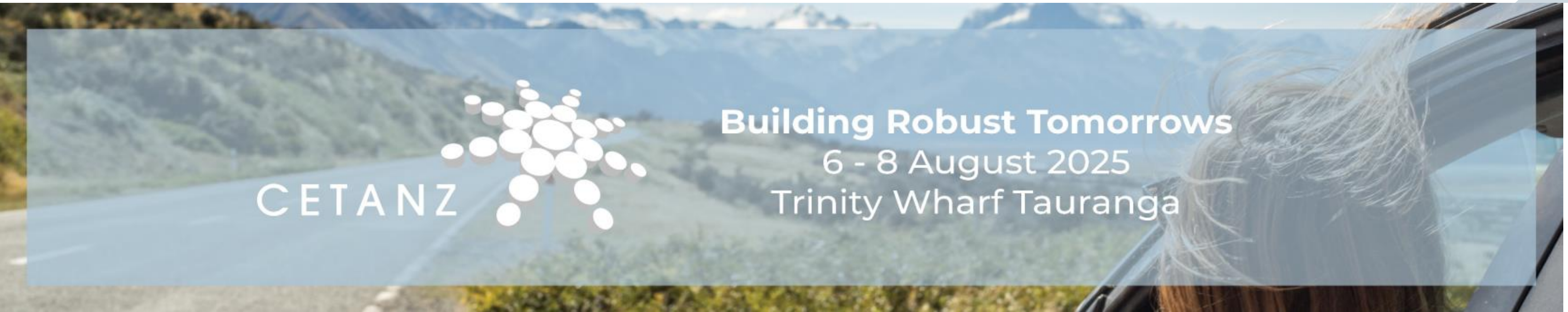
Presentation and Workshop:
CBR and DCP testing in pavement investigations

Rob Damhuis

NZTA Principal Pavement Engineer



WAKA KOTAHI
NZ TRANSPORT AGENCY

Review of State Highway Pavement Delivery

January 2020

Closing remark in the report:

"Risk could only be managed by reducing the probability of failure by

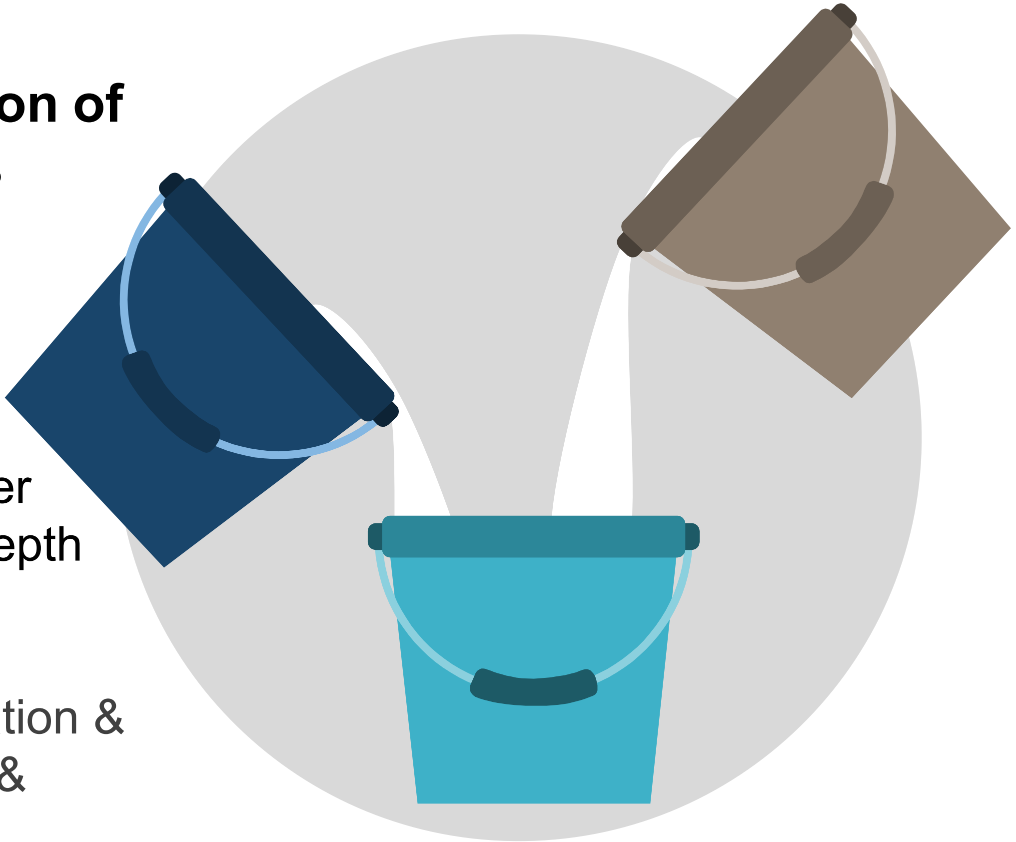
- *achieving accurate characterisation of material properties*,
- adopting *lower risk pavement designs*, and
- a focused attention on the *quality of the construction process.*"

NZTA focus on pavements

Accurate characterisation of Material Properties

Recent improvements
- M03, M04
- P03 & P04
- T24, T28, T29, etc.
- Density Compliance: Layer >100mm, NDM DT Full depth testing.

Underway
- Standard NZGS investigation & testing contract template & requirements.
- NZTA T19 Mix design & ITS of Modified and Bound Materials.
- NZTA T15: RLT



Lower Risk Pavement Designs

- Pavement Design Standard
  - Still underway.
- Standardised investigation & testing requirements for rehabs and greenfields.
  - Alignment to Reliability Factor, Design Risks & Pavement Performance.

Construction Quality

- B-series update to include random sampling and NDM DT testing

NZTA focus on pavements

Lower-Risk, Cost-Effective pavement designs

- More accurate characterisation of Subgrade Material Properties
  - Crucial for effective road design
  - Influences pavement thickness
  - Affects ultimate pavement performance!
- Subgrade's resistance to deformation under load:
  - California Bearing Ratio (CBR) Vs Dynamic Cone Penetrometer (DCP)
  - Materials type: Modulus of subgrade reaction (k-value)
  - Determines design resilient modulus (MR).

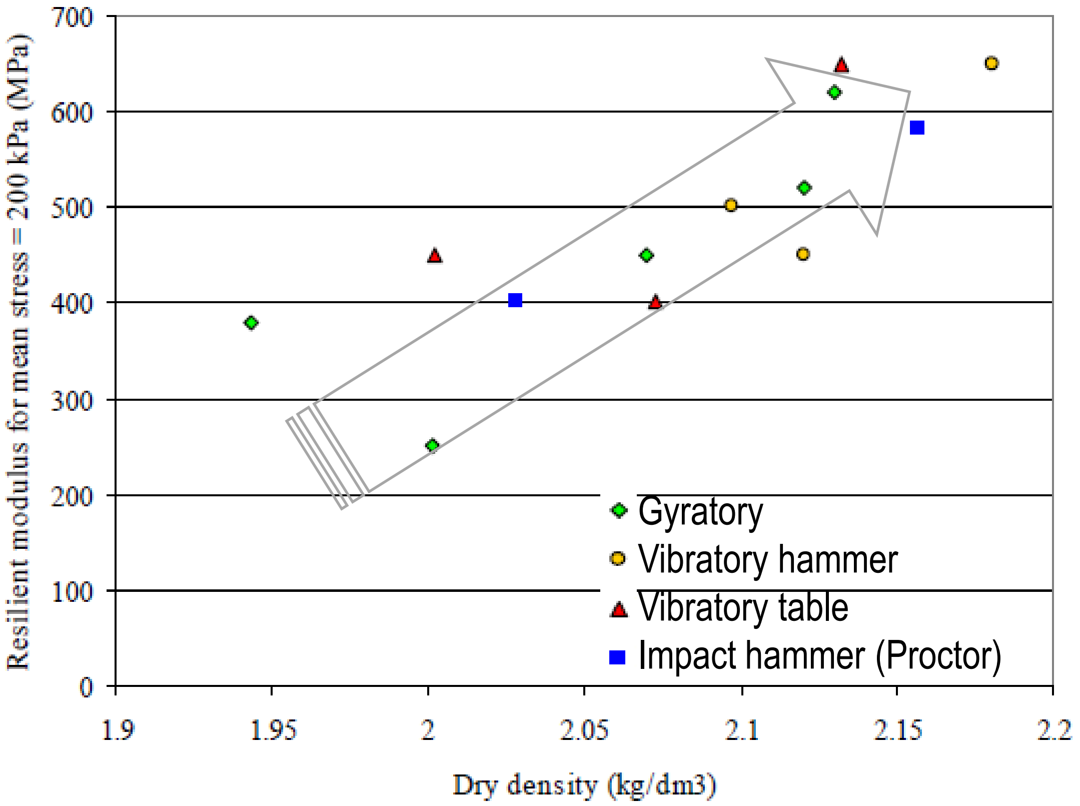
CBRs and DCPs in pavement Investigation

Present NZ practice for rehabilitation

1. Undertake FWDs at single points & determine D_0 and CF
2. Undertake test pits at random & chosen points. Sample layer works and subgrade.
3. Layers: Determine CBR at insitu %MC.
4. Subgrade:
   a. Generally: DCP & Shear vane (if clay)
   b. Sometimes: CBR, PSD, PI
   c. Rarely MDD/OWC
5. Determine M_R's for pavement design

Higher density = Higher strength

Effect of compaction density on Resilient Modulus (MR)



Extract from: Inge Hoff, Leif J. Bakløkk and Joralf Aurstad, *Influence Of Laboratory Compaction Method On Unbound Granular Materials*, 6th International Symposium on Pavements Unbound !

Findings:

- Increase in resilient modulus and resistance against permanent deformation with increasing compaction effort, irrespective of compaction type.
- Both bound and unbound aggregates are
  - Stress dependent; and
  - Get stiffer with increasing stress.
- Low construction density will likely result in early life rutting and possible shallow shear.

Note: This paper reports on a Swedish aggregate and cannot be translated to NZ aggregates without testing.

NZTA focus on pavements

More accurate characterisation of Subgrade Material Properties

- California Bearing Ratio (CBR)
  - Poor Repeatability & Reproducibility
  - Usually undertaken to determine:
    1. Subgrade cover, normally CBR<10 in NZ.
    2. Material's suitability in pavement layers.
- Dynamic Cone Penetrometer (DCP)
  - Poor Repeatability & Reproducibility
  - Usually undertaken to determine:
    1. Subgrade cover, normally CBR<5 in NZ.

California Bearing Ratio (CBR)

CETANZ Technical Committee

- Tech Working Group:
  - Scope: Review and improvement of CBRs
  - Danny Wyatt, Portly Griffiths, Francois Fonternel, Rob Damhuis
- ISO17025: lab to participate in PT or ILC to verify their testing and calibration competence.
- Laboratories to analyse performance in PT/ILC, identifying any deviations or areas for improvement.
- If deviations or unsatisfactory results are observed, laboratory to implement corrective actions.
- PT/ILC help lab meet specific customers and regulatory body requirements.

California Bearing Ratio (CBR)

Poor Repeatability & Reproducibility

The CBR Test – A Case For Change?

Ralph Rallings, *Australian Geomechanics Vol 49 No 1 March 2014*
https://australiangeomechanics.org/admin/wp-content/uploads/2015/06/49_1_2.pdf

Review of NATA's proficiency test programs between 1992 and 2011 with <u>specified moisture contents</u>.

Table 3: % proficiency test results within ±10, 20 and 30% of <u>median</u>, shows <60% of results within ± 30% of median value.

