# Webinar: Part 1 – Concepts
# Advanced Method for Compaction Quality Control

# Today’s Moderator

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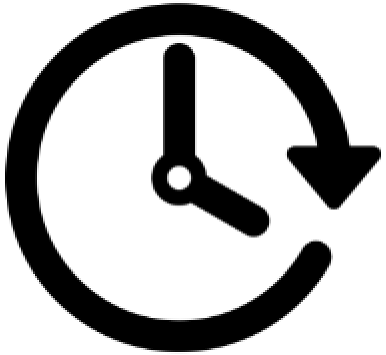
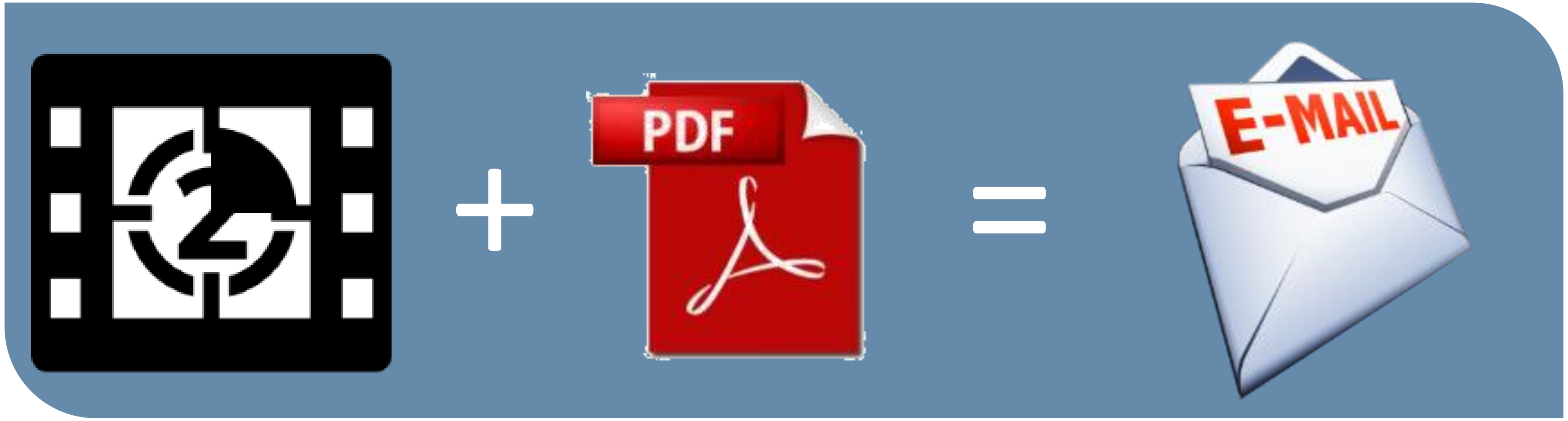
# Housekeeping



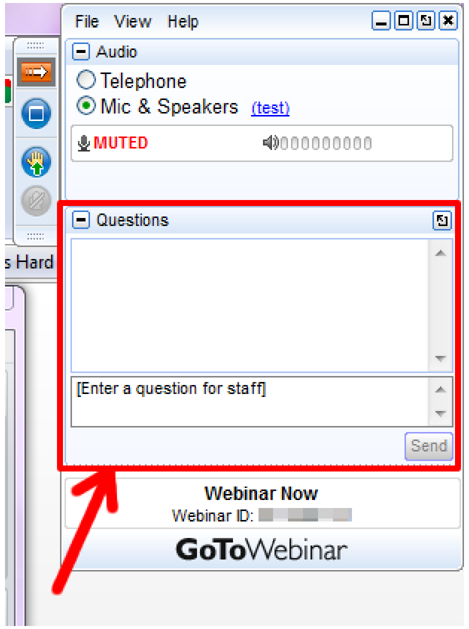


Webinar is = 50 mins

Question time = 10 mins

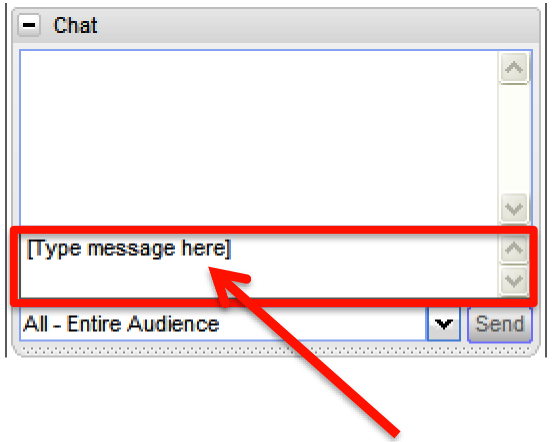


# GoTo Webinar functions




Please type your questions here

Raise your hand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Part 1 – An Overview **(Conceptual)**

- ✓ Density Basics
- ✓ Rationale for this equipment research
- ✓ Equipment over view + a few initial findings

Part 2 – Test Results **(Technical)**

- Details of testing from various sites
- Correlations with “Standard” practice
- Time vs Reliability vs Useful Data

Part 3 – Moving Forward **(Procedural)**

- Procedures and Specifications
- Advantages and limitations
- Implementation

This Presentation

Future Presentations

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# P60: Best practice in compaction quality assurance for subgrade materials

ARRB Project Leader: Dr. Jeffrey Lee

TMR Project Manager: Siva Sivakumar

http://nacoe.com.au/

# NACOE P60

## Aim and Background of the Project

- Aim
  - To modernise testing procedure for compaction quality assurance
- Background
  - Conventionally been verified using density measurements
  - Alternative methods have been developed over the past two decades
  - Many of these methods takes less time to do, results become available in a much shorter time frame, and be able to measure insitu stiffness.


Source: http://www.befreetoday.com.au/the-horse-and-the-rope/

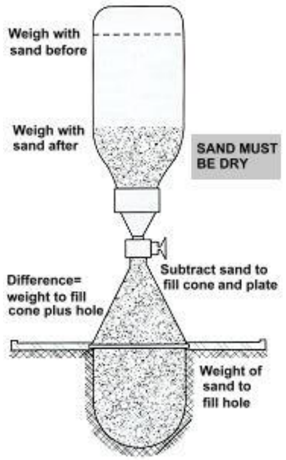
# Why we should be looking at other Testing Methods / Equipment

# Issues with Density Measurement



Reliance of density testing and CBR results for QA purposes have issues/limitations:

- ✓ ***Lag indicators*** – Several days / one week typical to complete. Contractor typically continues work and advances fill placement above the lift – before QA results are available.
- ✓ ***Density Oversize correction*** – This applies when greater than 20% of material exceeds 19 mm or 38 mm for Mould A and B size, respectively. This is not consistently being applied across the industry, with 22% of 235 samples examined not applying that correction.




- ✓ ***Strength and modulus parameters*** - Density is neither a strength nor a modulus parameter → simply assumed that such a relationship exists for the purposes of QA. ↑γ = ↑E assumed. E = 10 x CBR correlation has a significant associated correlation variation.
- ✓ **The CBR test -** not applicable for materials with > 20% retained on 19 mm sieve; (Australian Standards). Differences in material preparation Road Authority Standards would result in different CBR test values being determined and reported.

# Compaction Quality Control



A state-of-the-industry study completed in 2017 → identified test methods that have the potential to:

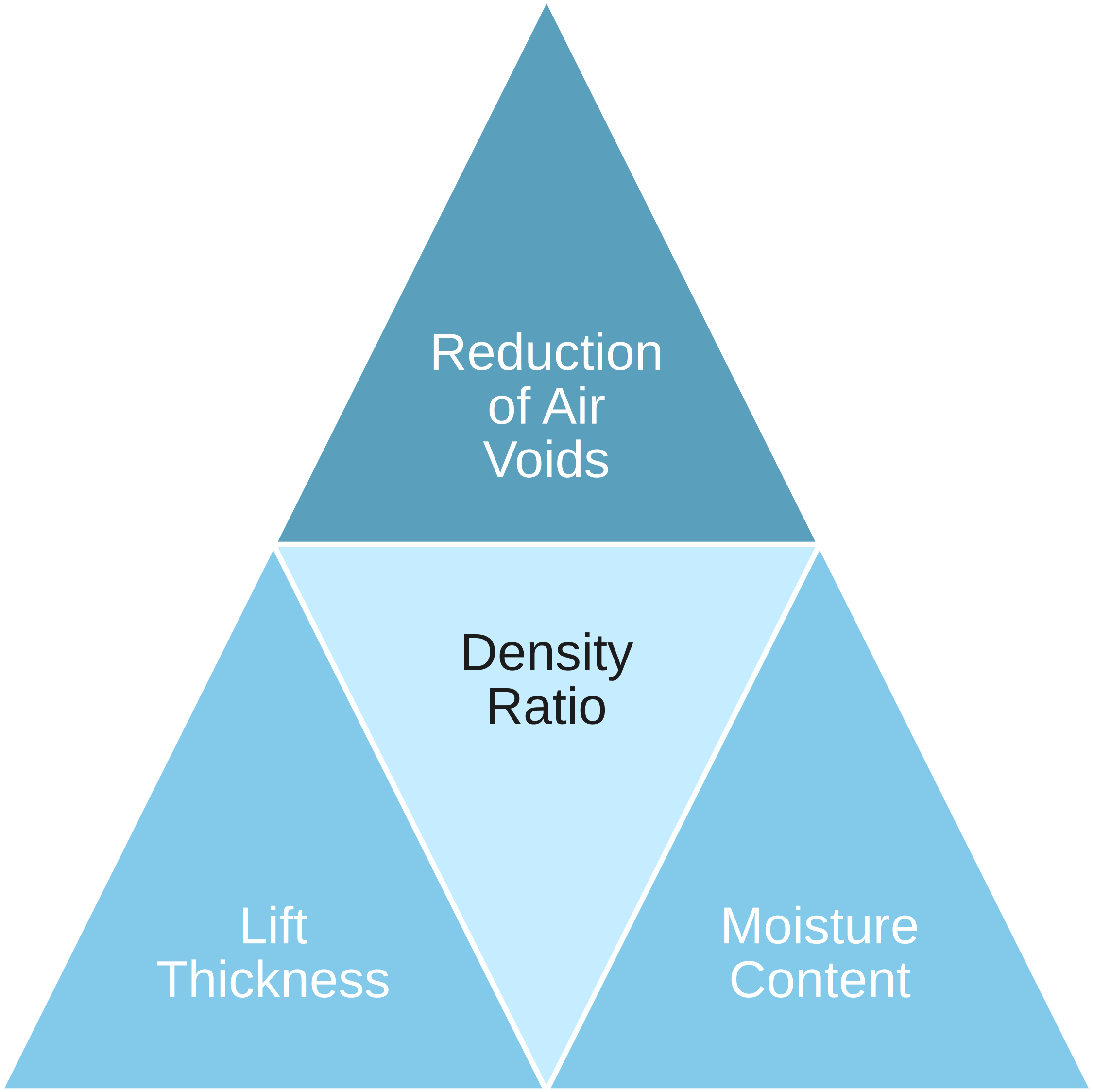
(a) reliably provide a direct measure of the strength or insitu modulus value; and

(b) offer significant time savings in turnaround time of QA test results.

2017 Summary + A few Preliminary results of 2018 field trials of the identified innovative QA test methods will be presented.

