Webinar: Part 3 – Procedures
Advanced Method for Compaction Quality Control

Rosemary Pattison

Webinar Moderator

Professional
Knowledge Hub - ARRB Group

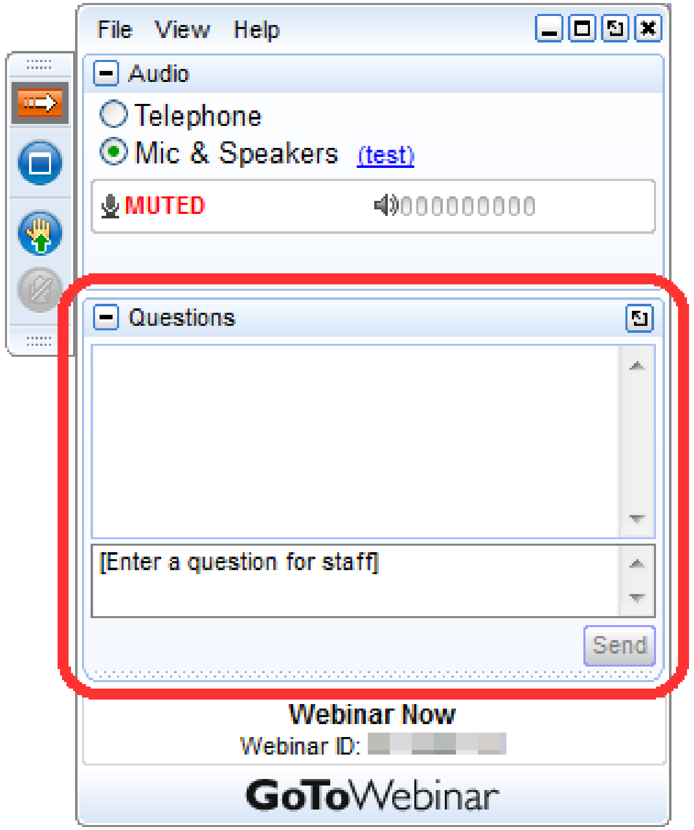
P: +61 3 9881 1590
E: training@arrb.com.au

Housekeeping

Webinar 60 mins

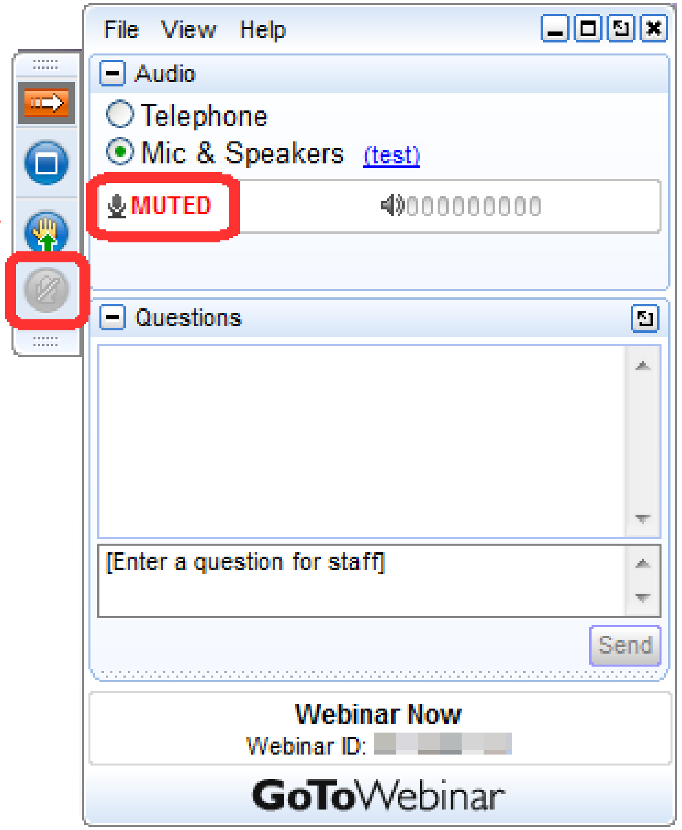
Questions 5 mins

GoTo Webinar functions



Attendee microphones are muted

Please type your questions here



Dr Jeffrey Lee
Principal Professional Leader
ARRB

Ph: +61 7 3260 3527
jeffrey.lee@arrb.com.au

Dr Burt Look
FSG Geotechnics + Foundations

Ph: +61 7 3831 4600
blook@fsg-geotechnics.com.au

Dr David Lacey
FSG Geotechnics + Foundations

Ph: +61 7 3831 4600
dlacey@fsg-geotechnics.com.au

NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

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.

Density Ratio

Moisture Ratio

- Compaction

Material Quality

- CBR / Gradings /. Atterbergs

Underlying Material

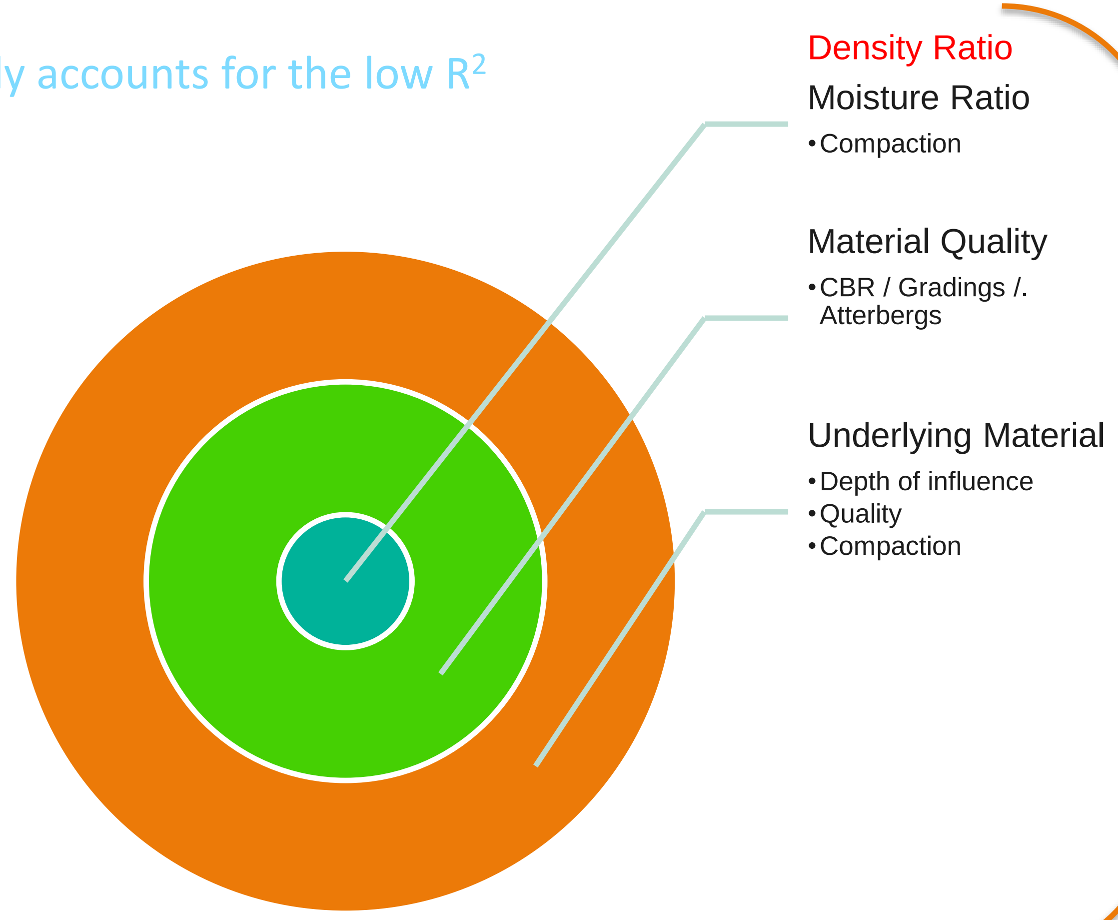
- Depth of influence
- Quality
- Compaction

Summary of Previous 2 Webinars + Basics

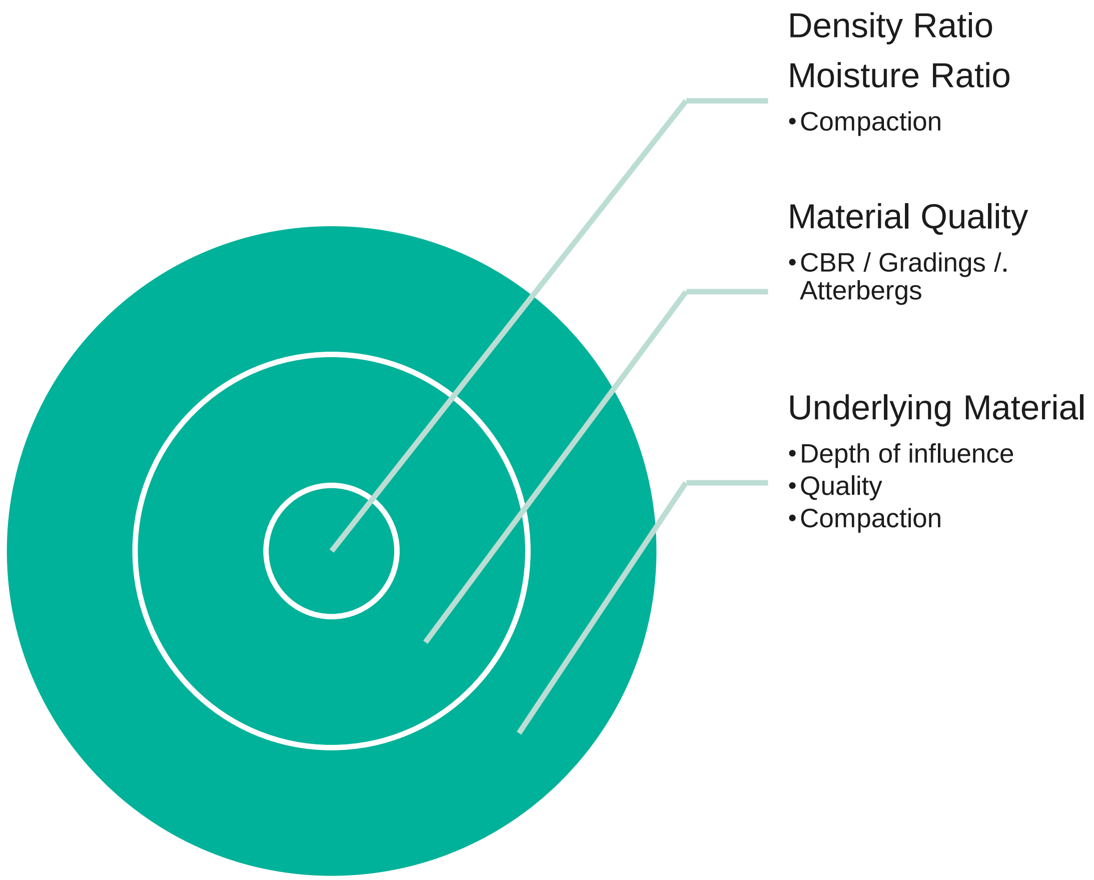
Multiple Targets measured: DR + Quality + Underlying interaction

Alternate Tests are measuring more than 1 variable

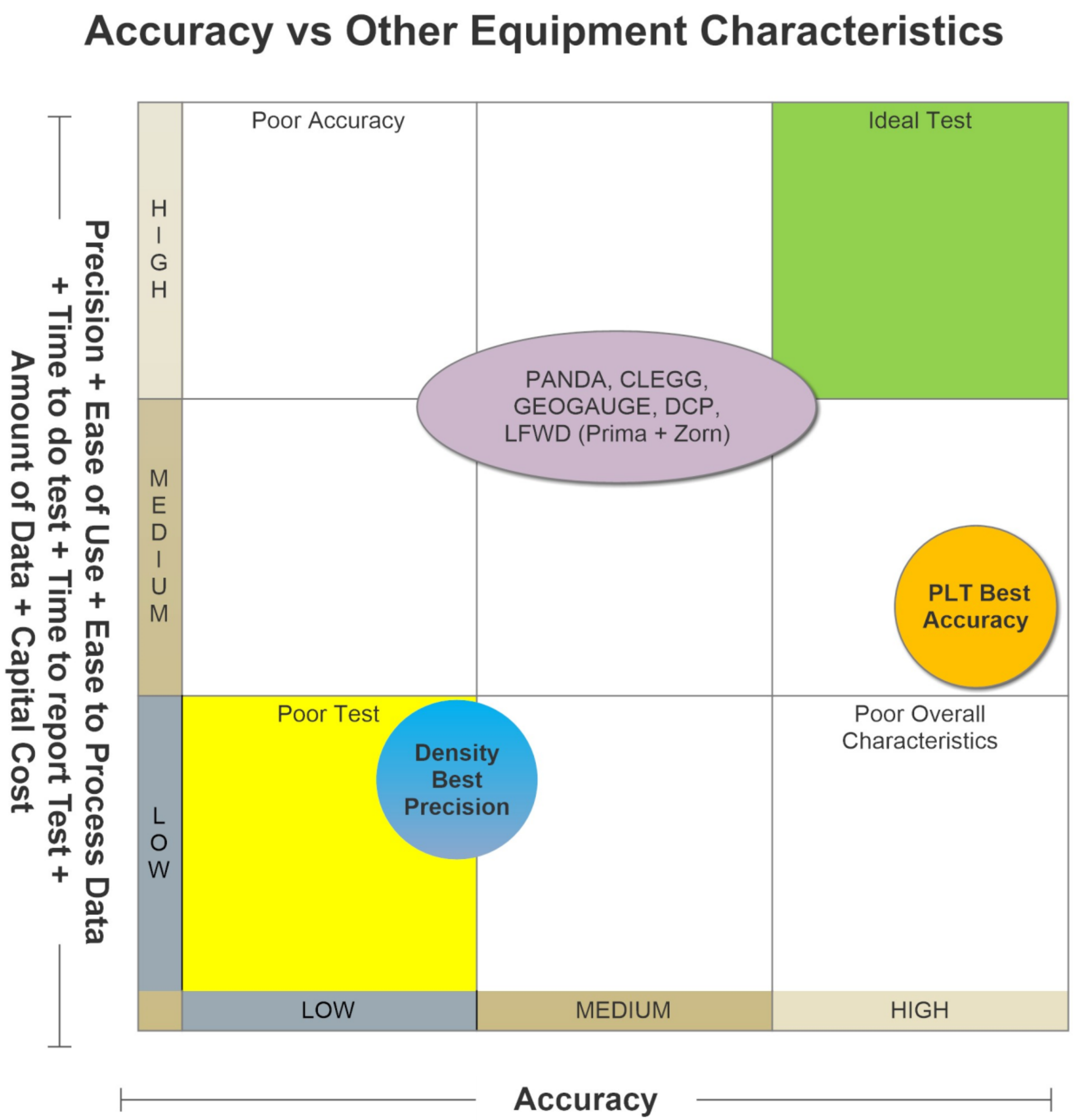
Partly accounts for the low R^2



Alternate Tests measure – One Target



What industry wants and equipment position



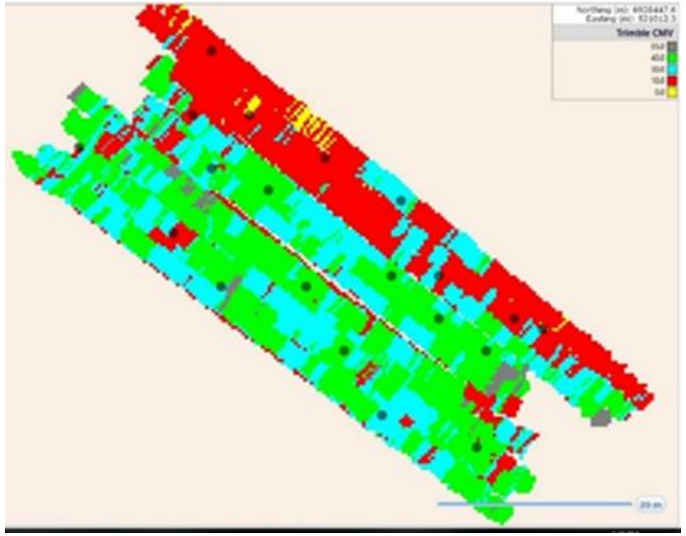
Intelligent Compaction implementation (FHWA 2011)

Univariate Correlations

Correlation of ICMV to NG dry unit density

Figure 96 presents the correlation results between ICMVs and the NG dry unit density r_d. The main conclusions are summarized as follows:

- ICMV increases with increasing r_d as expected, and overall a poorer correlation is achieved than that of E_{LWD}, E_{FWD}, and E_{V1} and E_{V2};
- Dependent on the specific test strip and materials, either the direct linear, or the logarithmic scaled linear function may achieve better correlation;
- For some cases, significant scatter in the relationships is shown (e.g. MS TBs1, 2, 4 CCV, and KS TB1 and TB2 MDP80). These values are likely influenced by different material type encountered and narrow range of MDP80 values on each material type.
- Different materials show different correlation results and variation trends (e.g. KS TB3 foundation shale and clay materials). These separate trends could be a result of differences in the underlying support, material, and moisture conditions.



Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials

Final Report

Publication No. FHWA-IF-12-002

July 2011

U.S. Department of Transportation
Federal Highway Administration

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS + FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

The future of Modulus Based Measurements

READY RESULTS
Next Steps to Put NCHRP Research into Practice

NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

FOCUS ON: NCHRP Project 10-84

May 2017

Measuring Modulus for Better-Performing Pavements

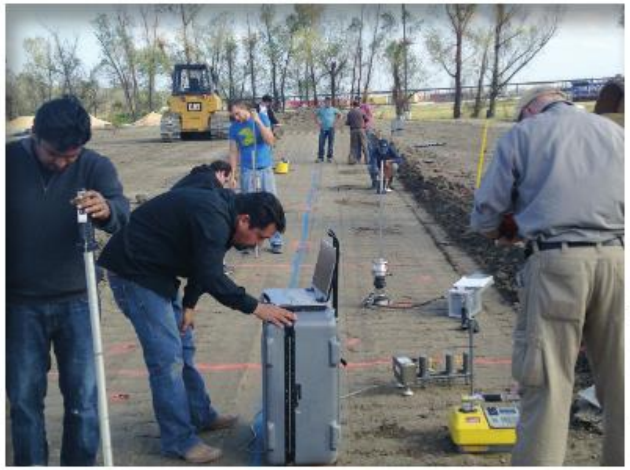


Image from contractor's final report

During field tests, researchers compared several devices for measuring compacted geomaterials, including lightweight deflectometers, portable seismic property analyzers, and the GeoGauge.

REAL-WORLD NEED

Proper compaction of roadway base and subbase is vital to ensuring good performance of a pavement throughout its life span. While density measurement has traditionally been used to indicate geomaterial compaction, this practice has limitations. Modulus, a measure of stiffness, is a better predictor of performance and provides inputs necessary for mechanistic-empirical design. Measuring modulus is particularly important for predicting the performance of recycled materials since there is little data relating the density of these materials to their strength.

NEXT STEPS
Put It into Practice

DEMONSTRATE
Introduce the new specification gradually in pilot projects with your staff and contractors who are open to the new approach.

COLLABORATE
Work closely with your staff and contractors to ease the culture shock that may result from the new approach.

EVALUATE
As projects are built using the new specification, collect feedback and adjust protocols as needed.

ADAPT
Take advantage of the

WHAT WE LEARNED

The proposed Standard Specification for Modulus-Based Quality Management of Earthwork and Unbound Aggregates provides a flexible method for measuring the modulus of compacted geomaterials that can be adapted to local requirements and materials. The proposed specification also includes a process for selecting a target modulus for specific compacted geomaterials. Several devices successfully measured modulus, although lightweight deflectometers are recommended due to their ease of use and widespread availability. Different kinds of deflectometers provided different measurements, however, so construction specifications should specify which model of deflectometer should be used.

WHY IT MATTERS

Several technologies for measuring the modulus of compacted geomaterials performed reasonably well, but lightweight deflectometers are recommended due to their ease of use and widespread availability.

Modulus is one material property that directly relates to the long-term performance of pavement. As a result, it can be used in mechanistic-empirical design, which can help agencies maximize the value they get from their construction investments by designing roads to meet performance needs without using more construction materials than necessary. A specification for measuring modulus will also be valuable as agencies use more recycled geomaterials in construction.