NATA Programme	No. Results	**Median $CBR_{2.54mm}$ Value (%)**	Percentage within ±10%	Percentage within ±20%	Percentage within ±30%
710	49	**8**	20	35	45
396	32	**18**	30	45	50
453	50	**22.5**	15	35	40
607	58	**50**	20	40	55
695	43	**113**	15	40	55
457	38	**140**	30	40	55

Reproducibility data shows:

- Subgrade CBR could range from 4% versus 6%, translating to **±150mm Subgrade cover difference**.
- Mechanistic design E = 10 x CBR for Resilient Modulus, **large difference in depth**.
- Soaked CBR of base course gravel : Range of 70% (**Non-conforming**) to 120% (**Conforming**)

California Bearing Ratio (CBR)

CBR Working Group

- Review of recent CETANZ Proficiency Tests

NATA Programme	No. Results	Median $CBR_{2.54mm}$ Value (%)	Percentage within ±10%	Percentage within ±20%	Percentage within ±30%	Percentage over ±30%
710	49	8	20	35	45	55
396	32	18	30	45	50	50
453	50	22.5	15	35	40	60
607	58	50	20	40	55	45
695	43	113	15	40	55	45
457	38	140	30	40	55	45
CETANZ or Member Programmes	No. Results	Median CBR2.54mm Value (%)	Percentage within ±10%	Percentage within ±20%	Percentage within ±30%	Percentage over ±30%
2022 Ash	15	3	27%	47%	53%	47%
2020 Ash	15	9	53%	61%	99%	1%
2024 Silty Sand	14	14.5	29%	50%	50%	50%
2024 Silty Sand	14	14.5	29%	50%	50%	50%
2024 Sand /Silt	10	25	40%	60%	20%	80%
2020 Agg	12	70	38%	54%	77%	23%
2024 AP40	19	95	16%	16%	26%	74%

SIGNIFICANT DESIGN THICKNESS RISK

FAIR SIL NC RISK

FAIR DESIGN THICKNESS RISK

FAIR SIL NC RISK

SIGNIFICANT PASS/FAIL RISK

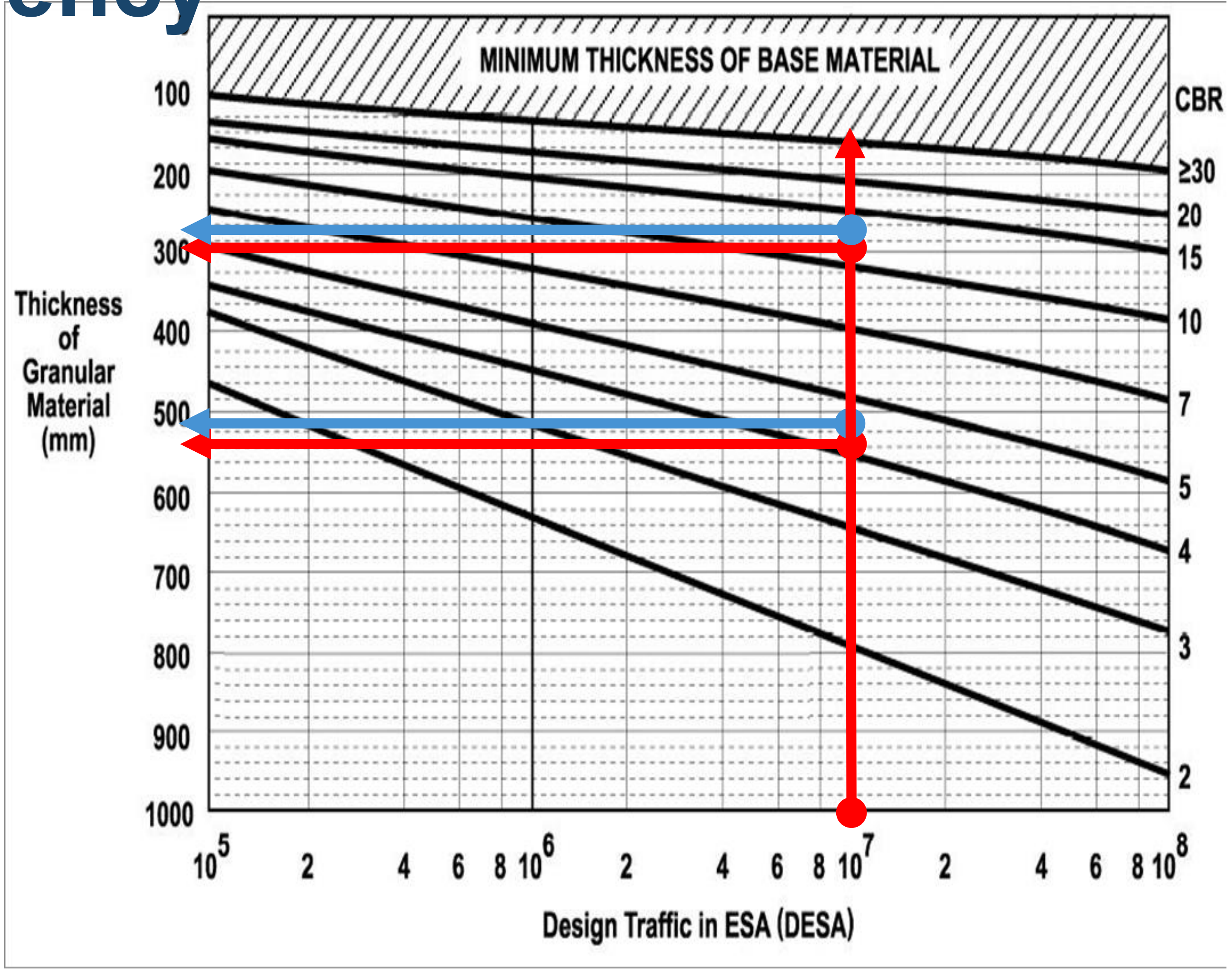
NATA vs NZ Proficiency

10 Million ESAs on AGPT02

Fig 8.4 Design thickness using tested Soaked CBR:

- (50% higher or lower than median)
- NATA (Median CBR 8%)
  - CBR 4% : 540mm
  - CBR 12% : 300mm
- NZ (Median CBR 9%)
  - CBR 4.5% : 280mm
  - CBR 13.5% : 540mm

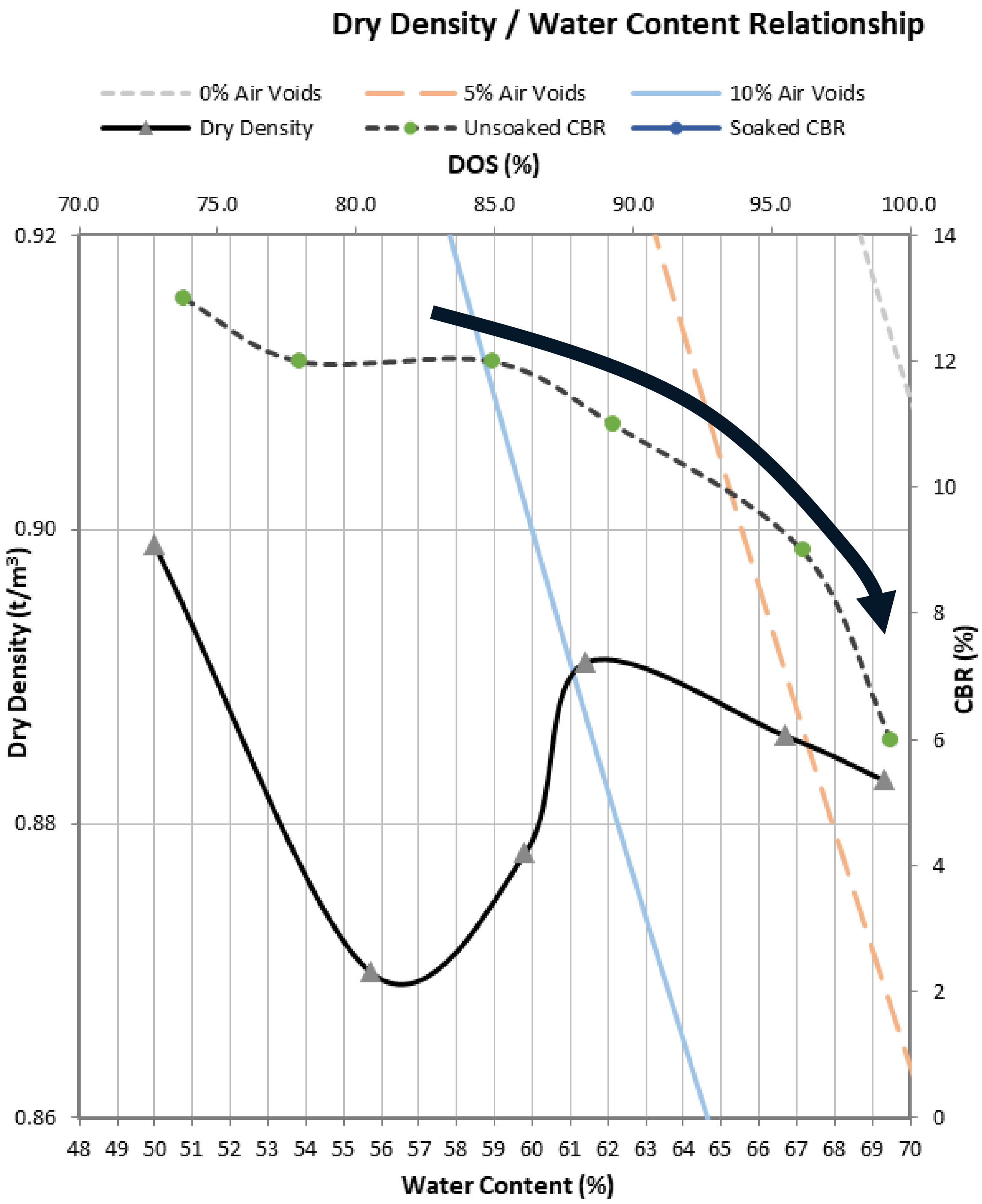
Potential difference of ±260mm.



