Pavement Construction QA

Predicting Finished Level Deflections (FLD) from in-situ deflection testing during construction at subgrade and/or subbase level

Sam Wong, Gina Schmitz, Dave Stevens & Graham Salt

16TH NZ TRANSPORT AGENCY & NZIHT ANNUAL CONFERENCE

NZ TRANSPORT AGENCY WAKA KOTAHI / nzihT institute of highway technology

Introduction

Current QA Practice for Greenfield Projects

- Typically require deflection testing at different levels as a quality assurance check
- To confirm assumptions made during design are achieved/appropriate
- Often confirmation is only obtained after basecourse or surfacing has been placed, and intervention at that stage, if needed, is typically more expensive.
- Therefore, it is proposed that deflection testing is done at an early stage (on exposed subgrade, subgrade improvement layer and/or subbase) to confirm if:
  - subgrade stiffness assumed is suitable,
  - expected finished level deflection is within the targeted value, and
  - sufficient compaction has been done on the applied layer(s).

Introduction

Advantages of construction QA and finished level deflection prediction at the early stage of construction include:

- Early confirmation on whether final design expectations (or contractual requirements) can be met
- Possibility of intervention (e.g. additional overlay requirements, additional compaction) at an early stage if existing design requirements cannot be met.

Any form of in situ deflection testing could be used, but in order of preference:

(i) FWD with plate stress level appropriate for the finished condition (or due allowance made otherwise)

(ii) LWD with correction for stress level

(iii) Benkelman Beam with correction for stress level

(iv) Static plate load test (with correction for stress level and dynamic loading)

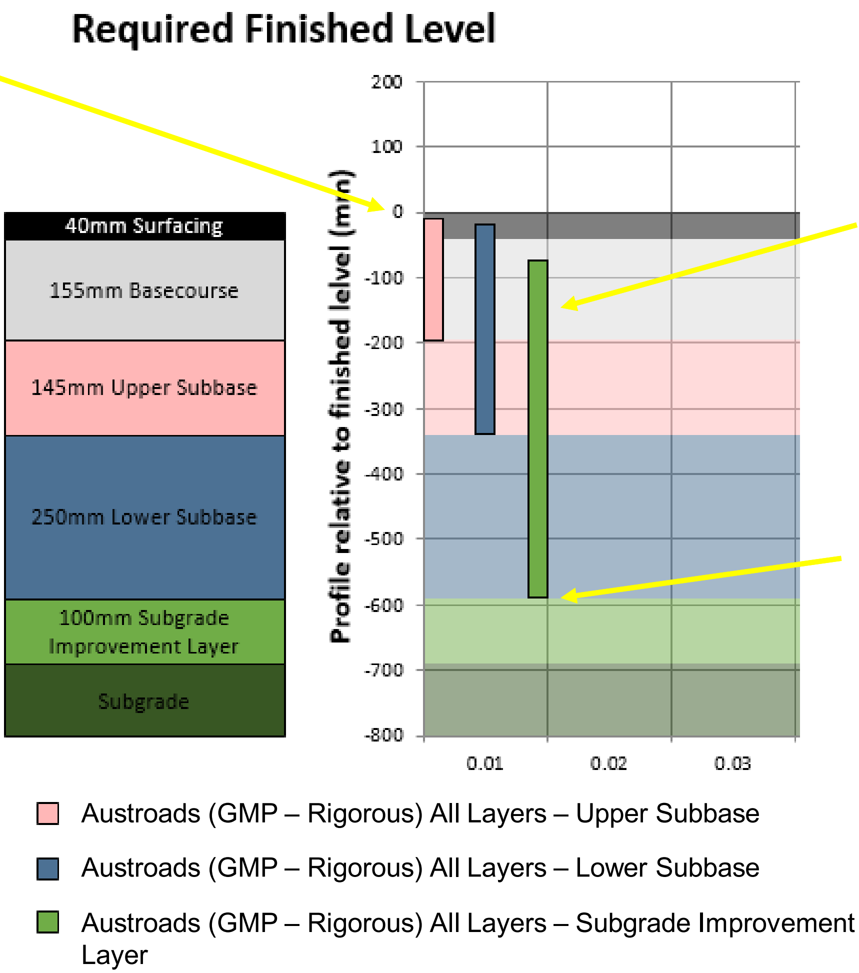
Possible outcomes from this process include:

- Additional aggregate thickness requirements
- Finished level deflections – if any specification requirements
- Comparisons with Austroads' modular ratios – compares construction quality with Austroads expectations

QA Output – Additional Aggregate Requirement

Design finished level.

Vertical bars that exceed this level indicate design thickness may be insufficient at the tested location.

