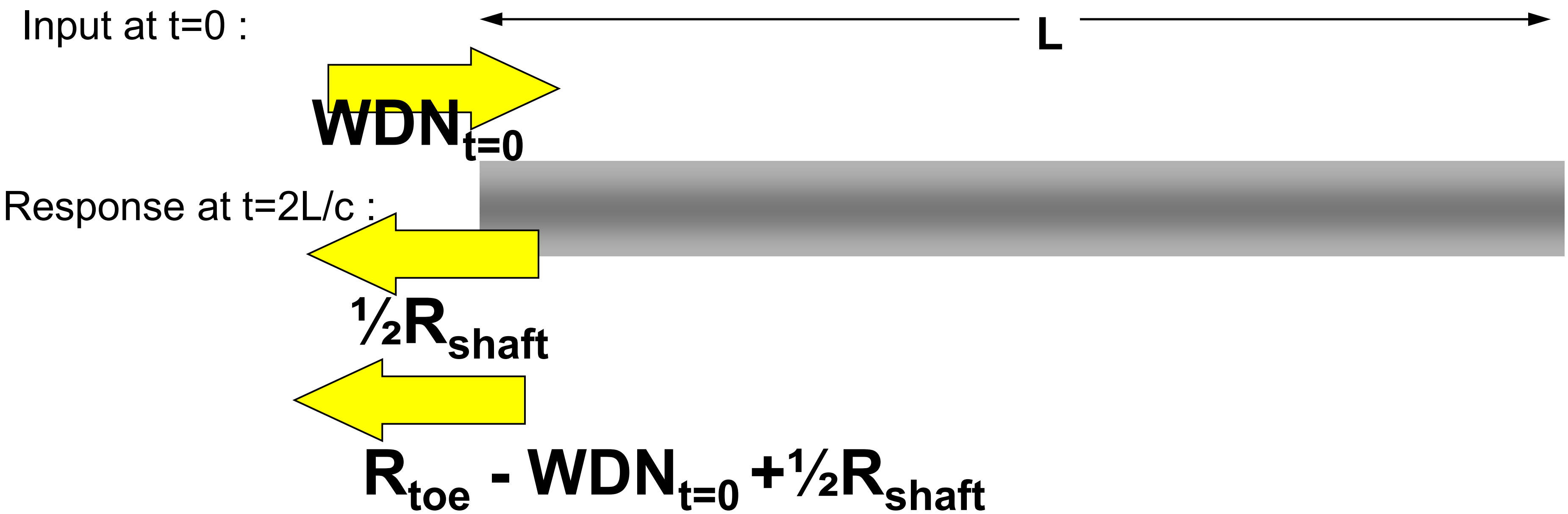
Maximum Resistance – Dynamic Test





- In a dynamic test, the maximum resistance is mobilized just prior to rebound or unloading
- ALL shaft and ALL toe resistance has been 'ENGAGED' or MOBILIZED
- Resistance = Input + Response : $R_{total} = WDN_{t=0} + WUP_{t=2L/c}$

Case-Goble TOTAL Capacity



$$R_{case} = R_{toe} + R_{shaft} = WDN_{t=0} + WUP_{t=2L/c}$$

- This is the **Total (Static and Dynamic) Pile Resistance**
- The Dynamic or DAMPING component must be removed

Case-Goble Static Resistance

$$R_{total} = R_{toe} + R_{shaft} = WDN_{t=0} + WUP_{t=2L/c}$$

$$-$$

$$R_{dyn} = J_c \, Z \, v_{toe}$$

$$=$$

$$R_{static} = (1- J_c)\, WDN_{t=0} + (1+ J_c)\, WUP_{t=2L/c}$$

- It is normally assumed that the Case Damping factor, J_c, is a function of soil type (see next slide)
- It is also often assumed that every site has a unique Case Damping factor.
- **Neither of these assumptions can be assumed to be true**

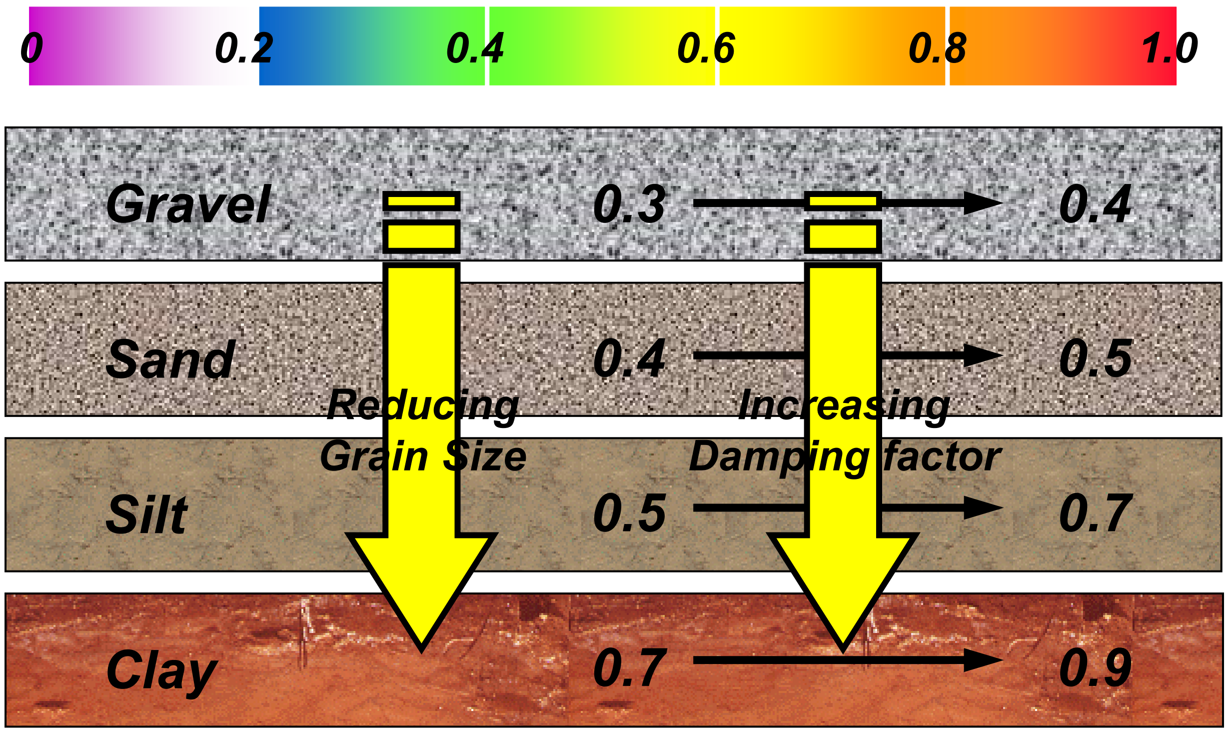
- **Case Damping factor will vary as a function of anything which affects pile velocity - hammer type, pile type, hammer stroke, hammer efficiency, site variations, pile set-up etc. etc.**

Case-Goble Other Comments

- Case Method is limited to UNIFORM section piles
- Where pile velocity is high (e.g. low capacity, easy driving), Case Method is very sensitive to J_c - but not typically interested in capacity at that stage.
- Where pile velocity is low (e.g. high capacity, hard driving), Case Method is less sensitive to J_c - this is when we most want to know capacity
- **Don't apply too much energy and generate high velocity and high pile set (pref <10mm), as capacity may be poorly estimated and typically overestimated**

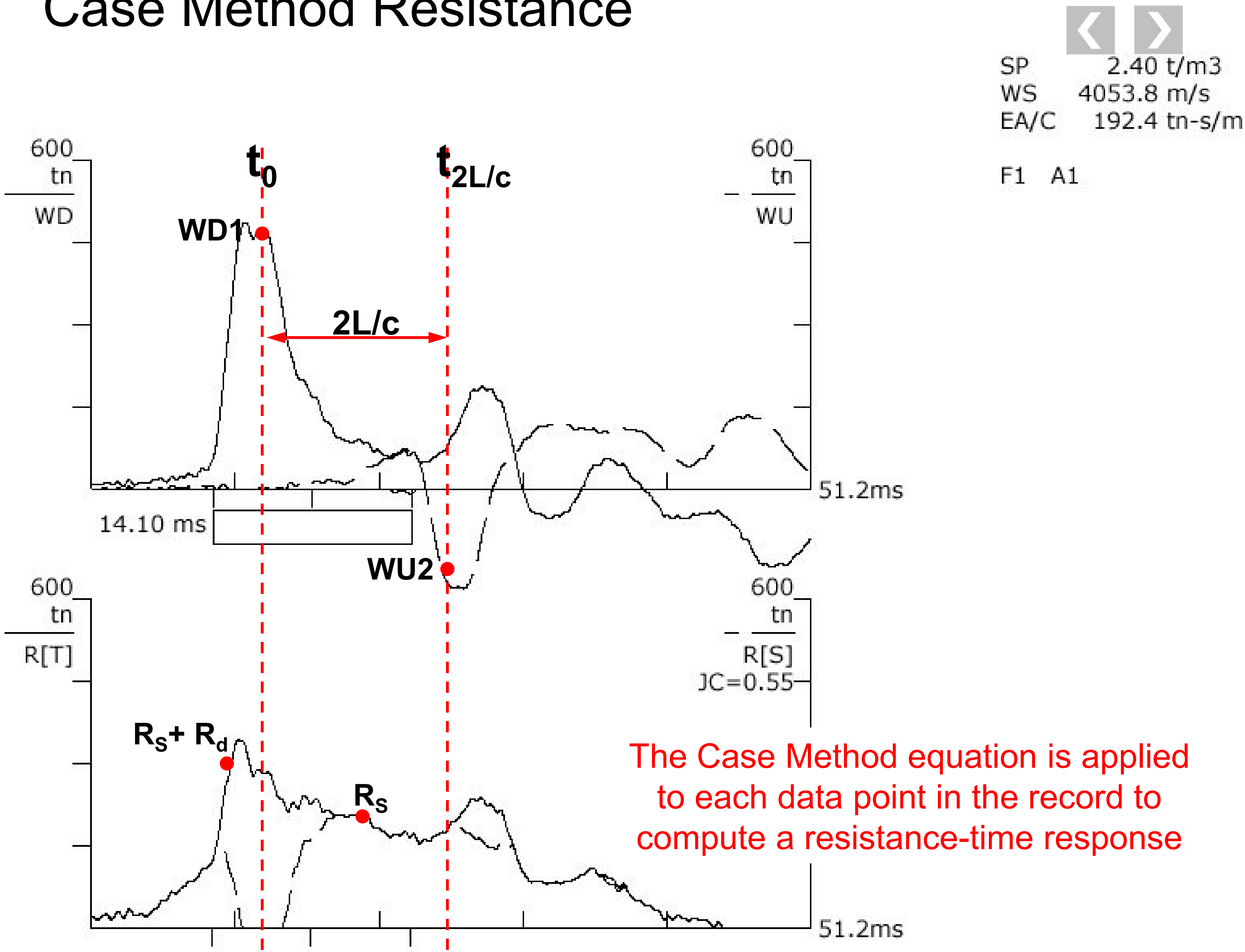
$$R_{dyn} = J_c \, Z \, v_{toe}$$

Case Damping Factor J_c



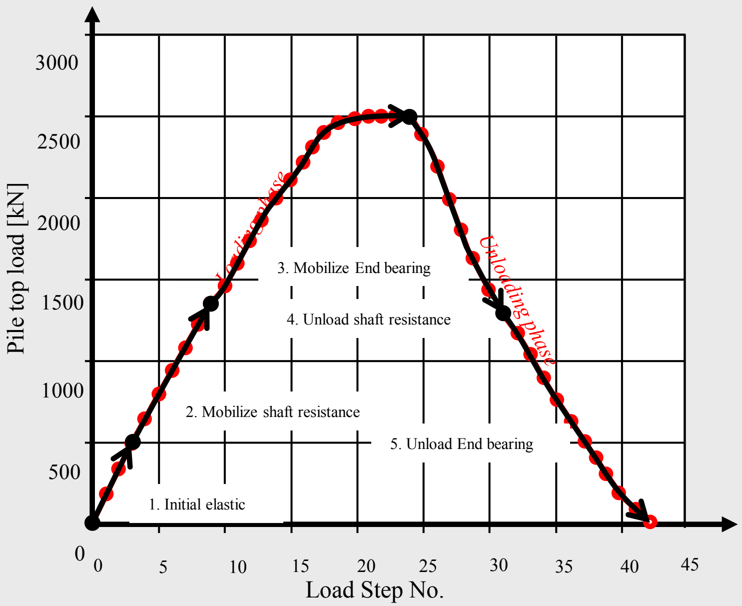
- This is only a BROAD INDICATION to allow an initial estimate of capacity
- Other physical variations (see previous slide) affect the Case Damping factor
- The Case Method capacity is approximate only, and for field estimates
- CAPWAP analysis is generally accepted as the definite capacity estimate

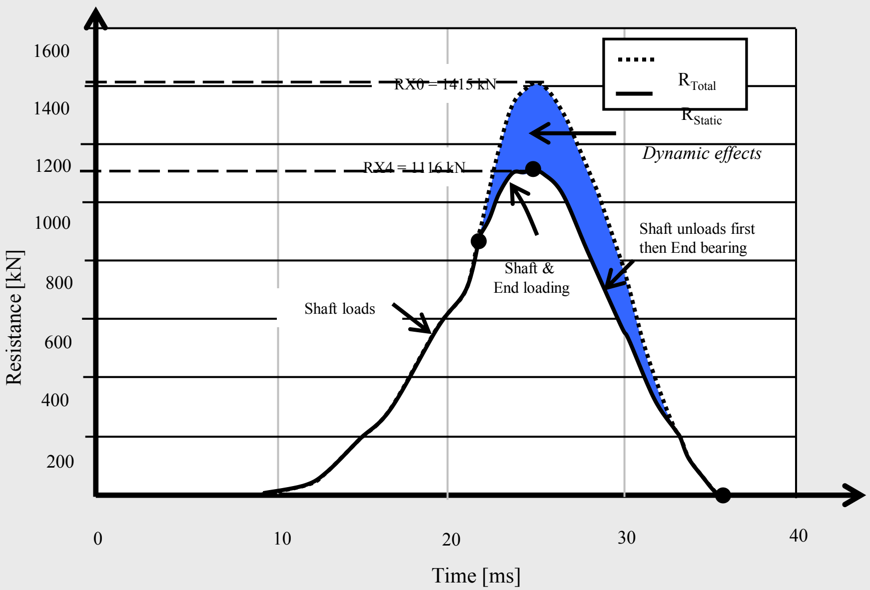
Case Method Resistance



The Case Method equation is applied to each data point in the record to compute a resistance-time response

