Updated Guidelines for Bitumen Stabilization

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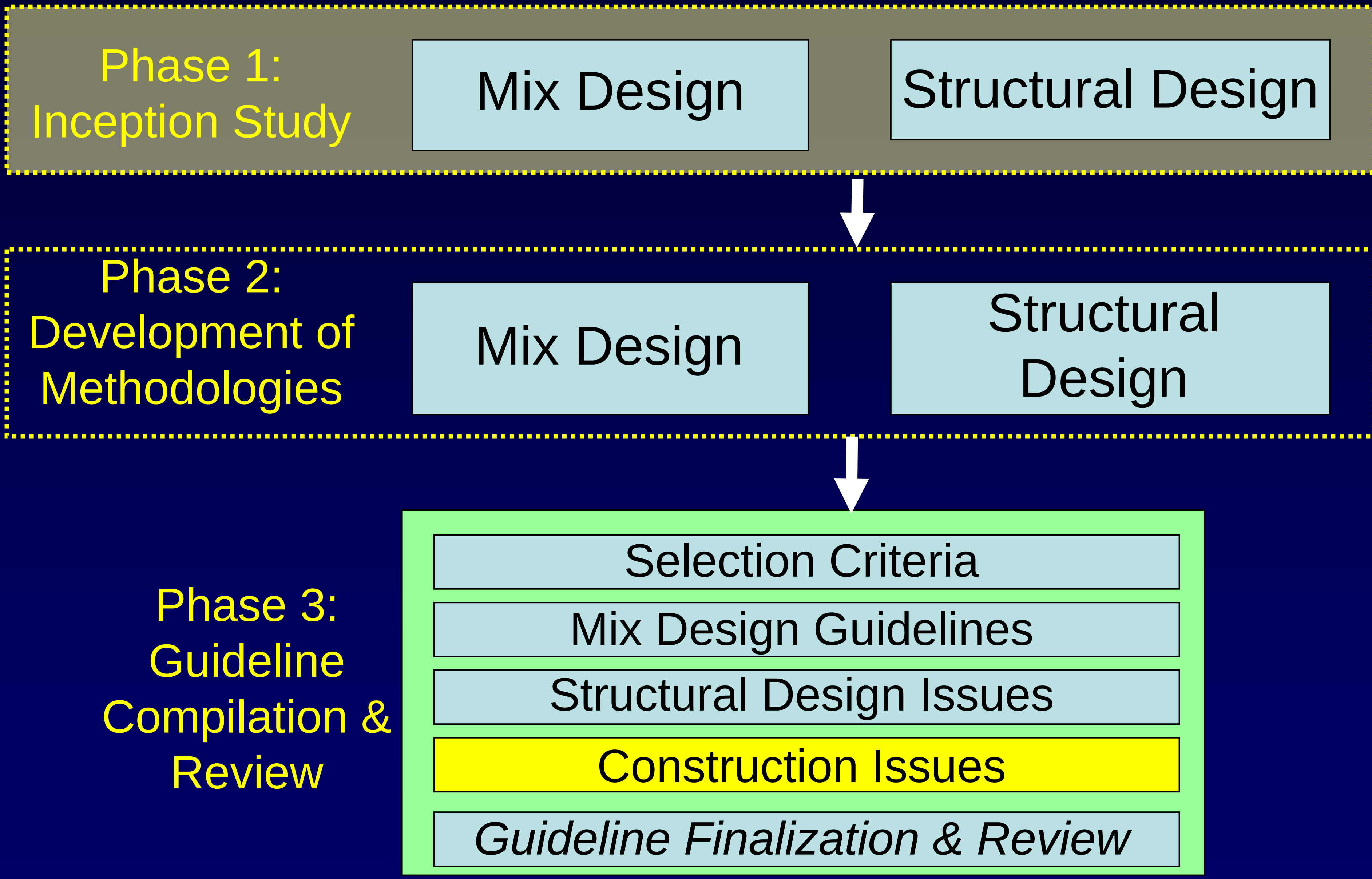
Existing Cold-Mix Guidelines

- Emulsion materials
  - Sabita Manual 14 (1993)
  - Sabita Manual 21 (1999)
- Foamed bitumen materials
  - TG2 Interim Guideline (2002)

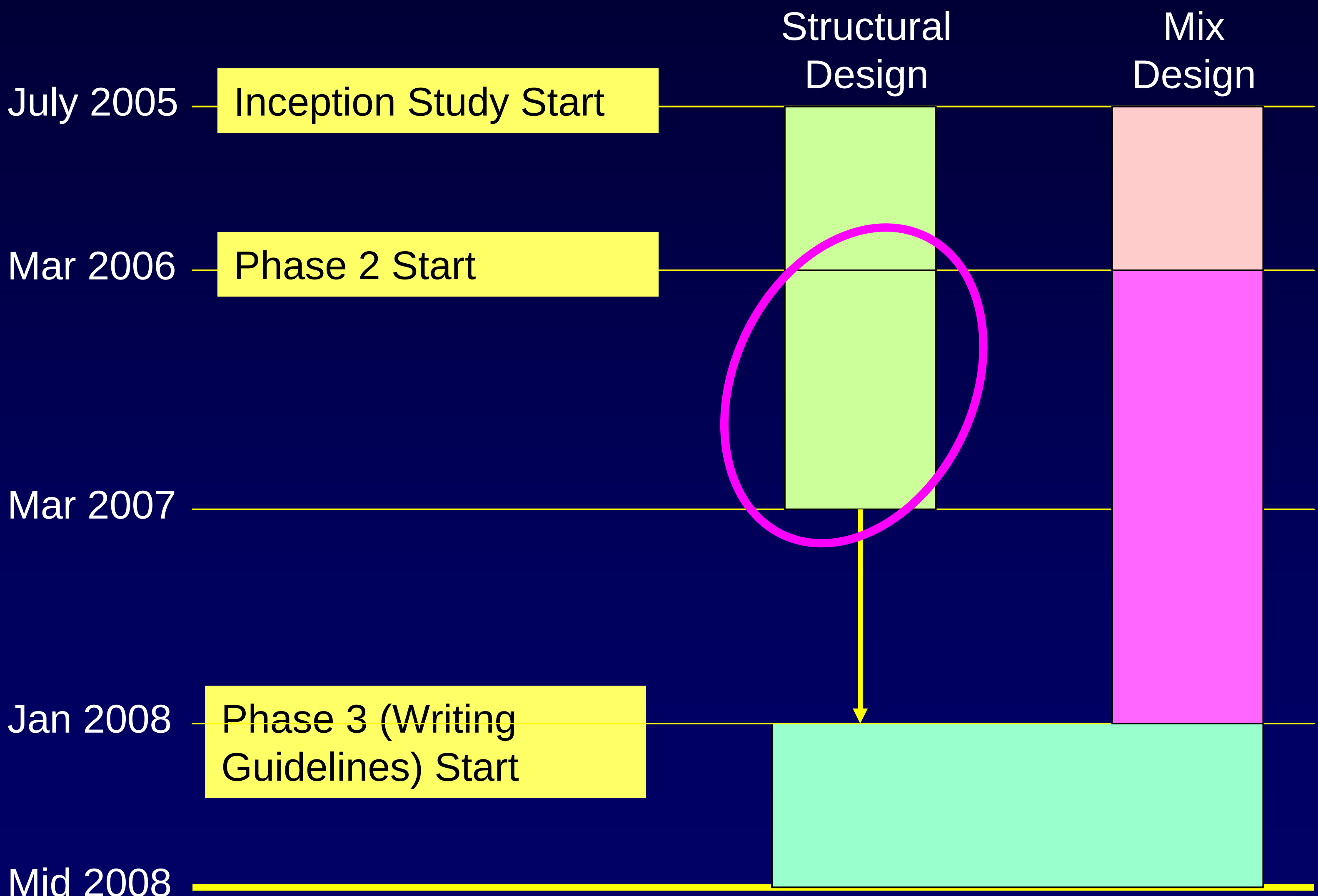
Guidelines widely used, but need to

- Modernize & Improve
- Create a single, combined guideline

Project Structure



Project Mileposts



In This Presentation…

- Structural Design Method
  - Basic Approach and Motivation
  - Method Description
  - Calibration and Validation
- Materials Classification Method
  - Approach and Motivation
  - Basic Concepts
  - Test Indicators and Interpretation Guidelines
- Final Remarks
  - Where to from here?
  - Linkage to new SAMDM project