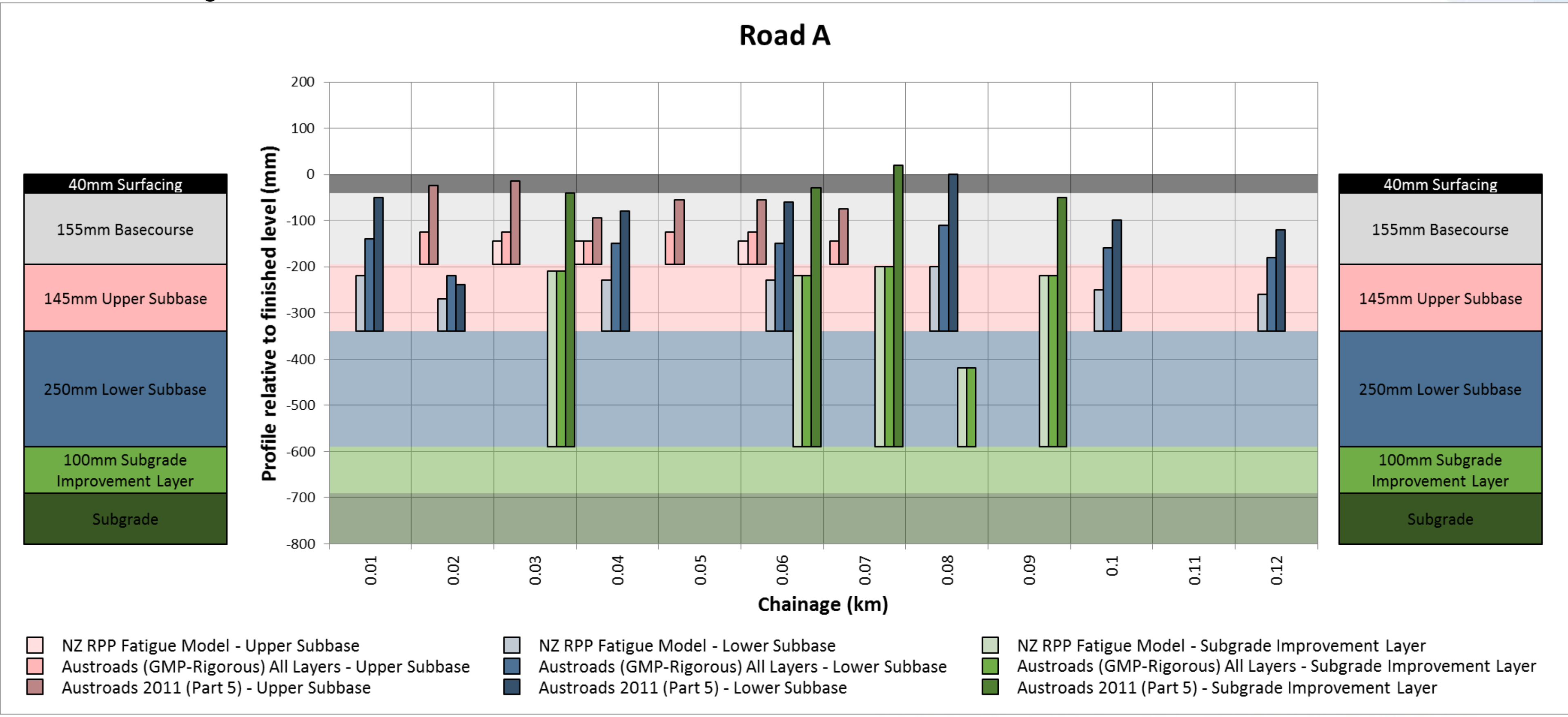


Vertical bars on the graph show additional aggregate thickness required (mm) from the tested level. In this example, the Austroads GMP method is used.

Tested level (in this case, the subgrade improvement layer)