Otorohanga Silty Clay

Geotechnics Hamilton: Small pilot test

- MDD curve maybe problematic, but Unsoaked CBR trend shows great picture:
- Max CBR at lower moistures contents
- Rapid reduction in ‘strength’ with moisture increase



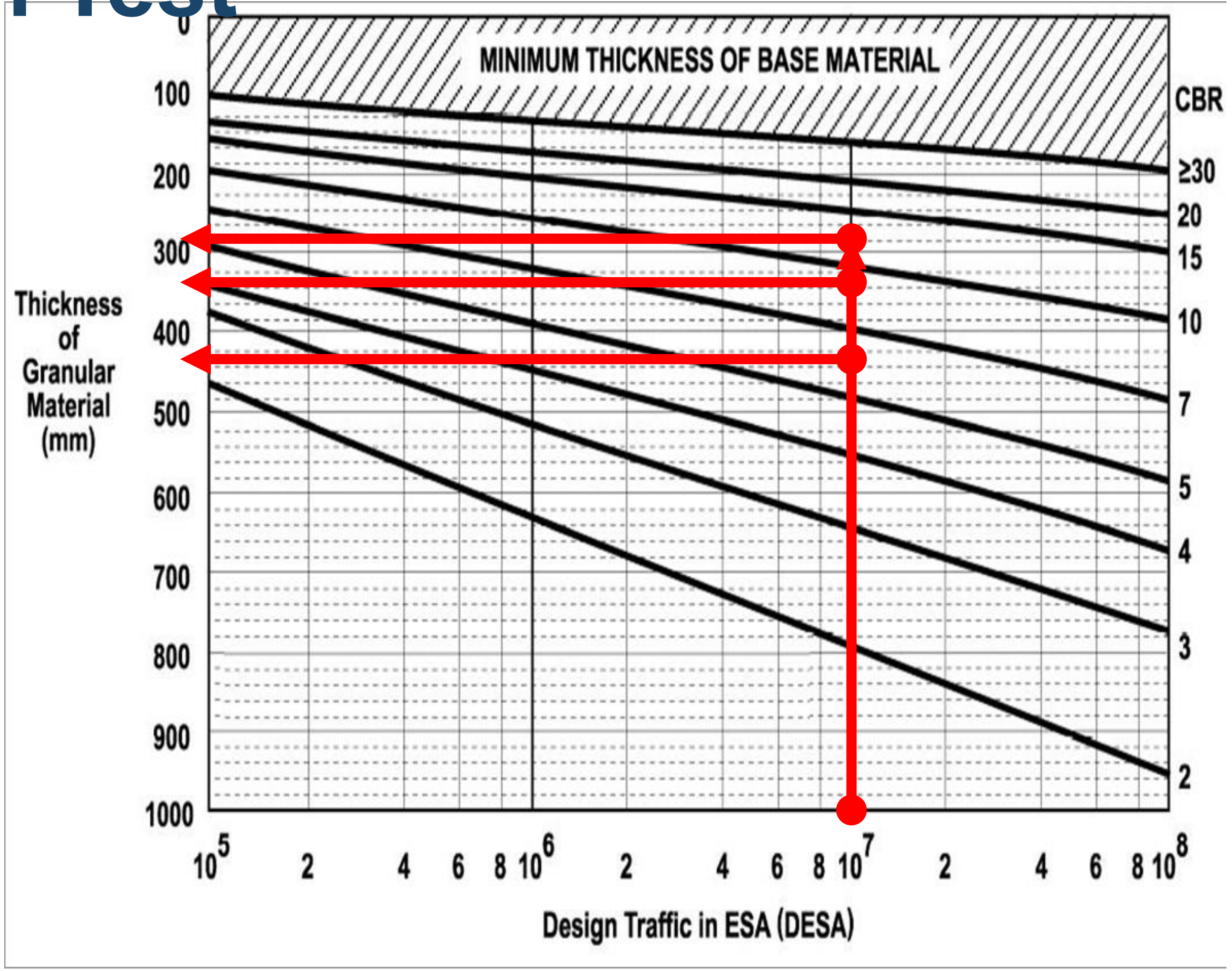
Otorohanga Design Test

10 Million ESAs on AGPT02

Fig 8.4 Design thickness using tested Unsoaked CBR:

- CBR 6% @ 99% DOS: 440mm
- CBR 9% % @ 90% DOS : 340mm
- CBR 12% % @ 85% DOS : 280mm

Potential difference of ±160mm.



Subgrade CBR test records

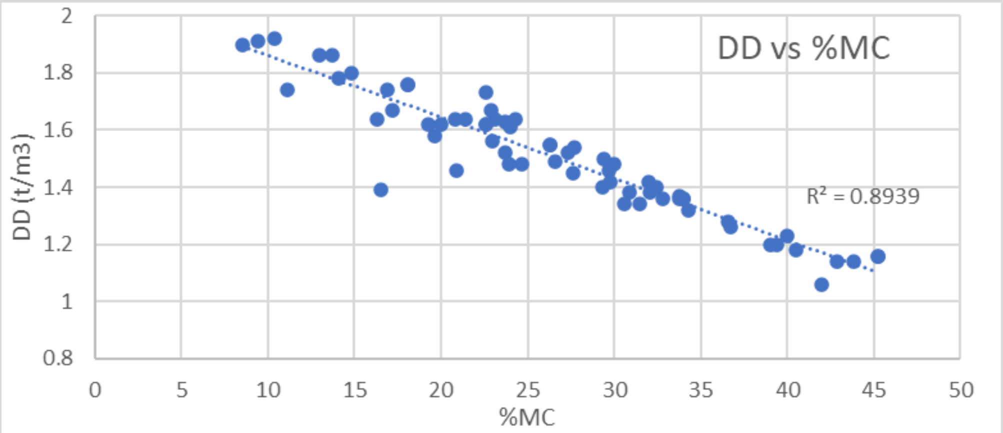
N.I Clays, Silty clays, Clayey Silts & Sandy clays Clayey sands

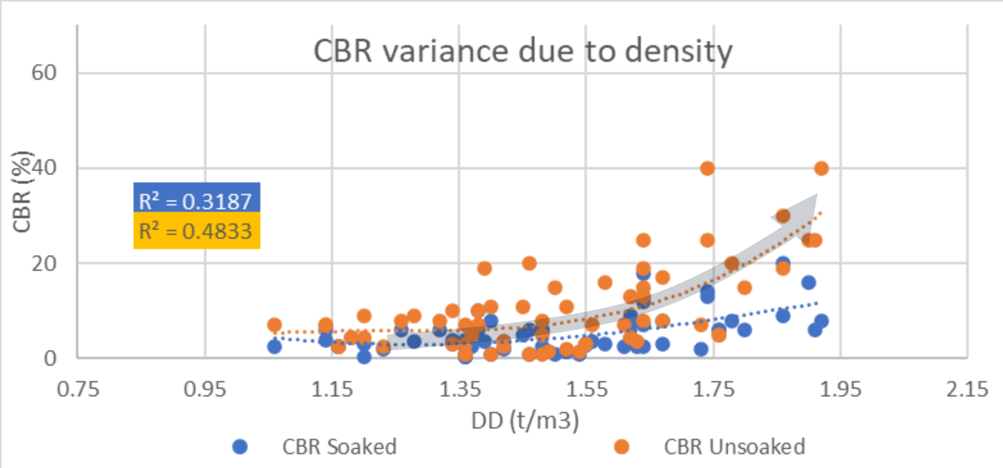
- Trends only: Not from a single source so inherent variability, however….
- MDD vs %MC: Good trend (R^2 = 0.89)
- CBR vs DD:

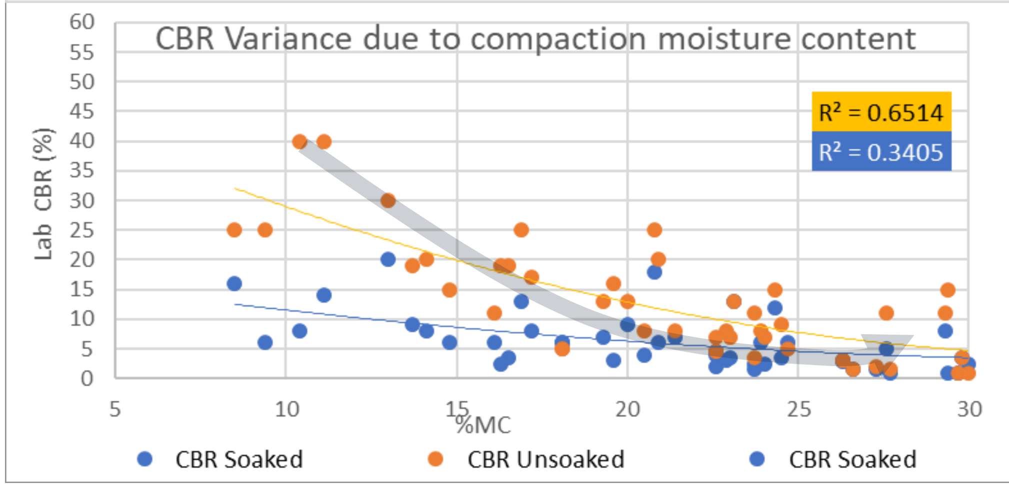
  Each sample has Soaked & Unsoaked CBR.

  - As the density increases, so does the CBR whether Unsoaked or Soaked.
- CBR vs %MC:
  - Both Unsoaked and Soaked CBRs have a similar trend, but the Soaked CBR reduces from 15% to 2%.

This is the expected trend…







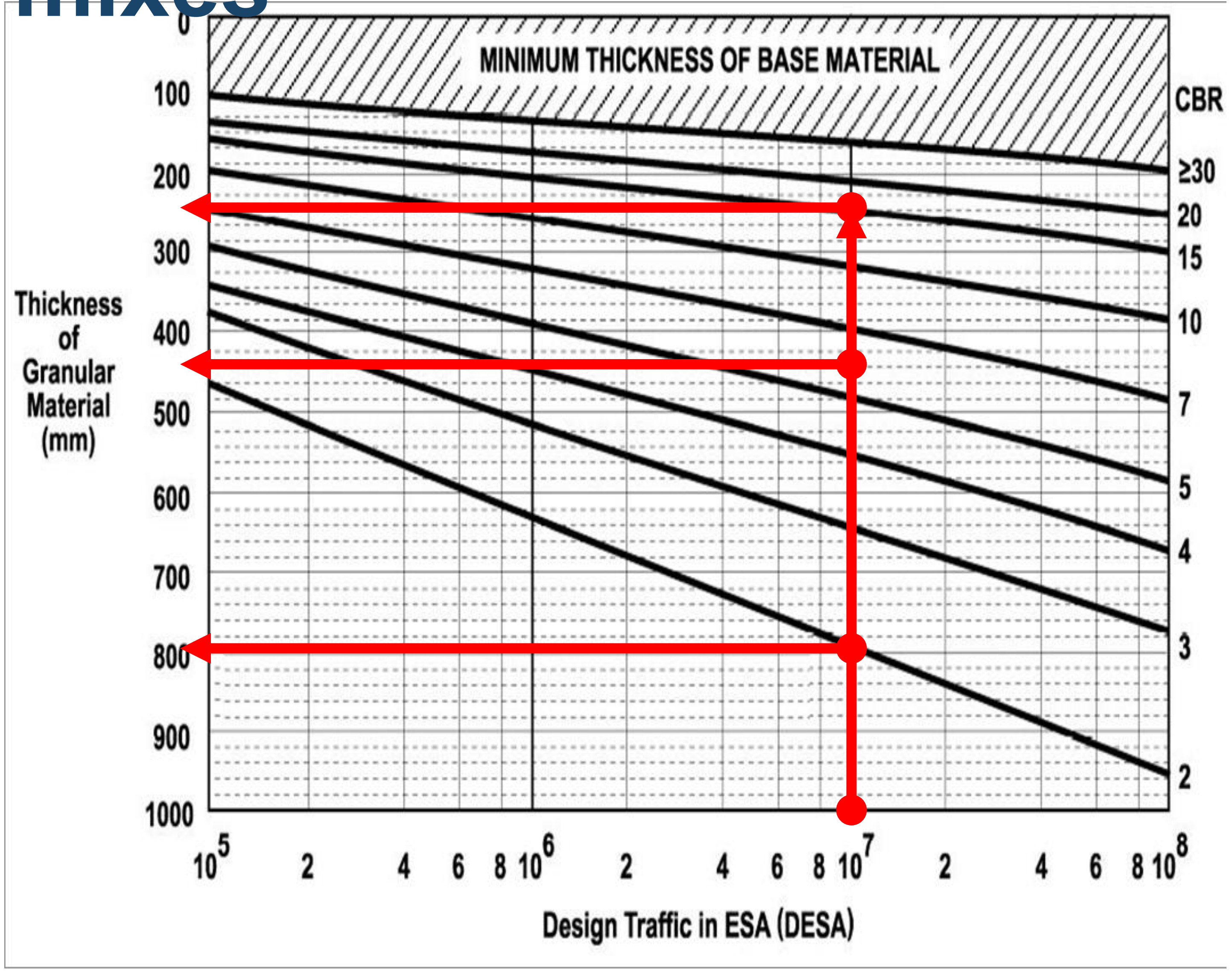
Ni.I Clays and clay mixes

10 Million ESAs on AGPT02

Fig 8.4 Design thickness using tested Unsoaked CBR:

- CBR 2% @ 90-120% DOS: 800mm
- CBR 8% % @ 85-100% DOS : 350mm
- CBR 15% % @ 75-80% DOS : 250mm

Potential difference of ±500mm.