Static and Dynamic Resistance Curves





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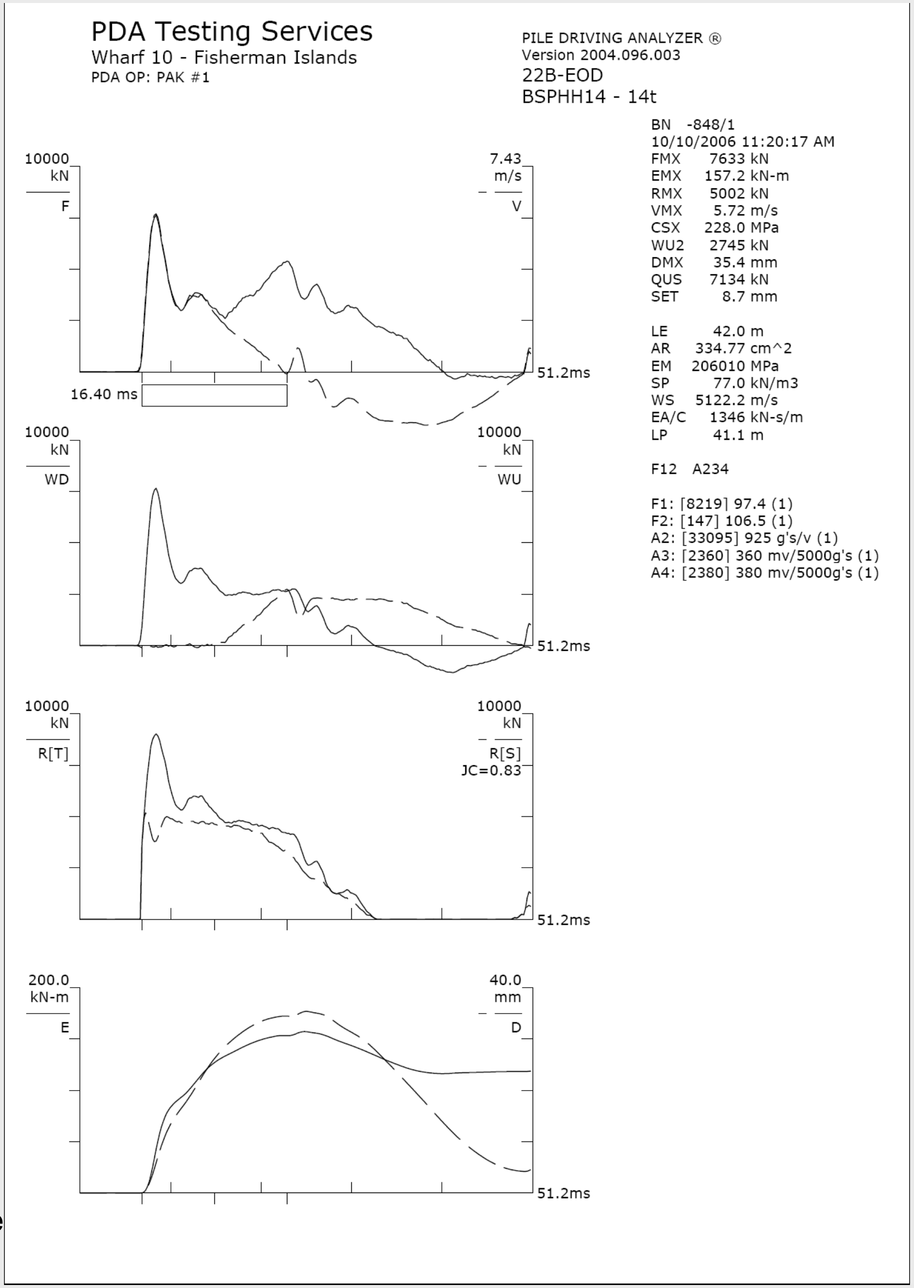
Standard 4-graph output

PDA Standard graphical outputs are:

- F and VZ vs time
- WD and WU vs time
- RT and RS vs time
- E and D vs time

These can be interpreted using the approach we have been discussing.

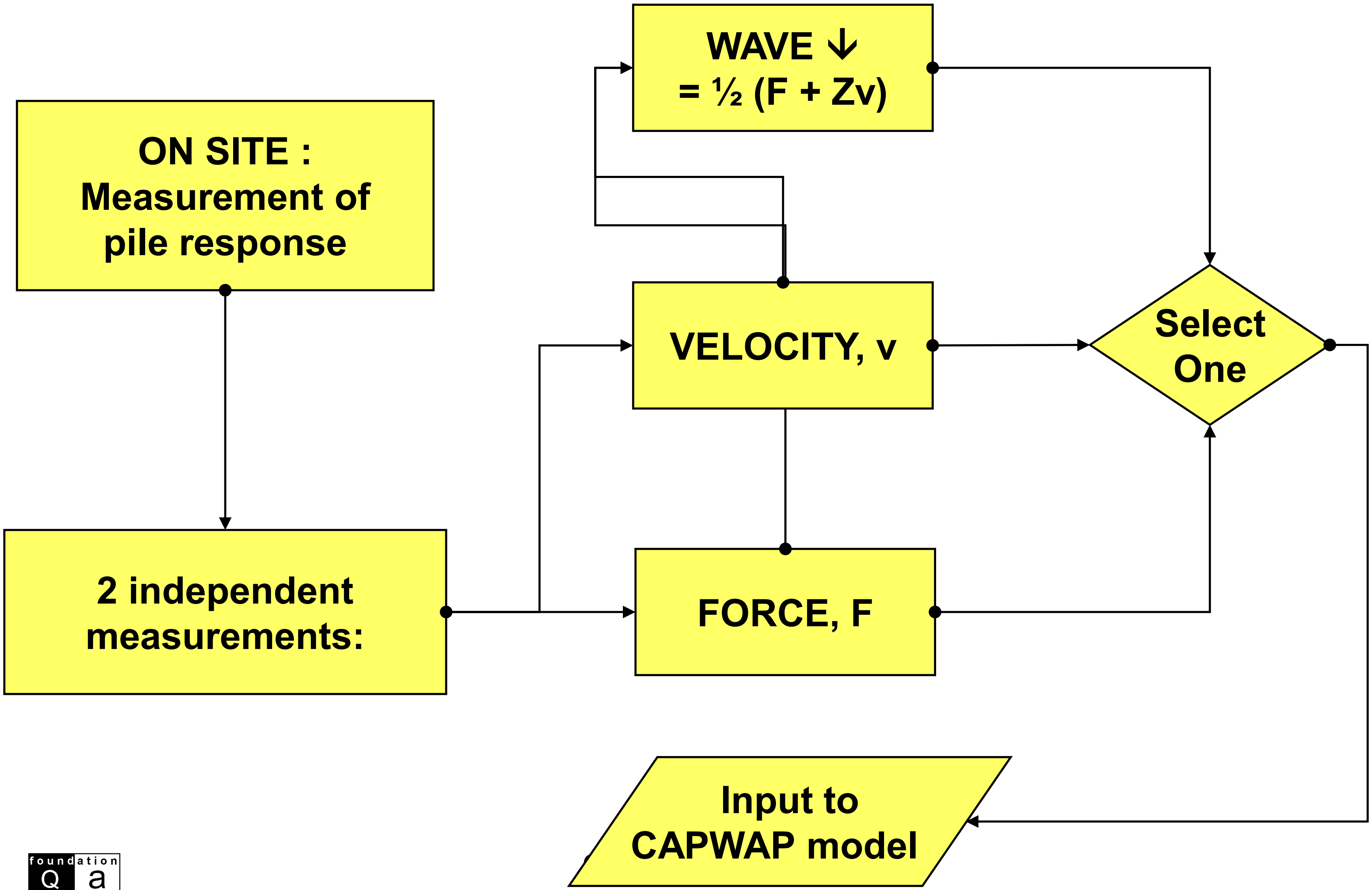
With some practice any engineer can start to interpret these graphs

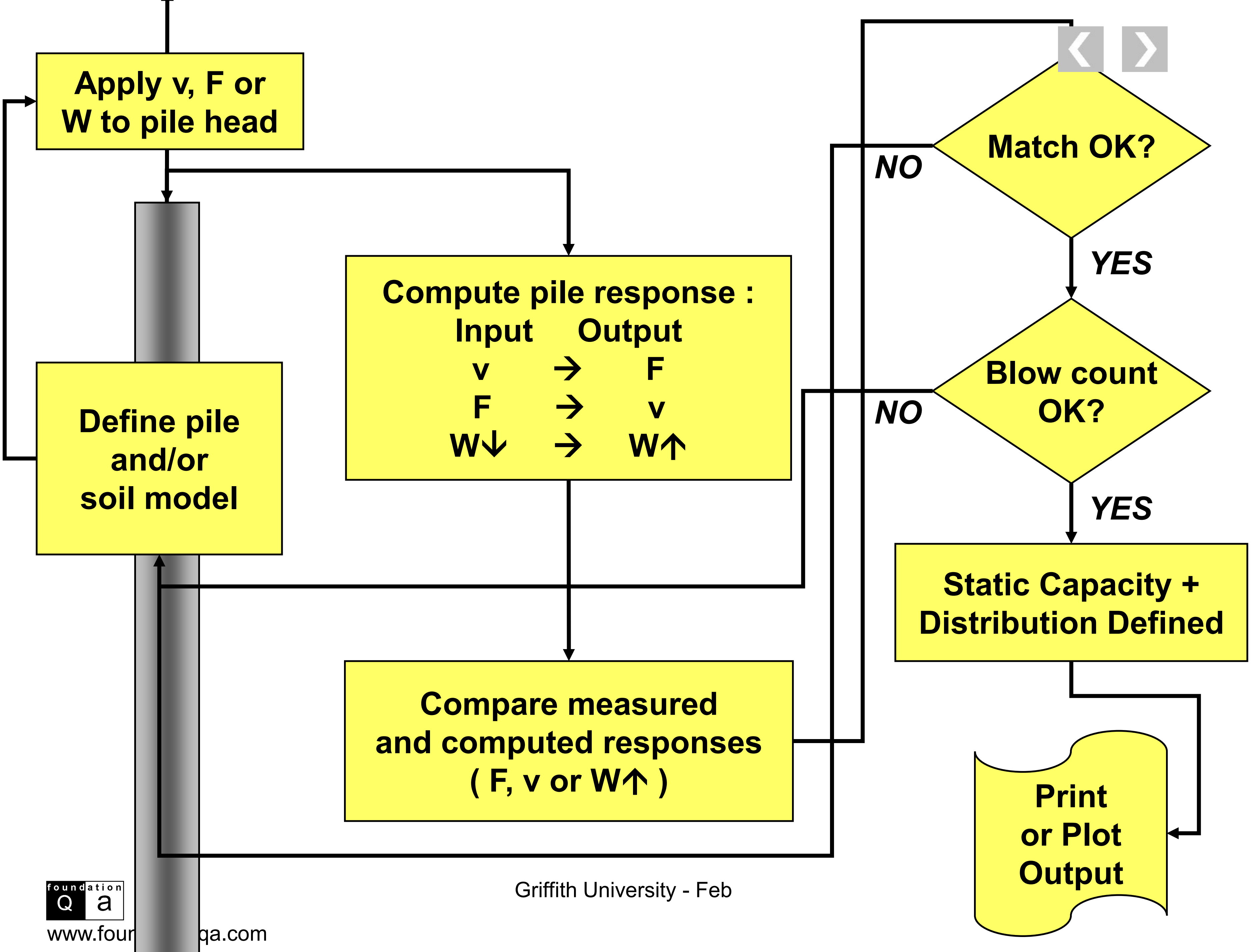


Capacity by Wave Matching

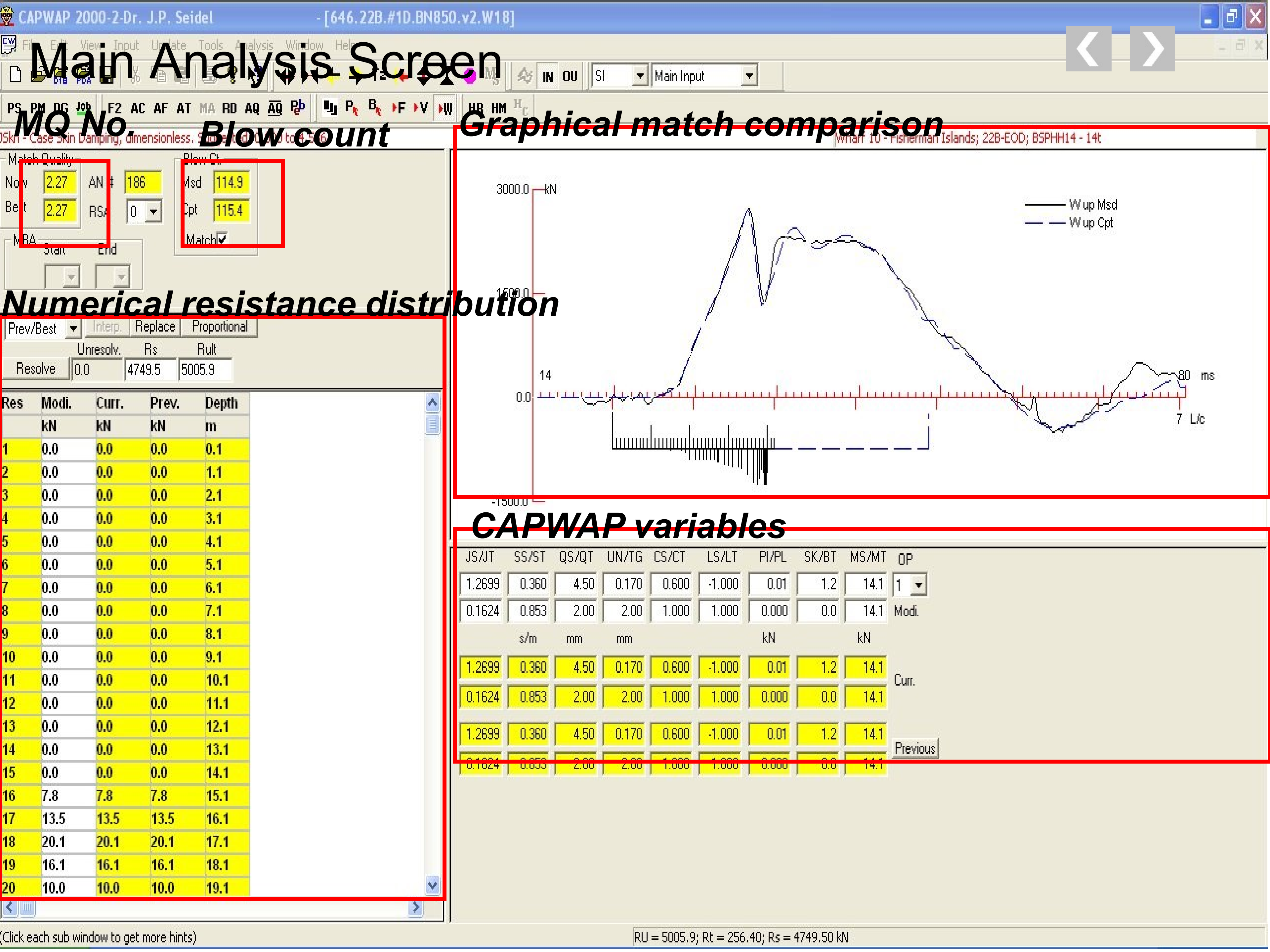
- Case Method is a ‘closed form’ solution which can conveniently be applied in real-time in the field to provide immediate guidance
- It is now usual to undertake a full Wave Matching analysis on the data for each pile tested using the program CAPWAP (Case Pile Wave Analysis Program).
- CAPWAP is accepted as the definitive method of capacity determination.
- CAPWAP output results include
  - Pile capacity
  - Resistance distribution
  - Predicted static load-movement response
- The CAPWAP process is an iterative process in which the analyst adjusts the available parameters to progressively improve the predicted response

