Moving on from CBR – Embracing a Modulus-Based Approach

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Conference Presentation

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Overview

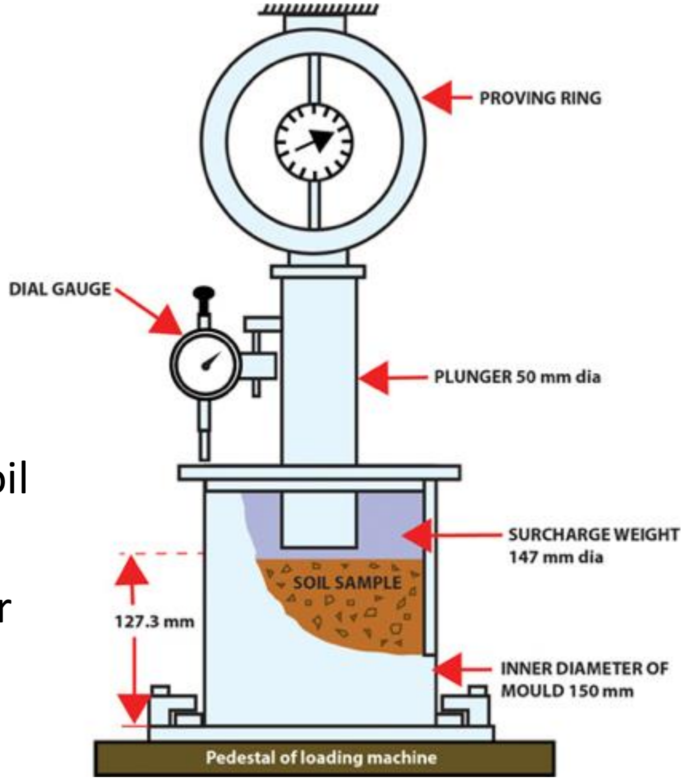
- Why this topic matters
- Structure: Moisture → CBR → Limitations → Modulus → Field Testing Methods → Benefits → Case Studies → Pathway to Adoption

Sensitivity of Pavement Materials to Moisture

- Moisture regime strongly influences pavement performance
- Modulus/strength and CBR depend on moisture content
- Design CBR should reflect 'equilibrium' moisture (worst case - post wettest season)
- Sensitivity by soil type:
    - Gravels / Sandy soils: Minor effect on strength/modulus
    - Silty soils: Large strength/modulus changes
    - Clay: Major changes in volume & strength/modulus.
- For design modulus, test at expected field moisture & compaction at road shoulder
- Use soaked conditions for areas where pavement likely to be regularly inundated, or where subgrade within 1m of water table
- Moisture is critical for both modulus and CBR approaches

What is CBR and What it's not?

- Index test
  - Penetration resistance vs crushed stone
  - INDEX of strength
- Plunger penetration into soil at controlled rate
- 50mm plunger – result at 2.5mm or 5mm
- Not a true engineering property
  - CBR was never intended to be a universal soil strength measure
  - Neither a strength nor a modulus parameter