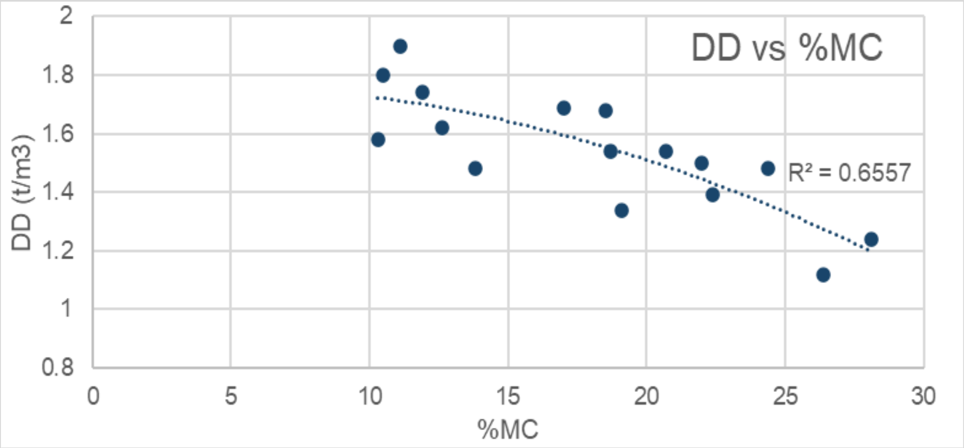
Subgrade CBR test records

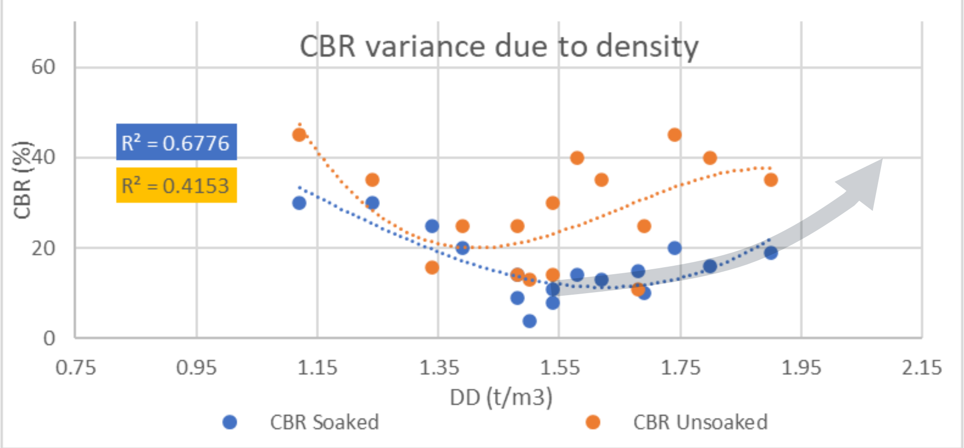
Fine-grained Pumiceous Silts, Silty sands & Sandy silts

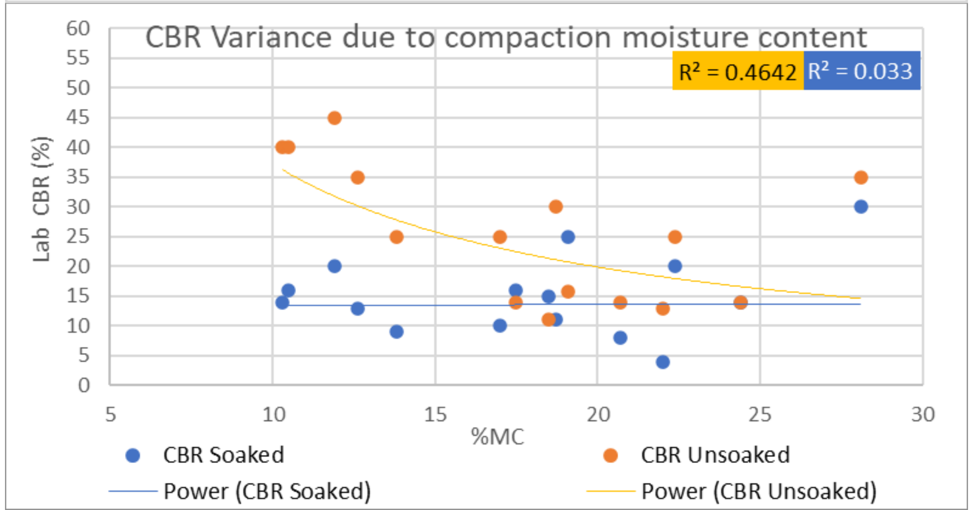
- Trends only: Not from a single source so inherent variability, however
- MDD vs %MC: Good trend (R^2 = 0.66)
- CBR vs DD:

  Each sample has Soaked & Unsoaked CBR.

  - Pumice is collapsable therefore drop in CBR at collapse density, & increase thereafter (my hypothesis)
- CBR vs %MC:
  - Max Unsoaked CBR seems to be at, or just under OWC in most materials.
  - For Soaked CBR ???



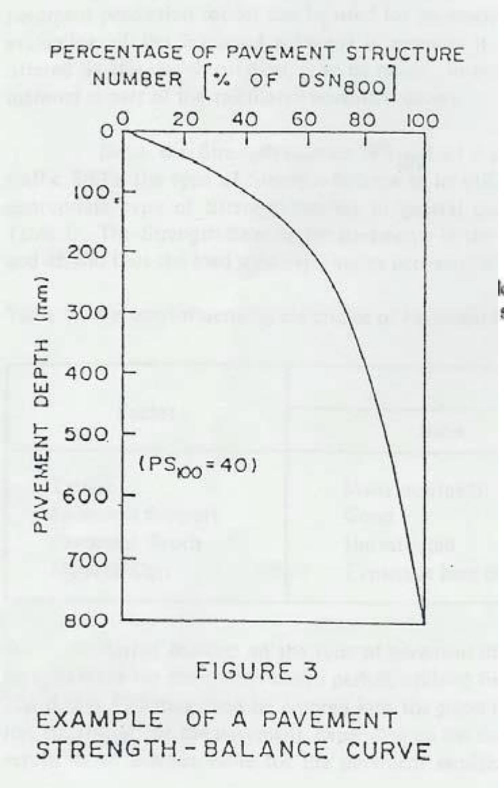




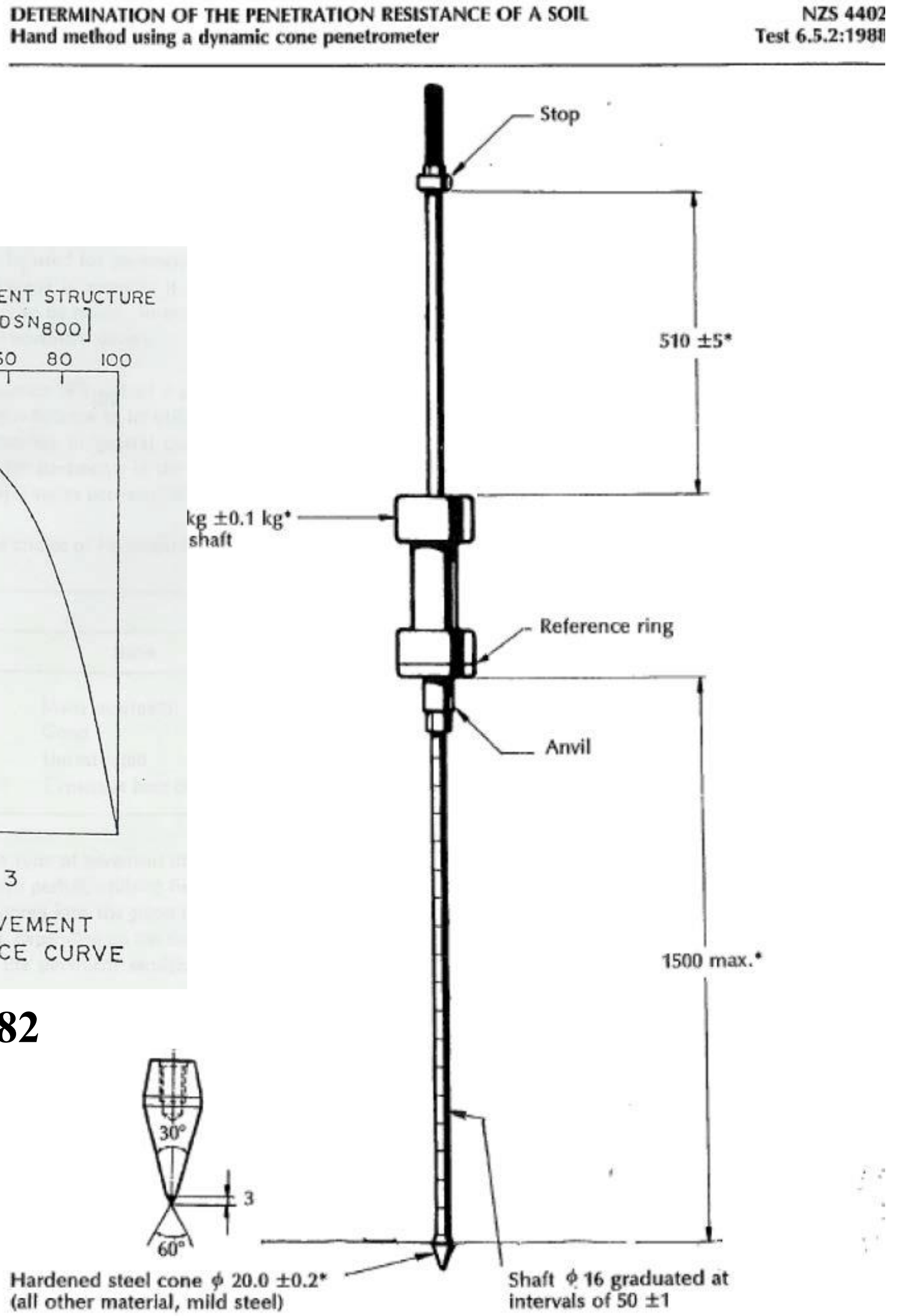
Dynamic Cone Penetrometer (DCP)

Theory

- Underlying soil strength/ stiffness measured by the penetration of the cone into the soil after each hammer blow.
- 1969 – 2000s multiple comparisons DCP vs CBR.
    - Smith & Pratt
    - Log (*CBR*) = 2.56 - 1.15 Log (*PR*)
    - NCDOT



