Pavement Number
- PN -

Acknowledgements

Dr Fritz Jooste

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Pavement Number (PN) Design

Structural Number on Steroids

- Robust and easy to use
- Develop clear, strong links to field testing (material classification) and specifications
- First version 2008, update 2020
- Data Sets
  - 69 field sites
  - SATCC and TRH4 Catalogues
  - Construction, maintenance & performance information

NEW

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Pavement Number (PN)

- Stuctural Number
  - Modified with **rules of thumb**
- Relies on "accurate" **Material Class** input
- **Calibrated** & **validated**
  - Field data
  - Catalogues of design
  - Experience

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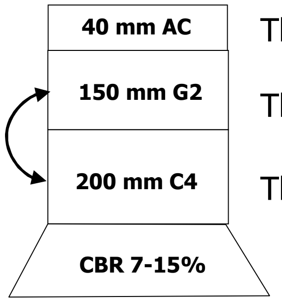
Disadvantages of SN Approach

- 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".

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Rules of Thumb: General

- Structural capacity is a function of:
  - The combined **long-term load spreading** of all pavement layers
  - Relative **quality of subgrade**
- 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*

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Rules of Thumb: Layers

- Effective Long Term Stiffness (ELTS)
- Modular Ratio
- Maximum Allowable Stiffness
  - *Predetermined based on Material Class*
- Base Confidence Factor

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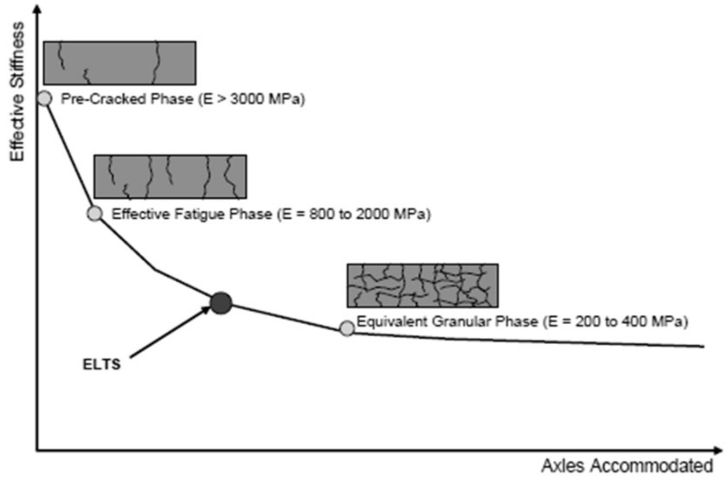
Effective Long Term Stiffness (ELTS)



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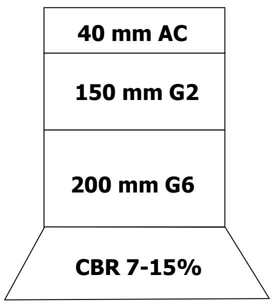
Modular Ratio

- The stiffness of one layer as a ratio of the layer underneath



$$\frac{E1 = 300}{E2 = 150} = 2$$

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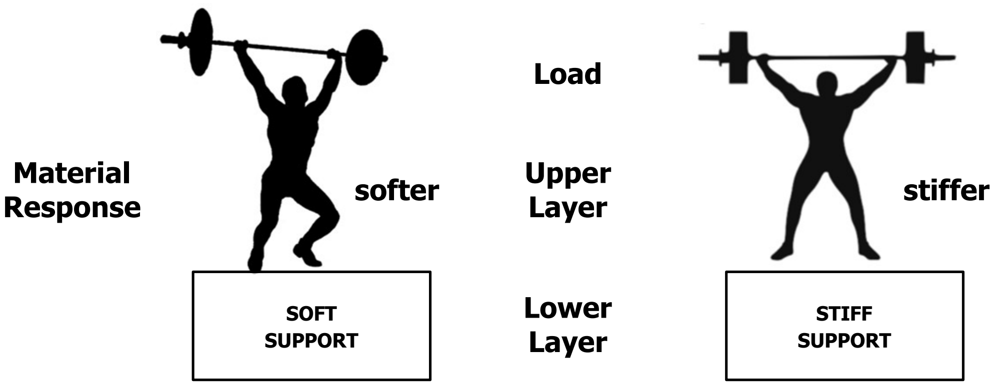
Pavement Balance



