Webinar: Part 2 – Equipment Testing
Advanced Method for Compaction Quality Control

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Housekeeping

Webinar 60 mins

Questions 10 mins

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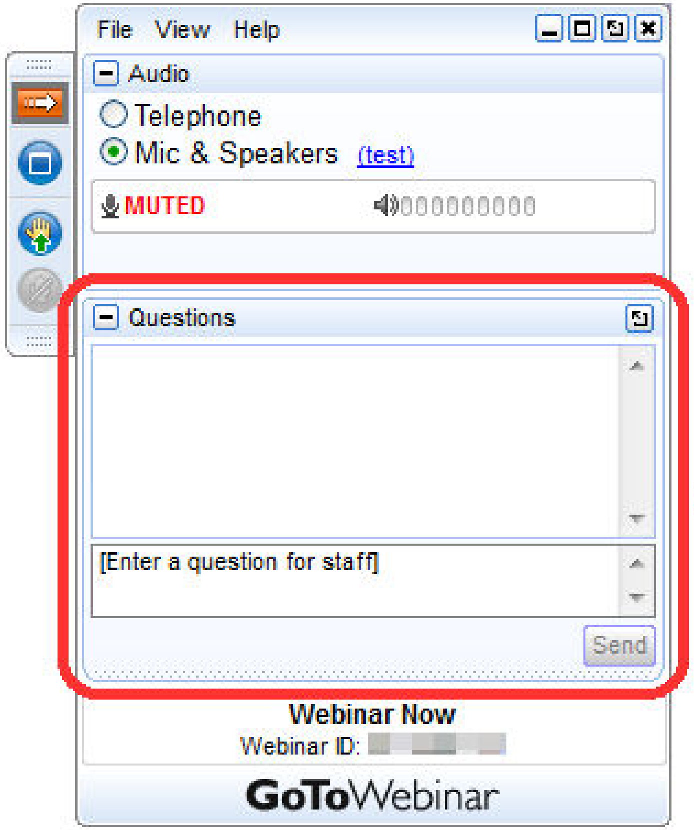
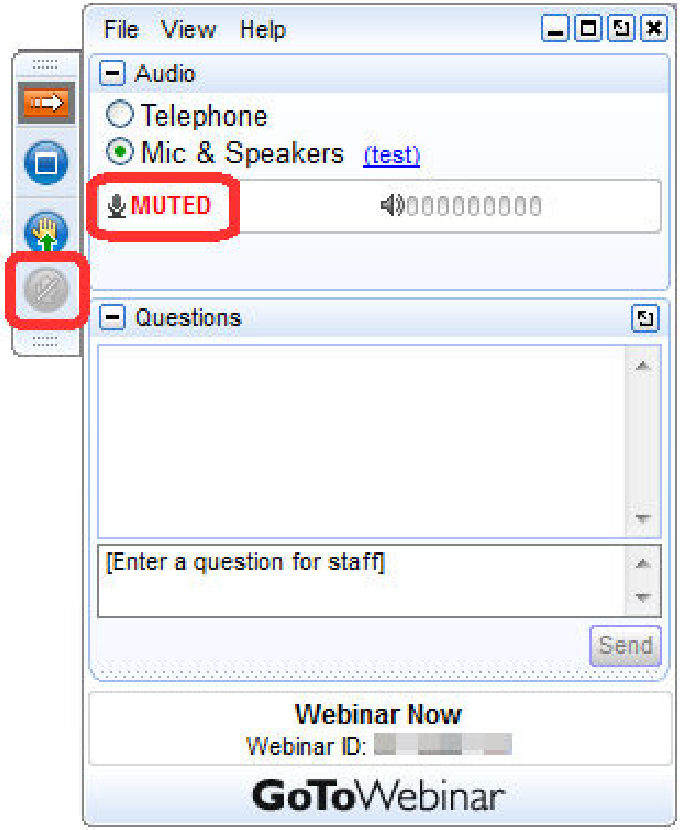


Attendee microphones are muted

Please type your questions here



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Part 1 – An Overview **(Conceptual)**

- ✓ Density Basics
- ✓ Rationale for this equipment research
- ✓ Equipment overview + 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

2018 Presentation

2020 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/

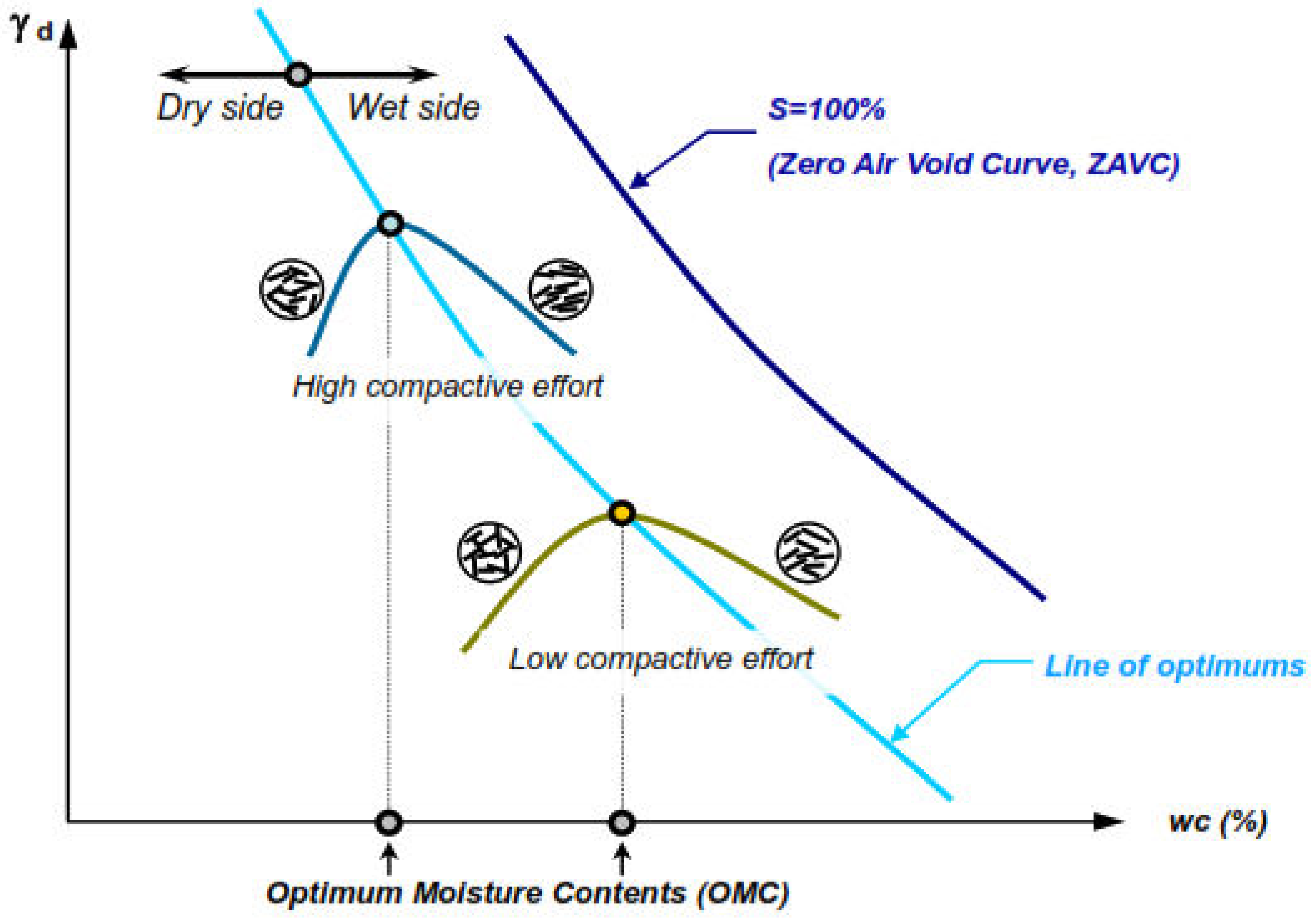
NACOE P60

Aim and Background of the Project

- Aim
  - To modernise testing procedure for compaction quality assurance
- Background
  - Quality is 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 is able to measure in situ stiffness.

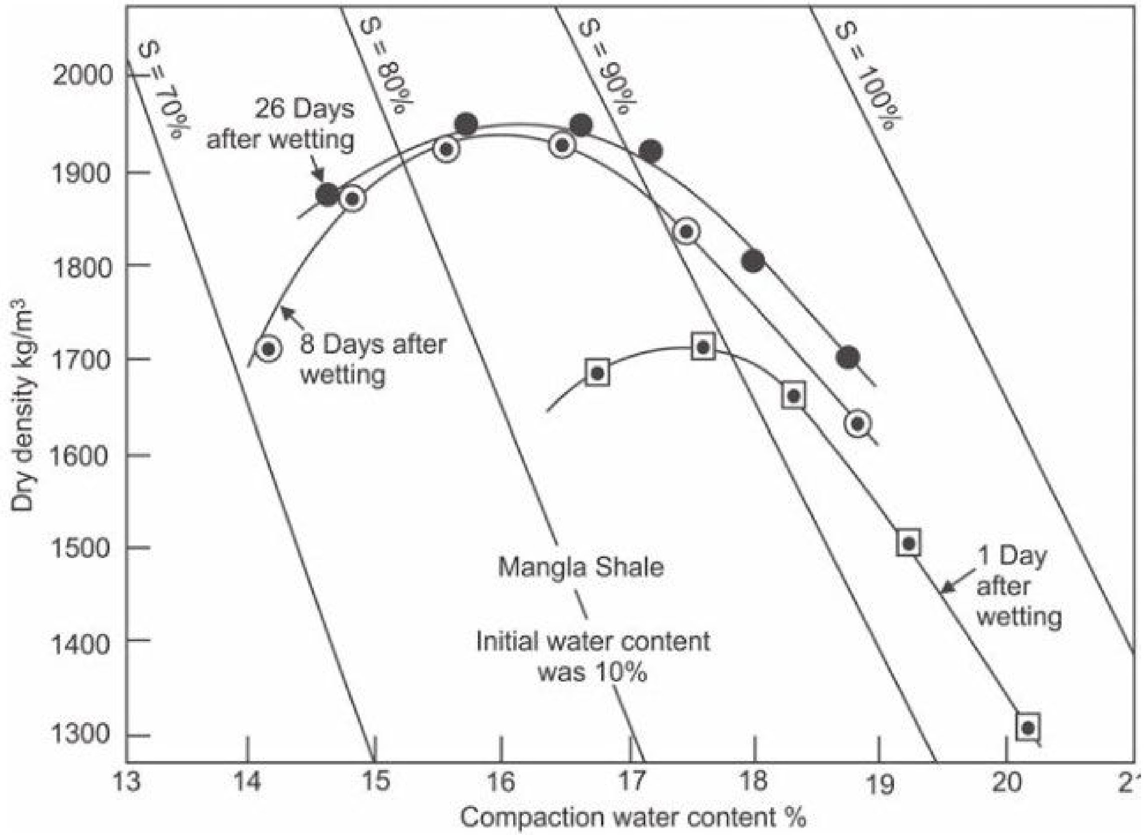
Compaction Basics
In 5 slides

Target low air voids →Line of optimums



Examples of compaction curves (modified after Lambe 1962).

Sampling Curing is required



Blight, 2013

TABLE 4

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%.

LEGEND:

LL – liquid limit

OMC – optimum moisture content

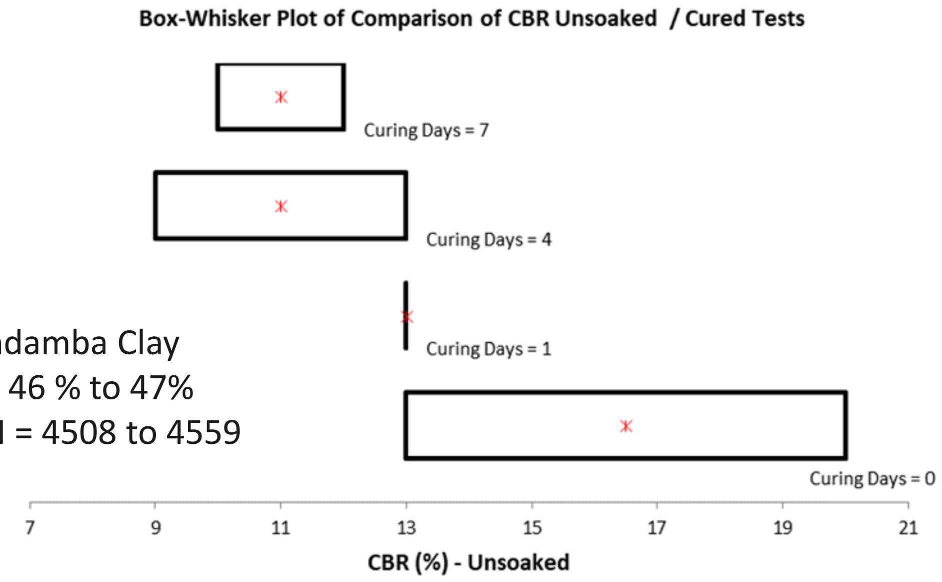
Australian Standard®

AS 1289.5.1.1:2017

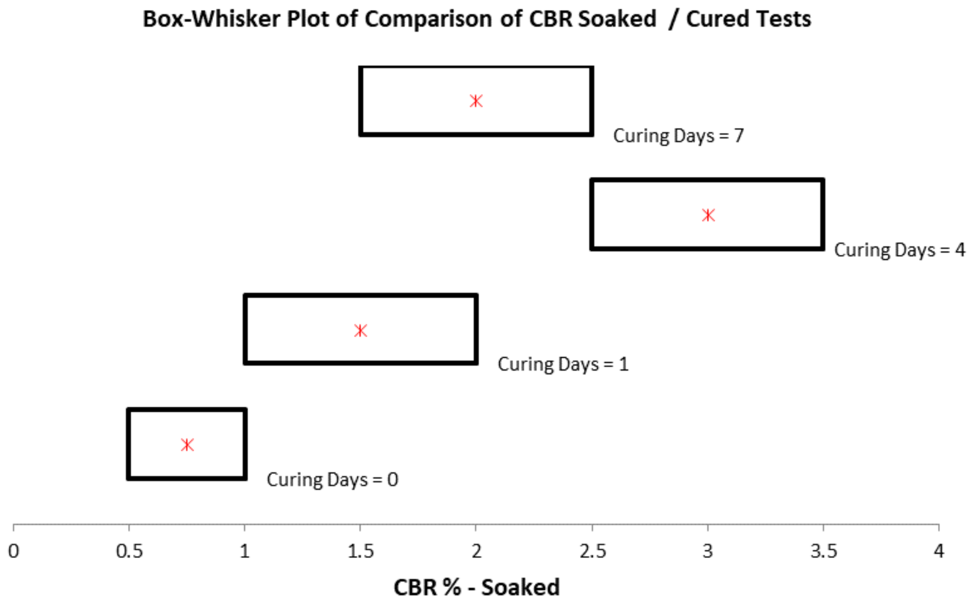
Methods of testing soils for engineering purposes

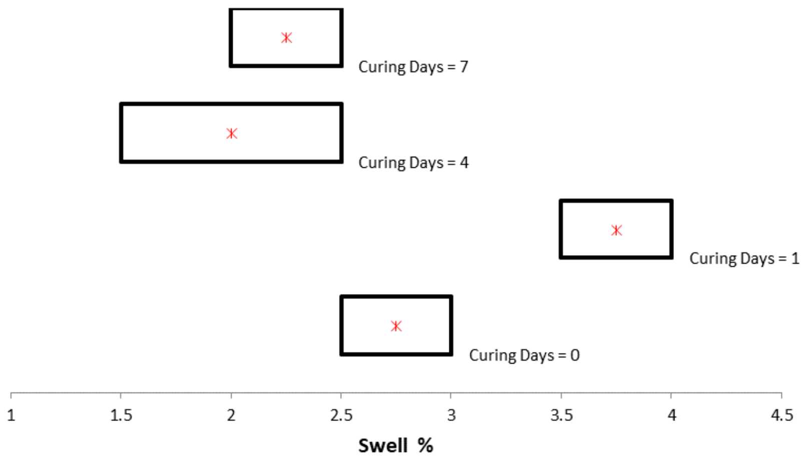
Method 5.1.1: Soil compaction and density tests—Determination of the dry density/moisture content relation of a soil using standard compactive effort