CAPWAP Program Flow

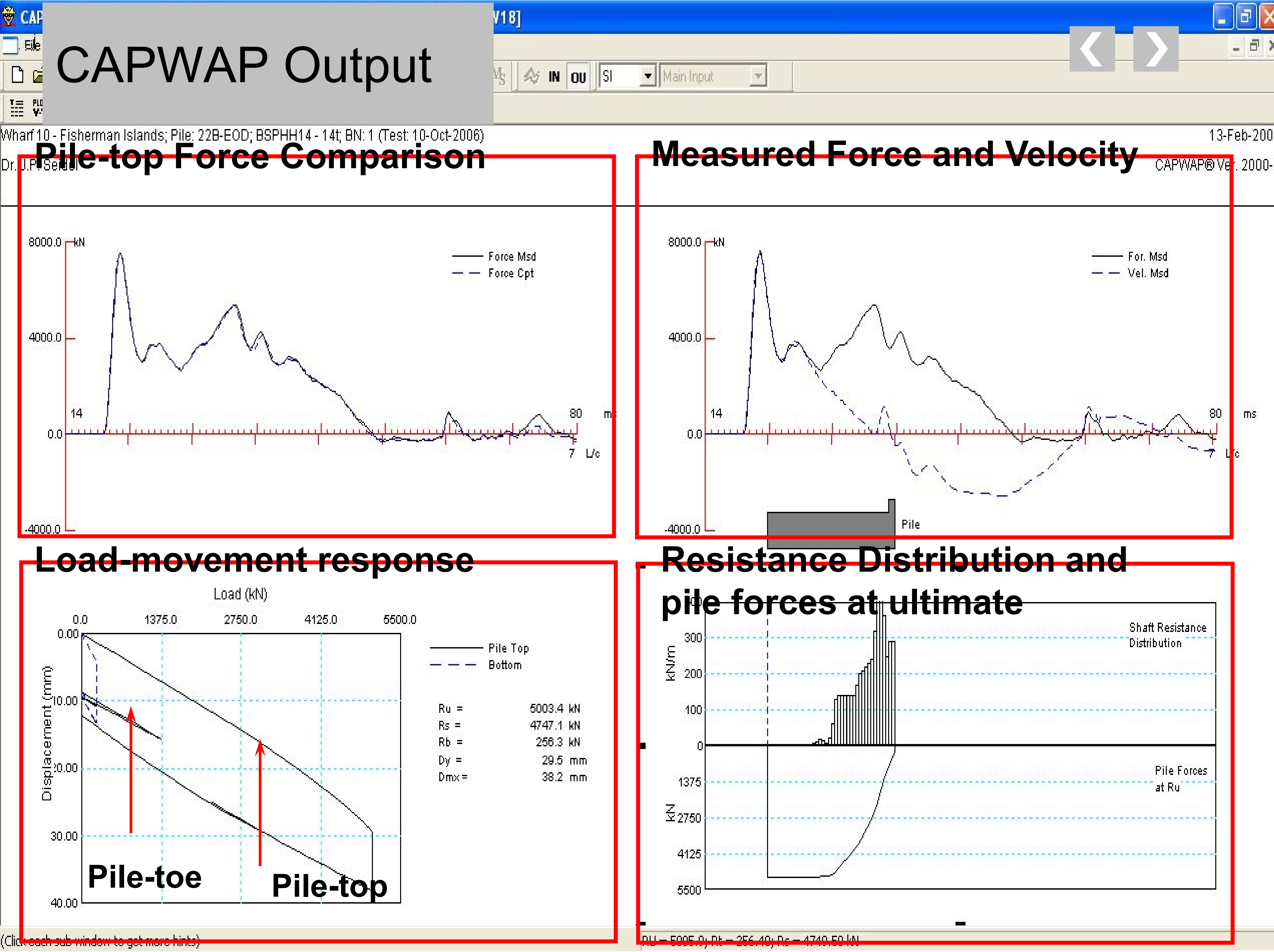



Apply v, F or W to pile head
Define pile and/or soil model
Compute pile response :
Input Output
v → F
F → v
W↓ → W↑
Compare measured and computed responses (F, v or W↑)
Match OK?
NO
YES
Blow count OK?
NO
YES
Static Capacity + Distribution Defined
Print or Plot Output

Main Analysis Screen



CAPWAP Output



CAPWAP – Match Quality Number

- The better the match between measured and computed responses in CAPWAP, the greater the confidence in the solution.
- A quantitative ‘Match Quality Number’ (MQNo) represents a weighted average percentage difference between measured and computed responses. The weighting is greater for key areas of the response.
- The loading phase is a key area; the unloading is less important, but should still be matched if possible
- There is no absolute standard for what constitutes a reasonable MQNo. Typically MQNos. in the range 2.0 to 4.0 could be expected, but equally, it is sometimes possible to achieve MQNo < 1.0. A match with an MQNo. of even 7 or more may still be acceptable.
- The minimum MQNo. is affected by the applicability of the soil models

CAPWAP – Other match quality measures

- The visual match should also be as good as possible.

- **In general, if the computed curve lies AT OR BELOW the measured response, or oscillates around the measured response, then the match is valid or conservative**

- The blow count (BLCT in blows/metre) should also be matched. A blow count AT OR BELOW the measured blow count is valid or conservative.
- The blow count number can be easily manipulated.

Capwap - Reliability

- CAPWAP does not provide a unique solution. Given the number of variables which can be adjusted, different solutions are possible
- However, in general, valid solutions will lie within ± 5 to 10%, and in most cases within ± 25%. In some cases, the range of credible solutions can exceed ± 25%. This should prompt either checking by static testing or review of the factor of safety / capacity reduction factor
- The distribution of resistance is subject to greater variation
- This then affects the separation of shaft and toe resistance, and hence estimation of tension capacity must be appropriately cautious
- CAPWAP will be most reliable for preformed piles and in soil conditions which are well modelled by the elasto-plastic static model and linear viscous dynamic model.
- These are quite adequate in most cases for shaft resistance, but not so realistic for end bearing.

Capwap Reliability contd

- Therefore, generally expect best modelling and matching for long friction piles, and less satisfactory matching for piles dominated by end bearing
- Match quality could be expected to be poorer where the soils are not well characterized by these linear models
- Statistical analyses suggest that CAPWAP analysis is marginally conservative. However, statistical analyses are often relatively meaningless

- **Any uncertainty of the solutions can be compensated for in design with a corresponding increase in FOS or reduction in φ_g.**

- **Actually the fact that we can predict static load-settlement response to within 25% from a hammer impact is a significant engineering feat.**
- **Even with a 25% error, that is fully compensated by increasing FOS from 2.0 to 2.5.**

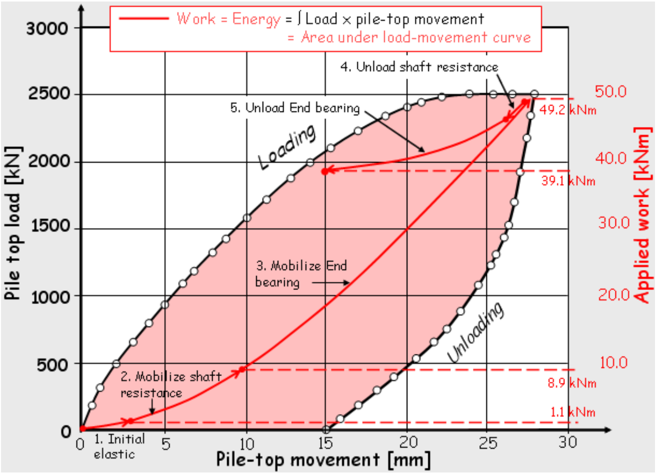
Construction Control Issues

- Construction control is as important a function of PDA testing as determination of capacity, however, it is often overlooked

- Control of hammer performance
- Control of pile stresses
- Control of pile damage
- Control of pile acceptance

Hammer Performance
Computing Hammer energy

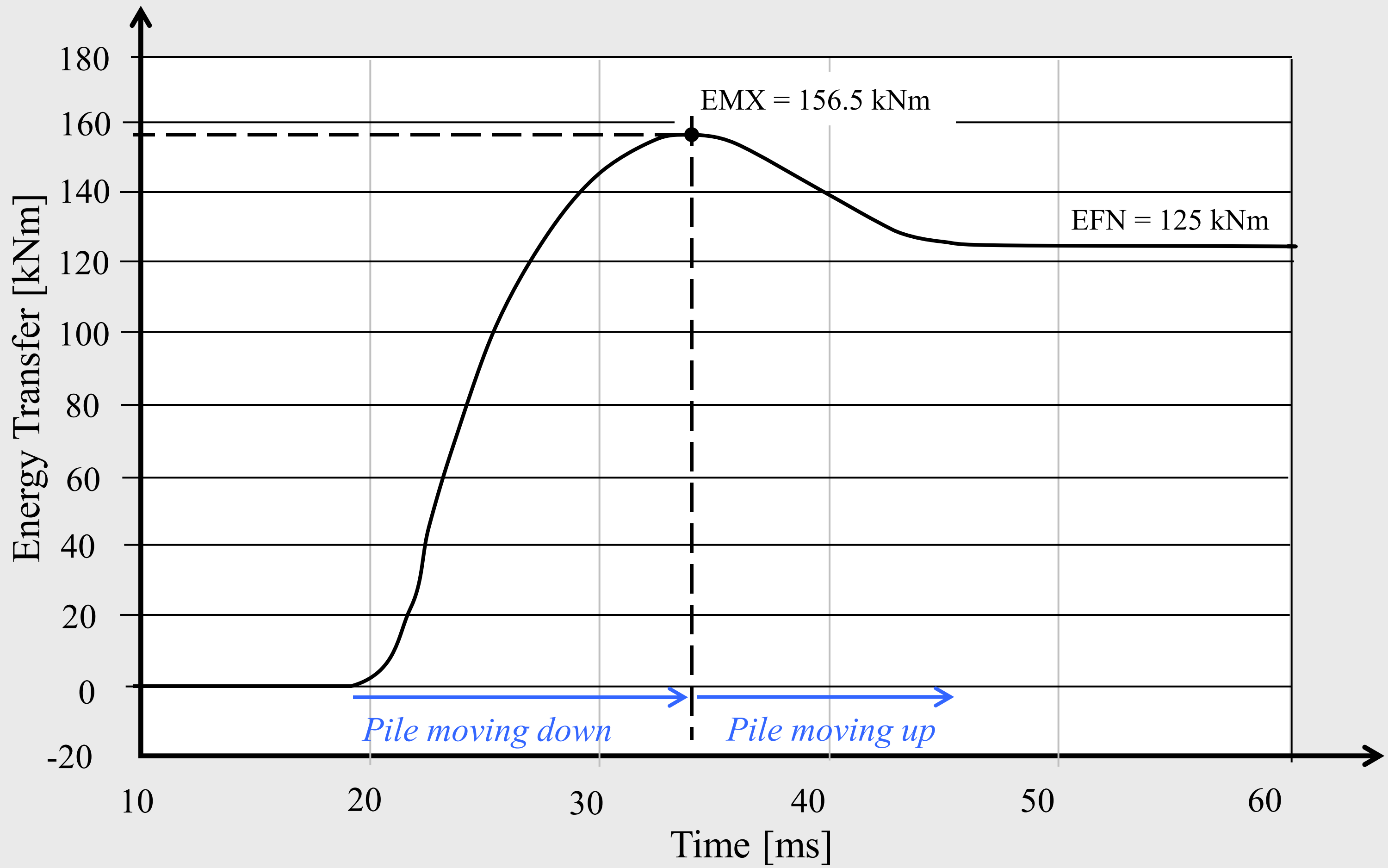
- For static : Energy = Work = Force x Distance or ∫(Force).dx
- For dynamic : Distance = ∫(Velocity).dt
- Hence Energy = ∫(Force x Velocity).dt
- When pile is moving down and Force and Velocity are both +ve, Integral is positive and energy enters pile from hammer
- When pile is rebounding (velocity is –ve), integral is negative and energy is leaving pile and pushing hammer back up
- Compare dynamic and static energy responses



Hammer Energy = ∫(Force x Velocity).dt

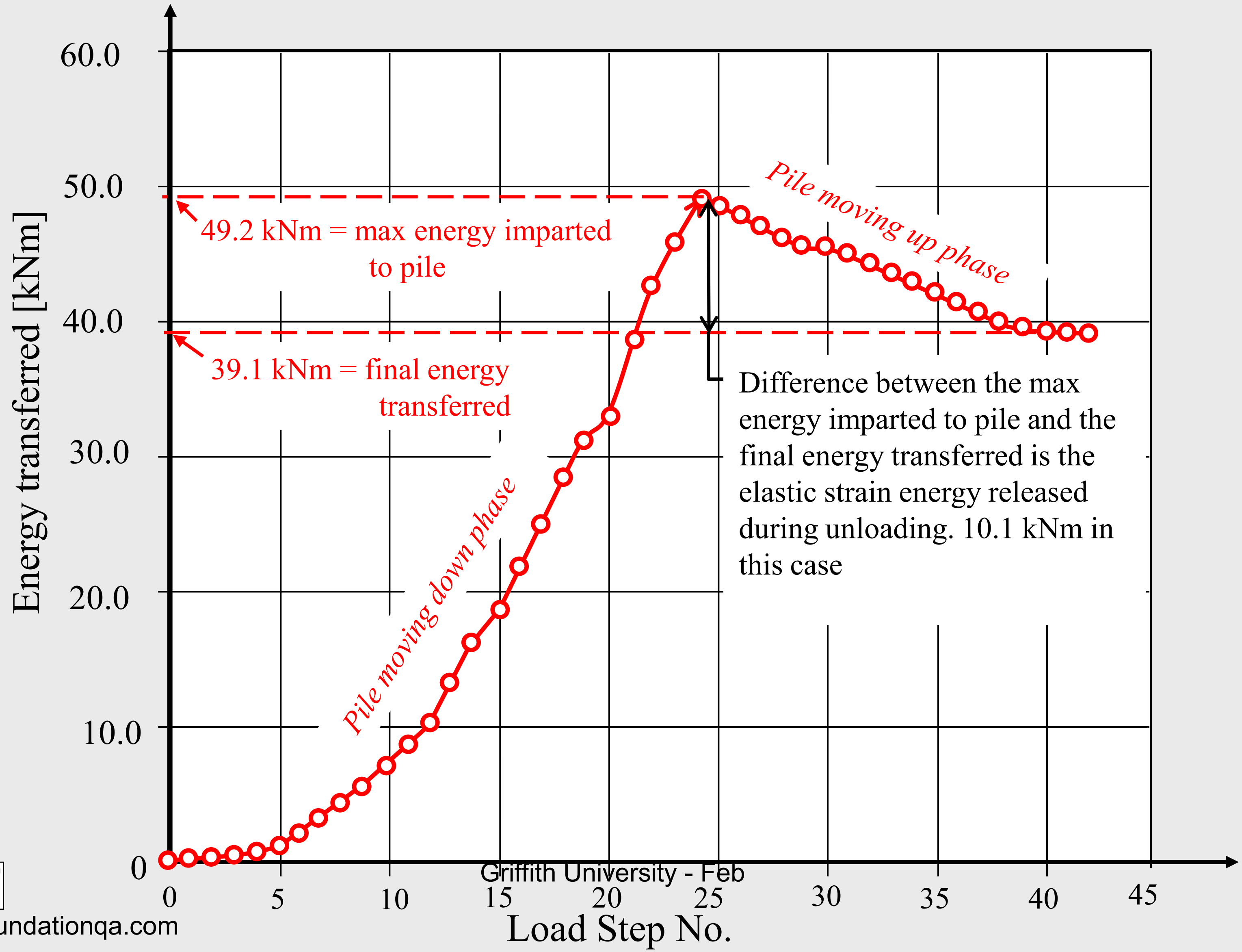
Dynamic energy response

Replay



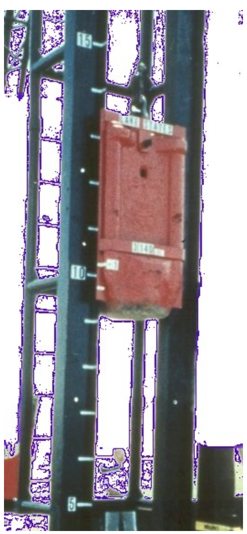
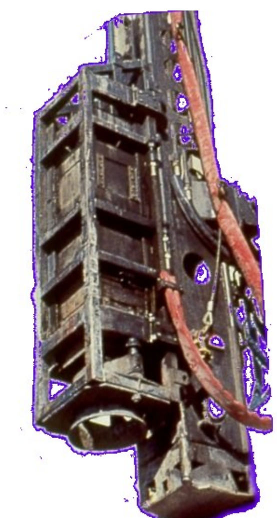
Static energy response