The Design Process

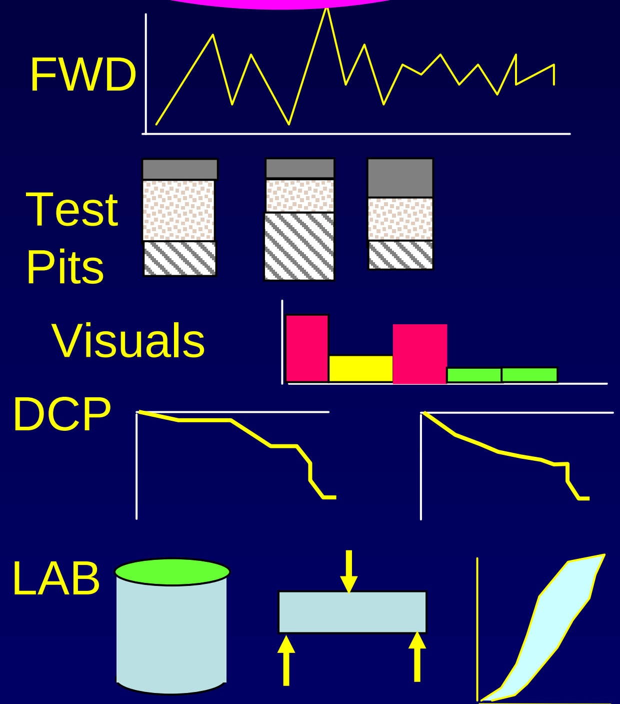
Design Inputs

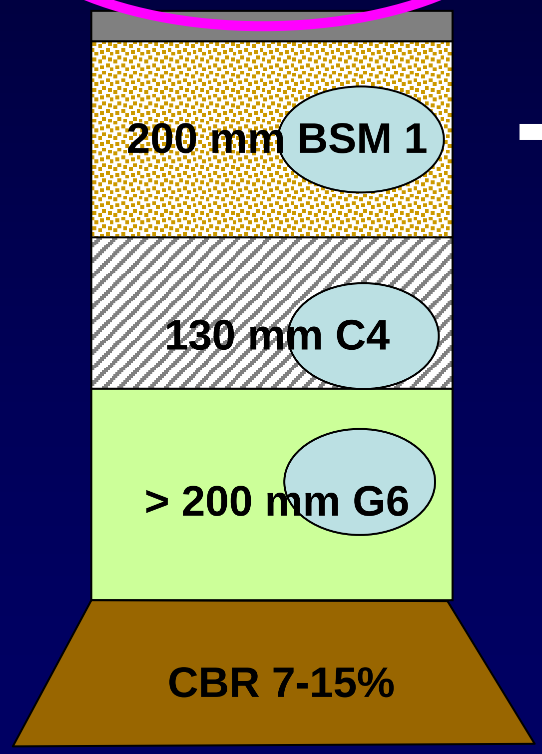
Materials Classification

Capacity Assessment

Specifications

Mix Design



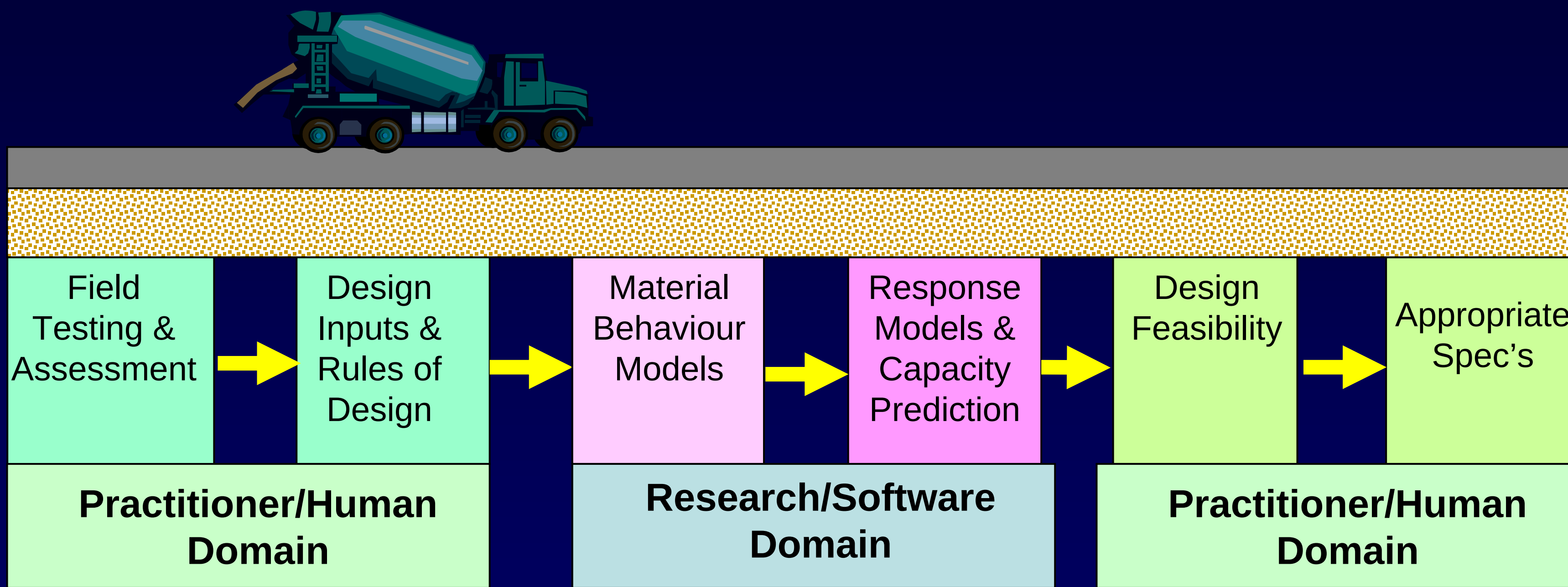


Project Constraints

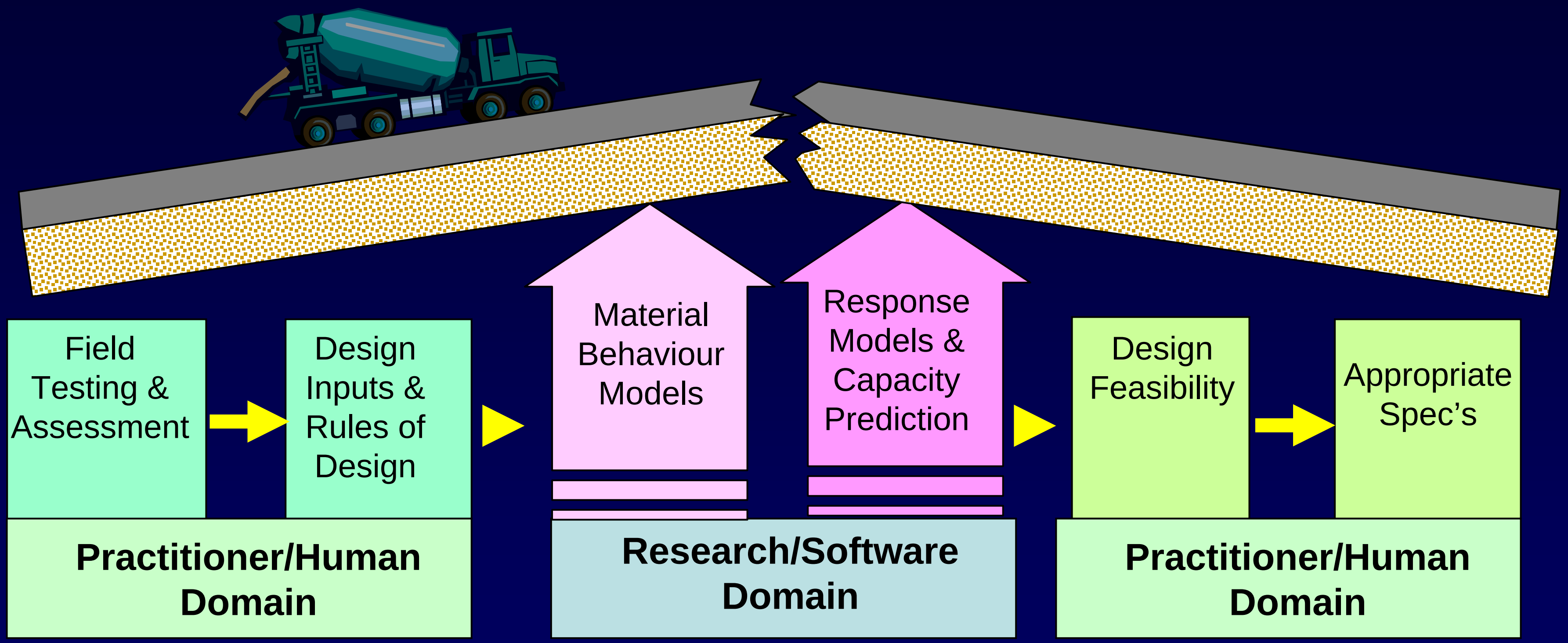
- Reasonable knowledge base of performance (long-term and accelerated loading), but …
- Not very detailed information, no fundamental material properties
- Current M-E design method has deficiencies
- Limited budget and timeframe

- ➢ Adopted a Heuristic or Knowledge-based pavement design approach
- ➢ Simplified design method, more emphasis on correct materials assessment, mix design and construction

Pavement Design Elements

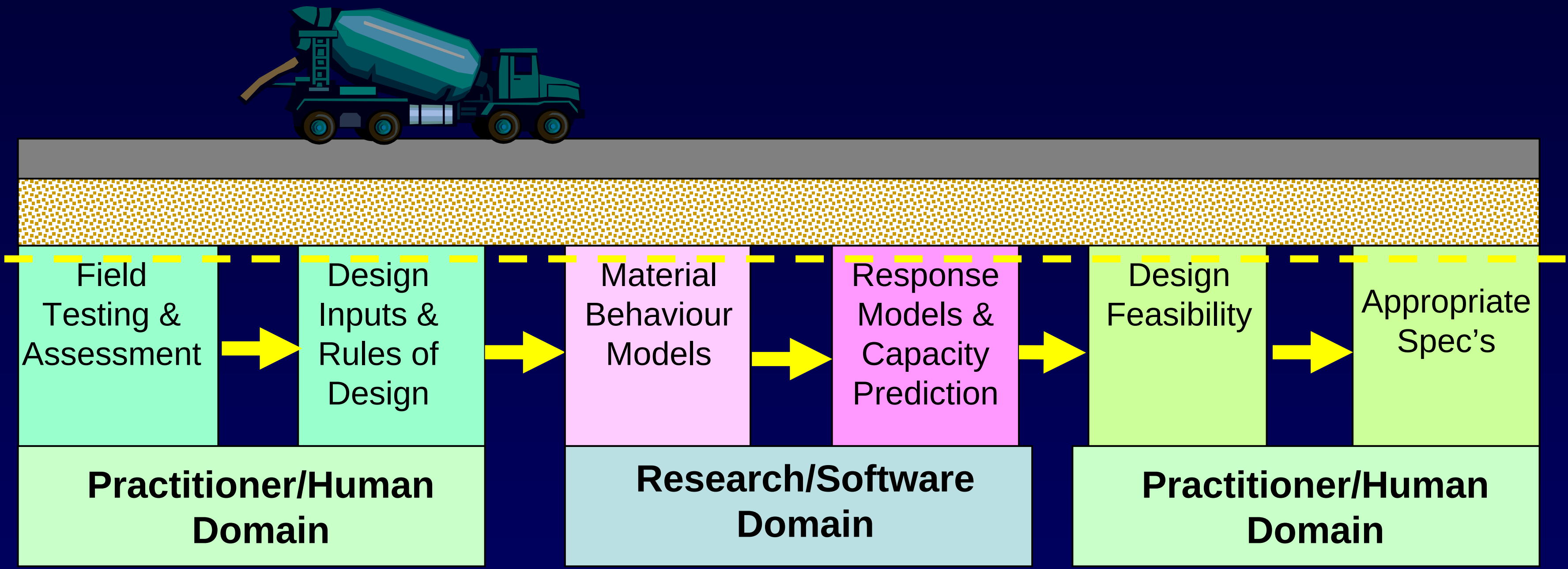


Pavement Design Elements



Traditional ME Research Approach: Focus mainly on model and software development. Determining inputs, implementation and knowledge transfer is often neglected

Pavement Design Elements



<u>Vision for Medium Term Outcome</u>: A practical design method that incorporates best practice elements of mechanistic analysis, field testing and construction

Knowledge Based Approach

- Gather all available field performance data
- Distil best elements of mechanistic analysis
- Validate and refine for robustness
- Develop clear, strong linkage to field testing and specifications

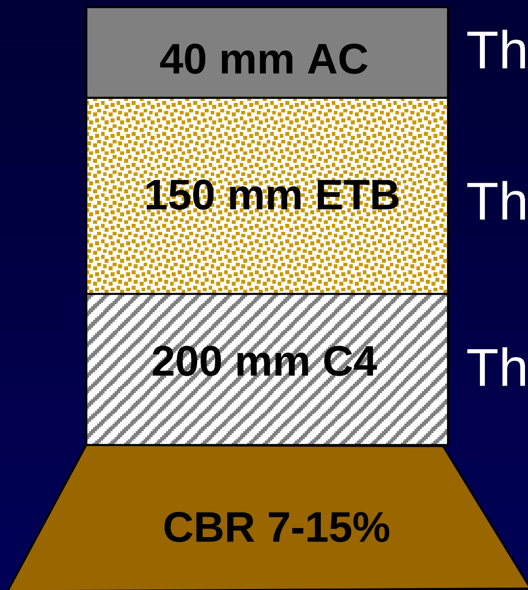
<u>Data Sets:</u>

- More than 20 field sites with construction, maintenance & performance info
- 7 HVS Sites (22 test sections) with construction & performance

Structural Design Method

- Based on the Structural Number Concept
- Improved by incorporating established design principles and local experience
- Calibrated for long term field performance