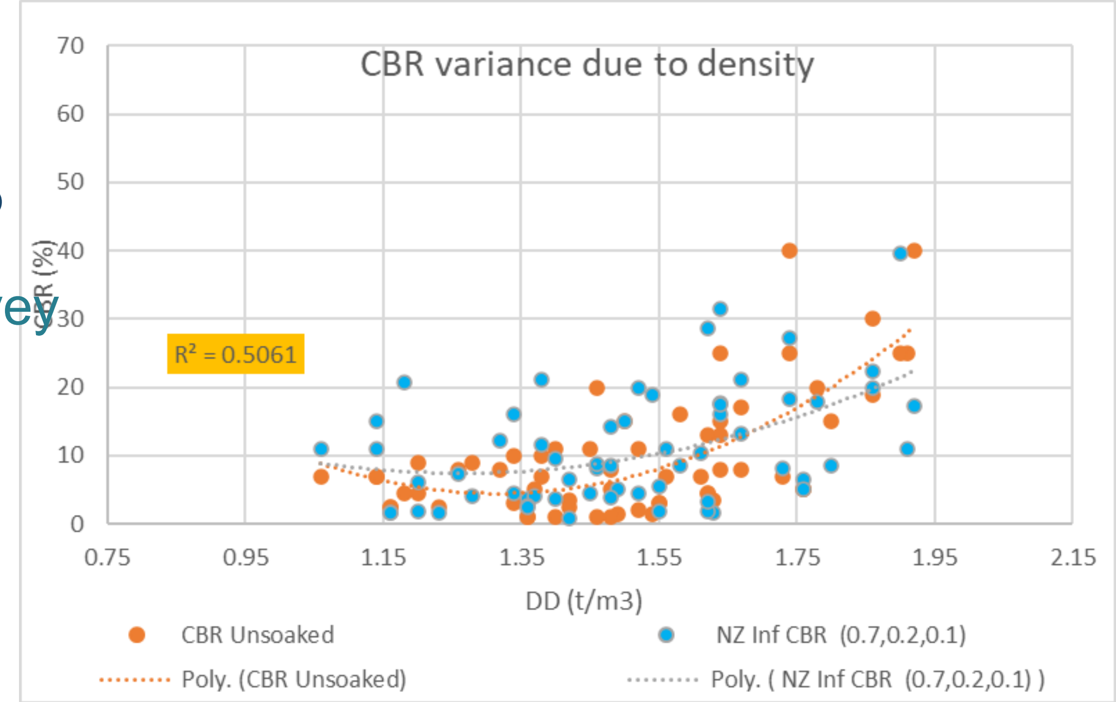
from Kleyn 1982

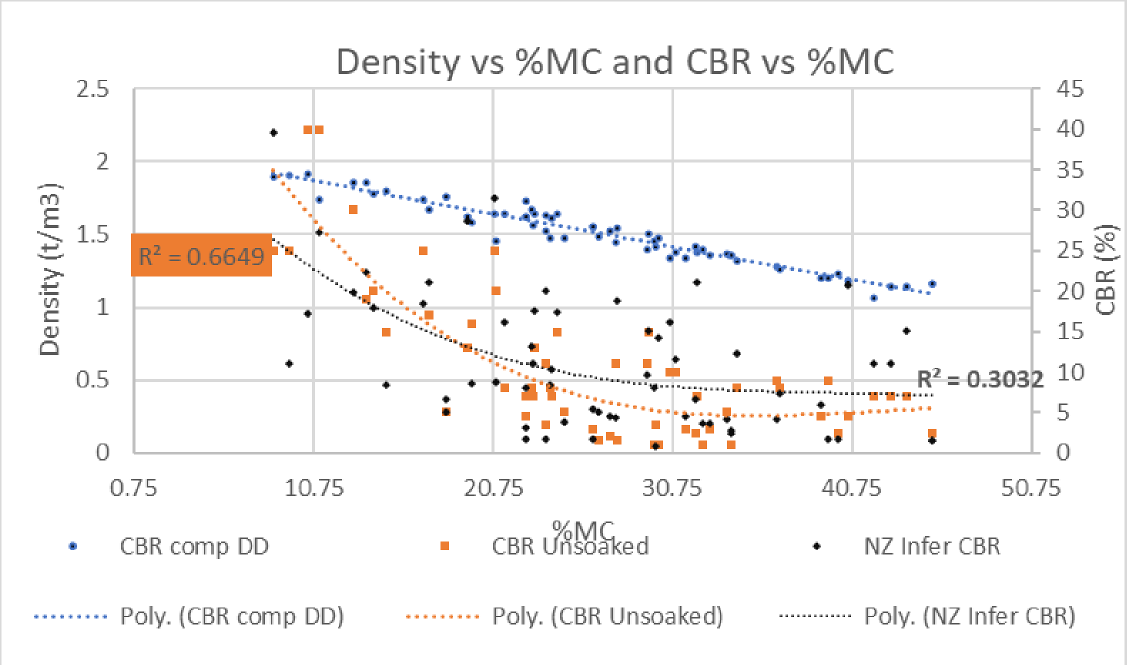


Subgrade DCP/CBR tests

N.I Clays, Silty clays, Clayey Silts & Sandy clays, Clayey sands

- Trends only: Not from a single source so inherent variability, however….
- Each sample has DCP Inferred CBR & Unsoaked CBR.
- CBR & Inf CBR vs DD:
  - Similar (?) trends
- CBR vs %MC: ??
  - Good Unsoaked CBR correlation
  - Fairly poor DCP Inferred CBR correplation

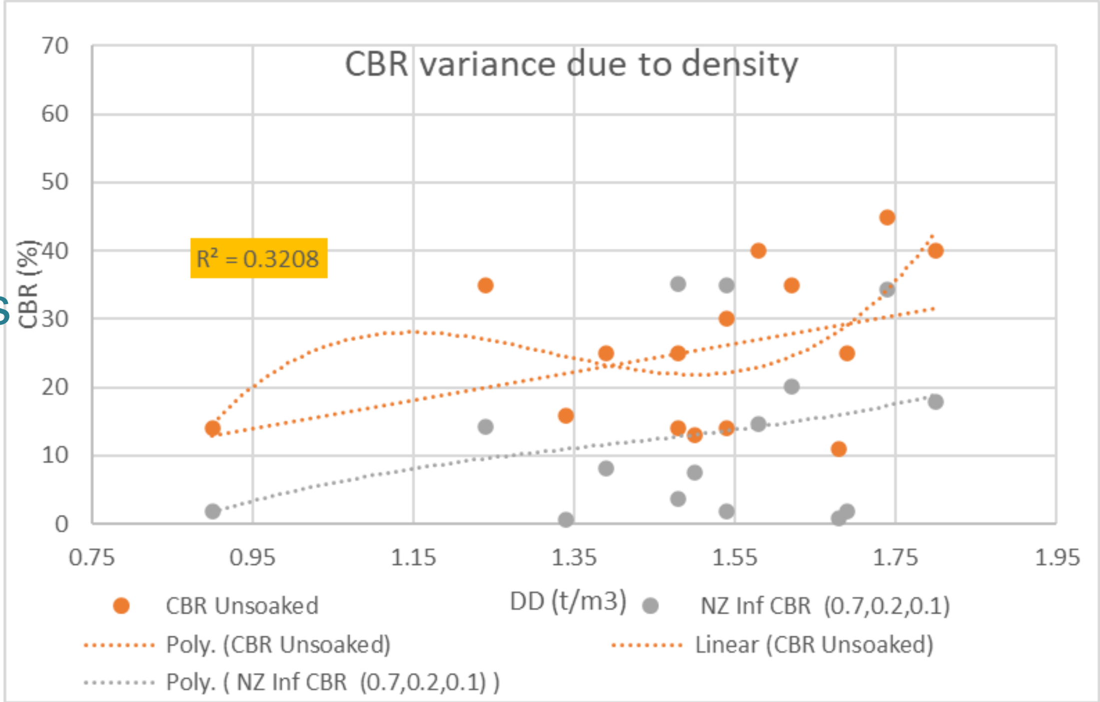


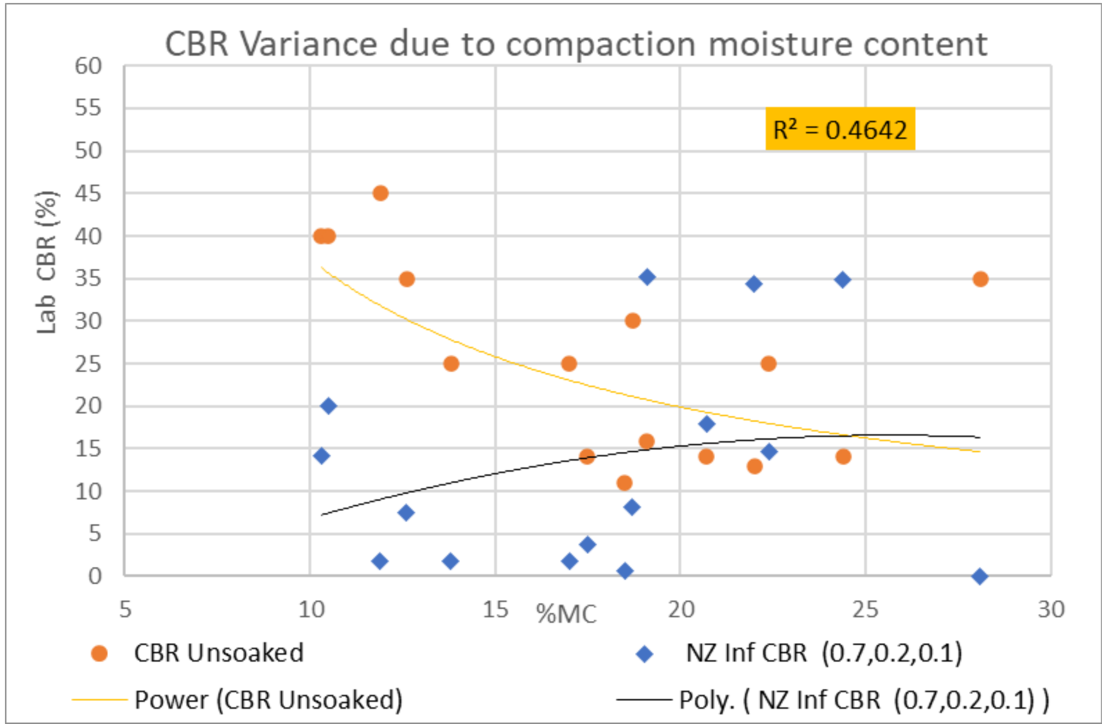


Subgrade DCP/CBR tests

Fine-grained Pumiceous Silts, Silty sands & Sandy silts

- Same set as previous
- Each sample has DCP Inferred CBR & Unsoaked CBR.
- CBR vs DD: Similar trend, but shift…
- CBR vs %MC: ??