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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

Minimum

Maximum Allowable Stiffness

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Quality of Base Material

– Base Confidence Factor (BCF)
  - *Suitability of material to serve as a base layer*
– Ensures poor designs are disqualified

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Material Class	Thickness Limits	Modular Ratio	Max Allow. Stiffness	Base Confidence
Asphalt surfacing	20 - 100	4	2000	1
Asphalt base	20 - 200	4	1500	1
Seals	10	2	1000	N/A
BSM1	100 - 300	3	700	1
BSM2		2	600	0.7
G1	100 – 150	3	600	1
G2	100 - 200	2	450	0.8
G3		1.8	400	0.7
G4	100 - 300	1.8	375	0.2
G5		1.8	350	0.1
G6		1.8	250	-2
G7	100 - 350	1.7	140	-2.5
G8		1.6	100	-3.0
G9		1.4	90	-4.0
G10		1.2	70	-5.0
C3	100 - 350	4	500	0.6
C4		3	400	0.4
EG4	100 - 350	2	400	0.2
EG5		1.8	300	0.2

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Climate Adjustment (Thornthwaite/Weinert)

Climate	Adjustment Factor
Wet	0.6
Moderate	0.9
Dry	1.0

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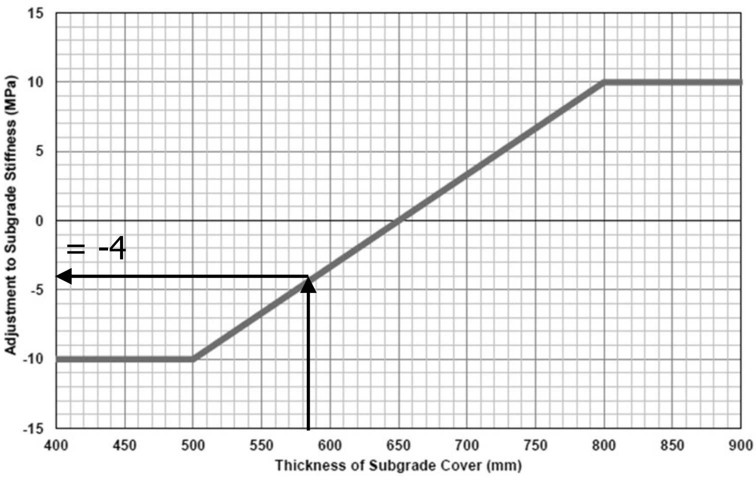
Quantifying the Subgrade

Mat class	Thick
Seal	10
BSM2	200
C4	200
G6	180
G7	N/A

= 590 mm



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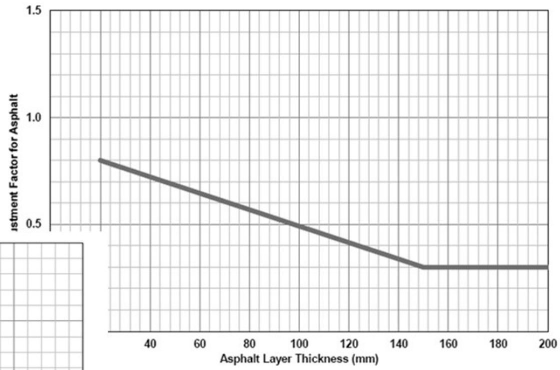
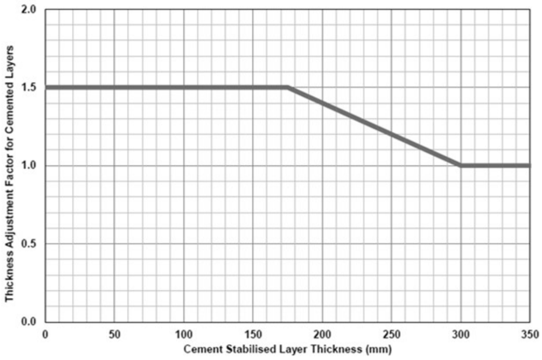
Thickness Adjustment Factors