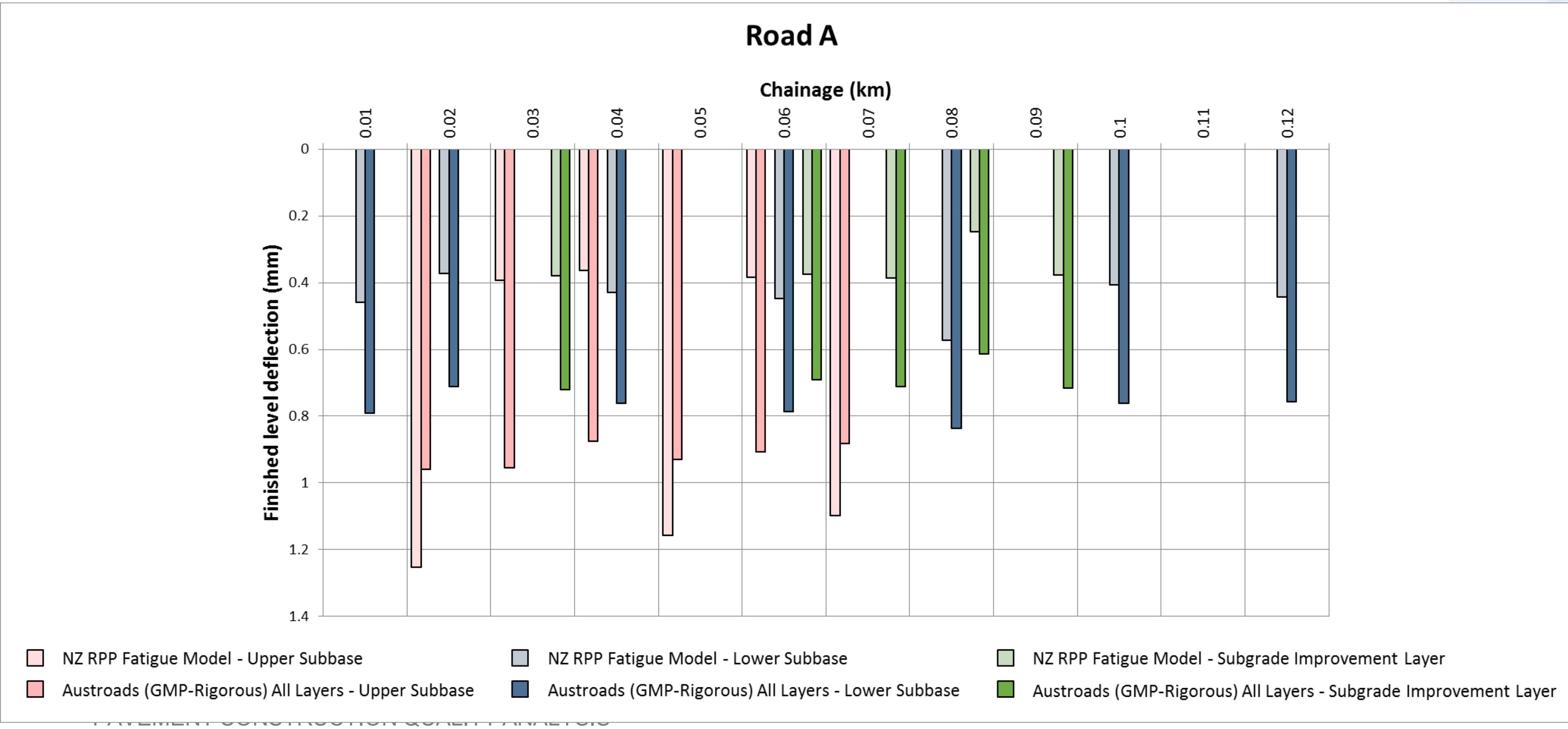
Example QA Output - Additional Aggregate Requirement

Additional aggregate thickness requirements from testing on subgrade improvement layer, lower subbase and upper subbase. Three design criteria were used here.



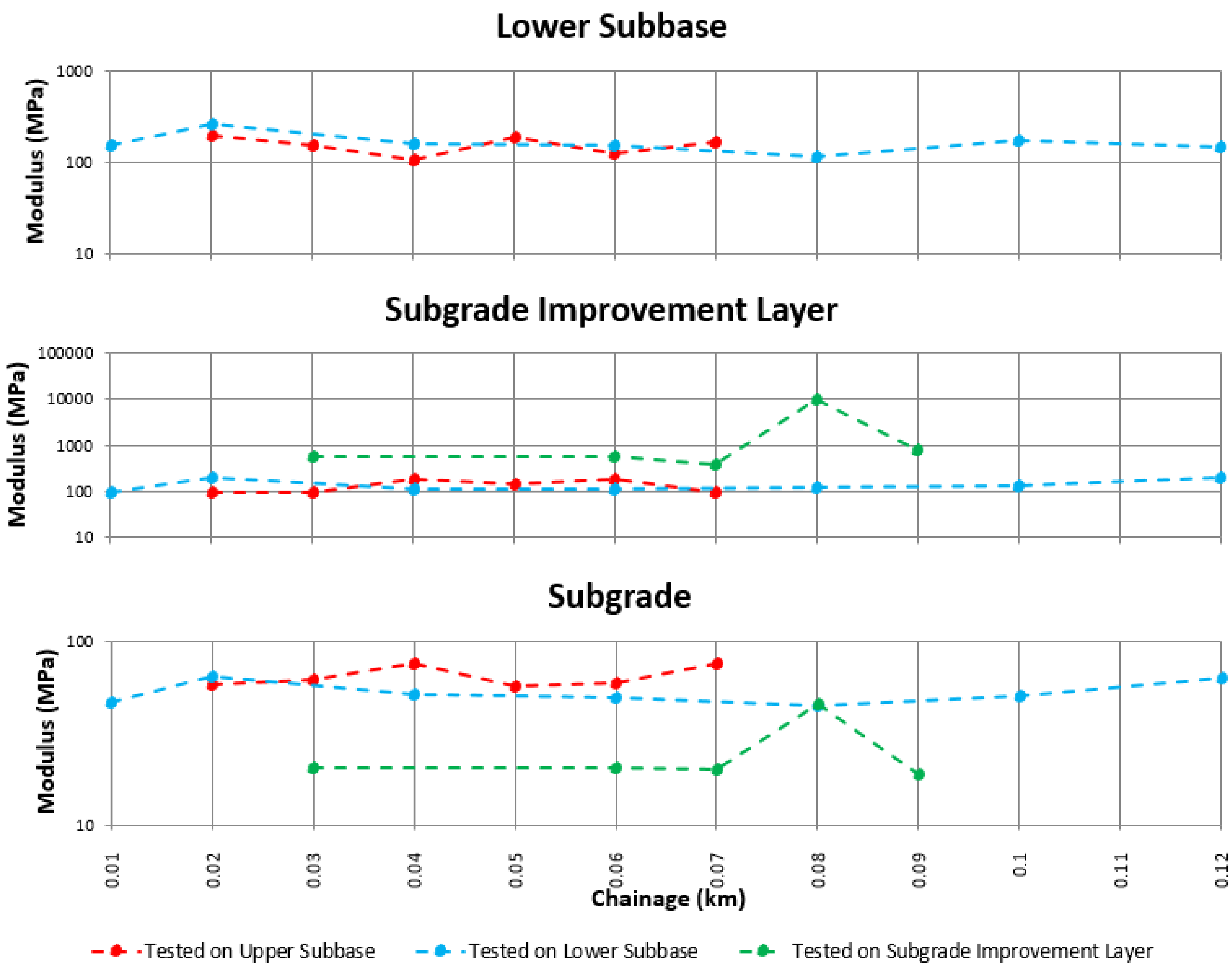
Example QA Output –
Alternative Presentation for Finished Level Deflections