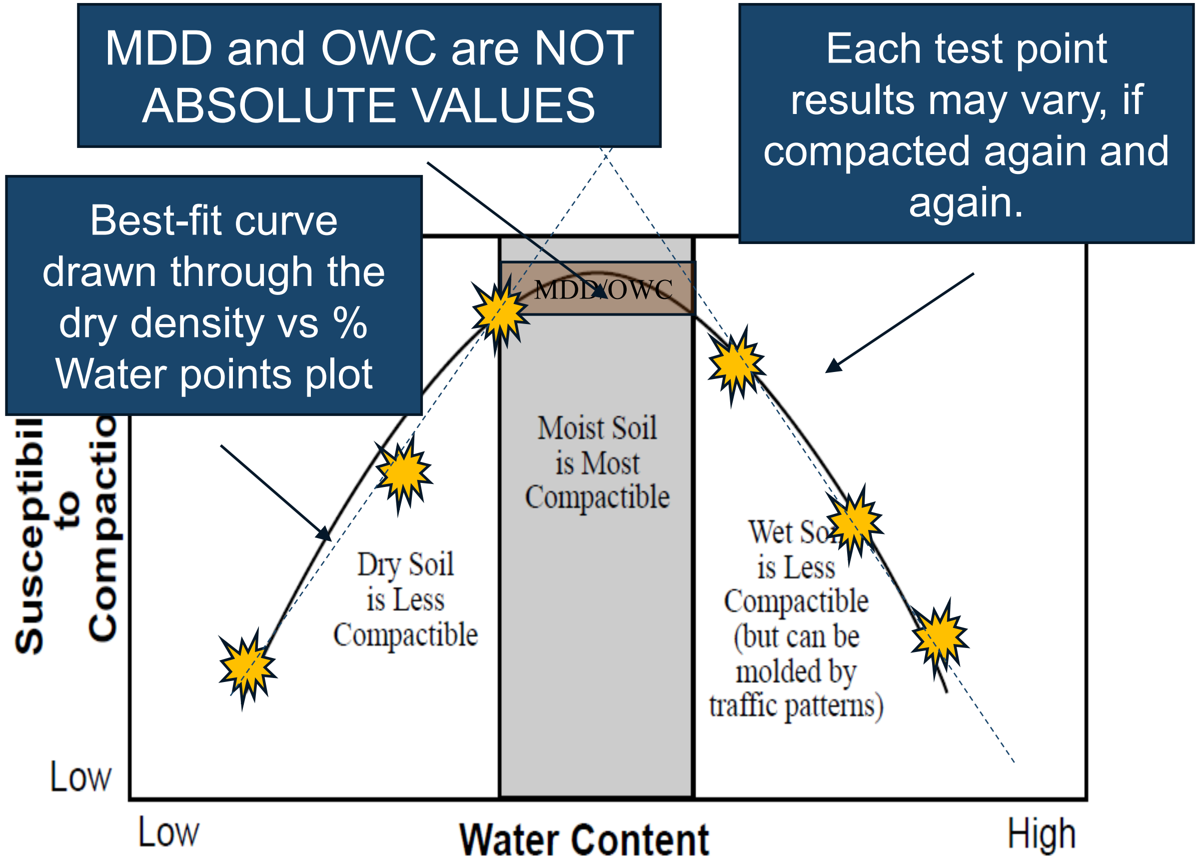
What can we change??

Factors affecting compaction

1. **Moisture Content (MC)**

2. **Material type -** grading, shape, maximum size, plasticity

3. **Compaction –**

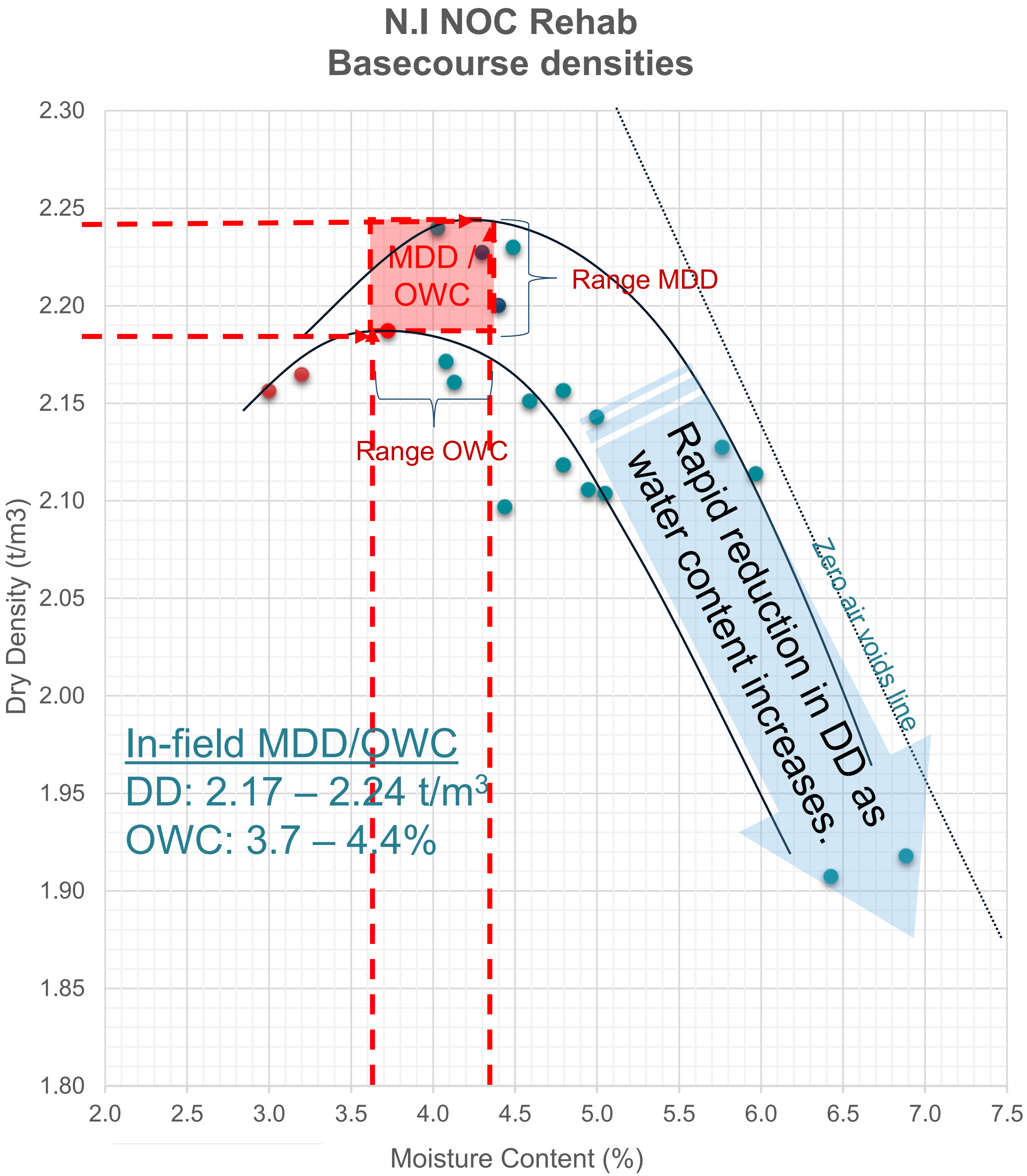


Extract from "Soil Compaction: Problems and Solutions", Department of Agronomy, Kansas State University

1. Water

MDD vs compaction water content

- Each point's result may differ slightly if tested again and again.
- Maximum dry density & optimum water content. achieved when dry density starts decreasing as water content increases.
- MDD and OWC not an exact point but a range.
- Similar trends for ALL material types but non-cohesive materials *may* have another (apparent) MDD at very low water contents.
- Equally applicable in field and laboratory.



1. Water

Compaction water

Different results for individual tests with similar moisture. This is Measurement Uncertainty (ISO/IEC 17025).

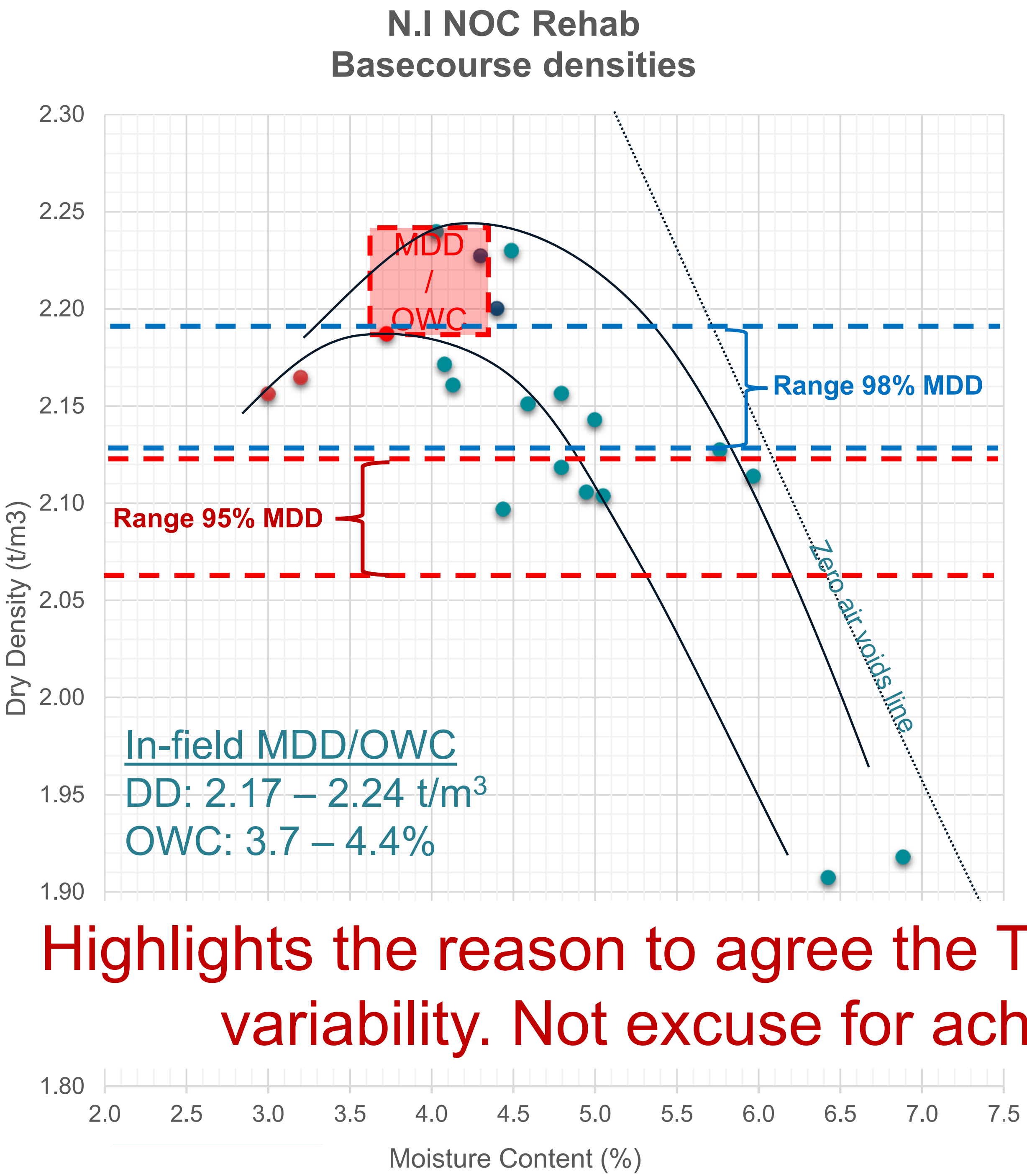
Compaction under or over OWC lead to lower than desired compaction.

Increased risk of:

- Rutting due ‘shakedown’.
- Moisture sensitivity due to increased permeability.
- Shallow shear.

Affect on asset life:

- Decreased pavement stiffness.
- Reduced fatigue life (stabilised layers).
- Ultimately accelerated deterioration.