– Stabilised layers
  - *Asphalt surfacings and bases*
  - *BSMs*
  - *Cemented layers*





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NEW

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Five Layer Limit

- Pavement must have 5 layers
- Surfacing must be modelled separately
- If have got 4 layers or less
  – Add selected layer(s) 150 mm thick of same material class as subgrade
- If have more than 5 layers
  – Start with combining below subbase
    - Material class should be that of the thicker layer
    - If layers same thickness then use lower material class
    - If combine with subgrade, then assign material class of upper layer to new subgrade
  – Thickness limits must not be exceeded

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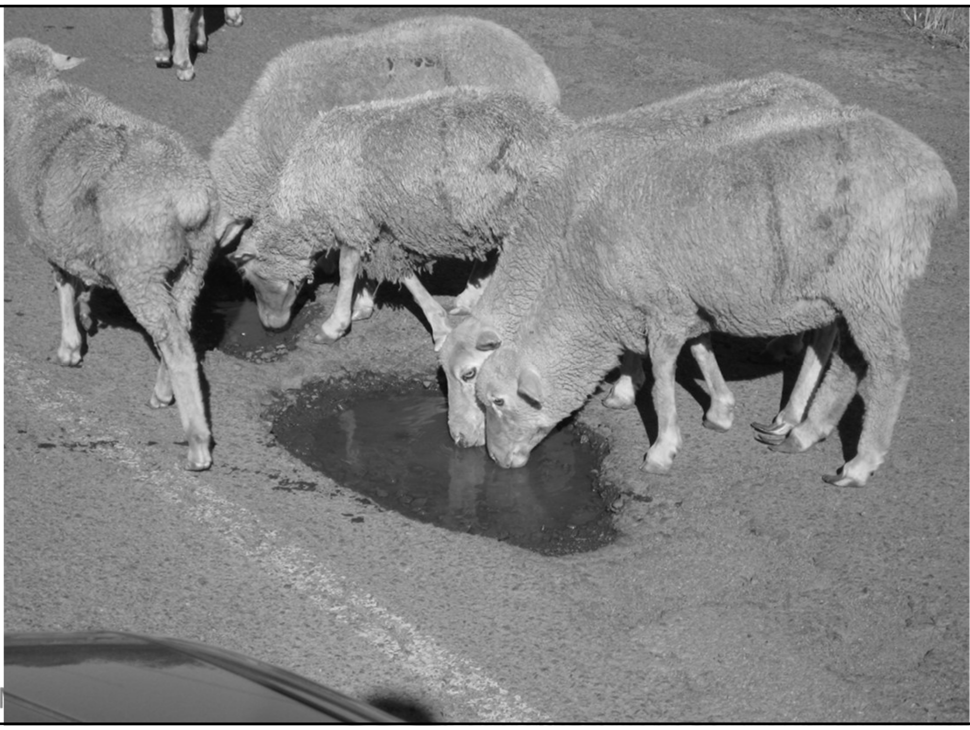

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How Does the PN Work?

1. Determine **subgrade stiffness** based on material class
2. Adjust subgrade stiffness for **climate** and **cover depth**
3. For each layer, determine the **Modular Ratio** and **Maximum Allowed Stiffness** based on material class
4. Work up from the subgrade and determine the **ELTS** of each layer
5. Adjust base stiffness using **BCF**
6. For **stabilised materials,** adjust ELTS based on thickness
7. Multiply thickness and ELTS for each layer and sum to obtain **PN**

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Example, Moderate Region

1. Material Classes	**5. Assign modular ratio's and max stiffness**	**6. Calculate Layer ELTS Values**
150 mm BSM2	**MR = 2.5, E_{Max} = 600**	**ELTS = 600, BCF = 0.7** **Thickness Adj = 1.0**
200 mm C4	**MR = 3, E_{Max} = 400**	**ELTS = 400** **Thickness Adj = 1.4**
180 mm G6	**MR = 1.8, E_{Max} = 250**	**ELTS = min(212,250)** **ELTS = 212**
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