NCHRP PROJECT 10-84

FINAL PRODUCTS
NCHRP Research Results Digest 391: Modulus-Based Construction Specification for Compaction of Earthwork and Unbound Aggregate
trb.org/Main/Blurbs/172045.aspx

Contractor's report and appendices
apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2908

NCHRP SENIOR PROGRAM OFFICER
Edward Harrigan | eharrigan@nas.edu

PRINCIPAL INVESTIGATOR
Soheil Nazarian | nazarian@utep.edu

ADDITIONAL RESOURCES
Modulus-Based Construction webinar
trb.org/ElectronicSessions/Blurbs/173279.aspx

MnPAVE pavement design tool
mndot.gov/app/mnpave/index.html

Pooled Fund Study TPF-5(285)
pooledfund.org/Details/Study/527

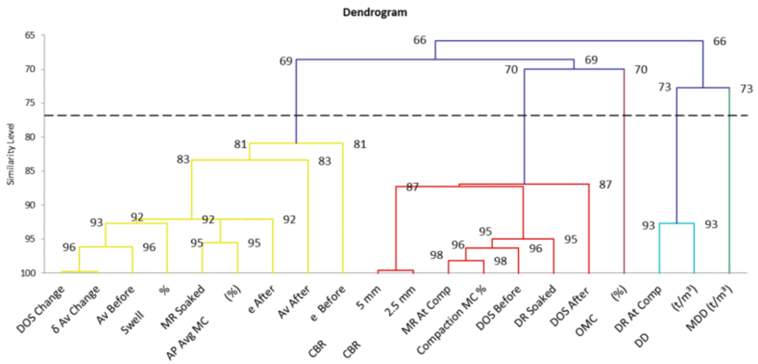
The National Academies of SCIENCES · ENGINEERING · MEDICINE
TRB TRANSPORTATION RESEARCH BOARD

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS + FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Dendrogram Clusters (20 variables)



3rd Order Clustering
- OMC
- MDD

2nd order Clustering
- e before
- Air voids after
- DOS after

Density Cluster
- DR at compaction
- Dry Density

Swell Cluster
- Swell
- [DOS Change / Air Voids Change] / Air Voids before
- MR soaked / AP Avg MC / e after

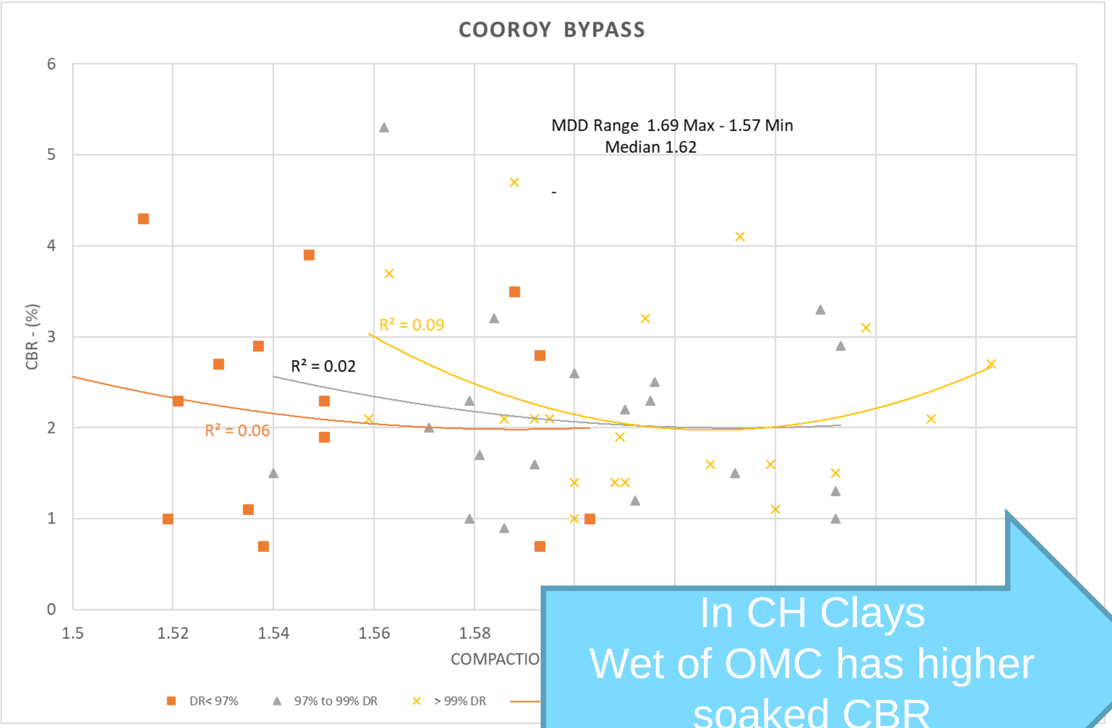
CBR Cluster
- 2.5 / 5.0mm
- MR at compaction / Compaction MC
  - DOS Before
  - DR Soaked

Measuring Density may not be indicative of strength / modulus

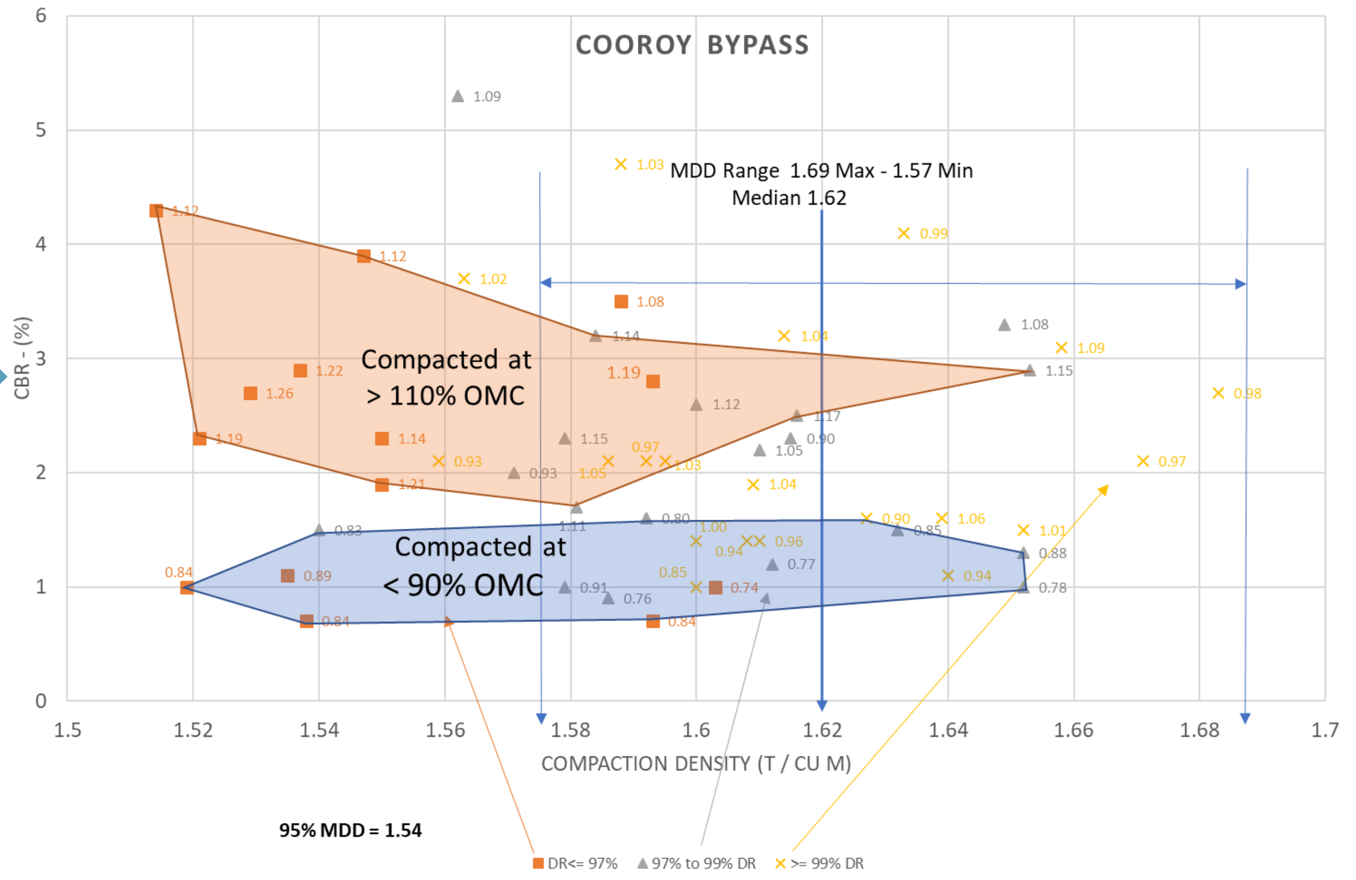
Not clustered

CBR related mainly to MC and MR at compaction

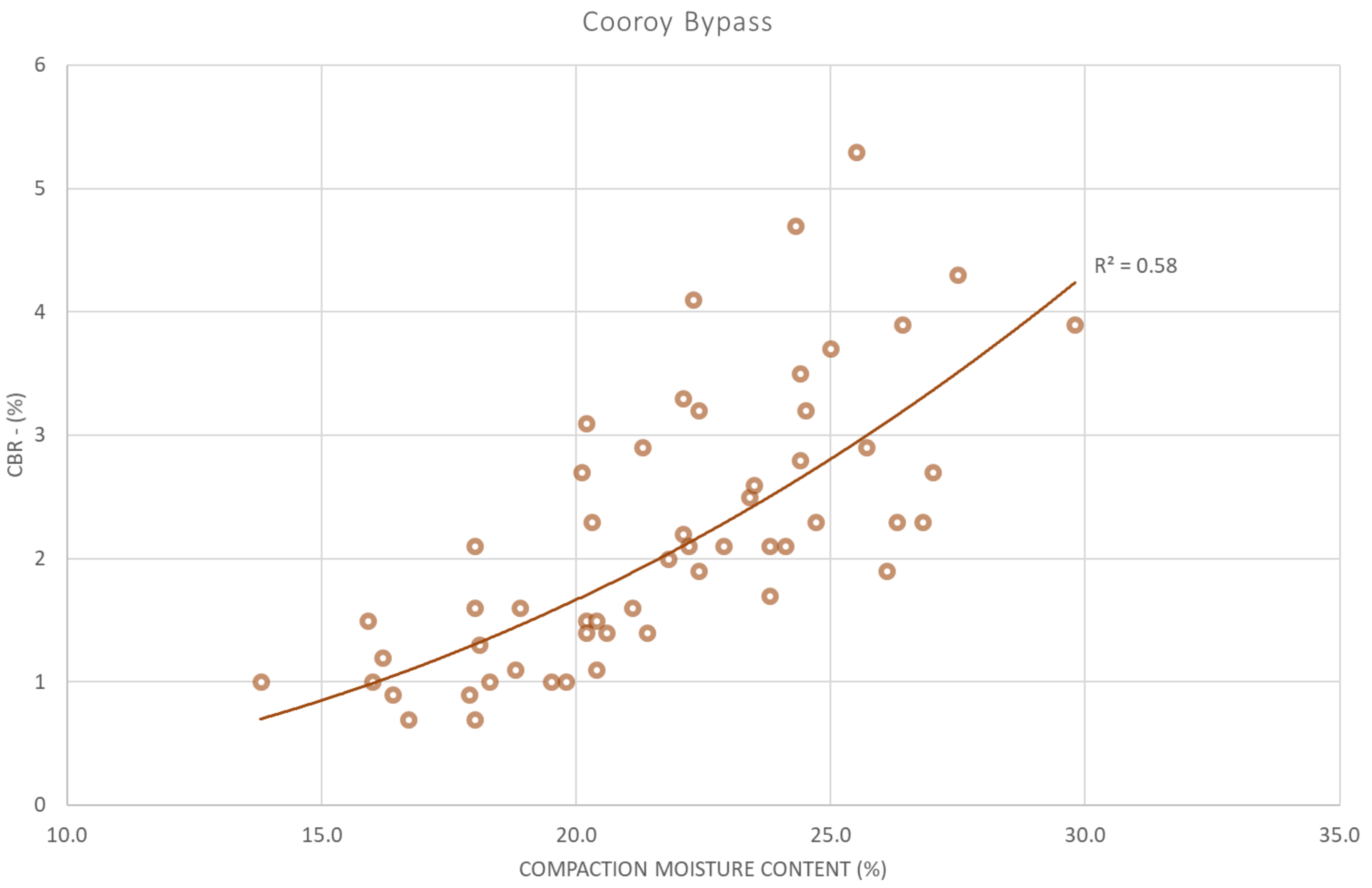
CBR (~Modulus) is less related to compaction density



In CH Clays
Wet of OMC has higher
soaked CBR



CBR (Modulus) is related to compaction MC



Unsaturated soil models based on VMC

Note Dry Density is only a minor part of these strength models

Fredlund DG, Xing A, Fredlund MD, Barbour SL. The relationship of the unsaturated soil shear to the soil-water characteristic curve. Can Geotech J 1996;33(3):440–8.

$$\tau = c' + (\sigma - u_w)\tan\emptyset' + (u_a - u_w)\,[\,\vartheta^{\kappa}\ \tan\emptyset'\,]$$

$\tau = unstaurated\ sher\ strength$

$c' = effective\ cohesion$

$\begin{pmatrix}\sigma = total\ confining\ stress \\ u_w = pore\ water\ pressure\end{pmatrix}$

$\emptyset' =$ effective friction angle

ϑ = normalized volumetric moisture content

= θ/θ_s where θ = volumetric moisture content

and θ_s = volumetric water content at saturation

Volumetric Moisture Content (θ)

= Volume of water / Total Volume

$\theta = w\,\gamma_d / \gamma_w$

γ_w = unit weight of water

γ_d = dry unit weight of soil

κ = fitting parameter dependent on the Plasticity Index

$\kappa = -0.0016\, I_p^2 + 0.0975\, I_p + 1$

Other relationships for κ (eg Tang et al. (2019), "Model Applicability for prediction of residual soil apparent cohesion)

$$\tau = c' + (\sigma - u_w)\tan\emptyset' + (u_a - u_w)\,[\,\tan\emptyset'\ \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)]$$

Vanapalli SK, Fredlund DG, Pufahl DE, Clifton AW. Model for the prediction of shear strength with respect to soil suction. Can Geotech J 1996;33(3):379–92.

where θ = volumetric moisture content

and θ_s = volumetric water content at saturation

θ_r = residual volumetric water content

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS +FOUNDATIONS

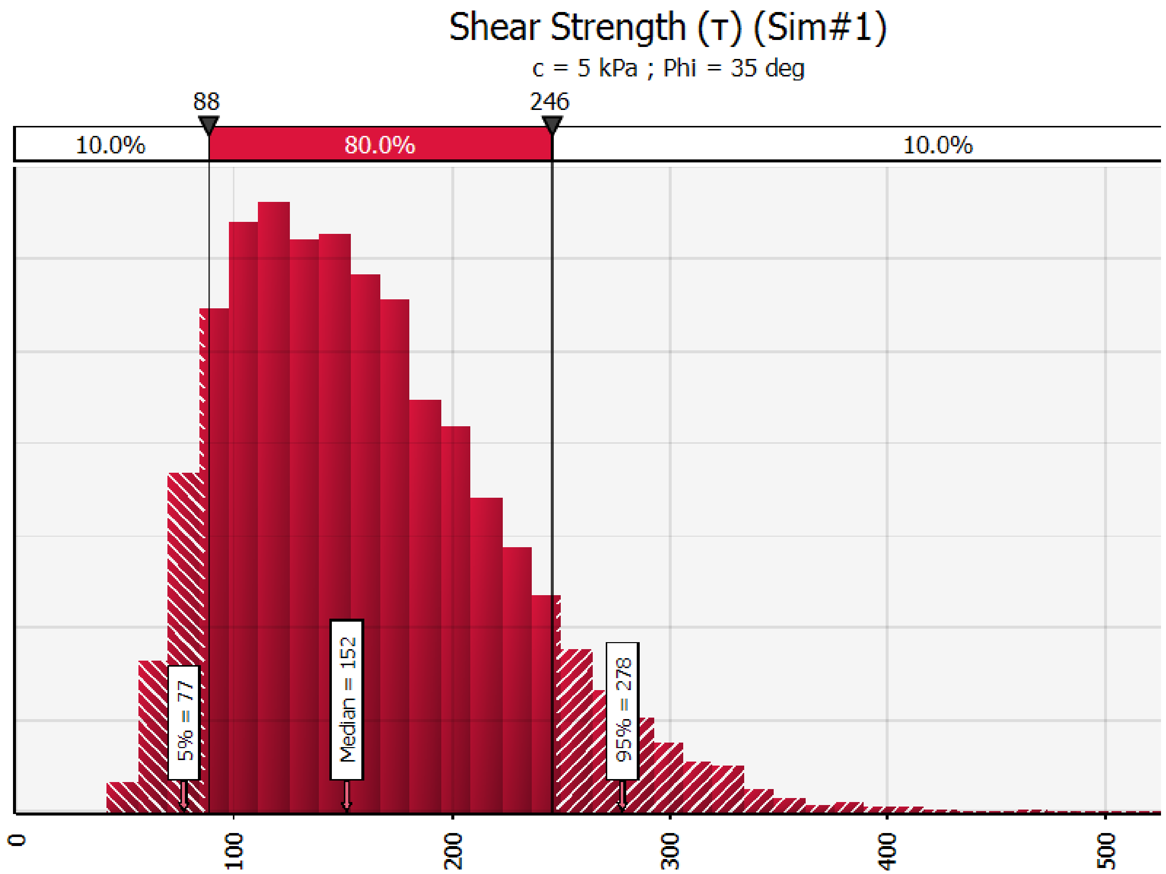
arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

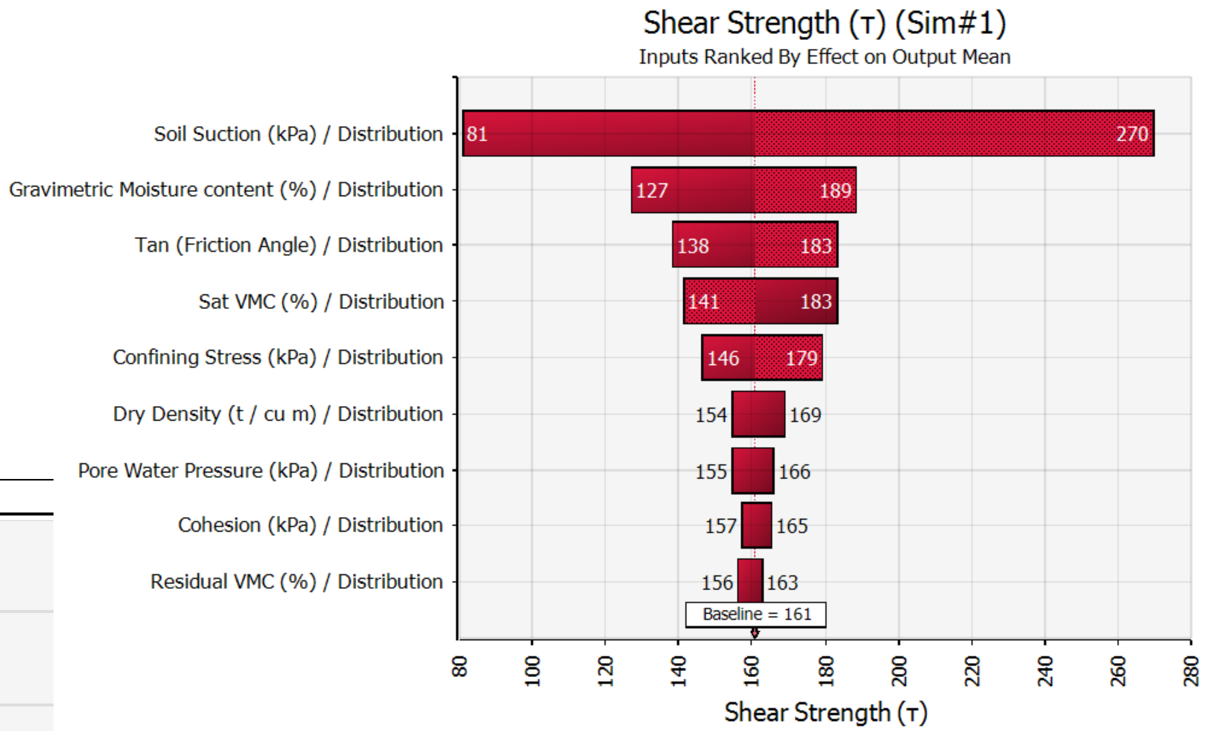
Monte Carlo Simulation of all variables

$$\tau = c' + (\sigma - u_w)\tan\emptyset' + (u_a - u_w)\,[\tan\emptyset' \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)]$$