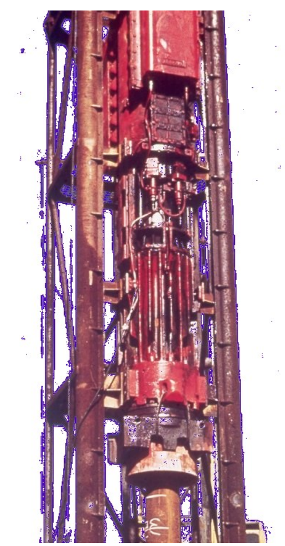
Replay



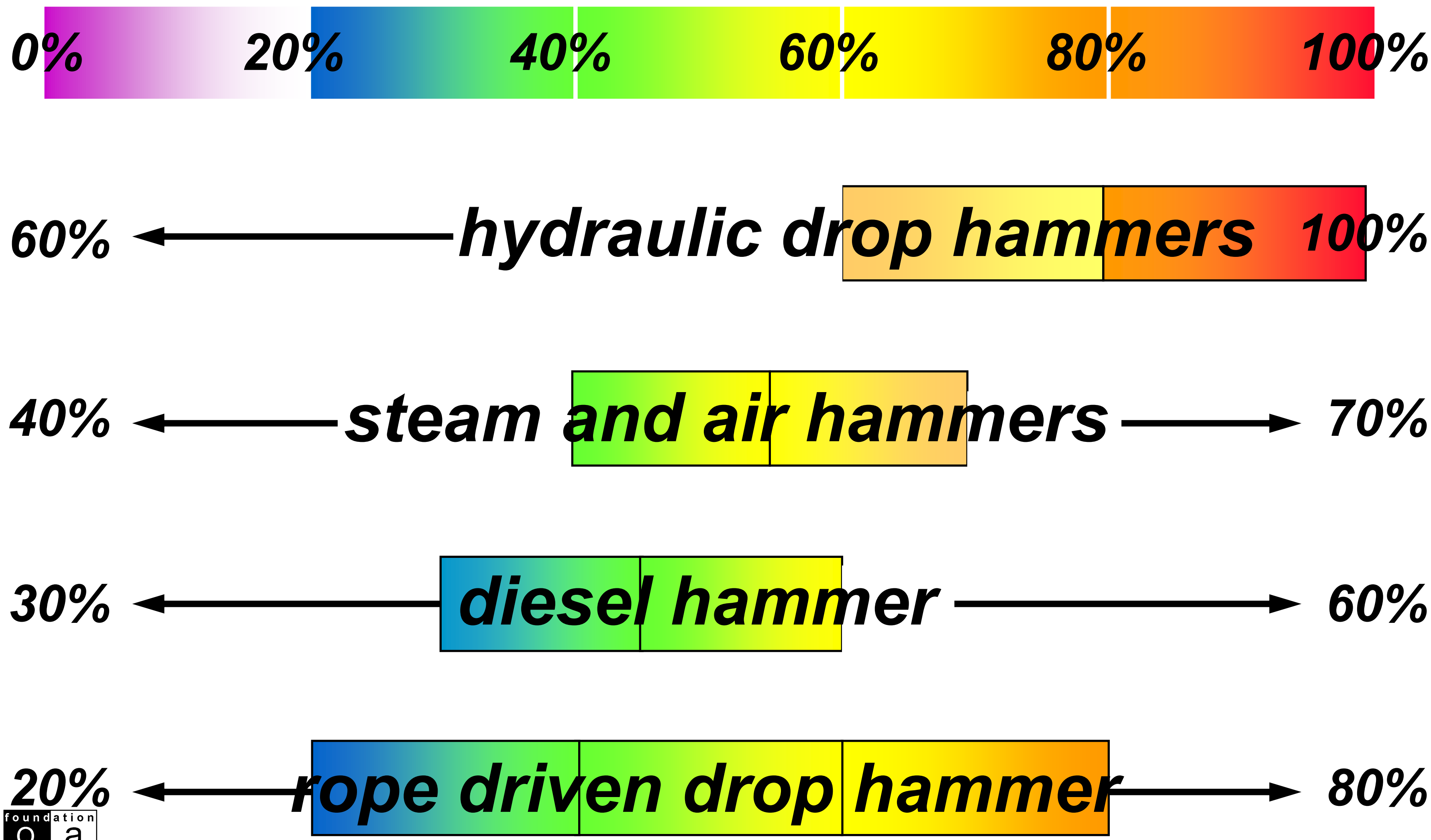
Hammer Performance

- There are many different types of pile driving hammer, e.g.
  - hydraulic drop hammers
  - diesel hammers
  - steam and air hammers
  - rope driven drop hammers
- The efficiency of each of these hammer types and makes differs
- The efficiency of any one hammer varies over time

Typical net measured efficiencies



Comments on Hammer Performance

- Even though hammer performance may not change, the energy delivered to the pile can change during driving of any pile.
- Transfer efficiency will be highest for easy driving (pile most accepting) and lowest for hard driving (pile rebounds and energy is returned to hammer)

- Hammer efficiency can and does vary over a contract period, especially for large projects due to variations in soil and hammer maintenance issues
- Hammer transfer efficiency varies with cushioning.

- Test hammer performance regularly over time during a contract, also taking into account likely changes in soil conditions
- Evaluate hammer efficiency at the target pile capacity and with nominated cushioning
- Institute tight control over pile cushioning
- **Base pile acceptance criterion on likely lowest energy transfer**

Control of Pile Stresses

Pile Compression Stresses – pile top

- An essential requirement of any driven foundation is that the piles are not overstressed during installation
- Piles can be overstressed in compression, tension or bending
- The PDA directly measures strain AT THE PILE TOP, so maximum compressive stress (CSX) and local stress (CSI) can be determined with a knowledge of pile modulus
- The stress will be a function of hammer WEIGHT, DROP and CUSHION
- These can be compared with allowable stresses in the relevant Standards or Codes of Practice

Pile Compression Stresses – pile toe

- Piles can be overstressed in compression, local overstress or bending, especially when driving to a (sloping) hard rock
- Pile toe stresses are greatest when the rock is at shallow depth or has soft overburden soils
- The PDA INFERS THE AVERAGE COMPRESSIVE STRESS AT THE PILE TOE (CSB) from Principles of 1-D Wave Mechanics .
- The stress will be a function of hammer WEIGHT, DROP and CUSHION
- These can be compared with all
or Codes of Practice

Pile Tensic

- Concrete pile
- They can alsc stresses are (overburden soils
- The PDA ESTIMATES THE MAXIMUM TENSION STRESS IN THE PILE SHAFT (TSX) and LOCATION from Principles of 1-D Wave Mechanics .
- The stress will be a function of hammer WEIGHT, DROP and CUSHION
- These can be compared with allowable stresses in the relevant Standards or Codes of Practice

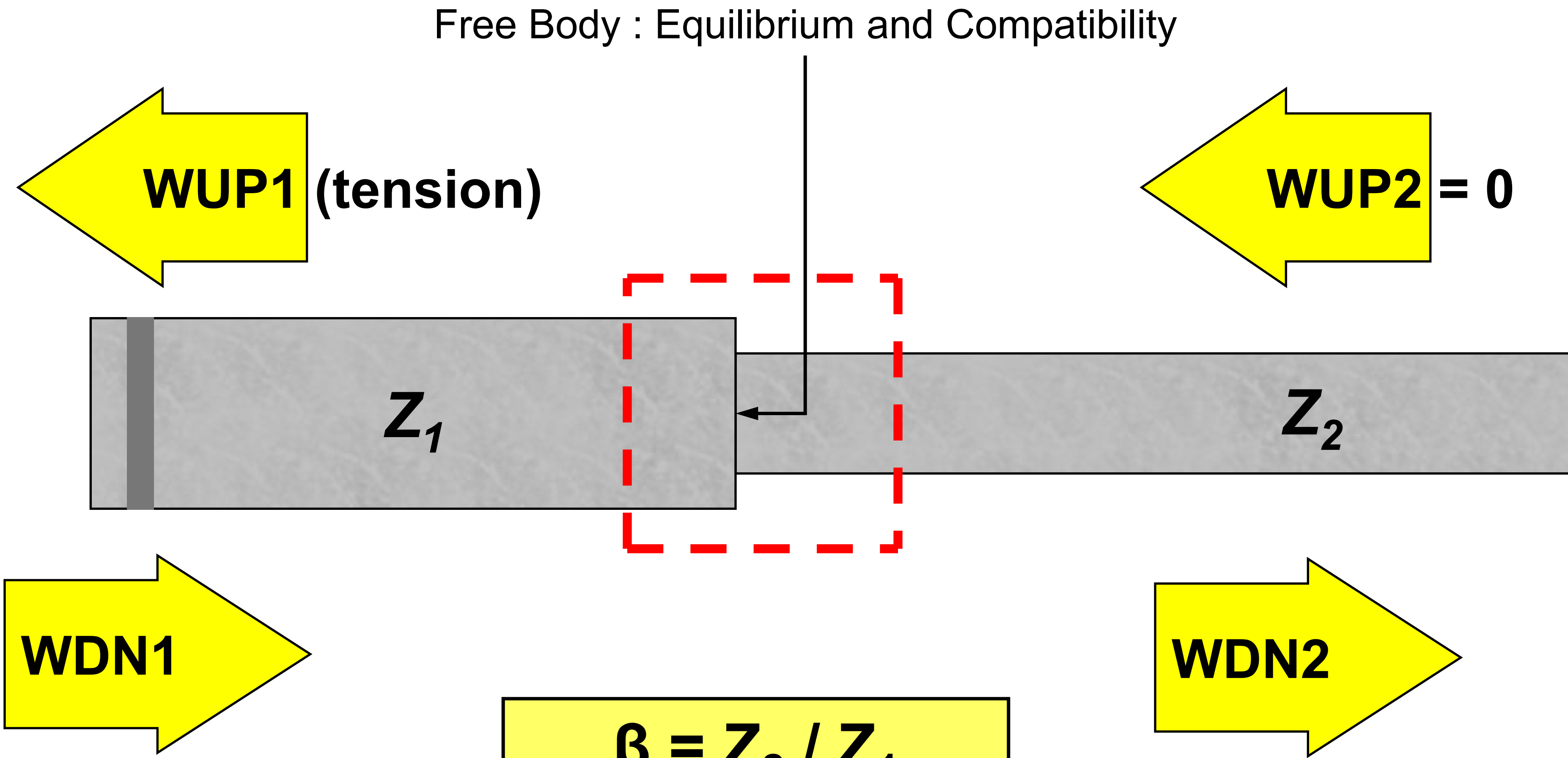
Pile Stress

- Steel : typical
- Concrete in c
  the time of dr
- Concrete in tension : typically 80% of SQUARE ROOT of compressive strength <u>at the time of driving</u> PLUS prestress (if applicable)
- Check applicable Standard or Code of Practice

Control of Pile Damage

- Ideally, construction control should be implemented by ensuring driving stresses are acceptable. This minimizes the risk of pile damage.
- Where such control measures are not taken, pile damage may occur

Damage : Impedance Reduction Model



$$\beta = Z_2 / Z_1$$

β (the integrity factor) is the ratio of impedances and a measure of pile damage

Model limitation

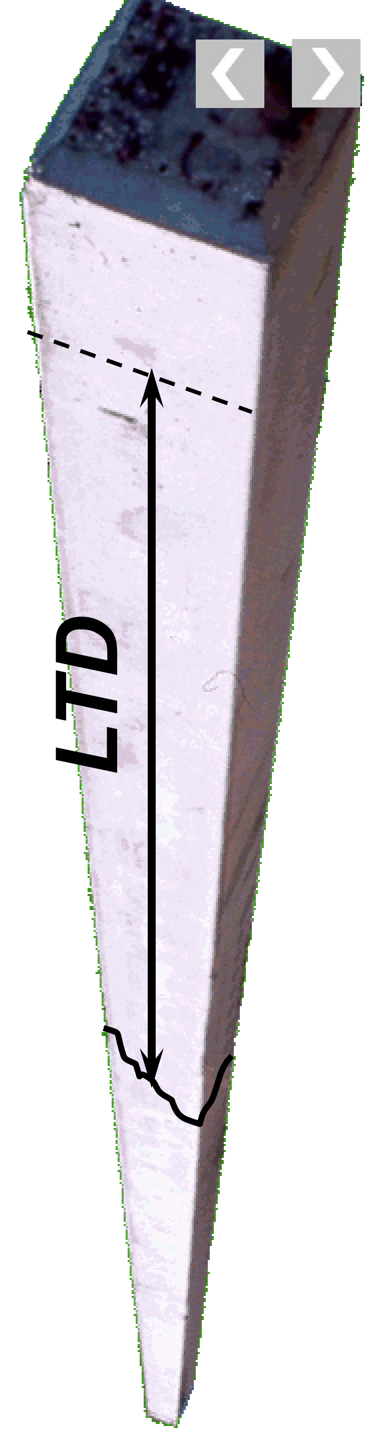
- The β calculation is based on an impedance reduction of substantial length

- **For isolated pile damage, a compressive reflection from the impedance increase below the damage will partly mask the damage tension reflection, leading to an underestimate of pile damage**

Damage Location

- Pile damage causes a tell-tale tension response before 2L/c
- The time at which a tension reflection first arrives at the gages determines the depth to the impedance reduction (damage)
- Length to Damage (LTD) is assessed by the PDA as follows :

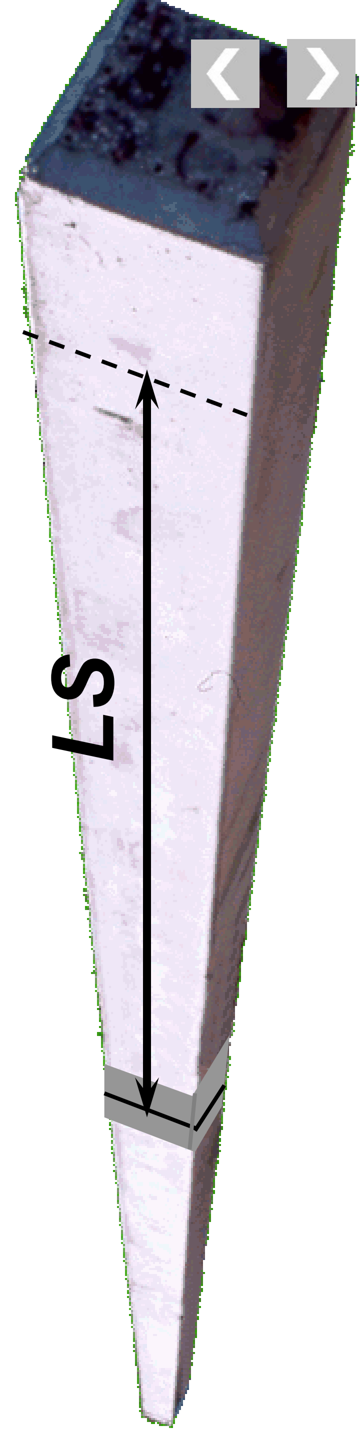
$$LTD = t_{damage} / 2c$$



Pile Joints

- Pile joints give a similar reflection to pile damage – i.e. a tension response before 2L/c
- The time of the response from a joint should be compatible with the known joint location
- Alternatively the pile wavespeed can be assessed from the time of joint response
- “Tight” joints give almost no reflection (β≈100%)
- “Loose” joints give a large tension reflection (β<<100)
- Joints that are fatiguing give increasingly large reflections
- The Length to Splice (LS) parameter is a convenient way to confirm joint location

$$LS = t_{splice} / 2c$$



Beta guidelines

- Beta is at best an empirical guide to damage
- Lower beta – greater damage
- Relationship to actual damage is speculative
- But it is the best tool that we have

□	Condition
100	Uniform
80 - 100	Slight damage
60 - 80	Significant damage
<60	Broken

Pile damage – comments 1

- Damage is normally detected on site by an inability to achieve set, or by a pile which approaches set, and then “loses” set.
- Any such pile, or a pile significantly longer than adjacent piles should be tested to assess damage
- The PDA can only determine damage at the time of testing
- The susceptibility to long-term degradation should be considered based on type of damage (may not be known), location and depth of damage, exposure condition, soil or water chemistry, type of pile, type of loading (compression, tension, lateral) access to oxygen supply, and other factors
- It may be impossible to distinguish between a single crack and a distribution of small cracks.