Finished Level Deflections predicted from testing on subgrade improvement layer, lower subbase and upper subbase.



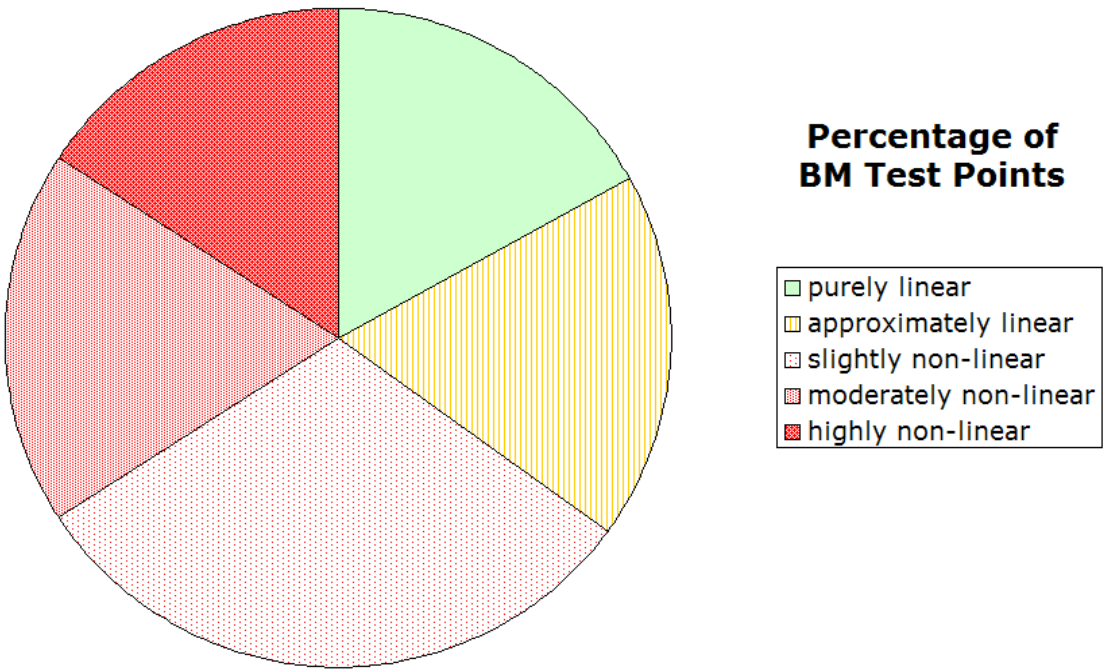
Example QA Output - Layer Moduli   Stress/Strain Dependence

Layer moduli achieved from testing on subgrade improvement layer, lower subbase and upper subbase.



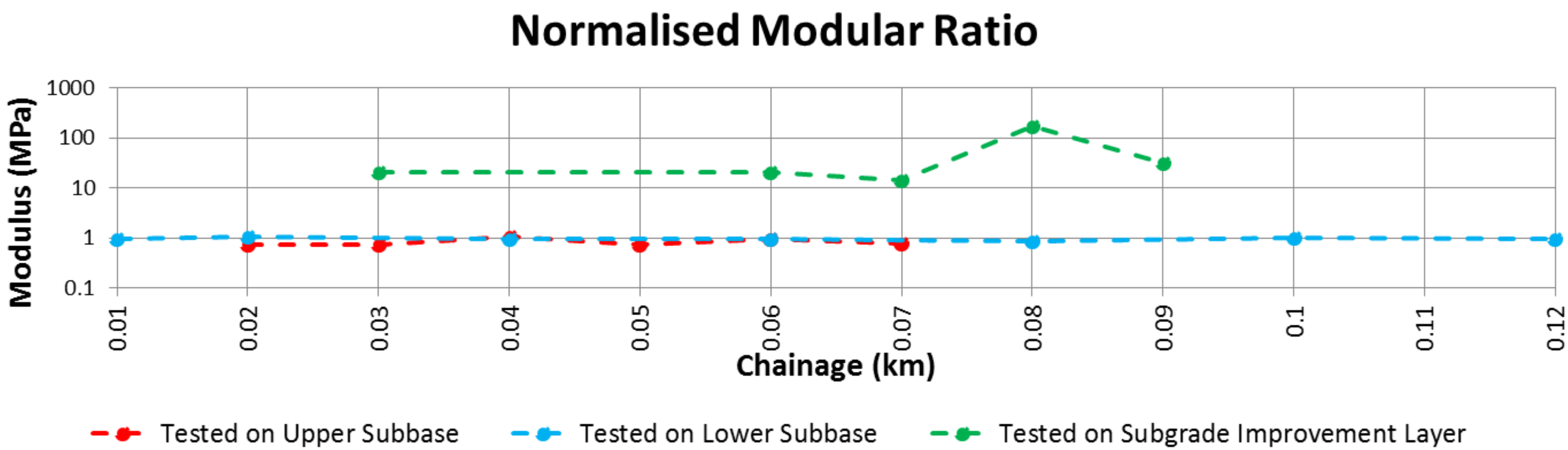
Non-Linear Moduli - Are they significant?