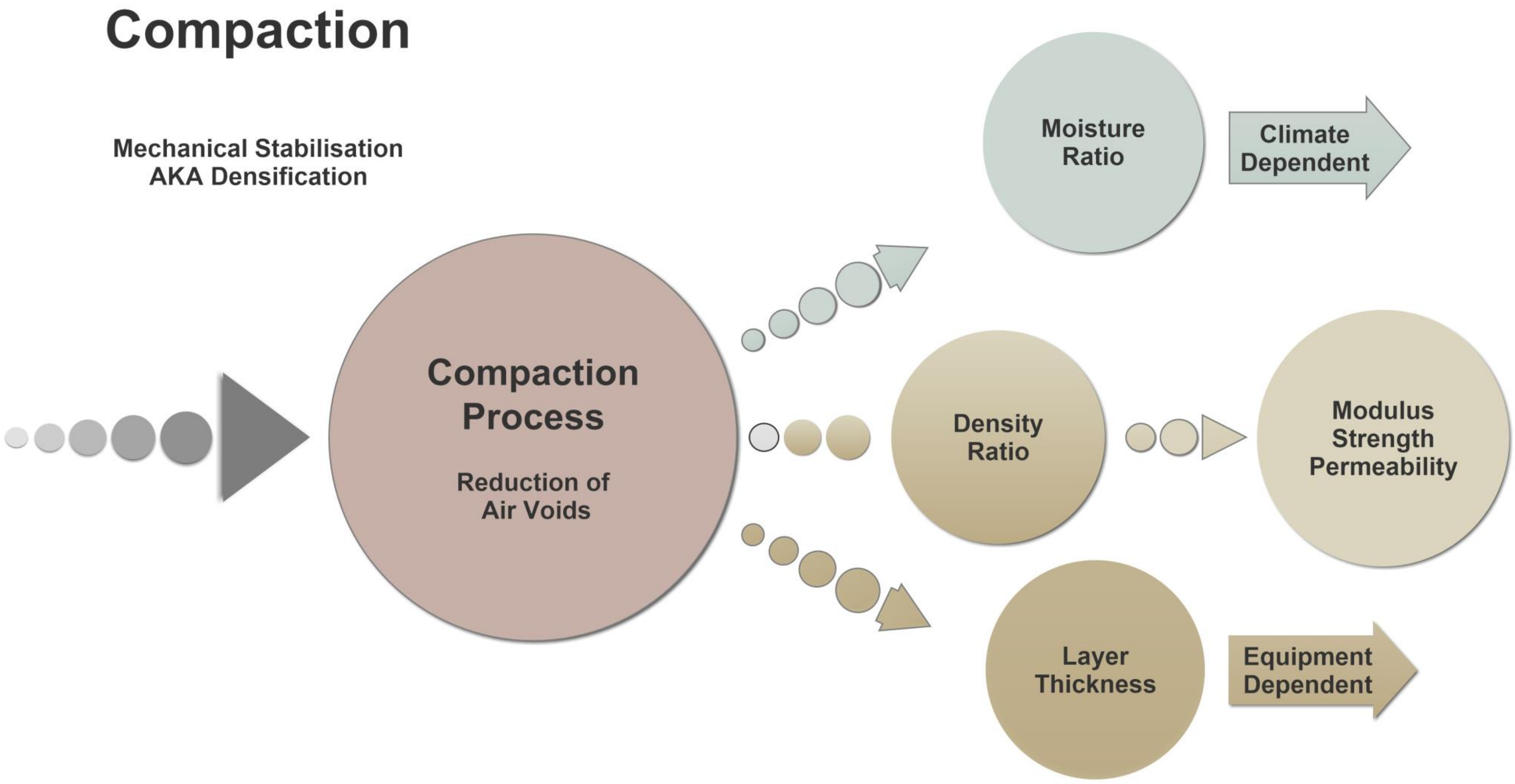
# Recommendations vs Requirements are confused

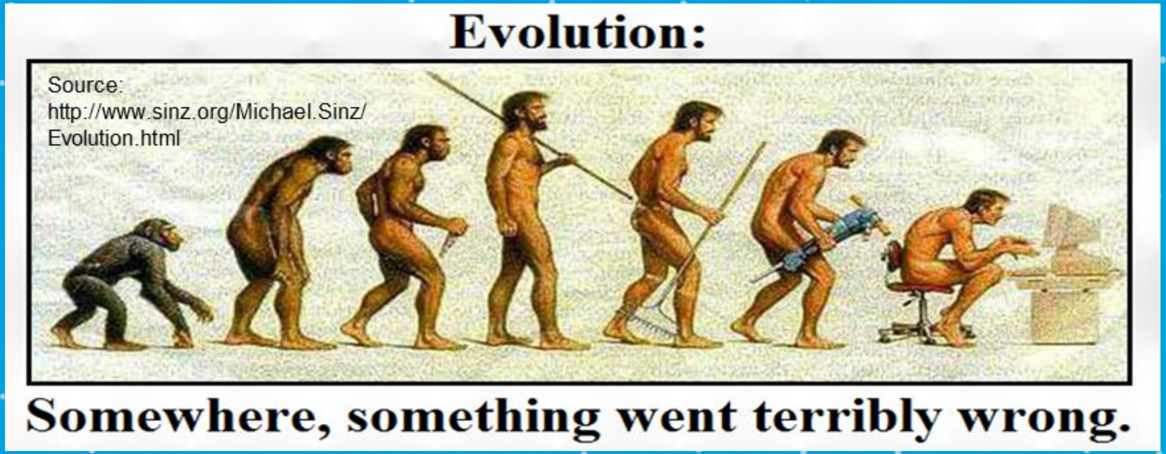




# Contributing Factors ≠ Objective








# Historical Perspective

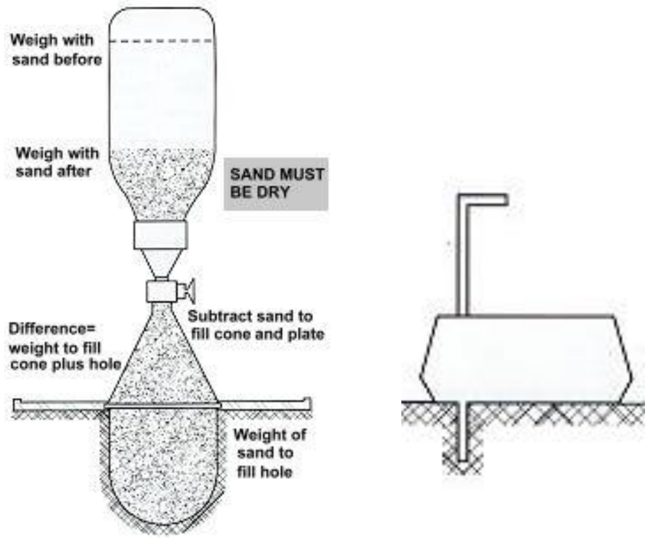
# Equipment vs Testing change with Time

**1960**
- HRB Bulletin 272, 1960
- Output < 100m$^3$ / hr
- 9 – 14 t rollers

**1980**
- Forssblad, 1981
- 500 – 1500 m$^3$ / hr
- 15 t rollers

**2001**
- Bomag, 2001
- 800 – 2200 m$^3$ / hr
- 19 – 24 t rollers

200mm lift thickness set for “heavy” equipment




No change due to testing limitation of 200 to 300mm

# Historical Basics

## Properties of Field Compacted Soils

E. T. SELIG, Manager, Soil Mechanics, and W. B. TRUESDALE, Research Engineer
IIT Research Institute, Chicago

Soil compaction tests were conducted in the field by constructing test sections of soil in single lifts on a prepared foundation using a variety of commercial rollers. The test results were obtained using the following specific independent variables: (a) four subgrade soils, A-6(13), A-6(9), A-4(1) and A-4(8); (b) four moisture contents for each soil ranging from dry to wet of optimum; (c) two lift thicknesses, 6 and 12 in.; (d) four rollers, sheepsfoot, pneumatic tire, vibratory smooth-wheel, and segmented pad, at two levels of effort for each roller; and (e) roller coverages up to 16. Measurements were made of the strength, stiffness and density of the soil using a variety of techniques. A full factorial experiment consisting of 256 test sections to represent all combinations of these selected variables was designed to detect, using analysis of variance techniques, the effects of the variables on the measured soil properties, taking into account the large variability exist-

**Symposium on Compaction of Earthwork and Granular Bases, Highway Research Record 177 (1967)**

Table 1 lists the soil measurements and ranks the effects of the independent variables in order of significance. In addition to the five independent variables, the ten possible combinations of these variables are included. (The independent variables ar[e] designated as follows: M = moisture level, T = lift thickness, S = soil type, C = compactive effort, and E = compaction equipment. Combinations of any two letters indicate joint effects.) The significance is expressed in terms of a probability of err[or] in an assumption that the given variable really affects the measurement rather than being a chance occurrence. The categories range from less than 0.1 percent to 10

M – Moisture Content
T – Lift Thickness
S – Soil Type
C – Compactive Effort
E – compaction Equipment

TABLE 2

RANGE AND AVERAGE OF PROPERTIES FOR ALL EFFECTS

| Measurement | Dimension | Range | Average | Range / Average (%) |
|---|---|---|---|---|
| Moisture content ✗ | % | 13.5 | 12.1 | 112 |
| Field CBR ✗ | % | 26.6 | 15.0 | 177 |
| Wet density | pcf | 29.8 | 127.6 | 23 |
| Moisture density | pcf | 10.9 | 12.6 | 87 |
| Dry density | pcf | 21.5 | 115.0 | 19 |
| Penetration resistance ✗ | lb | 529 | 364 | 145 |
| Seismic velocity | fps | 890 | 1192 | 75 |
| Plate load | lb | 1814 | 1719 | 105 |

TABLE 3

RELATIVE SIGNIFICANCE OF INDEPENDENT VARIABLES ON GROWTH CURVE SHAPE

| Measurement | Individual Effects | | | | | Joint Effects | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | T | S | C | E | MT | MS | MC | ME | TS | TC | TE | SC | SE | CE |
| Portable nuclear $\gamma_w$ | | | 2 | 6 | 1 | 6 | 4 | | 5 | | | | | | |
| Portable nuclear $w_d$ | | | | | 6 | | 6 | | | | | | | | |
| Portable nuclear $\gamma_d$ | | | | 6 | 1 | | 6 | | 5 | | | | | 3 | |
| Plate load | 1 | | | | 1 | | | | | | | | 6 | 5 | 6 |
| Pen. resistance | 1 | | 4 | | | | 5 | 5 | | | | | | | 6 |
| Seismic velocity | 2 | | | | | 5 | 2 | | 2 | | | | | | |

Note: Error probability (%): 1 = 0.1, 2.= 0.5, 3 = 1.0, 4 = 2.5, 5 = 5.0, 5 = 5.0, 6 = 10.0.