The Structural Number Revisited



$Thick_1 \times A_1 = SN_1$

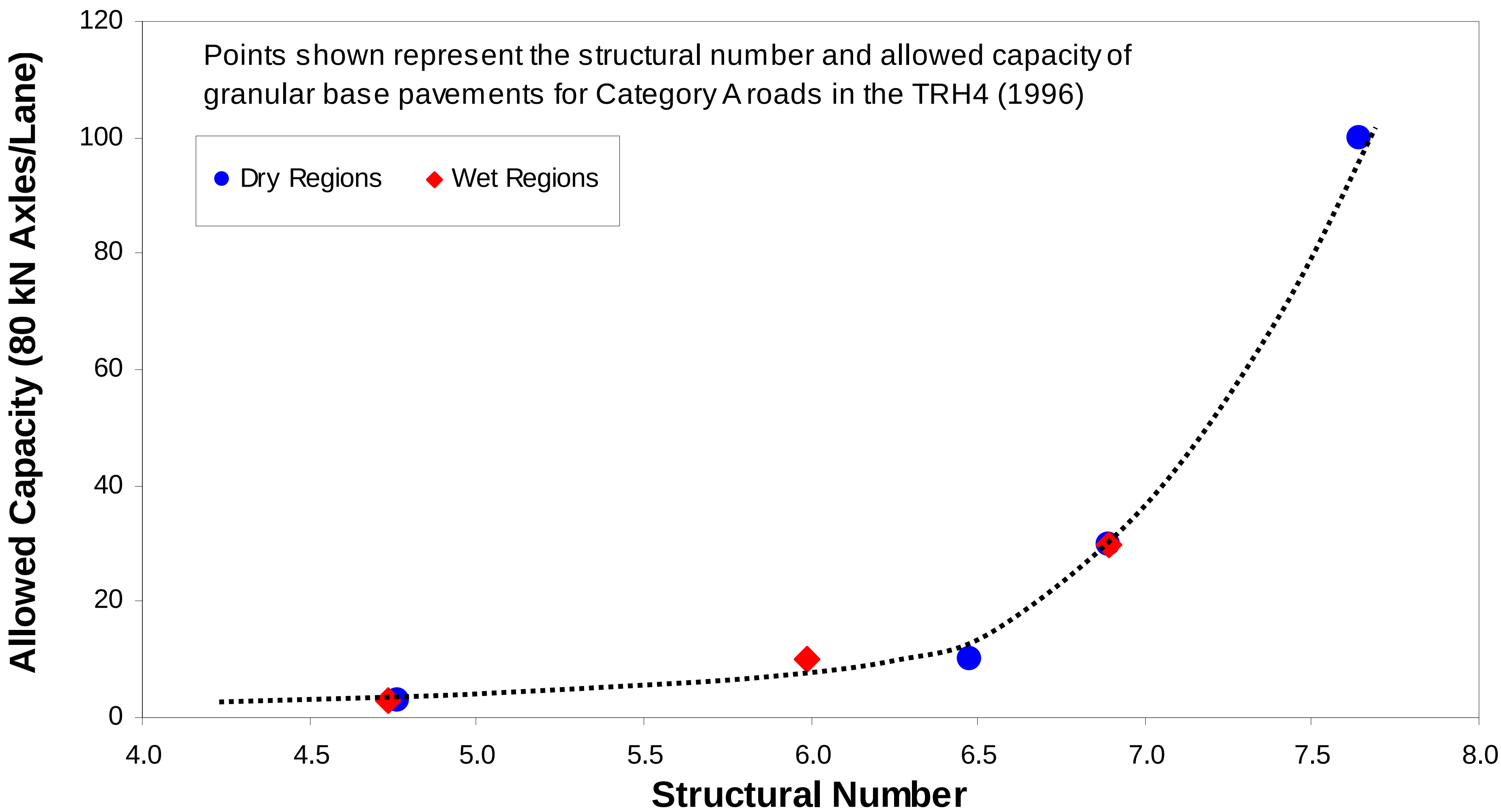
$Thick_2 \times A_2 = SN_2$

$Thick_3 \times A_3 = SN_3$

$$SN = SN_1 + SN_2 + SN_3$$

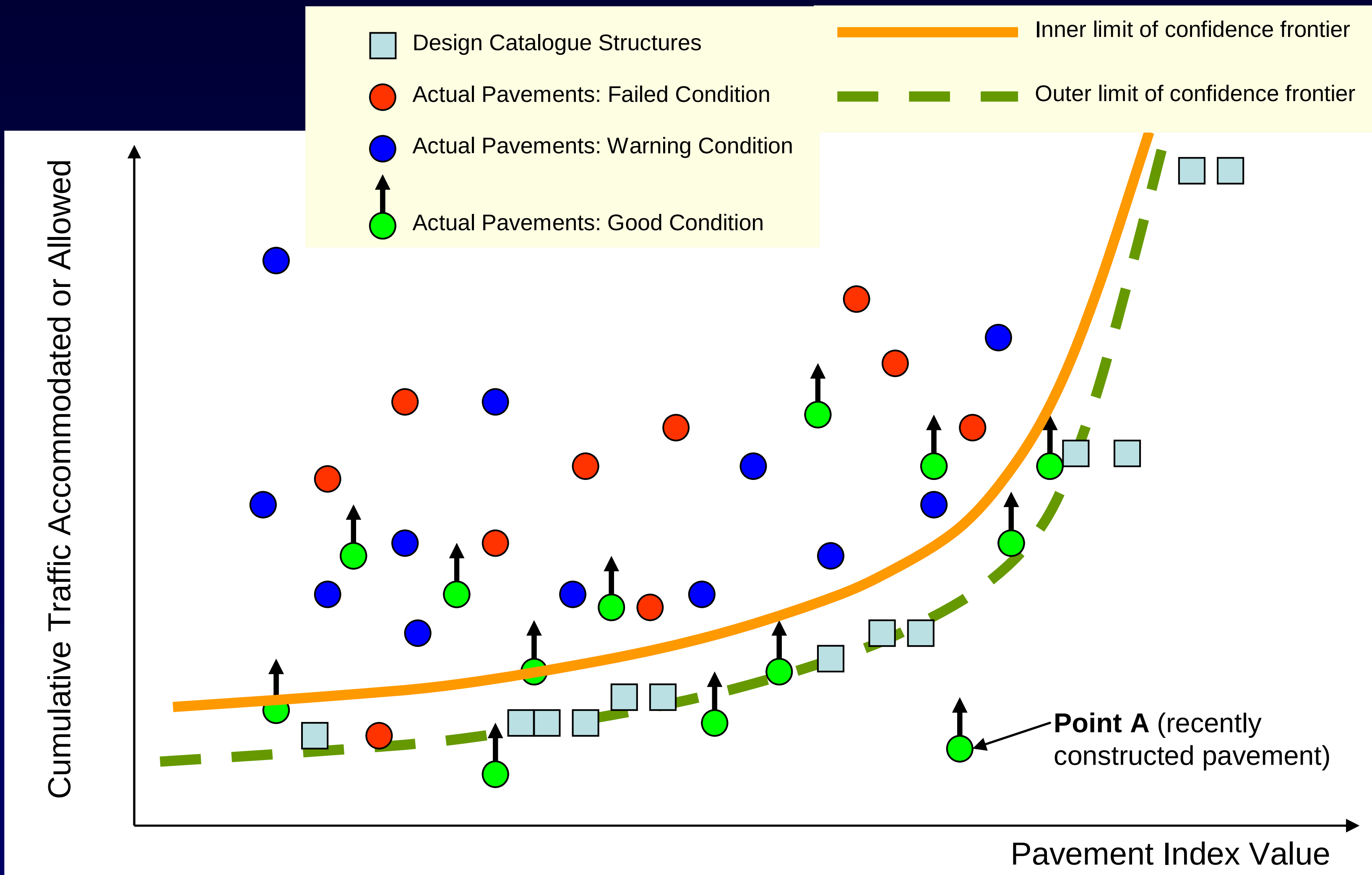
Adjusted for Subgrade Conditions

The Structural Number Revisited



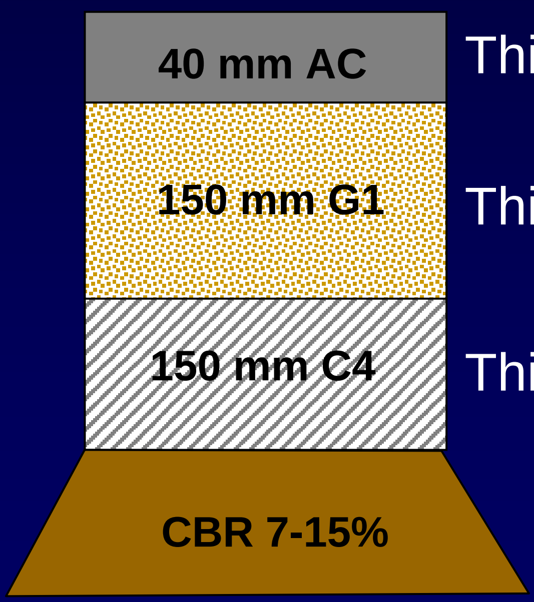
Development Advantage: easy to calibrate to observed performance

Linking to Observed Performance



Disadvantages of SN Approach

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



$Thick_1 \times A_1 = SN_1$

$Thick_2 \times A_2 = SN_2$

$Thick_3 \times A_3 = SN_3$

$$SN = SN_1 + SN_2 + SN_3$$

Both of these limitations can be overcome by incorporating design rules of thumb that make the SN more intelligent.

Rules of Thumb

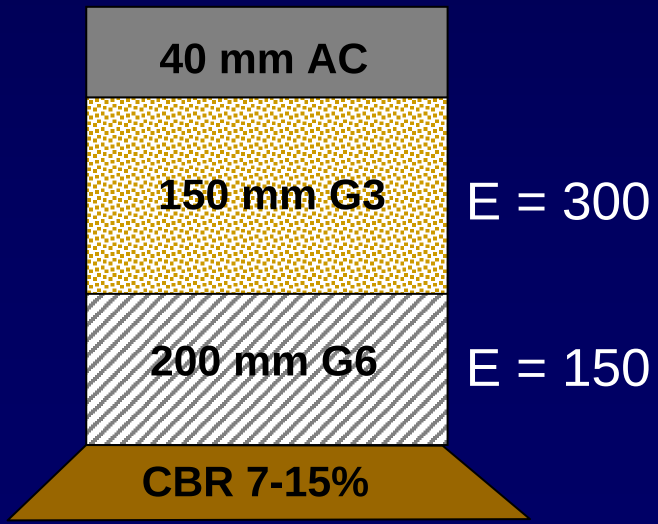
1. Structural capacity is determined by the combined long term load spreading capacity of all pavement layers
2. Subgrade quality is the point of departure for design, as it effects all layers above it
3. The type and quality of the base layer is critical, and suitable base material depends on design situation

Says Who?

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

Effective Long Term Stiffness (ELTS)

- Represents the average stiffness of the material over the design life
- Depends on the material type/quality
- Depends on layer situation within the pavement
- Modular Ratio is used to determine the ELTS of a material



MR = 300/150 = 2

Determining a Layer's ELTS

For each material class (G1, G2, C4, etc):

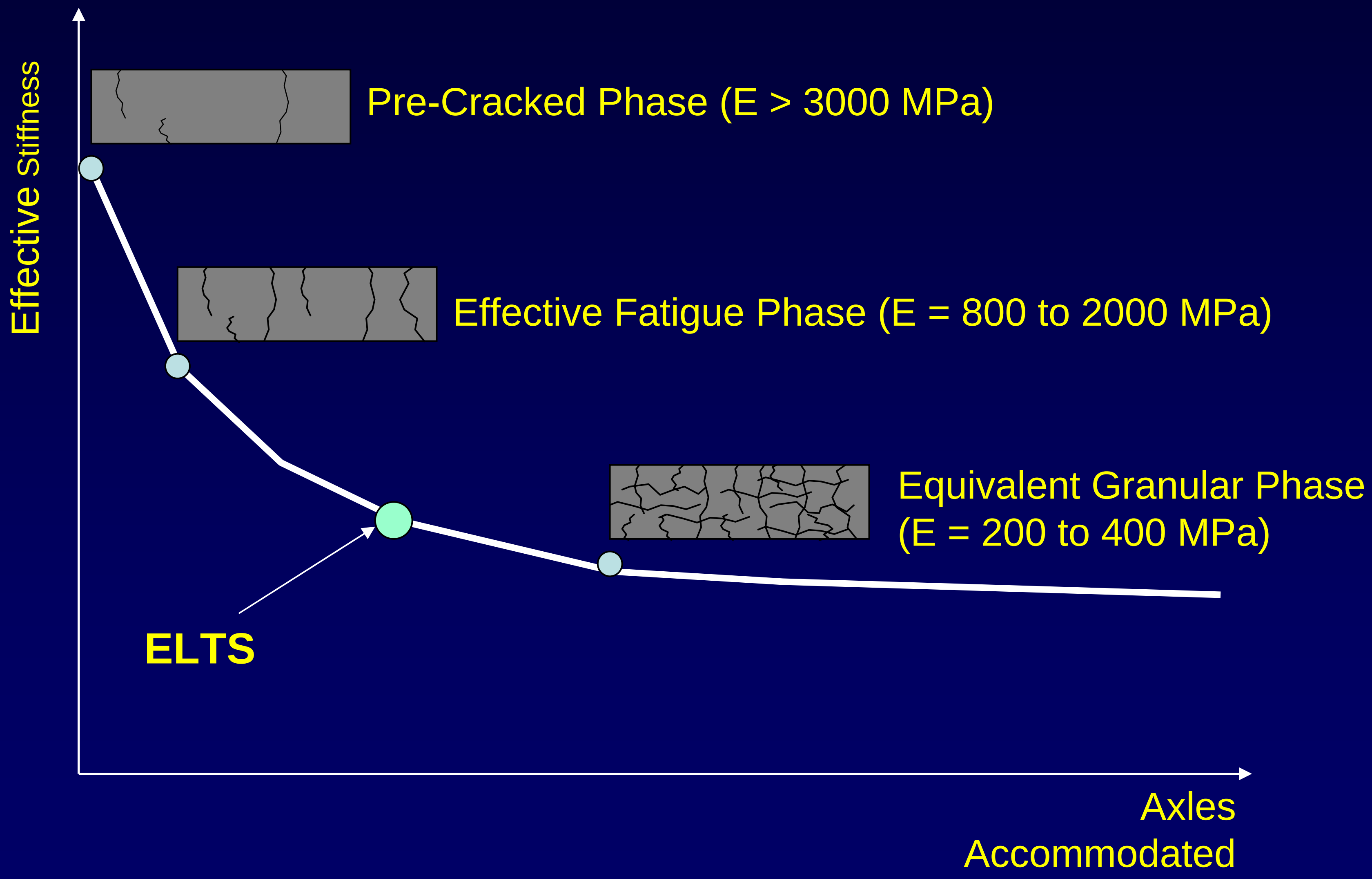
- Suitable modular ratio
- Maximum allowed modulus

ELTS is the minimum of:

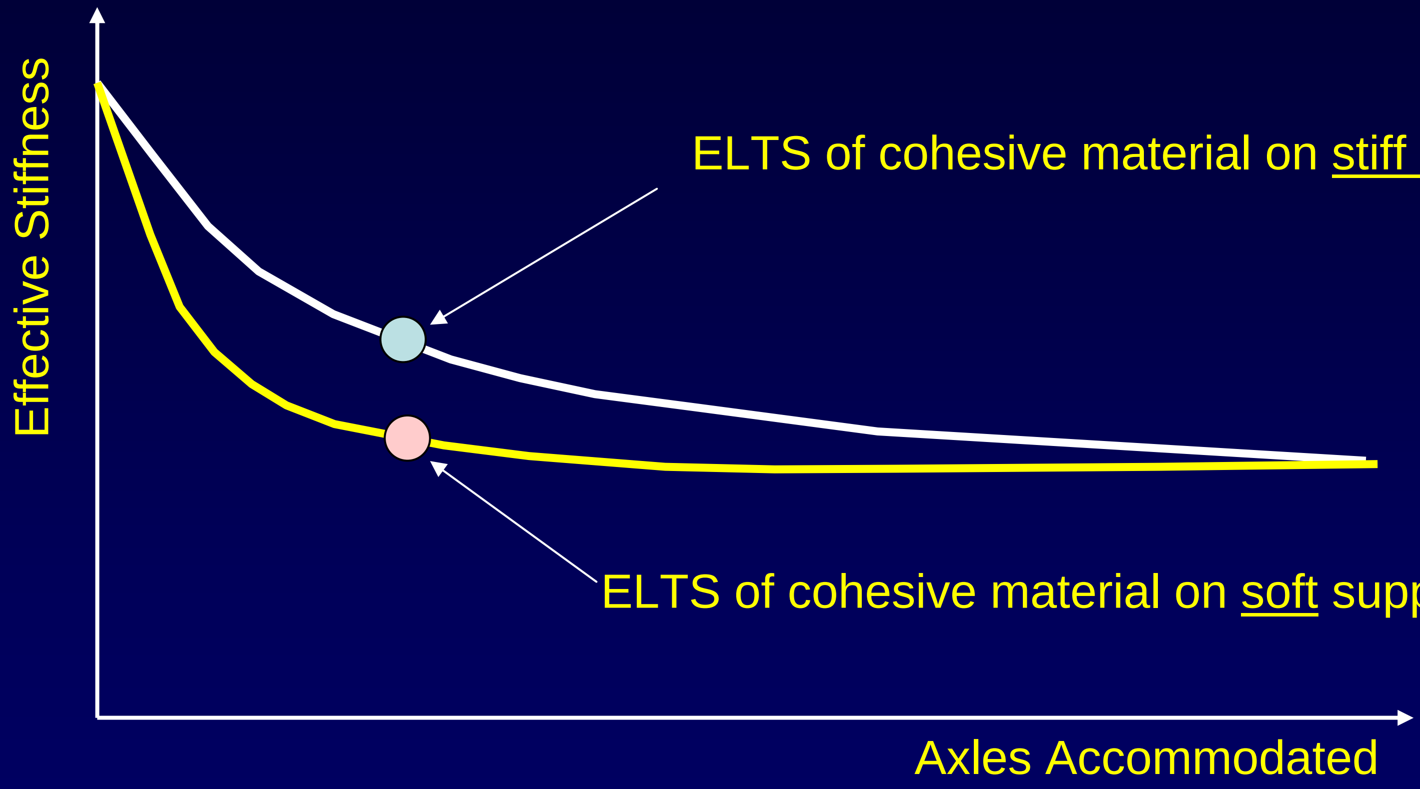
- (Modular Ratio) x (Support Stiffness)
- Maximum Allowable Stiffness

