The Pavement Number as a Structural Design Method

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Rubicon Solutions

Background

- TG2 (Foamed bitumen) (2002)
  - *Uncomfortable with structural design method*
  - *Conservative designs*
  - *Loose links between mix and structural design*
- SAMDM
  - *Powerful, but many flaws*
  - *Loose guidelines for inputs*
  - *Very difficult to validate new criteria (transfer functions) with real field data*

Background

- Relook at methods
  - *Sponsored by SABITA and Gauteng (GDPTRW)*
  - *Started process in 2005*
  - *Much discussion with relevant role players*
- Priorities
  - *Use real field data to develop and validate structural design methods*
  - *Robust systems, not open to abuse*
  - *Strong links between mix design, structural design and specifications*
  - *Clear guidelines for use*

Background

- Resulted in Material Classification and Pavement Number Methods
  - *Formally published in TG2 (2009)*
  - *Not only applicable to BSMs*

Pavement Design Methods

- Empirical
  - *Primarily based on observations of performance*
- Mechanistic-empirical
  - *Considers the pavement as a mechanism, with stresses and strains*
  - *Links the calculated stresses and strains under loading to observations of performance*

Pavement Design Methods

- Empirical
  - *AASHTO*
  - *DCP*
  - ***PAVEMENT NUMBER (knowledge based)***
- Mechanistic-Empirical
  - *South African Mechanistic Design Method (SAMDM)*
  - *With it's associated failure criteria and transfer functions*

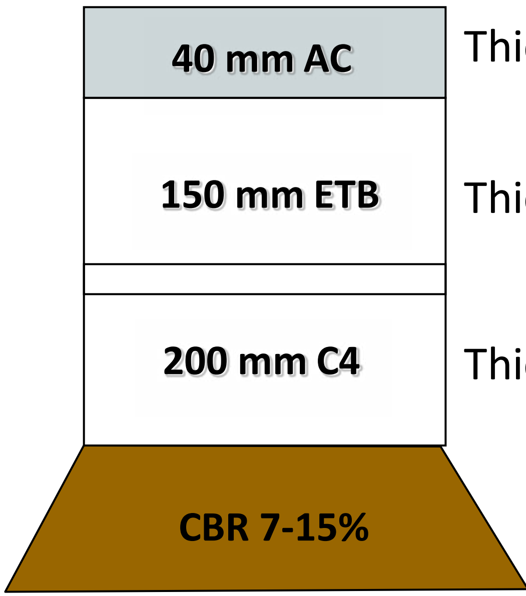
Knowledge Based Approach

- Gather all available field performance data
- Utilise best elements of mechanistic analysis
- Robust and easy to use
- Validated!
- Develop clear, strong links to field testing (material classification) and specifications
- Data Sets
  - *20 field sites*
  - *7 HVS Sites (22 test sections)*
  - *Construction, maintenance & performance information*
  - *TRH4 catalogue*

Pavement Number

- Based on the Structural Number Concept
  - *Old AASHTO method*
- Improved by incorporating
  - *Established design principles*
  - *Local experience*
- Calibrated for long term field performance

Structural Number Revisited



$Thick_1 \times A_1 = SN_1$

$Thick_2 \times A_2 = SN_2$

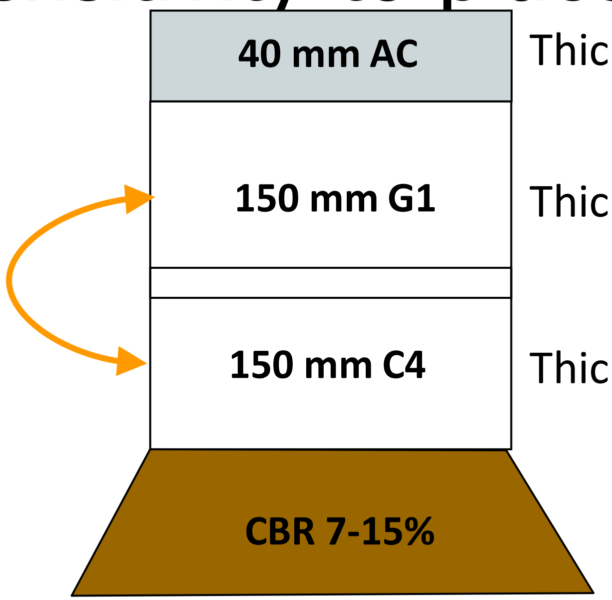
$Thick_3 \times A_3 = SN_3$

$$SN = SN_1 + SN_2 + SN_3$$

Adjusted for Subgrade Conditions

Disadvantages of SN Approach

- Non-uniqueness of the index
  - *Switching base and subbase give same SN*
- Insensitivity to placement of weak layers



