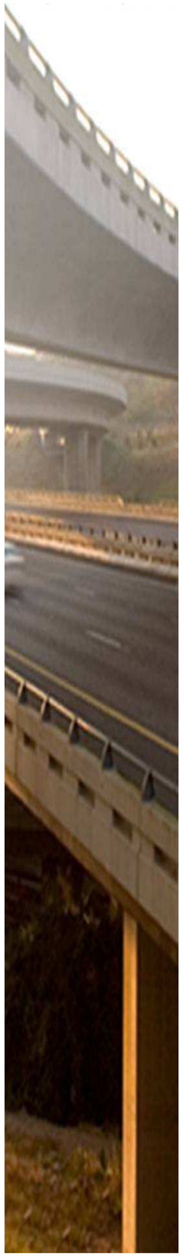
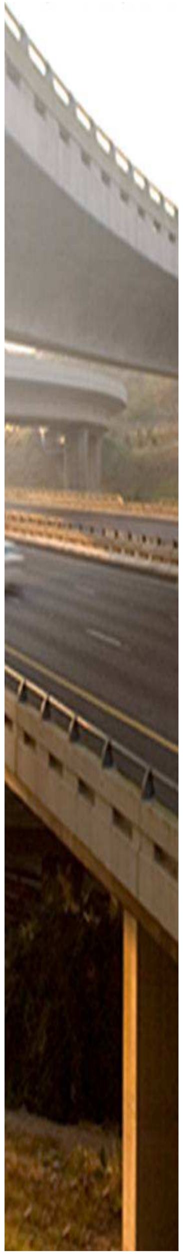


RPF November 2011: Progress Report on the SAPDM

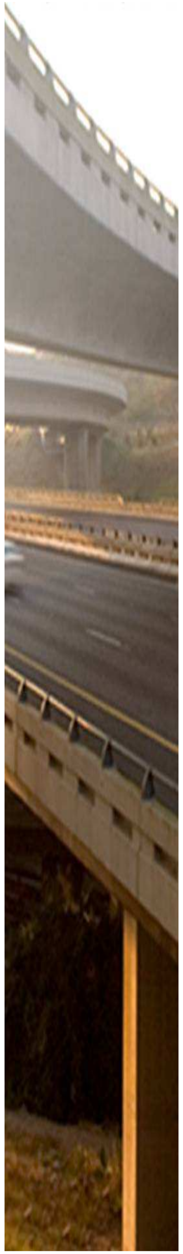
The design and performance of stabilised material

H L Theyse



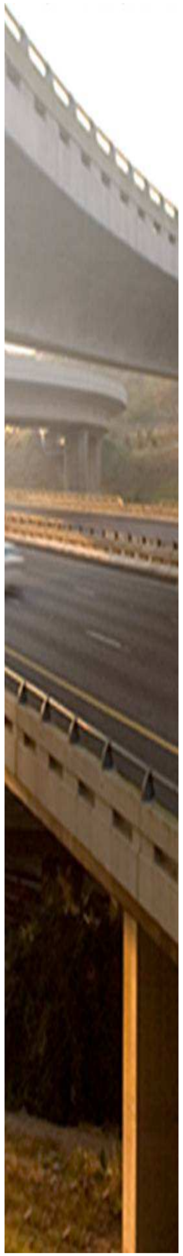
Opening statement

- I am not employed by C&CI or SABITA nor have I done any research for either of these organisations for the past 5 years. I also gain no benefit from promoting the use of <u>cement</u> or <u>bitumen</u>.



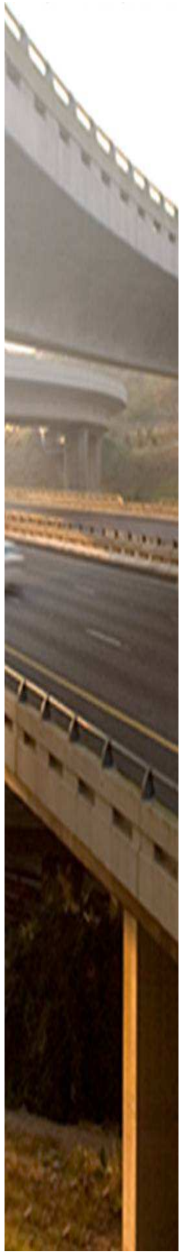
Introduction

- Stabilisation options for SAPDM
  - Cement
  - Emulsified bitumen
  - Foamed bitumen
- Focus on foamed bitumen stabilization
  - Development/evolution of design procedures (TG2)
  - Laboratory properties
  - Field behaviour and performance
  - Design procedures revisited