Not practical to measure these parameters

$c' = 5\ kPa$
$\emptyset' = 35\,°$





NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

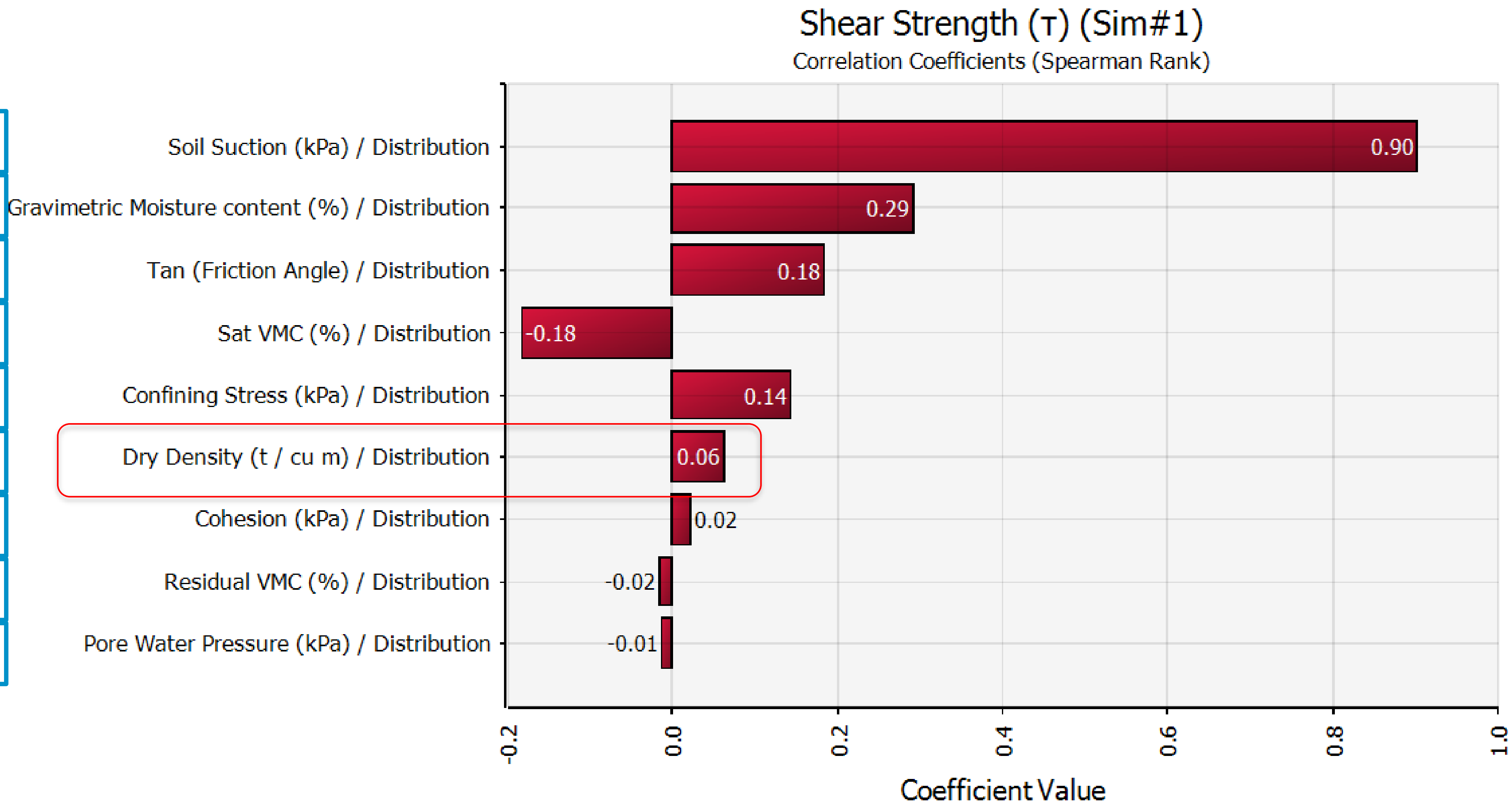
FSG GEOTECHNICS +FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Spearman Rank of all variables

$$\tau = c' + (\sigma - u_w) \tan \emptyset' + (u_a - u_w)\left[\tan \emptyset' \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)\right]$$

1
2
3
4
5
6
7
8
9



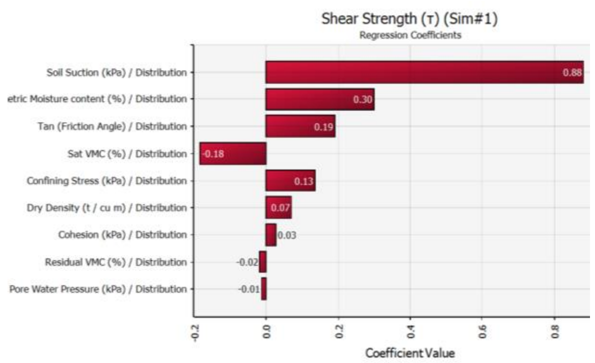
NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

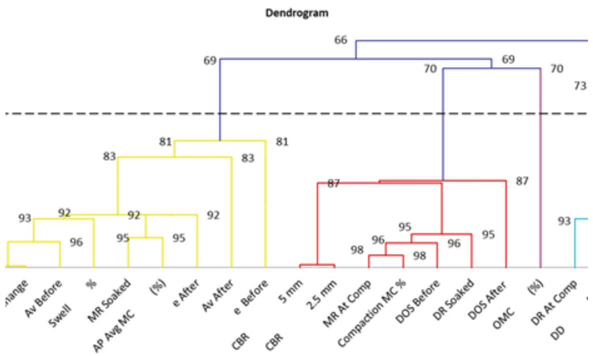
FSG GEOTECHNICS + FOUNDATIONS

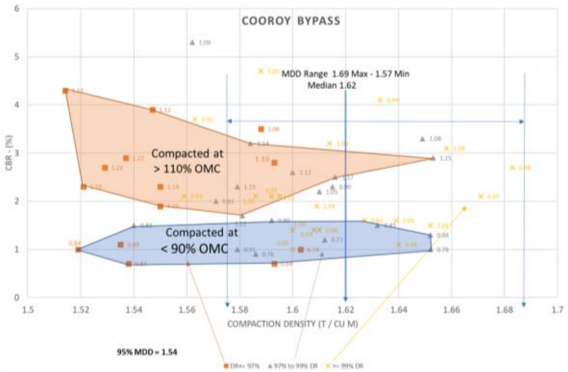
arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

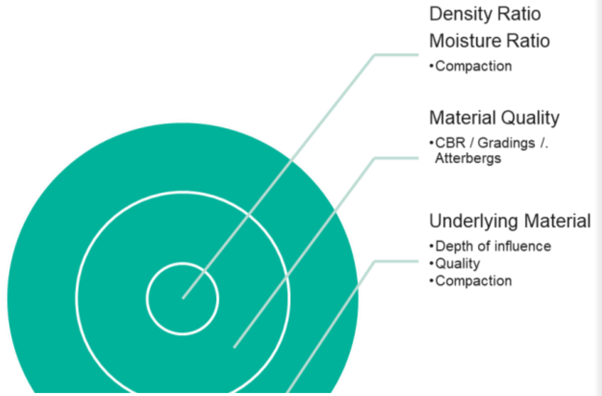
Summary

We emphasise density in QC but it is not the primary parameter









- **Unsaturated soil models**
- 9 Variables
- MC effect is No. 3
- DD effect is No. 6

- **Dendrogram Clustering analysis**
- 20 Test variables
- CBR affected by MC more than DR

- **Lab Correlations**
- CBR affected by MC more than DR

- **Field Testing**
- Modulus has low correlation with DR
- Instruments well correlated to each other

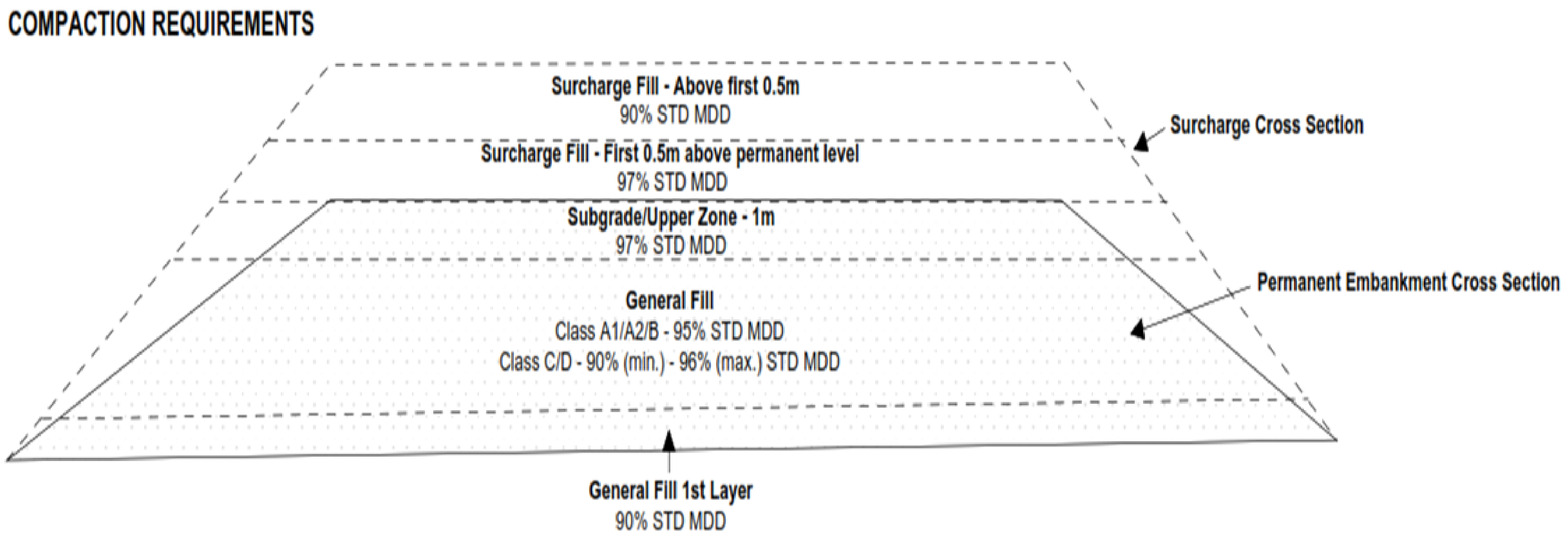
Total unit weight = Total density (ρ_b) = W / V

Dry unit weight = Dry density = W_s / V = ρ_b / (1 + w)

2019 Test site Lessons Learnt

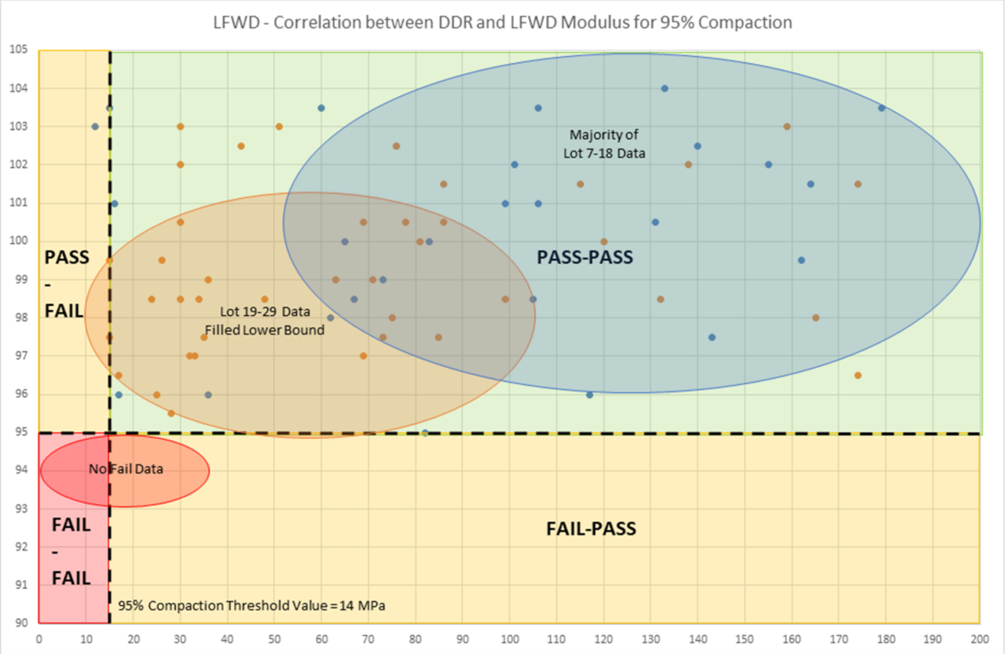
Compaction Levels

Med
Very Dense
Dense
Med Dense



Test QA – Thresholds Related to RDD

Available data used to develop correlations during ‘Live’ Construction Project



Based on 72 Tests using Prima 100 LWD

Threshold		Fail / Fail	Pass / Pass	Density = Fail LFWD = Pass	Density = Pass LFWD = Fail
RDD	LFWD				
96%	15 MPa	0	69	2	1
98%	30 MPa	5	50	11	6
100%	60 MPa	16	30	18	8
103%	160 MPa	54	1	9	8

Correct Assessment (RDD + LFWD Agree)	RDD + LFWD Disagree (1 Test Passes / 1 Test Fails)
96%	4%
77%	22%
64%	36%
76%	24%

A density pass → but fail LFWD → disagreement

Variation in Material Moisture content

Spot check with NDG testing may not be able to effectively identify the “soft” spots such as wet zones

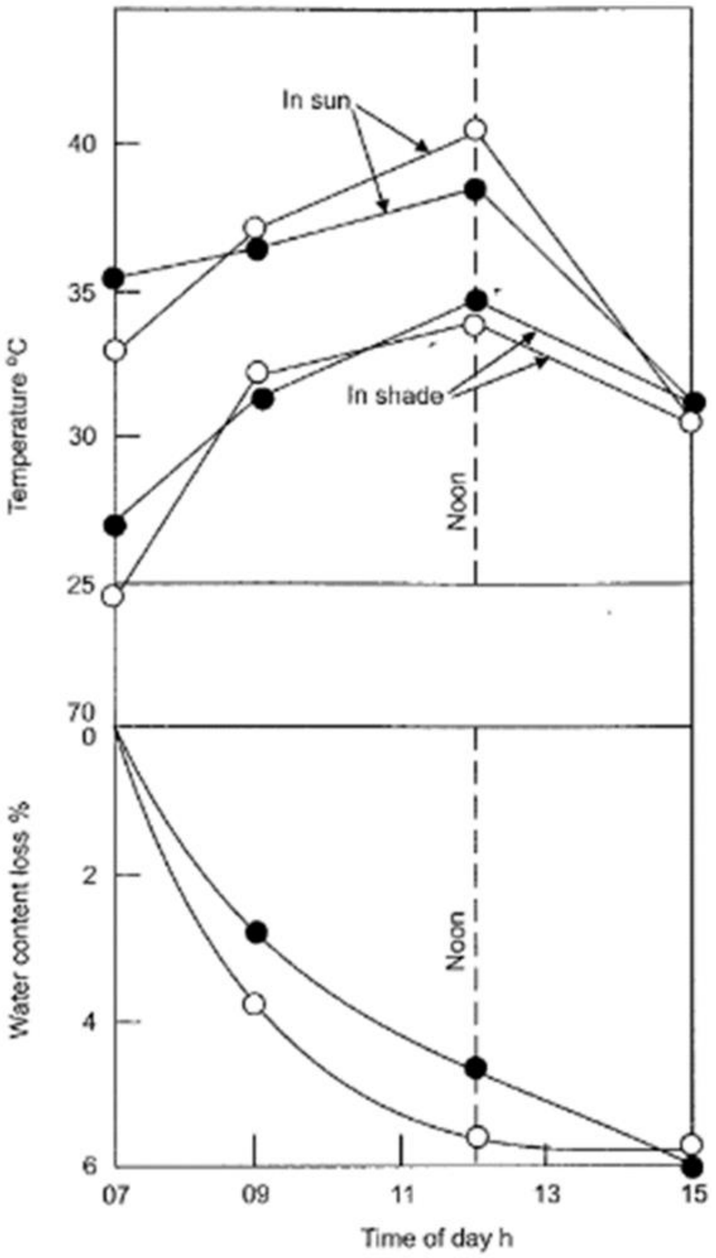
Test area selected for NDG testing surrounded by relatively higher moisture content

Lot 24 - LFWD Tests

- Lot 24 LFWD "failing" ≠ assumed density "passing" results
- Recheck of values: allow to dry back → increase of modulus values. Is this allowed? Density had already passed
- < 12 hr dry back : Median 125% of Dry Value: 163% of quartile
- 24 hr dry back : 3.5 – 5.1 increase in modulus

Testing Period	No. of Tests	LFWD Modulus (MPa) @					
		50kPa	100kPa	50kPa	100kPa	50kPa	100kPa
		Median		Quartile		Ratio Change Median / Quartile	
Shortly after fill compaction	4	46.5	23.0	28.4	15.6	Reference Value	
Next Day – Dry backed	4	58.0	37.4	18.2	16.3	1.25 / 0.6	1.6 / 1.0
Further Dry Back	10	167.0	116.5	99.4	70.2	3.6 / 3.5	5.1 / 4.5

Water content evaporation loss



Blight and Leong, 2012

Water content losses through the entire thickness from
- 2 X 200mm thick, loose,
- Uncompacted soil layers
- Arid conditions

5% loss in 5 hrs whether in shade or sun
Varies on wind and ambient temperature

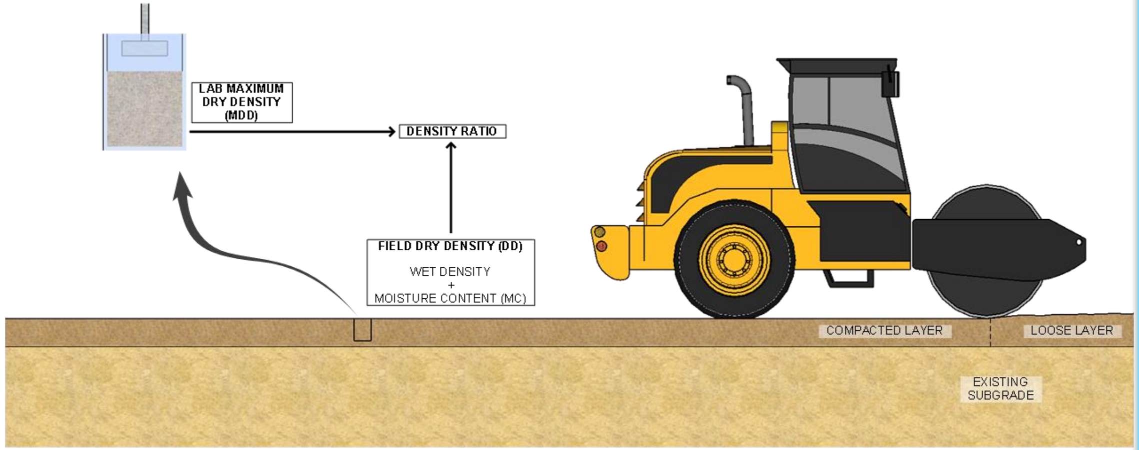
Water content is not a constant

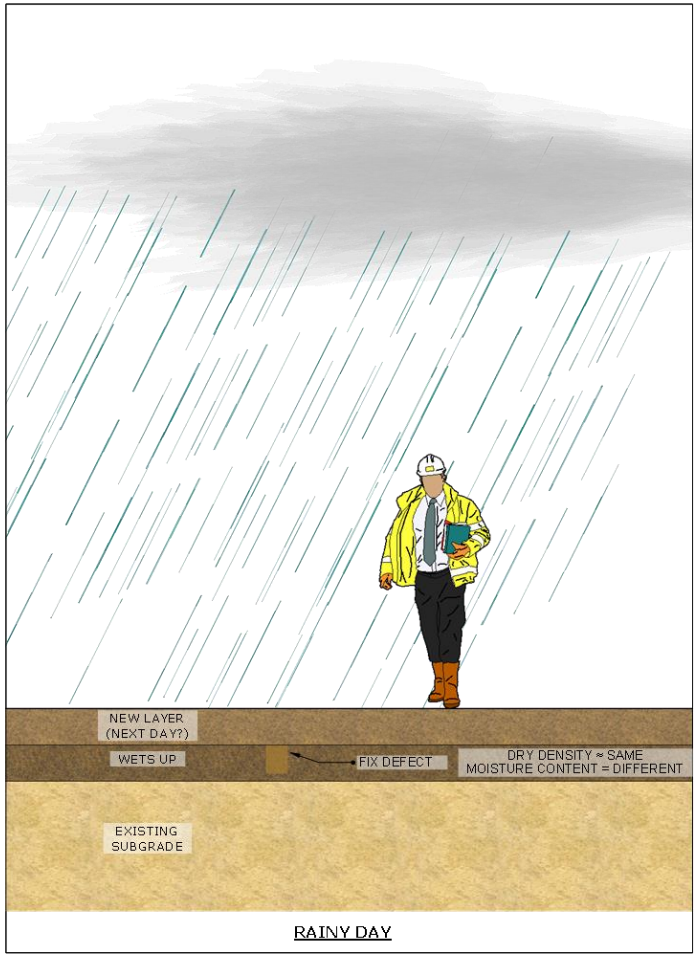
NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS +FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Sun, wind or rain after density test





NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS +FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Lot 21 - LFWD Tests

- Density testing was carried out shortly after final layer compaction occurred.
- A period of rain then occurred shortly after testing
- Tests 2 days after compaction shows significant changes due to rainfall wetness
- Density testing was business as usual i.e. proceeding without explicitly acknowledging or taking action for changing conditions

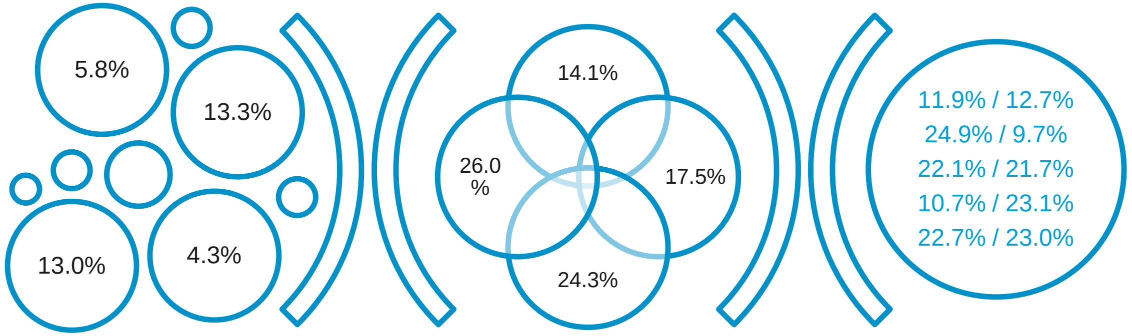
Testing Period	No. of Tests	LFWD Modulus (MPa) @					
		50kPa	100kPa	50kPa	100kPa	50kPa	100kPa
		Median		Quartile		Ratio Change Median / Quartile	
Dry – shortly after fill compaction	4	116.9	113.0	64.1	72.8	Reference Value	
Rain fell – adjacent to previous tests	4	91.1	98.3	59.6	67.4	0.78 / 0.93	0.87 / 0.93

- 13% Compacted LFWD value

Lot 21 – Field Volumetric Moisture Content

ProCheck TEROS-12

- A passing density should not mean that subsequent layers can be placed, especially following rainfall.
- VMC X 2 following rainfall
- 88% X Initial Modulus values
- PANDA – little change - deepens by 0.03m



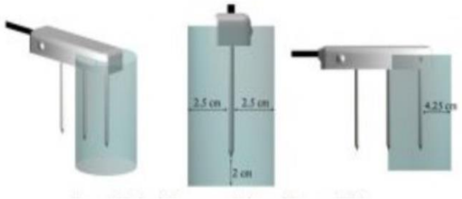
27 Feb 19 | 1 Mar 19 24 hr later | 1 Mar 19 Additional tests

Median = 9.9% → 20.9% / 21.9%

FSG GEOTECHNICS +FOUNDATIONS

Field Moisture Content Report

Client:
Project:
Project N
Location:
Test Meth



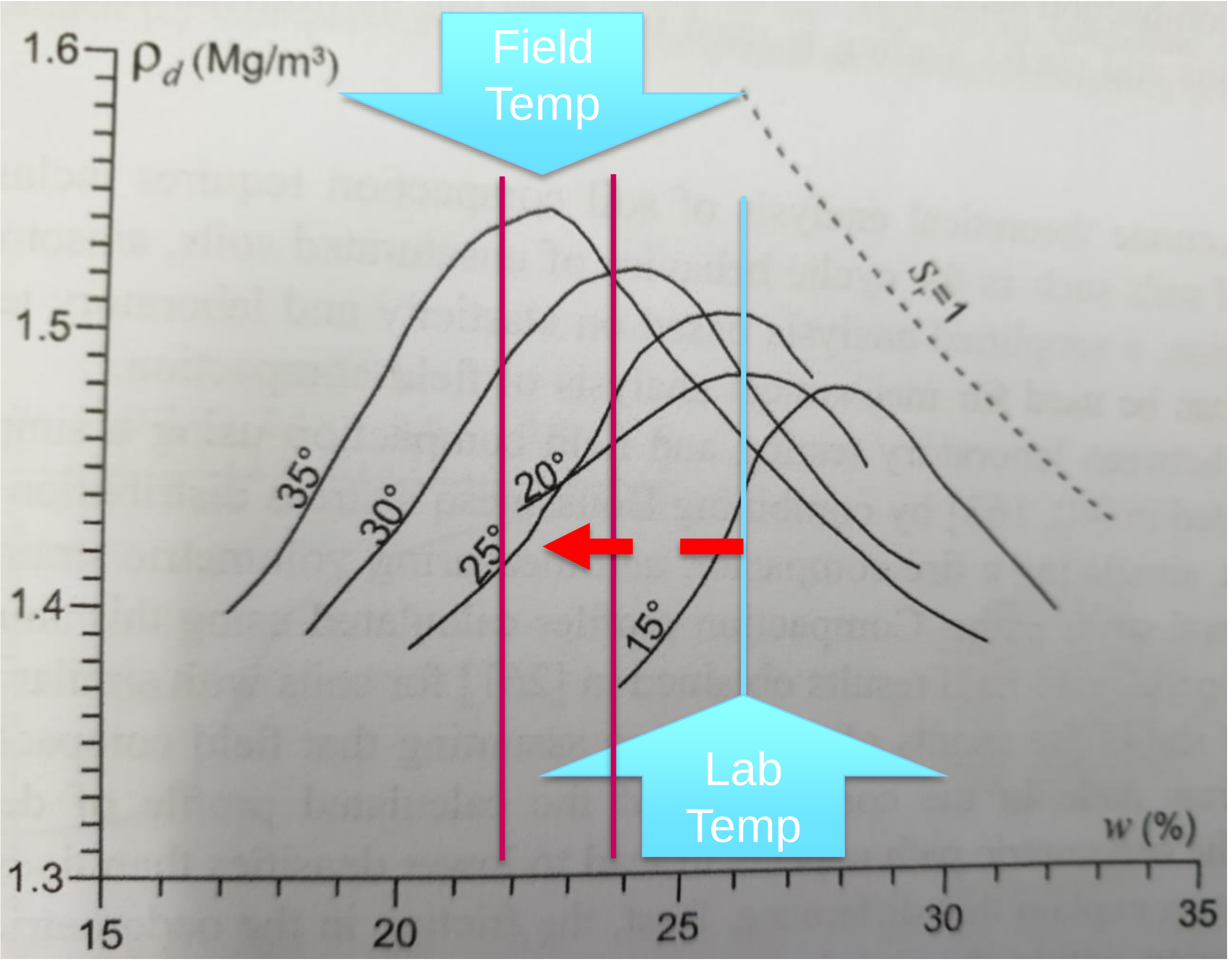
Sheet: 2 / 4
Test Date: Various
Tested By: RM
Checked By: DWL
er Content (VWC), Temperature and
ıalyser (for data collection)

Test Details			*Insitu* Testing of Soil Condition (at time of test)		
Site	Date of Test	Sub-site ID (Test Location)	Field Volumetric Water Content (m^3/m^3, %)	Soil Temperature (^oC)	Bulk Electrical Conductivity (EC, dS/m)
Site 21 *(Continued)*	27/02/2019	21-2	13.27%	33.4	0.015
	1/03/2019	21-2 (+24hrs)	17.50%	30.5	0.035
	27/02/2019	21-3	13.01%	35.3	0.023
	1/03/2019	21-3 (+24hrs)	24.26%	30.6	0.081
	27/02/2019	21-4	4.25%	36.7	0.010
	1/03/2019	21-4 (+24hrs)	25.95%	31.5	0.037
	1/03/2019	21-5	11.94%	33.1	0.019
		21-6	12.71%	32.6	0.026
		21-7	24.87%	32.4	0.039
		21-8	9.70%	32.2	0.018
		21-9	22.08%	32.0	0.046
		21-10	21.68%	31.9	0.040
		21-11	10.66%	31.6	0.012
		21-12	23.12%	31.7	0.038
		21-13	22.69%	31.6	0.038
		21-14	23.01%	30.3	0.063

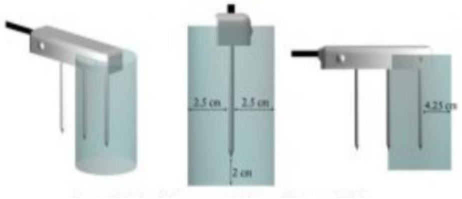
Site 21	27/02/2019	21-1	5.82%	33.5	0.007
	1/03/2019	21-1 (+24hrs)	14.12%	30.5	0.030

Effect of Temperature on Proctor compaction curves

Soil Temperature varied by up to 6.2 °C - ambient would be more ~ 10 °C warmer than lab. → Not usually considered



Fry (1977) - Figure is here from Caicedo (2019), "Geotechnics of Roads: Fundamentals



Test Details			*Insitu* Testing of Soil Condition (at time of test)		
Site	Date of Test	Sub-site ID (Test Location)	Field Volumetric Water Content (m^3/m^3, %)	Soil Temperature (°C)	Bulk Electrical Conductivity (EC, dS/m)
Site 21 *(Continued)*	27/02/2019	21-2	13.27%	33.4	0.015
	1/03/2019	21-2 (+24hrs)	17.50%	30.5	0.035
	27/02/2019	21-3	13.01%	35.3	0.023
	1/03/2019	21-3 (+24hrs)	24.26%	30.6	0.081
	27/02/2019	21-4	4.25%	36.7	0.010
	1/03/2019	21-4 (+24hrs)	25.95%	31.5	0.037
	1/03/2019	21-5	11.94%	33.1	0.019
		21-6	12.71%	32.6	0.026
		21-7	24.87%	32.4	0.039
		21-8	9.70%	32.2	0.018
		21-9	22.08%	32.0	0.046
		21-10	21.68%	31.9	0.040
		21-11	10.66%	31.6	0.012
		21-12	23.12%	31.7	0.038
		21-13	22.69%	31.6	0.038
		21-14	23.01%	30.3	0.063
Site 21	27/02/2019	21-1	5.82%	33.5	0.007
	1/03/2019	21-1 (+24hrs)	14.12%	30.5	0.030

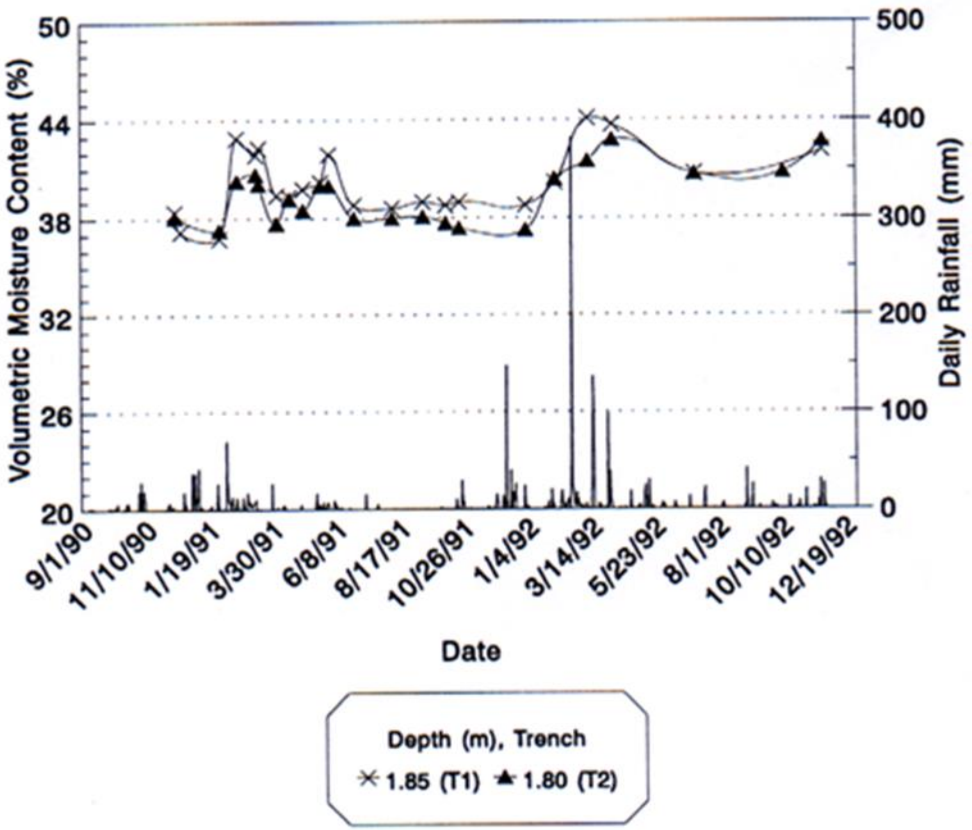
NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

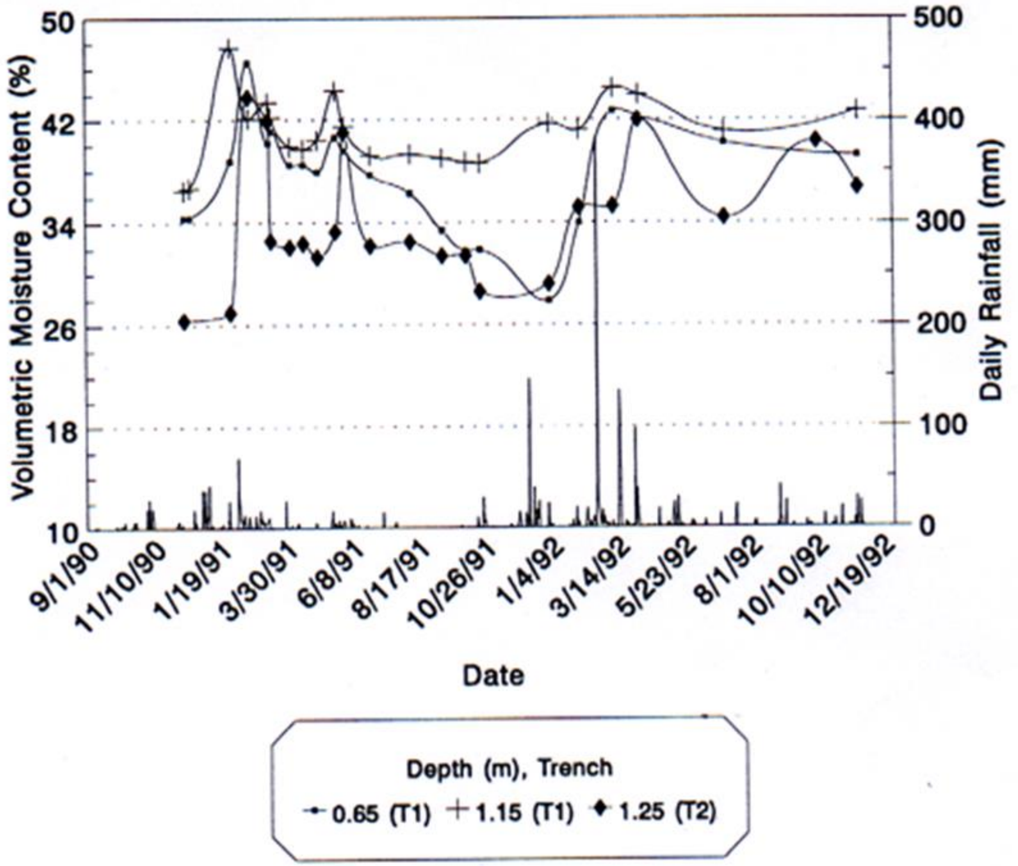
FSG GEOTECHNICS + FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Moisture measurements in active + (assumed) stable zone

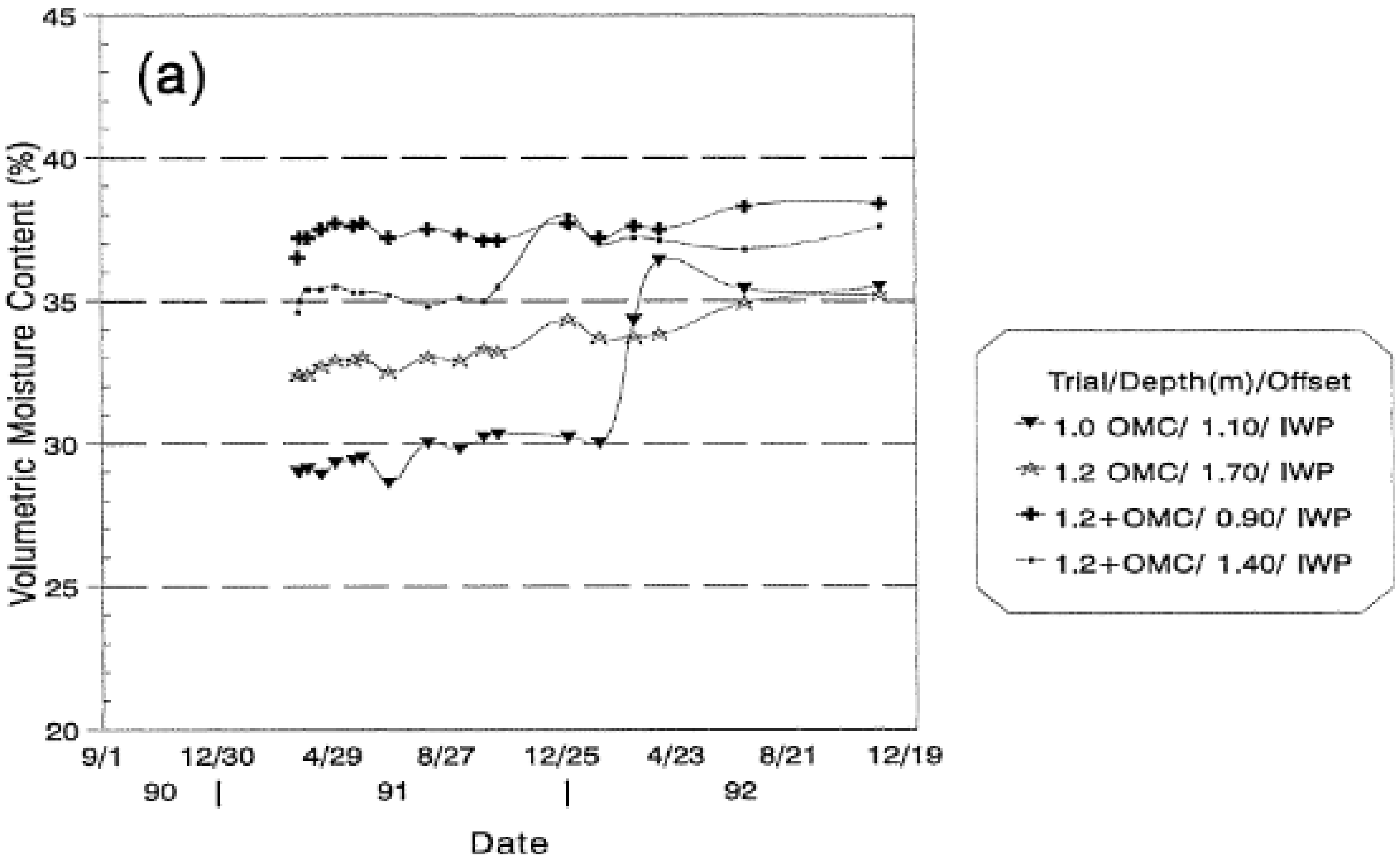
Below existing (30yr) road at Cooroy (1700mm annual rainfall)





Monitoring of trial embankments

Constructed at various moisture contents (Cooroy – CH clays)



Moisture Content at construction is not the long term moisture content

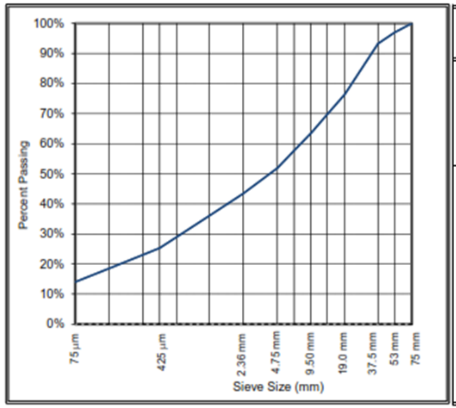
Equilibrium Moisture Content (EMC) determines long term strength NOT the OMC at construction which is the short term construction condition