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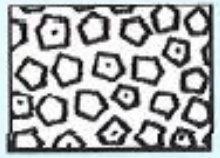
# Lift heights : medium-heavy compaction equipment

| Machine | Operating weight | Lift height compacted in (m) | | | |
|---|---|---|---|---|---|
| | | Rock | Gravel, sand | Mixed soil | Silt, clay |
| | t |  |  |  |  |
|  | 1.5 - 2.5 | - | • 0.20 - 0.30 | • 0.20 - 0.25 | 0.10 - 0.15 |
| | 3.0 - 4.5 | - | • 0.25 - 0.30 | • 0.20 - 0.25 | 0.15 - 0.20 |
| | 7 - 9 | - | • 0.30 - 0.40 | • 0.20 - 0.30 | 0.15 - 0.20 |
| | 10 - 12 | - | • 0.30 - 0.50 | • 0.25 - 0.40 | 0.15 - 0.20 |
|  | 2 - 3 | - | • 0.20 - 0.35 | • 0.20 - 0.35 | 0.15 - 0.20 |
| | 6 - 8 | 0.30 - 0.50 | • 0.30 - 0.50 | • 0.25 - 0.35 | • 0.15 - 0.20 |
| | 9 - 12 | 0.50 - 0.80 | • 0.50 - 0.60 | • 0.30 - 0.45 | • 0.20 - 0.25 |
| | 13 - 16 | • 0.80 - 1.20 | • 0.50 - 0.80 | • 0.40 - 0.60 | • 0.20 - 0.35 |
| | 19 - 25 | • 1.00 - 2.00 | • 0.80 - 1.50 | • 0.60 - 1.00 | • 0.30 - 0.50 |
|  | 6 - 7 | • 0.50 - 0.80 | • 0.40 - 0.60 | • 0.30 - 0.45 | • 0.20 - 0.30 |

• Machine particularly suitable for this type of soil

Bomag, 2001

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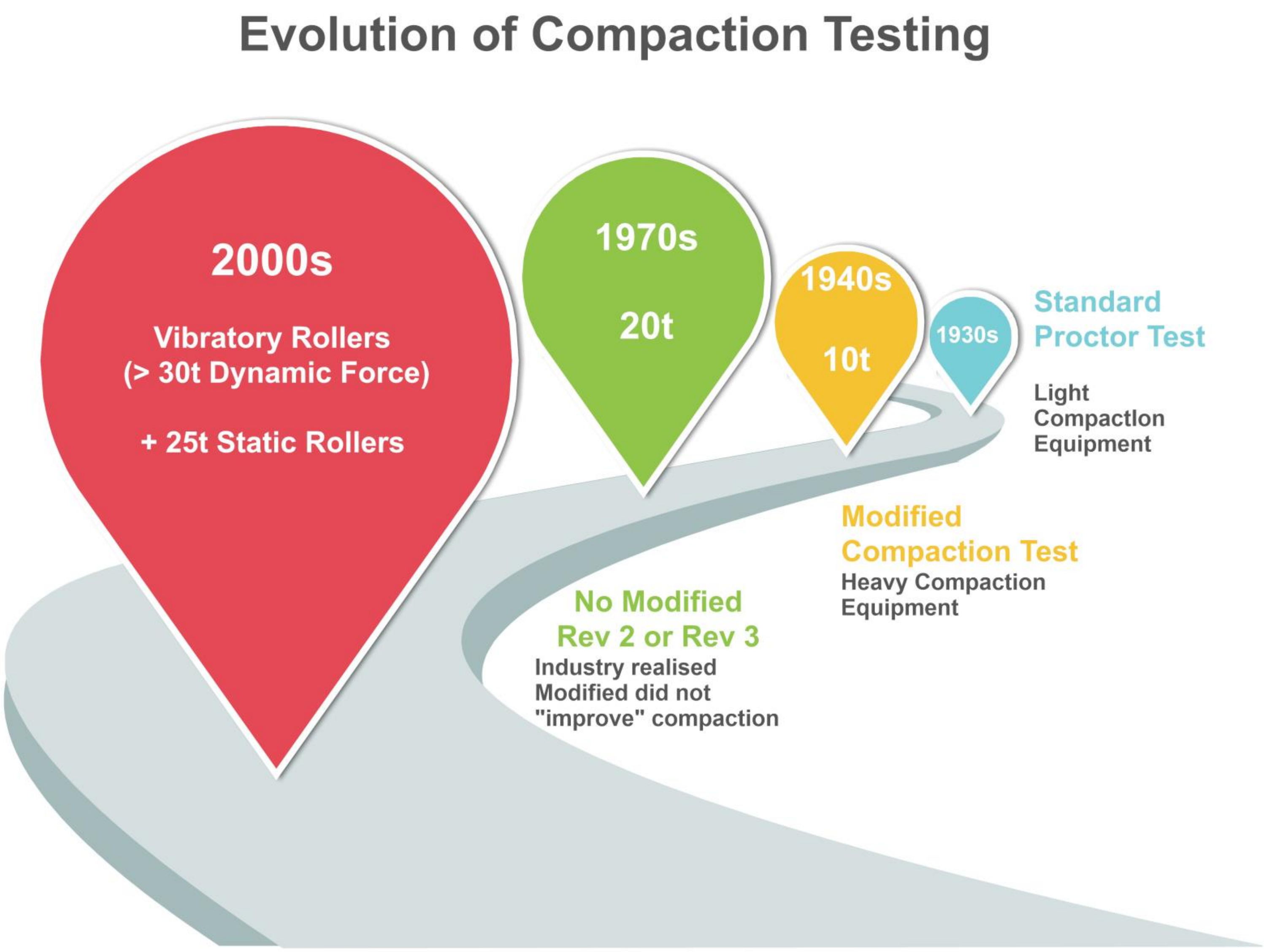
# Compaction History

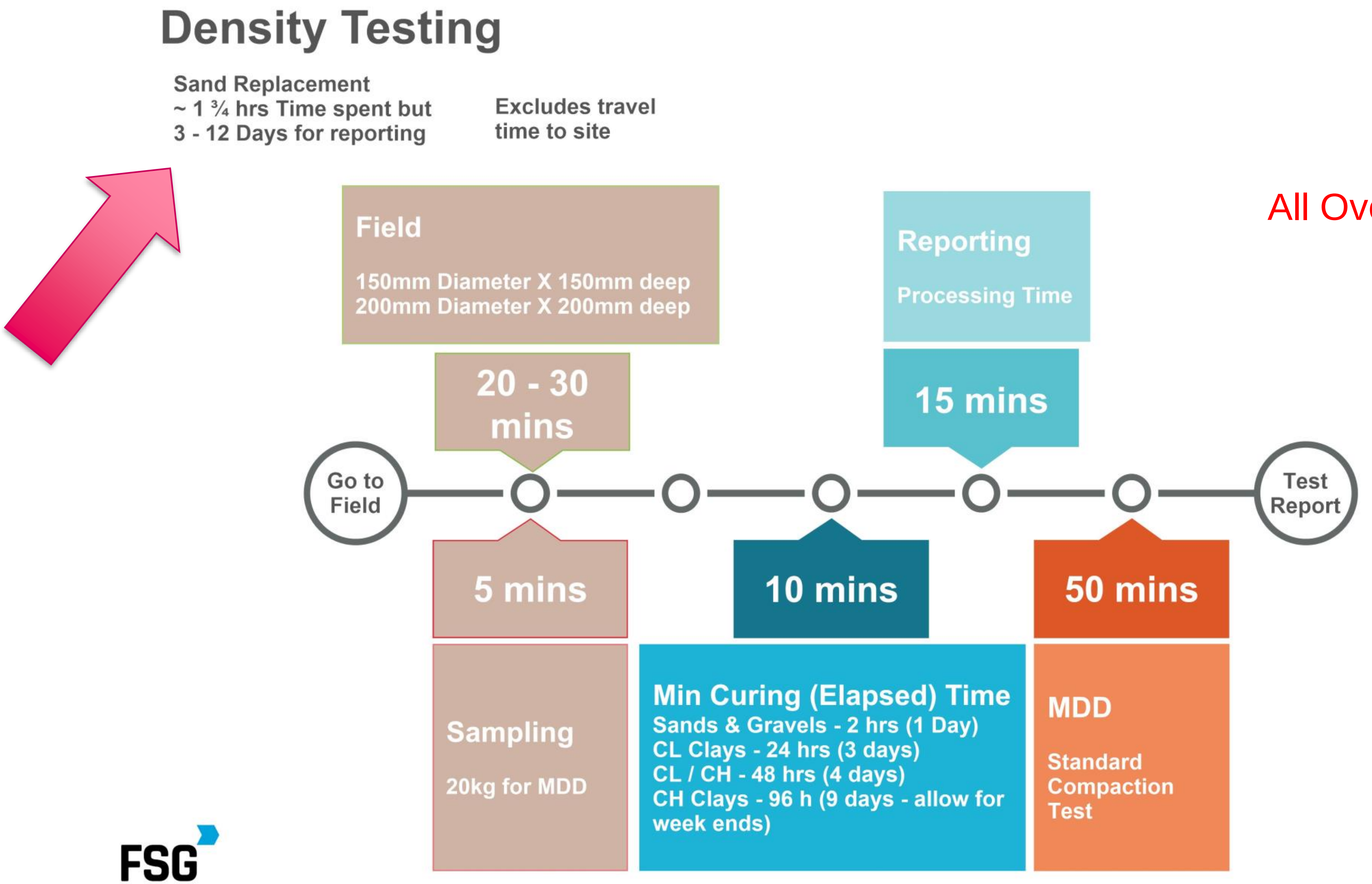




http://favoritememes.com/news/close_enough/2014-07-27-342

# Density + CBR Testing Basics

# Density Testing




All Overhead time excluded

# CBR – A.S. vs QTMR vs RMS Standards



| Standard | Q113A – CBR (Standard) 2016 | AS1289: 6.1.1 (Standard) 2014 | RMS T132 (Standard or Modified) |
|---|---|---|---|
| Particle size | Any size OK<br>Crush to pass 19mm | Not applicable for > 20% retained on 19mm. Discard mat'l retained on sieve. | Applicable to that portion that passes the 19mm sieve. Do not crush |
| Preparation | Sands, Gravels, crushed rock (fines < 12%) → 2 hrs<br><br>Low (LL ≤ 35%) → 48hrs<br>Medium (35 < LL ≤ 55%) → 4 days<br>High (LL> 55%) → 7 days | (see Minimum Curing Time table below) | Sands → 1hr<br>Clays → Several days |
| Surcharge | 4.5kg only | 4.5kg + (depends on overlying material) – up to 18kg | 4.5kg only |
| Soaking | 4 days only | 4 days unless otherwise specified | 4 days unless otherwise specified |
| Reporting | CBR 1- 10 nearest 0.5 units<br>CBR 11- 30 nearest 1 unit<br>31 to 120 nearest 2 units<br>> 120 nearest units | CBR ≤ 5% nearest 0.5<br>CBR 6 to 20 nearest 1<br>CBR 21 to 50 nearest 5<br>CBR > 50 nearest 10 | CBR ≤ 5% nearest 0.5<br>CBR 5 to 20 nearest 1<br>CBR 20 to 50 nearest 5<br>CBR > 50 nearest 10 |