$Thick_1 \times A_1 = SN_1$

$Thick_2 \times A_2 = SN_2$

$Thick_3 \times A_3 = SN_3$

$$SN = SN_1 + SN_2 + SN_3$$

These limitations are overcome by incorporating design ***rules of thumb*** that make the SN more "**intelligent**".

Pavement Number

- Structural Number
  - *modified with rules of thumb*
- Calibrated & validated
  - *Field data*
  - *Catalogues of design*
  - *Experience*

Rules of Thumb

- Structural capacity is a function of the combined long term load spreading of all pavement layers
- Subgrade quality is the point of departure for design
- The type and quality of the base layer is critical

Says Who?

- *Established knowledge in guidelines and textbooks*
- *Trends in well established design catalogues (TRH4)*
- *Trends in LTPP and HVS section performance*

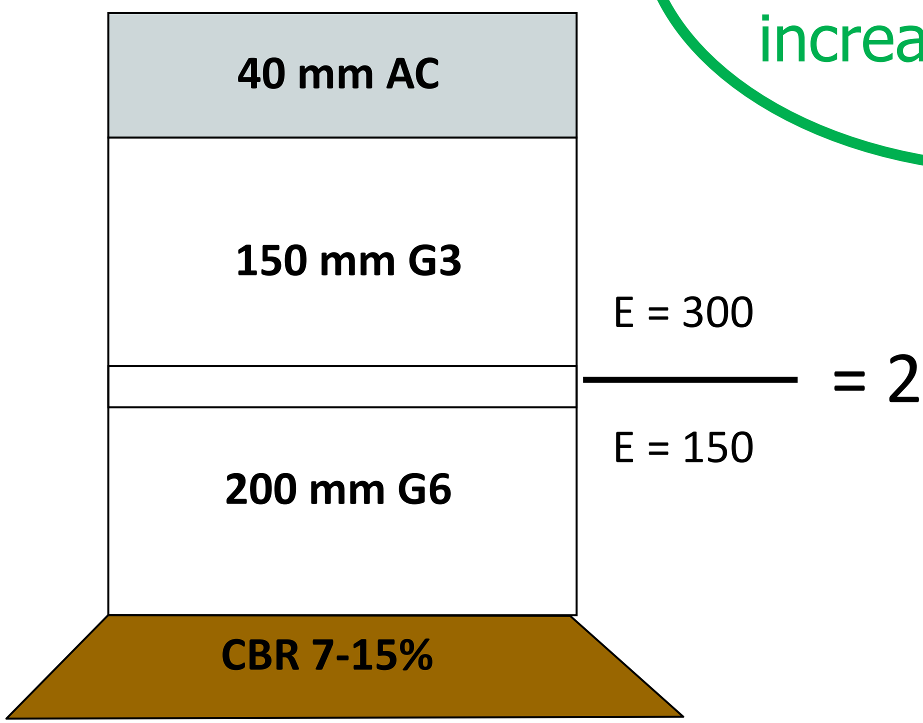
Rules of Thumb

- Effective Long Term Stiffness (ELTS)
- Modular Ratio
- Maximum Allowable Stiffness
- Base Confidence Factor

Modular Ratio

- The stiffness of one laye
  layer underneath

MR for BSMs higher than granular materials due to increased cohesion



Effective Long Term Stiffness (ELTS)

- Represents the average stiffness of the material over the design life
- Depends on the material type/quality
- Model-specific parameter
  - *Not measured in the lab or field*
- To calculate:

Given values for DEMAC

Modular Ratio x Support Stiffness

Maximum Allowable Stiffness

Minimum

Quality of Base Material

- Base Confidence Factor (BCF)
  - *Recognizes the importance of appropriate base material*
  - *Ensures poor designs are disqualified*