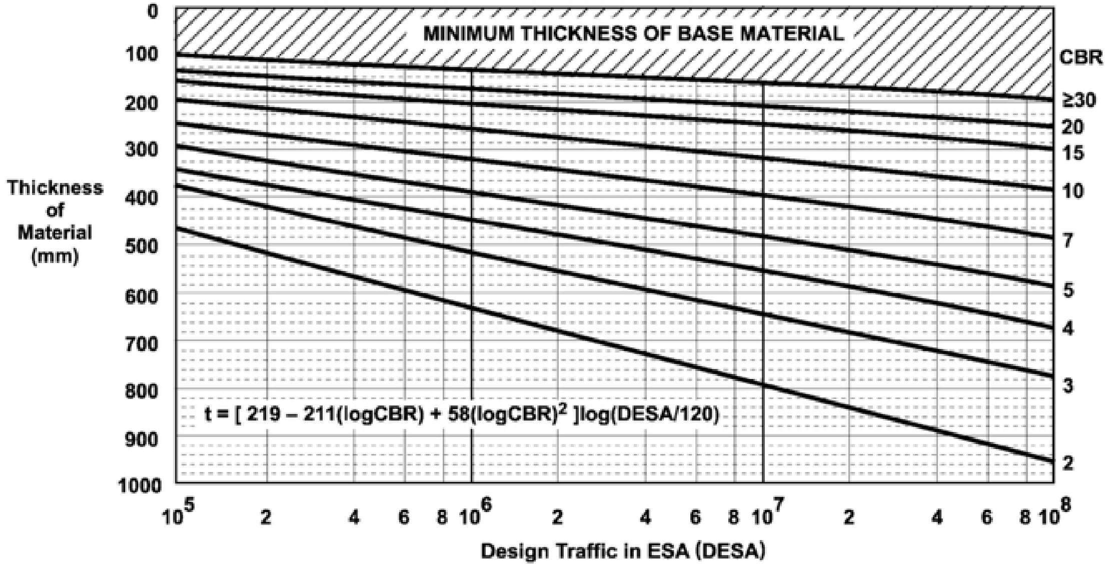
CBR Origins

- California Bearing Ratio
- Developed 1930s by California Division of Highways
- Still used in low-volume road design
- Simple and cheap, but outdated

How CBR is Used

- Layer thickness design for pavements
- Embedded in Austroads & NZTA standards
- Charts from airfield/runway design origins from 1950 US Corp of Engineers, in-situ CBR tests and subgrade shear failure

Figure 8.4: Design chart for granular pavements with thin bituminous surfacing



Misuses of CBR

- Applied to foundations, slope stability, rigid pavements
- Empirical only – no shear strength or modulus
- Can lead to risky or conservative designs
- Allowable design CBR for a multi-layer pavement configuration is capped

Table 7.3.5 – California bearing ratio requirements – Type 3

Property	Subtype						
	3.1		3.2		3.3	3.4	3.5
Compaction standard (refer Clause 8.4.3)	Modified	Standard	Modified	Standard	Standard	Standard	Standard
CBR (unsoaked)	Not specified	≥ 80	Not specified	≥ 60	≥ 45	≥ 35	≥ 15

MRTS05 Unbound Pavements - July 2022 – Department of Transport and Main Roads, Queensland

Limitations of CBR

- Empirical, not mechanistic
- Moisture and compaction sensitive
- Inability to capture cyclic behavior
- Poor repeatability/reproducibility
- Not suitable for coarse materials (>19mm)
- Slow turnaround times

Variability & Risks

Review of recent NATA vs NZ PT/ILC 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 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