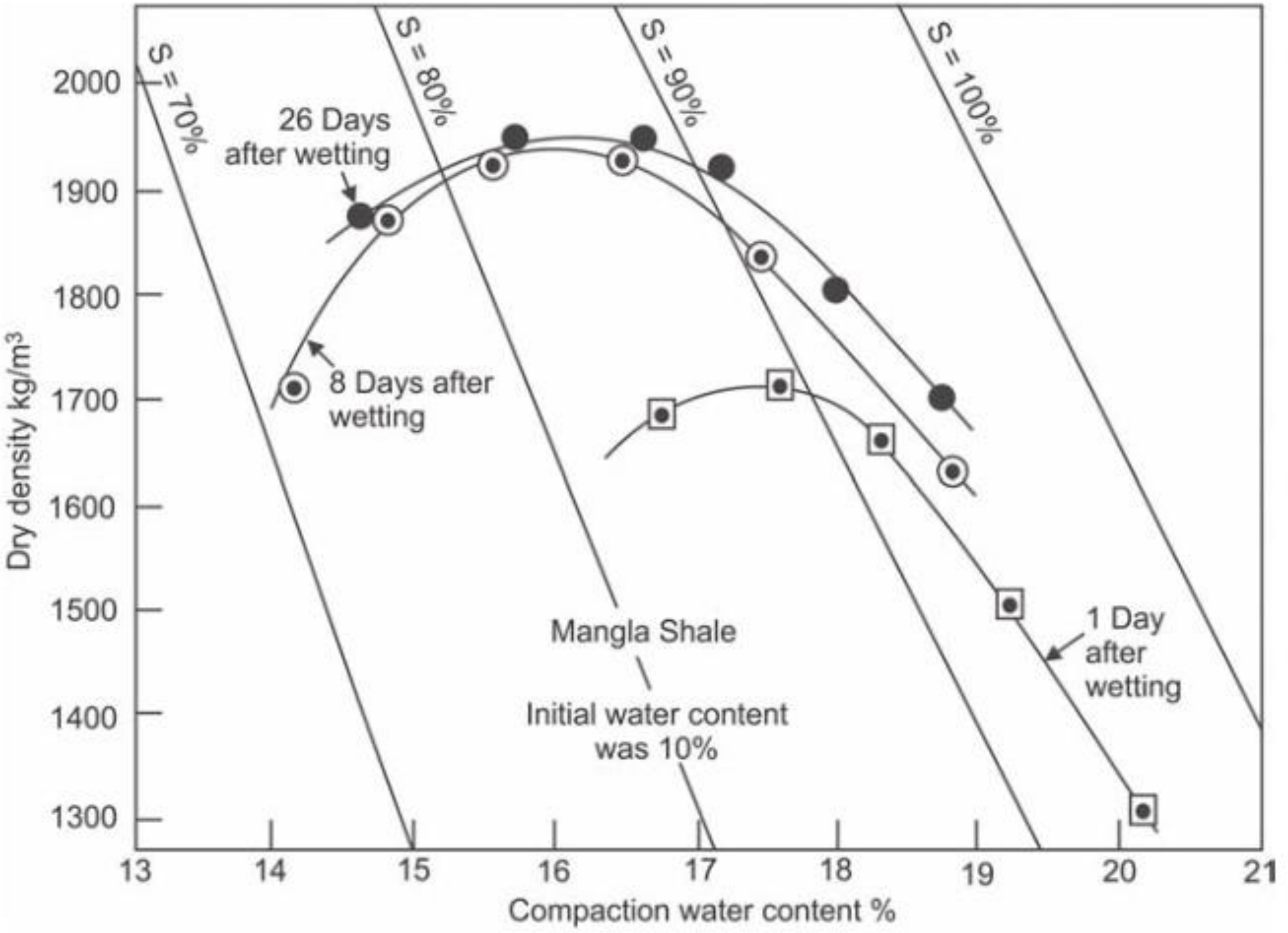
**MINIMUM CURING TIME**

| Plasticity | Condition of prepared sample | |
|---|---|---|
| | Within 2% of OMC | Greater than 2% from OMC |
| Sands and granular material* | 2 h | 2 h |
| Low (LL ≤ 35%) | 24 h | 48 h |
| Medium (35% < LL ≤ 50%) | 48 h | 96 h (4 days) |
| High (LL > 50%) | 96 h (4 days) | 168 h (7 days) |

* These can include naturally occurring sands and gravels, crushed rocks and manufactured materials with fines content typically less than 12%.

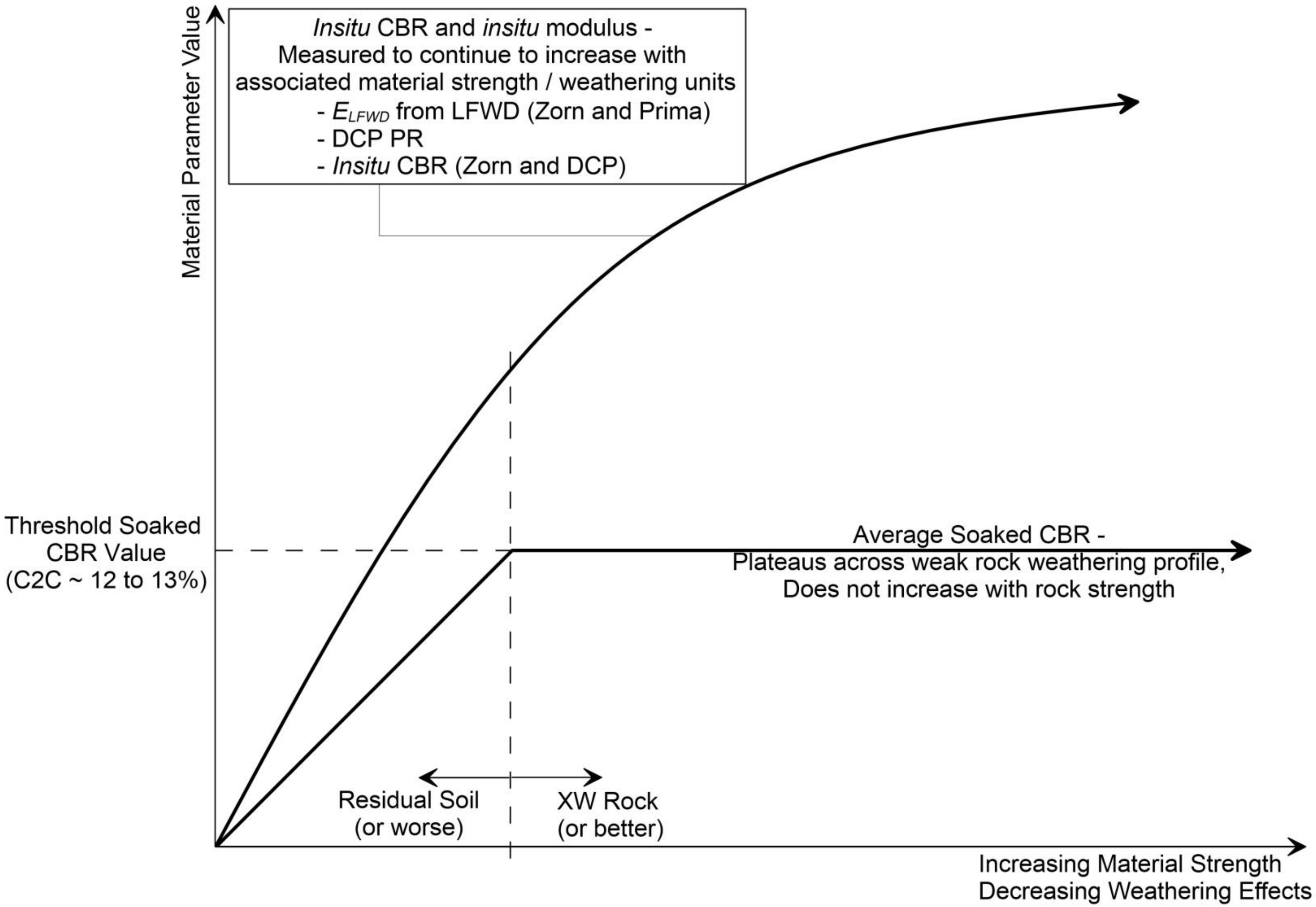
# Effect of preparation time for a clayey soil






Blight, 2013

# Lab Soaked CBR vs Field Value

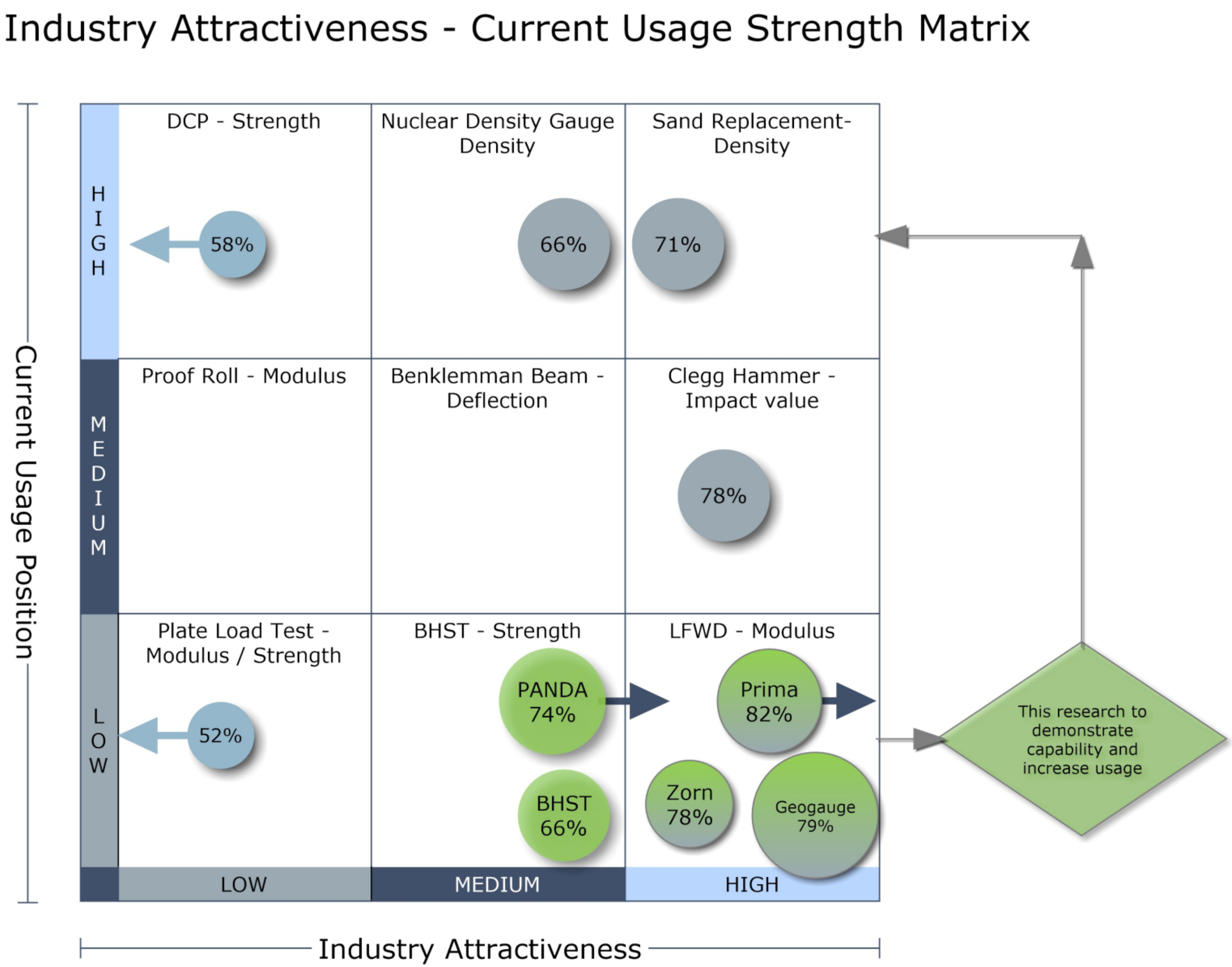



Lacey, Look and Marks (2016)