Material Class	Modular Ratio	Max Allowable Stiffness	Base Confidence
Asphalt	5	2500	1
Seals	2	800	N/A
BSM1	3	600	1
BSM2	2	450	0.7
G1	3	700	1.1
G2	2	500	0.8
G3	2	400	0.7
G4	1.8	375	0.2
G5	1.8	320	0.1
G6	1.8	180	-2
G7	1.7	140	-2.5
G8	1.6	100	-3.0
G9	1.4	90	-4.0
G10	1.2	70	-5.0
C1 & C2	9	1500	0.8
C3	4	550	0.6
C4	3	400	0.4

Subgrade Characterization

- Starting point for design
- Determine stiffness based on Material Class

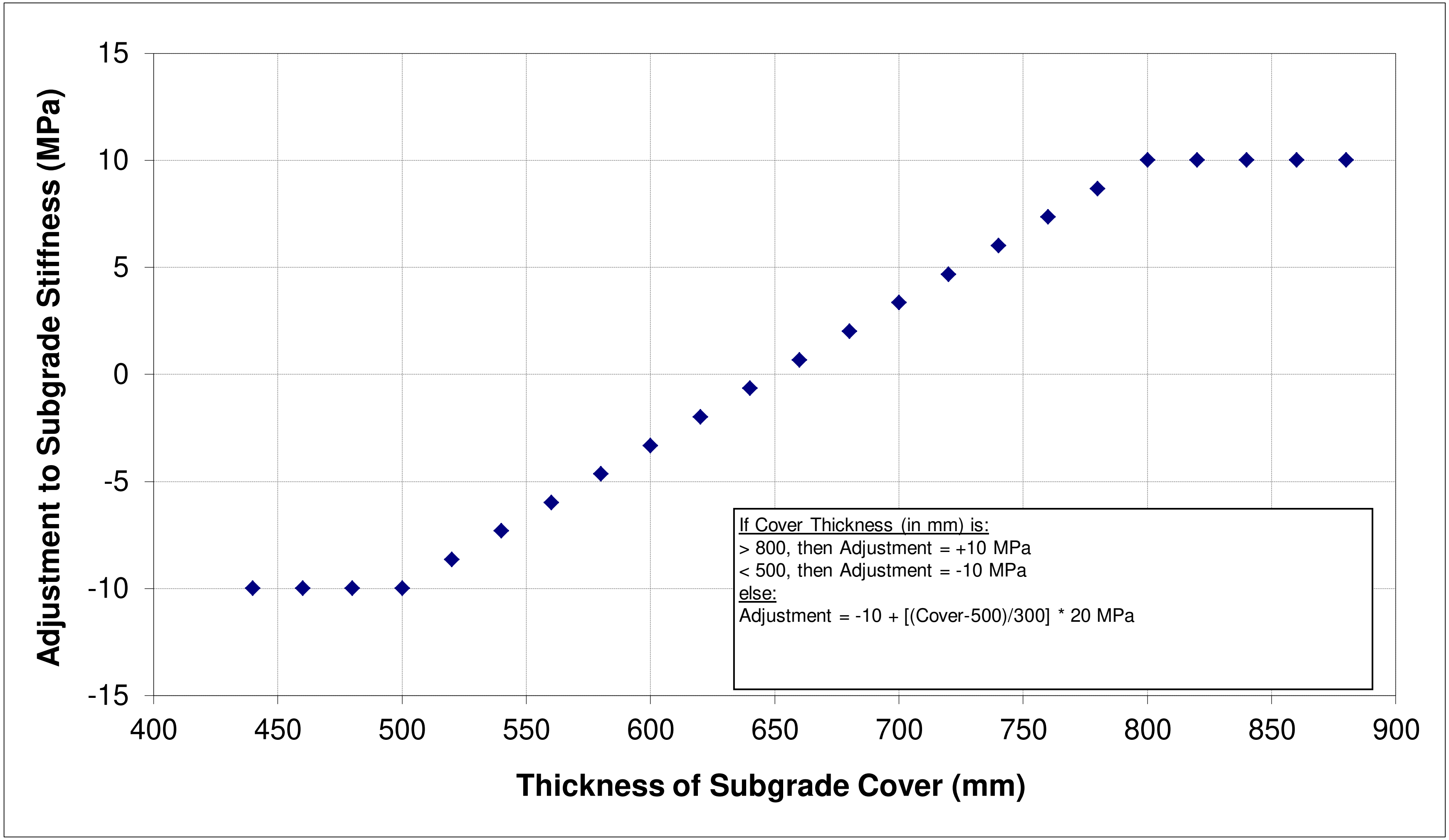
Design equivalent material class	Stiffness value (MPa)
DE-G6 or better	180
DE-G7	140
DE-G8	100
DE-G9	90
DE-G10	70