Important!!! ELTS is a model-specific parameter. It is not a stiffness that can be measured in the laboratory or field

ELTS for Cohesive Materials



Modular Ratio for Cohesive Materials



For cement stabilized materials, stiffness is also adjusted based on thickness, to account for crack propagation rate

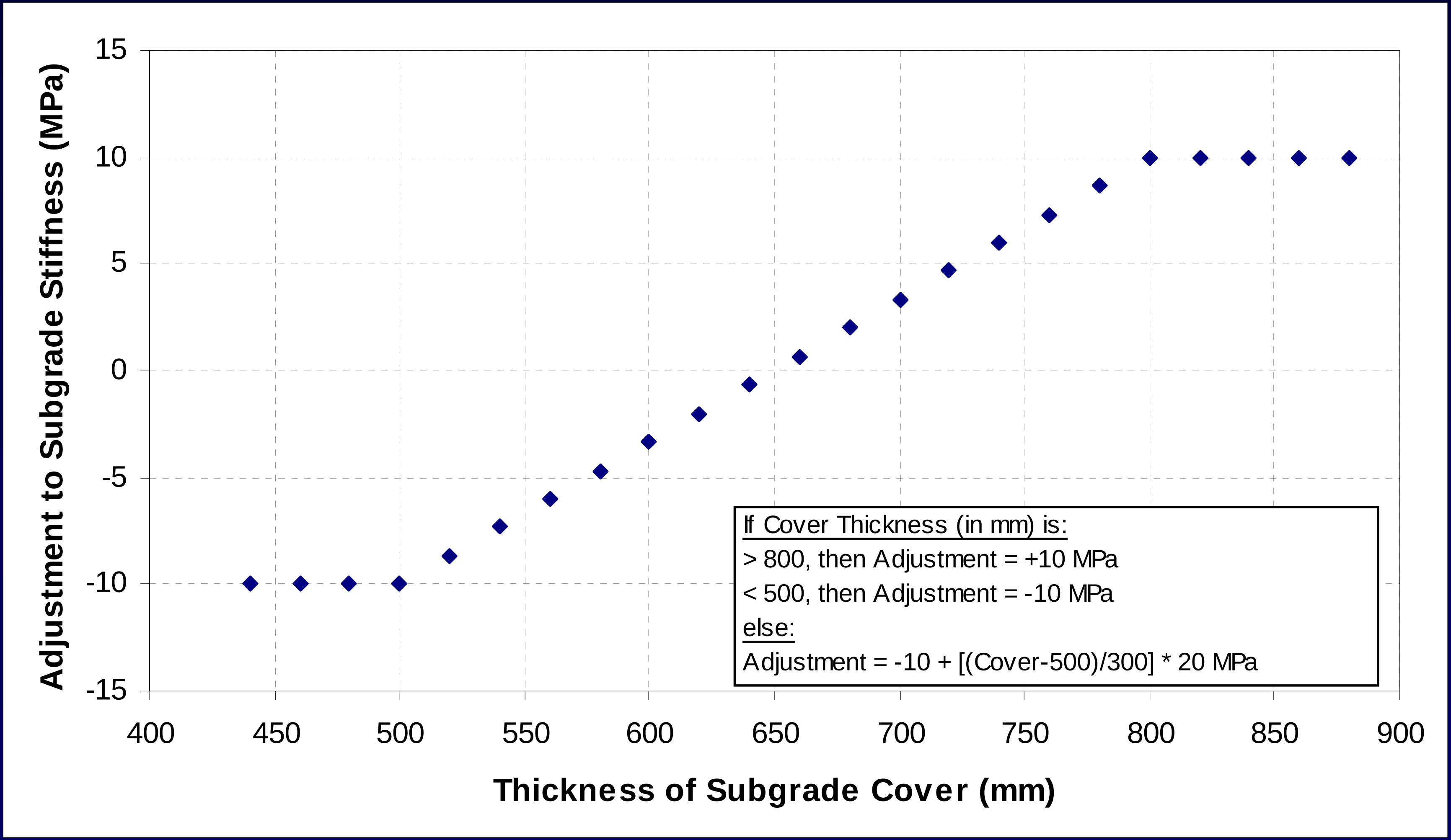
Subgrade Characterization

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

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

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

Adjusting for Subgrade Cover



Quality of Base Material

- Recognizes the importance of appropriate base material
- “Base Confidence Factor” (BCF) is incorporated to indicate suitability of material to serve as a base layer
- Ensures poor designs are disqualified

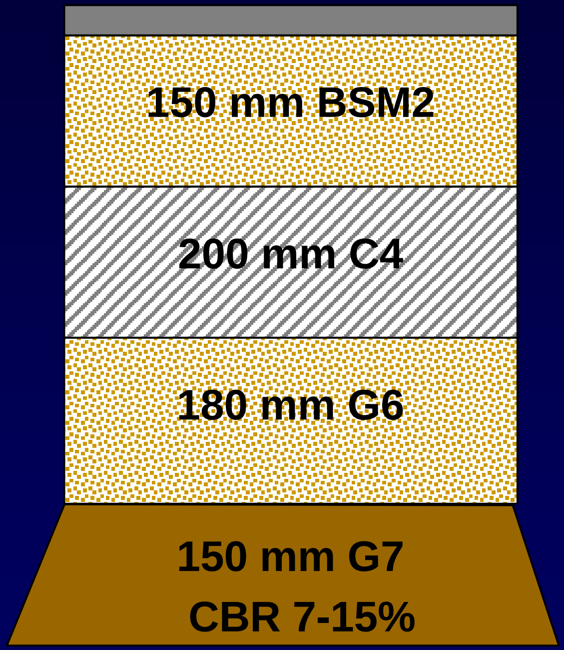
Design equivalent material class	**BCF**
G1	1.1
C4	0.4
G6	-2.0

Putting it Together

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 cemented materials, adjust ELTS based on thickness
7. Multiply thickness and ELTS for each layer and summarize to obtain PN

Example, Moderate Region

1. Material Classes



2. Determine subgrade stiffness (140 MPa)

3. Adjust for climate (126 MPa)

4. Adjust for cover (118 MPa)

5. Assign modular ratio's and Maximum Emods	6. Calculate Layer ELTS Values
MR = 2, E_{Max} = 450	ELTS = 450 BCF = 0.7
MR = 3, E_{Max} = 400	ELTS = 400 Thickness Adj = 0.4
MR = 1.8, E_{Max} = 180	ELTS = min(212,180) ELTS = 180
118 MPa	**118 MPa**

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

7. Layer PN = thickness * ELTS

8. PN = Σ layer PN

Calibration of the PN Model

<u>Calibration Process:</u>

- Assumed best estimates for material constants
- Pavement number (PN) evaluated
- PN plotted again structural capacity of pavements in the calibration dataset
- Identify structures not fitting general pattern
- Material constants adjusted

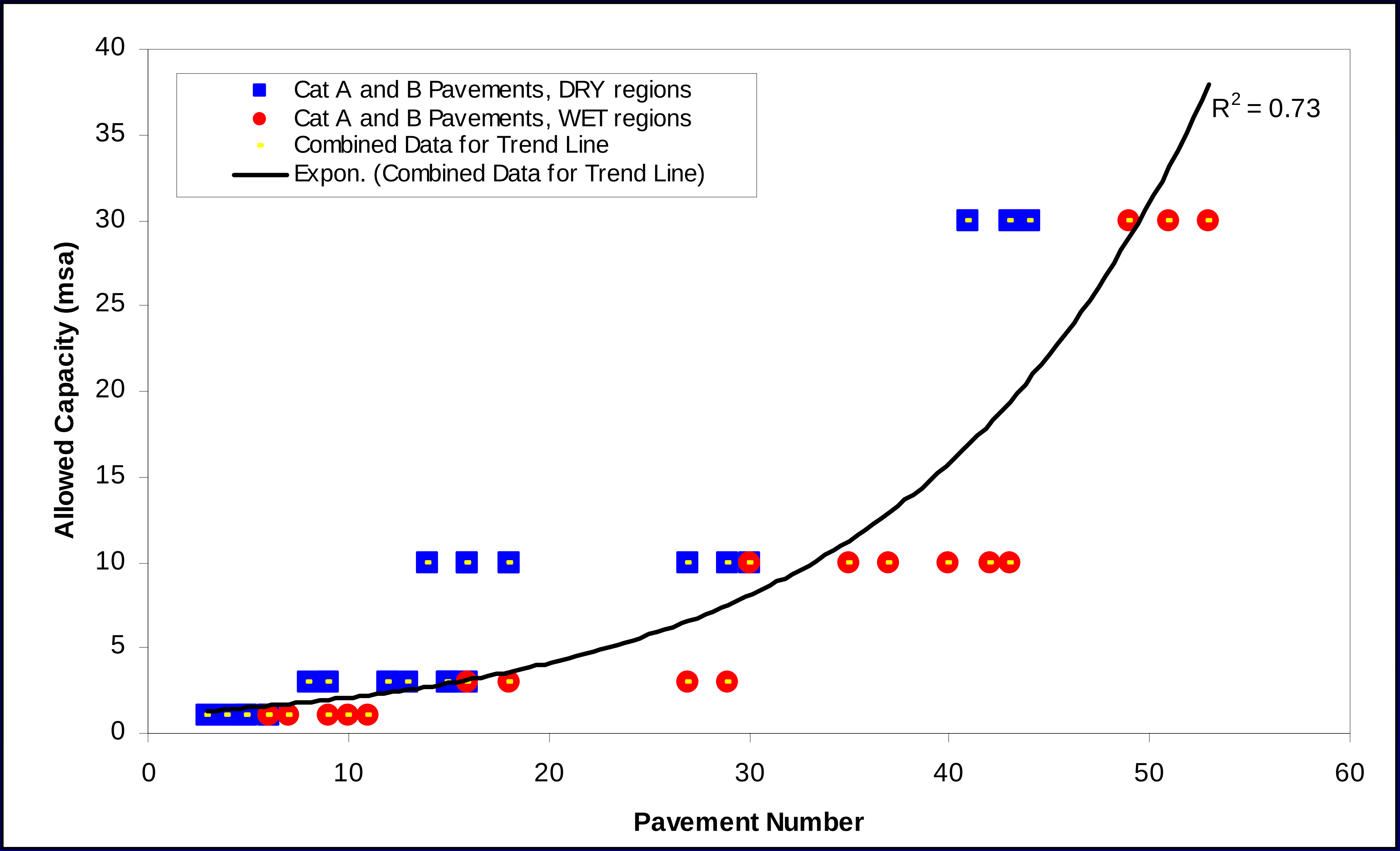
<u>Calibration Datasets:</u>

- TRH4 design catalogue set
- LTPP dataset for BSM materials
- HVS dataset for BSM materials