Test site with 100% passing 75mm

Mainly 100% Passing 75mm

For Use As:	Embankment	Lot Number:	SBP-EF-6
Remarks:	-	Spec Number:	-

Page 1 of 1

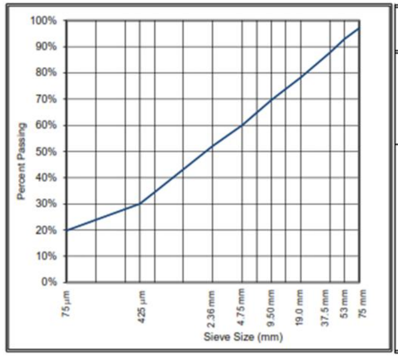


Particle Size Distribution

Test Method AS1289.3.6.1

A.S. Sieve Size	Specification Minimum	Result % Passing	Specification Maximum
75mm		100	
53mm		97	
37.5mm		93	
19.0mm		76	
9.5mm		64	
4.75mm		52	
2.36mm		43	
0.425mm		25	
0.075mm		14	

Page 1 of 1

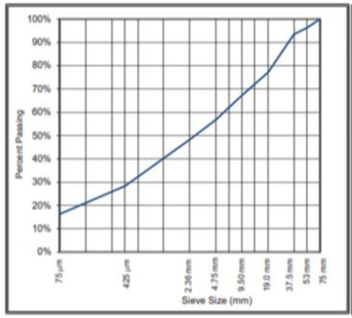


Particle Size Distribution

Test Method AS1289.3.6.1

A.S. Sieve Size	Specification Minimum	Result % Passing	Specification Maximum
75mm		97	
53mm		93	
37.5mm		88	
19.0mm		78	
9.5mm		70	
4.75mm		60	
2.36mm		52	
0.425mm		30	
0.075mm		20	

Page 1 of 1

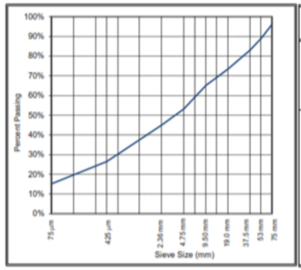


Particle Size Distribution

Test Method AS1289.3.6.1

A.S. Sieve Size	Specification Minimum	Result % Passing	Specification Maximum
75mm		100	
53mm		96	
37.5mm		94	
19.0mm		77	
9.5mm		67	
4.75mm		57	
2.36mm		48	
0.425mm		28	
0.075mm		16	

Page 1 of 1



Particle Size Distribution

Test Method AS1289.3.6.1

A.S. Sieve Size	Specification Minimum	Result % Passing	Specification Maximum
75mm		96	
53mm		89	
37.5mm		83	
19.0mm		73	
9.5mm		65	
4.75mm		53	
2.36mm		45	
0.425mm		26	
0.075mm		15	

Sampling – Test site in practice

Excavations not vertically sided

Shallow excavation samples crushed material at top

Discarding boulders (> 200mm) from samples

225mm

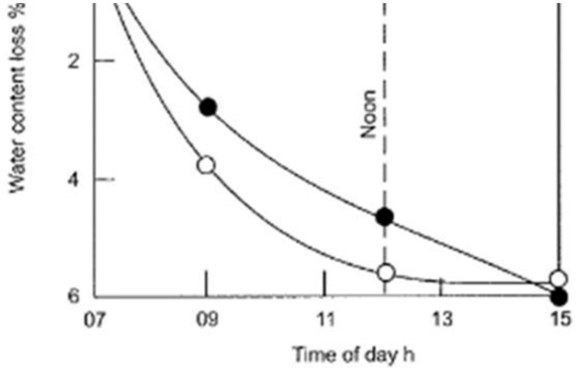
Sampling – Ideal hole

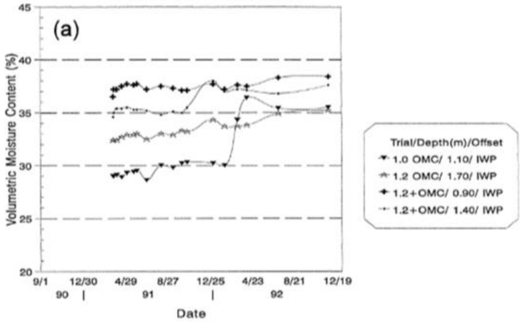
- ✓ Sampling requires that all material from a vertical-sided hole (excavated to the depth that the NDG source rod was placed) must be recovered for laboratory testing.
- ✓ The hole permitted to be enlarged in plan, but no deeper than the depth of test, to obtain sufficient material for moisture content and laboratory compaction testing.
- ✓ It is extremely important to take the sample from the full depth of the test, this captures any moisture gradient in the layer being tested. Failure to take the sample properly can lead to very erroneous results.

RMS: Technical Guide | L-G-002 | February 2015
Field density testing by using a nuclear density gauge

Summary

Moisture Content + Construction





Assessment (RDD + LFWD Agree)	Disagree (1 Test Passes / 1 Tes Fails)
96%	4%
77%	22%
64%	36%
76%	24%

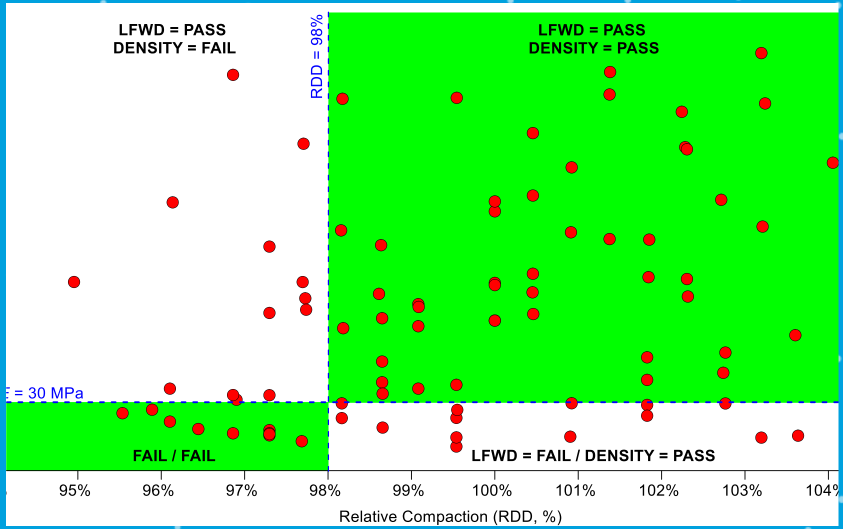
- **Water content loss**
- Varies significantly during placement

- **Equilibrium Moisture Condition**
- EMC – Long term
- OMC – short term

- **Field density Sampling**
- Often non representative
- Gradings + oversize + depth

- **Field Testing**
- 1/3 to ¼ disagreement between high density and modulus controls
- OK at lower density values

Density is not a fundamental indicator of strength or modulus +
Moisture content (a better indicator of modulus) is highly variable and changes

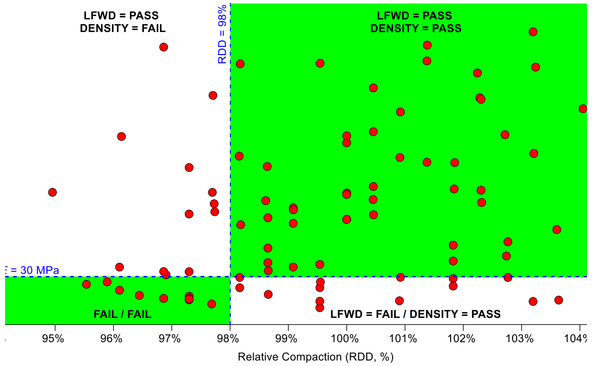


Contractor Risk		Good	Poor
Acceptance Decision	Accept	**Correct**	Type II Error QTMR's Risk Not Rejecting a Lot when it is Not OK
	Reject	Type I Error Contractor's Risk Rejecting a Lot when it is OK	**Correct**

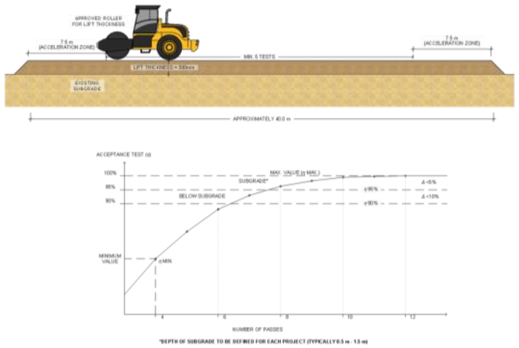
QA OPTIONS

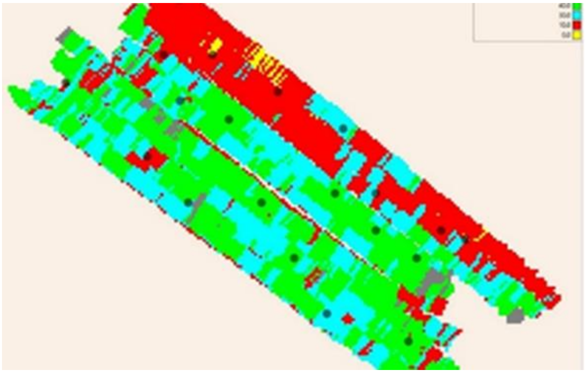
Specifications options

Specify Values?



Contractor Risk		Good	Poor
Acceptance Decision	Accept	**Correct**	Type II Error QTMR's Risk Not Rejecting a Lot when it is Not OK
	Reject	Type I Error Contractor's Risk Rejecting a Lot when it is OK	**Correct**





- Correlation Approach linked to Standard Density approach
- Project and material specific. Parallel Testing
- Likely to be most variable. Many “good” values fail and “bad” values pass
- Skews QA approach

- Method Of matching PDFs linked to Standard Density approach
- Project and material specific. Parallel Testing
- Uses 10% QA – acceptance decision

- Method of change reduction
- Not linked to Standard Density approach
- Parallel testing not mandatory
- Uses QA acceptance decision

- Intelligent Compaction verification
- NCHRP 676 Options
- Various approaches linked with parallel non density testing

Typical Specifications – Values

Issues with correlations to DDR

DDR	$LFWD_{100\ kPa}$	Correct Assessment (RDD + LFWD Agree)	RDD + LFWD Disagree (1 Test Passes / 1 Test Fails)
96%	15 MPa	**96%**	4%
98%	30 MPa	**77%**	22%
100%	60 MPa	**64%**	36%
103%	160 MPa	**76%**	24%

When correlated with DDR

In situ E correlated to 95% Density ratio - Values

Varies with each material

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

Various acceptance LFWD for Base Course materials & Layers

TENTATIVE EQUIVALENCES BETWEEN PERCENT COMPACTION AND COMPOSITE MODULUS AT OPTIMUM WATER CONTENT FOR BASE AND SUBBASE COURSE AGGREGATE

Relative Compaction Based on AASHTO T180 (%)	Equivalent LWD Composite Modulus (MPa) at Optimum Water Content
90	92
95	115
98	130
100	139

Steinart et al. (2005)

FACTOR TO CORRECT COMPOSITE MODULUS MEASURED AT FIELD WATER CONTENT TO EQUIVALENT VALUE AT OPTIMUM WATER CONTENT

Water Content Relative to Optimum		Correction Factor to Be Added to Composite Modulus (MPa) Measured at Field Moisture Content
Dry of OMC	-4%	-31
	-3%	-23
	-2%	-15
	-1%	-8
At OMC		0
Wet of OMC	+1%	8
	+2%	15
	+3%	23
	+4%	31

Laying and compaction specification for road construction in Germany

Soil layers	**Density** (Standard Proctor)	**Bearing capacity** (load bearing test, EV2)	**Eveness** (4 m straight edge)
Subbase	**100 - 103 % ***	**100 - 150 MN/m² ***	**20 mm**
Capping layer	**100 - 103 % ***	**100 - 120 MN/m² ***	**40 mm**
Formation	**97 - 100 % ***	**45 - 80 MN/m² ***	**60 mm**

* **depending on road classification and road design**

From BOMAG

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS +FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

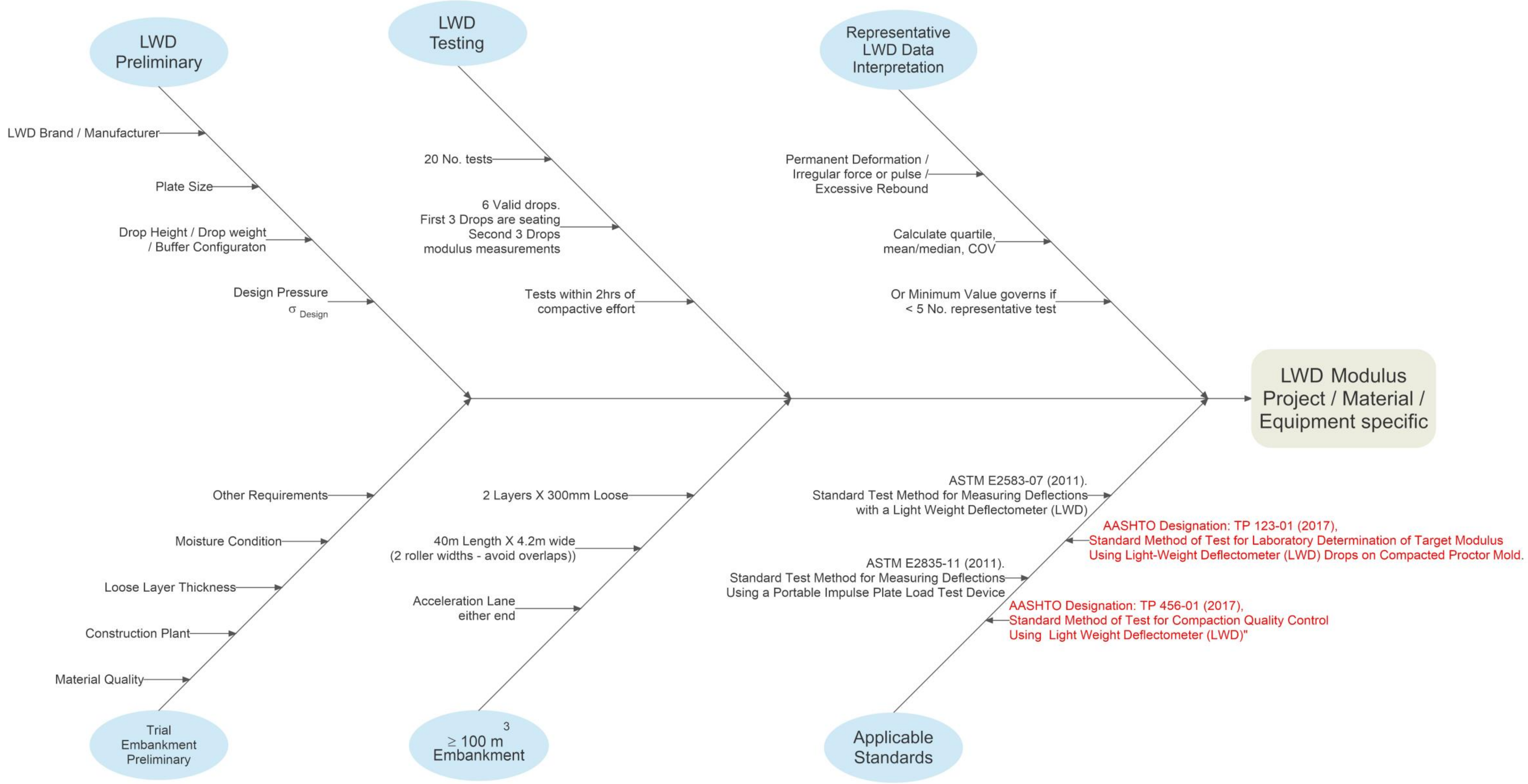
LFWD PROCEDURE QA

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS +FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Key Elements in LWD specification



Proposed LWD Specification

1. Define Initial Inputs – LWD Configuration

What **design pressure** is to be verified by onsite testing? → σ_{Design}

What **LWD Brand** is proposed to be utilised for onsite testing? → **LWD Type**

Is the **LWD Configuration** capable of achieving the σ_{Design} pressure? (and +/- 20% of σ_{Design}) → **Defined LWD Variables** – Plate Diameter, Drop Weight, Buffer Arrangement & Drop Height

What equipment will be utilised to **assess the Insitu Moisture Condition** at time of LWD Testing? → **Defined Insitu Moisture Content Assessment Technique**

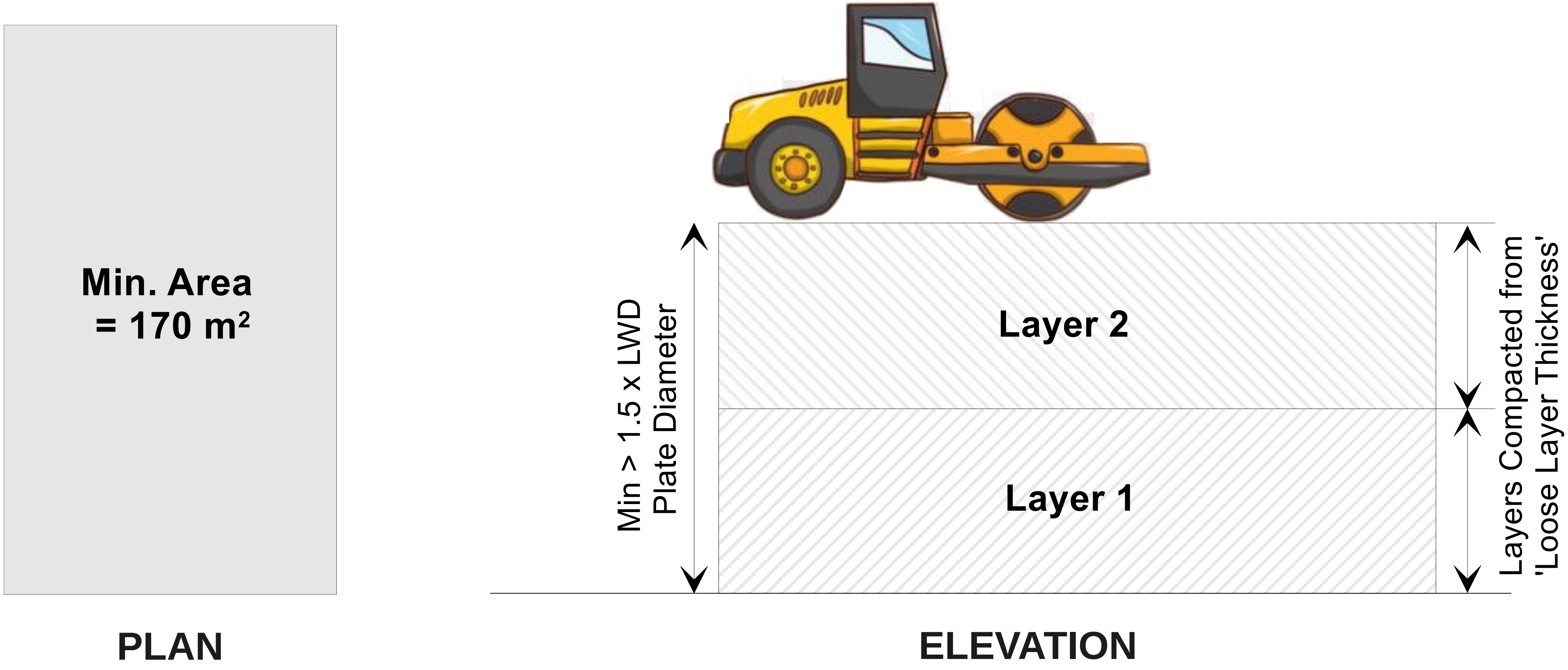
Proposed LWD Specification

2. Define Initial Inputs – Earthworks Variables

What **Material** is to be used as the source for Earthworks?	**Material Type and Quality**
What **Loose Layer Thickness** is to be utilised during Earthworks?	**Lift Thickness**
What **Compaction Equipment & Methodology** is to be utilised to achieve effective compaction	**Compaction Technique – Equipment & Method**
What **Moisture Conditioning** will occur prior / during completion of compaction?	**Insitu Moisture Condition (at time of LWD Testing)**

Proposed LWD Specification

3. Construct Trial Embankment



NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

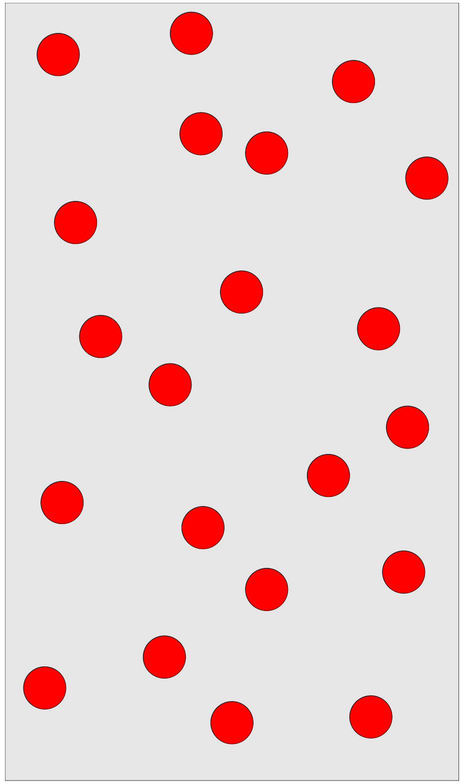
FSG GEOTECHNICS +FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