1. Water

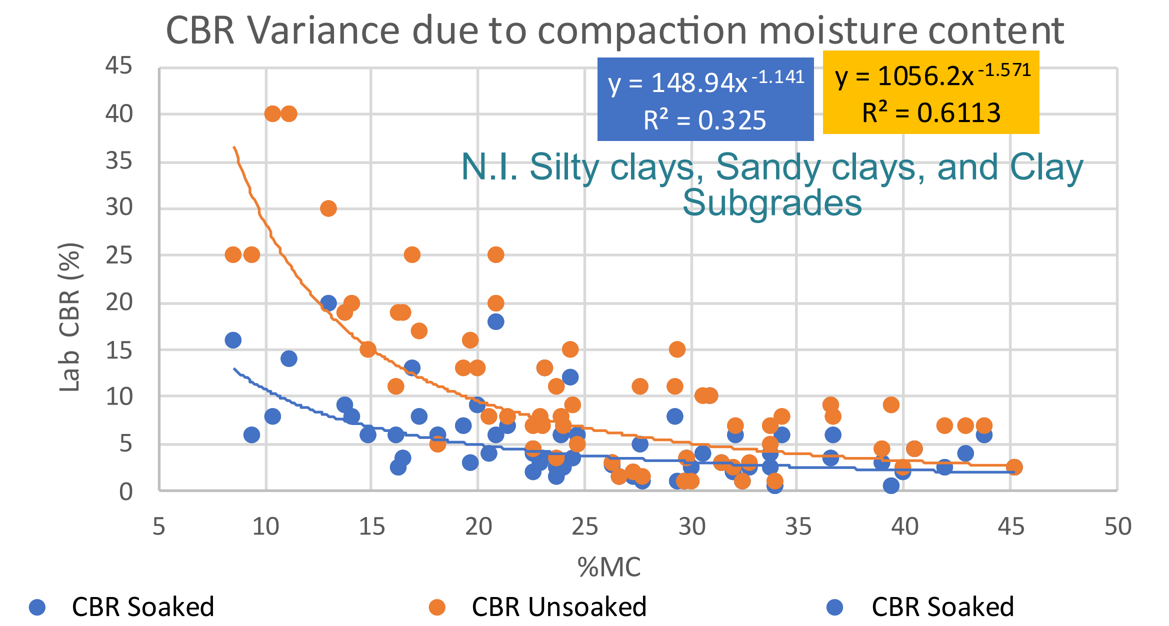
Compaction moisture and in-situ water

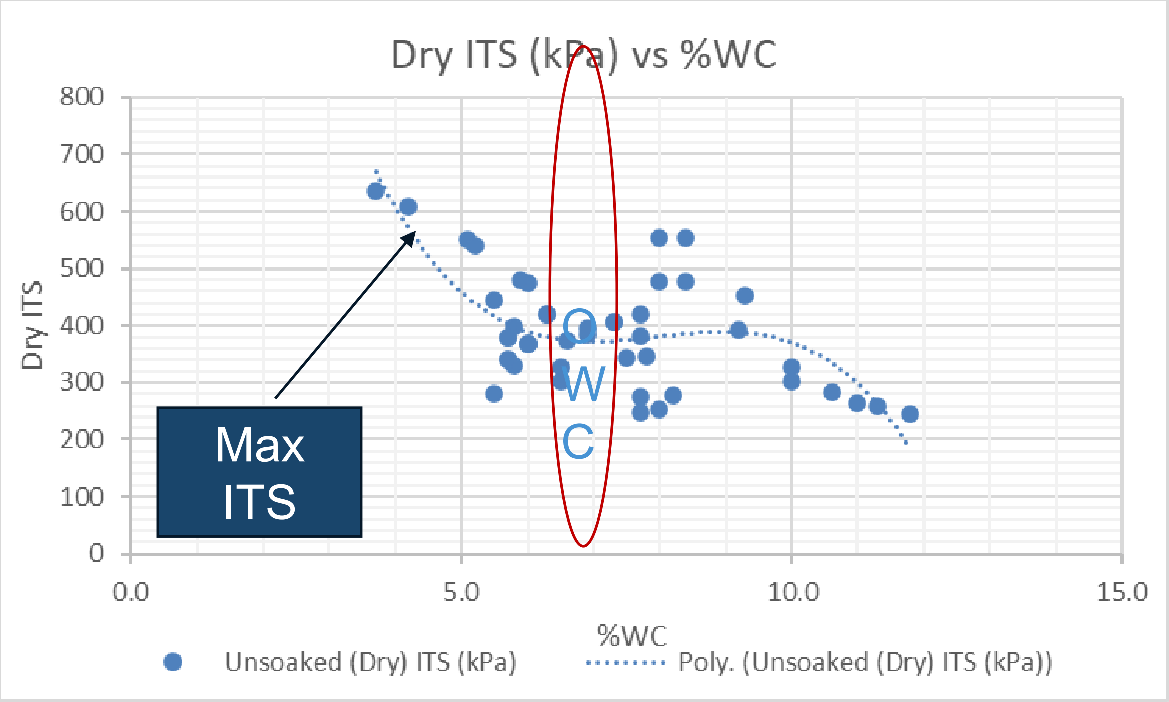
- High %WC (>OWC) leads to low density
- Increased risks:
  - Compliance failure – density normally drops rapidly on the wet side of the curve;
  - Reduced bearing capacity of layer;
  - Rutting and shallow shear.
- Compaction specs allow for variability.

Highlights the reason to agree the Target Density & understand densities variability. Not excuse for achieving low compliance density.

1. Water

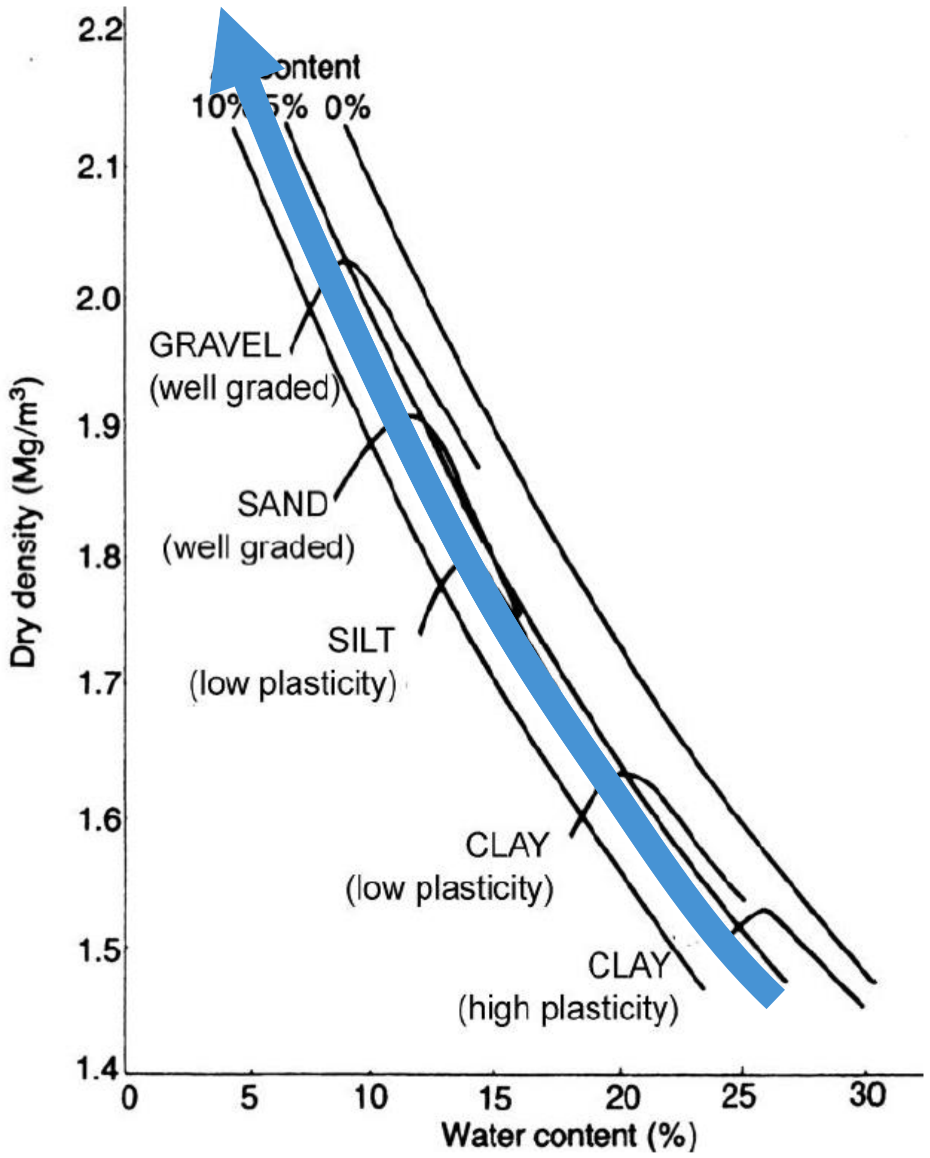
- *Increase in moisture* causes reduction in soil strength, *irrespective of soil type or test type (CBR, ITS, UCS, RLT)*.
- *Main factor in road damage*, especially in thin flexible pavements, causing
  - Weaving during construction (lower layers especially)
  - Shallow shear failures
  - Rutting
  - Potholing
  - Pavement deformation





2. Material Type

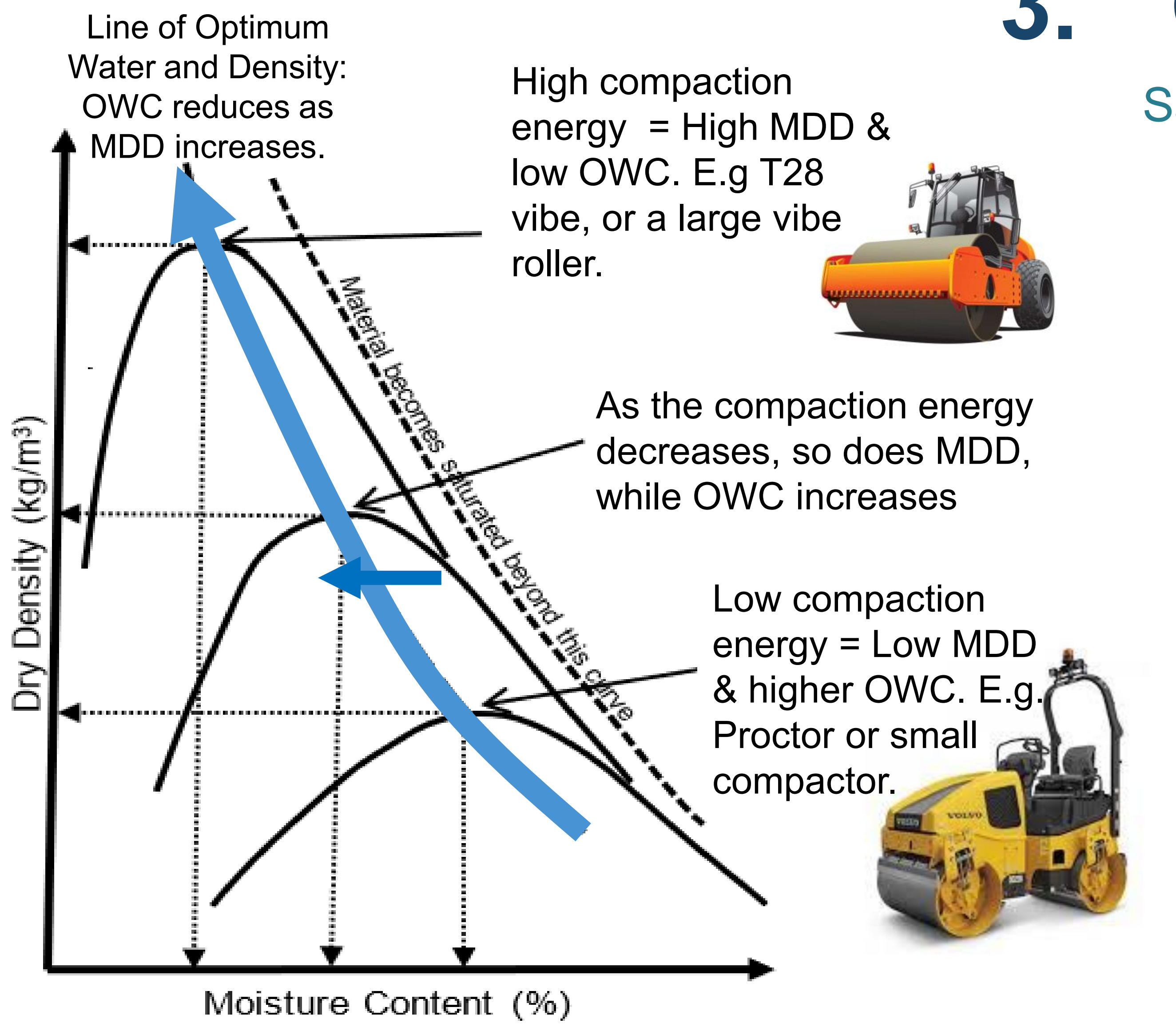
- Increased DD with ‘better’ material, but lower OWC.
- Particle Size Distribution: Well graded soil compact to higher density and generally have a higher load bearing capacity.
- Clay particles
  - Low quantities - Compaction aid.
  - High quantities - difficult to expel air and wate, and low shear resistance.
- Prime driving factors in choosing <u>type</u> of compaction equipment.