Introduction (continued)

- Objective of presentation
  - The objective is not to prove that foamed bitumen or any other type of stabilisation does not work
  - The objective is to question the current design philosophy behind foamed bitumen treatment
    - Based on laboratory data and field observations, not philosophical argument

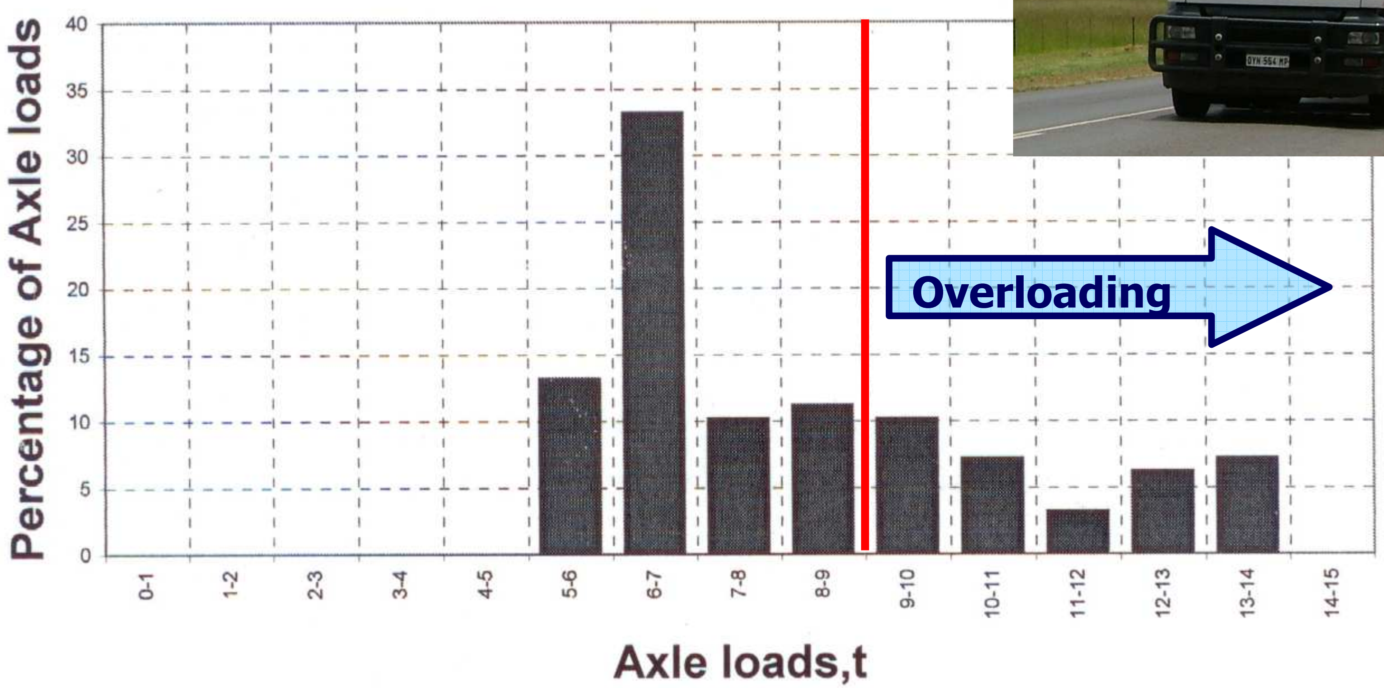


Background

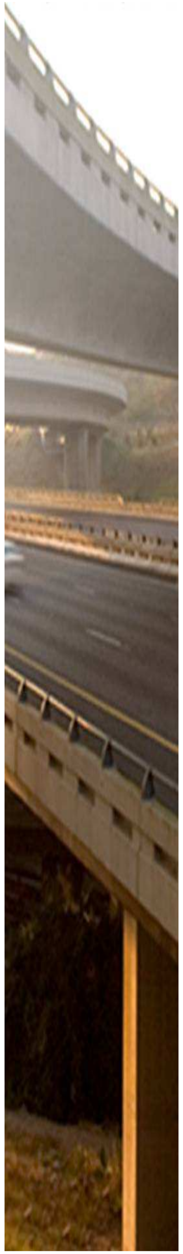
- Changing conditions
  - Aggressive traffic loading soon after construction
  - Changes in construction equipment
    - DISR offers benefits of high production rates and minimal traffic disruption but …
    - we are building out-of-balance pavements