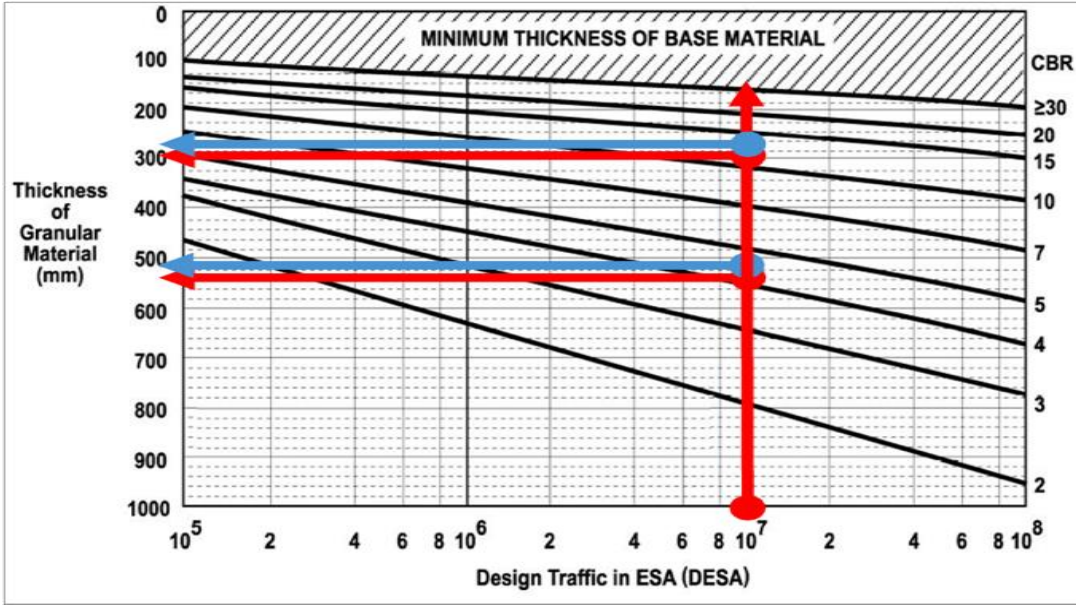
FAIR SIL NC RISK

SIGNIFICANT PASS/FAIL RISK

Proficiency Test Variability & Implications - NZTA CBR Working Group

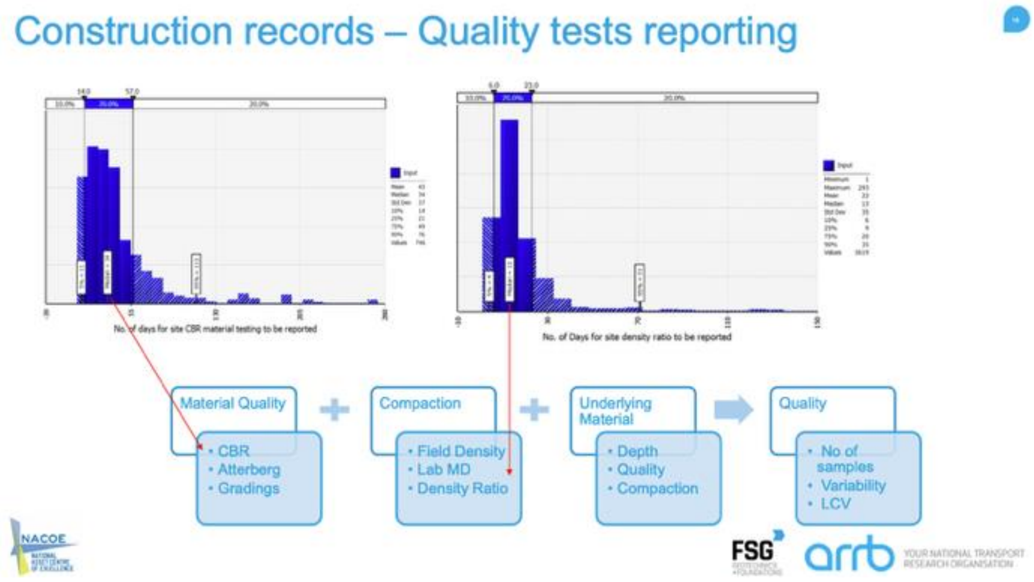
Variability & Risks

- Significant scatter in test results
- Reproducibility issues across labs
- Example: pavement thickness difference ±260mm from variability



Turn around time and Complexity

- Based on 746 CBR
- Time from site testing to certificate issue:
  - 5% within 11 days
  - 70% between 14 - 57 days
  - Median: 34 days