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PN 2009 - Issues

- 20 actual pavement structures, heavy reliance on TRH4 catalogue
- Over contribution of asphalt
- Under contribution of cemented materials
- Asphalt surfacing
  - Limited to < 50 mm
- No asphalt bases
- Increase in PN, no increase in life
- Limited to 30 MESA

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PN ~~2009~~ 2020

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- ~~20~~ actual pavement structures, ~~heavy reliance on TRH4 catalogue~~
  9 different combinations of pavement structures, plus asphalt and seal surfacings
- Over contribution of asphalt ✓
- Under contribution of cemented materials ✓
- Asphalt surfacing ✓
  - Limited to < 50 mm 20 – 100 mm
- No asphalt bases ✓ 20 – 200 mm
- Increase in ~~PN~~, no increase in life ✓ New Frontier Curve
- Limited to ~~30~~ MESA ✓ 40 MESA

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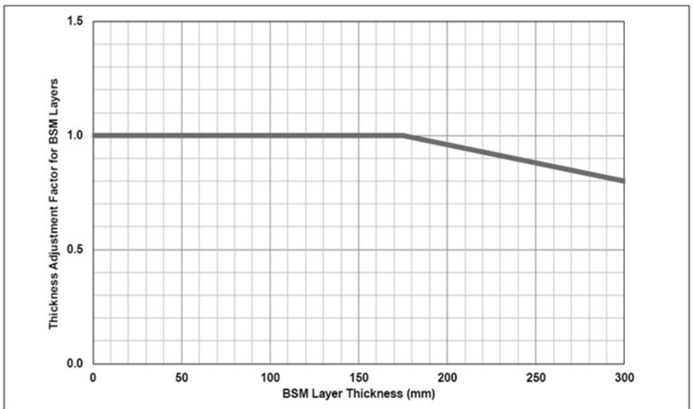
PN 2020 – What Else is New?

- Thickness adjustment factor for stabilized layers
  - Asphalt
  - Cemented
  - BSMs
  - Effect of empirical method

- Materials
  - Asphalt bases
  - EG 4 & 5

- Seals are 10 mm thick



Thickness of BSM Layer	Thickness Adjustment Factor
20 – 175 mm	1.0
175 – 300 mm	= - (0.0016 * thickness) + 1.28

Figure C.6 Thickness Adjustment Factor for BSM Layers

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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	10							
BSM2	200							
C4	200							
G6	180							
G7	N/A							

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PN Example

Design equivalent material class	Stiffness value (MPa)
G6 or better	250
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	10	10	2	1000			N/A	
BSM2	200	✓	2.5	600		0.96	0.7	
C4	200	✓	3	400		1.40	N/A	
G6	180	✓	1.8	250			N/A	
G7	N/A		N/A	N/A			N/A	

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PN Example

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

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	10	10	2	1000			N/A	
BSM2	200	✓	2.5	600		0.96	0.7	
C4	200	✓	3	400		1.40	N/A	
G6	180	✓	1.8	250			N/A	
G7	N/A		N/A	N/A			N/A	

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PN Example

DEMC	BSM1	BSM2
Modular Ratio	3.0	2.5
Max Allowed Stiffness	700	600
BCF	1.0	0.7
Thickness limit	100 to 300 mm	100 to 300 mm

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	10	10	2	1000			N/A	
BSM2	200	✓	2.5	600		0.96	0.7	
C4	200	✓	3	400		1.40	N/A	
G6	180	✓	1.8	250			N/A	
G7	N/A		N/A	N/A			N/A	

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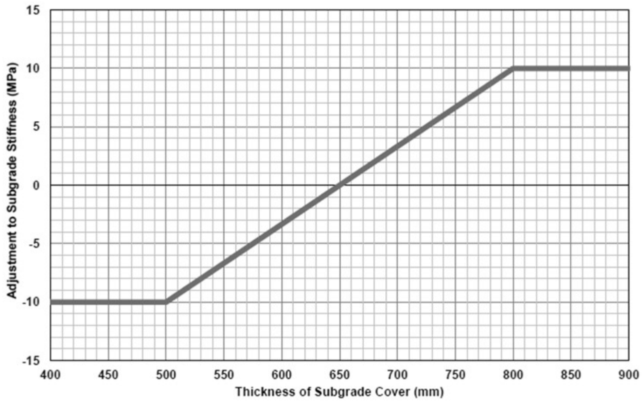
PN Example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	590
Cover adj.	-4
SG ELTS	