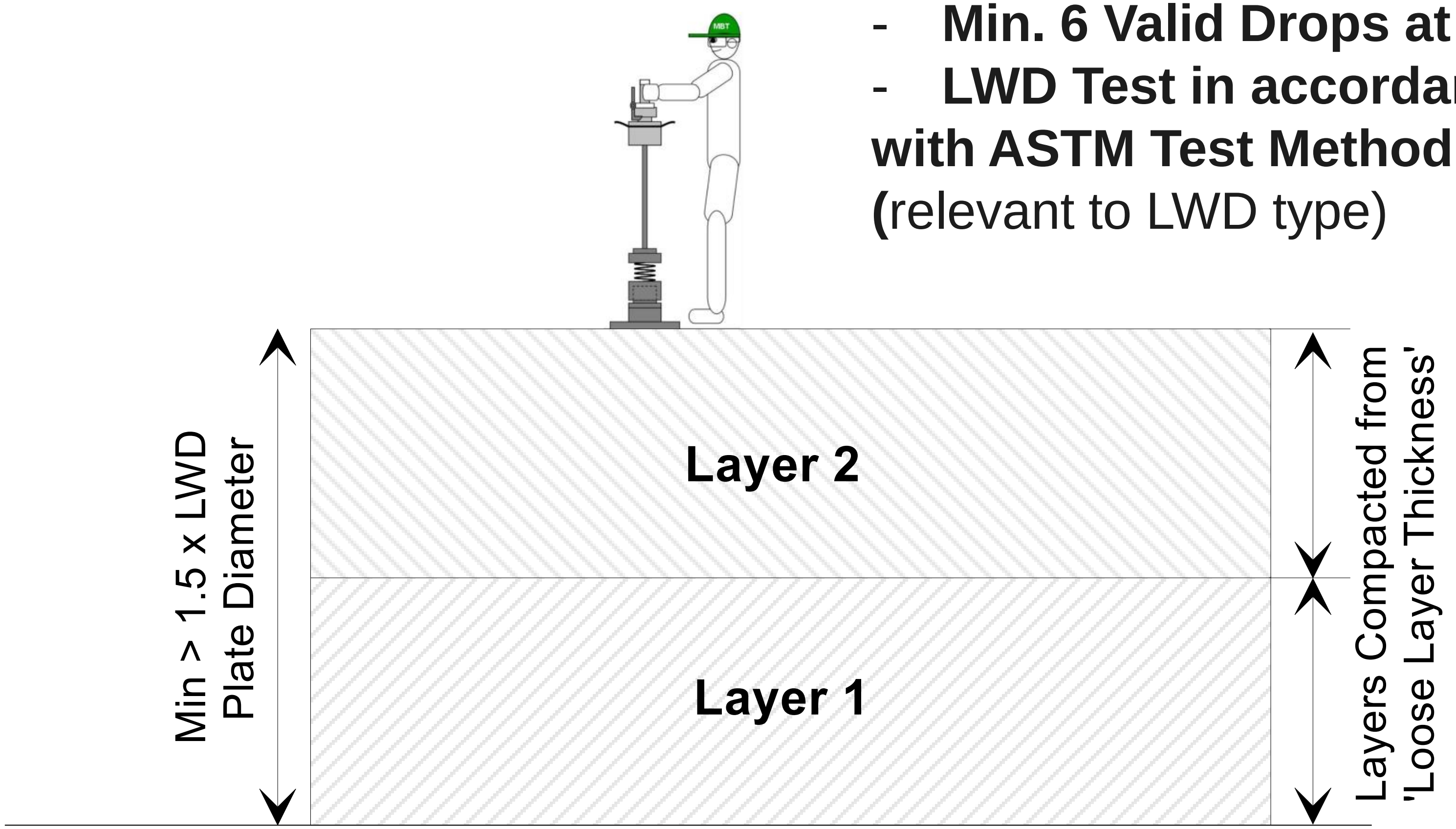
Proposed LWD Specification

4. Test Completed Trial Embankment with LWD

- **20 No. Locations (min.)**
- **Min. 6 Valid Drops at σ_{Design}**
- **LWD Test in accordance with ASTM Test Method (**relevant to LWD type)



PLAN



ELEVATION

Proposed LWD Specification

5. Inspect and Standardize LWD Dataset

- Identify and Remove all **‘Seating’** Test Records
- Identify and Remove any Test Records that demonstrate **irregular load / deformation shape**
- Identify and remove all Test Records that **departed from σ_{Design} pressure**

→ **Valid LWD Test Data**

- Review all Test Records for demonstration of **permanent deformation under σ_{Design} pressure**

→ **REVIEW – Indicative of Bearing Capacity Issue!**

Proposed LWD Specification

6. Assess Insitu Modulus-Moisture Relationship *(if Present)*

Determine **Insitu Modulus (E_{LWD})** parameter for each Test Site

$E_{LWD\text{-}SITE}$

Pair individual $E_{LWD\text{-}SITE}$ with corresponding Insitu Moisture Condition at time of LWD Testing

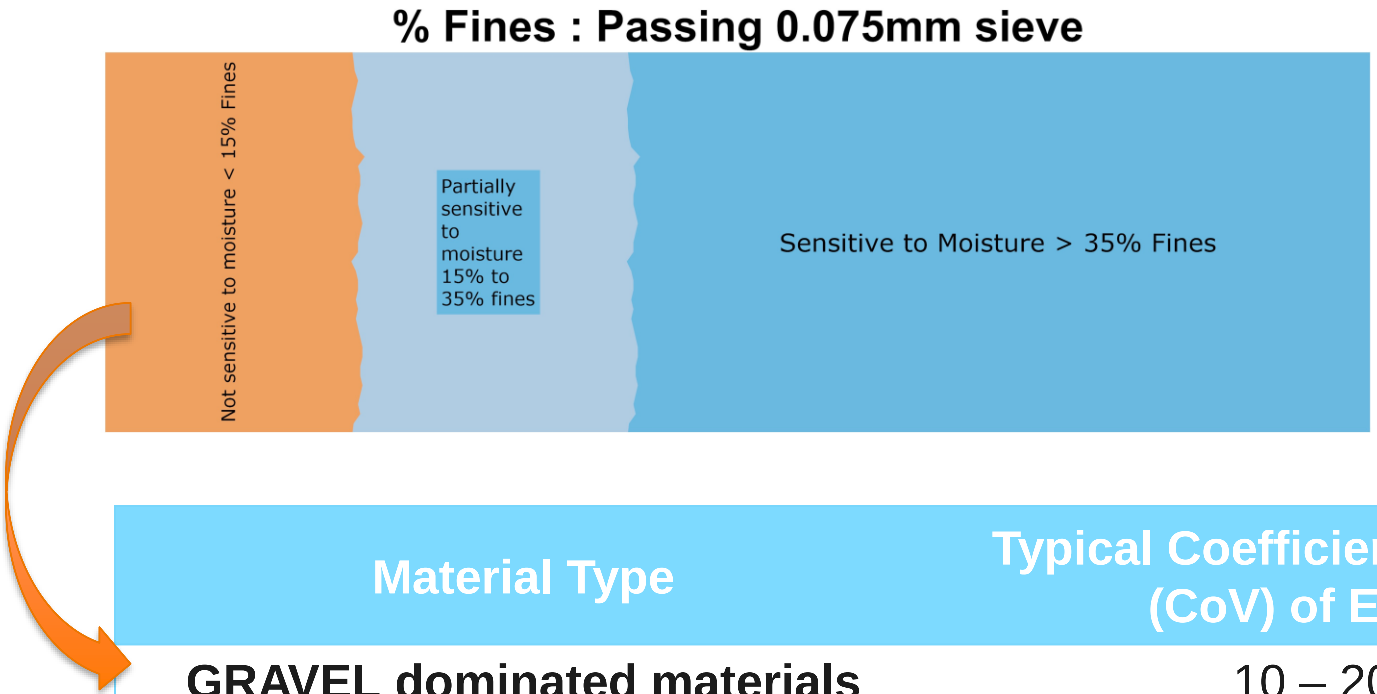
Evaluate paired [$E_{LWD\text{-}SITE}$, Moisture Content] dataset for **presence of modulus-moisture relationship**

E_{LWD} Parameter is **NOT Moisture Dependent**

E_{LWD} Parameter **IS Moisture Dependent**

Define **Function of E_{LWD} – Moisture Condition** Relationship

Moisture dependent



Material Type	Typical Coefficient of Variation (CoV) of $E_{LWD\text{-}SITE}$
GRAVEL dominated materials	10 – 20 %
SAND dominated materials	15 – 35 %
FINES dominated materials	30 – 60 %

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS +FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Proposed LWD Specification

7. Define E_{LWD} Acceptance Thresholds (for Production Earthworks QA Testing)

A. For Materials where E_{LWD} IS NOT Moisture Dependent

Criteria #1 – All E_{LWD} results for a single earthworks Lot must exceed the minimum $E_{LWD\text{-}SITE}$ value
(i.e. Assessment that minimum insitu modulus parameter has been achieved at all locations)

Criteria #2 – Mean E_{LWD} within a single earthworks Lot must exceed 80% of the mean of the $E_{LWD\text{-}SITE}$ dataset
(i.e. Assessment that typical insitu modulus parameter has been achieved across a Lot)

Criteria #3 – Lower Characteristic E_{LWD} within a single earthworks Lot must not fall below the Lower Characteristic of the $E_{LWD\text{-}SITE}$ dataset
(i.e. Assessment that variability of insitu modulus parameter does not exceed expectations)

Proposed LWD Specification

7. Define E_{LWD} Acceptance Thresholds (for Production Earthworks QA Testing)

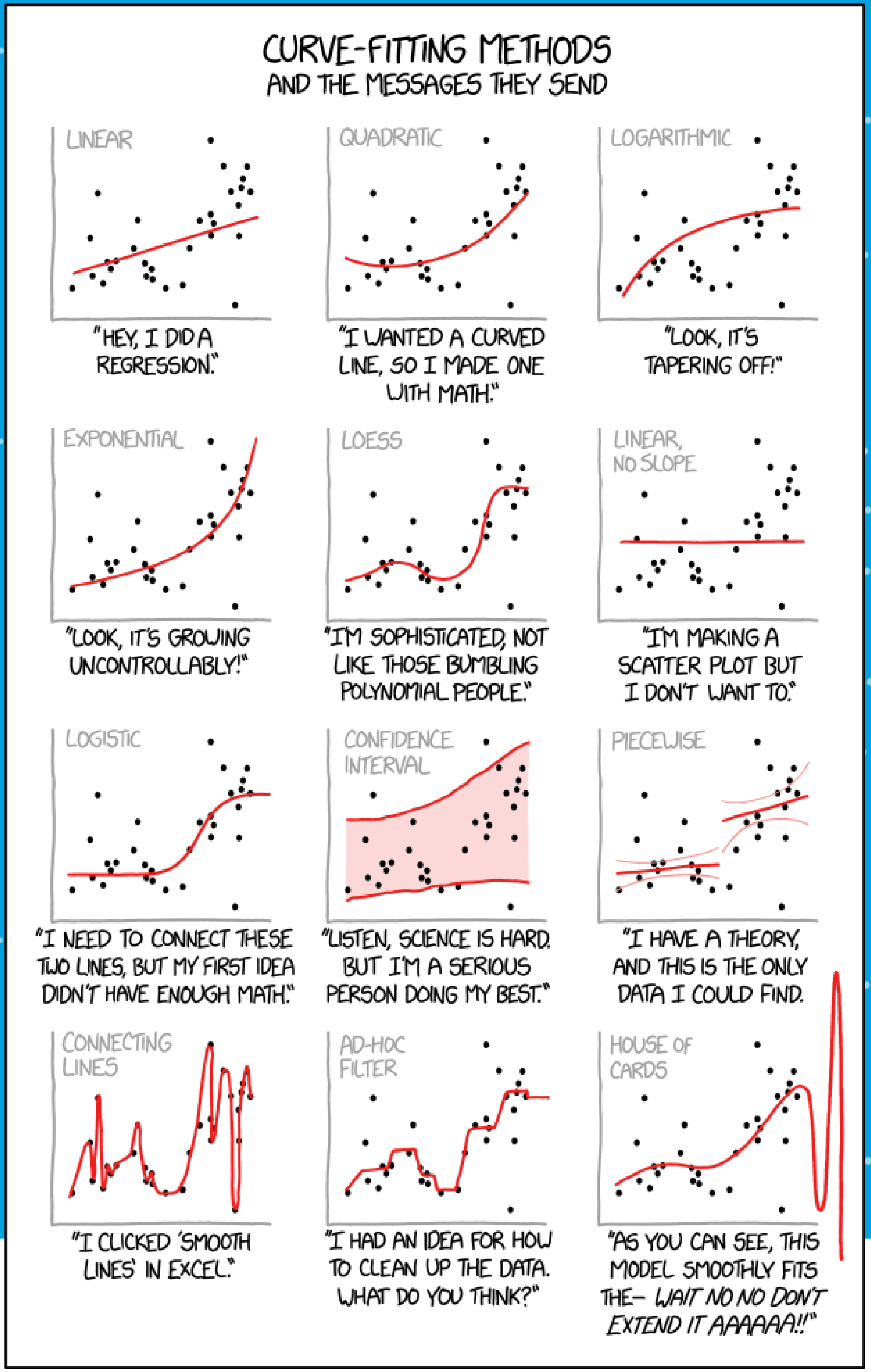
B. For Materials where E_{LWD} IS Moisture Dependent

Criteria #4 – Measured E_{LWD} must exceed [$E_{LWD\text{-}SITE}$ – Average of Function Residuals] when E_{LWD} & $E_{LWD\text{-}SITE}$ are determined at corresponding Insitu Moisture Contents

(i.e. Assessment that observed insitu modulus parameter achieves typical value)

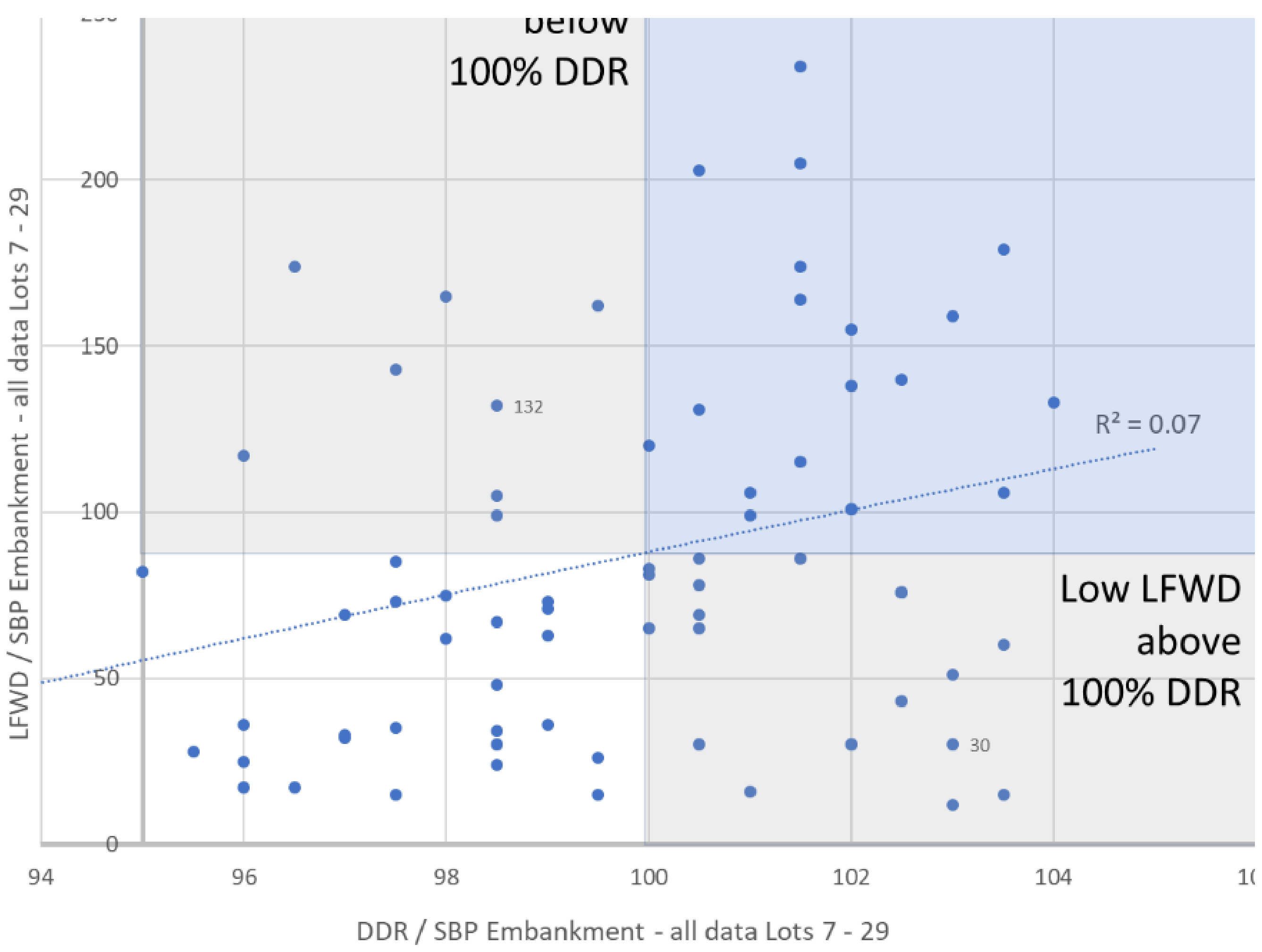
Criteria #5 – Measured E_{LWD} must remain above the Lower Bound 95^{th} Confidence Interval Value for defined $E_{LWD\text{-}SITE}$ – Insitu Moisture Content relationship

(i.e. Assessment that observed insitu modulus parameter exceeds minimum requirement)