Pile damage – comments 2

- The tension reflection from damage "competes" with the compression reflections from shaft resistance.
- Damage may therefore be less evident where there is high shaft friction
- Damage should be assessed during driving or as soon as possible after driving to minimize the masking of pile-set-up effects
- All damage should be assessed. A β greater than 80% does not mean the pile is OK. A β less than 80% does not mean the pile should be condemned.
- Poor data or data from piles with significant bending may be misinterpreted as damage – require good data on piles tested with hammer properly aligned.
- Capwap analysis can provide an independent assessment of pile damage

Control of Pile Acceptance

- Not all piles on a site will be tested – maybe 5 to 10%
- As little as 0.5% and as much as 25% depending on country and engineer’s preference
- Between 75% and 99.5% remain untested
- How do we ensure the non-tested piles are OK?
- We need an integrated approach

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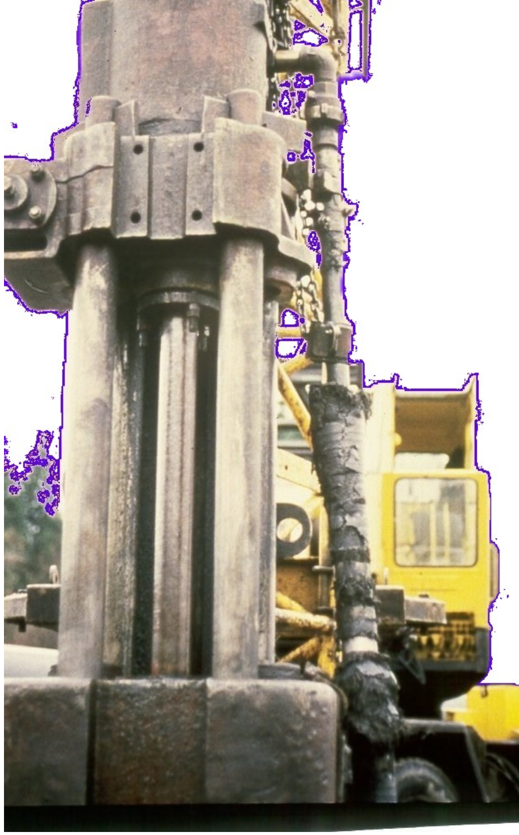
Pile Acceptance Criteria Approaches

1. Correlate GRLWEAP against PDA and CAPWAP results from preliminary or early contract pile tests
2. Undertake GRLWEAP-like extension to CAPWAP, called CAPWEAP
3. Establish pile set based on Driving Formula only, and use PDA only to a) confirm energy input and b) confirm random piles have achieved capacity – this approach is NOT recommended
4. Establish target pile set and hammer stroke based on set and stroke for pile which has achieved capacity by PDA testing – this approach is NOT recommended
5. Establish pile set based on CORRELATION of Driving Formula with results of PDA/CAPWAP.
6. Establish Pile Acceptance Chart based on correlation with Driving Formula

Correlated Driving Formula



- Determine lower bound hammer performance
- Develop a correlation between dynamic testing and simplified Hiley Formula
- Apply a correction factor to the Hiley Formula – this is typically a reduction factor of between 0.6 and 1.0
- Account for time effects
- Establish a safe driving criterion for each capacity
- Convert to Chart

$$R = \frac{n.W_r.h.}{(s+\Sigma c/2)} \cdot \frac{W_r + e^2 W_p}{W_r + W_p}$$

Hiley Formula

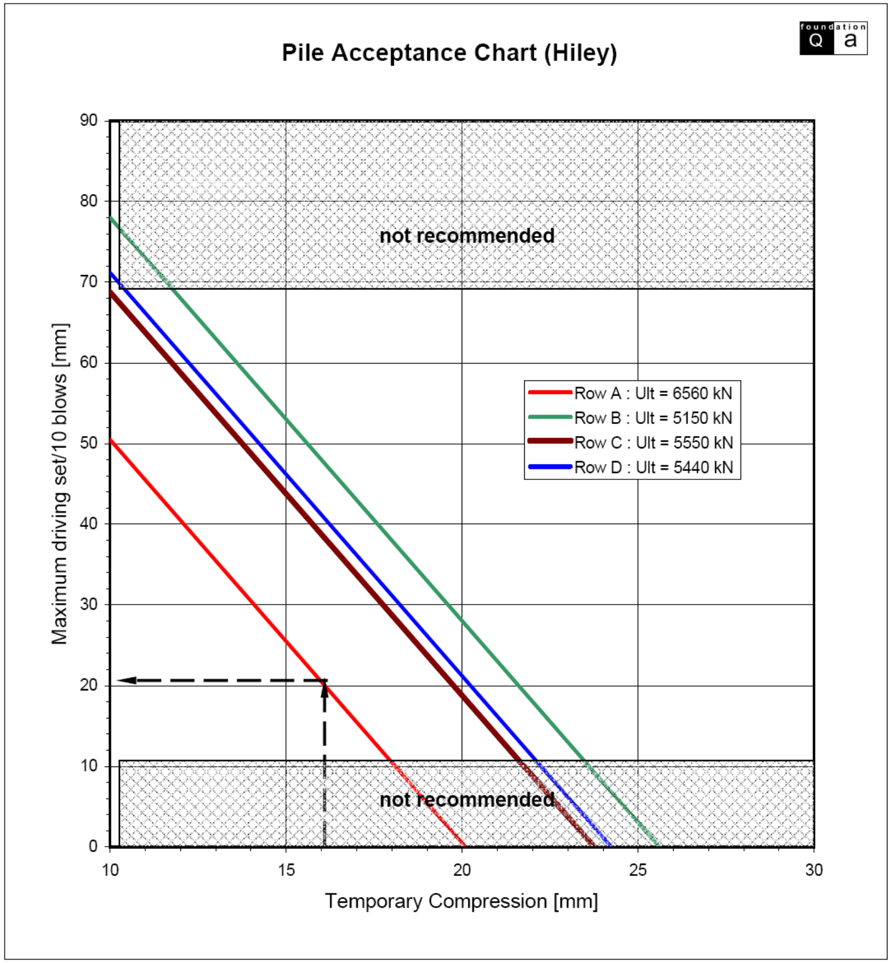
$$R = \frac{EMX}{(s+c/2)}$$

Simplified Hiley Formula

Pile Driving Chart (Hiley)

Hammer ID	Banut	Hammer Weight [t]	8.0
Hammer drop [m]	1.20	Hammer Efficiency	84%
Hiley/PDA factor	1.20	Pile Diameter	0.700
Case 1 :	Row A	Case 2 :	Row B
Case 3 :	Row C	Case 4 :	Row D

- Chart shows the combination of set and temporary compression required to achieve a given capacity
- It is implicit that the hammer energy is maintained at or above the assumed efficiency and that the drop applied is correct
- If the energy is less than assumed, both set and temporary compression will reduce
- The formula will predict a HIGHER capacity!

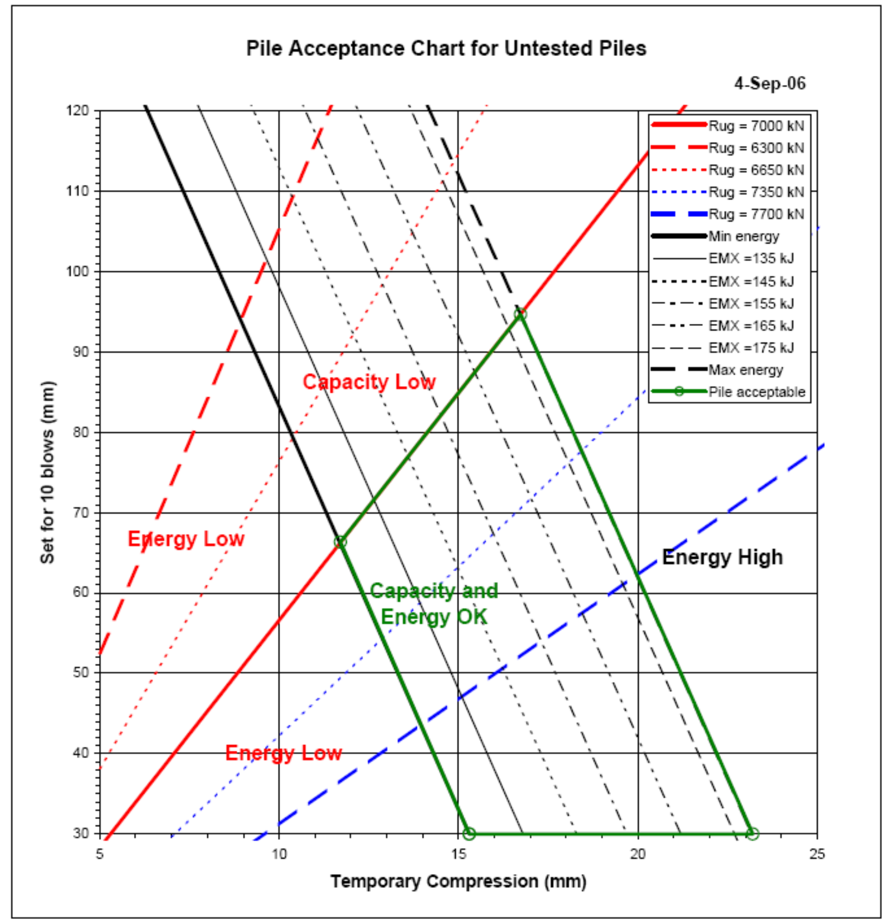


Pile Driving Chart (Seidel Energy Correction)

- The Chart is developed by correlation with PDA testing
- Chart shows the combination of set and temporary compression required to achieve a given capacity
- Chart also estimates the hammer energy for any set and temporary compression combination.
- If the energy is less than assumed, both set and temporary compression will reduce
- The chart will predict a LOWER capacity

Piling Acceptance Chart (Seidel)

Issue No.:	E/2
Date of Issue :	4-Sep-06
Relevance :	
Hammer ID :	
Hammer Weight (t) :	14 t
Target hammer drop :	1.3 m
Minimum hammer transfer efficiency :	70%
Ultimate capacity requirement, Rug :	7000 kN
Capacity check limits	10%



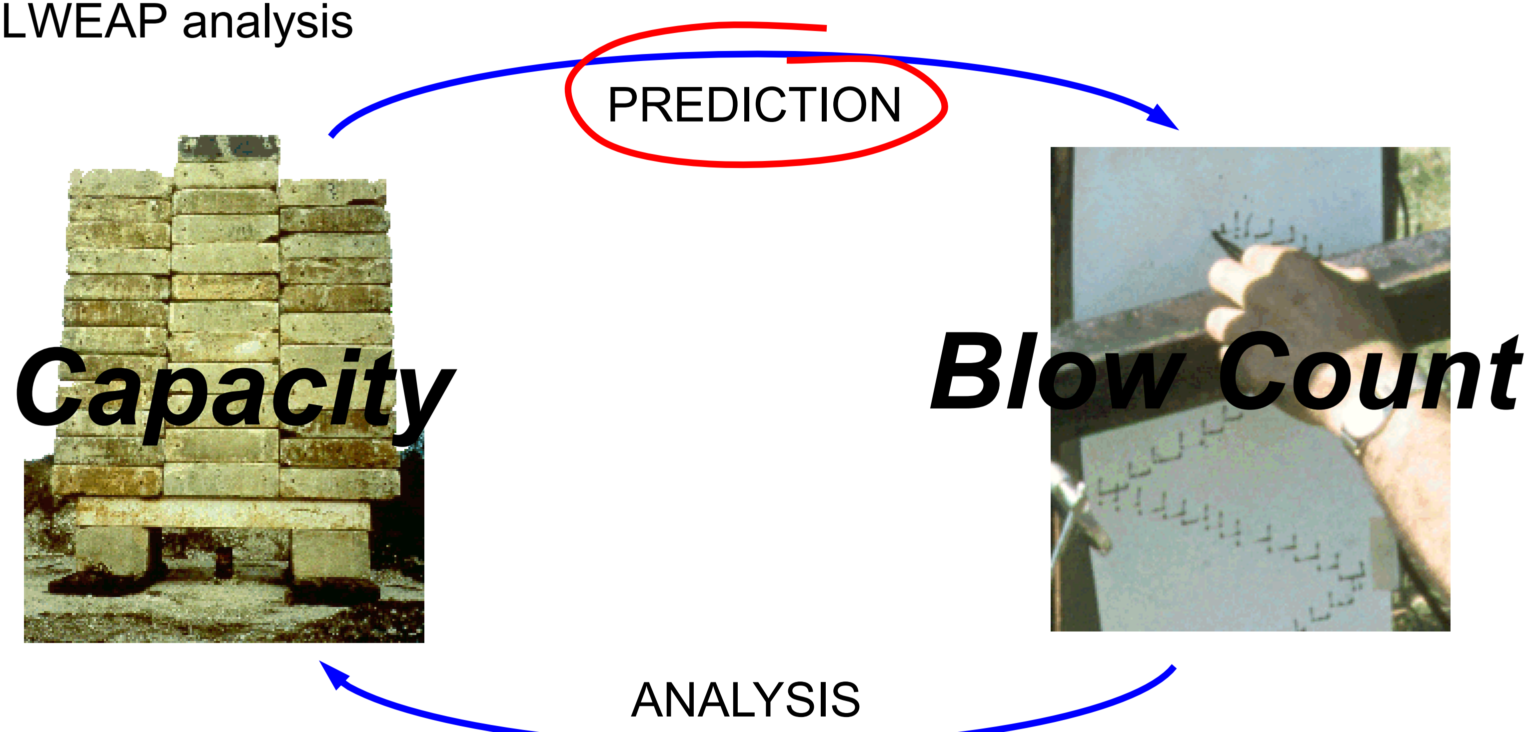
Pile Acceptance - Comments

- It is necessary to undertake a testing program which is regular throughout the contract piling. Undertake a higher percentage of pile tests at commencement, but continue to test regularly
- Design the test program to cover the site geographically, particularly taking into account any changes in subsurface conditions, such as dipping layers, changes of material, pile length variations
- Test any pile which has an abnormal installation, drives short or long
- Test piles installed by different hammers on a site, or if hammers are repaired, retest
- Ensure consistency of replacement of cushioning materials
- Review, revise and reissue acceptance criteria if necessary