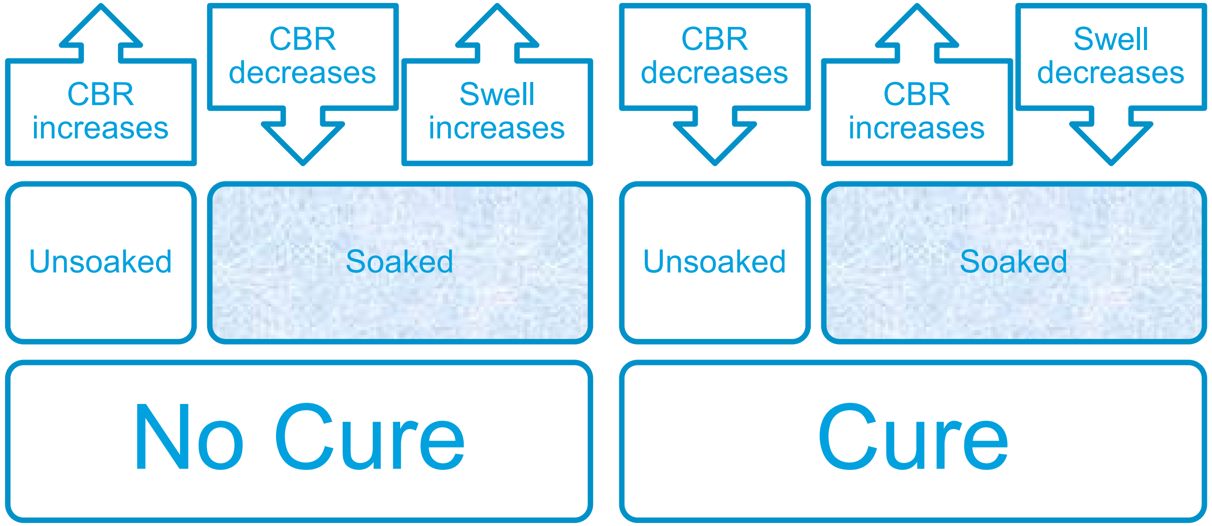
Unsoaked + CBR – Effect of curing



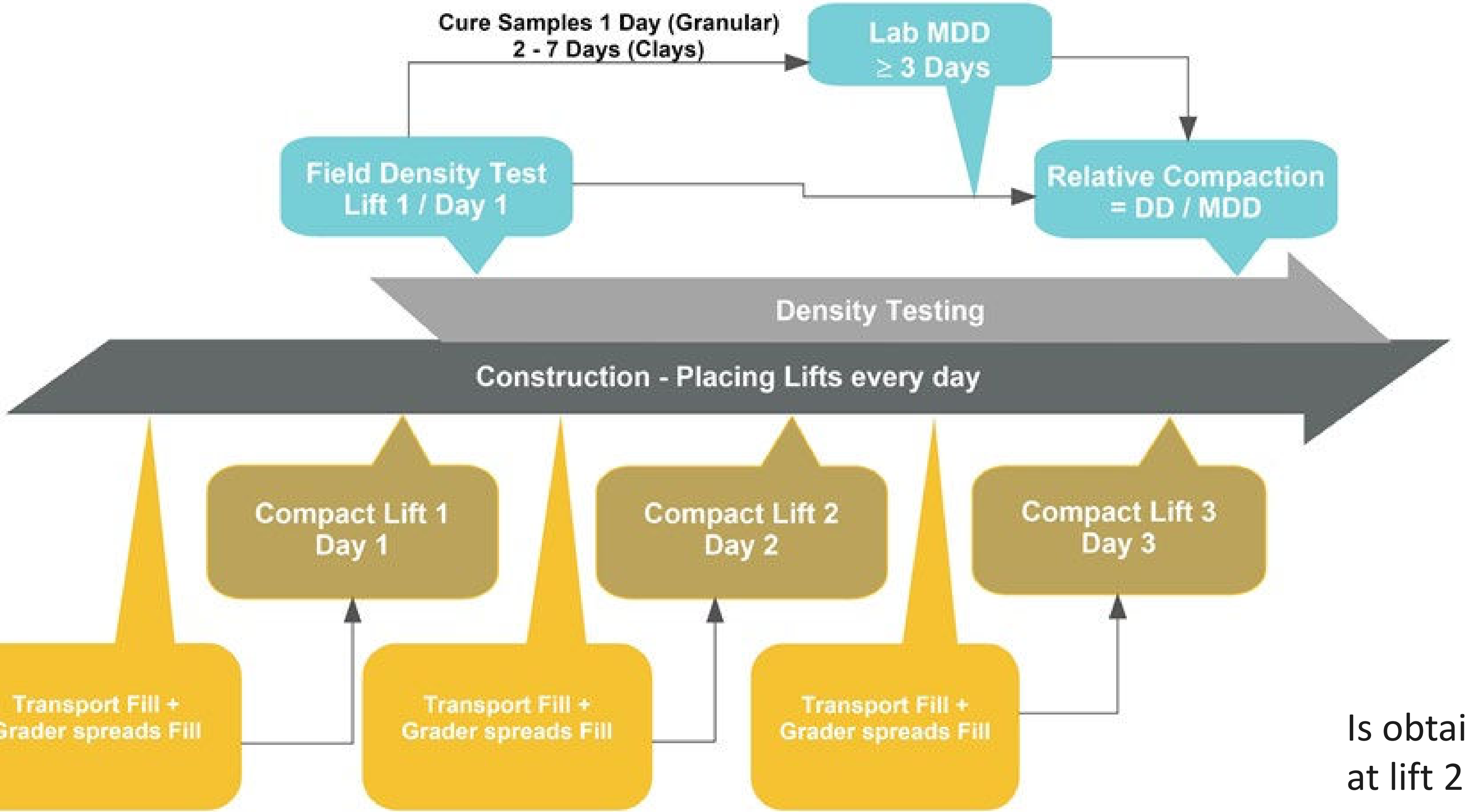
Bundamba Clay
PI = 46 % to 47%
WPI = 4508 to 4559



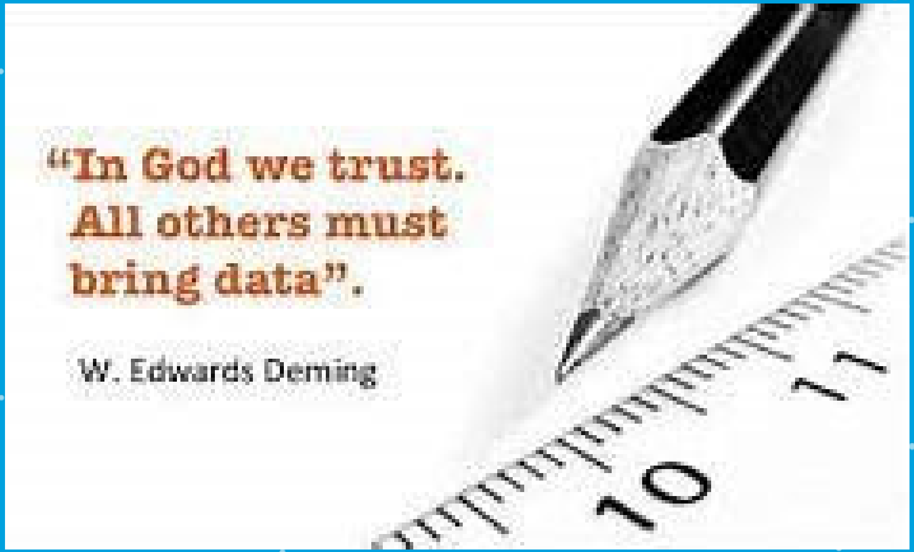




Density Ratio compaction tests are lag indicators



Is obtaining density results at lift 2 or 3 QA or QC ?



What does Quality look like ?

Quality Control (QC) vs Quality Assurance (QA)

QA is *process* oriented (**verification**) vs QC is *product* oriented (**validation**).

QA aims to prevent defects. QC aims to identify and fix defects

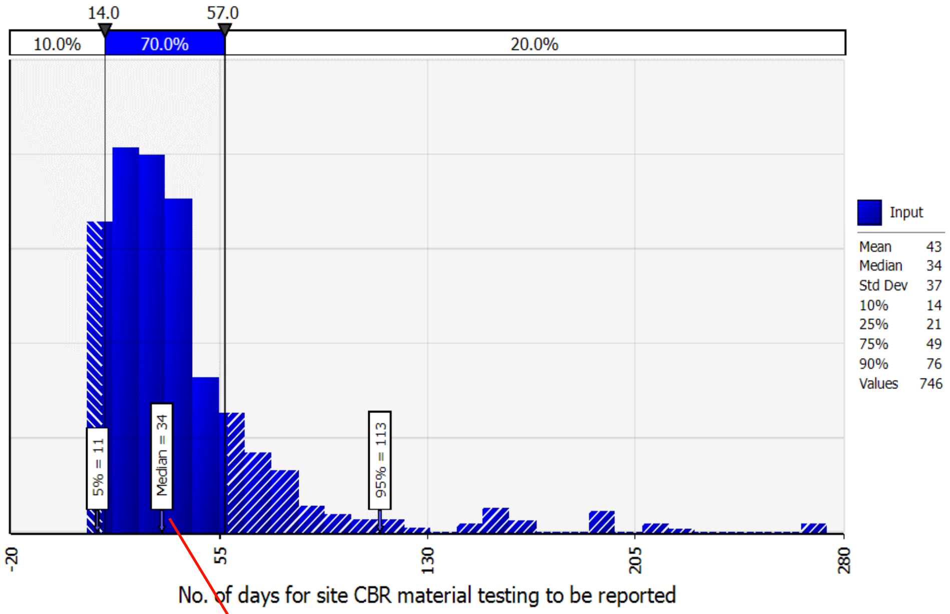
- Quality **Assurance** makes sure you are doing the right things, the right way
- Quality **Control** makes sure the results of what you've done are what you expected.

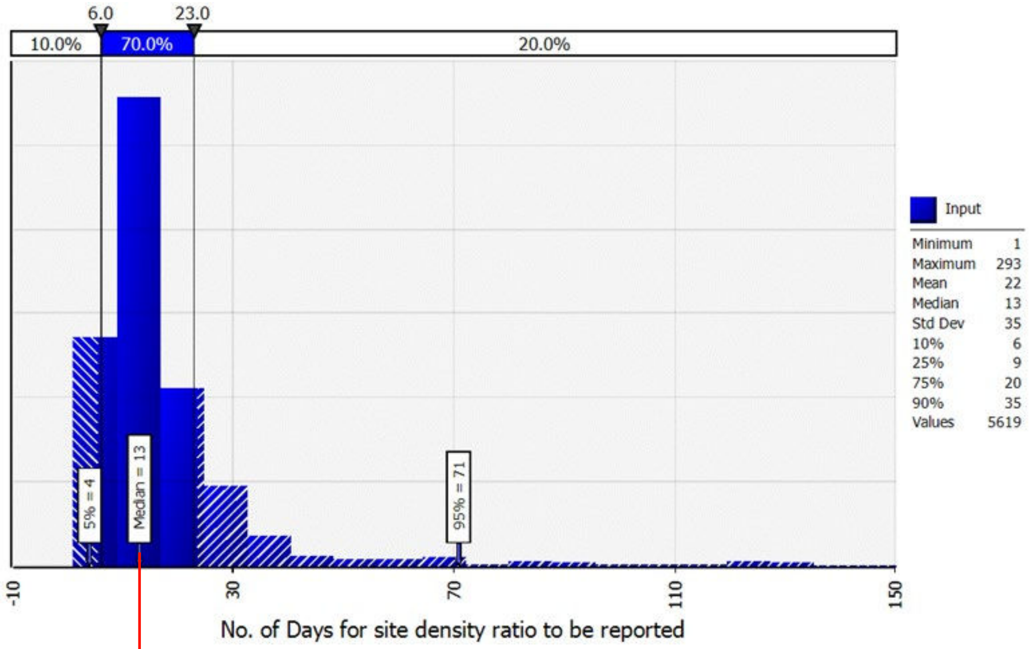
Quality Control (QC) vs Quality Assurance (QA)

QA → process → verification → The right way

QC → product → validation → Results are what you expected

Construction records – Quality tests reporting





Material Quality
- CBR
- Atterberg
- Gradings

+

Compaction
- Field Density
- Lab MD
- Density Ratio

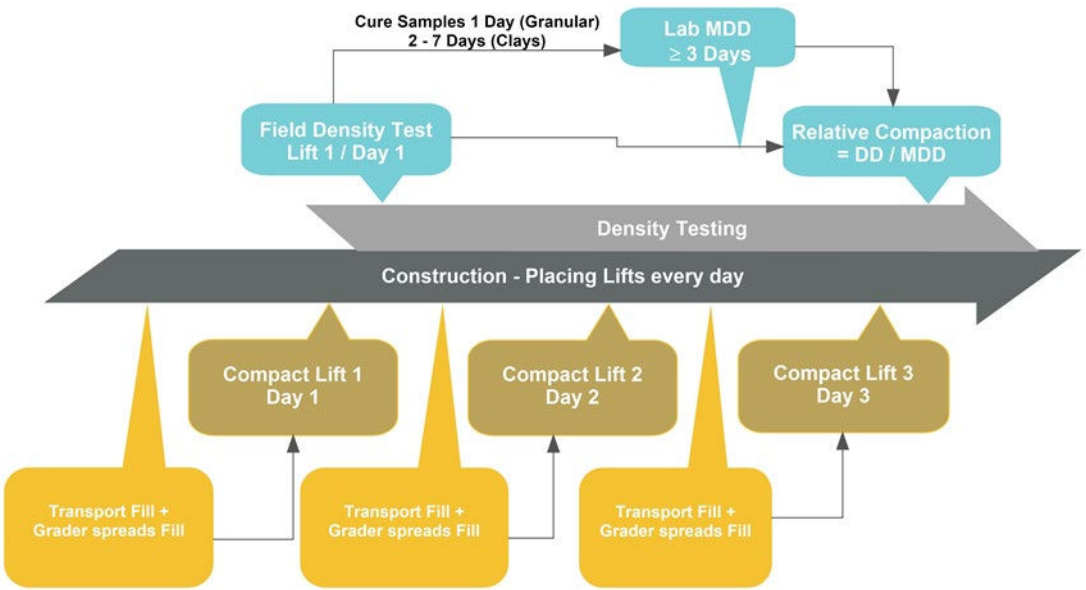
+

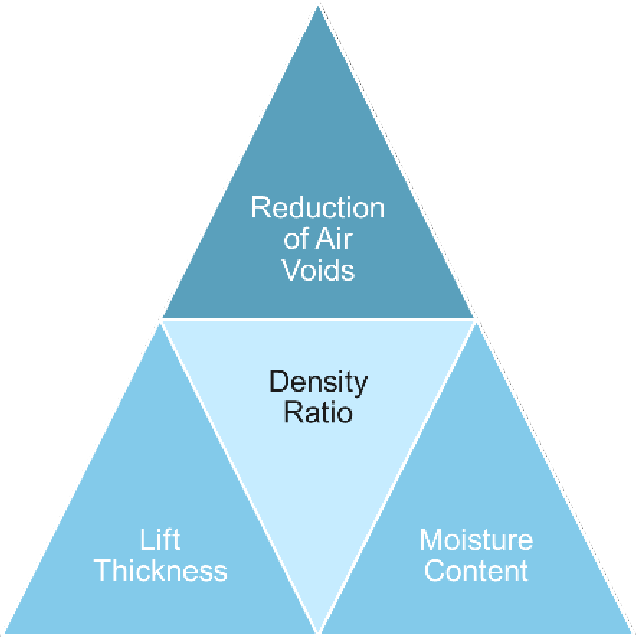
Underlying Material
- Depth
- Quality
- Compaction

→

Quality
- No of samples
- Variability
- LCV

Density Ratio tests – Objectives + Process



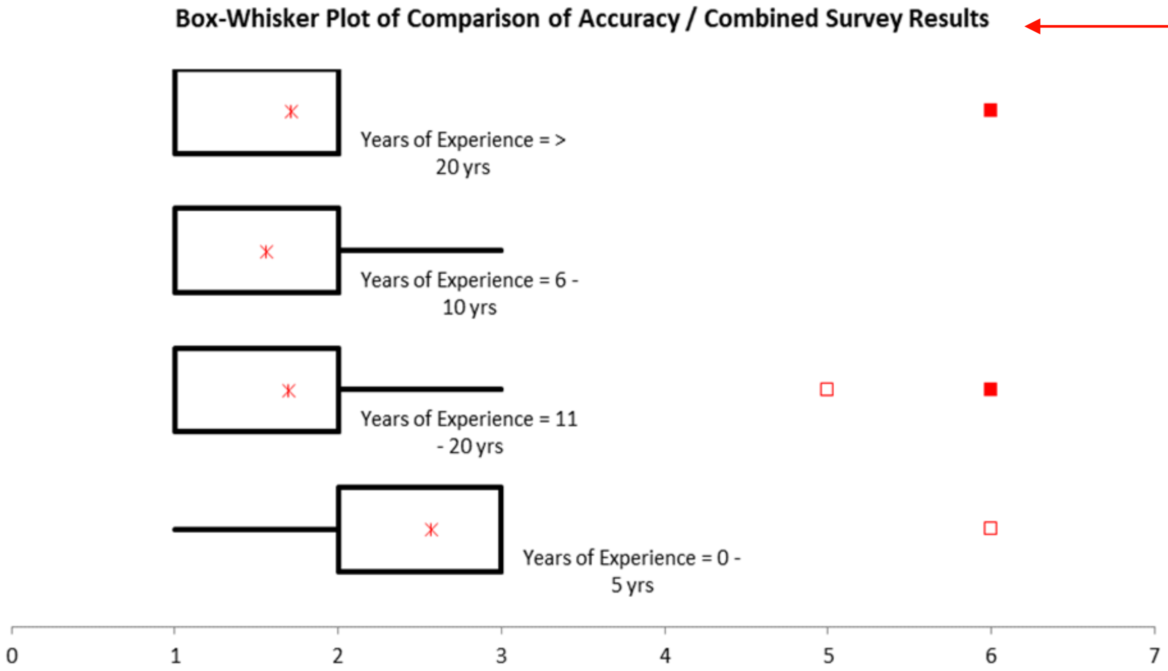


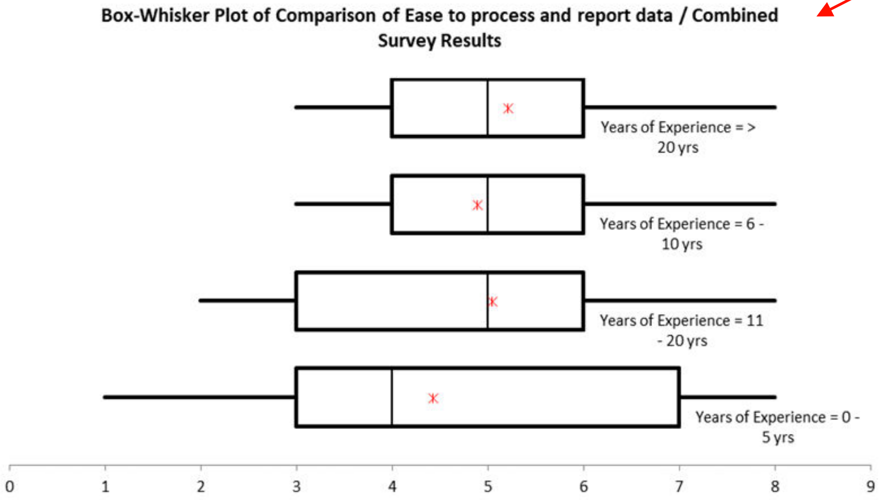
Many contractors, often place additional lifts before the test results are known / reported.