# QUESTIONS?


# Alternative Equipment / Testing

# Attractiveness vs Usage



# Factors considered in Ranking of Equipment

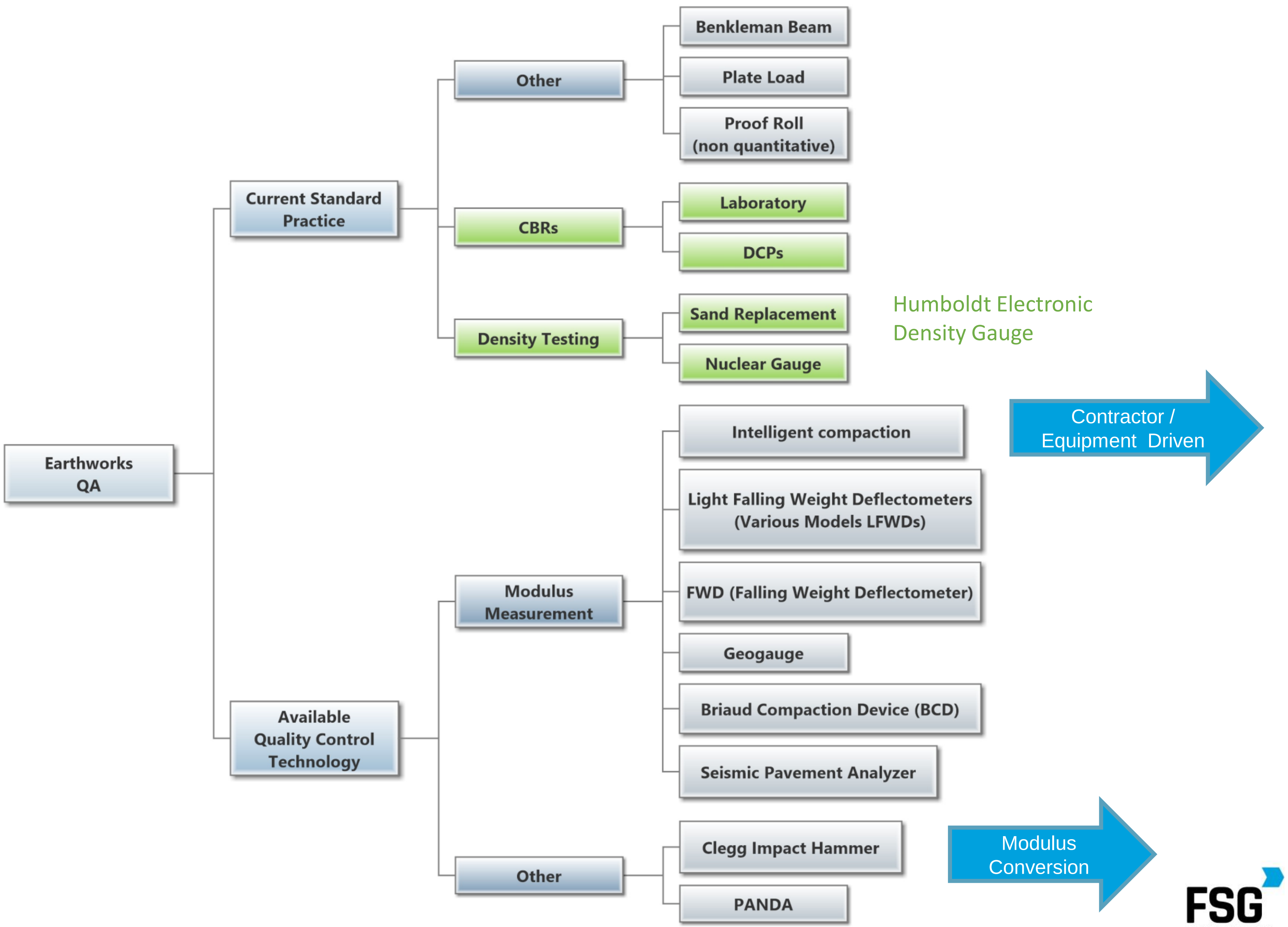
- ❑ Accuracy, repeatability and reliability of equipment (30%)
- ❑ Requirement/Duration/Ease of results processing to report measured parameter (25%)
- ❑ Duration of field completion of test (20%)
- ❑ Operating Cost (15%)
- ❑ Principal Cost (10%).

% in rankings open to discussion

# Traditional vs 21st century equipment

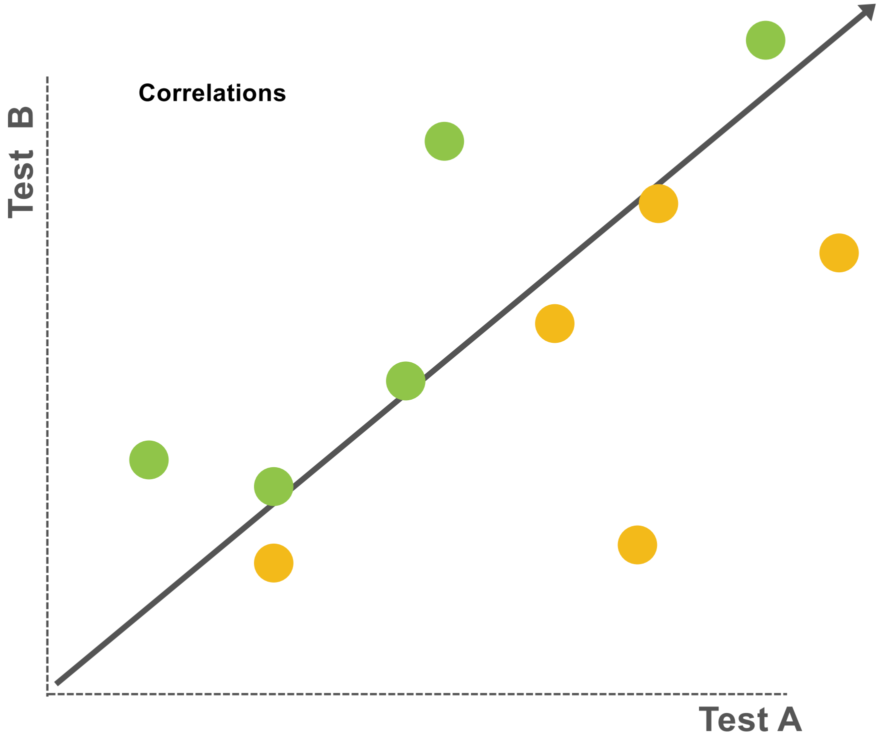
- ✓ Density / CBR / DCP testing limitations outlined.  However tests are “standardised”
- ✓ If other tests are introduced then similarly one should identify its limitations
- ✓ Modulus and strength can now be cost effectively measured in situ during construction.  This was not possible 50 years ago.
- ✓ However lack of test / equipment standardisation limits its implementation