Aggressive traffic loading

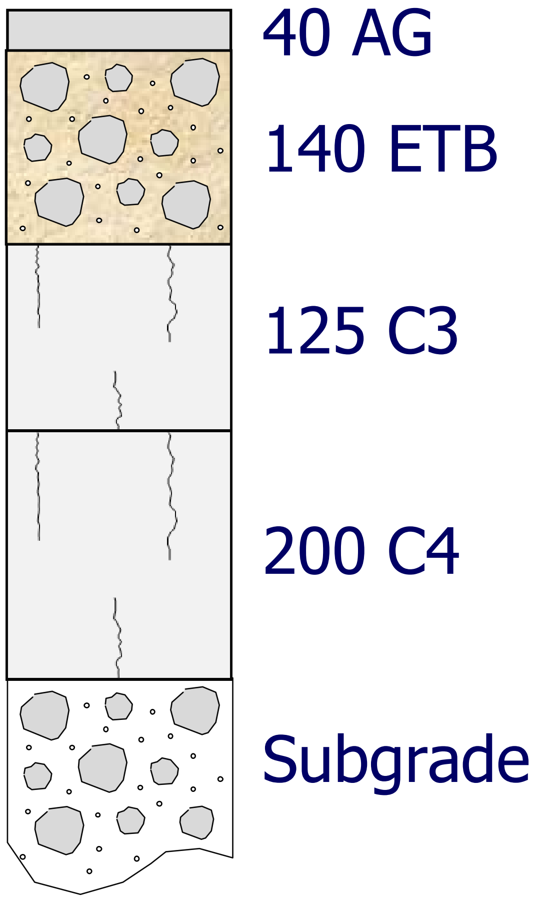
- Weighbridge in Mpumalanga
  - 12 E80/HV