This has a risk, but is based on the assumption that they have achieved compaction and the tests are simply validating (QC) what they already known based on

- ✓ No. of passes
- ✓ Lift Thickness
- ✓ Moisture Content

What do Engineers want





1. Accuracy
2. Precision
3. Time to conduct test
4. Ease of use
5. Time to process results
6. Ease to process and report
7. Amount of data obtained
8. Capital cost of equipment

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Preference Ranking based on years of experience

Rank	0 - 5 yrs	6 - 10 yrs	11 - 20 yrs	> 20 yrs
No in Sample	**7**	**9**	**23**	**15**
1. Accuracy	No. 2 / 3	No. 1 / 2	No. 1 / 2	Narrow Band No. 1 / 2
2. Precision	No. 3	Wide Band No. 3	Wide Band No. 3 / 4 / 5	Narrow Band No. 2
3. Time to conduct test	Wide Band No. 4 / 5	Wide Band No. 5	Wide Band No. 3 / 4	Wide Band No. 4 / 5 / 6
4. Ease of use	Wide Band No. 4	Wide Band No. 5	Wide Band No.5	Wide Band No. 4
5. Time to process results	Wide Band No. 4 / 5	Wide Band No. 4 / 5	Wide Band No. 3 / 4	Wide Band No. 5
6. Ease to process and report	Wide Band No. 4	No. 5	No. 5	No.5
7. Amount of data obtained	Narrow band No. 7	Wide Band No. 6	Wide Band No. 5	Wide Band No. 5
8. Capital cost of equipment	No. 7	Wide Band No. 6 /7	Wide Band No. 5 / 7	Narrow band No. 7

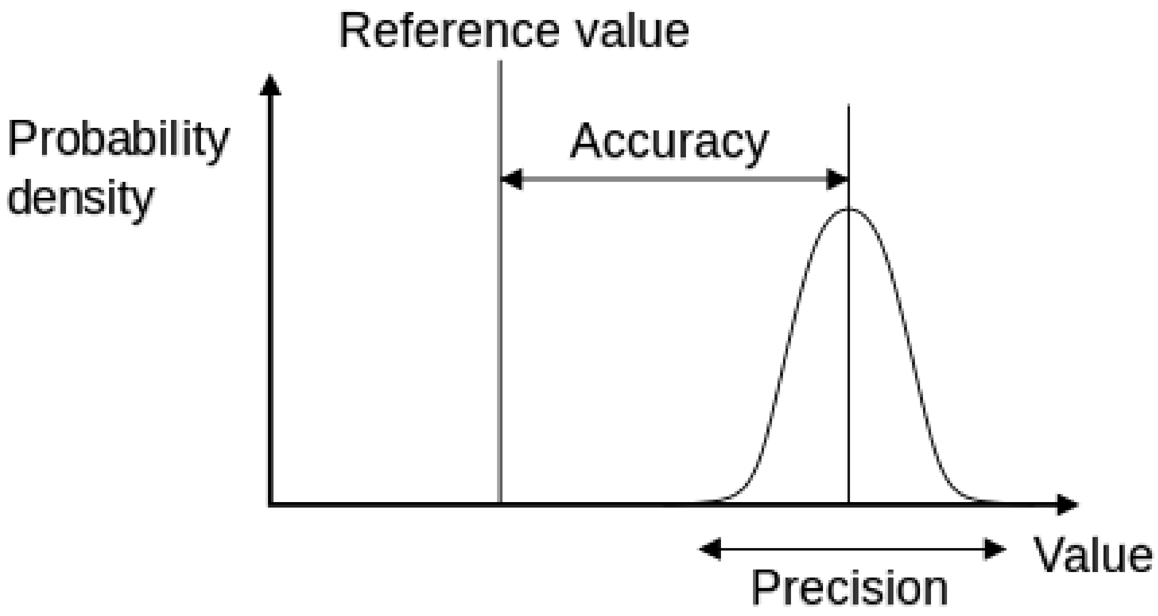
A survey of 54 engineers ranked what attributes are desirable in a test equipment

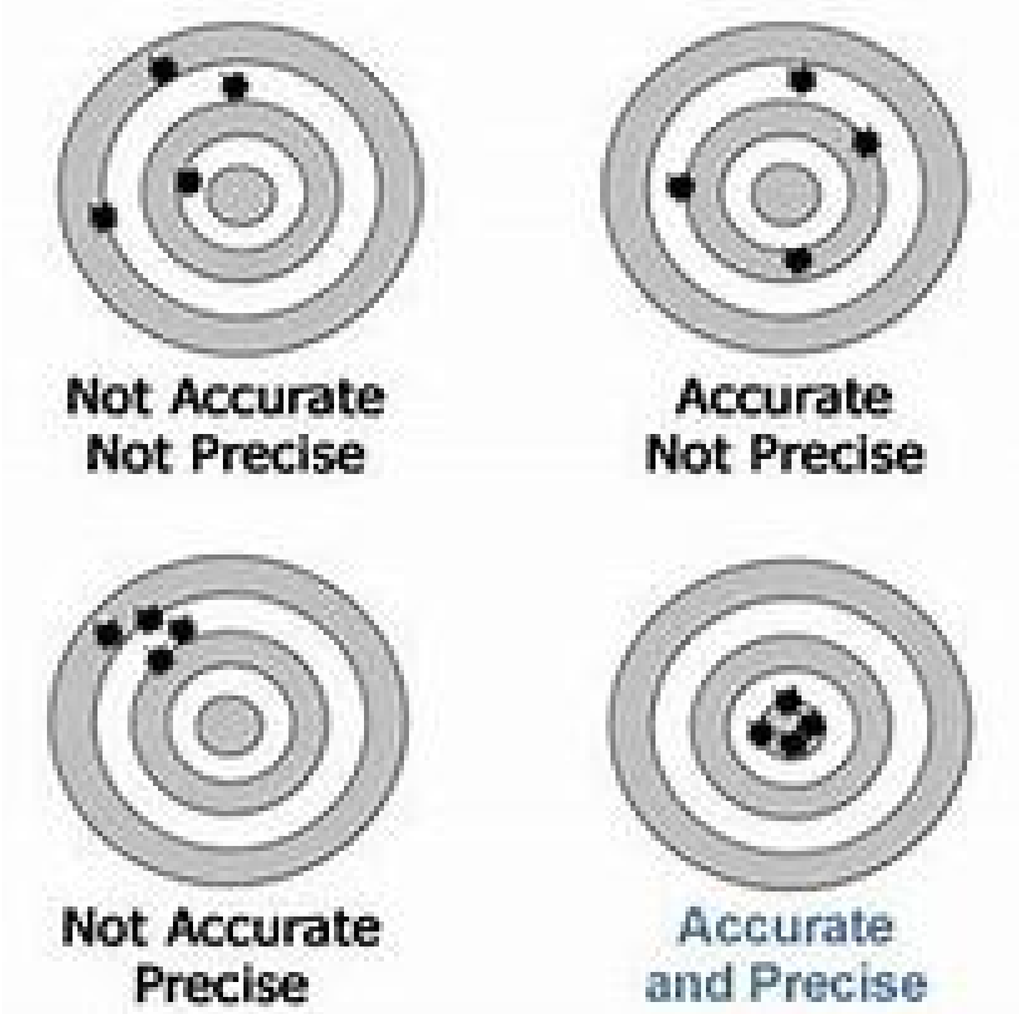
Attributes were ranked

1. Accuracy

Accuracy refers to closeness of the measurements to a “true” value, while precision refers to the closeness of the measurements to each other (repeatability).

Accuracy vs Precision

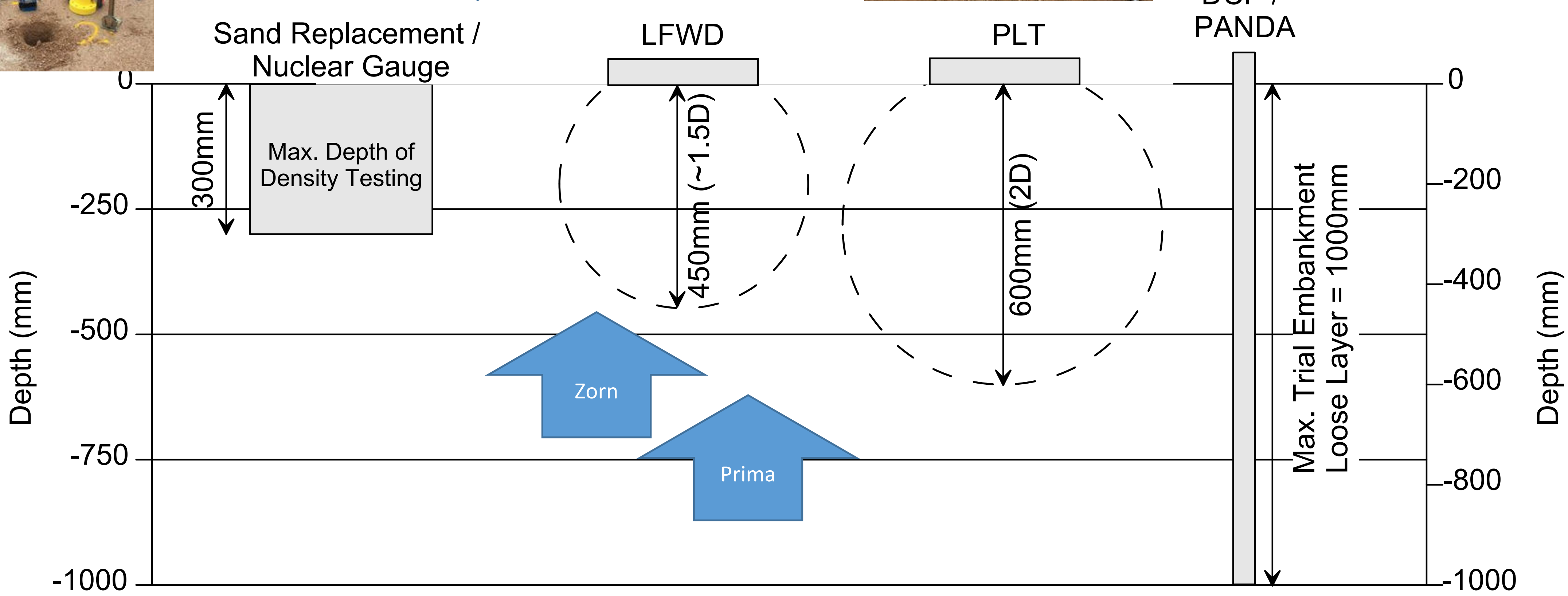




https://en.wikipedia.org/wiki/Accuracy_and_precision

Comparison of Test Equipment

Zone of Influence



Testing

Clegg Hammer

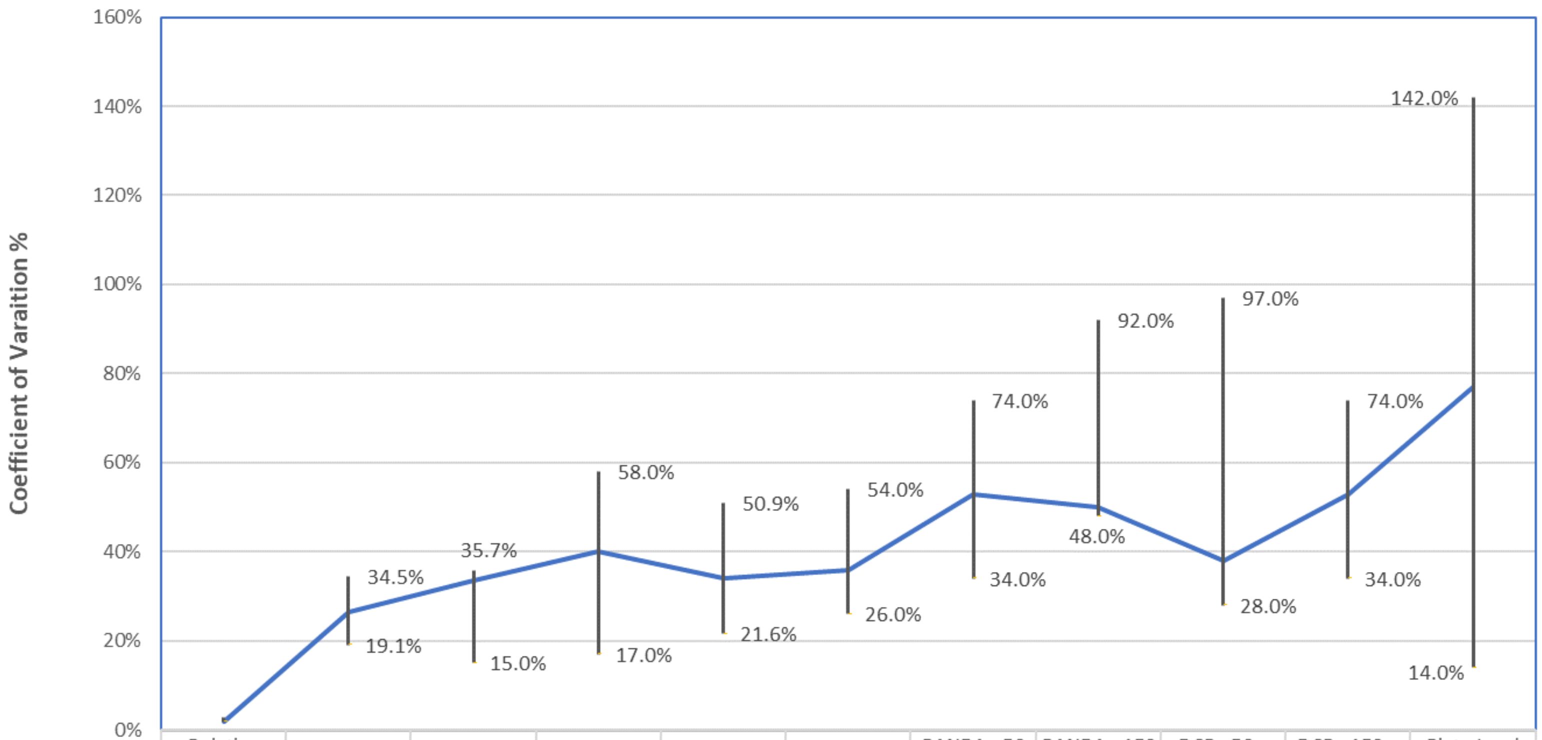
LFWD - Blue Tooth Connectivity

Plate Load Test

Intelligent Compaction - Testing with roller

CMV – Compaction Meter Value

Equipment Precision



	Relative Compaction	Geogauge	Prima LFWD	CBR	Zorn LFWD	Clegg	PANDA - 50 + 100mm	PANDA - 150 + 200mm	DCP - 50 + 100mm	DCP - 150 + 200mm	Plate Load Test
High	2.9%	34.5%	35.7%	58.0%	50.9%	54.0%	74.0%	92.0%	97.0%	74.0%	142.0%
Median	2.0%	26.5%	33.5%	40.0%	34.1%	36.0%	53.0%	50.0%	38.0%	53.0%	77.0%
Low	1.8%	19.1%	15.0%	17.0%	21.6%	26.0%	34.0%	48.0%	28.0%	34.0%	14.0%