- Adjust for climate
- Adjust for cover depth (stress-sensitivity)

Climate Adjustment

Climate / Weinert N Values	Adjustment Factor
Wet (N < 2)	0.6
Moderate (N = 2 to 5)	0.9
Dry (N > 5)	1.0

Subgrade Cover Adjustment



Thickness Limits

- Must have 5 layers

Material type	Layer situation	Thickness limits	
		Minimum	Maximum
Asphalt	Surfacing	20	50
Seals	Surfacing	5	5
BSMs	Base and subbase	100	350
Cement stabilised	Subbase	100	400
Granular (G1-G10)	Base, subbase & selected	100	300

Traffic Limits

- PN applicable to
  - *1 to 30 MESA*

PN example

Example, Moderate Region

1. Material Classes	5. Assign modular ratio's and max stiffness	6. Calculate Layer ELTS Values
150 mm BSM2	MR = 2, E_{Max} = 450	ELTS = 450 BCF = 0.7
200 mm C4	MR = 3, E_{Max} = 400	ELTS = 400 Thickness Adj = 0.4
180 mm G6	MR = 1.8, E_{Max} = 180	ELTS = min(212,180) ELTS = 180
150 mm G7 CBR 7-15%	118 MPa	118 MPa

2. Determine subgrade stiffness

3. Adjust for climate

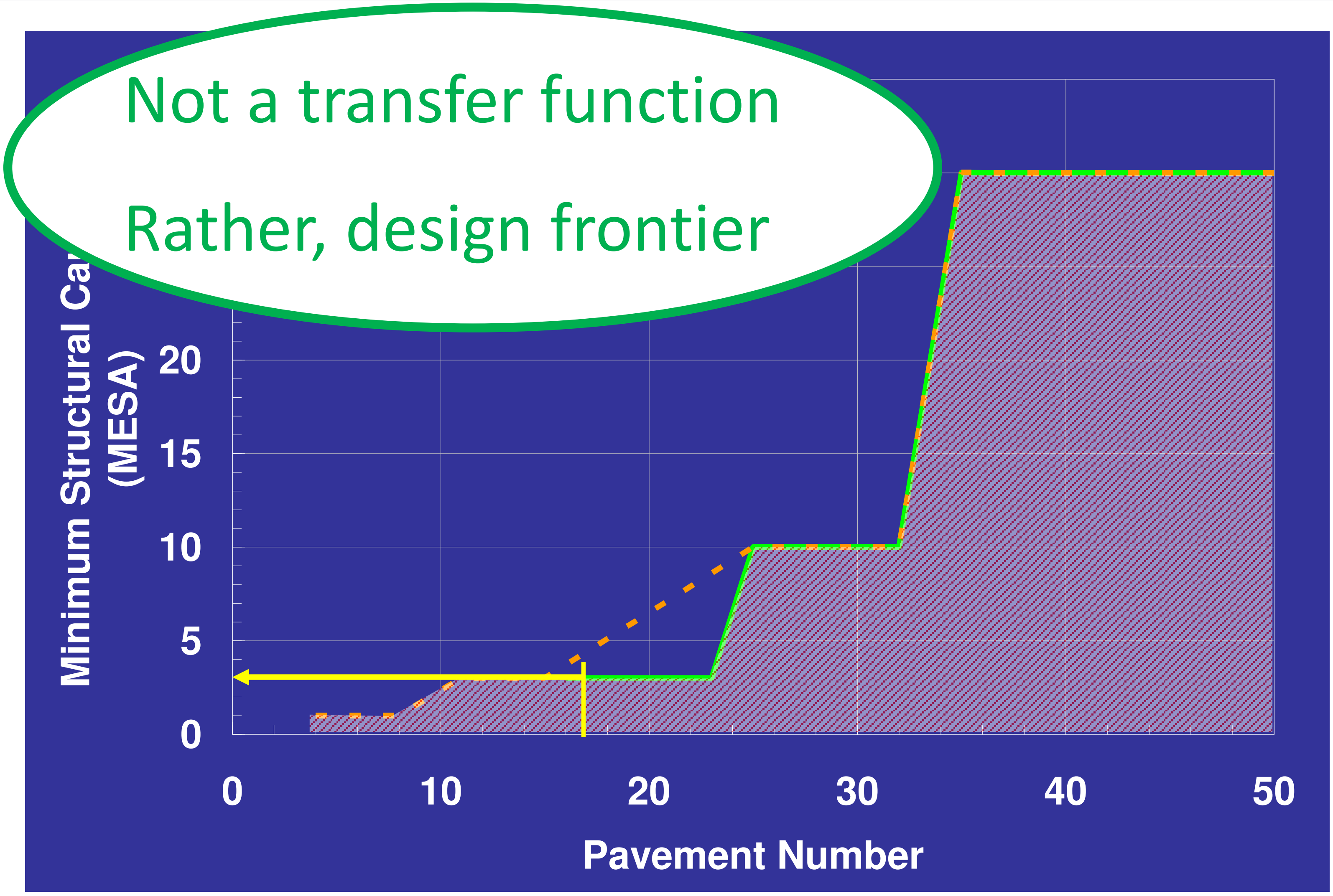
4. Adjust for cover

6. ELTS = min ($E_{support}$ * MR , E_{max})

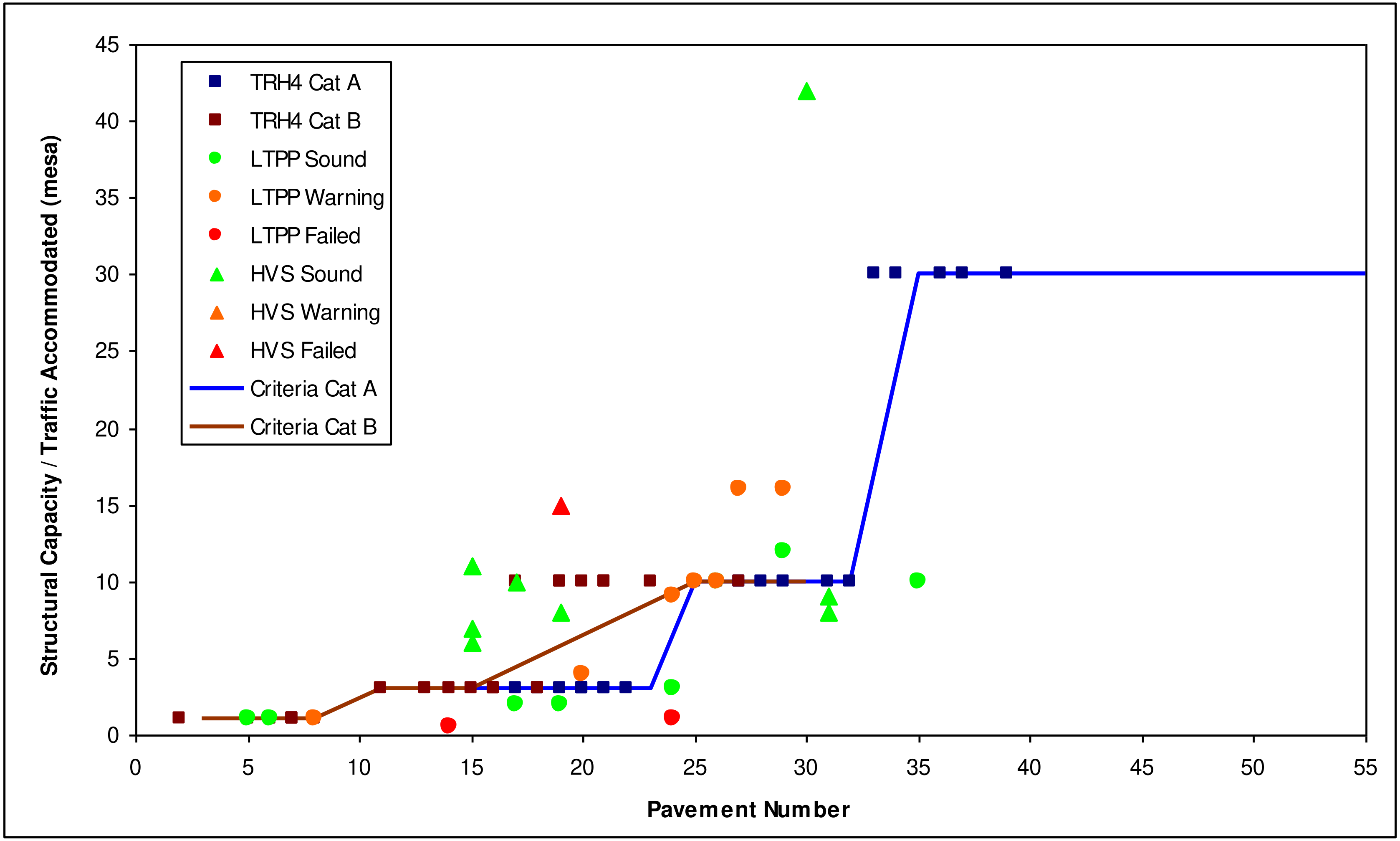
7. Layer PN = thickness * ELTS

8. PN = Σ layer PN

Design Criteria



Calibration



Advantages of PN

- Simple method for determining structural capacity
- Valid for most SA materials
- Easy to understand & use
- Robust, and cannot be easily manipulated
- Utilizes well known rules of thumb
- Well and explicitly validated with TRH4, LTPP and HVS datasets
- Requires Material Class as design inputs

PN Software

- www.asphaltacademy.co.za/bitstab
- Any changes in constants will be posted on website

PN example

Subgrade class	G7
Initial stiffness	
Climate	Moderate
Climate adj	
Cover depth	
Cover adj.	
SG ELTS	

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5							
BSM2	200							