Pile Driveability Issues

- Pile Driveability should be addressed as a fundamental part of pile design, and is also a key consideration of the pile driving contractor

- GRLWEAP analysis



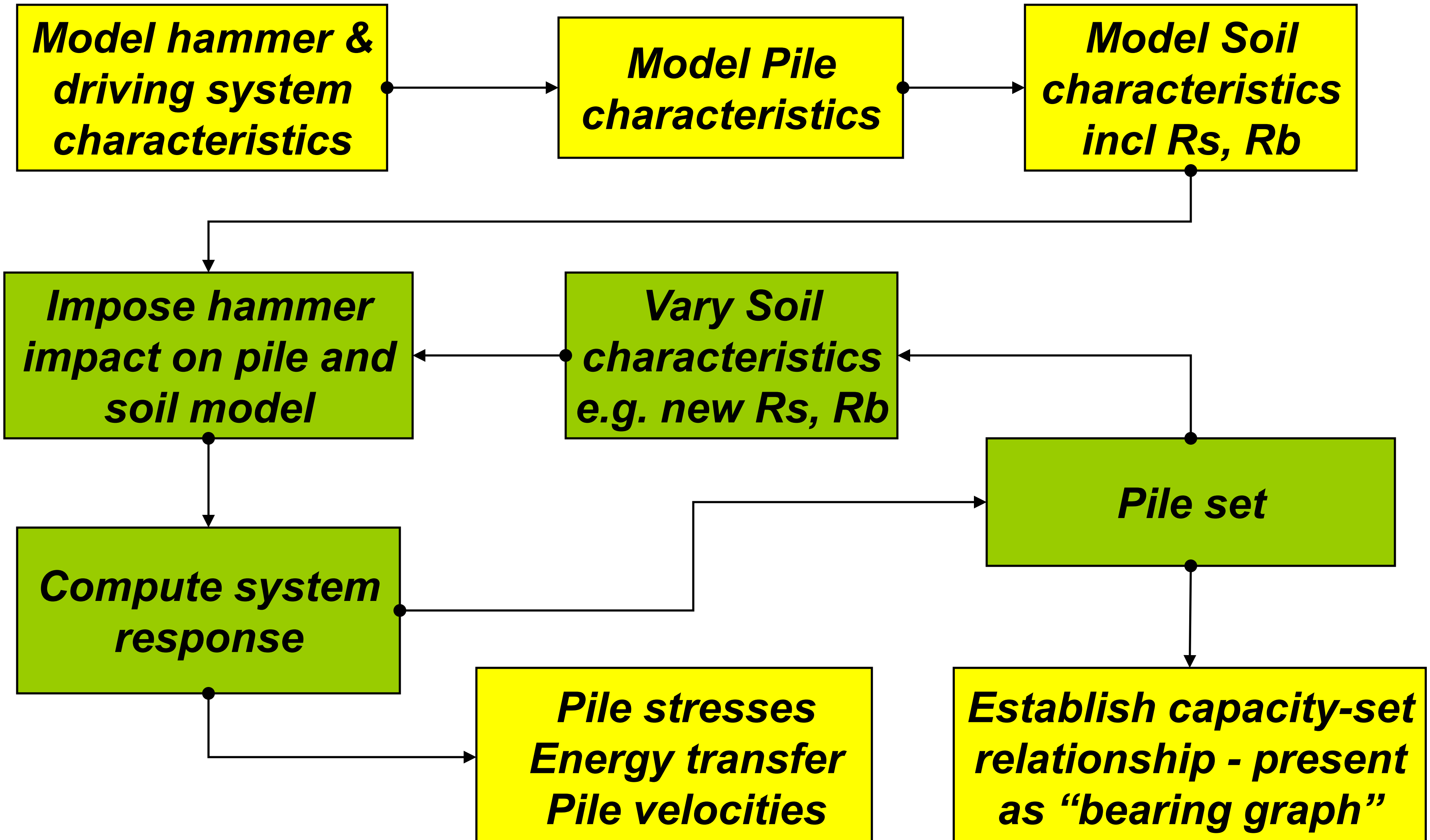
Pile Driveability

- Pile driveability is a function of pile, soil and equipment
- Even though a pile may be structurally capable of sustaining the design loads, the ability of a hammer to drive the pile to the required geotechnical capacity must be separately established
- This could be done based on experience (i.e. a contractor's knowledge that piles of the same geometry have previously been driven to similar or greater capacity)
- Alternatively, a predictive Wave Equation analysis can be undertaken using a program such as GRLWEAP
- GRLWEAP has 2 main functions :
  1. To confirm whether a particular hammer is capable of driving a pile SAFELY (STRESSES) and EFFICIENTLY (NOT EXCESSIVE BLOWS) to the required CAPACITY
  2. To establish a PRELIMINARY relationship between STROKE (or ENERGY), PILE CAPACITY and PILE SET. This is called a BEARING GRAPH.

GRLWEAP - Principles

- Pile is modelled as a series of masses (distributed pile weight) and springs (pile elasticity) each pair representing about 1m pile length
- Each 1m segment is acted on by an elasto-plastic spring representing STATIC resistance and a linear dashpot representing DYNAMIC RESISTANCE
- The STATIC and DYNAMIC soil resistances and distribution of resistances must be assumed in a PREDICTIVE analysis
- These parameters may be derived from CAPWAP analysis where PDA testing has been undertaken and the results of the tests are to be extrapolated
- The hammer (weight, geometry, drop, thermodynamics) and driving system (cushions, capblocks etc.) must also be modelled.

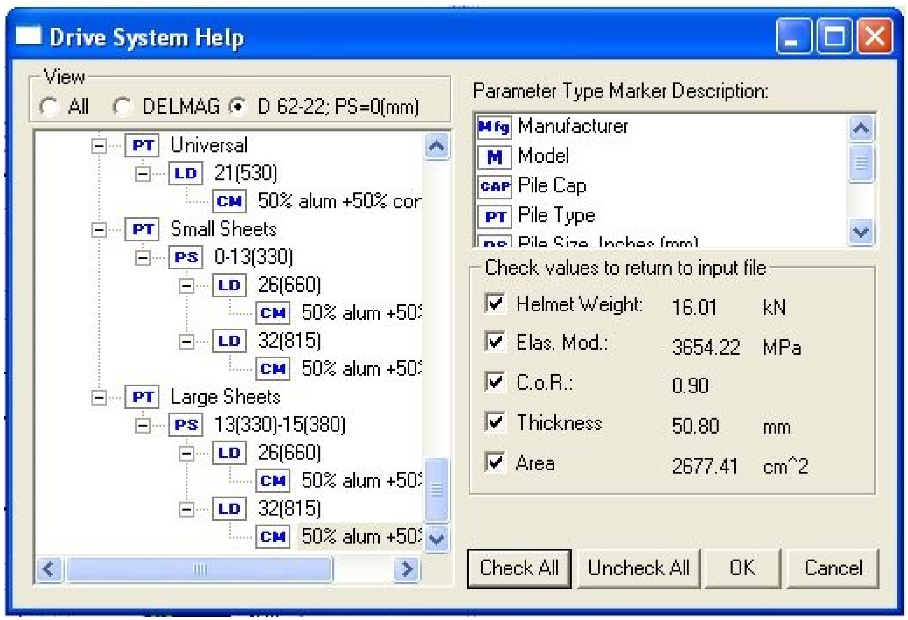
GRLWEAP Program Flow

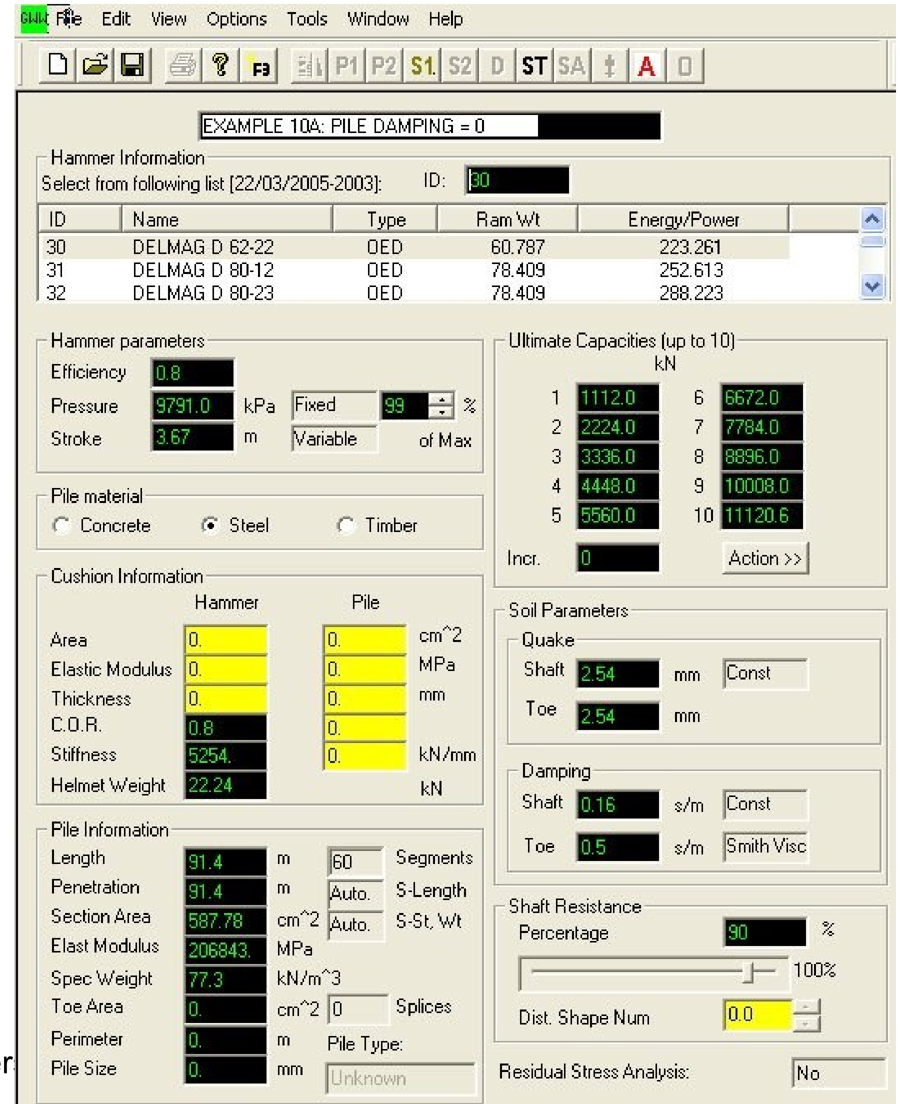


GRLWEAP Input Screens

Main Input screen

Driving system help screen





GRLWEAP Hammer database

- The hammer database contains input data on the majority of commercial piling hammers

Hammer Maintenance [Hammer File Date: 22/03/2005] - [Hammer2003.gw]