# Testing overview

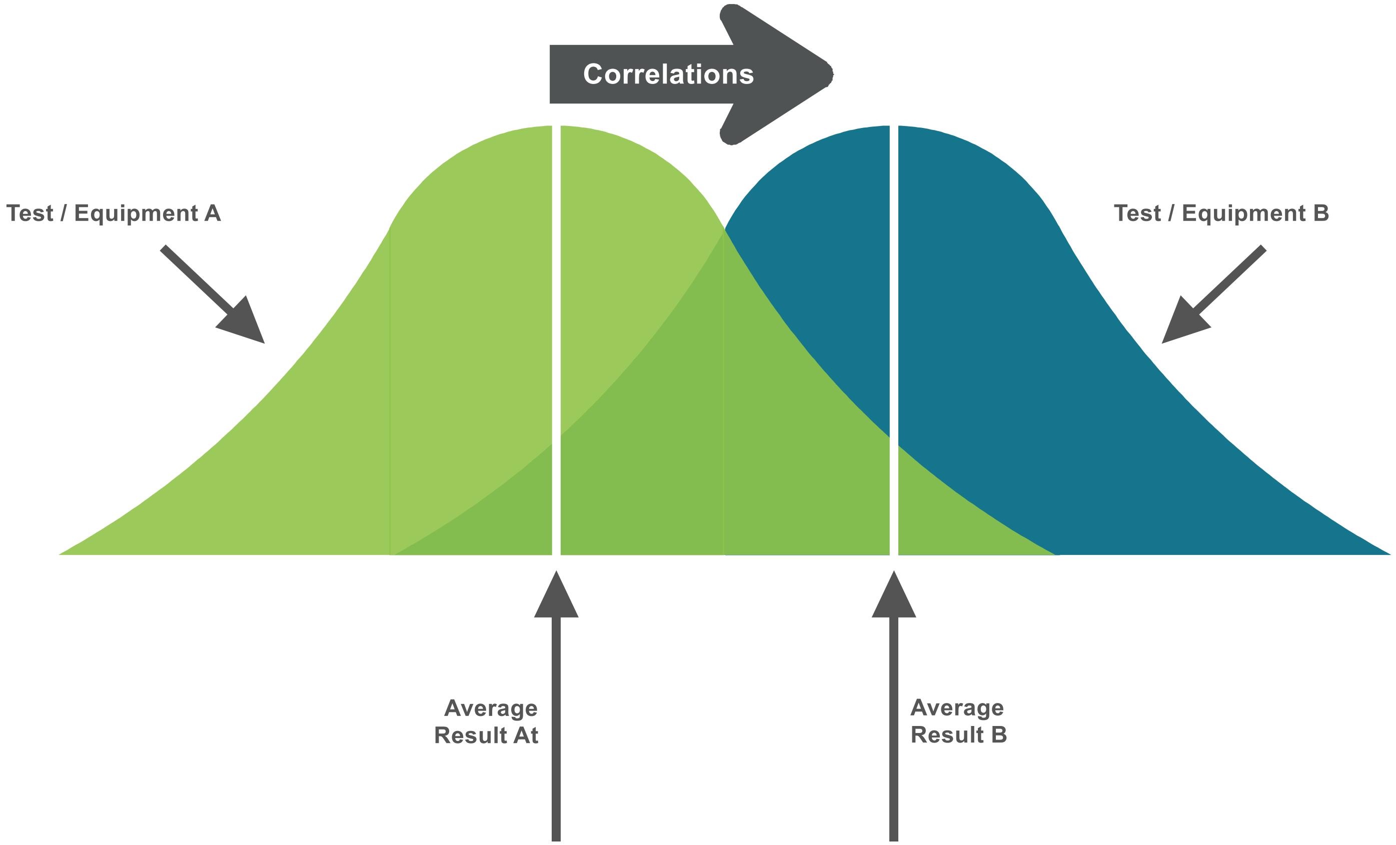


# Correlations + Reliability

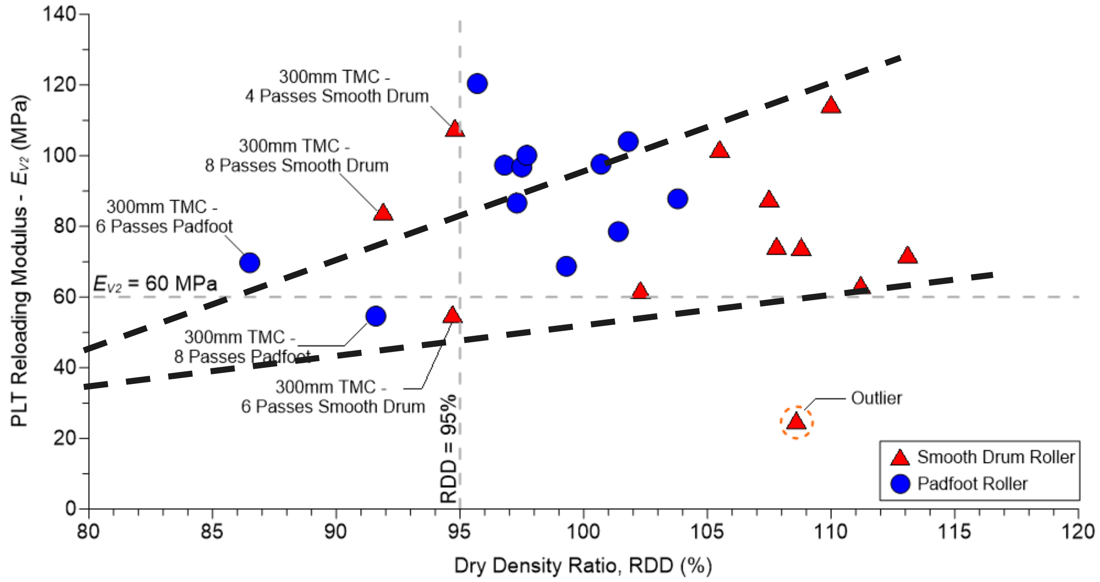





## Comparison between Tests



# PLTs & LFWD correlated to Dry Density Ratio




## HW /SW Sandstone

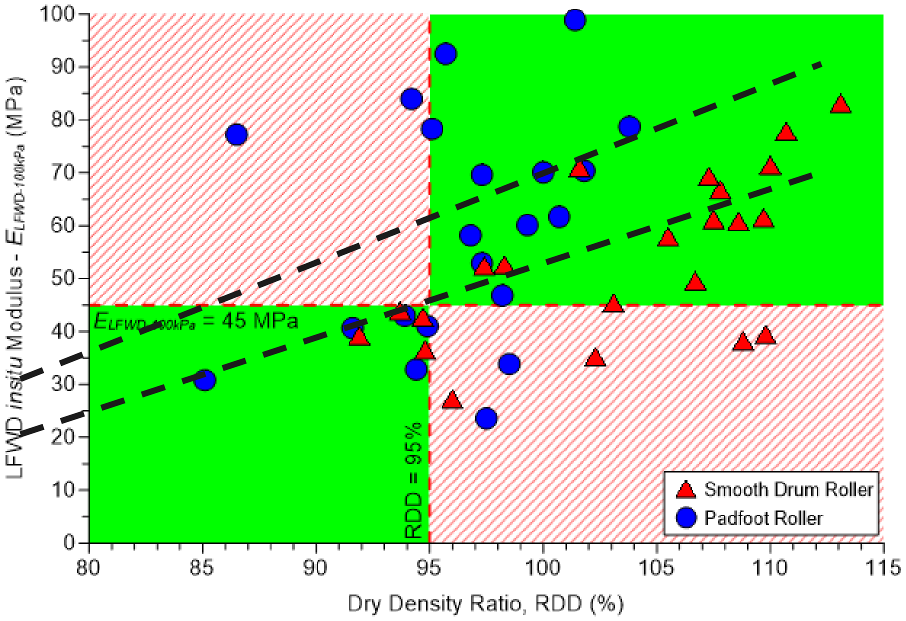
**21 Tests with Pad Foot**

| 7 LFWD Failed RDD | 7 RDD Failed Modulus |
|---|---|
| 2 Incorrectly Failed – Type 1 Error | 2 incorrectly passed RDD – Type II Error |

**22 Tests with Smooth Drum**

| 4 LFWD Failed RDD | 8 RDD Failed Modulus |
|---|---|
| No Type 1 Error | 4 incorrectly passed RDD – Type II Error |

| QTMR vs Contractor Risk | | Quality of Lot: Good | Quality of Lot: Poor |
|---|---|---|---|
| Acceptance Decision | Accept | Correct | Type II Error<br>QTMR's Risk<br>Not Rejecting a Lot when it is Not OK |
| | Reject | Type I Error<br>Contractor's Risk<br>Rejecting a Lot when it is OK | Correct |

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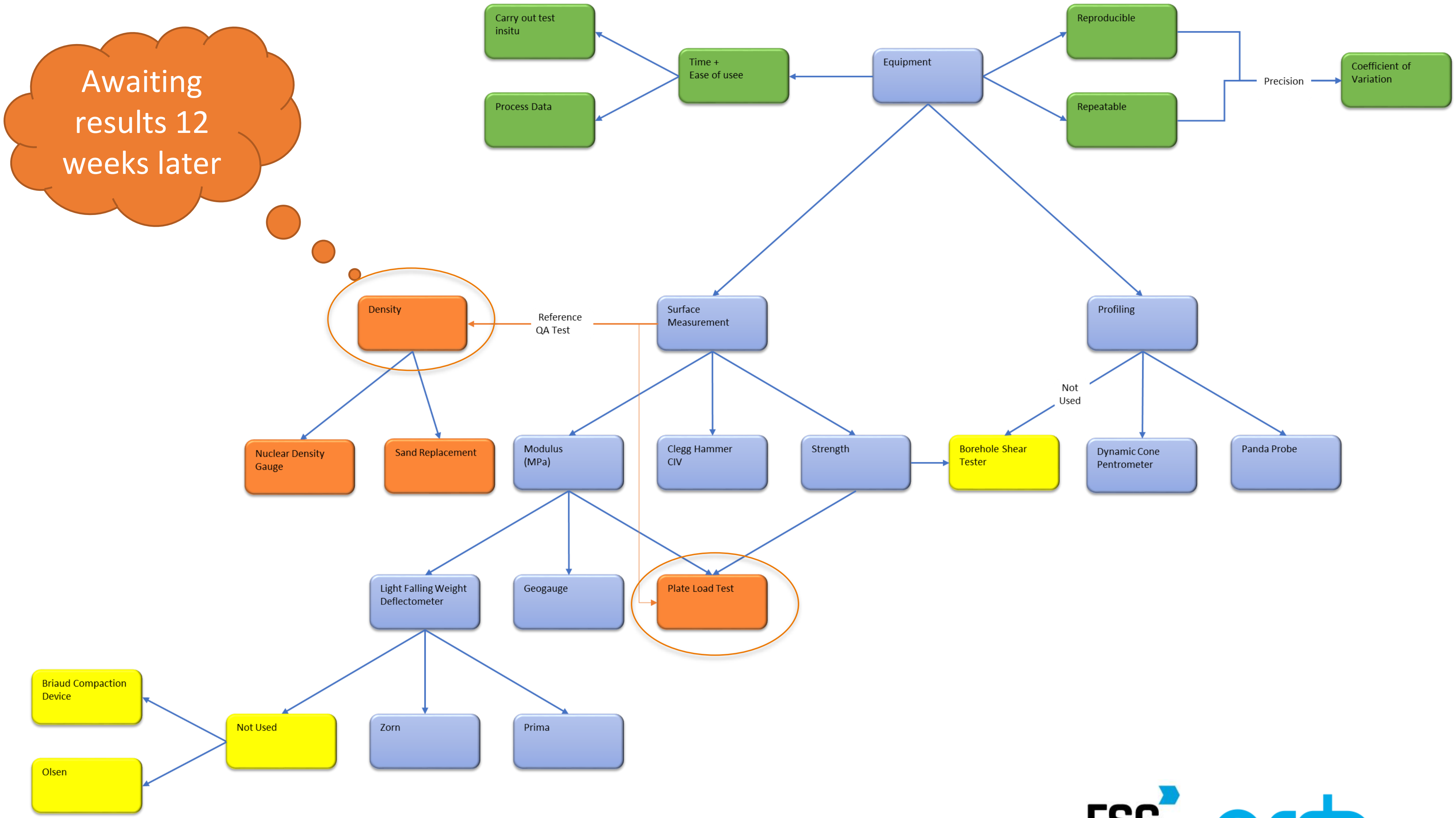
568 ml is not realising the metric benefit → 2017 Legacy issue in a "metric" country 50+ years on

# Legacy issues may hinder proper use / benefits

# Testing Aims & Actual carried out



# Test Equipment

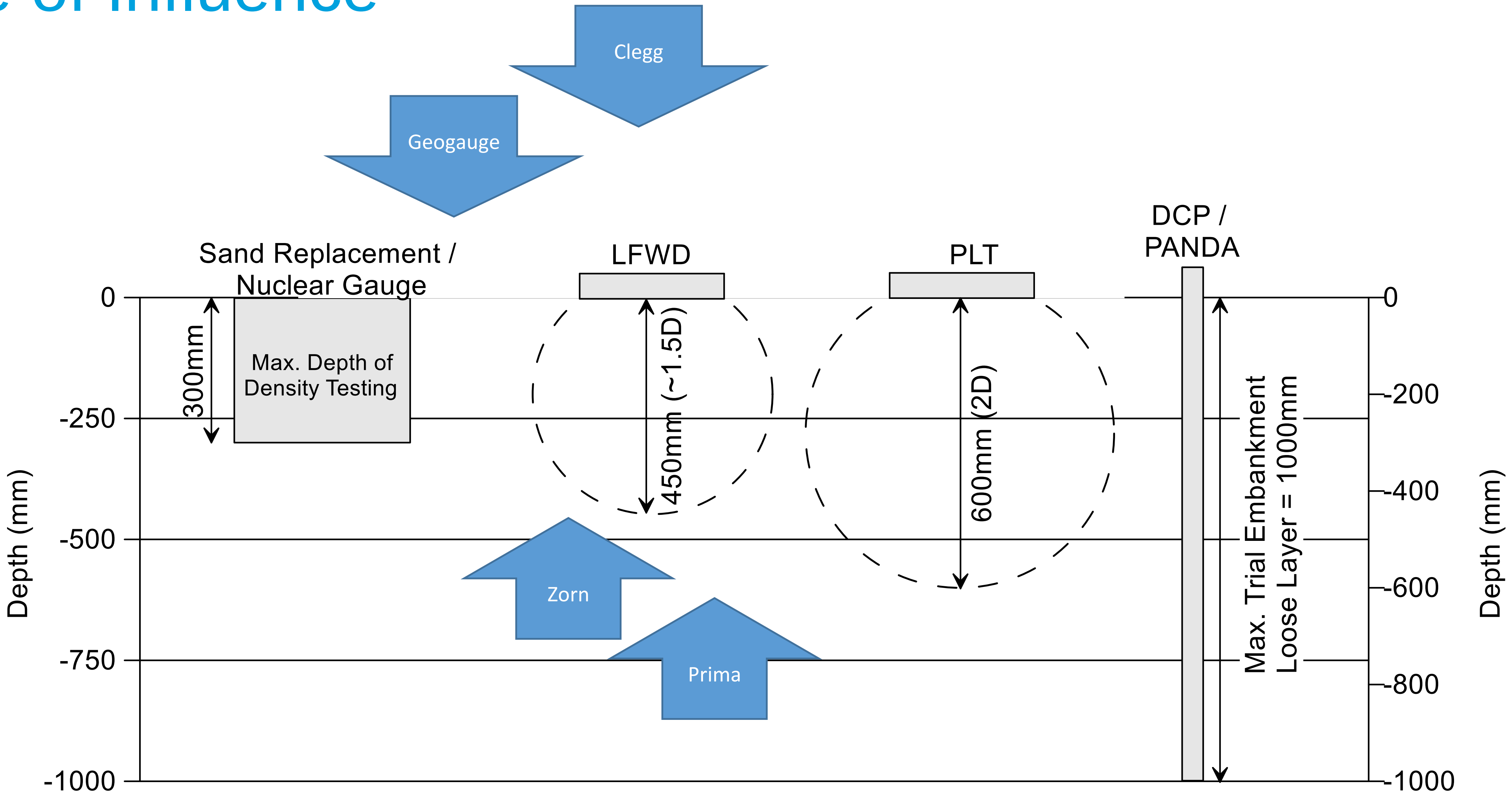
| Device | |
|---|---|
| Nuclear Density Gauge [NDG] [Troxler Model 3440] |  |
| Sand-Cone Density Apparatus |  |

| | |
|---|---|
| LFWD<br><br>Zorn<br><br>Prima<br><br>Olsen – Not available |  |

| | |
|---|---|
| Dynamic Cone Penetrometer [Utility DCP] |  |
| Dynamic Cone Penetrometer [Standard DCP] | |
| Geogauge |  |
| Clegg Hammers [10-kg & 20-kg Hammers] |  |
| PANDA |  |