High precision
- Relative Compaction
- (Density)

Medium
- Geogauge
- PRIMA LFWD
- CBR
- Zorn LFWD / Clegg

Medium – High (Penetration Tests)
- PANDA 50 - 100mm_
- PANDA 150 – 200mm
- DCP – 50 – 100mm
- DCP – 150 – 200mm

Low Precision
- Plate Load Test

Equipment matches to other tests (5 sites)

Accuracy	PLT	Density	Geogauge	LFWD - ZORN	LFWD - PRIMA	Clegg	PANDA - 100mm	PANDA - 200mm	DCP 100mm	DCP 200mm	CBR	Moisture Ratio
PLT		1	0	0	3	3	4	2	0	5	3	1
Density	1		0	1	1	1	1	2	0	4	1	1
Geogauge	0	0		3	5	0	0	0	2	0	0	1
LFWD - ZORN	0	1	3		3	0	0	1	2	0	0	1
LFWD - PRIMA	3	1	5	3		0	0	0	2	1	0	1
Clegg	3	1	0	0	0		3	3	2	0	3	0
PANDA -50/100mm	4	1	0	0	0	3		3	0	2	5	1
PANDA -150/200mm	2	2	0	1	0	3	3		1	1	3	1
DCP 50/100mm	0	0	2	2	2	2	0	1		0	0	0
DCP 150/200mm	5	4	0	0	1	0	2	1	0		1	1
CBR	3	1	0	0	0	3	5	3	0	1		1
Moisture Ratio	1	1	1	1	1	0	1	1	0	1	1	
No. of Matches	22	13	11	11	16	15	19	17	9	15	17	9
Rank ito cross matching	**1**	8	9	9	5	6	**2**	**3**	11	6	3	11

- ❑ High
- ❑ Median
- ❑ Low

Sites compared for 5 sites tested

No. of matches used as an indicator of accuracy

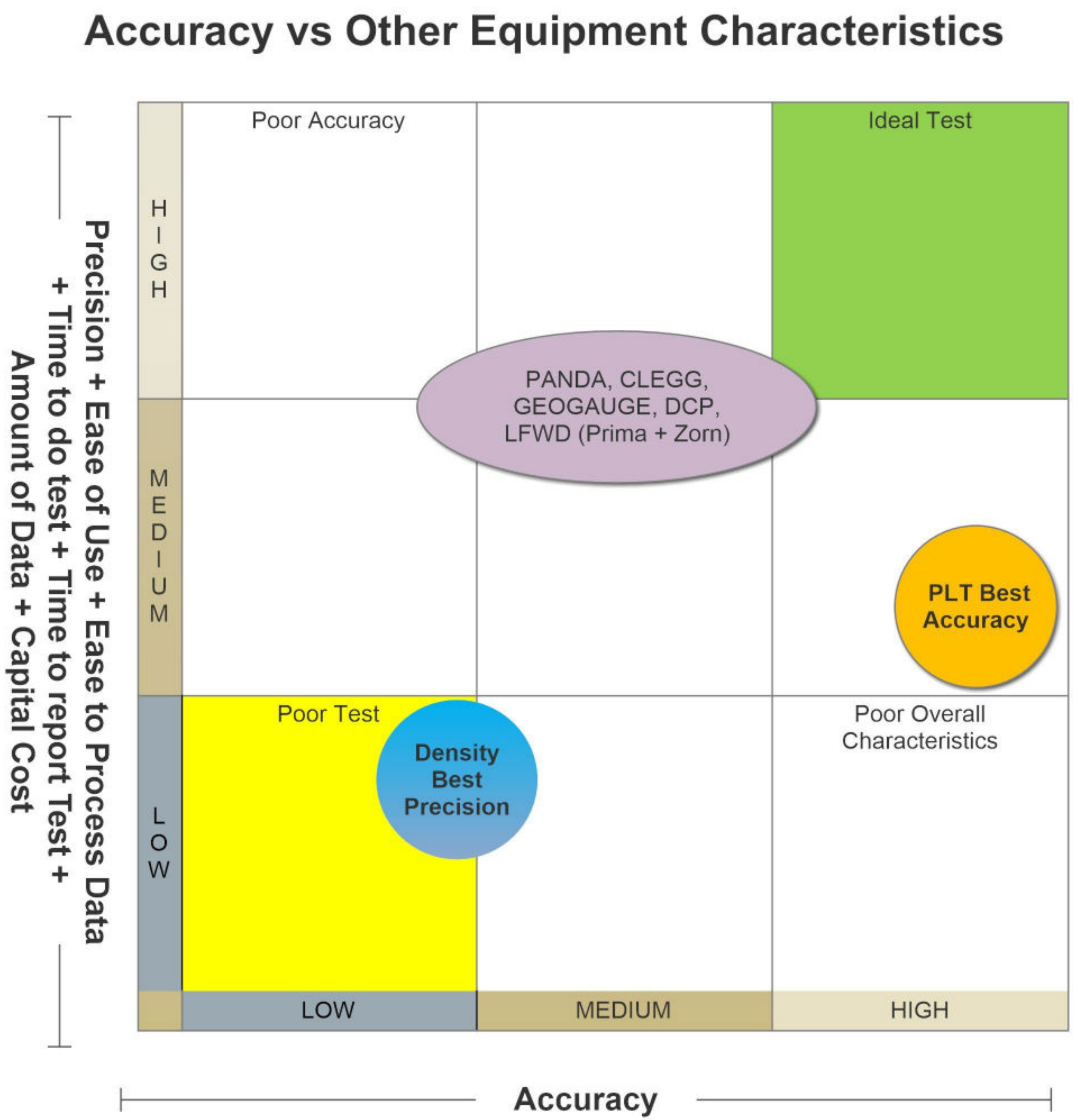
Summary of some field test equipment attributes

Accuracy	Amount of Data / Capital Cost	Precision	Time
1. PLT	1. Plate Load $$$$$	1. Sand Replacement	1. LFWD – Zorn - T
2. PANDA	2. LFWD – Prima $$$$	2. Nuclear Density	2. Geogauge – 1.3 T
3. LFWD - Prima	3. Clegg Hammer $$$	3. Geogauge	3. Panda – 1.4 T
4. Clegg Hammer	4. Panda $$$$$	4. LFWD – Prima	4. DCP - 1.8T
5. DCP: 100 – 200mm	5. LFWD – Zorn $$$$	5. LFWD – Zorn	5. Clegg Hammer – 2.3T
6. Density Ratio	6. Geogauge $$$	6. Clegg Hammer	6. LFWD – Prima* - 2.6T
7. LFWD – Zorn	7. DCP $	7. PANDA	7. Nuclear Density ↑ - 6T
8. Geogauge	8. Sand Replacement $$	8. DCP / 100 – 200mm	8. Plate Load* Test – 6T
9. DCP: 0 -100mm	9. Nuclear Density $$	9. DCP / 0 – 100mm	9. Sand Replacement ↑- 10T
		10. PLT	

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

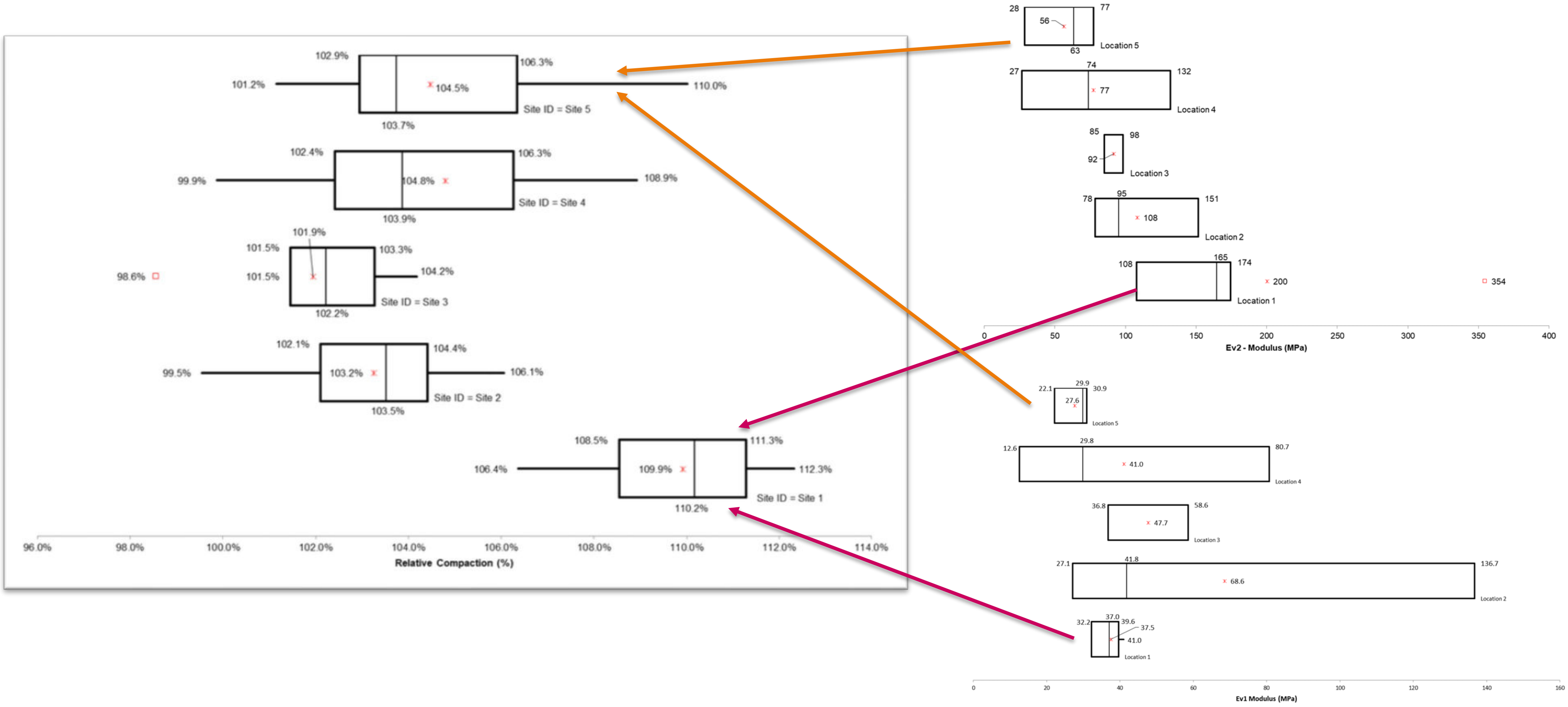
↑ Larger Reporting time. Moisture or air voids may be determined

What industry wants and equipment position



Alternative Equipment / Testing

Tests results – 5 sites



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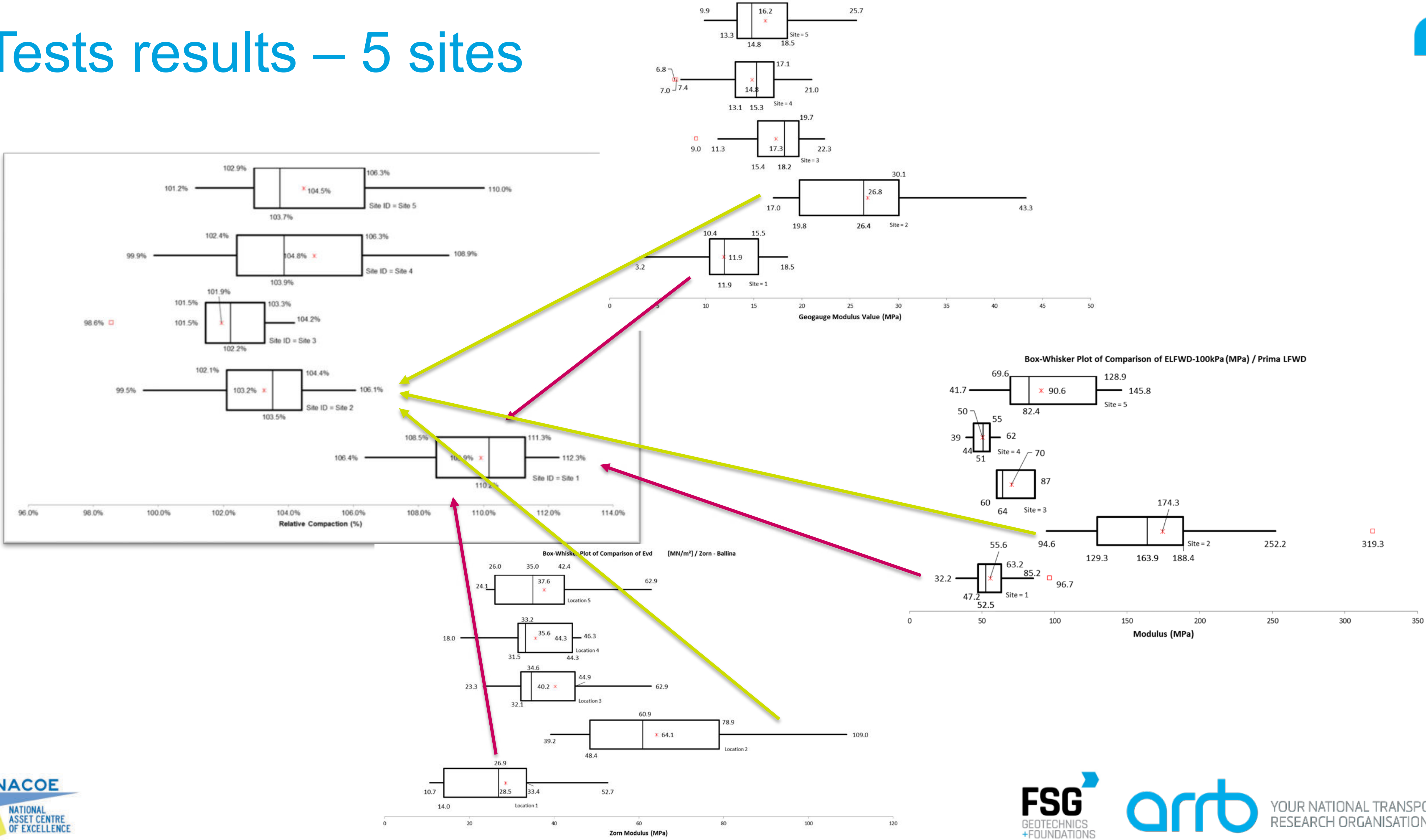
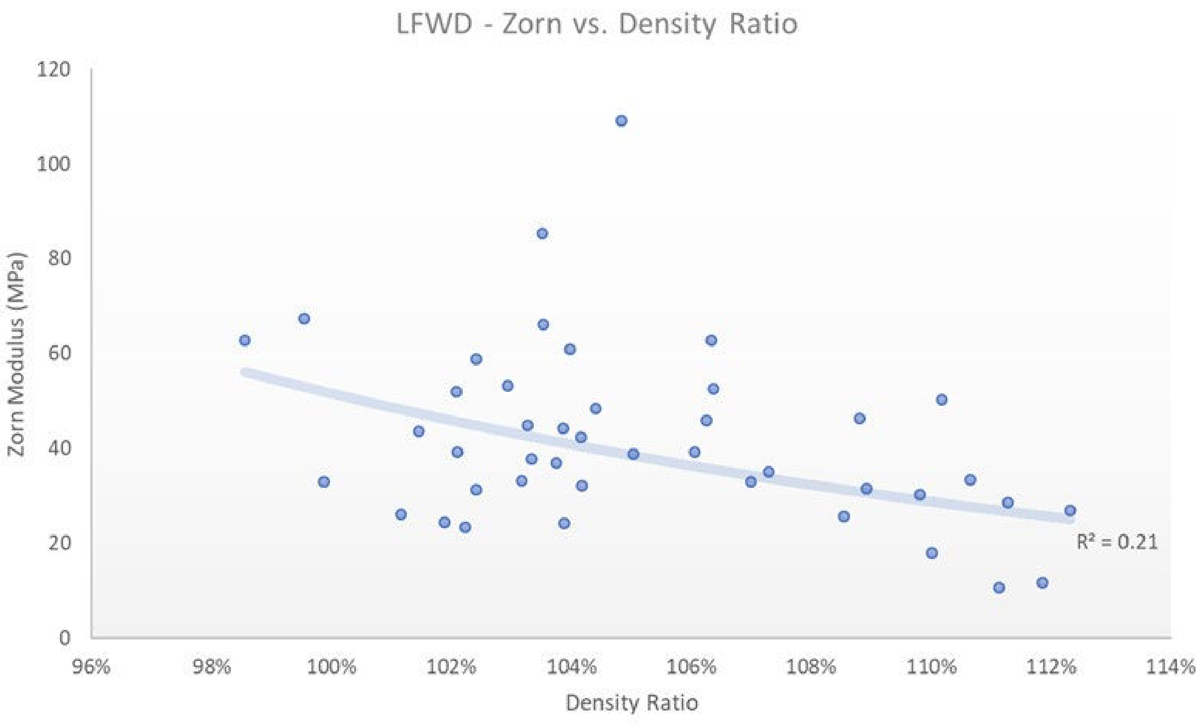
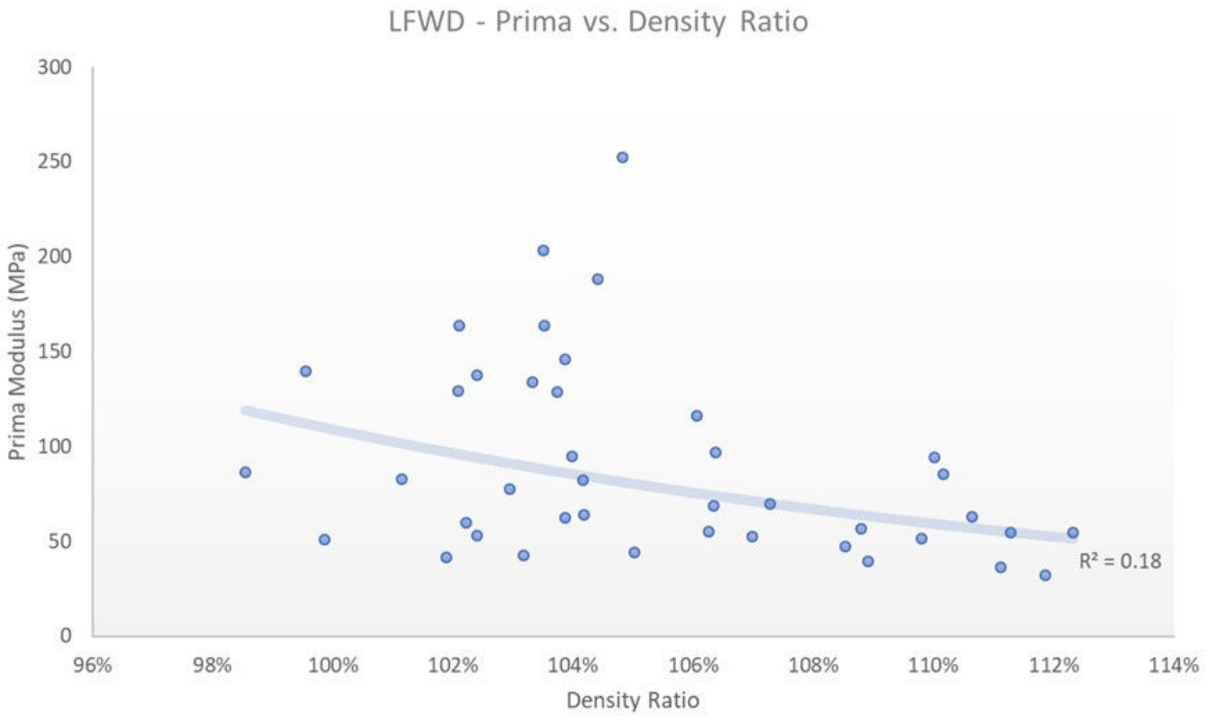
Tests results – 5 sites