Two thirds of NZ pavements have non-linear subgrades (much greater percentage than in Australia). Due consideration is essential for meaningful predictions.



Example QA Output - Modular Ratio Achieved cf Austroads Expectations

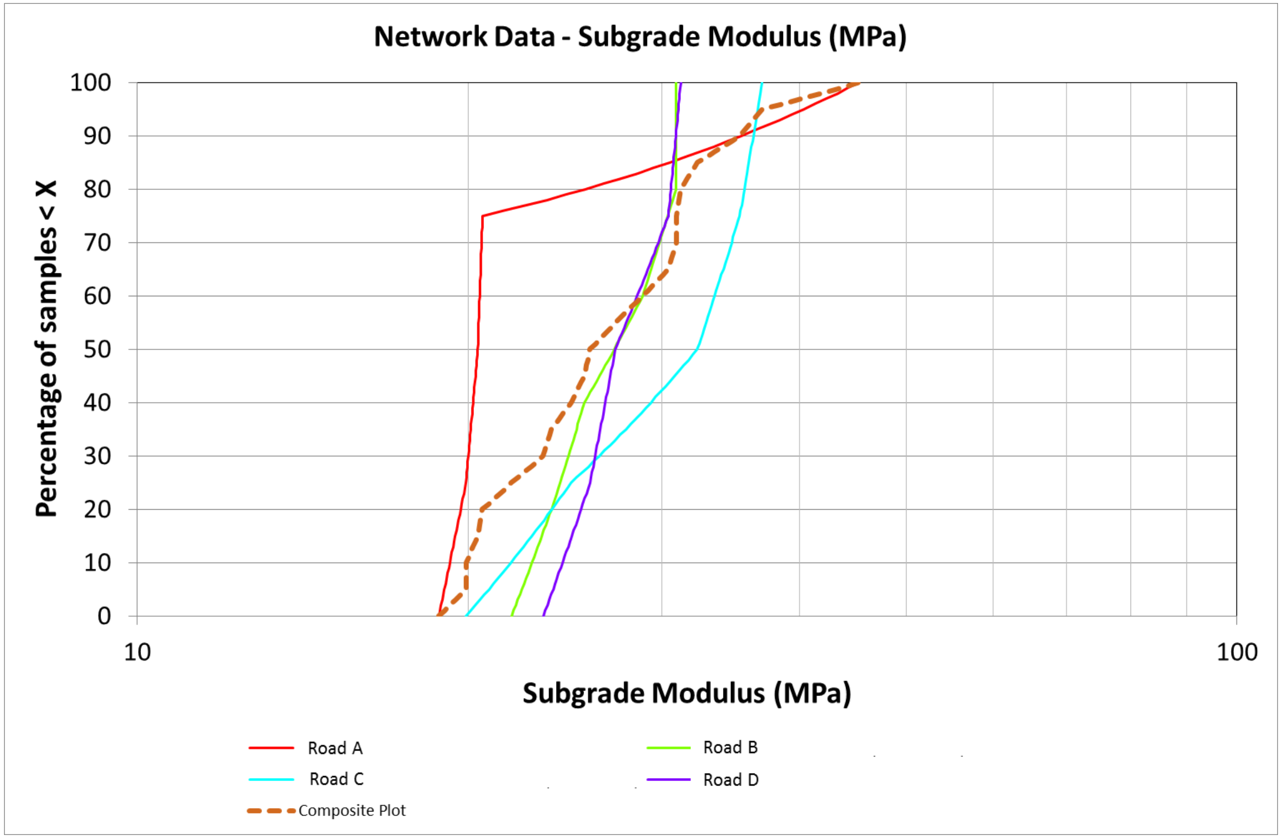
Ratio of moduli between successive overlying layers, compared with Austroads expectations for a new pavement. Values greater than 1.0 indicate good compaction. Example of results from testing on lower subbase and upper subbase shown below.



$$NMR = (E1/E2)_{\text{measured}} \; / \; (E1/E2)_{\text{Austroads}}$$

Example QA Output – Subgrade Modulus (Cumulative Distribution)