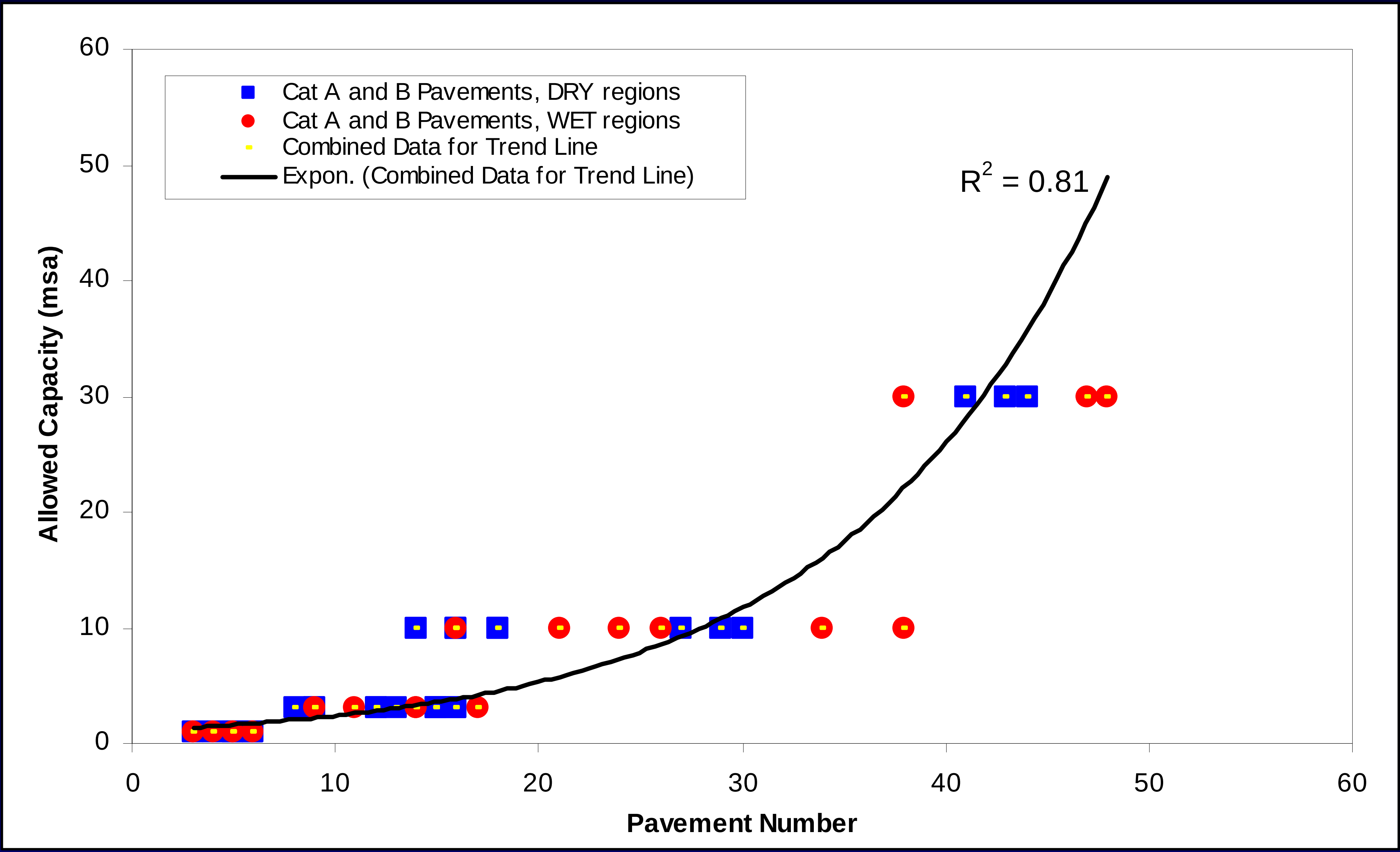
TRH 4 Dataset

- All pavements for unbound materials
- Wet and dry climates
- 1 to 30 msa
- 3 subgrade types
- TOTAL 51 pavement structures
- Used upper limit of design traffic class

TRH4 Data - Uncalibrated



TRH4 Data – Calibrated for Climate



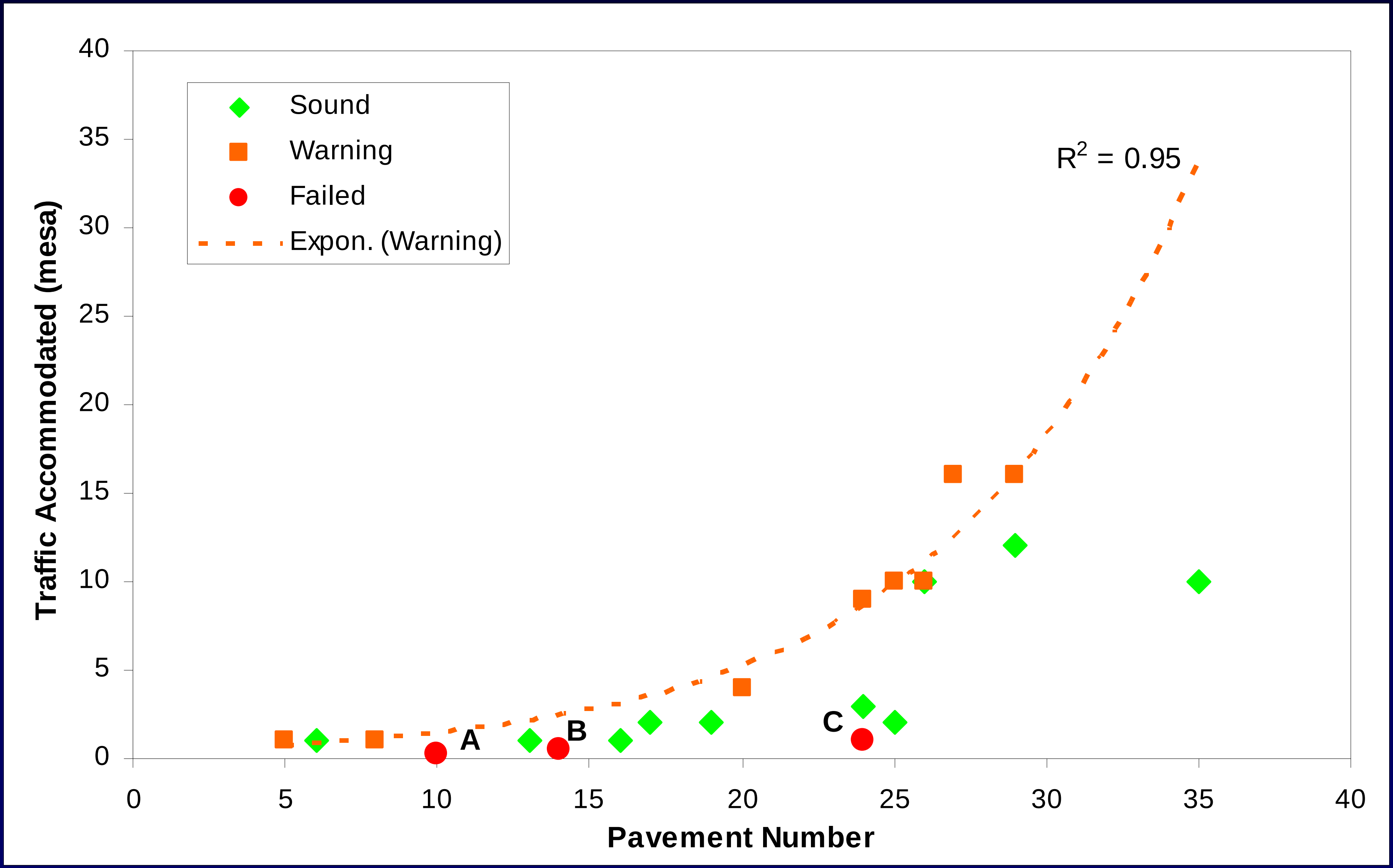
Emulsion LTPP Sections

- D2388 (Cullinan)
- MR27 (near Stellenbosch)
- N1 / 1 (Kraaifontein)
- N1 / 13 (Springfontein to Trompsburg)
- N1 / 14 (Springfontein to Trompsburg)
- N2 / 16 (Kwelera, East London)
- N2 / 20 (Mount Frere to Mount Ayliff)
- N3 / 4 (near Mooi River)
- N3 / 12 (Johannesburg) x 2
- N4 / 1 (Pretoria)
- N4 / 5X (Wonderfontein to Crossroads) x 2
- N7 / 7 (Kammieskroon)
- N12 / 19 (Daveyton) x 2
- P23 / 1 (Kroonstad to Steynsrus)
- Road 1386 (Moloto, Pretoria) x 2

Foamed Bitumen LTPP Sections

- MR504 (Shongweni) x 3
- N11 / 8 (Ermelo to Hendrina)
- P24/1 (near Vereeniging)
- P243/1 (near Vereeniging)
- R22-4 / MR439 (Phelandaba)
- Same-Himo (Tanzania) x 3
- TR16-3 / R27 (Nieuwoudtville to Calivinia)