LFWD (Zorn + Prima) correlated to density ratio





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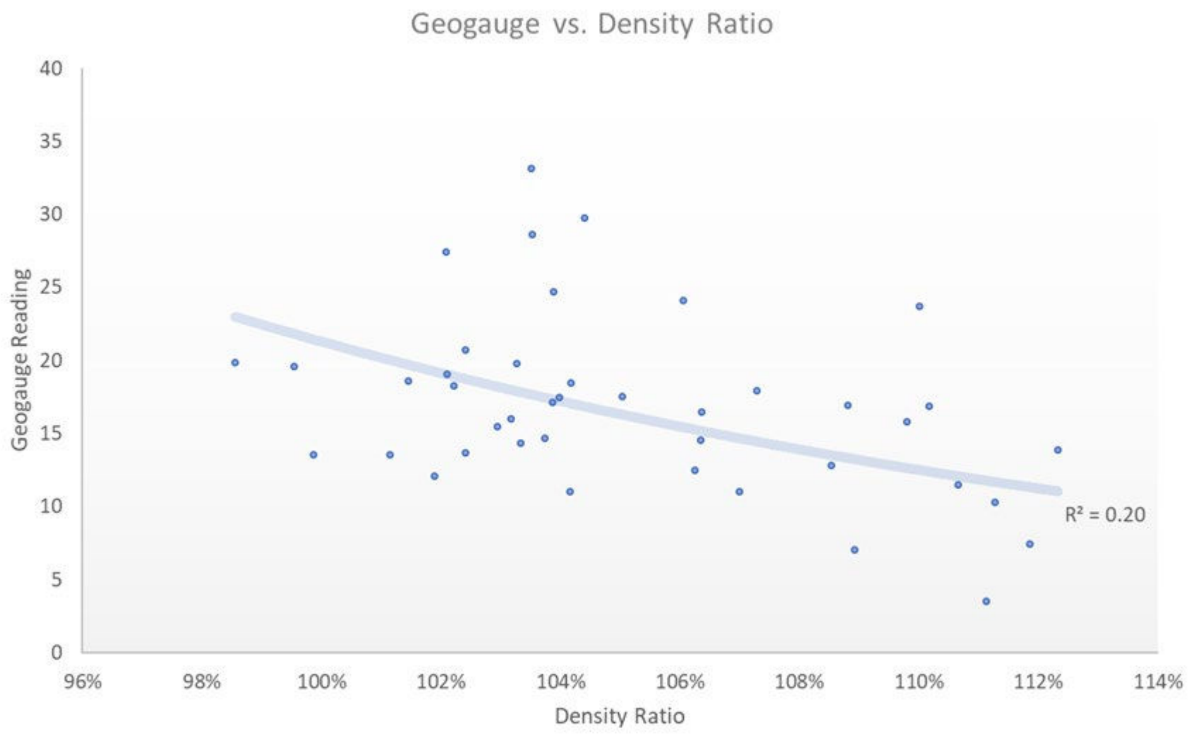
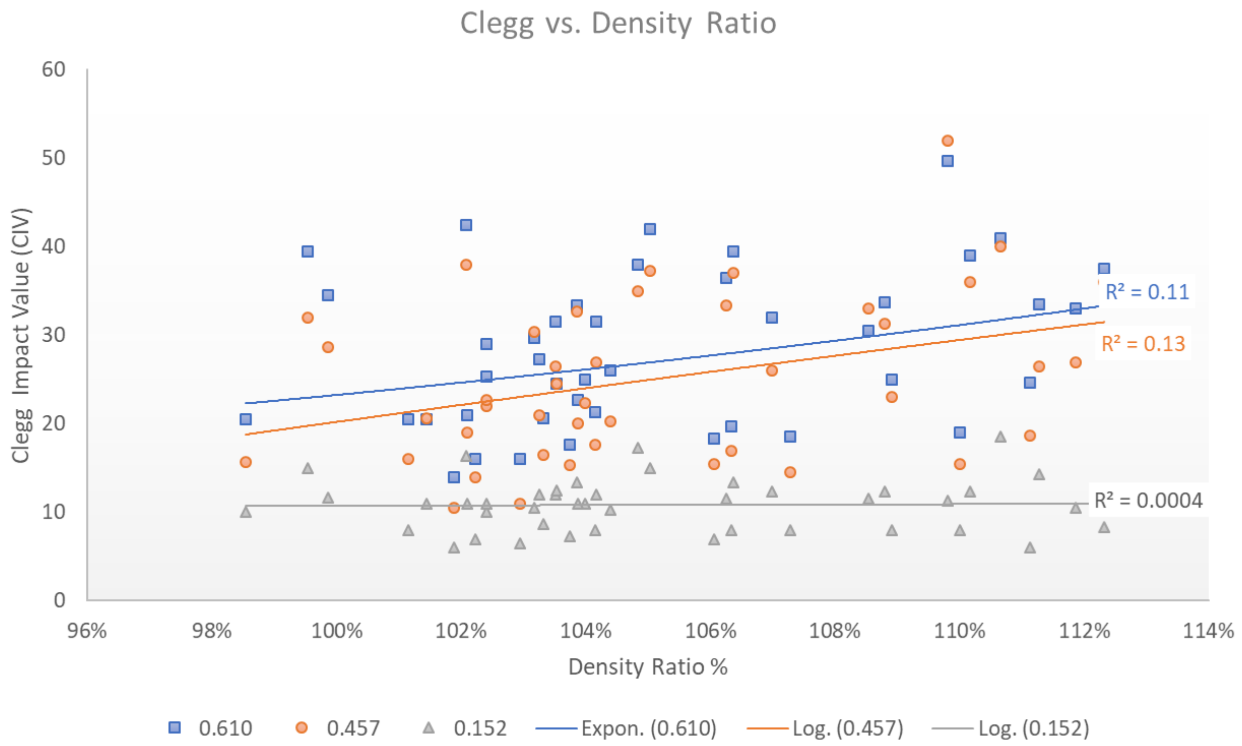
Geogauge and Clegg correlated to density ratio





Paired Correlations

Some base assumptions made

- As density ratio increases the CBR, modulus, or strength increases
- A suitable trend line would be apparent - may not necessarily be linear
- Relative Compaction (Density ratio) as the well-established measurement would be correct (accurate)

Density Ratio compared with modulus measured with 2 different LFWD (ZORN + PRIMA) + CLEGG + GEOGAUGE

- Low correlation ($R^2 \sim 0.2$) shows such relationships should not be used
- More importantly as density ratio increased, all alternate tests decreased. Suggests that as compacted density increases to high values the modulus decreases. This is counter intuitive.
- Results for this data show common assumption that ↑ DR→ ↑ modulus may be incorrect.

QUESTIONS?

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Alternative Equipment / Testing

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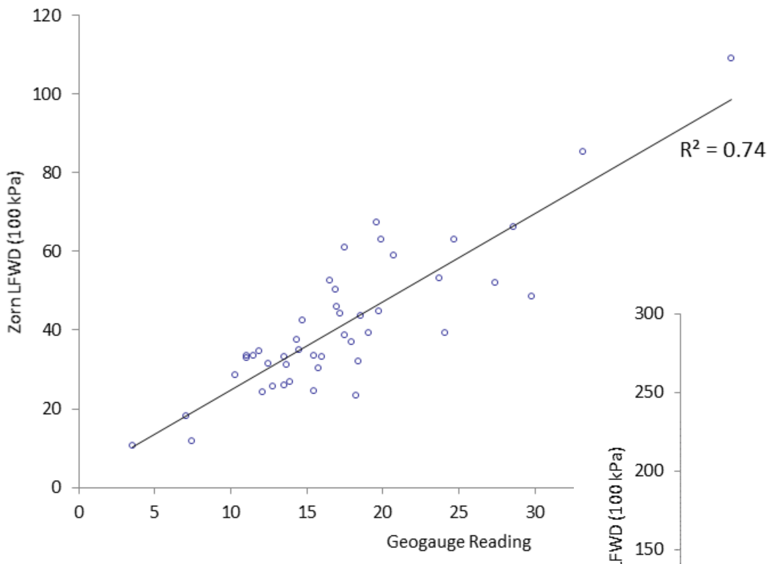
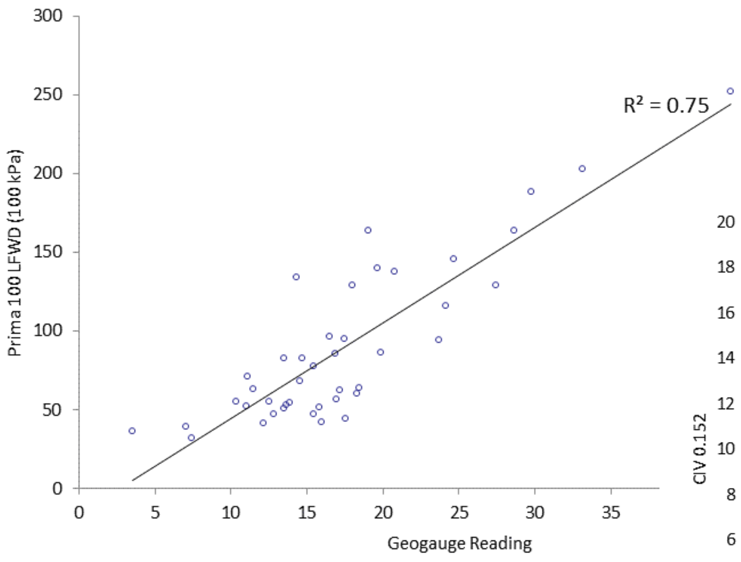
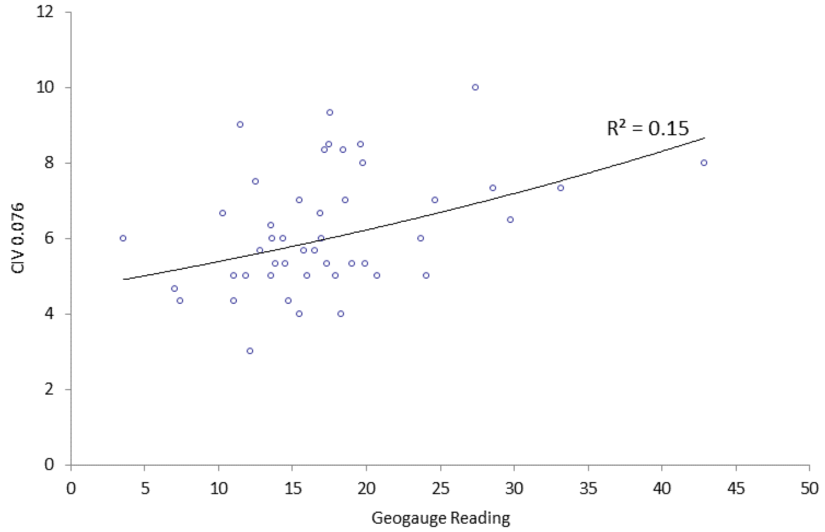
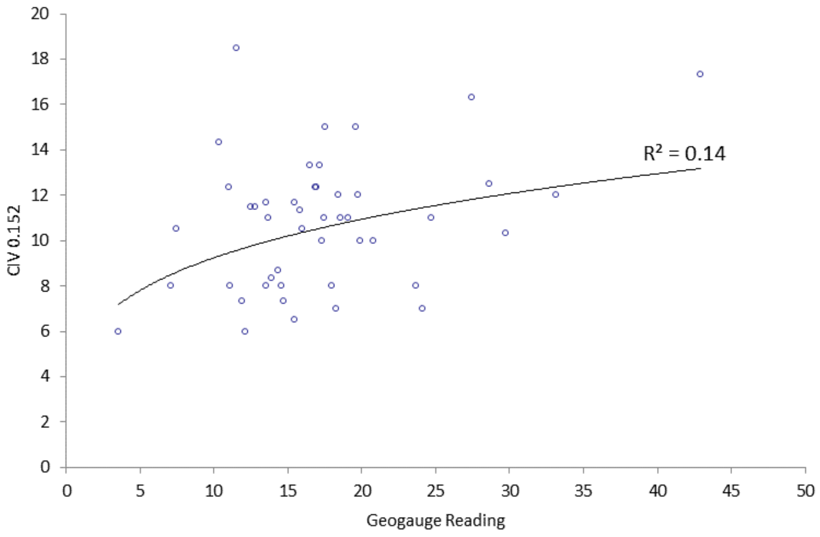
But Alternate Tests correlate to each other









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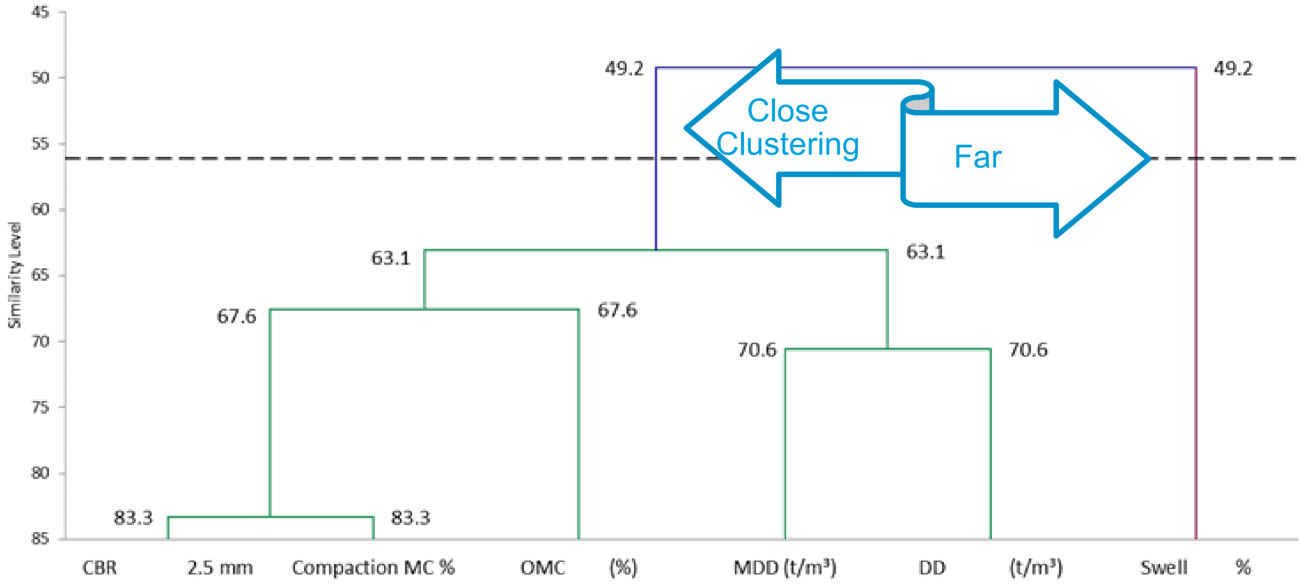
Dendogram Analysis