C4	200							
G6	180							
G7	N/A							

PN exa

Design equivalent material class	Stiffness value (MPa)
G6 or better	180
G7	140
G8	100
G9	90
G10	70

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	
Cover adj.	-4
SG ELTS	

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800		1	N/A	
BSM2	200	✓	2	450		1	1	
C4	200	✓	3	400		0.4	N/A	
G6	180	✓	1.8	180		1	N/A	
G7	N/A		N/A	N/A		1	N/A	

PN example

Subgrade class	**G7**
Initial stiffness	**140**
Climate	**Moderate**
Climate adj	**0.9**
Cover depth	
Cover adj.	**-4**
SG ELTS	

Climate / Weinert N value	Adjustment factor
Wet (N < 2)	0.6
Moderate (N = 2 to 5)	0.9
Dry (N > 5)	1.0

Mat class	Thick	T check	MR	Max		adj		PN
Seal	5	5	2	800		1	N/A	
BSM2	200	✓	2	450		1	1	
C4	200	✓	3	400		0.4	N/A	
G6	180	✓	1.8	180		1	N/A	
G7	N/A		N/A	N/A		1	N/A	

PN example

Subgrade class	
Initial stiffness	
Climate	
Climate adj	
Cover depth	
Cover adj.	
SG ELTS	