Cumulative distribution of empirical and mechanistic outputs

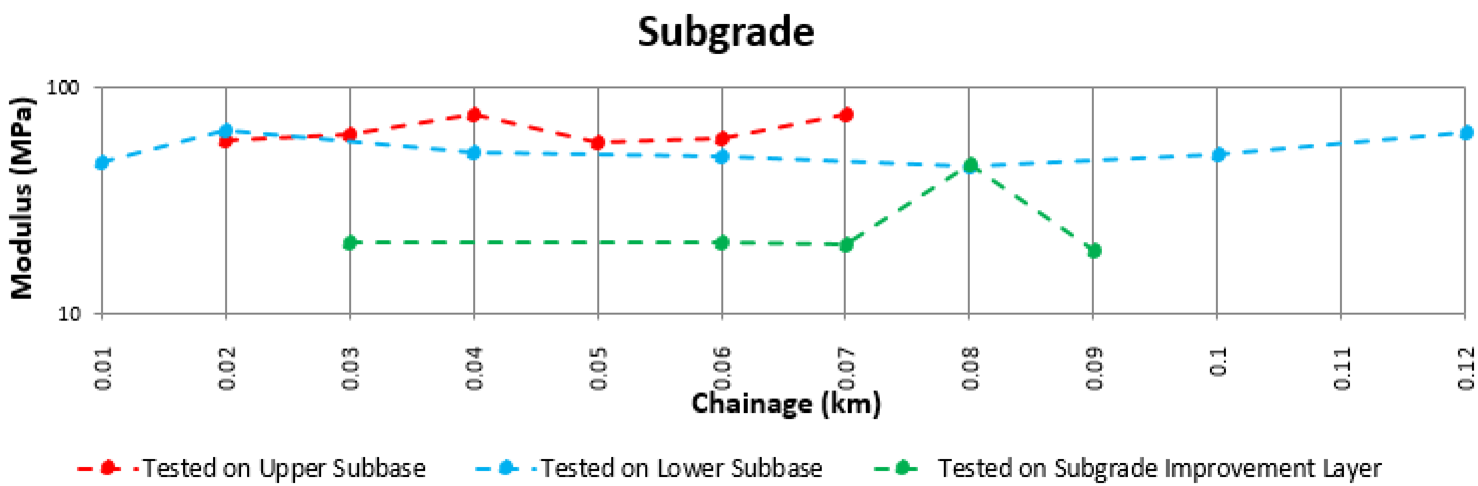


FLD Research

In practice, the stiffness of each pavement layer (which ultimately affects the finished level deflection) is far from constant, as shown in the example below.

Main factors affecting the stiffness include:

- Applied stress level (for non-linear elastic materials)
- Depth of confinement
- Seasonal variations (e.g. temperature and rainfall)



Research Objectives

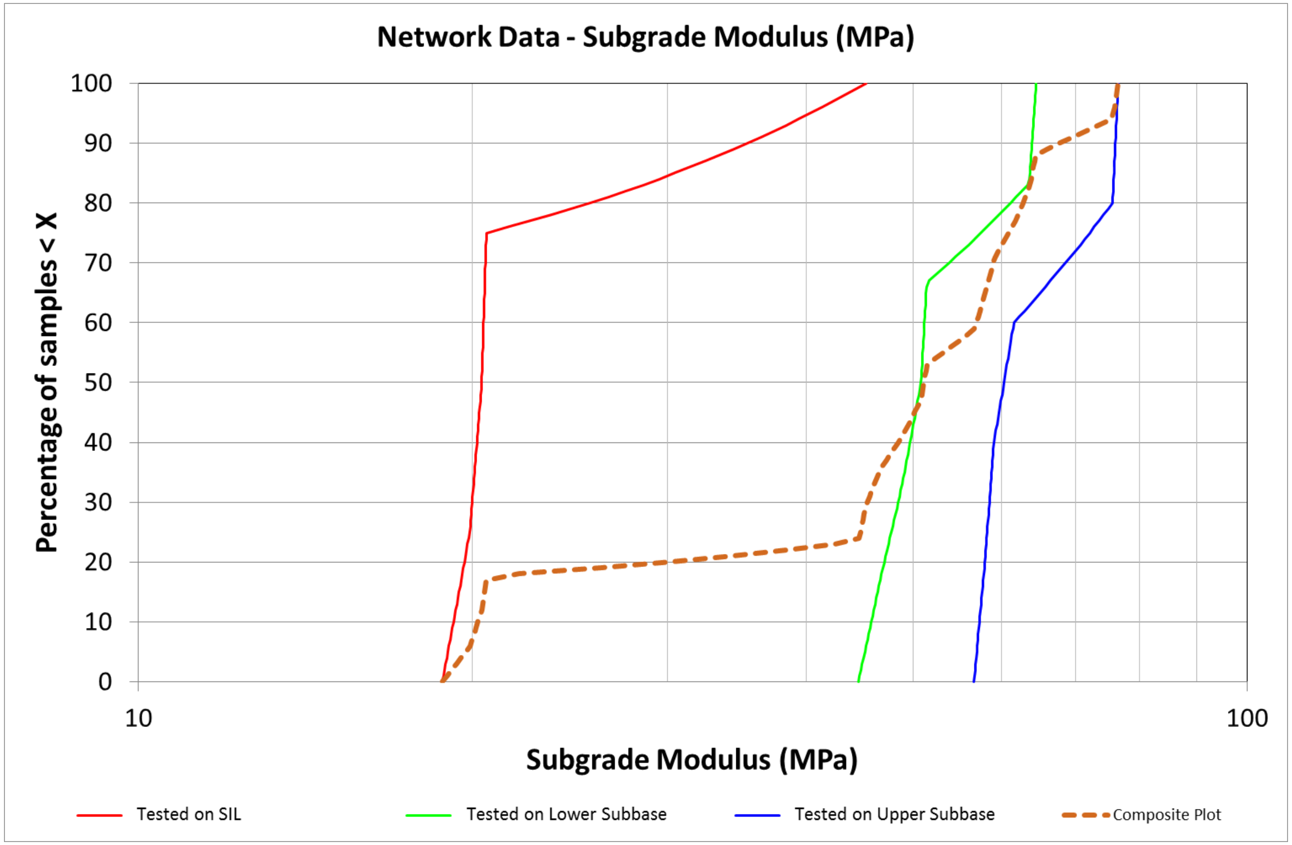
1. To quantify benefits of detailed construction QA testing, particularly during early stages of construction
2. To refine models for predicting the deflection on a finished pavement utilising measurements during construction of deflection on subgrade and/or subbase layers