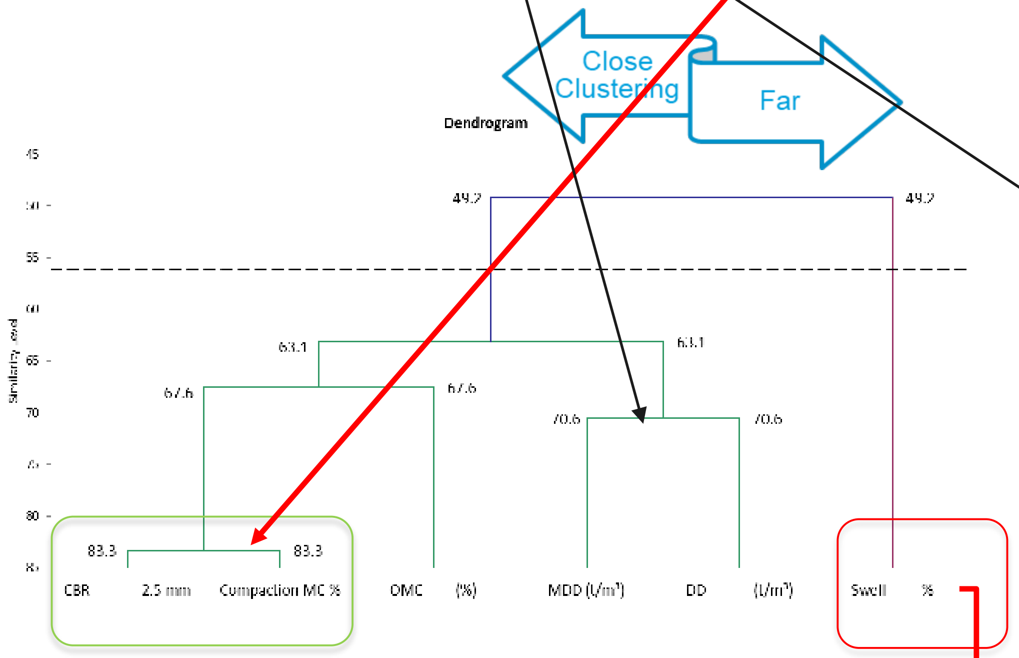
- In statistics, hierarchical clustering builds cluster trees (Dendograms) to represent clustered data.
- Groups of data are nested and organized as a tree with each group in liking to other successor groups. StatTools (version 7) - an add-in to Microsoft Excel was used for this cluster analysis.
- The Cluster Analysis command searches for patterns in a data set → classify observations or variables into groups of similar items. Analysis supports a variety of agglomerative hierarchical methods and distance measures. The *clade* is a branch in the tree. Clades that are close to the same height are similar to each other and clades with different heights are dissimilar. Greater distance in height the more dissimilarity



- Dendogram for Cooroy (CH) clay Soaked CBR.
- Clustering provides visual evidence that CBR is more closely clustered to compaction moisture and the OMC rather than the density.

Dendogram vs correlation matrix (6 variables)

- CBR most strongly correlated with compaction MC (0.691)
- Least with the MDD (-0.04)
- CBR negatively correlated with swell (-0.834).



Correlation Matrix	Comp MC %	DD (t/m³)	OMC (%)	MDD (t/m³)	CBR @ 2.5mm	Swell %
Comp. MC %	1.00					
DD (t/m³)	-0.30	1.00				
OMC (%)	0.23	-0.38	1.00			
MDD (t/m³)	-0.04	0.46	-0.34	1.00		
CBR @2.5 mm	0.69	0.04	0.40	0.32	1.00	
Swell %	-0.85	0.06	-0.14	-0.38	-0.83	1.00

Correlation Matrix Soaked CBR

Correlation	Compaction MC %	DD (t/m³)	OMC (%)	MDD (t/m³)	OVMC (%)	CBR 2.5 mm	CBR 5 mm	Swell %	Avg MC after soak	DD (t/m³) after soak	MC Top Layer (%) AP	Avg MC (%) AP	δ GMC (%)
Compaction MC %	1.00												
DD (t/m³)	-0.84	1.00											
OMC (%)	0.84	-0.89	1.00										
MDD (t/m³)	-0.88	0.97	-0.92	1.00									
OVMC (%)	0.82	-0.84	0.98	-0.86	1.00								
CBR 2.5 mm	-0.47	0.61	-0.49	0.59	-0.47	1.00							
CBR 5 mm	-0.56	0.66	-0.49	0.66	-0.46	0.90	1.00						
Swell %	0.41	-0.62	0.57	-0.64	0.55	-0.79	-0.75	1.00					
Avg MC after soak	0.43	-0.84	0.72	-0.82	0.62	-0.61	-0.65	0.66	1.00				
DD (t/m³) after soak	0.39	0.20	-0.04	0.22	0.13	0.53	0.52	-0.58	-0.68	1.00			
MC Top Layer (%) AP	0.33	-0.71	0.61	-0.74	0.49	-0.71	-0.76	0.79	0.94	-0.76	1.00		
Avg MC (%) AP	0.55	-0.89	0.78	-0.87	0.71	-0.64	-0.69	0.71	1.00	-0.67	0.94	1.00	
δ GMC (%)	-0.24	-0.23	0.16	-0.28	0.11	-0.84	-0.86	0.89	0.58	-0.60	0.70	0.56	1.00
δ DD (t/m³)	-0.77	0.45	-0.45	0.32	-0.50	-0.60	-0.60	0.74	0.22	-0.73	0.48	0.21	0.78
VMC at Comp.	0.96	-0.72	0.75	-0.76	0.73	-0.39	-0.49	0.29	0.31	0.45	0.21	0.41	-0.35
VMC after soak	0.18	-0.71	0.46	-0.63	0.24	-0.29	-0.26	0.18	0.85	-0.25	0.64	0.86	0.17
δ VMC	-0.85	0.13	-0.21	0.07	-0.30	-0.91	-0.89	0.85	0.49	-0.51	0.64	0.47	0.97
MR at comp	0.42	-0.05	-0.07	-0.06	-0.10	0.03	-0.08	-0.34	-0.27	0.48	-0.33	-0.21	-0.64
MR soaked	-0.02	-0.19	-0.11	-0.11	-0.18	-0.76	-0.73	0.68	0.50	-0.53	0.57	0.47	0.66
DR at Comp	0.01	0.27	-0.04	0.05	-0.06	0.18	0.11	-0.05	-0.29	0.14	-0.13	-0.33	0.05
Dr soaked	0.64	-0.17	0.36	-0.28	0.39	0.56	0.55	-0.59	-0.36	0.85	-0.53	-0.35	-0.66
VMC at comp	0.40	-0.01	-0.07	-0.05	-0.10	0.01	-0.10	-0.30	-0.29	0.46	-0.34	-0.23	-0.63
VMR soaked	-0.29	0.01	-0.47	0.13	-0.65	-0.51	-0.47	0.44	0.49	-0.24	0.52	0.50	0.44
Gs assumed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gs Interpreted	-0.03	0.13	0.07	0.12	0.16	0.03	0.11	0.03	0.55	0.14	0.47	0.64	0.14
e before	0.74	-1.00	0.89	-0.92	0.83	-0.38	-0.45	0.45	0.84	-0.20	0.71	0.87	0.23
e after	-0.39	-0.20	0.04	-0.22	-0.13	-0.53	-0.52	0.58	0.68	-1.00	0.76	0.67	0.60
Av before	-0.69	0.16	-0.22	0.15	-0.24	-0.55	-0.52	0.50	0.16	-0.52	0.27	0.11	0.76
Av after	-0.59	0.37	-0.36	0.37	-0.30	-0.31	-0.33	0.43	-0.12	-0.58	0.10	-0.13	0.44
δ Av	-0.62	-0.15	0.01	-0.10	-0.07	-0.81	-0.78	0.62	0.57	-0.35	0.58	0.56	0.78
n before	0.74	-1.00	0.89	-0.92	0.83	-0.38	-0.45	0.45	0.84	-0.20	0.71	0.87	0.23
n after	-0.39	-0.20	0.04	-0.22	-0.13	-0.53	-0.52	0.58	0.68	-1.00	0.76	0.67	0.60
δ n	-0.77	0.45	-0.45	0.33	-0.50	-0.60	-0.60	0.74	0.22	-0.72	0.48	0.21	0.78
DOS before	0.79	-0.27	0.33	-0.27	0.35	0.45	0.41	-0.39	-0.04	0.51	-0.16	0.00	-0.68
DOS after	0.58	-0.40	0.37	-0.40	0.30	0.28	0.30	-0.39	0.16	0.55	-0.06	0.18	-0.42
δ DOS	-0.68	-0.08	-0.04	-0.04	-0.12	-0.84	-0.81	0.66	0.54	-0.36	0.58	0.53	0.82

Correlation Matrix Soaked CBR

CBR ~ Modulus

- > 0.80
- VMC / GMC
- δ DOS / δ Air Voids

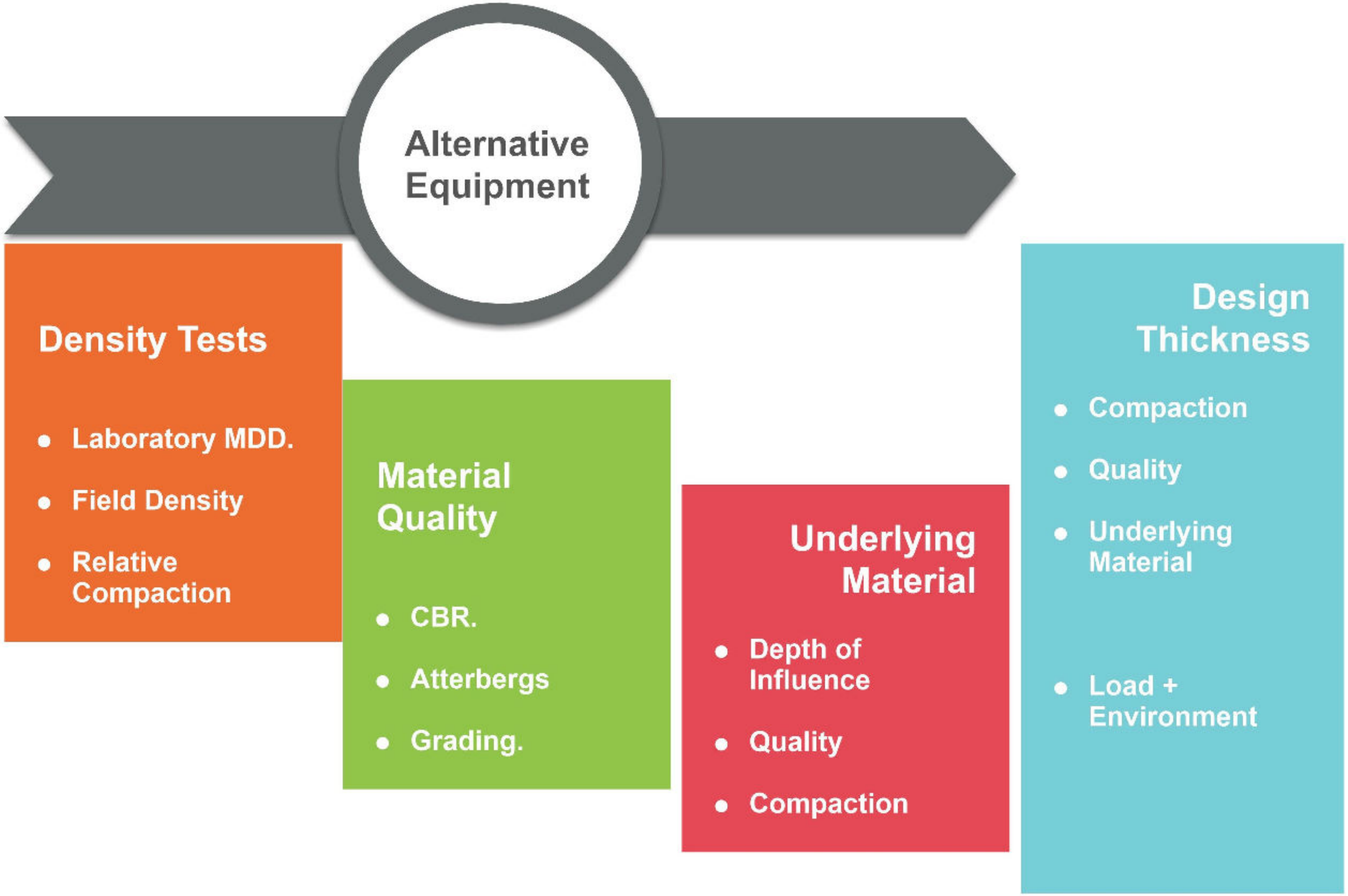
DR 0.18 / 0.11

MR 0.03 / -0.08

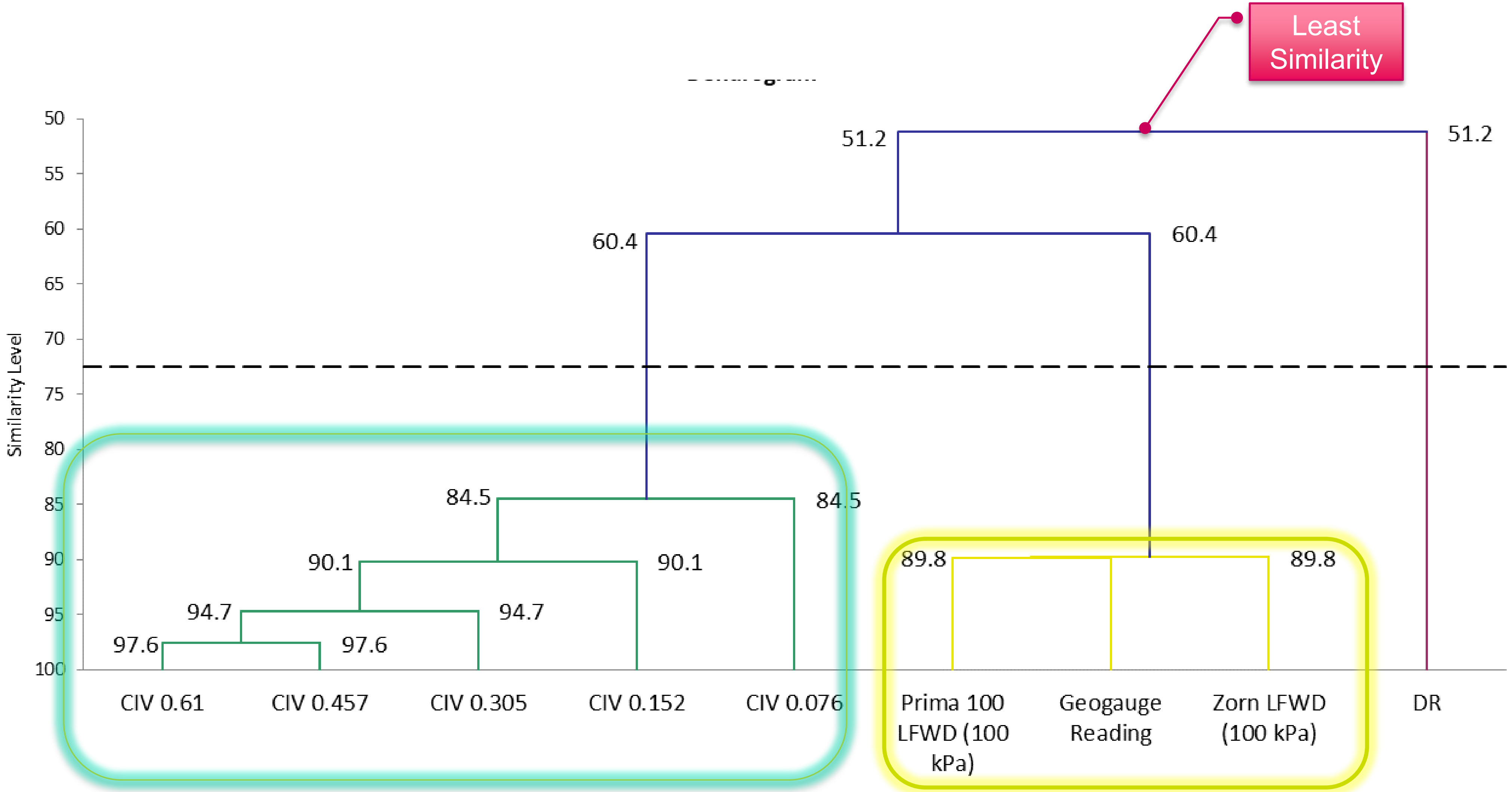
		CBR 2.5 mm	CBR 5 mm
1	CBR 5 mm	0.898	1.000
2	CBR 2.5 mm	1.000	0.898
3	δ VMC	-0.912	-0.889
4	δ GMC (%)	-0.843	-0.858
5	δ DOS	-0.838	-0.810
6	δ Av	-0.814	-0.783
7	MC Top Layer (%) AP	-0.706	-0.759
8	Swell %	-0.787	-0.754
9	MR soaked	-0.762	-0.728
10	Avg MC (%) AP	-0.637	-0.688
11	MDD (t/m³)	0.589	0.662
12	DD (t/m³)	0.606	0.661
13	Avg MC after soak	-0.608	-0.652
14	δ n	-0.602	-0.604
15	δ DD (t/m³)	-0.602	-0.604
16	Compaction MC %	-0.471	-0.564
17	Dr soaked	0.558	0.552
18	DD (t/m³) after soak	0.529	0.520
19	n after	-0.529	-0.520
20	e after	-0.529	-0.520
21	Av before	-0.548	-0.517
22	VMC at Comp.	-0.391	-0.488
23	OMC (%)	-0.488	-0.488
24	VMR soaked	-0.511	-0.471
25	OVMC (%)	-0.465	-0.460
26	n before	-0.382	-0.449
27	e before	-0.382	-0.449
28	DOS before	0.446	0.408
29	Av after	-0.309	-0.326
30	DOS after	0.280	0.298
31	VMC after soak	-0.286	-0.256
32	DR at Comp	0.185	0.111
33	Gs Interpreted	0.026	0.109
34	VMC at comp	0.009	-0.099
35	MR at comp	0.026	-0.081
36	Gs assumed	0.000	0.000