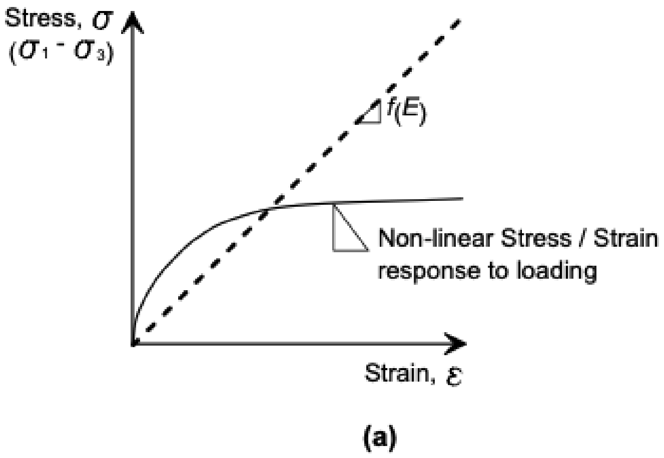


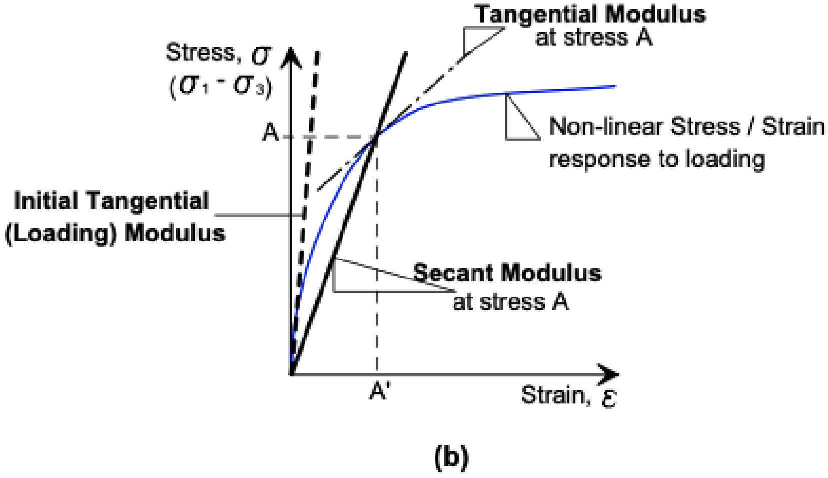
Turn around time and Complexity

- Timing affected by:
  - Material type
  - Required surcharge & soaking period
  - Laboratory workload
- Soaked CBR results often take longer than project timelines
- Frequently, materials are covered before results are available
- Logistics for samples in remote areas

Modulus as a Fundamental Property

- Stress-strain stiffness = true engineering property
- Directly used in mechanistic-empirical design
- Types: Elastic Modulus (E), Resilient Modulus (Mr)





a) elastic phase modulus (Young's modulus, E) (b) definition of typical modulus values

CBR vs Modulus Relationship

"The vertical modulus of subgrade can be determined from laboratory testing of conditioned specimens (Thompson & Robnett 1976) or by using the empirical relationship (Equation 2).

This equation is, at best, an approximation and modulus has been found to vary in the range 5 × CBR to 20 × CBR (Sparks & Potter 1982).

This equation may overestimate the subgrade moduli for soils with relatively high CBRs and hence should only be used for CBR ≤ 15. A maximum value of 150 MPa is normally adopted for subgrade materials."

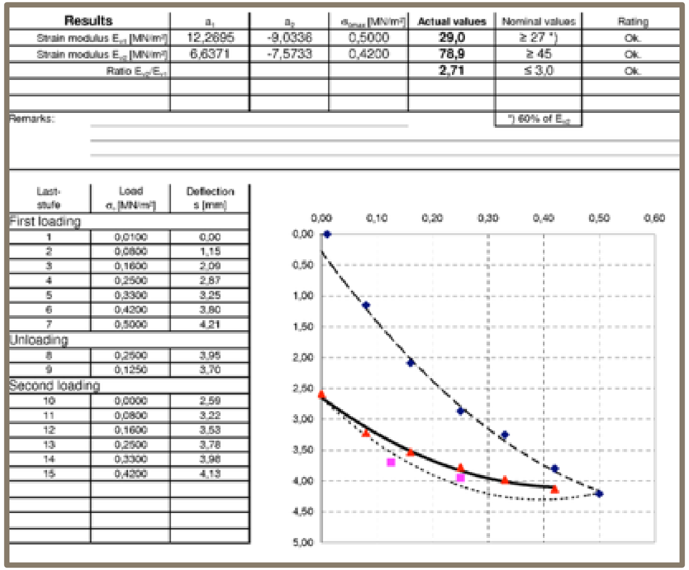
- E = 10 × CBR (approximation, unreliable)
- Range 5–20 × CBR → ±300% error possible
- Modulus is the preferred input for design – used in Circly

Advances in Modulus Testing

- Plate Load Test (PLT)
- Light Weight Deflectometer (LWD)
- Falling Weight Deflectometer (FWD)
- Intelligent Compaction (IC)

Plate Load Test (PLT)

- Measures Ev1, Ev2, k-value
- Reliable, repeatable (<10% variation)
- Zone of influence ~2 × plate diameter



Results	a_1	a_2	σ_{0max} [MN/m²]	Actual values	Nominal values	Rating
Strain modulus E_{v1} [MN/m²]	12,2695	-9,0336	0,5000	**29,0**	≥ 27 *)	Ok.
Strain modulus E_{v2} [MN/m²]	6,6371	-7,5733	0,4200	**78,9**	≥ 45	Ok.
Ratio E_{v2}/E_{v1}				**2,71**	≤ 3,0	Ok.