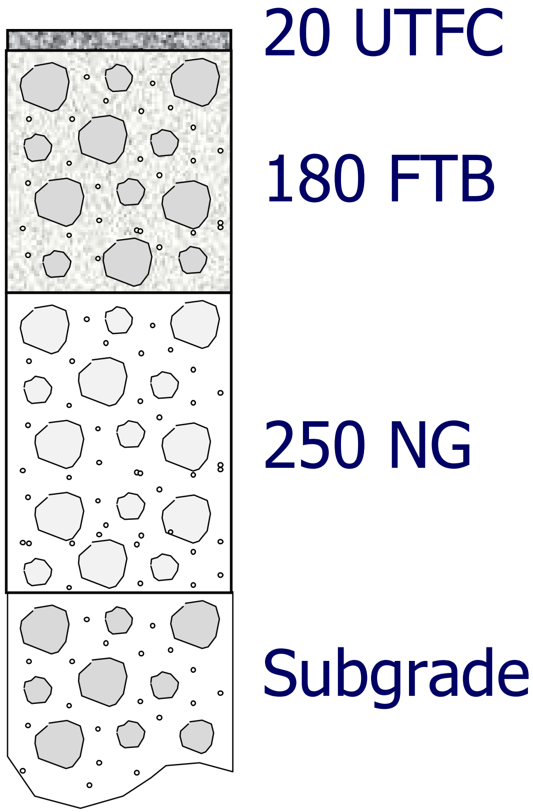
Unbalanced pavements



- N2-16 East London
  - 1980

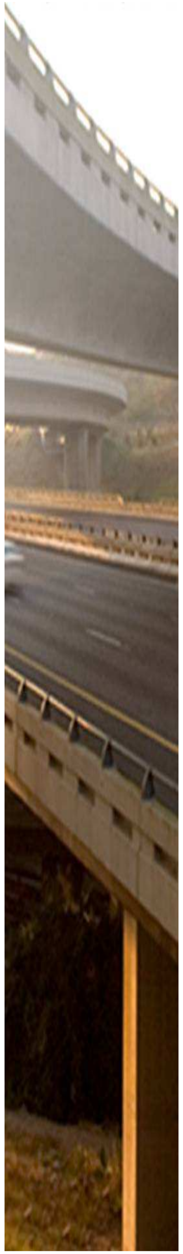


- N11-08 Hendrina
  - 2003/04

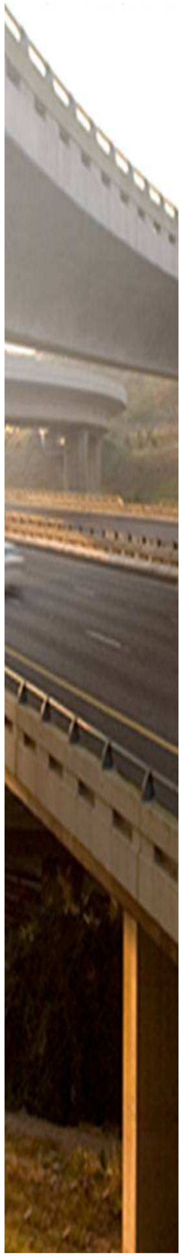


Example

- Combination of …
  - Strongly cemented base on below average support
  - High traffic volumes and axle loads
  - Above average rainfall
- .. resulted in failure during construction



FOAMED BITUMEN TREATMENT - DEVELOPMENT OF DESIGN PROCEDURES

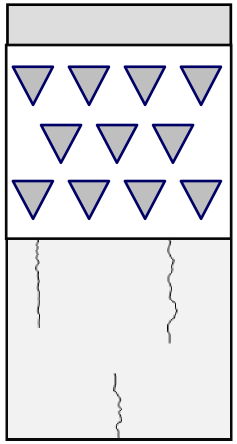


Design procedures

- Design procedures formalised by TG2 2002
- Mix design
  - Combination of UCS and ITS criteria in an attempt to establish a balance between
    - Shear strength for permanent deformation resistance
    - Flexural strength
- Structural design
  - Mechanistic-empirical design procedure
    - Catalogue of design for new construction
    - Design charts for DISR

TG2 2002 structural design: Catalogue for new construction

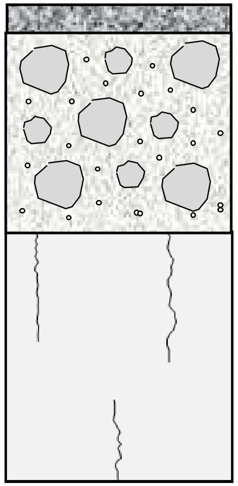
- Category A – 3 miSA



40 AC

150 G2

150 C3



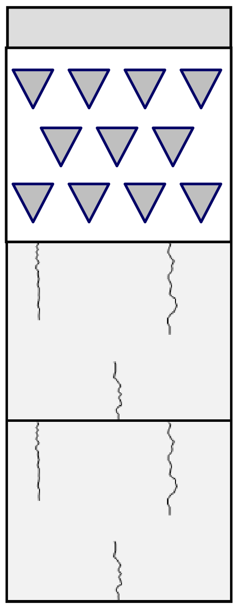
30 AC

150 FB2

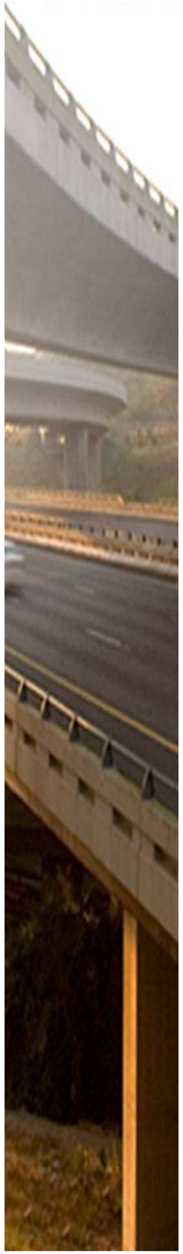
200 C4

TG2 2002 structural design: Catalogue for new construction

- Category A – 10 miSA

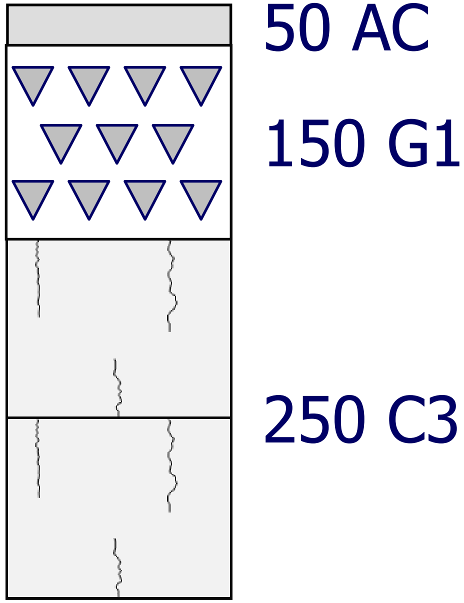


No FB design!