FWD Testing

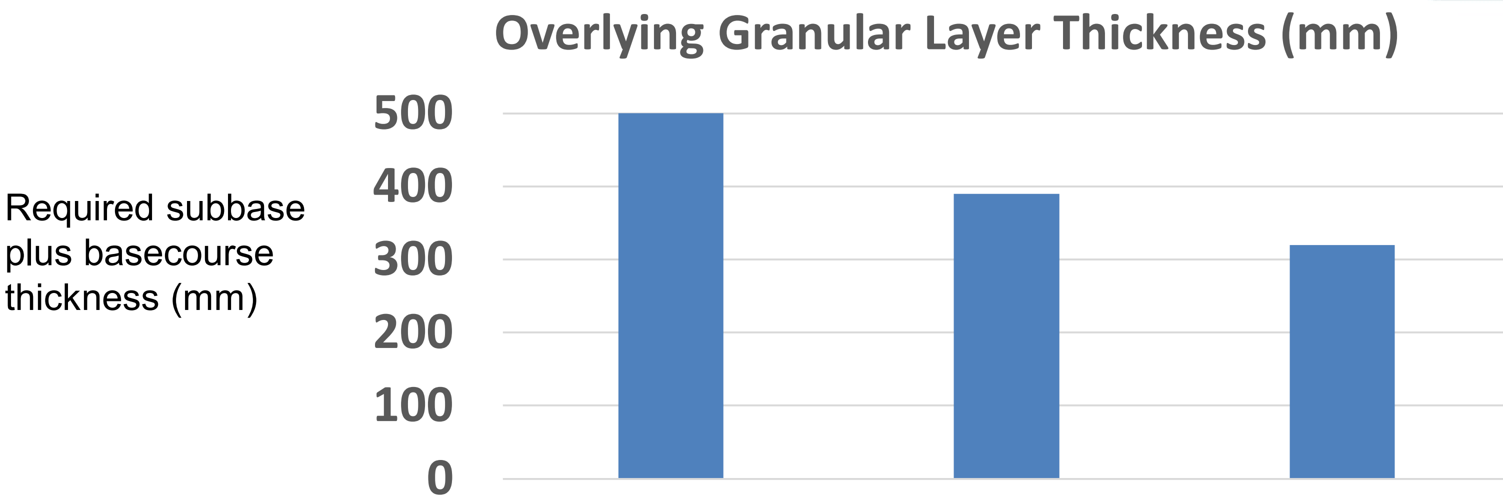
Method :		Austroads deflection (linear elastic similar)		ELMOD		ELMOD plus regional calibration.
Modulus Dependence		Constant		Deviator Stress		Deviator Stress plus Confinement
Comments		Inclusion of psuedo rigid layer at depth, can generate any lesser deflection that is desired but vertical strain at top of subgrade will be wrong.		Traditional method, good when the total increment in pavement thickness is minimal, say less than 100 mm. Otherwise result varies significantly from reality.		Uses regional database of structural analyses to provide a reality check adjustment for confinement, after ELMOD's deviator stress model has been applied.

Effects of Non-Linearity

Stress softening – Moduli increases as stress experienced decreases



Conclusion from FWD Testing on Top of SIL Layer



Method		Austroads deflection (linear elastic similar)		ELMOD		ELMOD plus regional calibration.
Modulus Dependence		Constant		Deviator Stress		Deviator Stress plus Confinement
Function		C		$f\,(1/\sigma 1)$		$f\,(1/\sigma 1, \sigma 3)$

Precedent Performance Design Spreadsheet

Spreadsheet now adapted to automate the iterative procedure for calculating non-linear moduli and strains. Increasing the subgrade modulus results in increases in moduli of overlying granular layers, which in turn provides better loadspread i.e. less stress at top of subgrade and hence greater subgrade modulus. The process is then iterated and essentially converges after 3 or 4 iterations.