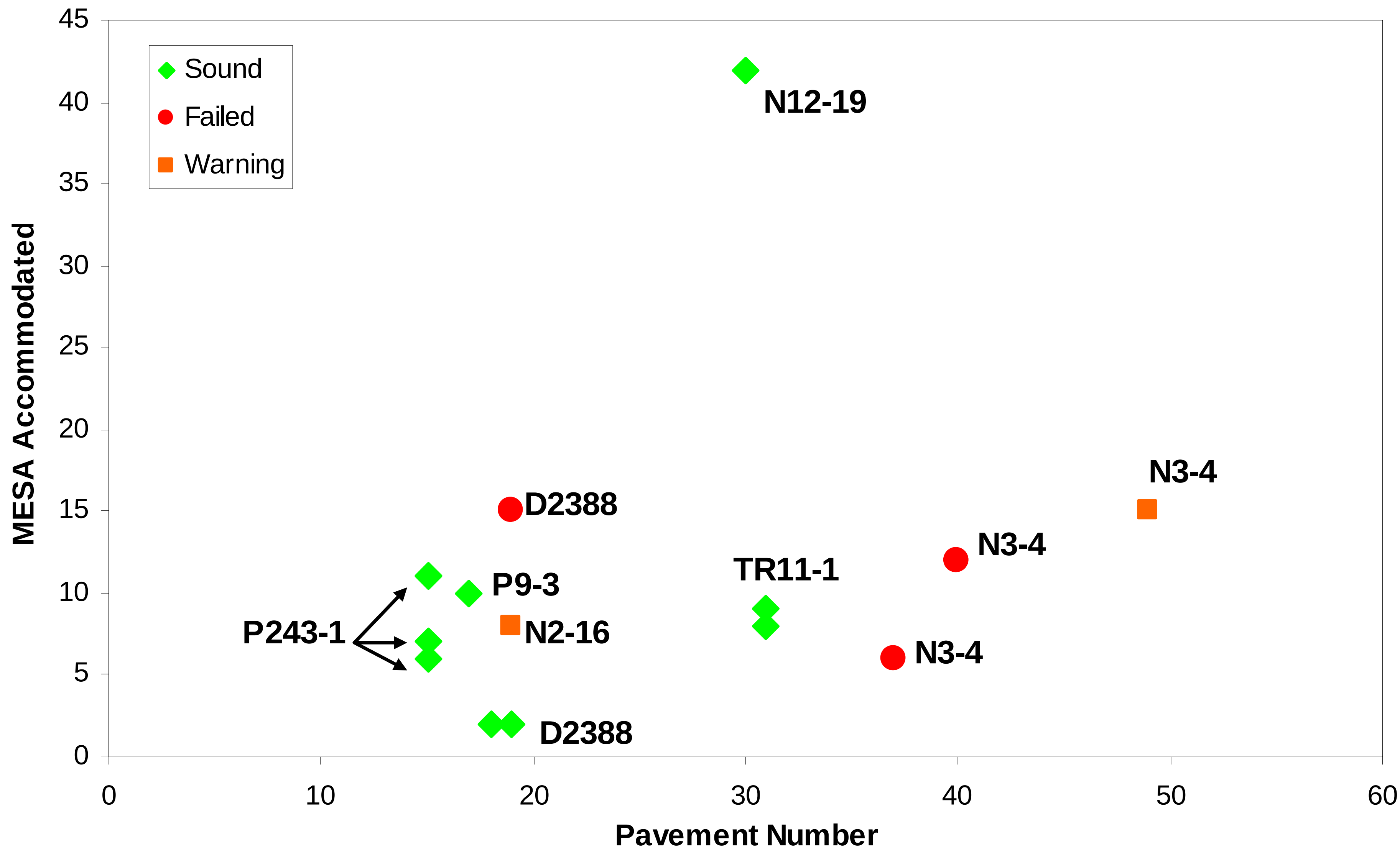
LTPP Dataset



HVS Dataset

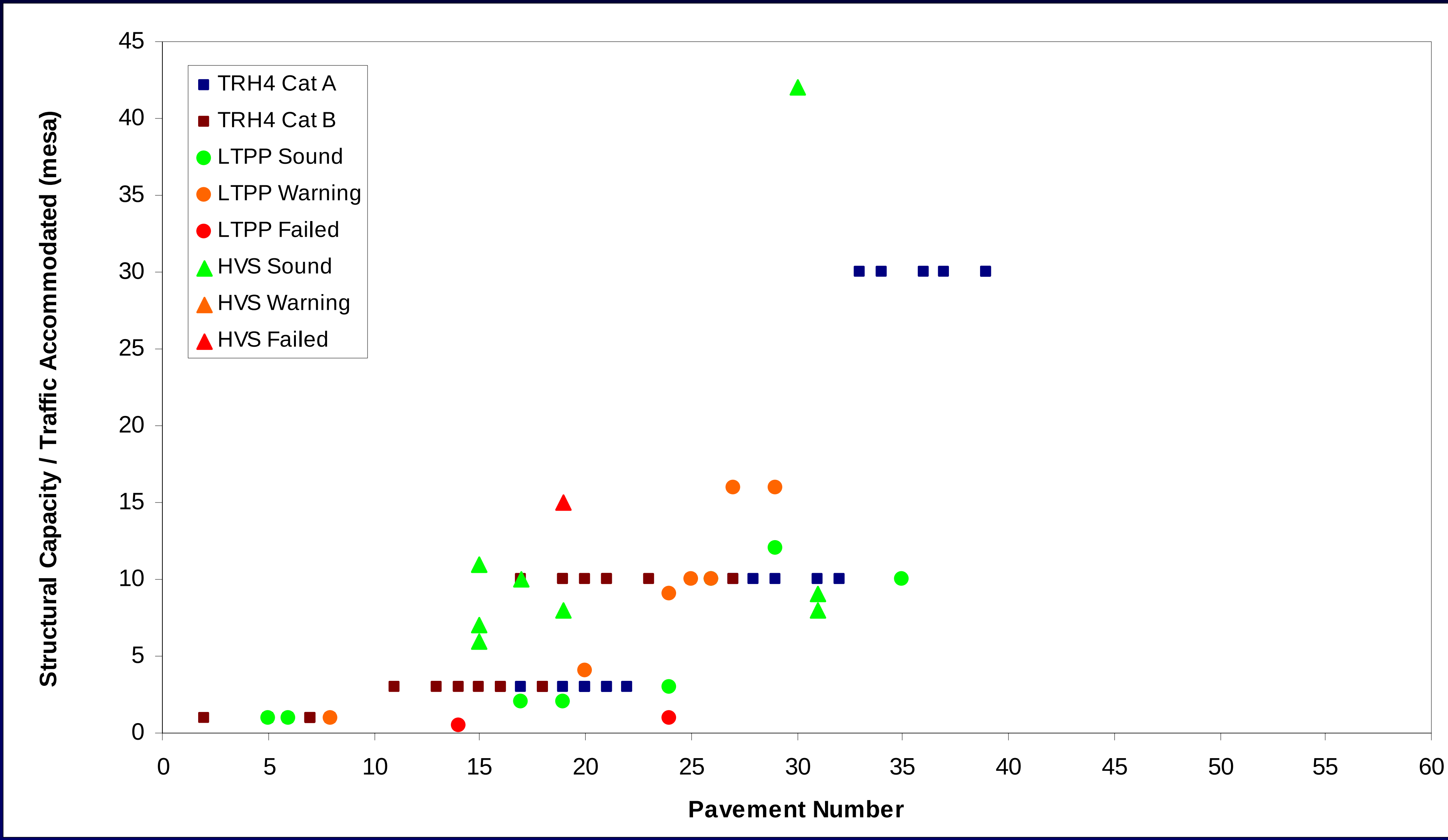
- N3-4 (Mooi River)
- N2-16 (Kwelera, East London)
- P9-3 (Heilbron)
- D2388 (Cullinan)
- P243/1 (Vereeniging)
- N7-7 (Cape Town)
- N12-19 (Daveyton)

HVS Dataset

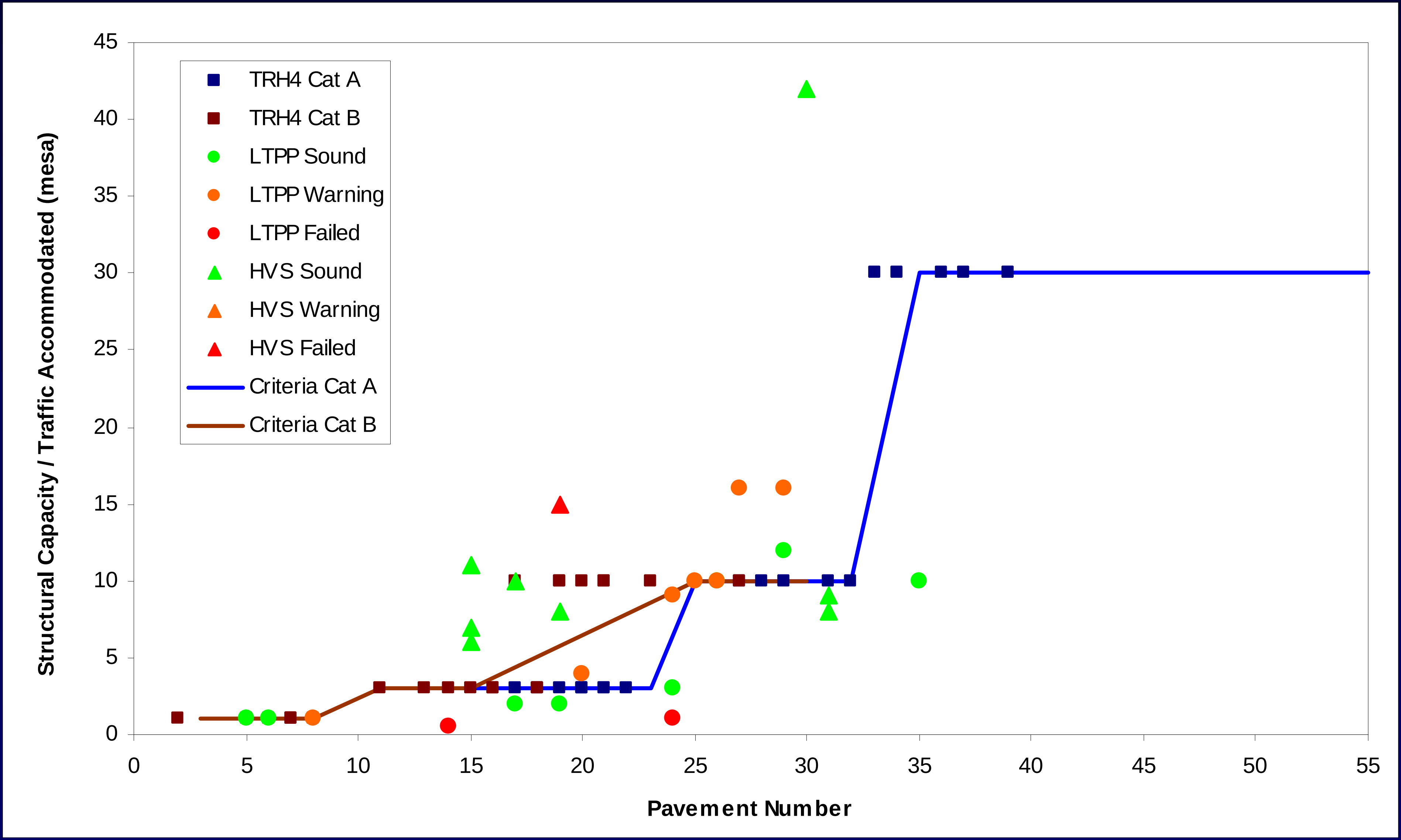


Sound
Failed
Warning
N12-19
D2388
N3-4
N3-4
TR11-1
P9-3
N2-16
P243-1
N3-4
D2388
MESA Accommodated
Pavement Number
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50
60

Combined Datasets



Design Criteria



Suitability of PN-Based Method

- Method not applicable to:
  - Design traffic > 30 msa
  - Design traffic < 1 msa (catalogue required)
  - Presence of thin, weak lenses
  - Subgrade CBR < 3 %

Summary: Structural Design

- Simplified method for determining structural capacity
- Robust, Easy to understand
- Well and explicitly validated with TRH4, LTPP and HVS datasets
- Valid for design traffic up to 20 mesa (majority of SA roads)
- Should not use independently for traffic > 30 mesa
- Requires Material Class as design inputs

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Material Classification System

Allows engineers to make a rational and consistent decision about the material class to use for design purposes, based on routine materials tests

Difficulties:

- Uncertainty in available evidence/small samples
- Uncertainty between evidence and conclusions that can be drawn from it
- Vagueness/Subjectivity of assessment

Handle Difficulties by:

- Encouraging a holistic approach that incorporates many test/indicator types
- Clear guidelines for interpreting test results
- Method to synthesize results using aspects of Certainty Theory and Fuzzy Logic
- Introduce Design Equivalent Material Class

Handling Vagueness

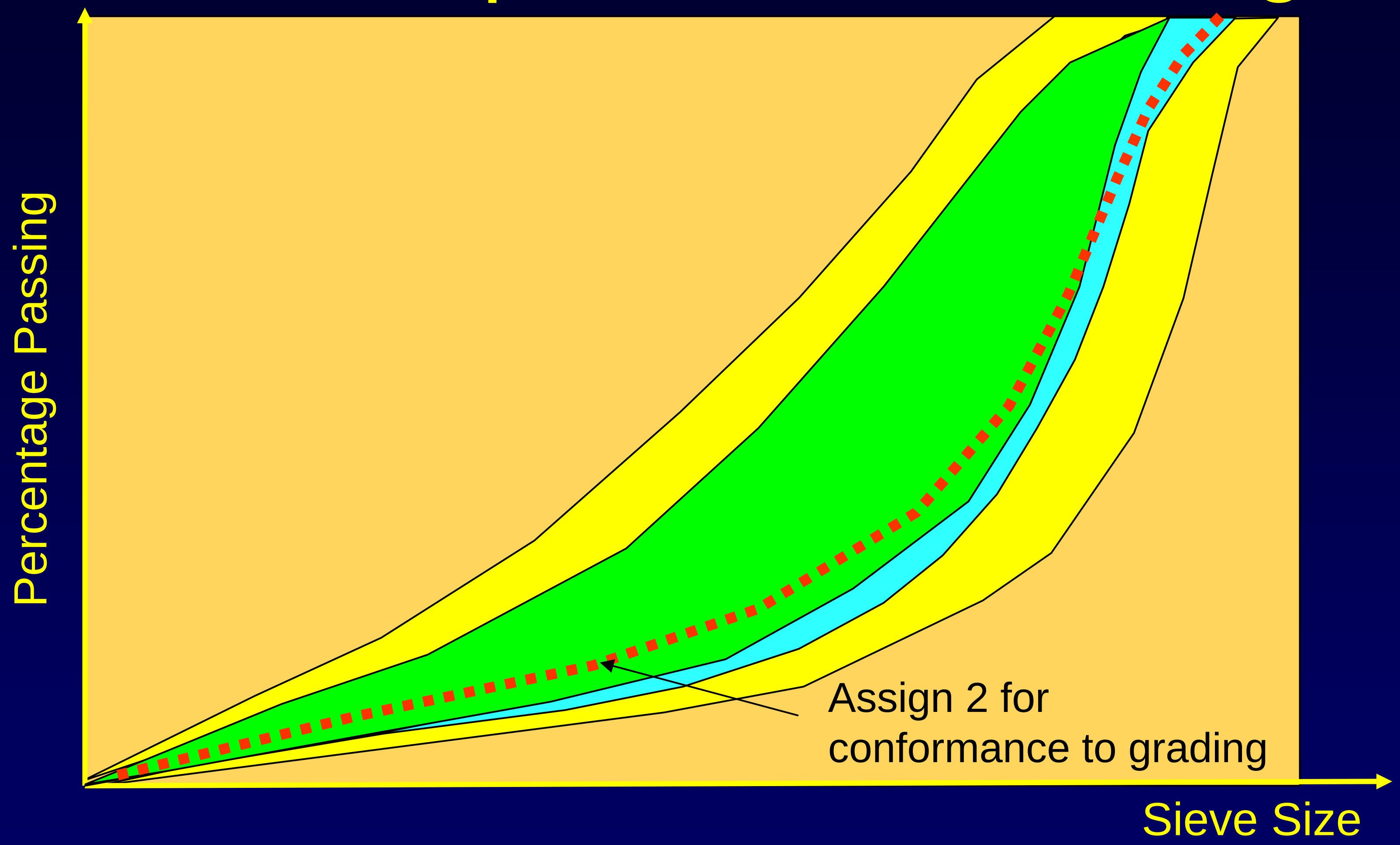
- Clear guidelines for interpretation
- Obtain either a direct test result that can be processed statistically (e.g. CBR, DCP)
- Or, obtain a rating that can be processed statistically

Material Type	**Plasticity Index Measured on Fraction Passing 0.425 mm Sieve**									
Crushed Stone	< 4	4 and 5	6 and 7	8 to 10	>10					
Natural Gravel			<4	5 and 6	6 to 10	10 to 12	>12			
Gravel-Soil						<11	11 or 12	13 to 15	>15	
Sand, Silty Sand, Silt, Clay							<12	12 to 14	14 to 20	>20
PI Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Guidelines for Interpretation

Material	PI of Material Passing 0.425 mm Sieve						
Crushed Stone	<4	4,5	6,7	8-10	>10		
Natural Gravel			<4	5,6	6-10	10-12	>12
Gravel-Soil						<11	11, 12
Sand, Silt, Clay							
Rating	1	2	3	4	5	6	7