Correlation which avoids curve fitting Method of Matching PDFs QA

Paired matching of DR and LFWD (Prima) tests

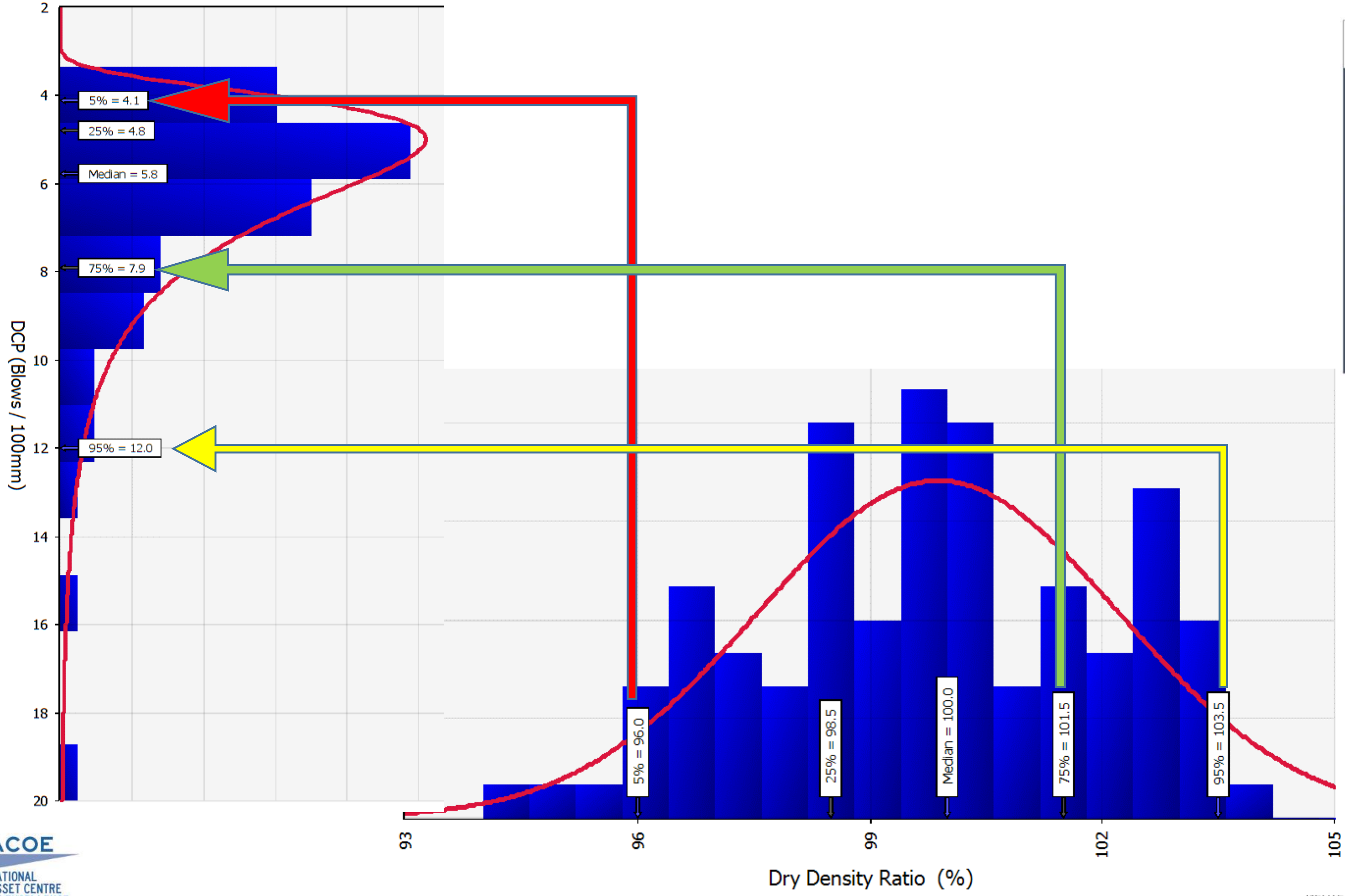


High Modulus values (> 100 MPa) can "fail" a 100% DR tests

And

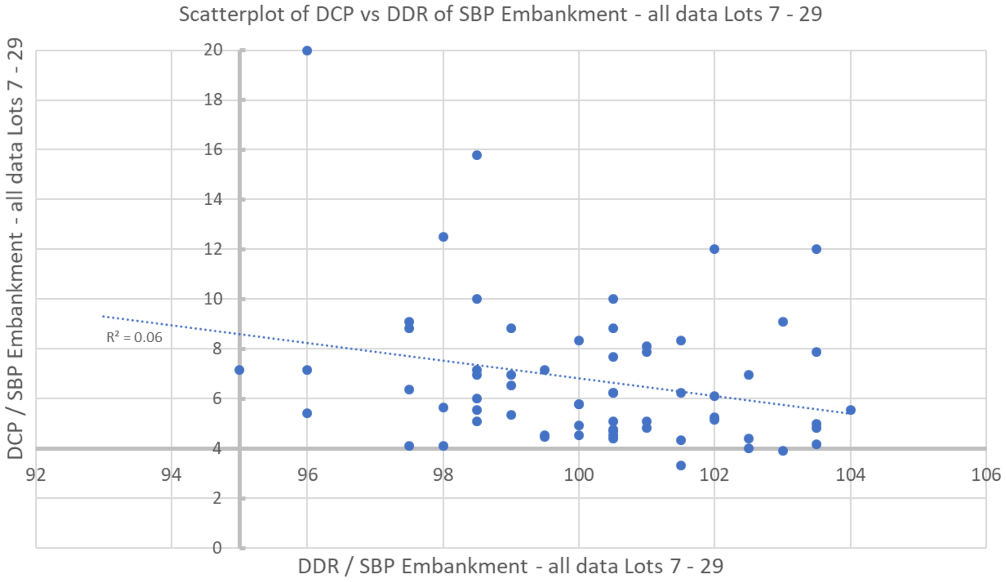
values below 30 MPa can "pass" a DR criterion

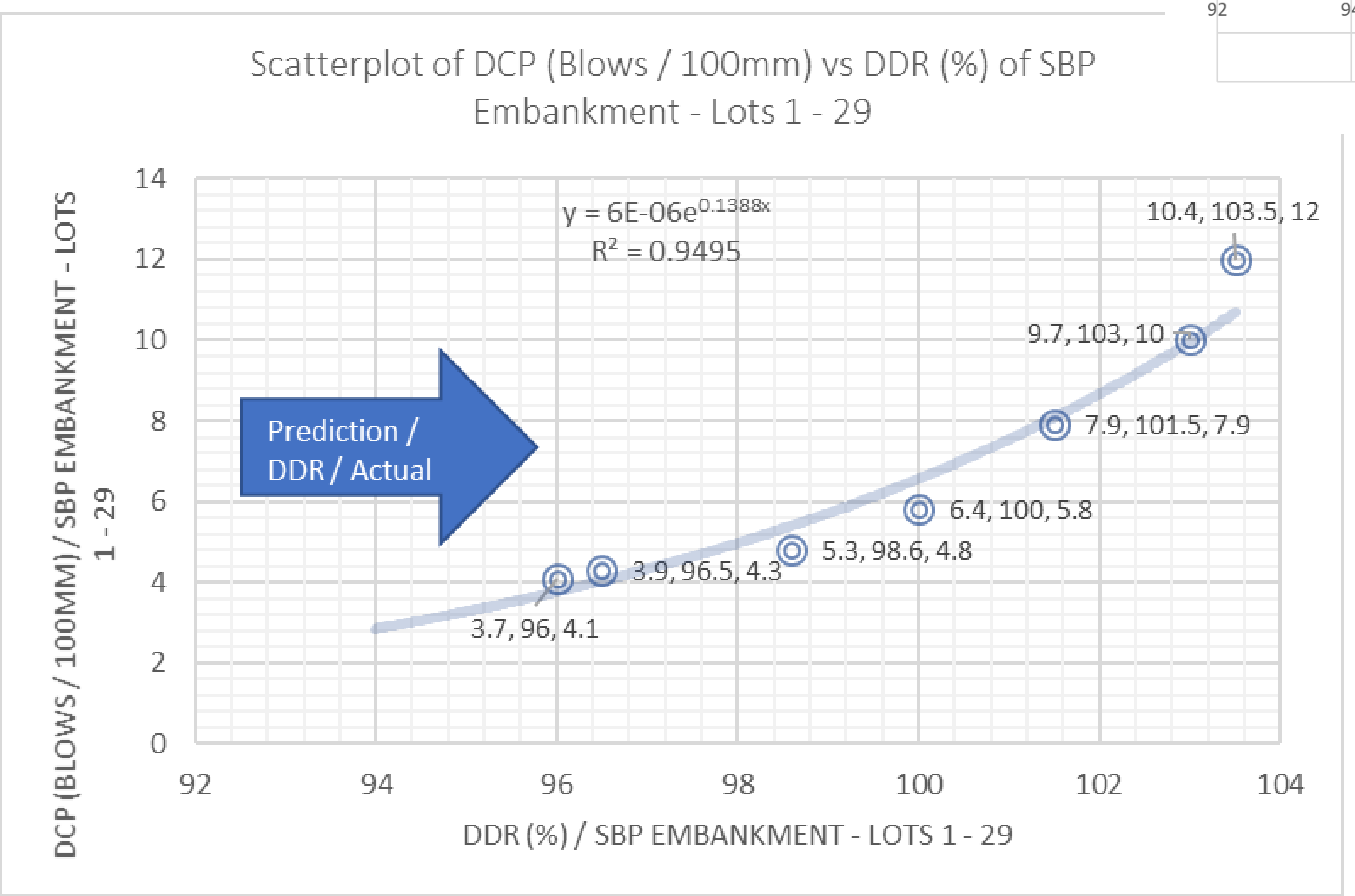
Method of Matching PDFs



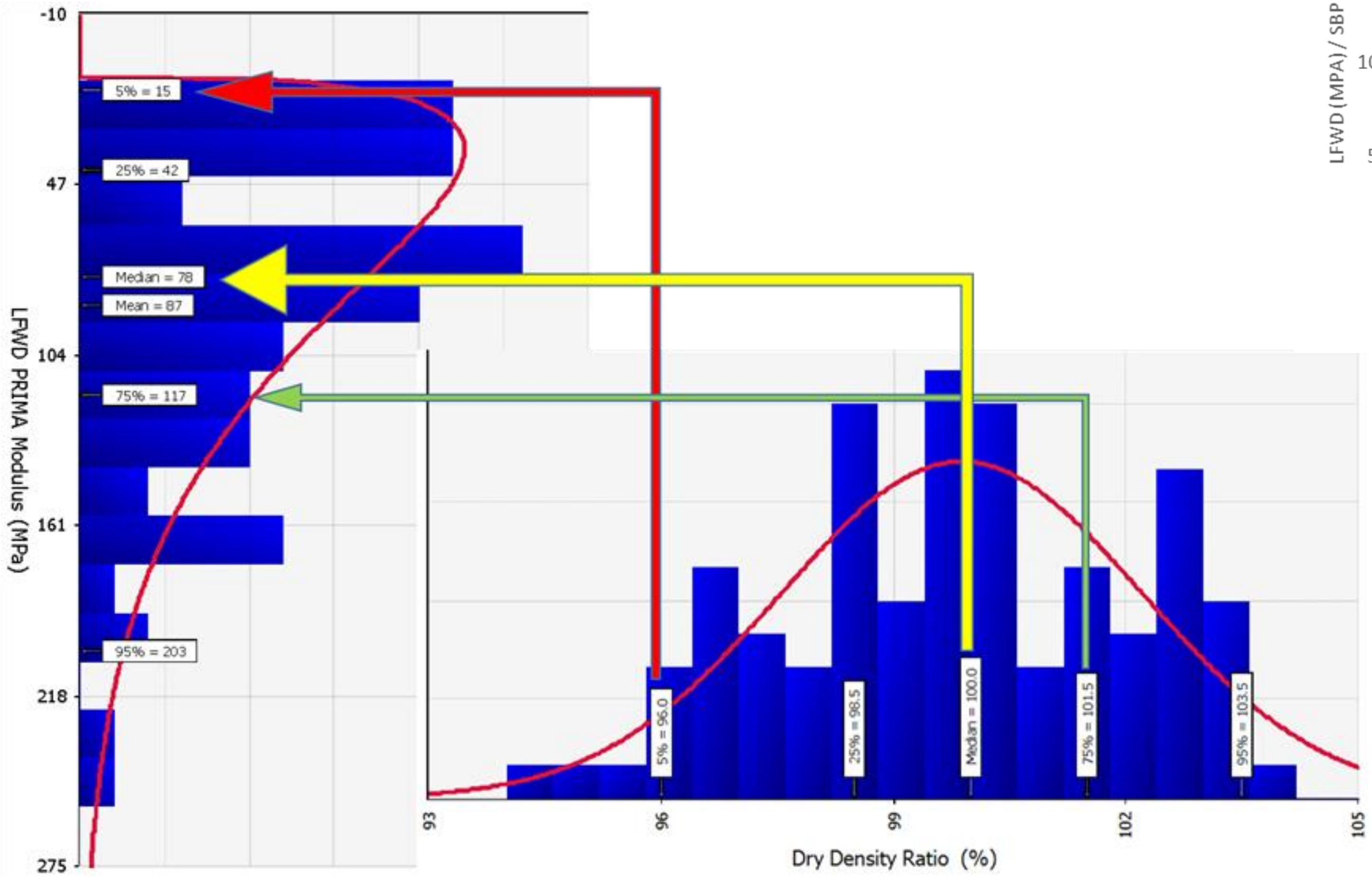
QTMR vs Contractor Risk		Quality of Lot: Good	Quality of Lot: Poor
Acceptance Decision	Accept	**Correct**	Type II Error QTMR's Risk Not Rejecting a Lot when it is Not OK
	Reject	Type I Error Contractor's Risk Rejecting a Lot when it is OK	**Correct**

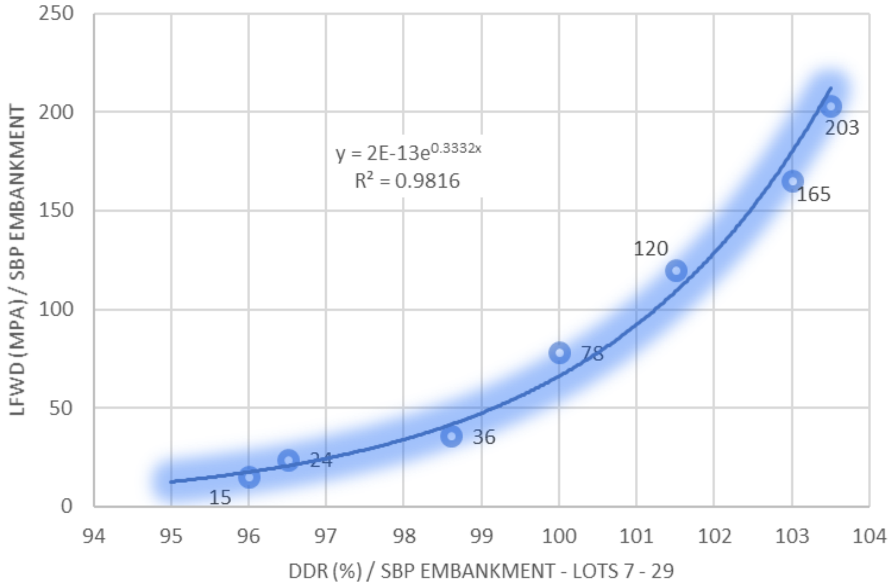
Relating PDFs to DDR

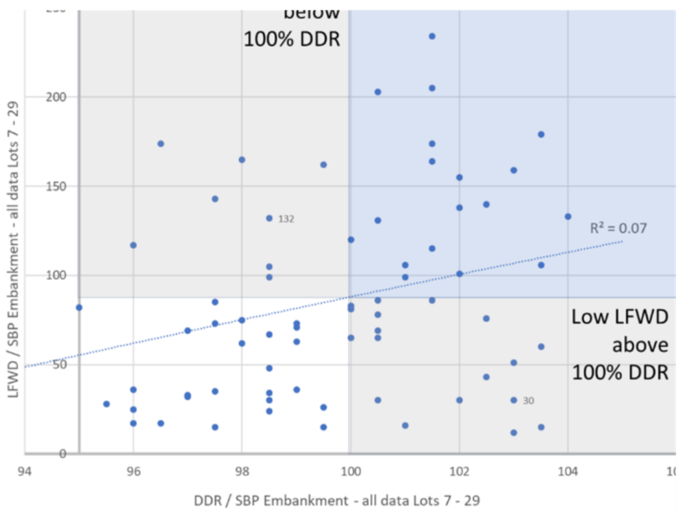




Matching the Dry Density Ratio and LFWD PDFs





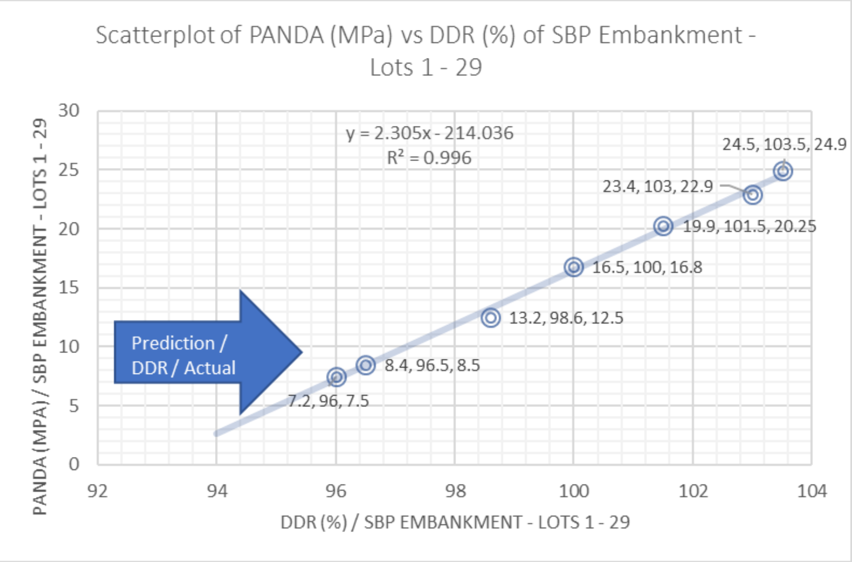


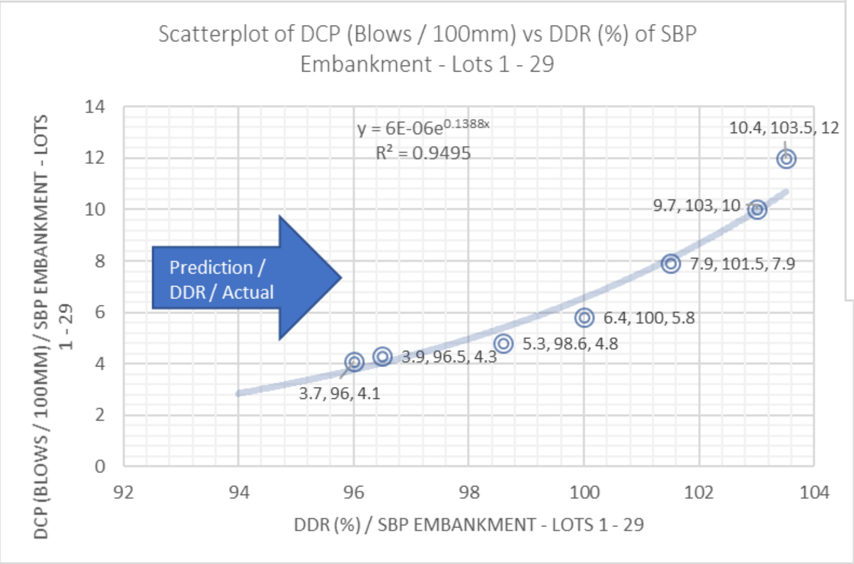
NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

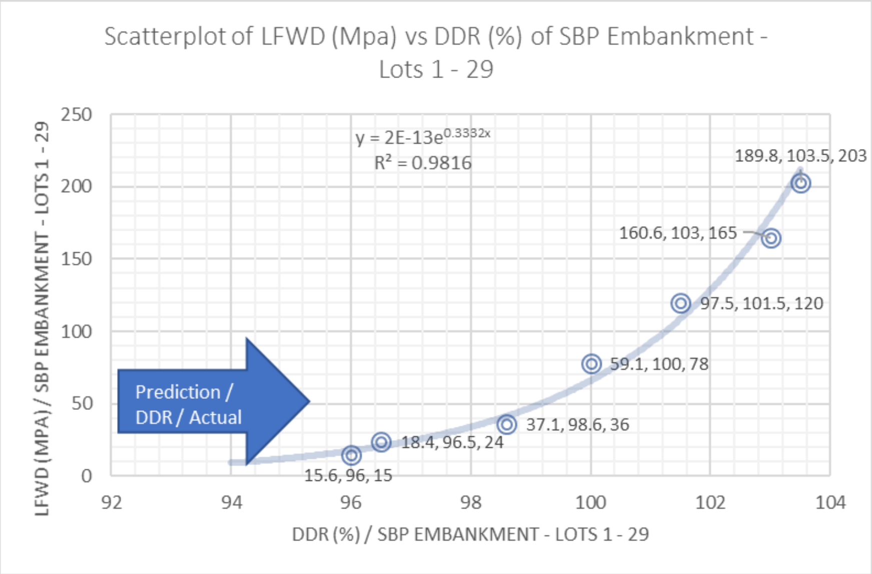
FSG GEOTECHNICS + FOUNDATIONS

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Relating PDFs to DDR





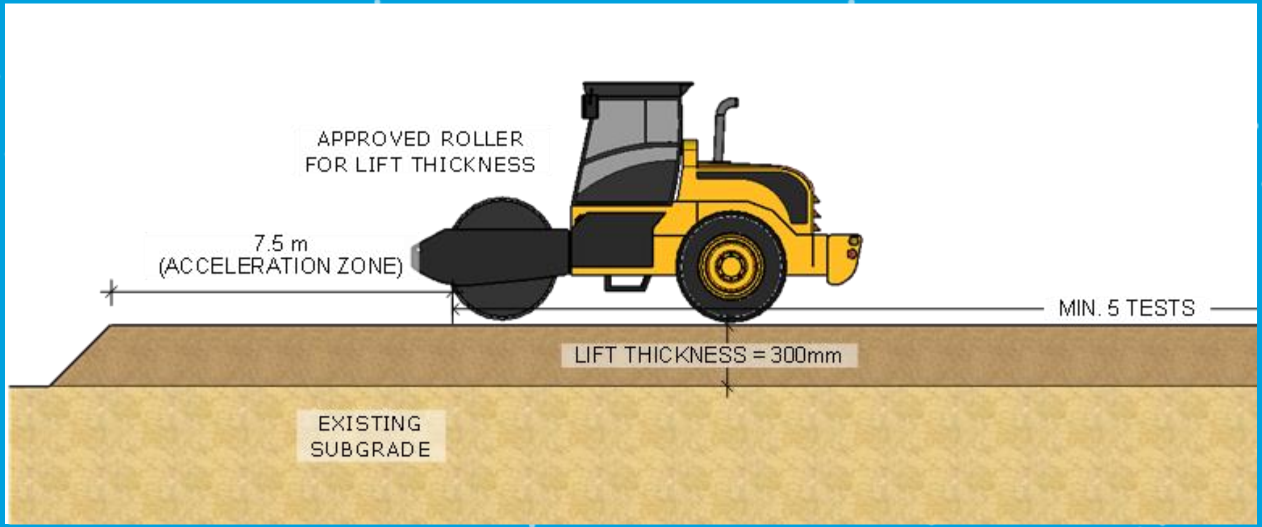


DDR	$LFWD_{100\ kPa}$	Correct Assessment (RDD + LFWD Agree)	RDD + LFWD Disagree (1 Test Passes / 1 Test Fails)
96%	15 MPa	**96%**	4%
98%	30 MPa	**77%**	22%
100%	60 MPa	**64%**	36%
103%	160 MPa	**76%**	24%