Example of density increase vs optimum water content change due to material type under <u>the same compaction effort</u>.

3. Compaction Energy

Same material, different compaction

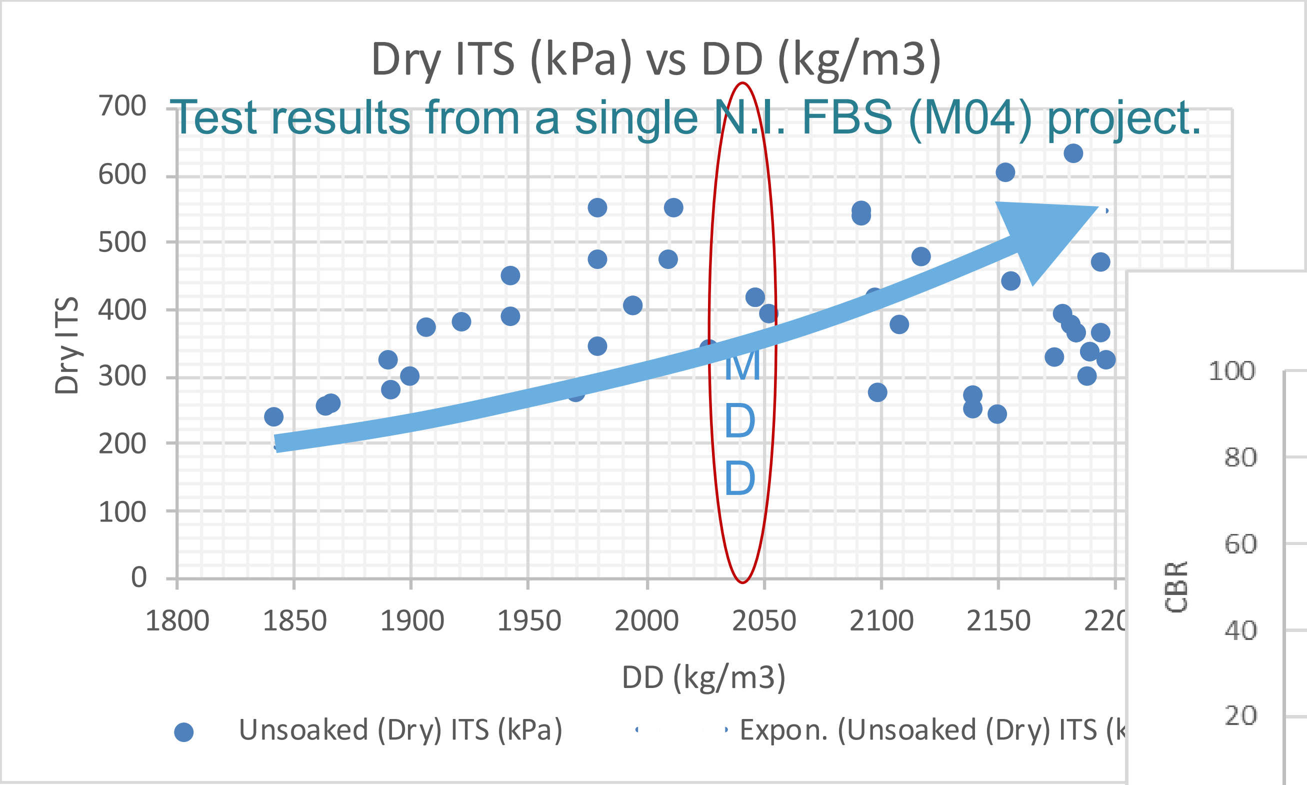


- As compaction effort increases, the MDD increases, and the OWC decreases.
- Similar trend for ALL materials.
- Equally applicable in field and laboratory.

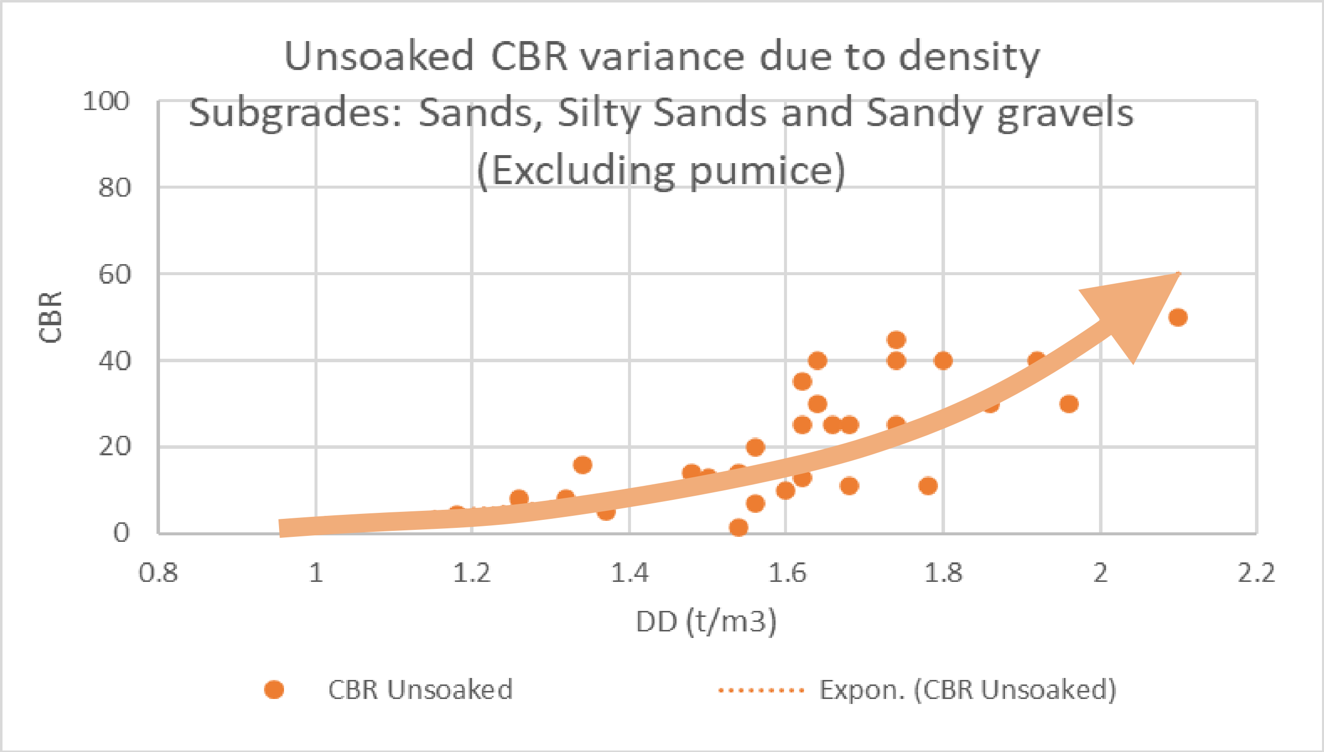
Increasing passes with will increase density but …. only to the effective depth, after which the density won’t increase, irrespective of the roller mass and number of passes.

3. Compaction Energy

Strength variance due to density

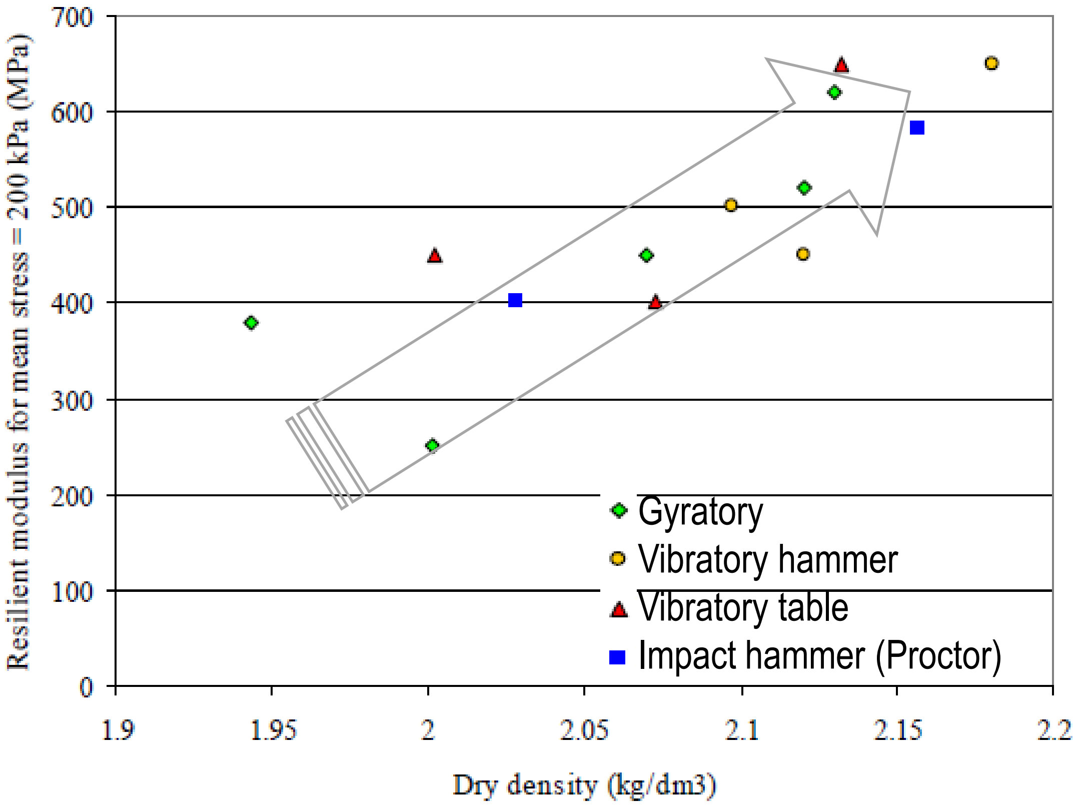


- Trend with significant variability – Increase in strength with increase in density, irrespective of material or test.



Compaction

Effect of compaction density on Resilient Modulus (MR)



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- Low construction density will likely result in early life rutting and possible shallow shear.

Note: This paper reports on a Swedish aggregate and cannot be translated to NZ aggregates without testing.

What can we change??

Factors affecting compaction

1. **Moisture Content (MC)**
   - Compact multiple MC% (OWC vs Dry vs Wet)?
2. **Material type -** grading, shape, maximum size, plasticity
   - Cant do anything about it. We haver what we have.
3. **Compaction –**
   - Compact multiple density (Std vs Heavy)?
   - Do MDD and then 1 x CBR?
   - DO 3 CBR at same %MC, making sure that DD are similar. Similar to T19 ITS & some AU states.

Questions?

Any questions, clarifications, or comments on guides or specifications, please send to

pavements@nzta.govt.nz