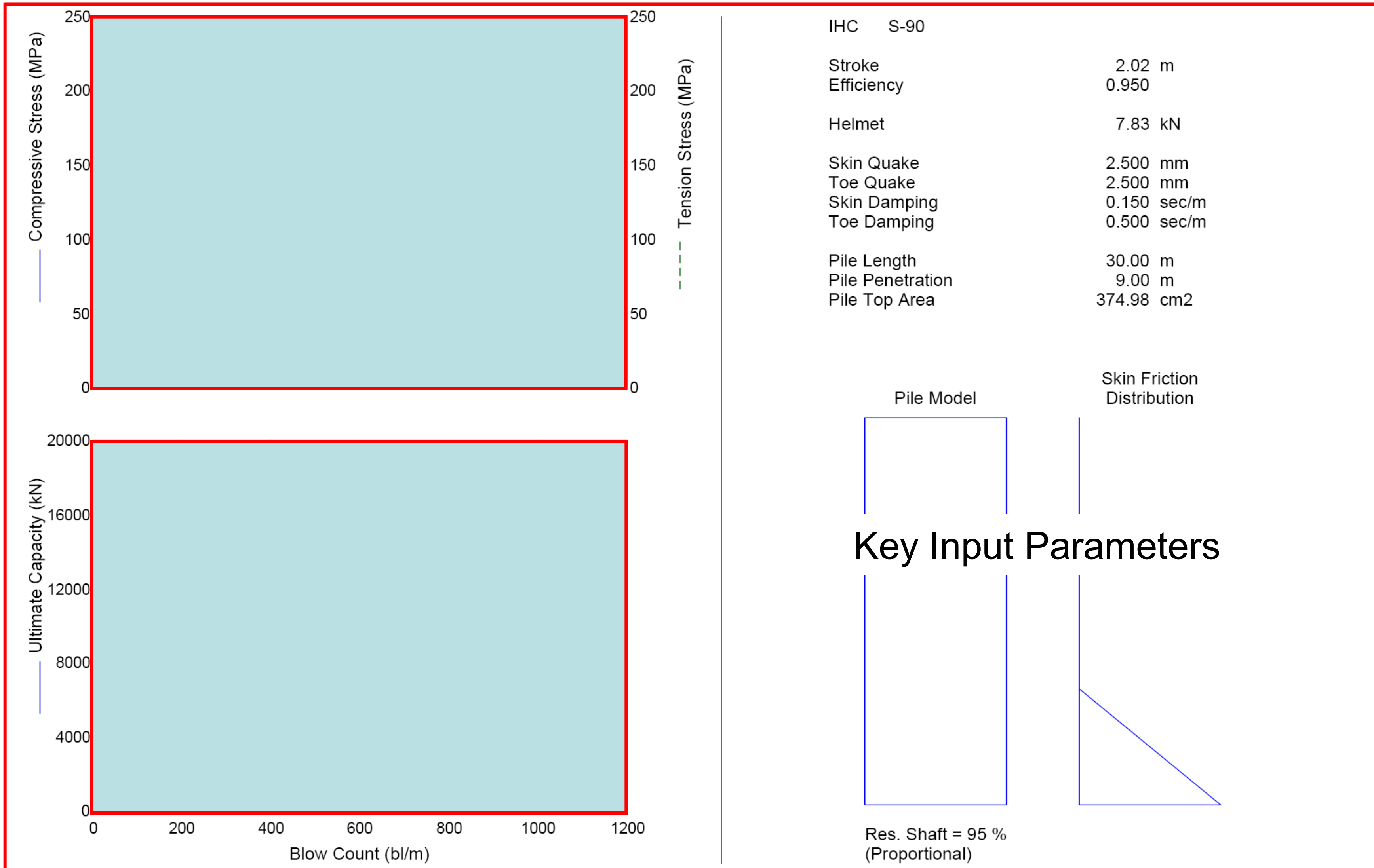
File Edit View Window Help

SI

ID*	Manufacturer*	Model	Energy/Power* (kJ)/(kW)	Ram Weight* (kN)	Eq. Ma…	Type*	No. Ram Se…	Ram Lengt…	Ram Diame…	Geom. Ma
1	DELMAG	D 5	14.24	4.895	2.93	OED	3	2211.578	210.058	2.93
2	DELMAG	D 8-22	27.25	7.832	3.67	OED	4	2390.140	249.936	3.67
3	DELMAG	D 12	30.65	12.237	3.29	OED	4	2652.014	299.974	3.29
4	DELMAG	D 15	36.74	14.685	3.29	OED	5	3048.000	299.974	3.29
5	DELMAG	D 16-32	54.51	15.664	3.58	OED	4	2880.360	320.040	3.58
6	DELMAG	D 22	55.06	21.849	2.90	OED	4	2836.926	389.382	2.90
7	DELMAG	D 22-02	65.77	21.582	4.10	OED	4	2458.720	419.354	4.10
8	DELMAG	D 22-13	65.77	21.582	4.10	OED	4	2458.720	419.354	4.10
9	DELMAG	D 22-23	69.45	21.582	4.10	OED	4	2458.720	419.354	4.10
10	DELMAG	D 25-32	89.96	24.519	4.19	OED	5	3129.280	419.354	4.19
11	DELMAG	D 30	80.99	29.370	2.90	OED	5	3537.458	389.382	2.90
12	DELMAG	D 30-02	89.76	29.370	4.10	OED	4	2999.740	419.354	4.10
13	DELMAG	D 30-13	89.76	29.370	4.10	OED	4	2999.740	419.354	4.10
14	DELMAG	D 30-23	100.06	29.370	4.10	OED	4	2999.740	419.354	4.10
15	DELMAG	D 30-32	102.29	29.370	4.18	OED	5	3129.280	419.354	4.18
16	DELMAG	D 36	113.66	35.288	3.22	OED	4	2710.180	498.094	3.22
17	DELMAG	D 36-02	113.66	35.288	3.96	OED	4	2710.180	499.364	3.96
18	DELMAG	D 36-13	113.66	35.288	6.09	OED	4	2710.180	499.364	6.09
19	DELMAG	D 36-23	120.00	35.288	3.96	OED	4	2710.180	499.364	3.96
20	DELMAG	D 36-32	122.80	35.288	4.01	OED	4	2715.260	499.364	4.01
21	DELMAG	D 44	122.25	42.275	2.90	OED	4	2641.854	549.402	2.90
22	DELMAG	D 46	145.20	45.123	3.22	OED	5	3500.120	498.094	3.22
23	DELMAG	D 46-02	145.20	45.123	3.94	OED	5	3500.120	499.364	3.94
24	DELMAG	D 46-13	130.90	45.123	3.94	OED	5	3500.120	499.364	3.94
25	DELMAG	D 46-23	145.20	45.123	3.94	OED	5	3500.120	499.364	3.94
26	DELMAG	D 46-32	165.69	45.123	3.99	OED	5	3500.120	499.364	3.99
27	DELMAG	D 55	169.51	52.777	3.40	OED	5	3299.460	549.402	3.40
28	DELMAG	D 62-02	206.72	60.787	3.87	OED	5	3789.680	549.402	3.87

Ready

GRLWEAP Graphical Output



GRLWEAP Text Output

- Standard GRLWEAP output table provides simple summary
- Significantly more detailed analysis results are available
- The entire pile driving process can be simulated in order to estimate driving times for planning and estimating purposes
- The effects of pile set-up and relaxation can be modelled where these might be critical to the ability to drive piles to a target toe level

GRLWEAP Comments

- The predictions of GRLWEAP can be highly sensitive to particular input parameters. For instance, driveability will be significantly affected by “toe quake” when toe resistance is high
- Driveability predictions can vary considerably. Consideration should be given to undertaking “best guess”, pessimistic and optimistic analyses, or in some other way undertaking sensitivity analyses.
- Direct experience at the site (PDA testing) or experience with similar piles in similar ground conditions should be taken into account.
- The “default” program parameters will not necessarily be conservative
- In the context of a driveability study, conservative parameters are those which will make driving harder (opposite to conservative design parameters)
- The results of GRLWEAP are preliminary, and are superseded by PDA testing and CAPWAP analysis
- Use of structurally efficient designs with high strength steels may not be practicable as hammers may not be available with sufficient stroke.

Difficulties in Establishing Foundation Adequacy and Safety

- Small percentage of piles tested †
- Time-dependent capacity changes †
- Inference of untested pile capacities †
- Variable ground conditions †
- Installation effects on stress regime †
- Friction fatigue and other poorly understood effects †
- Poor information on resistance distribution †
- Residual stresses for driven piles †
- Downdrag †
- Testing to proof not ultimate
- Rate-dependence of capacity
- Need to consider group effects
- Subsequent changes to ground or water levels
- Measurement errors
- Inaccurate analysis of indirect test methods
- Knowledge of true load effects

† These are issues which PDA testing can help to assess

Other Technical Issues

- Static – Dynamic comparisons
- Pile set-up
- Pile Relaxation
- Pile Acceptance Criteria and Test Method
- Restrike Testing
- Downdrag
- Mobilization of Capacity

Static test comparisons

- For piles which are installed in soils which demonstrate time-dependent capacity changes, care must be taken in comparing the results of tests performed at significantly different times
- Static and dynamic tests should be performed in close succession
- Dynamic tests can be performed both before and after the static test
- Multiple dynamic tests allow the variation of capacity with time to be measured

Griffit

Static/dynamic comparisons : points to consider

- Dynamic effects must be deducted from PDA test response
- Static tests may be subject to instrument and interaction errors
- Timing may be critical – (setup OR relaxation)
- PDA test may underestimate if hammer has insufficient energy
- Static test may underestimate if test load is insufficient
- Comparisons must be made with care taking all these effects into account
- Require estimate of working load DEFORMATION
- Require estimate of Ultimate CAPACITY

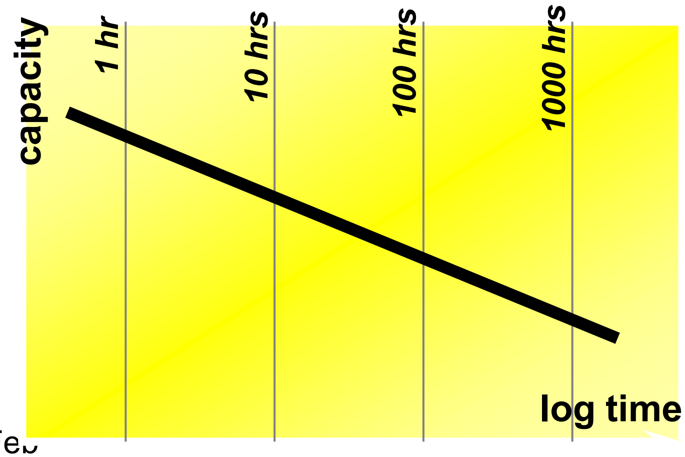
Pile set-up

- Is the observed increase of pile capacity after driving.
- It is commonly observed in fine-grained soils (silts and clays) and is due to -
  - increases in soil effective stresses as pore pressures dissipate
  - clay consolidation
  - re-establishment of clay bonds destroyed during driving
- Pile set-up is sometimes be observed in coarse-grained soils. There has been recent interest in this phenomenon

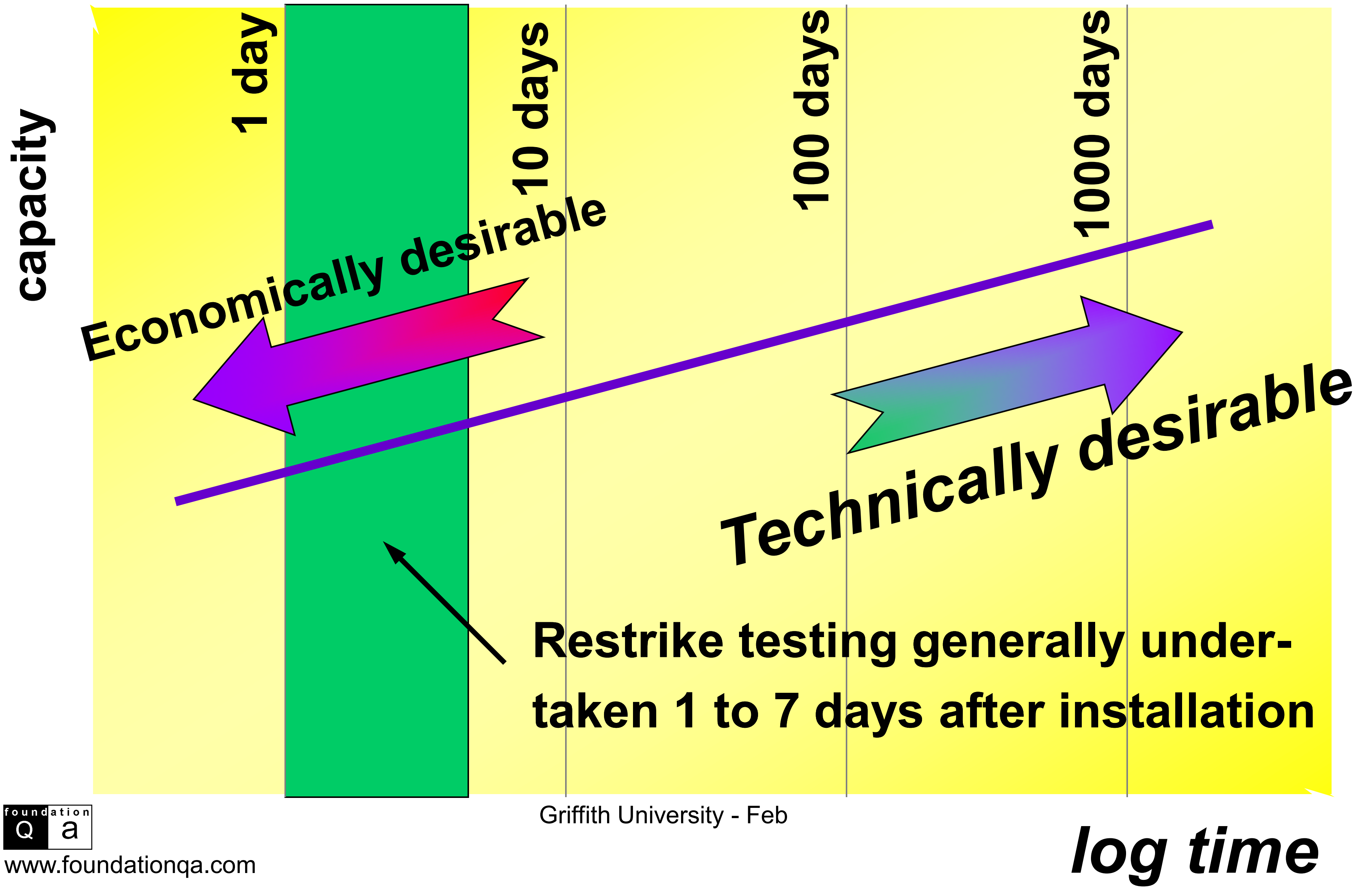
- The pile set-up phenomenon can be quantified by undertaking both driving and restrike testing
- The possibility of variations in set-up potential across a site should be taken into account
- Unless piles will be subjected to very high levels of two-way cyclic loading in service, pile set-up is a reliable phenomenon

Pile Relaxation

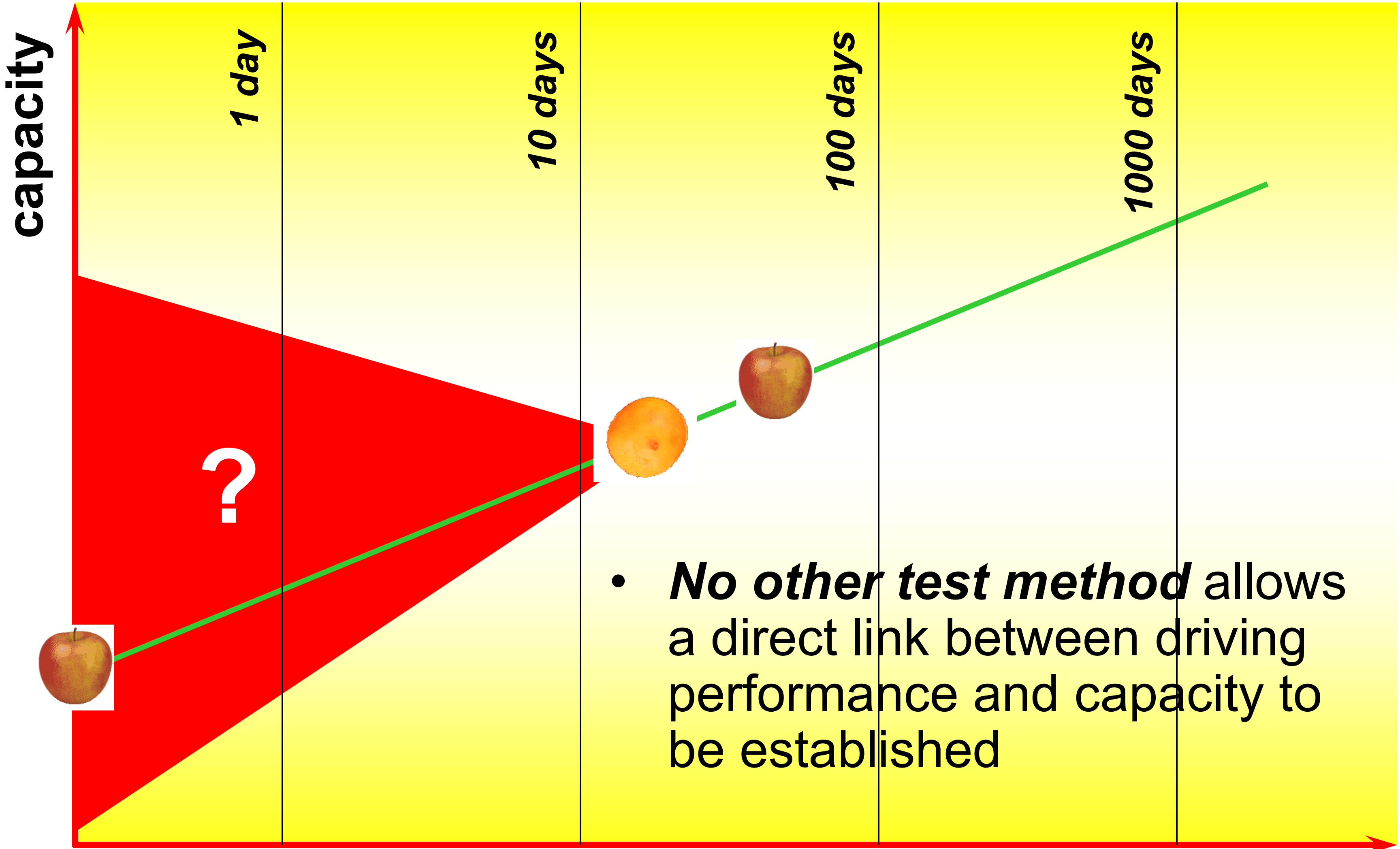
- Under certain conditions, pile end bearing may decrease with time. This is associated with a loss of set. The phenomenon is called pile relaxation
- Relaxation is particularly severe in closely-spaced pile groups
- Relaxation has been observed particularly in piles driven into soft rock formations such as shale and mudstones
- Relaxation may be associated with generation of negative pore pressures or with propagation of cracks around the pile
- Restrike testing should always be undertaken for piles which may be potentially subject to relaxation