Mat class	Thick	T check	MR					
Seal	10	10	2	1000			N/A	
BSM2	200	✓	2.5	600		0.96	0.7	
C4	200	✓	3	400		1.40	N/A	
G6	180	✓	1.8	250			N/A	
G7	N/A		N/A	N/A			N/A	

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PN Example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	590
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	10	10	2	1000			N/A	
BSM2	200	✓	2.5	600		0.96	0.7	
C4	200	✓	3	400		1.40	N/A	
G6	180	✓	1.8	250			N/A	
G7	N/A		N/A	N/A			N/A	

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PN Example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	590
Cover adj.	-4
SG ELTS	122

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	10	10	2	1000			N/A	
BSM2	200	✓	2.5	600		0.96	0.7	
C4	200	✓	3	400		1.40	N/A	
G6	180	✓	1.8	250			N/A	
G7	N/A		N/A	N/A	122		N/A	

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PN Example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	590
Cover adj.	-4
SG ELTS	122

Calculation of ELTS

122*1.8 = 220

220 < 250

max, 220

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	10	10	2	1000			N/A	
BSM2	200	✓	2.5	600		0.96	0.7	
C4	200	✓	3	400		1.40	N/A	
G6	180	✓	1.8	250	220		N/A	
G7	N/A		N/A	N/A	122		N/A	

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PN Example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	590
Cover adj.	-4
SG ELTS	122

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	10	10	2	1000	1000		N/A	
BSM2	200	✓	2.5	600	600	0.96	0.7	
C4	200	✓	3	400	400	1.40	N/A	
G6	180	✓	1.8	250	220		N/A	
G7	N/A		N/A	N/A	122		N/A	

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PN Example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	590
Cover adj.	-4
SG ELTS	122

Calculation of layer PN

(600 * 200)/10000 * 0.96 * 0.7 = 8.1

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	10	10	2	1000	1000		N/A	
BSM2	200	✓	2.5	600	600	0.96	0.7	8.1
C4	200	✓	3	400	400	1.40	N/A	
G6	180	✓	1.8	250	220		N/A	
G7	N/A		N/A	N/A	122		N/A	

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PN Example

Subgrade class	G7
Initial stiffness	140
Climate	Moderate
Climate adj	0.9
Cover depth	590
Cover adj.	-4
SG ELTS	122

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	10	10	2	1000	1000		N/A	1.0
BSM2	200	✓	2.5	600	600	0.96	0.7	8.1
C4	200	✓	3	400	400	1.40	N/A	11.2
G6	180	✓	1.8	250	220		N/A	4.0
G7	N/A		N/A	N/A	122		N/A	Σ 24.2

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Design Criteria

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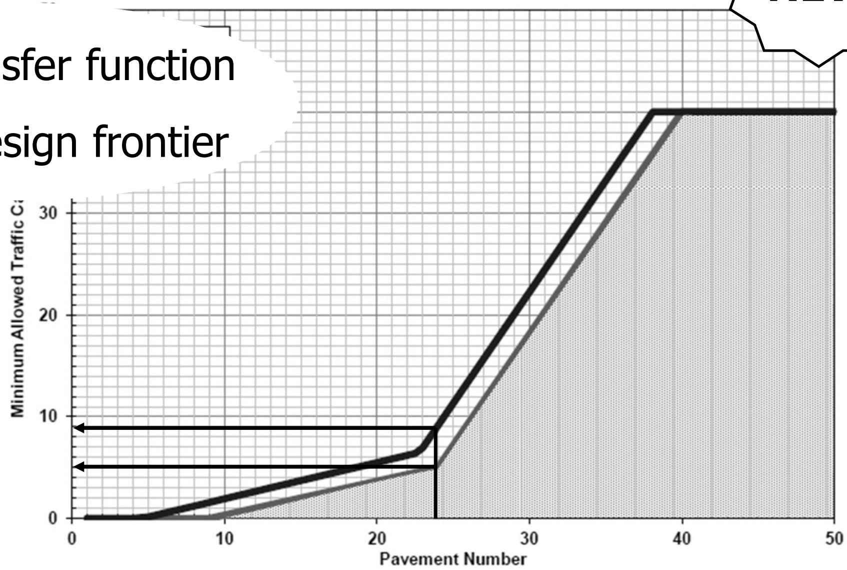
Not a transfer function