E.G Interpretation of Grading



1 Inside Envelope

2 Coarse, but follows envelope closely (well-graded)

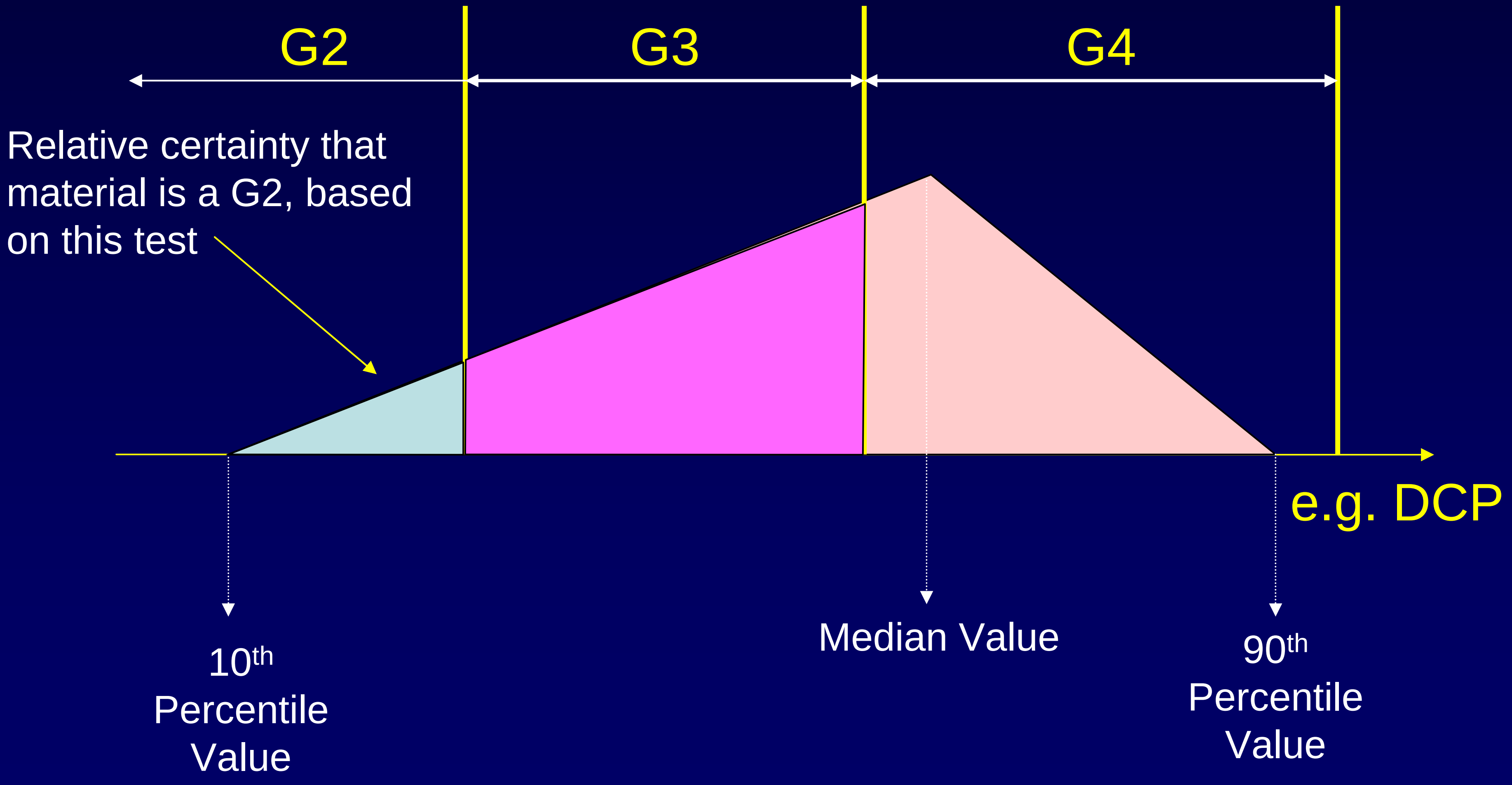
3 Fine or significantly coarse

4 Significant deviation from envelope

Grading Interpretation

Material Type	**Conformance to Grading Envelope**									
CS (use TRH 14 G1to G3 Spec)	1	2	3	4						
NG (use TRH 14 G4 Spec)				1	2	3	4			
GS (use TRH 14 G4 Spec)					1	2	3	4		
Grading Rating	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Assigning Material Class Confidence for Specific Indicators



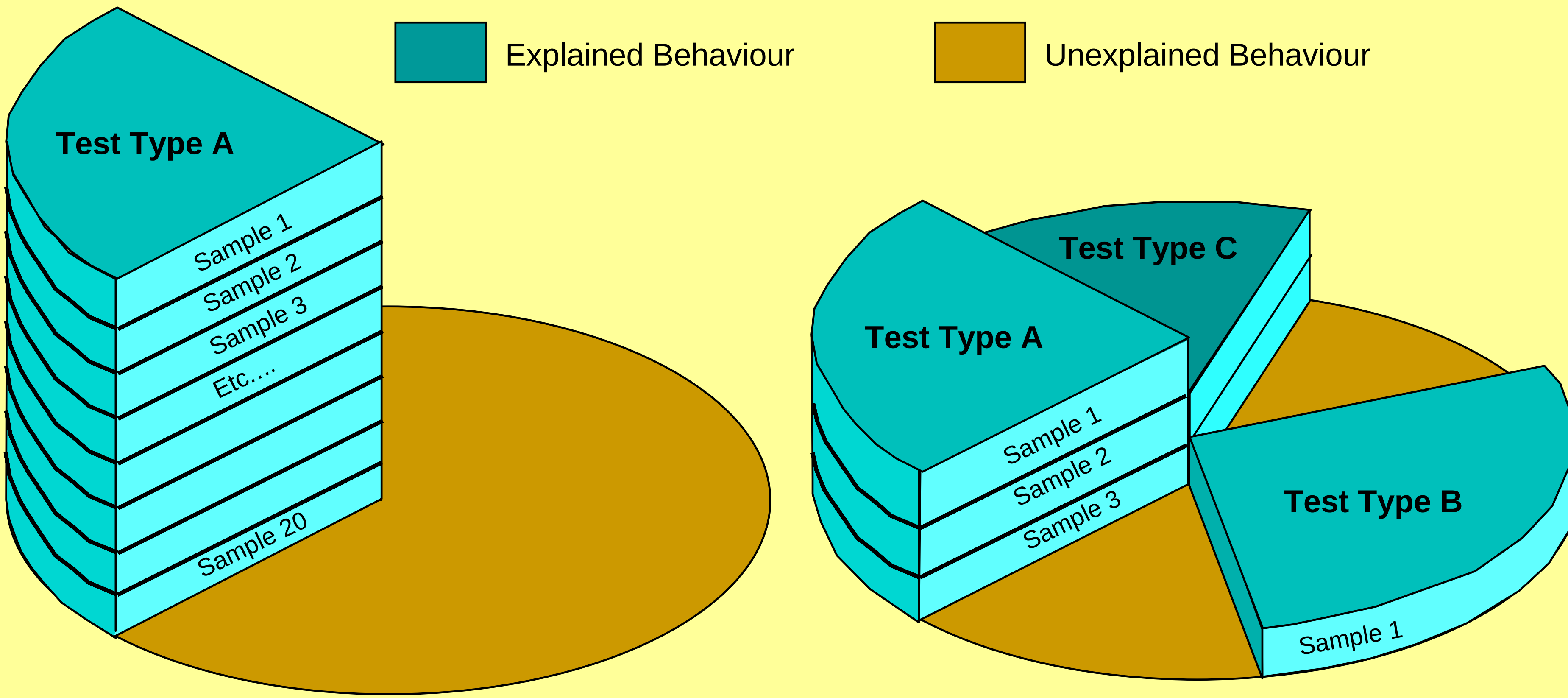
Classification Parameters and Certainty Factors: Granular and Cemented Materials

• Soaked CBR	(0.4)
• Grading, % passing 0.075, grading modulus	(0.4, 0.3, 0.2)
• Relative density	(0.3)
• DCP penetration	(0.4)
• FWD stiffness	(0.3)
• Consistency	(0.2)
• Plasticity Index	(0.4)
• Moisture content	(0.3, 0.2)
• Aggregate crushing value	(0.3)
• Number of fractured faces	(0.3)
• Historical performance	(0.4)
• Evidence of active cement	(0.3)

Also adjust for sample size

Small Samples: Holistic Assessment is the Key

Reliability versus Completeness



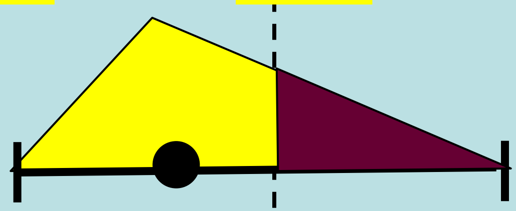
Situation 1: Reliable estimation of one indicator

Situation 2: Three indicators, but less reliable estimation each

Synthesis of Results

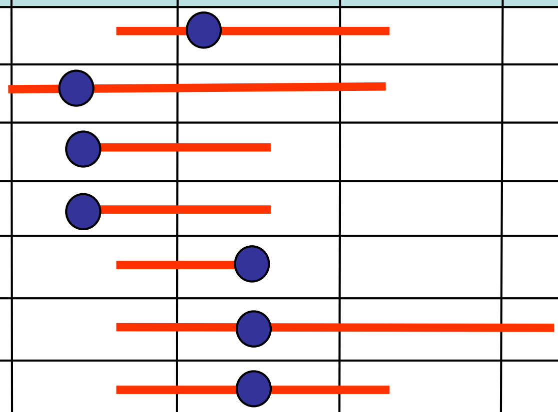
- Use Certainty Theory concepts
- Sequentially process data to obtain cumulative certainty that material is a G1, G2, etc. given the available evidence

Material Class

Available Information	G3	G4	G5	G6
Grading	0.1	0.2	0.0	0.0
Plasticity Index	0.1	0.35	0.1	0.0
DCP Penetration (mm/blow)	Refusal	1.5	3.0	6.0
Rule certainty = 0.3				
C(Hypothesis|DCP Info)	0.1	0.47	0.23	0.0
Backcalc. Stiffness	0.1	0.59	0.30	0.0

Materials Classification Report - Example

		Test Limits for Material Class				Cumulative Certainty for Material Class			
Test or Indicator	Samples	G4	G5	G6	G7	G4	G5	G6	G7
DCP Penetration	12					0.13	0.29	0.06	0.00
FWD Stiffness	67					0.26	0.32	0.11	0.00
Grading Analysis	3					0.37	0.34	0.11	0.00
% Passing 0.075	3					0.43	0.37	0.11	0.00
Plasticity Index	5					0.46	0.47	0.11	0.00
California Bearing Ratio	2					0.49	0.54	0.16	0.03
Relative Moisture Content	4					0.52	0.57	0.19	0.00



Outcome: Material is most likely a **G5** design equivalent

Confidence: Confidence of the assessment is **medium**. For structural rehabilitation, it is recommended that the sample size and number of test indicators be increased.

Classification Parameters: BSM

- Will be developed as a result of mix design project
- Should be based on:
  - Source material class
  - Overall shear strength
  - Cohesion
- 3 Classes:
  - BSM1: *high shear strength, > 6 mesa, crushed stone or RAP*
  - BSM2: *moderate shear strength, < 6 mesa, natural gravel or RAP*
  - BSM3: *soil-gravel with high binder contents, < 1 mesa*

Summary: Materials Classification Method

- Consistent, rational classification of materials
- Valid for all common materials used in SA

Where to next with project?