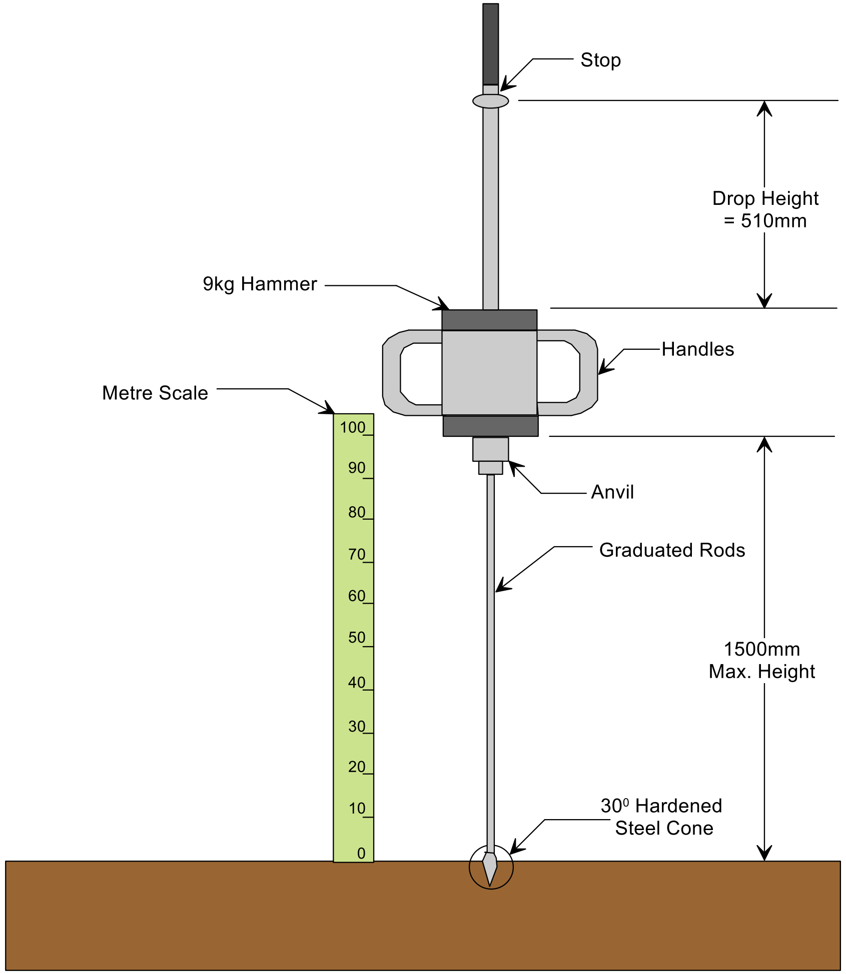
# Zone of Influence





# Dynamic Cone Penetrometer

| Element | | Australia (AS 1289.6.3.2:1997)<br>New Zealand (NZS 4402.6.5.2:1988) | United States (ASTM D6951)<br>South Africa (Method ST6 in TMH No. 6) | Europe / United Kingdom (BS EN ISO 22476-2:2005) – Dynamic Probe Light (DPL) |
|---|---|---|---|---|
| **Hammer / Weight Drop** | Mass | 9 kg | 8 kg | 10 kg |
| | Standard Drop | 510 mm | 575 mm | 500 mm |
| **Theoretical Energy per blow** | | 45.0 J | 45.15 J | 49.0 J |
| **Cone Dimensions** | Angle | 15˚ (from C.L. of cone) | 30˚ (from C.L. of cone) | 45˚ (from C.L. of cone) |
| | Diameter | 20 mm | 20 mm | 34 mm (min.) |
| | Mantle Thickness | 3 mm | 3 mm | 37.5 mm |
| | Surface Area (Lateral + Mantle) | 12.7 $cm^2$ | 6.9 $cm^2$ | 25.0 $cm^2$ |



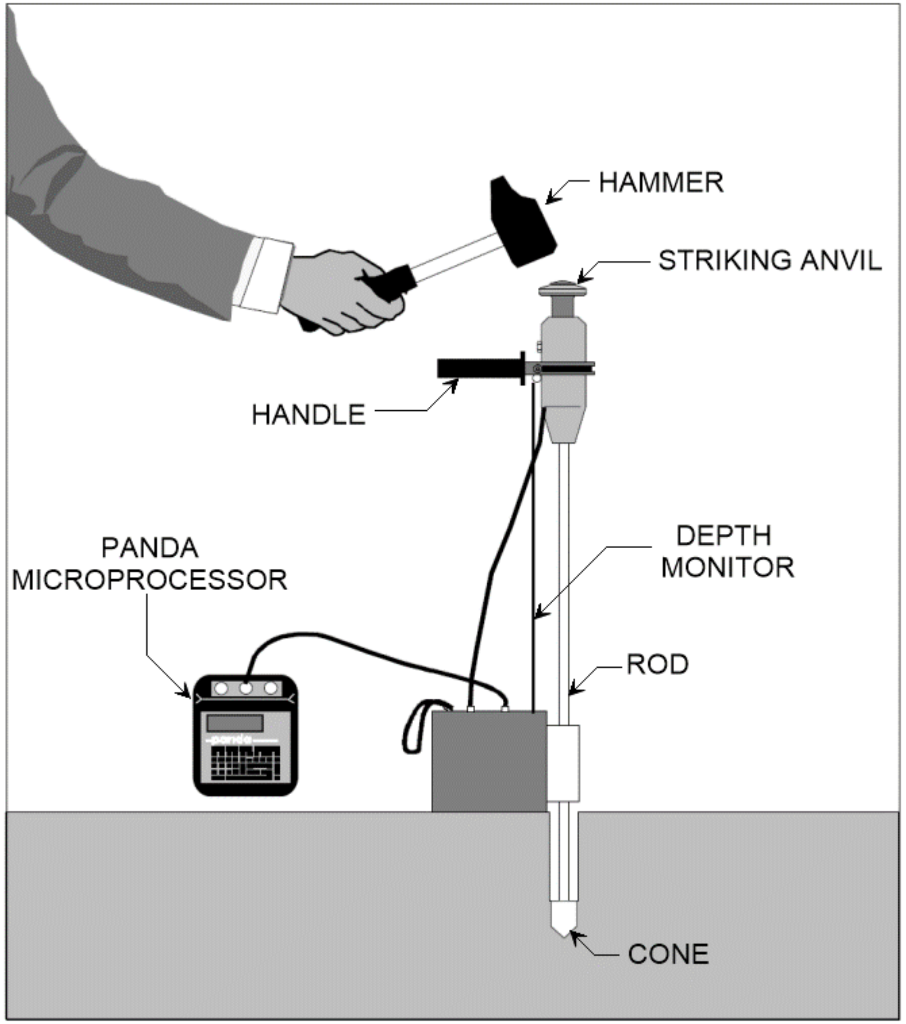
# PANDA probe



| Element | | PANDA Probe |
|---|---|---|
| **Hammer / Weight Drop** | Mass | 2 kg |
| | Standard Drop | Variable (each blow measured independently) |
| **Cone** | Angle | $86^0$ (from centreline of cone) |
| | Diameter | 16 mm |
| | Area | 2 $cm^2$ |

French Standard, 2012 – NF P 94-105, Soils: Recognition and testing – Control of the quality of compaction – Dynamic penetrometer with variable energy method - Penetrometer calibration, principles and methodology – Interpretation of results (in French)

No existing Australian Standard, ASTM or Australian Regulatory authority test method currently exists for use of the PANDA Probe. However, regardless of the absence of an approved test method the PANDA probe is already in use in Australia, and has been for a number of years (e.g. by Queensland Department of Main Roads).



# Plate Load Test

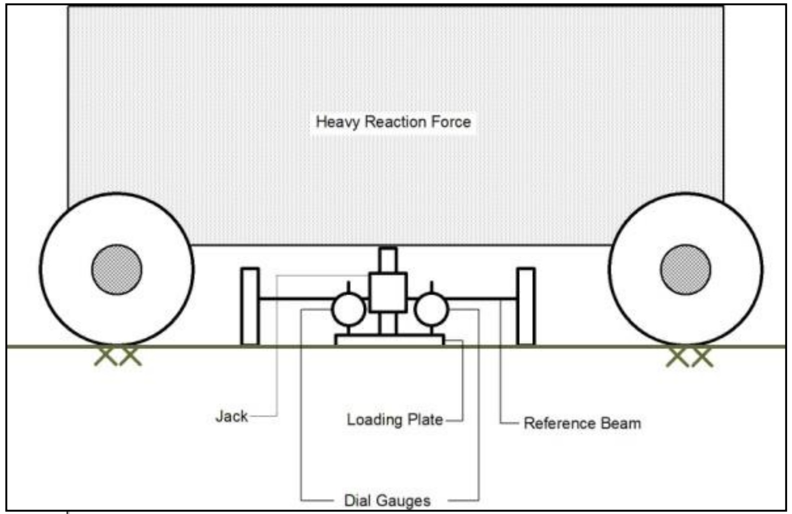
**Applicable Standards**

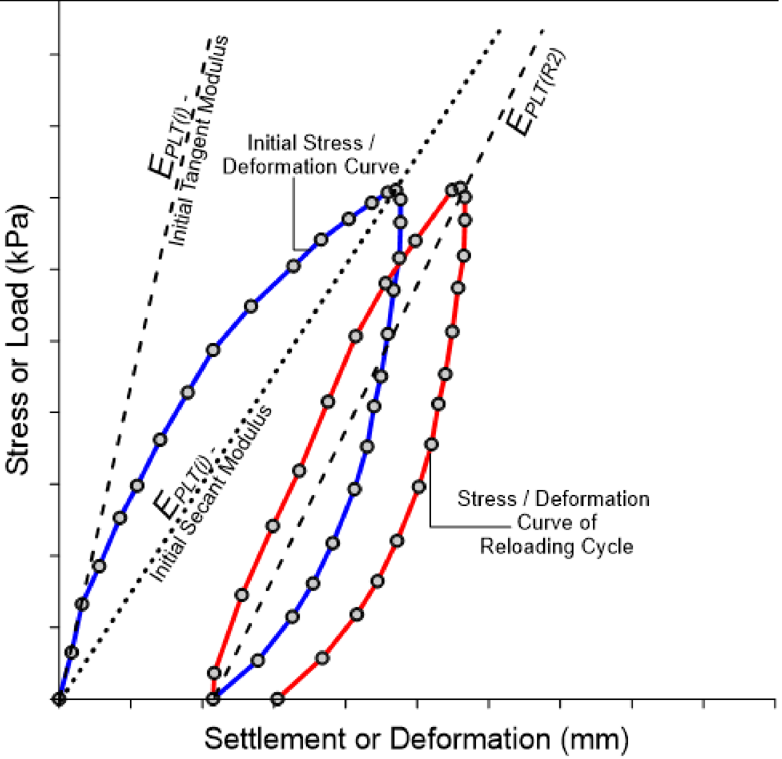
- DIN 18134 – *Soil – Testing Procedures and testing equipment – Plate Load Test, English translation of DIN 18134:2012-04*
- ASTM D1195 – *Standard Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements.*
- ASTM D1196 – *Standard Test Method for Non-repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements.*

**Parameters provided from test**

Static PLT testing allows the construction of a full loading stress / deformation curve for the range of stress magnitudes applied.