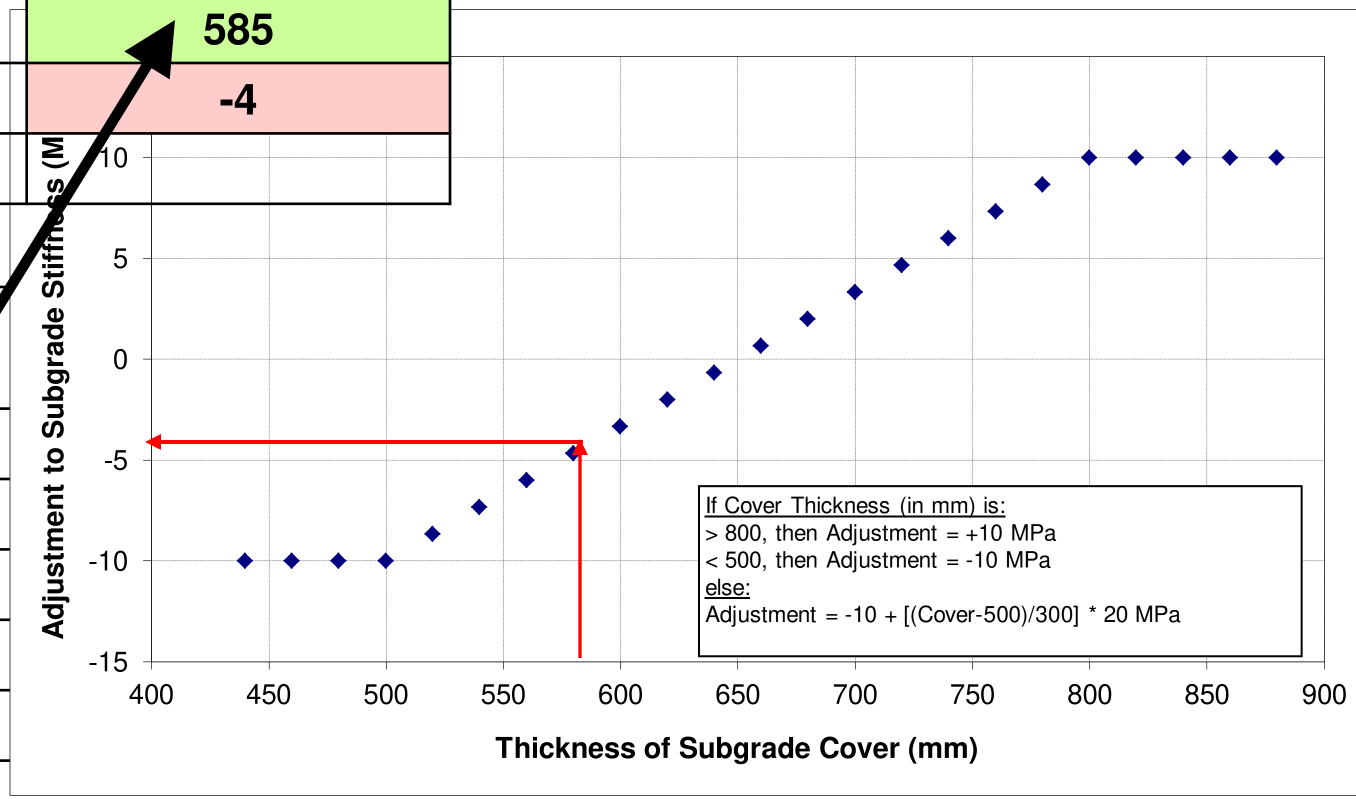
DEMC	BSM1	BSM2
Modular Ratio	3.0	2.0
Max Allowed Stiffness	600	450
BCF	1.0	0.7
Thickness limit	100 to 350 mm	100 to 350 mm

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800		1	N/A	
BSM2	200	✓	2	450		1	1	
C4	200	✓	3	400		0.4	N/A	
G6	180	✓	1.8	180		1	N/A	
G7	N/A		N/A	N/A		1	N/A	

PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	

Mat class	Thick
Seal	5
BSM2	200
C4	200
G6	180
G7	N/A



PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	122

140 * 0.9 - 4 = 122

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800		1	N/A	
BSM2	200	✓	2	450		1	1	
C4	200	✓	3	400		0.4	N/A	
G6	180	✓	1.8	180		1	N/A	
G7	N/A		N/A	N/A		1	N/A	

PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	122

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800		1	N/A	
BSM2	200	✓	2	450		1	1	
C4	200	✓	3	400		0.4	N/A	
G6	180	✓	1.8	180		1	N/A	
G7	N/A		N/A	N/A		1	N/A	

PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	122

122*1.8 = 220

But, max is 180

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800		1	N/A	
BSM2	200	✓	2	450		1	1	
C4	200	✓	3	400		0.4	N/A	
G6	180	✓	1.8	180		1	N/A	
G7	N/A		N/A	N/A	122	1	N/A	

PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	122

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800	800	1	N/A	
BSM2	200	✓	2	450	450	1	1	
C4	200	✓	3	400	400	0.4	N/A	
G6	180	✓	1.8	180	180	1	N/A	
G7	N/A		N/A	N/A	122	1	N/A	

PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	122

Calculation of layer PN

(450 * 200)/10000 * 1 = 9.0

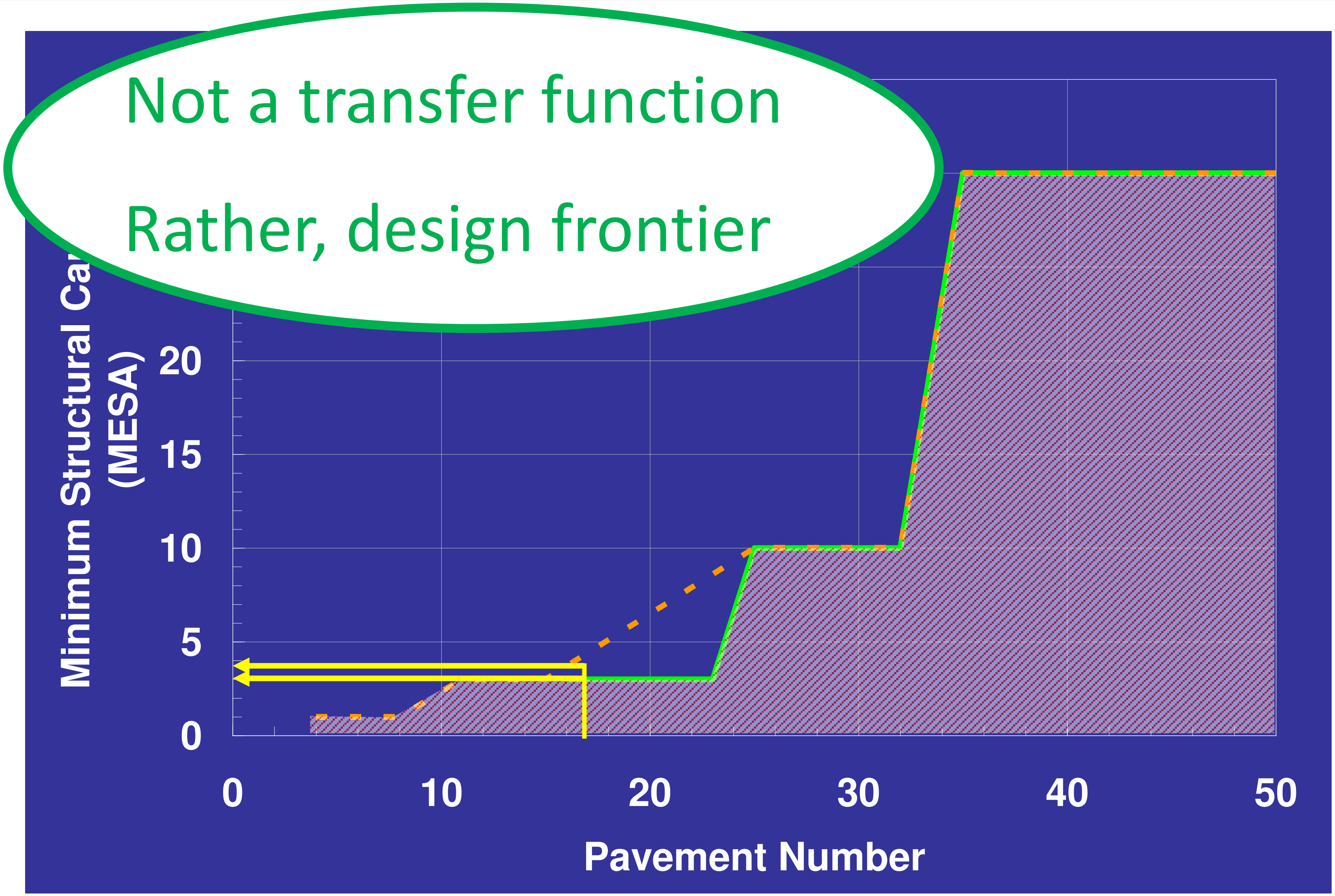
Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800	800	1	N/A	
BSM2	200	✓	2	450	450	1	1	9.0
C4	200	✓	3	400	400	0.4	N/A	
G6	180	✓	1.8	180	180	1	N/A	
G7	N/A		N/A	N/A	122	1	N/A	

PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	122

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800	800	1	N/A	0.4
BSM2	200	✓	2	450	450	1	0.1	9.0
C4	200	✓	3	400	400	0.4	N/A	3.2
G6	180	✓	1.8	180	180	1	N/A	3.2
G7	N/A		N/A	N/A	122	1	N/A	Σ 15.8

Design Criteria



PN example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	585
Cover adj.	-4
SG ELTS	122

Cat A	3.0
Cat B	3.6

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	5	5	2	800	800	1	N/A	0.4
BSM2	200	✓	2	450	450	1	0.1	9.0
C4	200	✓	3	400	400	0.4	N/A	3.2
G6	180	✓	1.8	180	180	1	N/A	3.2
G7	N/A		N/A	N/A	122	1	N/A	Σ 15.8