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS + FOUNDATIONS

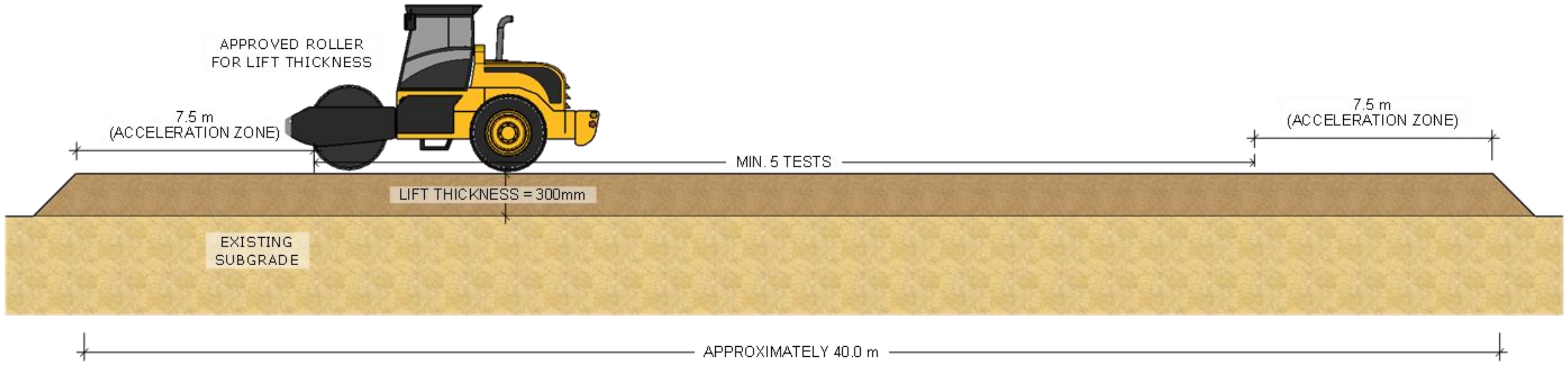
arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION



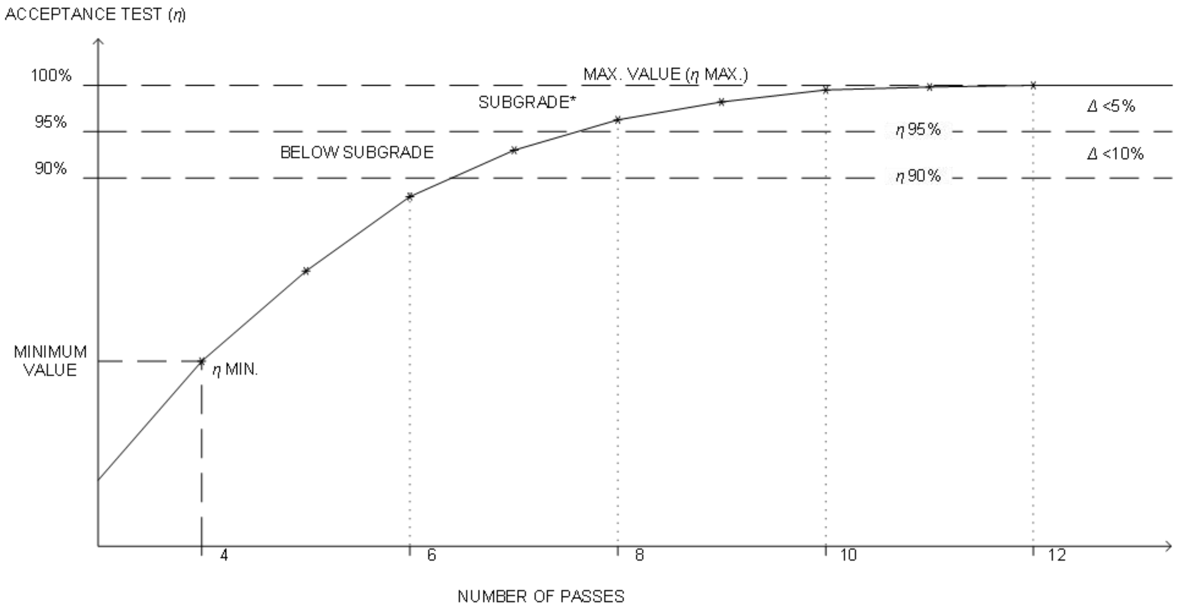
% Maximum Target Value
H
Method of Change Reduction QA

% Maximum Target values

Minimum Area = 40 m length X 4.2m wide: No. tests = 2 X 5 =10 Min / Layer : 2 Layers



2 Layers X
~ 300mm loose



*DEPTH OF SUBGRADE TO BE DEFINED FOR EACH PROJECT (TYPICALLY 0.5 m - 1.5 m)

Method of change
reduction

NACOE
NATIONAL
ASSET CENTRE
OF EXCELLENCE

FSG
GEOTECHNICS
+FOUNDATIONS

arrb
YOUR NATIONAL TRANSPORT
RESEARCH ORGANISATION

QA - Acceptance Criteria

10 Min Tests (Ideally 20 No.)

Minimum Values

- All values η_{min} at 4 passes in trial

4 → 6 → 8 → 10 → 12 Passes

- Measure η every 2nd pass

Maximum Values

- All values η_{max} at 12 passes in trial

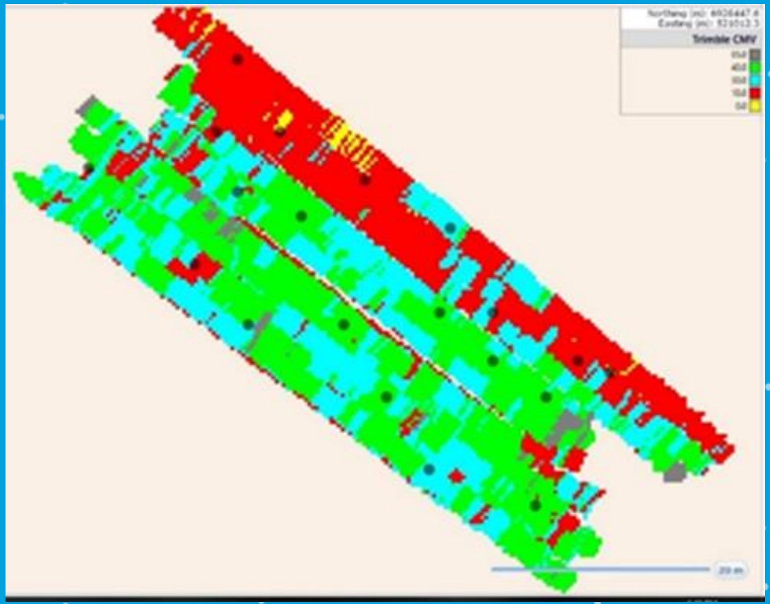
Acceptable values (LCV) from trial

- η_{95} < 5% increase (subgrade) or 95% η_{max}
- η_{90} < 10% increase (below subgrade) or 90% η_{max}

Variation at acceptable value

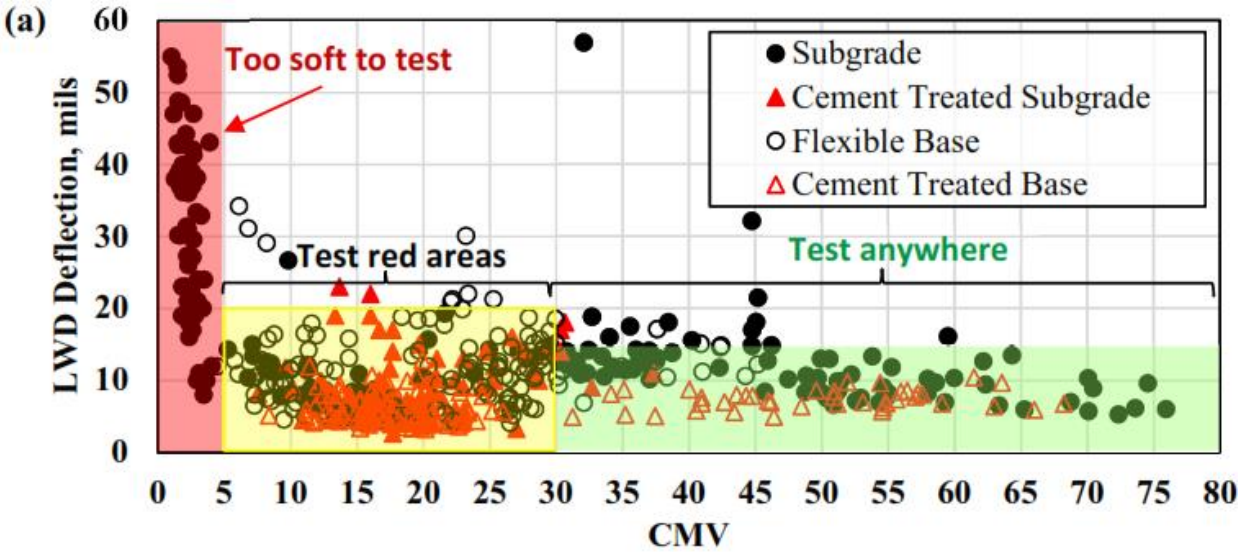
- COV < 20%(Gravels)
- COV < 35% (Sands) -?
- COV < 60% (Fines) -?

Varies with test equipment



Intelligent compaction QA

IC + Modulus testing



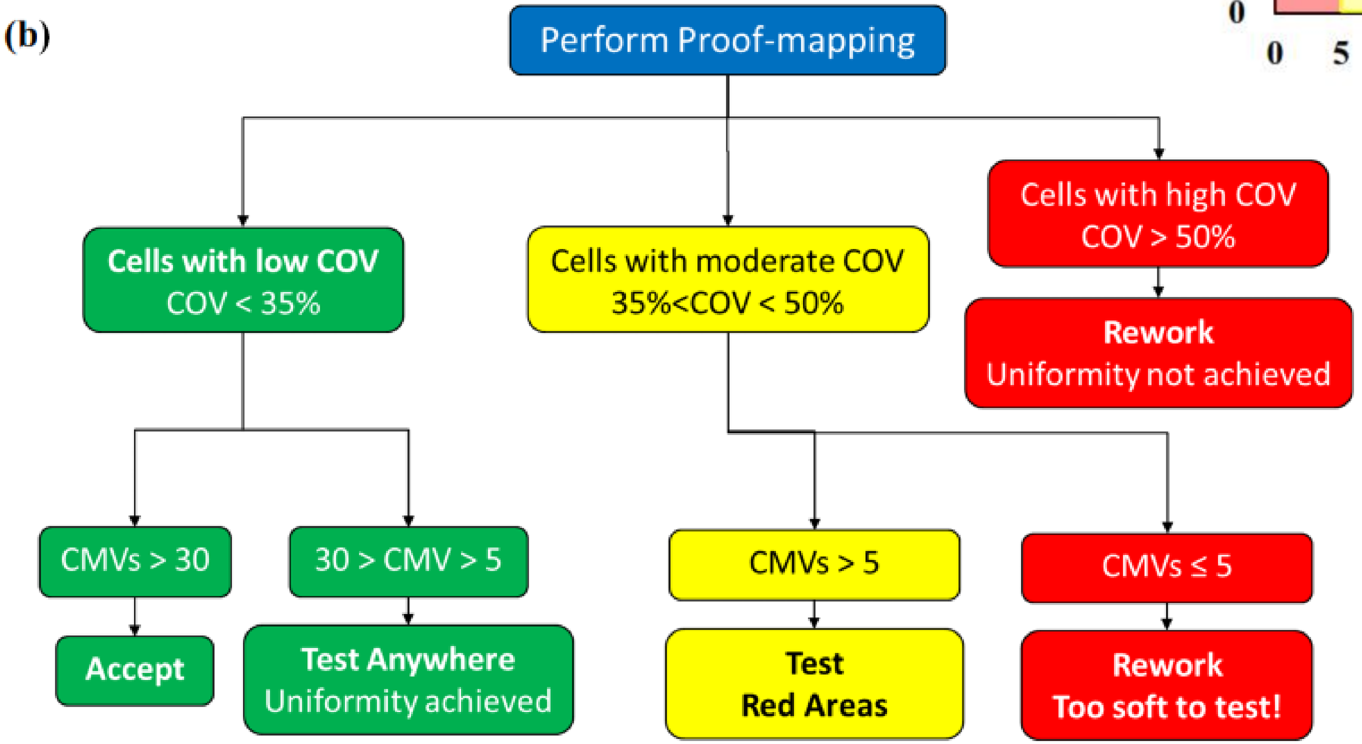
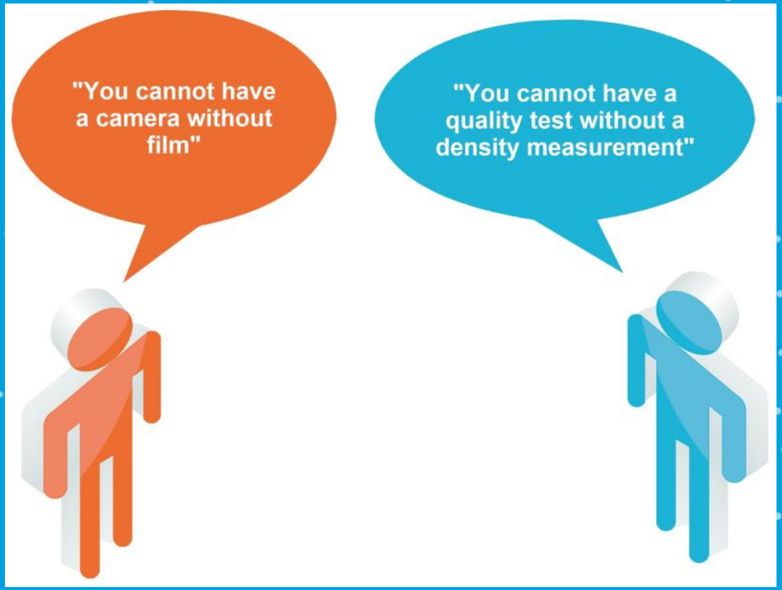


FIGURE 2 (a) Relationship between CMV and deflections measured from LWD mass drops for all sites and (b) proposed protocol for project acceptance.

Tirado, Fathi. Mazari and Nazarian (TRB 2019 Annual 98th Meeting), " Design Verification of Earthwork Construction by integrating intelligent compaction technology and modulus based testing



Is Density Ratio the end game ?

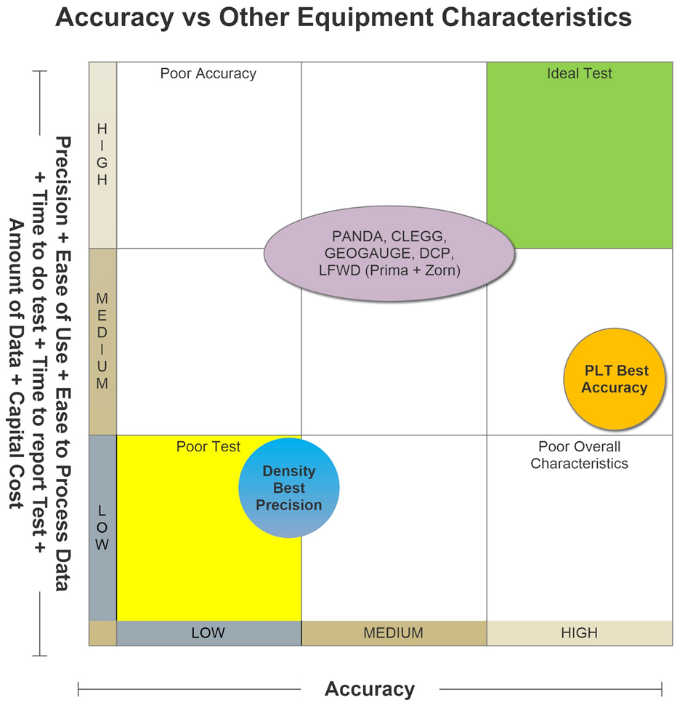
Summary and conclusions

3 most common tests are PLTs, Density and DCPs → do not correlate well with each other.

- ✓ Density Ratio testing is the most precise test. However, poor indicator of strength or modulus, once the pass compaction has been achieved
- ✓ PLT is very accurate, but low precision
- ✓ DCPs has a low precision but has other characteristics (ease of use and depth profiling) which make this test attractive

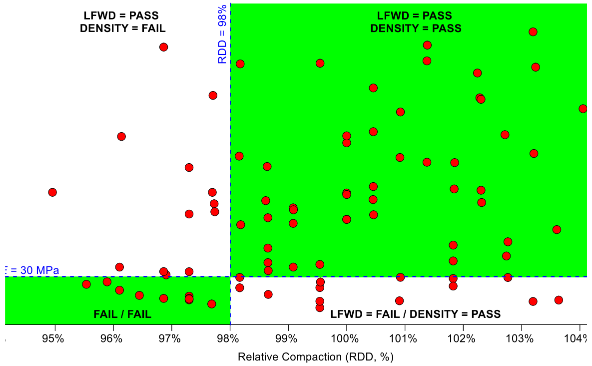
No clear leader for the combined 8 criteria used

- ✓ Direct or meaningful correlations should be project + material specific
- ✓ Many Alternative tests are more related to Moisture content rather than density
- ✓ Moisture content changes likely to occur and affect modulus values
- ✓ Correlating back to density is unlikely to advance the use of alternative testing

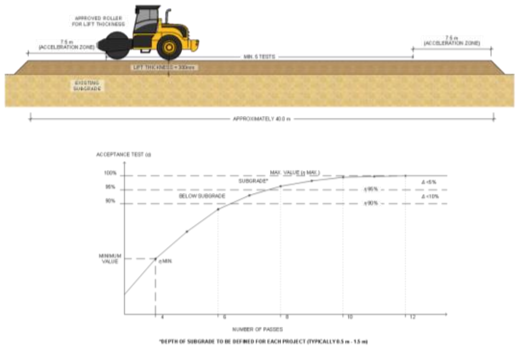


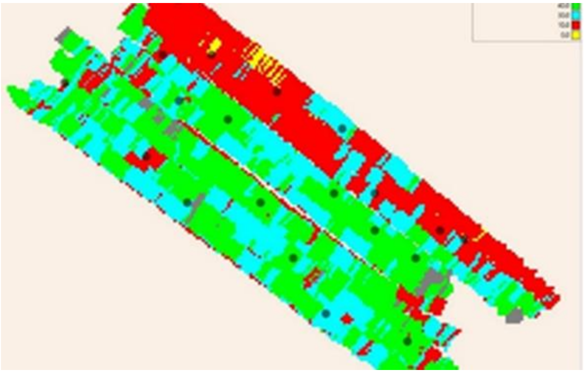
Specifications options

Target Value cannot be universal



Contractor Risk		Good	Poor
Acceptance Decision	Accept	Correct	Type II Error QTMR's Risk Not Rejecting a Lot when it is Not OK
	Reject	Type I Error Contractor's Risk Rejecting a Lot when it is OK	Correct





- Correlation Approach linked to Standard Density approach
- Project and material specific. Parallel Testing
- Likely to be most variable. Many "good" values fail and "bad" values pass
- Skews QA approach

- Method Of matching PDFs linked to Standard Density approach
- Project and material specific. Parallel Testing
- Uses 10% QA – acceptance decision

- Method of change reduction
- Not linked to Standard Density approach
- Parallel testing not mandatory
- Uses QA acceptance decision

- Intelligent Compaction verification
- NCHRP 676 Options
- LFWD parallel testing

Thank you for your participation today.

For further information on the topic, please contact:

Dr Jeffrey Lee jeffrey.lee@arrb.com.au
Dr Burt Look blook@fsg-geotechnics.com.au

Website:
https://www.nacoe.com.au

NACOE NATIONAL ASSET CENTRE OF EXCELLENCE

FSG GEOTECHNICS +FOUNDATIONS arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

QUESTIONS?