Remarks: *) 60% of E_{v2}

Last-stufe	Load σ_0 [MN/m²]	Deflection s [mm]
First loading		
1	0,0100	0,00
2	0,0800	1,15
3	0,1600	2,09
4	0,2500	2,87
5	0,3300	3,25
6	0,4200	3,80
7	0,5000	4,21
Unloading		
8	0,2500	3,95
9	0,1250	3,70
Second loading		
10	0,0000	2,59
11	0,0800	3,22
12	0,1600	3,53
13	0,2500	3,78
14	0,3300	3,98
15	0,4200	4,13

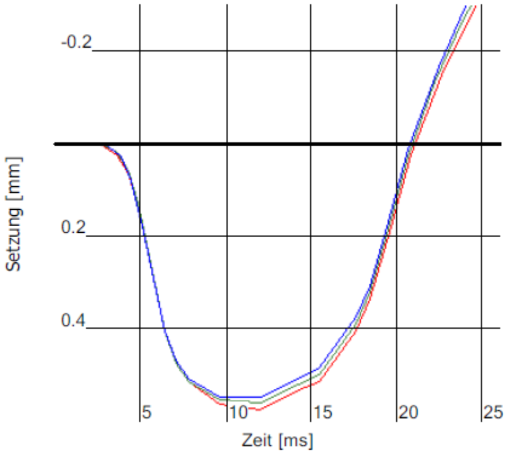
Light Weight Deflectometer (LWD)

- Portable, fast, provides modulus (Evd)
- Zone of influence ~1.5 × plate diameter
- Simulates truck wheel load
- Immediate GPS-located results

Stoß	v [mm/s]	s [mm]
1	181.9	0.575
2	184.4	0.563
3	183.6	0.554
Ø	183.3	0.564

Ergebnis **Evd: 39.89 MN/m²**

s/v: 3.077ms

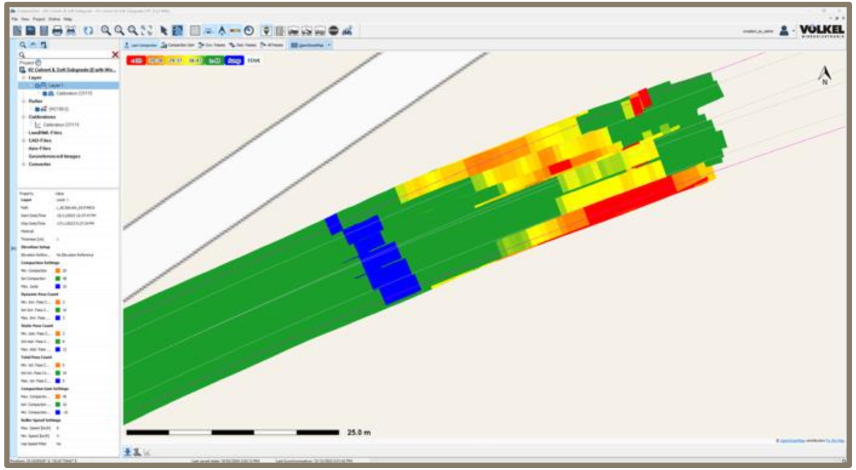


Falling Weight Deflectometer (FWD)