- $E_i$ or $E_{v1}$ = Modulus associated with initial loading cycle
- $E_{(R2,3,4)}$ or $E_{v2,3,4}$ = Modulus associated with reloading cycles
- $K_s$ = Subgrade Modulus / Modulus of Subgrade Reaction
- $q_{ult}$ = Ultimate bearing capacity
- $q_{allow}$ or $q_a$= Allowable bearing capacity



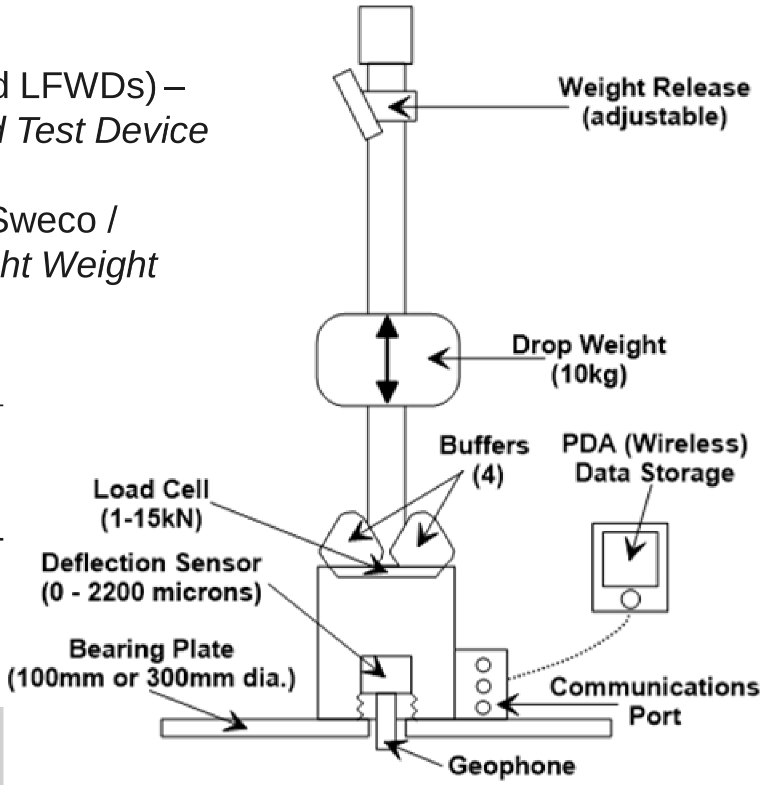



# Light Falling Weight Deflectometer (LFWD)



Two (2) ASTM standards, based on the class of LFWD instrument being utilised:
For LFWD instruments without a load cell and fitted with a plate mounted accelerometer (e.g. Zorn brand LFWDs) – ASTM E2835-11 – *Standard Test Method for Measuring Deflections using a Portable Impulse Plate Load Test Device*

For LFWD instruments fitted with a load cell and fitted with a geophone in contact with the ground (e.g. Sweco / Grontmij brand LFWDs) – ASTM E2583-07 – *Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)*




| LFWD Manufacturer | Deflection Transducer Header | | | Rigid Plate Thickness (mm) | Load Cell / Max. Load | Buffer |
|---|---|---|---|---|---|---|
| | Type | Location | Accuracy | | | |
| **Prima 100 (Sweco / Grontmij A/S)** | Geophone | Ground | ±0.002mm | 20 | Yes / 15.0kN | Rubber (Cone) |
| **Kerros (Dynatest)** | Geophone | Ground | ±0.002mm | 20 | Yes / 15.0kN | Rubber (Flat) |
| **Dynatest 3031 (Dynatest)** | Geophone | Ground | ±0.002mm | 20 | Yes / 15.0kN | Rubber (Flat) |
| **Zorn ZFG (Zorn)** | Accelerometer | Plate | ±0.02mm | 20 – 124 | No / 7.07kN | Steel Spring |

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# Clegg Hammer

**Applicable Standards**

- AS 1289.6.9.1: *Methods for testing soils for engineering purposes- Method 6.9.1: Soil Strength and Consolidation test - Determination of stiffness of soil - Clegg Impact Value (CIV).*
- ASTM D 5874 – *Standard Test Method for Determination of the Impact Value (IV) of a Soil*.


*Insitu* testing can be undertaken with various models of the instrument, which include a drop weight of 2.25 kg, 4.5 kg, 10 kg and 20 kg versions.

As per the LFWD tests, the varying weights utilised alter the stress magnitude imparted during a test and thus the 'zone of influence' varies depending on model used.

Clegg Impact Value (CIV) measured. Correlation with Modulus

# Geogauge (Soil Stiffness Gauge)



**Applicable Standards**

- ASTM D6758-08 – *Standard Test Method for Measuring Stiffness and Apparent Modulus of Soil and Soil-Aggregate In-Place by Electro-Mechanical Method.*

The Geogauge is a surface based plate stress test that measures the impedance of near-surface materials under known loads. The gauge imparts very small displacements of the soil (≤ 1.27 x $10^{-6}$ m) under 25 programmed steady-state frequencies between 100 and 196 Hz. The stiffness (modulus) parameter returned by the gauge – the Geogauge Stiffness ($H_{SG}$) parameter – is the average stiffness observed across all 25 frequencies.


Geogauge weighs ~ 10 kg, Diameter = 280 mm and Height = 254 mm.

# Trial Phase – "Live" projects

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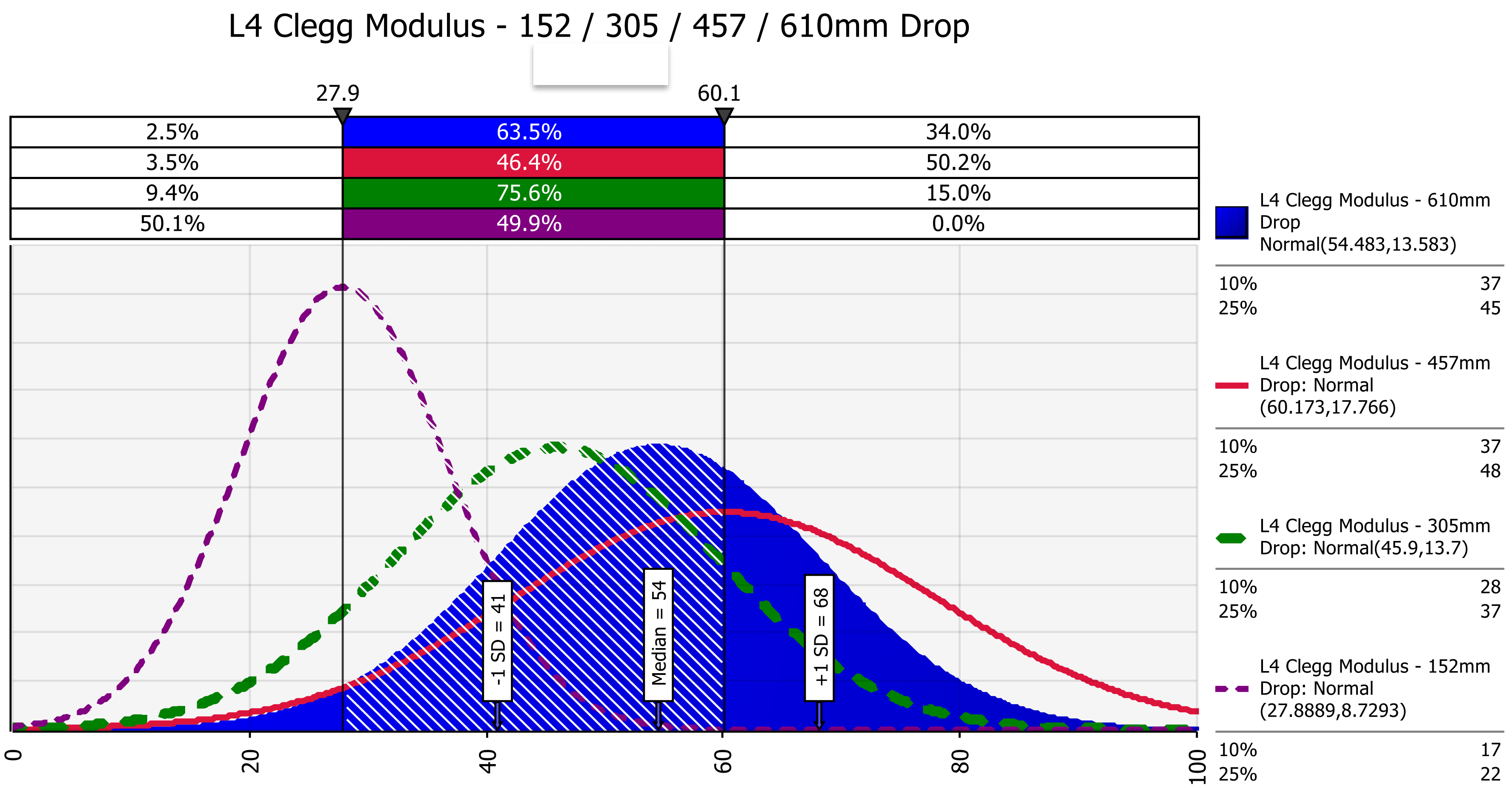
# Testing

## Clegg Hammer

## LFWD - Blue Tooth Connectivity

## Plate Load Test

# Clegg Modulus – L4 Varying Heights




| E = 23 / 28 | COV =32% | E = 36 /46 | COV =30% | E =50 /60 | COV =30% | E = 44 /56 | COV =25% |
|---|---|---|---|---|---|---|---|
| 152mm | | 305mm | | 457mm | | 610mm | |

L4 – Clegg Drop Heights 25% / Mean Modulus

# Summary – Preliminary only

| Accuracy | Amount of Data / Capital Cost | Precision | Time |
| --- | --- | --- | --- |
| Waiting on full Density Results + classification tests from test sites after 12 weeks | | | |
| 1. PLT | 1. Plate Load $$$$$ | 1. Sand Replacement | 1. LFWD – Zorn - T |
| 2. Prima | 2. LFWD – Prima $$$$ | 2. Nuclear Density | 2. Geogauge – 1.3 T |
| 3. Clegg | 3. Clegg Hammer $$$ | 3. Geogauge | 3. Panda – 1.4 T |
| 4. PANDA | 4. Panda $$$$$ | 4. Clegg Hammer | 4. DCP - 1.8T |
| 5. Zorn | 5. LFWD – Zorn $$$$ | 5. LFWD – Zorn | 5. Clegg Hammer – 2.3T |
| 6. DCP: 100 – 200mm | 6. Geogauge $$$ | 6. LFWD – Prima | 6. LFWD – Prima* - 2.6T |
| 7. Geogauge | 7. DCP $ | 7. DCP / 100 – 200mm | 7. Nuclear Density ↑ - 6T |
| 8. DCP: 0 -100mm | 8. Sand Replacement $$ | 8. DCP / 0 – 100mm | 8. Plate Load* Test – 6T |
| | 9. Nuclear Density $$ | 9. PLT | 9. Sand Replacement ↑- 10T |

* Complete Stress Strain response provided – not provided by other equipment

↑ Larger Reporting time

# What are we looking at ?



- The Bird

The Holes in the rock

The holes in the Boulder

- The Rock

Density → Density Ratio → Reduced Void Ratio → Strength / Modulus

# QUESTIONS?

*Thank you for your participation today.*

For further information on the topic, please contact: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