From 36 variables in a CBR test
Construction focuses on DR and MR
which are poorly correlated to CBR (Modulus)

Comparison of Density vs alternative testing



Alternate Testing Dendograms



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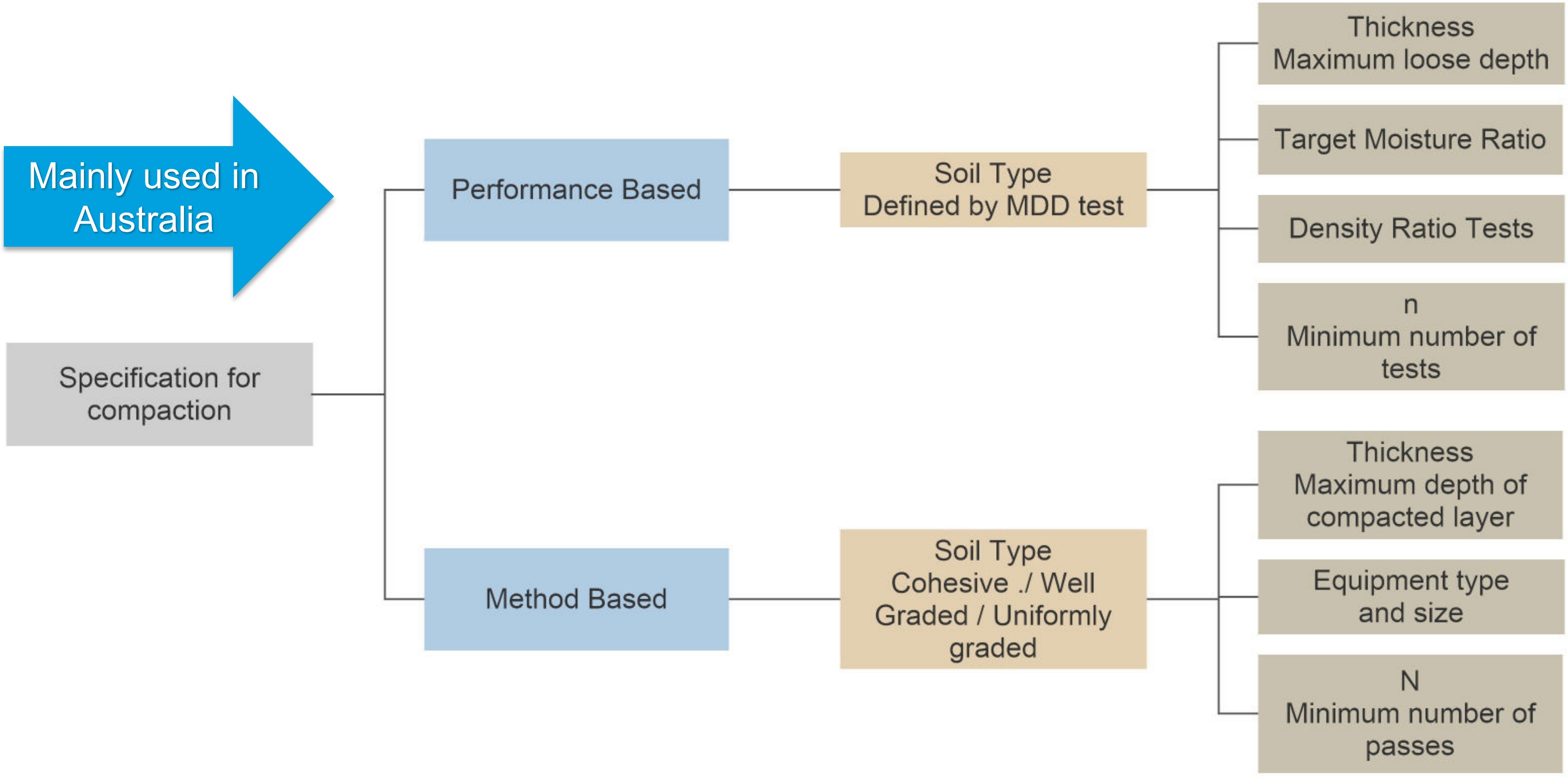
Density Ratio is least correlated to the other 4

Correlation	DR	Geogauge Reading	Zorn LFWD (100 kPa)	Prima LFWD (100 kPa)	CIV 0.076	CIV 0.152	CIV 0.305	CIV 0.457	CIV 0.61
DR	1.00								
Geogauge Reading	-0.32	1.00							
Zorn LFWD (100 kPa)	-0.23	0.79	1.00						
Prima 100 LFWD (100 kPa)	-0.30	0.77	0.81	1.00					
CIV 0.076	0.03	0.39	0.51	0.30	1.00				
CIV 0.152	0.10	0.24	0.40	0.17	0.79	1.00			
CIV 0.305	0.28	-0.02	0.13	-0.11	0.65	0.89	1.00		
CIV 0.457	0.35	-0.01	0.10	-0.13	0.62	0.83	0.94	1.00	
CIV 0.61	0.31	-0.06	0.10	-0.11	0.62	0.83	0.93	0.95	1.00

Is
Density Ratio
the end game ?

Performance based mainly used in Australia



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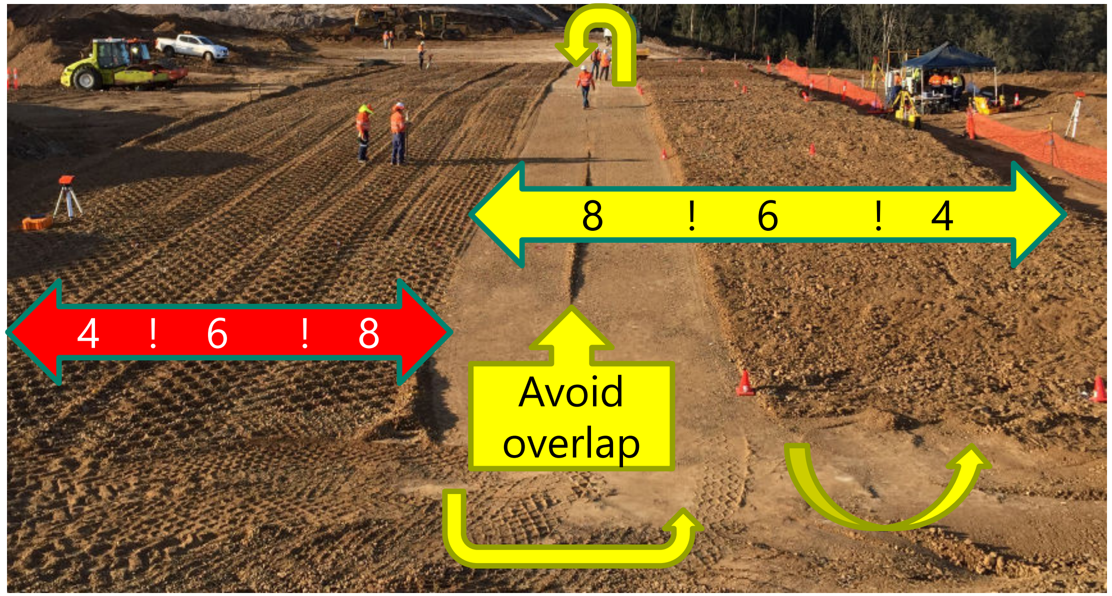
Performance based uncertainty

Performance based specification used as it has more certainty – Does it?

Pad Foot + Smooth Drum vibrating rollers



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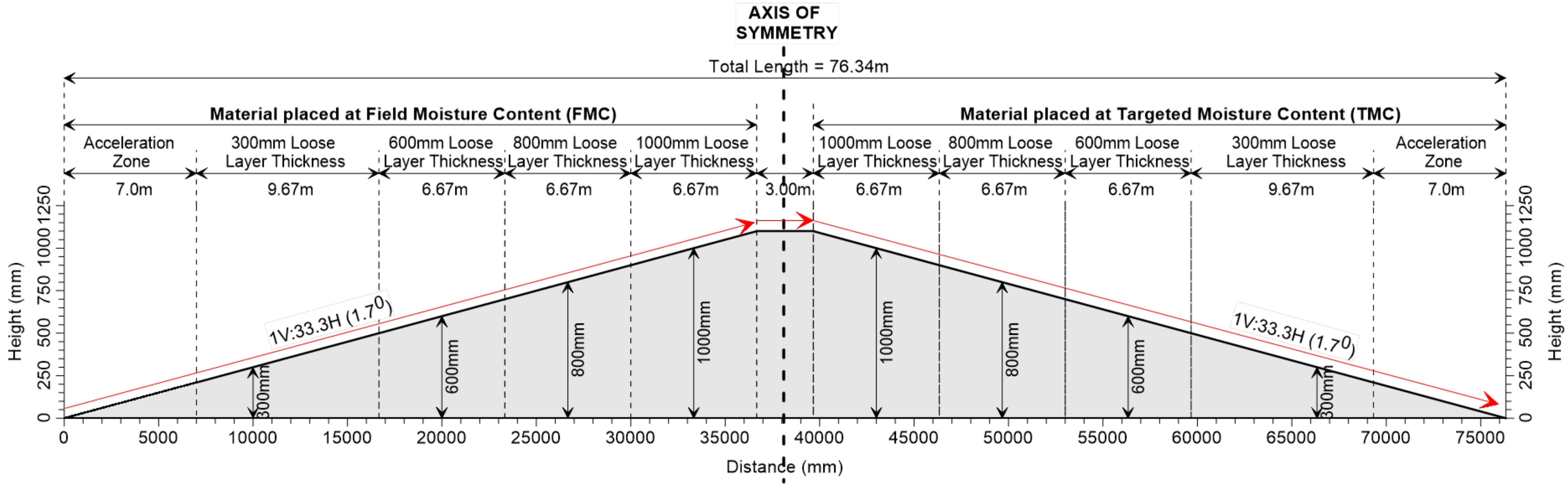
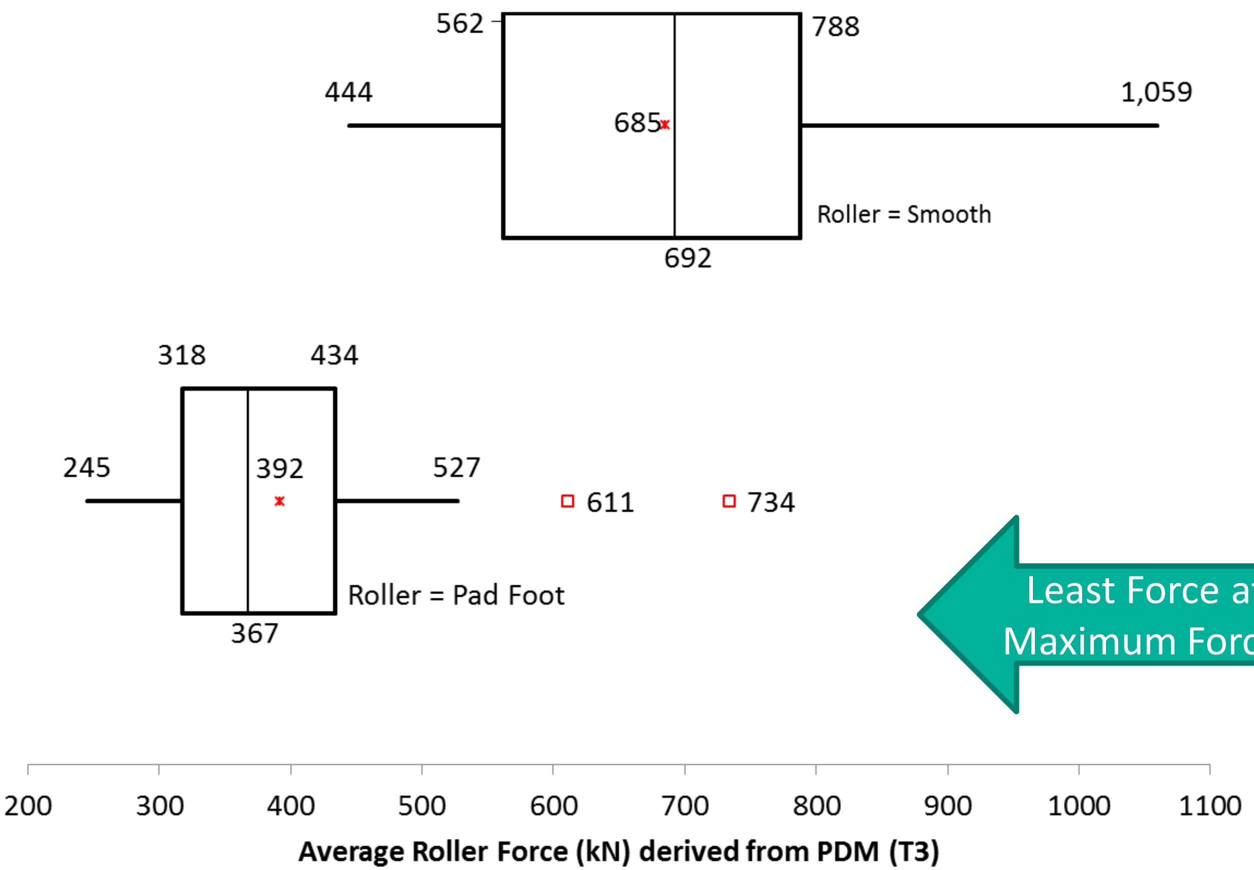
Trial Embankment Layout Elevation