Rather, design frontier



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PN example

Subgrade class	**G7**
Initial stiffness	**140**
Climate	**Moderate**
Climate adj	**0.9**
Cover depth	**590**
Cover adj.	**-4**
SG ELTS	**122**

Cat A	**5.5**
Cat B	**9.6**

Mat class	Thick	T check	MR	Max E	ELTS	Thick adj	BCF	Layer PN
Seal	10	10	2	1000	1000		N/A	1.0
BSM2	200	✓	2.5	600	600	0.96	0.7	8.1
C4	200	✓	3	400	400	1.40	N/A	11.2
G6	180	✓	1.8	250	220		N/A	4.0
G7	N/A		N/A	N/A	122		N/A	Σ 24.2

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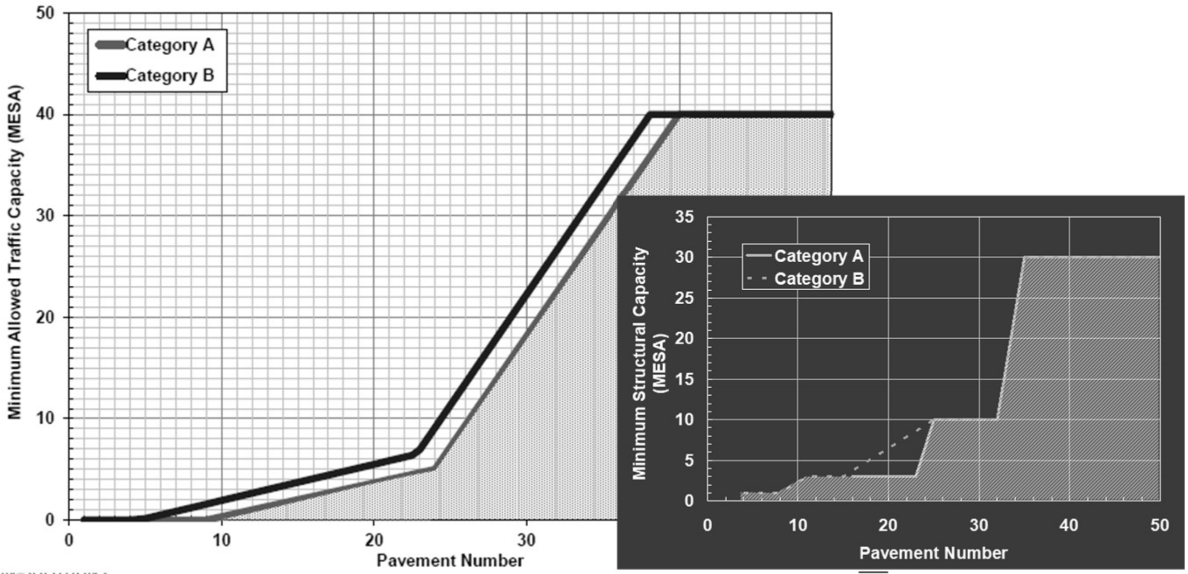
Design Criteria