Restrike testing - fine grained soils



Acceptance criteria and test method



- ***No other test method*** allows a direct link between driving performance and capacity to be established

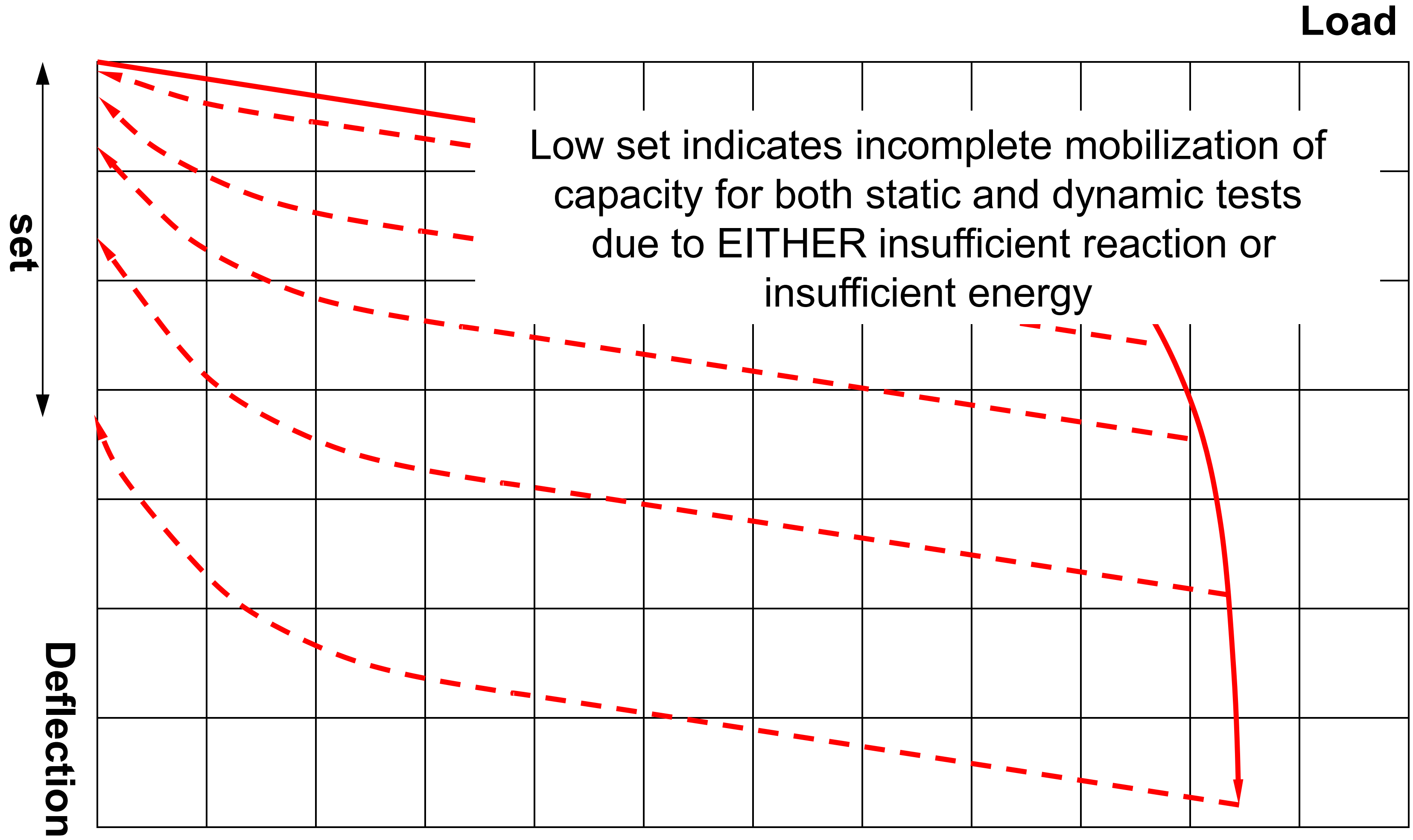
Downdrag

- Dynamic Pile Testing is an ideal tool for evaluation of the downdrag phenomenon
- It can be used to establish
  1. The shaft resistance in the settling zone
  2. The shaft resistance and end bearing in the stable zone
- Assist in developing realistic acceptance criteria to satisfy both serviceability and ultimate limit state criteria

Note!

- End bearing should normally be established during driving
- Shaft resistance in the stable zone should preferably be determined during restrike
- Shaft resistance in the settling zone MUST be determined on restrike and should be compared with geotechnical theory (e.g. 0.25 to 0.30 σ'_v).
- See Seidel (2004) Stresswave conference [www.foundationqa.com]

Mobilization of Capacity



QA and Specifications

- PDA testing is suffering a crisis of training and quality and hence confidence in some countries
- Given that it is a primary quality control technique, quality of training and interpretation is fundamental
- Foundation QA developed an Examination and Certificate in “High Strain Dynamic Pile Testing” in 2000. This is becoming an internationally recognized requirement for PDA testing
- This is a 3½ hour examination in 2 parts

  A : Data Acquisition (primarily for field testing personnel) and additionally

  B : Data Interpretation (for testing signatories)
- Certification is available at 5 levels - Pass and Intermediate for Testers and Advanced, Master and Expert for Signatories
- Certification may be renewed annually for up to 5 years before retaking exam

Endorsement of FQA Certification

U.S. Department of Transportation
Federal Highway Administration

Bridge Specification, May 2006
Chapter 11, Contract Documents

This section of the specifications applies to the Contractor's activities as they relate to the dynamic testing of piles. ***If the dynamic tests are to be performed by an independent firm retained by the Contractor and not transportation department personnel, an additional specification section detailing the dynamic test analysis and reporting requirements must be added. In addition, testing personnel should have attained an appropriate level of expertise on the Foundation QA Examination for providers of dynamic testing services.*** *Dynamic tests and the Foundation QA Examination are discussed in greater detail in Chapter 17 of this manual.*

PDA Certification Portal www.hsdptregister.org

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Events Calendar

February 2007

S	M	T	W	T	F	S
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	1	2	3

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Examination and Certificate in PDA Testing

High Strain Dynamic Pile Testing is a highly specialized area of foundation pile verification. The technology is now commonly in use and codified in many countries around the world. However, because the technique is so specialized, clients in general have no way of independently assessing the skills or critically evaluating the reported results of practitioners providing dynamic pile testing services. As it is unlikely that clients will meet the challenge of obtaining these evaluation skills, the alternative is to provide them with some standard measure of the skills of dynamic pile testing providers.

The need for quality assurance of dynamic pile testing providers:

Dynamic pile testing is a field of engineering demanding high skill levels in both instrumentation, analysis and engineering judgment. Like most technology, in the right hands it can either be a powerful tool with great benefits to the construction process, or in the wrong hands, a tool which is ineffectual, misleading or even wrong.

Because dynamic testing is specialized, many project owners and their engineer representatives are unlikely to have the skills to critically or independently evaluate the quality of the testing or the consequent advice. This places additional responsibility on the testing provider. As dynamic pile testing is used as a Quality Assurance technique for foundations, it is fundamental that persons providing such services are themselves the subject of a Quality Assurance process.

Specification - Personnel

15.1.2 Equipment and Personnel

The dynamic testing shall be performed using a Pile Driving Analyser Model PAK or PAL, or equivalent as approved by the Engineer.

An experienced specialist consultant, who has achieved an Advanced Level or better on the Foundation QA Examination for Providers of PDA Testing Services (or equivalent qualification as approved by the Engineer) shall be in charge of the Pile Driving Analyser (PDA) operation, result interpretation, CAPWAP analysis, and reporting.

At least two strain transducers and two accelerometers shall be used, and any holes required in the permanent works part of the steel pile for fixing of these gauges shall be completely filled with weld, ground flush, and the protective treatment repaired on completion of testing.

The proposed testing company's name, the proposed testing equipment, and curricula vitae and certification of qualification of staff proposed to undertake the testing shall be submitted to the Engineer at least 4 weeks prior to commencement of testing.

Specification – Framework suggestions

1. Personnel should be appropriately qualified
2. Testing data should be the property of the Client and all electronic records should be provided to the Client either progressively or at completion of the project
3. Client reserves the right to provide the data for independent review and analysis
4. Testing to be in accordance with appropriate standards – e.g, ASTM-D4945-00 and/or AS2159-1995
5. Allow for expert review on significant projects
6. Allow for sufficient testing recognizing that more testing increases confidence in foundation (should be reflected in higher φ_g.)

Specification – General suggestions

- Specify both FULL DRIVING monitoring and RESTRIKE testing.
  - Full driving monitoring is primarily for establishing construction control parameters and identifying any installation issues which may affect successful installation.
- Specify that a piling plan is to be developed as a result of the driving monitoring to ensure that piles are driven safely and consistently to the required capacities (e.g. plan to nominate cushion strategy) – see also pile acceptance.
- Restrike testing is primarily for confirmation of capacity.
- Allow for PDA tests to be across the site to take into account any spatial variation
- Allow for PDA testing to be undertaken progressively over the contract period to monitor any variation of hammer performance
- Weight frequency of testing at the commencement of pile driving
- Ensure that pile acceptance criteria are WELL CONNECTED to dynamic pile test results.

Specification – Pile Acceptance

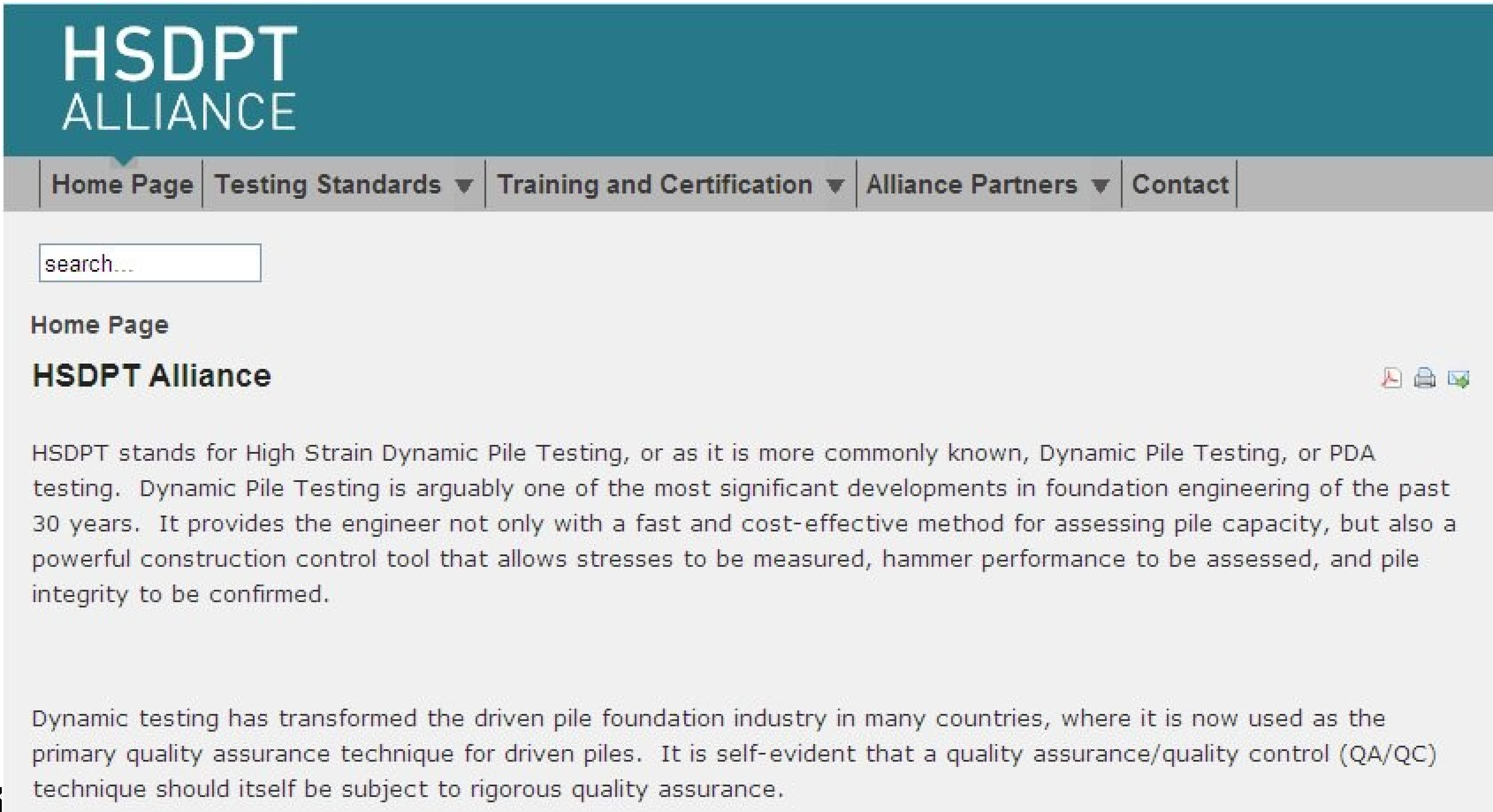
- Ensure that pile acceptance criteria are WELL CONNECTED to dynamic pile test results
- All pile acceptance should be traceable back to dynamic testing results (i.e. don't have unrelated acceptance for tested and untested piles)
- (My suggestion) is to base acceptance on a corrected driving formula – either Hiley or (better) Seidel Energy Correction Method !
- Allow for progressive review and modification of acceptance criteria as a result of changes in hammer performance and ground conditions

Specification - Equipment

- Specify acquisition and individual recording of minimum 2 functioning strain transducers and 2 accelerometers for testing of preformed piles in compression
- Specify acquisition and individual recording of minimum 4 functioning strain transducers and 2 accelerometers for any of the following cases :
  - Cast-in-situ piles of any kind greater than 300mm diameter
  - Piles of any kind 1200mm diameter or greater
  - Spiral-welded steel tube piles
  - Timber piles
  - Piles with critical tension capacity requirements

HSDPT Alliance Portal www.hsdptalliance.org

- Alliance between clients, testers and expert reviewers for the purpose of ensuring testing is undertaken to proper quality standards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HSDPT Alliance

HSDPT stands for High Strain Dynamic Pile Testing, or as it is more commonly known, Dynamic Pile Testing, or PDA testing. Dynamic Pile Testing is arguably one of the most significant developments in foundation engineering of the past 30 years. It provides the engineer not only with a fast and cost-effective method for assessing pile capacity, but also a powerful construction control tool that allows stresses to be measured, hammer performance to be assessed, and pile integrity to be confirmed.

Dynamic testing has transformed the driven pile foundation industry in many countries, where it is now used as the primary quality assurance technique for driven piles. It is self-evident that a quality assurance/quality control (QA/QC) technique should itself be subject to rigorous quality assurance.