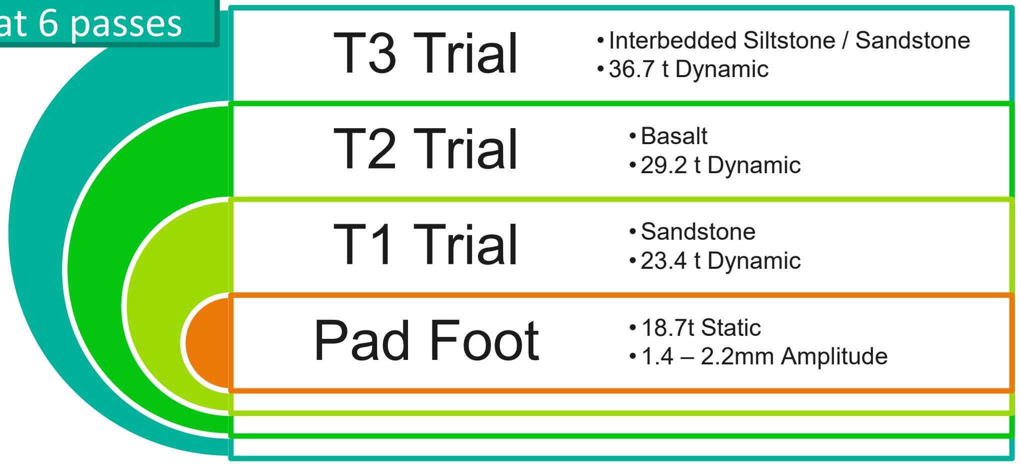


Dynamic Monitoring - Force

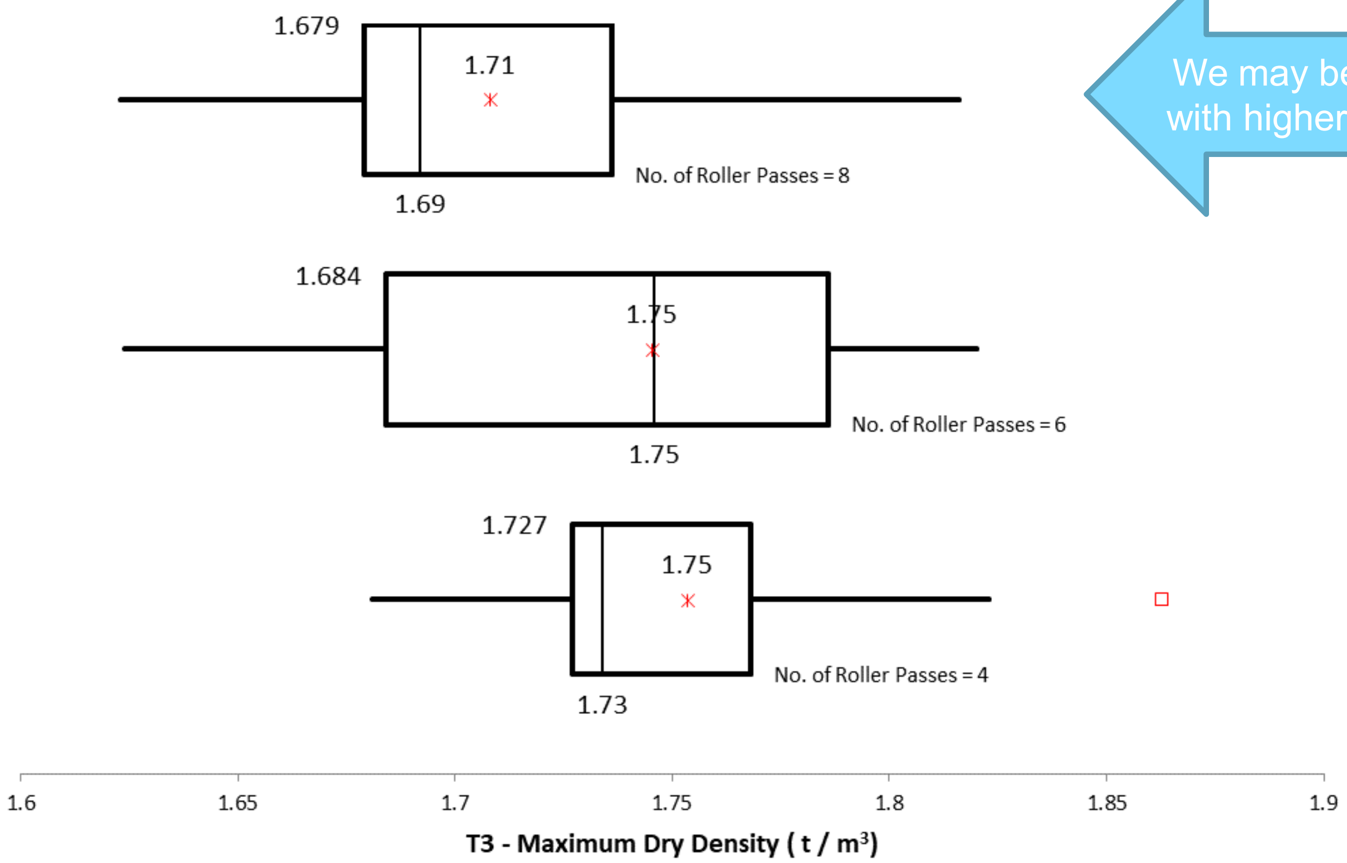


Dynamic Force
Smooth = 1.8 X Pad Foot for interbedded
Smooth = 0.9 x Pad Foot for sandstone

Least Force at Initial pass
Maximum Force at 6 passes



Maximum Dry Density – T3 interbedded Siltstone / Sandstone



We may be decreasing MDD with higher number of passes

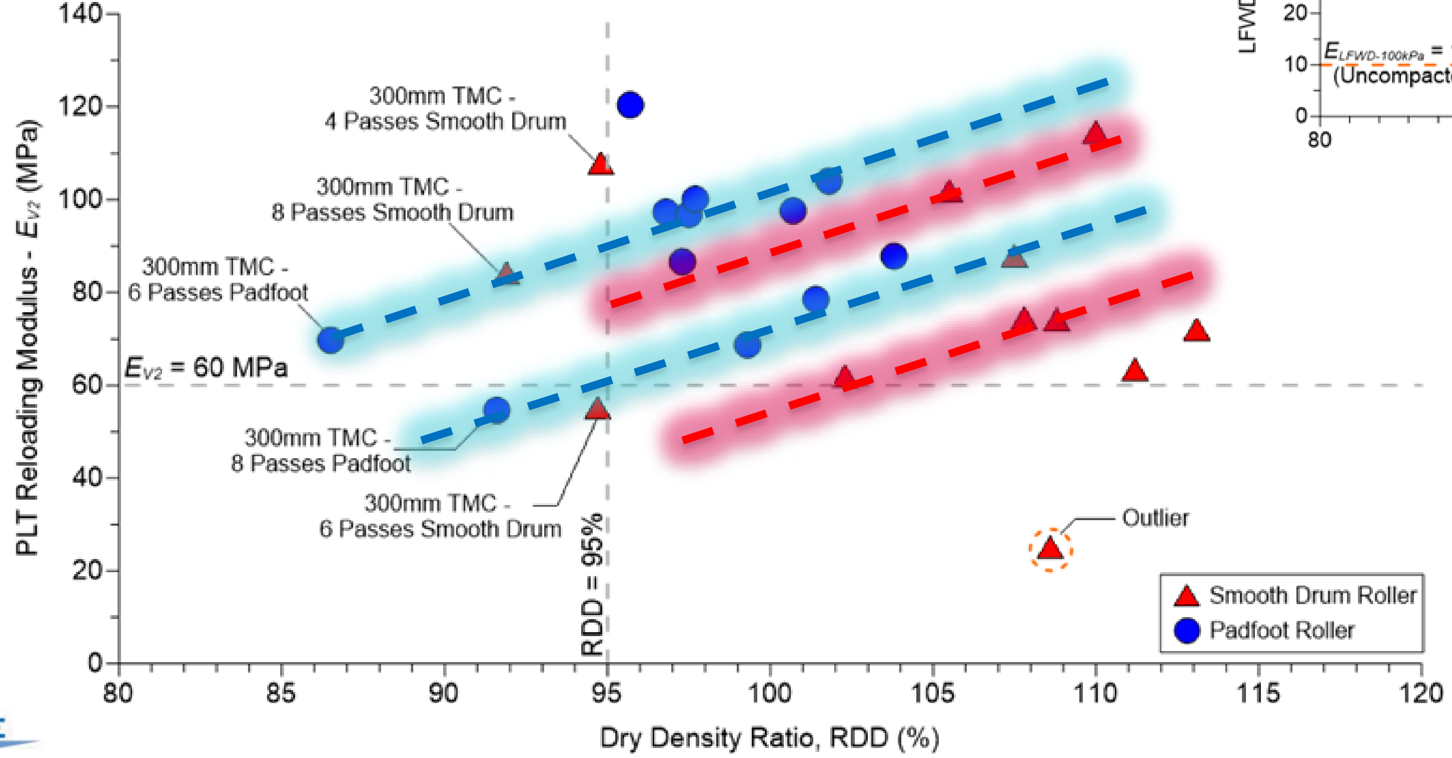
We think we are increasing the Field Density

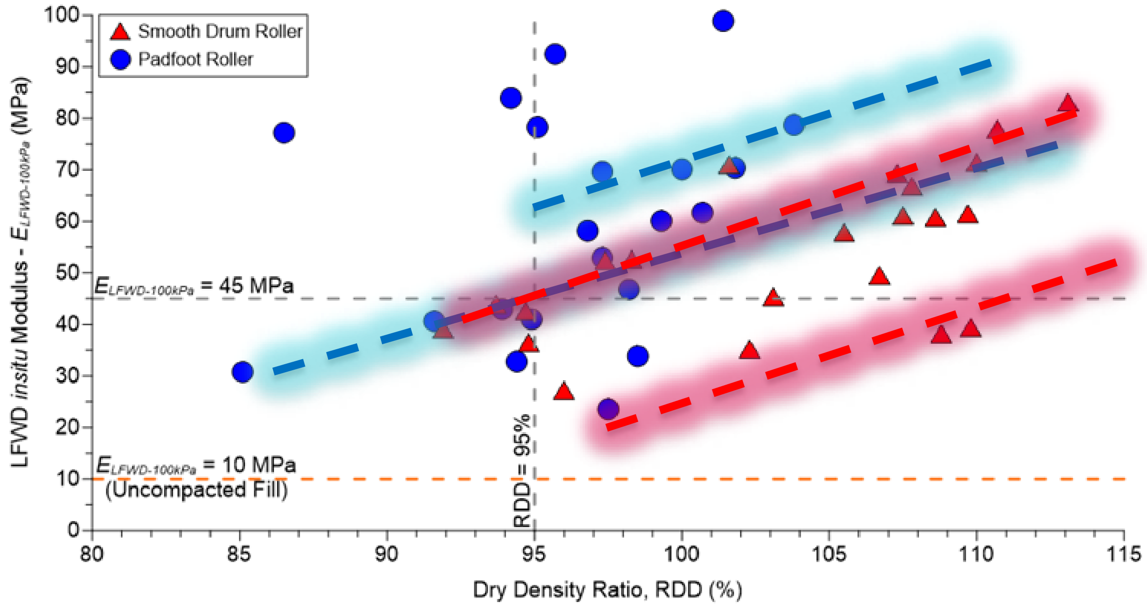
$$Density\ Ratio = \frac{Field\ Density}{Max\ Dry\ Density}$$

In situ E correlated to 95% Density ratio

Fill Material Origin	Plate Load Test (PLT) E_{V2} (MPa)	Light Falling Weight Deflectometer (LFWD) $E_{LFWD\text{-}100kPa}$ (MPa)
Sandstone: **70% Gravel size; 10% fines**	60	45
Interbedded Siltstone / Sandstone **70% Gravel size; 11% fines**	35	25
Basalt **65% Gravel size; 12% fines**	50	30

Modulus correlated to DR for sandstone material





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These findings are not unique

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A Comparison of Density-Based and Modulus-Based In Situ Tests for Earthwork Quality Control

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ABSTRACT: A series of density-based and modulus-based quality control tests were performed to evaluate and compare the performance of a number of in situ testing methods for control of soil compaction. This paper highlights the results from the study that focus on three in situ testing tools for compaction control: the Light Weight Deflectometer (LWD), the Dynamic Cone Penetrometer (DCP), and the Nuclear Density Gauge (NDG). In situ tests conducted using these tools were performed during construction of an embankment built with a coarse-grained soil in a series of lifts. Comparison of the in situ test results shows that that there is a notable variability in measured soil properties for each of the testing methods that were performed. All three in situ tests showed an increasing trend in the measured properties from pass-to-pass of the compactor, which indicates the suitability of these tests for proper control of the compaction process. However, the soil moduli measured by the LWD and DCP correlated poorly to the NDG dry unit weights.

Modulus-Based Construction Specification for Compaction of Earthwork and Unbound Aggregate

DRAFT FINAL REPORT

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9.2 General Conclusions

The general conclusions based on evaluation of the proposed modulus-based specification are the following:

- The adaption of the modulus-based specification needs to be approached in the context of the levels of uncertainty associated with the current well-established density criteria (especially when nuclear density gauges are used). It has been shown on many occasions in this study that achieving quality compaction (defined as achieving adequate layer modulus) is only weakly associated with achieving density.
- Among the modulus/stiffness-based technologies, devices based on the ultrasonic surface wave, lightweight deflectometer, and dynamic cone penetrometer technologies (PSPA, LWD, and DCP devices, respectively) perform reasonably well with the following caveats:
  - The PSPA exhibits the highest variability and needs the most training, but provides the most reasonable layer-specific information.
  - Different LWDs estimate different moduli at the same test spot. As such, the specification should be clear which LWD should be used. It is also important to consider the properties of the underlying layers in setting the LWD target values, especially when the layer of interest is overlying a layer with a significantly different modulus.
  - The DCP is simple to use and inexpensive. However, since DCP strictly measures the strength not the modulus of the layer, setting its target should be done with care. The DCP results were not very sensitive to moisture content and material changes.
- Among the modulus-based technologies evaluated, the LWD is recommended. This decision was partly made based on the familiarity of the highway agencies with the deflection concept, the ease of use of the device, and the availability of a network of providers of LWDs throughout the world.

DR used to assess Strength or modulus

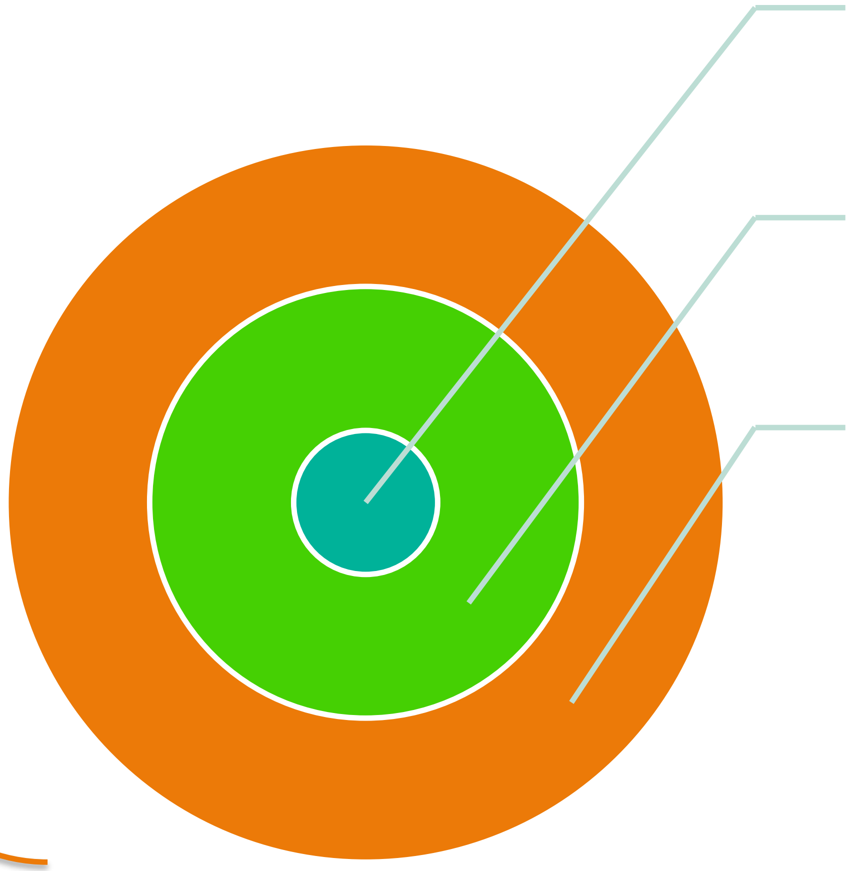
- ✓ DR is currently the basis to assess quality during construction
- ✓ Prior to this research we assumed higher density was also a higher strength or modulus

- ✓ We were wrong

- ✓ Correlating alternative testing to DR often results in a poor correlation
- ✓ Alternate testings generally correlate to each other
- ✓ These tests are combining DR + several other factors
- ✓ Modulus is more dependent on moisture rather than DR

- ✓ DR is a very precise test – but may not be accurate

Multiple Targets measured: DR + Quality + Underlying interaction



Density Ratio

Moisture Ratio
- Compaction

Material Quality
- CBR / Gradings /. Atterbergs

Underlying Material
- Depth of influence
- Quality
- Compaction

Alternate Tests are measuring more than 1 variable

Partly accounts for the low R^2

Alternate Tests measure – One Target

Density Ratio

Moisture Ratio

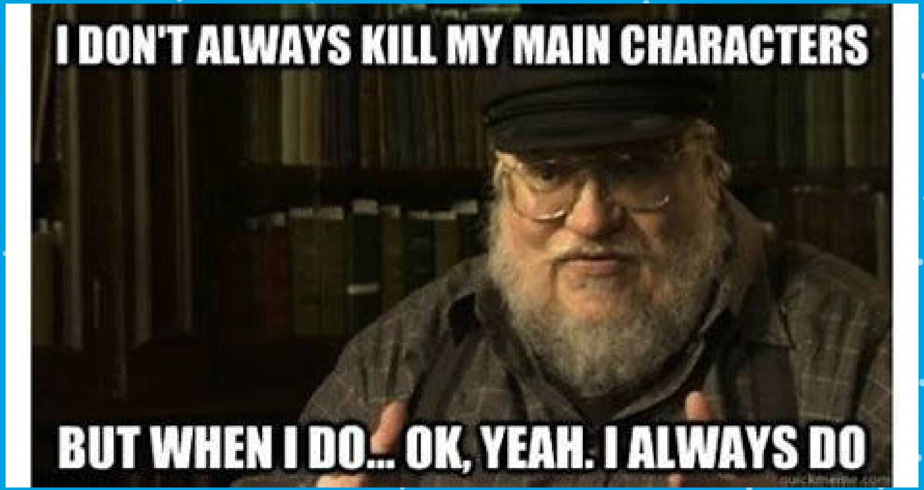
- Compaction

Material Quality

- CBR / Gradings /. Atterbergs

Underlying Material

- Depth of influence
- Quality
- Compaction



Stay tuned for part 3

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Thank you for your participation today.

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QUESTIONS?