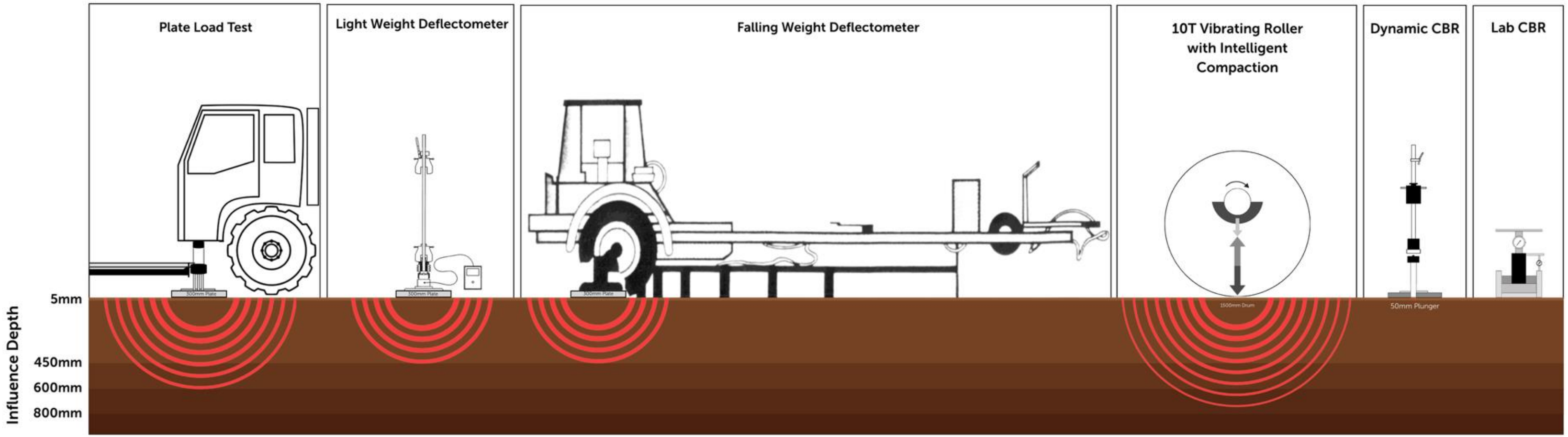
- Deflection bowl analysis → layer modulus
- Used for network-level pavement evaluation
- Quick non-destructive testing

Intelligent Compaction (IC)

- Roller-integrated stiffness measurement
- Real-time stiffness indication and pass count colour coded plots
- Still requires calibration (LWD/PLT)



A System of Pavement In-situ Modulus Testing



- Design inputs
- Enables the design parameters to be assessed in the field during construction
- Indication of how the pavement will perform under traffic loading
- Empower contractors - increase productivity, lower cost, improve quality, reduce risk

Lab & Field Linkages

- Resilient modulus Mr vs Elastic modulus E (PLT then to LWD)
- Lab-LWD on Proctor mould → strong correlations (R^2 0.79) for Lab-LWD vs Resilient modulus

Material Type	Degree of Compaction (D_{pr})	PLT – Reloading Cycle Modulus (E_{v2})	Zorn Brand Light Falling Weight Deflectometer (E_{vd}) – Modulus @ 100 kPa (300 mm Dia. Plate)
Gravel dominated materials – GW / GP (Inc. Aggregate materials)	≥ 103 %	≥120 MPa	≥ 65 MPa
	≥ 100 %	≥ 100 MPa	≥ 50 MPa
	≥ 98 %	≥ 80 MPa	≥ 40 MPa
	≥ 97 %	≥ 70 MPa	≥ 30 MPa
Sand dominated materials – SW / SP	≥ 100 %	≥ 80 MPa	≥ 50 MPa
	≥ 98 %	≥ 70 MPa	≥ 40 MPa
	≥ 97 %	≥ 60 MPa	≥ 35 MPa
Mixed and fine grained soils	≥ 100 %	≥ 45 MPa	≥ 25 MPa
	≥ 97 %	≥ 30 MPa	≥ 20 MPa
	≥ 95 %	≥ 20 MPa	≥ 15 MPa

CBR vs Modulus Comparison

- CBR: index only, poor repeatability, not cyclic
- Modulus: true stiffness, mechanistic, repeatable
- Better alignment with modern design

Property	CBR Test	Modulus-Based Tests
Measured Output	Penetration resistance (index)	Stress–strain stiffness (true property)
Repeatability	Low	Moderate - High
Suitability for Mechanistic Design	Poor	Excellent
Sensitivity to Field Conditions	High	Moderate
Relevance to Cyclic Loading	None	Direct

Engage. Envision. Excel.