Number of Loads	1	WMAPT (°C)	18	NZ - Queenstown	Deviatoric Stress Correction	c0	82.5	MPa	Granular Vertical Strain Criterion	ELMOD 2009 - Granular
Number of Layers	5	Measured Temp. (°C)	18	1.000		n	-0.002		Asphalt Tensile Strain Criterion	Austroads 2012 Figure 6.11
				TNZ Mix 20 (60/70) Basalt					Cemented Tensile Strain Criterion	Ramped Function (E = 3500
Design Life (years)	25	In-Situ AC Modulus (MPa)	2740	TNZ Mix 20 (60/70) Basalt	Confinement Depth Correction	Init Depth	495	mm	FBS Tensile Strain Criterion	NZ LTPP FBS
Asphalt Life (years)	25	In-service Vehicle Speed	10	Default		Init c0	67.0	MPa	Subgrade Vertical Strain Criterion	Austroads Isotropic - Subgrac
		Project Reliability	95.0%			Init n	-0.094			

Criterion	K	n
Granular Vertical Strain Criterion	29771	6.0
Asphalt Tensile Strain Criterion	5373	5.0
Cemented Tensile Strain Criterion	350	12.0
FBS Tensile Strain Criterion		
Subgrade Vertical Strain Criterion	4147	10.9

Load Number	Description of Load	Gross Weight (T)	Tyre Pressure (kPa)	% GW on Half Axle	Dual Spacing (mm)	Wheels per Half Axle	Tandem Factor	Wander Factor	Annual Passes	% Growth	Single Tyre Load (N)	Radius of Load (mm)	*Vertical Strains in the middle of each layer or top of subgrade* Vertical µStrain	Critical Layer	Deflection (mm)	Allowable Repetitions	*Tensile Strains at the bottom of each layer* Tensile µStrain	Critical Layer	Allowable Repetitions
1	ESA	8.2	750	50	330	2	1	1	400000	0	20104	92	1080	1	0.76	3.6E+07	-	-	-

Layer Number	Layer Type	Thickness (mm)	Resilient Modulus (MPa)	UCS (MPa)	Traffic Multiplier	Poisson's Ratio	Modular Ratio	Allowable MR	*Vertical Strain Calculations* CDF	Remaining Life (years)	*Horizontal Strain Calculations* CDF	Remaining Life (years)
1	Unbound Granular	155	450	-	1	0.35	1.8	2.3	0.278	90	0	99
2	Unbound Granular	145	250	-	1	0.35	2.27	2.99	0.16	99	0	99
3	Unbound Granular	250	110	-	1	0.35	2.16	2.64	0.138	99	0	99
4	Unbound Granular	100	51	-	1	0.35	0.62	1.32	0.134	99	0	99
	Subgrade	-	83	-	1	0.35			0.056	99	0	99
		650							0.278	89.9	0	99
	Austroads Fig 8.4 (mm)	292	Pass									

Calculations for Selected Load #: 1					
Design ESA	Vertical Strain	Horizontal Strain	Horizontal Stress	Central Deflection	Curvature
1.00E+07	1080	-326	156	0.76	0.48
1.00E+07	720	-391	48	1.06	0.71
1.00E+07	623	-261	4	1.55	1.17
1.00E+07	604	-178	6	2.17	1.85
1.00E+07	449	-	-	1.68	1.35

1, 566, 756.5, 275.7, 214.7, 156, 119.2, 93.1, 75.1, 54.6, 43.3

Precedent Performance Design Spreadsheet

- Input cells in yellow from FWD test (ELMOD output):
- a) Depth of material overlying subgrade during testing (accounts for confinement of subgrade)
- b) Subgrade modulus at 100 kPa reference stress
- c) ELMOD non-linearity exponent

Deviatoric Stress Correction	c0	82.5	MPa
	n	-0.002	
Confinement Depth Correction	Init Depth	495	mm
	Init c0	67.0	MPa
	Init n	-0.094	

Precedent Performance Design Spreadsheet

					Vertical Strains in the middle of each layer or top of subgrade				Tensile Strains at the bottom of each layer		
er r	Annual Passes	% Growth	Single Tyre Load (N)	Radius of Load (mm)	Vertical µStrain	Critical Layer	Deflection (mm)	Allowable Repetitions	Tensile µStrain	Critical Layer	Allowable Repetitions
	400000	0	20104	92	1080	1	0.76	3.6E+07	-	-	-

	Vertical Strain Calculations		Horizontal Strain Calculations		Calculations for Selected Load #:					1
ble	CDF	Remaining Life (years)	CDF	Remaining Life (years)	Design ESA	Vertical Strain	Horizontal Strain	Horizontal Stress	Central Deflection	Curvature
	0.278	90	0	99	1.00E+07	1080	-326	156	0.76	0.48
	0.16	99	0	99	1.00E+07	720	-391	48	1.06	0.71
	0.138	99	0	99	1.00E+07	623	-261	4	1.55	1.17
	0.134	99	0	99	1.00E+07	604	-178	6	2.17	1.85
	0.056	99	0	99	1.00E+07	449	-	-	1.68	1.35
	0.278	**89.9**	**0**	**99**						

1, 566, 756.5, 275.7, 214.7, 156, 119.2, 93.1, 75.1, 54.6, 43.3

Cumulative damage factor for proposed design is 0.056 for subgrade strain, <1 so design is OK (but basecourse life will govern as CDF is 0.278)

Predicted Finished Level Deflection (D0s)

END OF MAIN PRESENTATION