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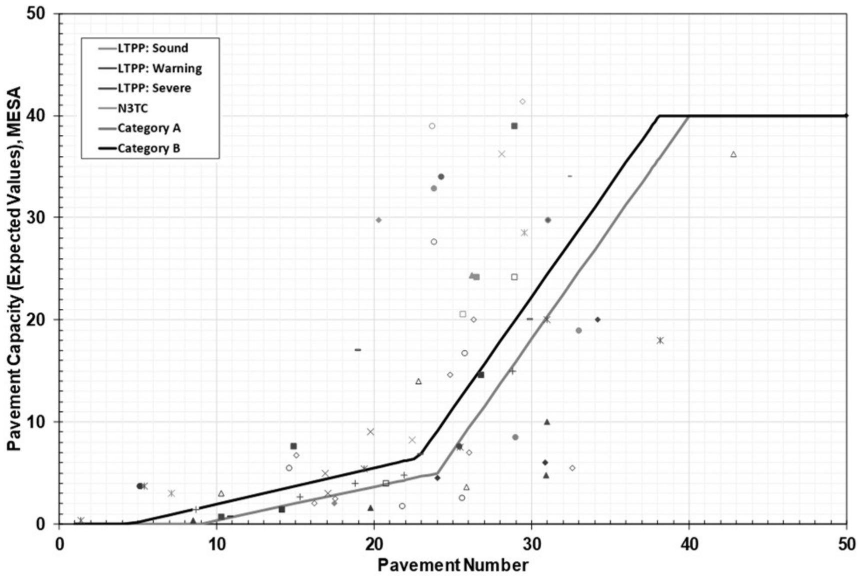
Calibration



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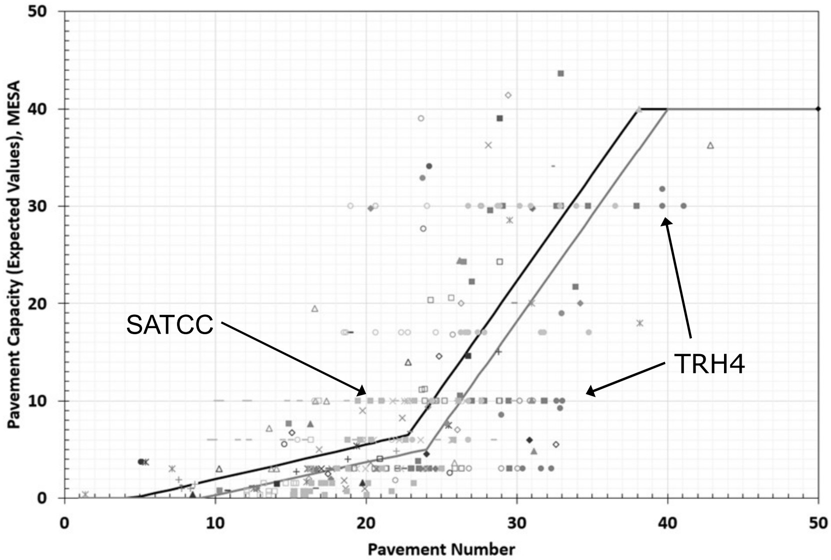
PN - FRONTIER CURVE UPDATE

Calibration



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Remarks

- Simple method, easy to understand and use
- Valid for most SA materials
- Robust, and cannot be easily manipulated
- Utilizes well known rules of thumb
- Results in balanced pavements
- Well and explicitly validated with TRH4, LTPP and HVS datasets
- Requires Material Class as design inputs
- System rigidness may limit application

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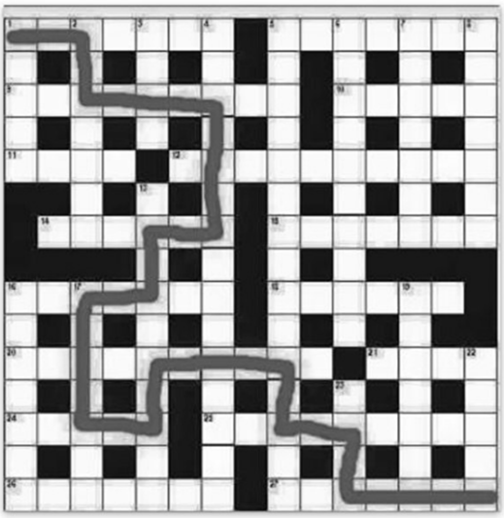
Hulle moet regtig die goed bietjie moeiliker maak !



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