Benefits of Modulus-Based Approach

- Real time results
- Improved accuracy
- Reduced conservatism
- Enhanced construction QA
- Supports risk management
- Longer-lasting, lower lifecycle cost pavements

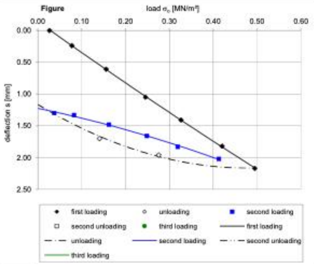
Case Study - RAAF Tindal P500

- Royal Australian Air Force (RAAF) Base Tindal
- Project part of the U.S. Force Posture Initiative (USFPI) and aims to support training exercises and enhance the collective response capability of both the U.S. and Australian air forces in the Indo-Pacific region
- Build a new apron capable of parking six large Code E aircraft, such as USAF B-52 bombers, and associated facilities including fueling infrastructure and lighting.
- The work has involved LWD and LWD with CBR extension as well as Plate Load Tests to assess CBR and Modulus rather than wait for lab results.

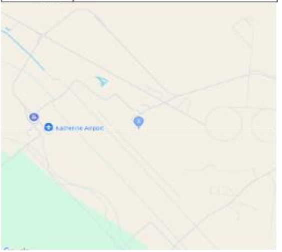
Plate Bearing Test according to DIN 18134-300

Institute:		Record number:	114
Client:	Bear Claw	Card number:	210422102458
Project:	Tindal	Start of test:	30/6/25 18:28
Test depth:	Surface	End of test:	30/6/25 18:44
Layer:	Lot 46	Device number:	8211
Remarks:		Ø-Plate:	300 mm
Weather/Temp.:		Lever ratio:	-1:1.00
Operator:	Geotechnics		
Equipment:	Manufacturer: Anix GmbH, LVDT sensor 15mm, force sensor 100kN	Lat.:	-14.5125150°
		Lon.:	132.3735867°

No.	Load σ_0 [MN/m²]	Deflection s [mm]
first loading		
1	0.0268	0.00
2	0.0779	0.24
3	0.1558	0.61
4	0.2457	1.05
5	0.3266	1.41
6	0.4203	1.82
7	0.4948	2.17
unloading		
8	0.2759	1.96
9	0.1409	1.70
second loading		
10	0.0376	1.30
11	0.0828	1.33
12	0.1625	1.48
13	0.2488	1.66
14	0.3191	1.83
15	0.4129	2.02
second unloading		
third loading		



Results			
	Actual	Nominal	Rating
σ_{1max} [MN/m²]	0.4948		
E_{v1} [MN/m²]	**48.35**		
E_{v2} [MN/m²]	**109.38**	45	OK
E_{v2}/E_{v1}:	**2.262**	2.2	failed
E_{v3} [MN/m²]			
E_{v3}/E_{v1}:			
Westergaard modulus:	94	MN/m³	
remarks:			



Case Studies

- Australian and New Zealand examples
  - Inland Rail – upgrade of freight route Melbourne to Brisbane
  - Ipswich Motorway Upgrade - Rocklea to Darra (R2D) - QLD
  - Bruce Highway (Cooroy to Curra) Section D - QLD
  - Wide Bay Highway and Bruce Highway interchange - QLD
  - Transmission Gully Motorway - NZ
  - NACOE Research (NTRO & DTMR) – P60 Best Practice in Compaction QA for Pavement and Subgrade Materials
  - Council roads
  - Access tracks (windfarms, mine haul roads)
  - Darwin Ship Lift Facility
  - RAAF Tindal P500

Case Studies

- Consistent modulus data → allows pavement designers to optimise pavement thickness with confidence
- Improved QA and performance outcomes

International Practice

- Caltrans abandoned CBR in the early 1950s in favour of R-value, and formally transitioned from R-value-based empirical pavement design to resilient-modulus-based mechanistic–empirical design on 20 May 2022.
- Caltrans (2022) and others have moved from CBR → modulus
- Aligns with mechanistic-empirical design globally

Roadmap for Adoption

- Encourage field modulus testing
- Continue raising industry awareness
- Update Austroads / NZTA specification

The tools exist - we need policy and practice shifts

Key Takeaways

- CBR is outdated and highly variable
- Modulus = fundamental, mechanistic, repeatable
- Field technologies make modulus practical now

Conclusion

- Time to move on from CBR
- Modulus supports smarter design, better QA, lower costs

Empowering You to Break New Ground

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