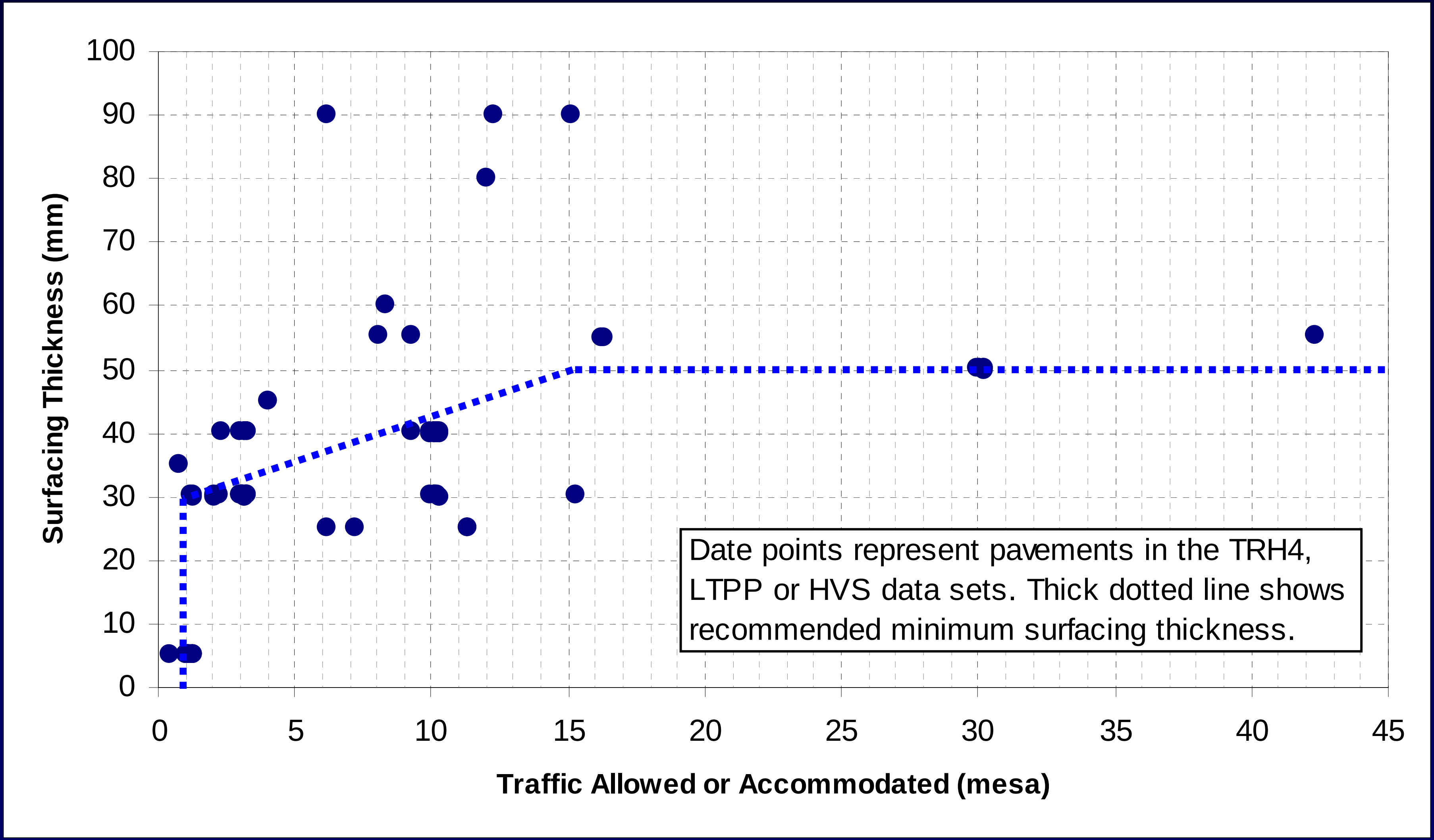
- Review of structural and materials design method by industry representatives
- Develop trial software for implementation by practitioners to test method
- Update methods based on outputs from mix design project
- Compile guideline document

Tying into SANRAL M-E Project

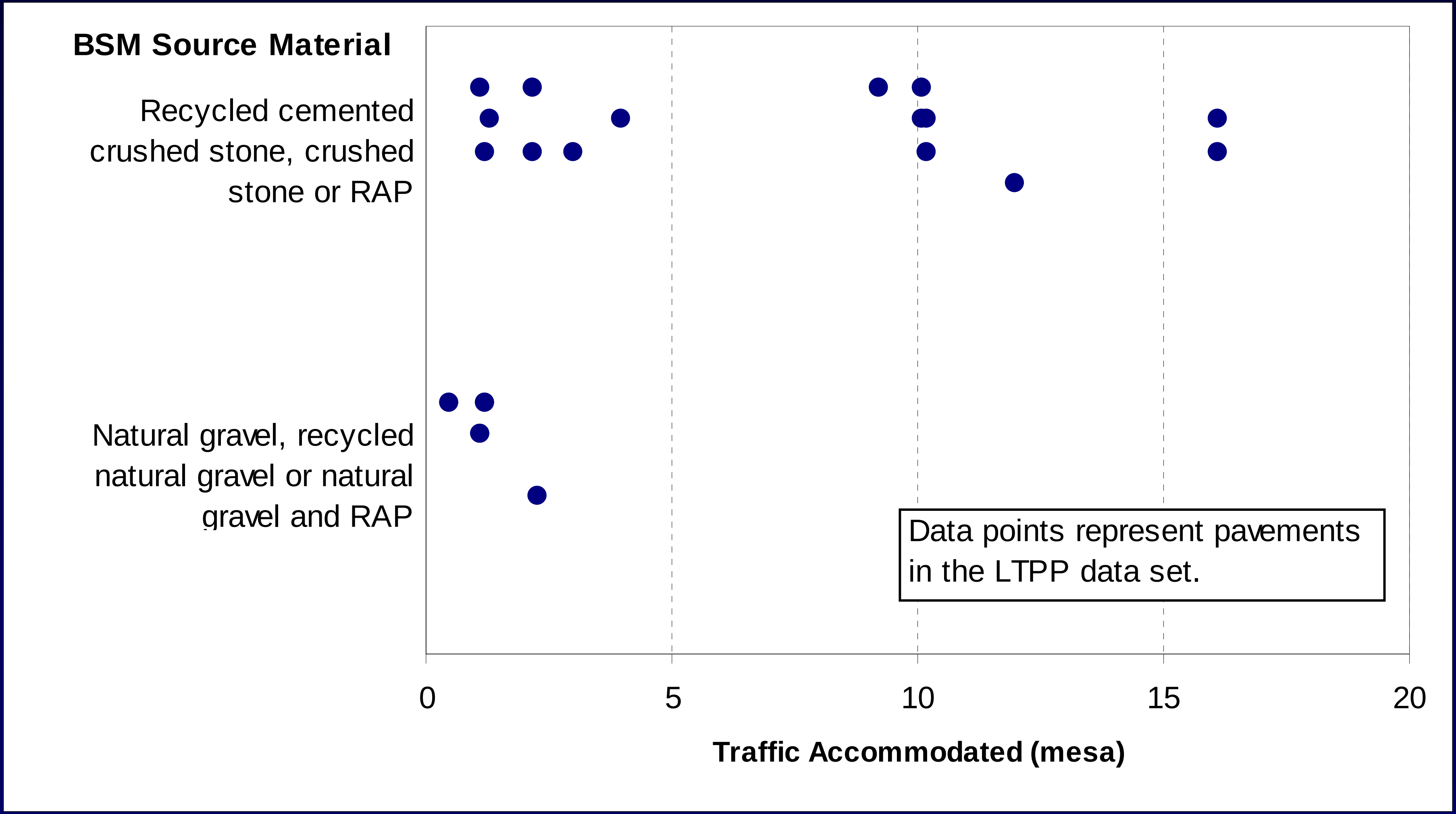
- Pavement Performance Information System
  - Enlarge and update LTPP dataset
  - Use for validating the M-E method
- Long term
  - First level approach for pavements carrying up to 20 mesa
  - Use as a check for “reasonableness” of more complex calculations and feasibility of designs

Thank You!

Appropriate Surfacings



Appropriate Source Material



Validation (Unbound subbase)

Road	Climate	Traffic	Condition	Validation
N1 - 14	Dry	10-13 (10)	Warning	Good, suitably conservative
N12 (1)	Mod	16-27 (17)	Warning	Good, suitably conservative
Same-Himo	Wet	1-2 (1)	Sound	Good, suitably conservative
MR504 (A)	Wet	0.7-2 (1)	Warning	Good, suitably conservative
MR504 (B)	Wet	0.7-2 (1)	Warning	Good, suitably conservative
P23/1	Mod	0.5-1.3 (3)	Failed	Pavement failed prematurely. Assessment reasonable, but didn’t identify early failure
D2388 (397)	Dry	1-3 (3-5)	< 5 mm rut	Good, suitably conservative
D2388 (403)	Dry	1-3 (3-6)	< 5 mm rut	Good, suitably conservative
D2388 (407)	Dry	11-22 (3-6)	20 mm rut	Good, suitably conservative
P243/1	Dry	5-10+ (3)	< 5 mm rut	Fair, perhaps overconservative
N7-7	Dry	6-10+ (10)	< 5 mm rut	Good, suitably conservative

Validation (Bound subbase)

Road	Climate	Traffic	Condition	Validation
N1-1	Mod	12-16 (10)	Sound	Good, suitably conservative
N1-13	Dry	10-13 (10)	Warning	Good, suitably conservative
N3-12 S	Mod	10-18 (30)	Sound	Seems appropriate
N3-12 N	Mod	10-18 (10)	Sound	Good, suitably conservative
N2-16	Wet	2-3 (3-4)	Sound	Good, suitably conservative
N3-4	Wet	9-21 (7-9)	Warning	Good, suitably conservative
N4-5X	Wet	1-5 (7-9)	Failed	Assessment seems appropriate, didn't identify early failure
N12-19 (2)	Mod	16-27 (10)	Warning	Fair, perhaps over-conservative
MR27	Mod	4-9 (3-7)	Sound	Good, suitably conservative
N2-16	Dry	5-12 (3-6)	15 mm rut	Good, suitably conservative
P9-3	Dry	5-12 (3-4)	<5 mm rut	Fair, perhaps over-conservative
N12-19	Dry	31-59 (10)	<10 mm rut	Seems over conservative for traffic, not for whole structure

Subgrade Stiffness

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

Back to Example

Subgrade Climate Adjustment

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

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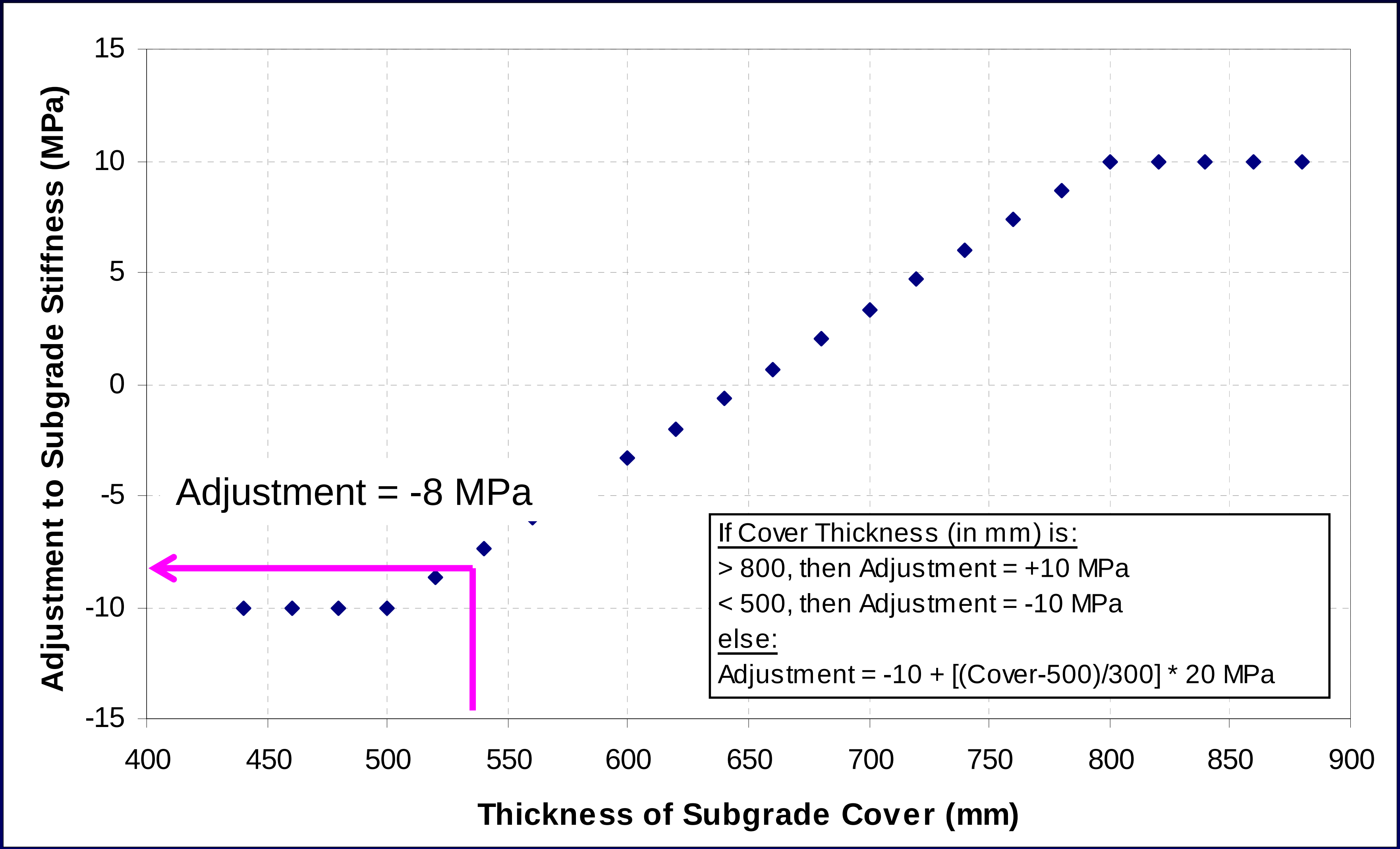
Cover Thickness Adjustment



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Modular Ratios & Max Stiffness

Design equivalent material class	Modular ratio limit	Max. allowed stiffness	Base confidence factor
AG, AC, AS, AO	5.0	3 500	1.0
BSM2	2.0	450	0.7
C4	3	400	0.4
G6	1.8	180	-2.0
Etc.	Etc.	Etc.	Etc.
G10	1.2	70	-5.0

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