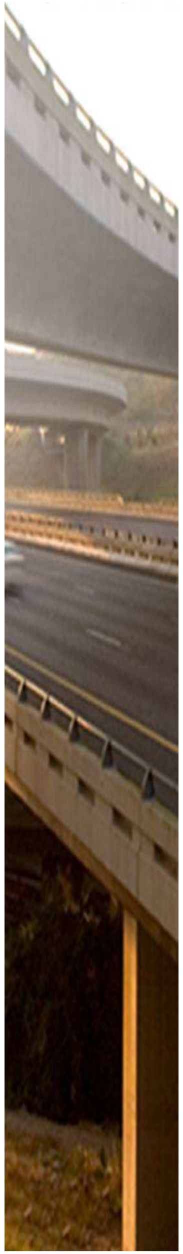


TG2 2002 structural design: Catalogue for new construction

- Category A – 30 miSA

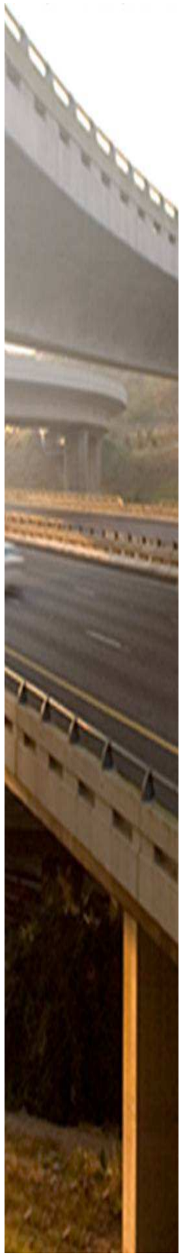


No FB design!



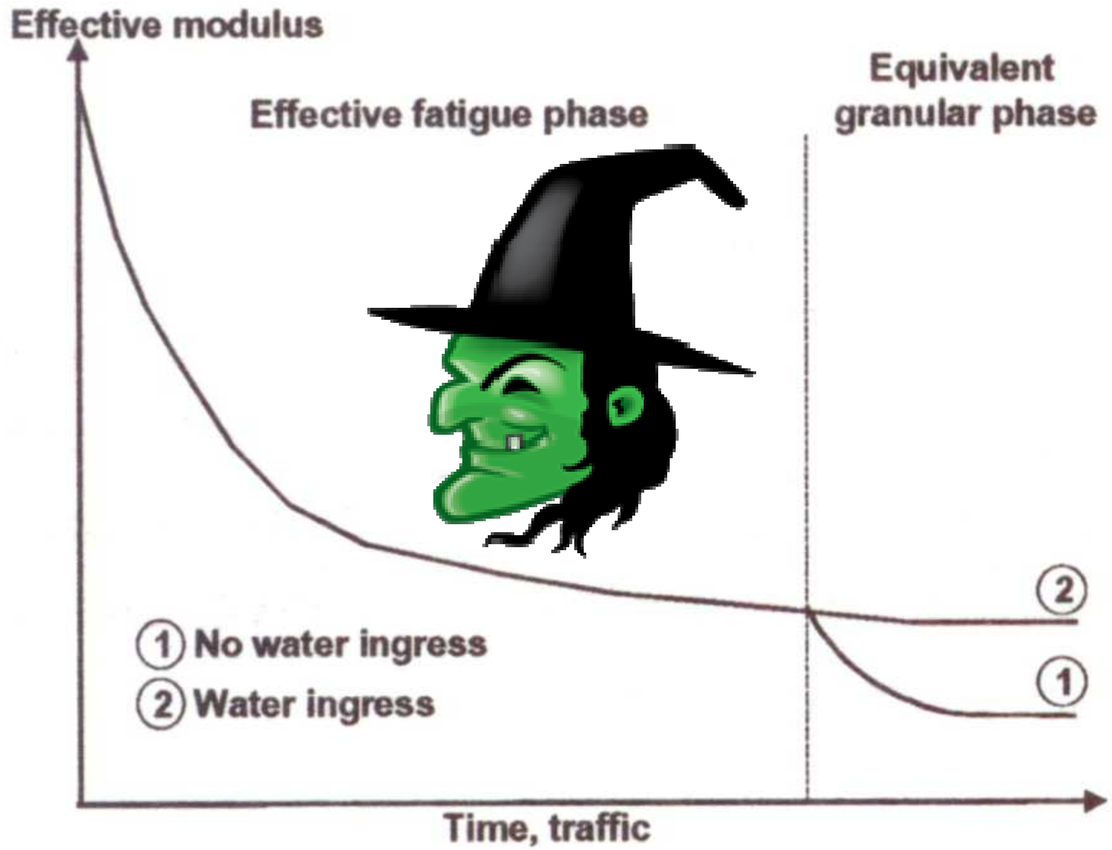
TG2 2002 structural design:

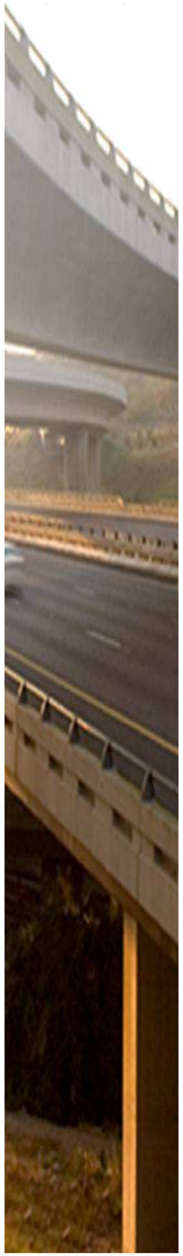
- Based on the mechanistic-empirical design method foamed bitumen treatment could not compete with crushed stone bases for design traffic higher than 3 meSA
- What was the origin of such heresy … ?



TG2 2002 structural design: Let the witch-hunt begin …

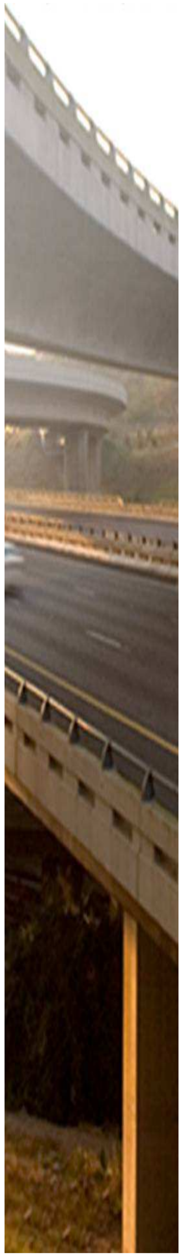
- TG2 2002 p 55 - we found the root of all evil!
  - She's called "stiffness reduction"





TG2 2002 structural design: Let’s burn the witch

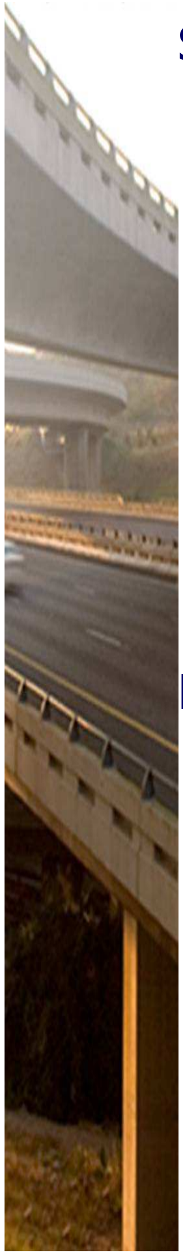
- The witch’s defense plea (included in TG2 2002)
  - “In the equivalent granular state the material is comparable to granular material only in the stiffness and not in physical composition. The term does not imply that the material is in a loose condition consisting of individual particles”
  - “Eventually the cohesive bond is destroyed through repeated flexing …” No mention is made of cracks that develop or not.
- The prosecutor’s closing argument
  - CAPSA’04
    - The prosecutor delivered the “knife-in-the-back” speech
    - The witch was set alight
  - 2004 – 2009
    - New group of witch-doctors appointed
    - 2009 - TG2 second edition released for bitumen stabilisation

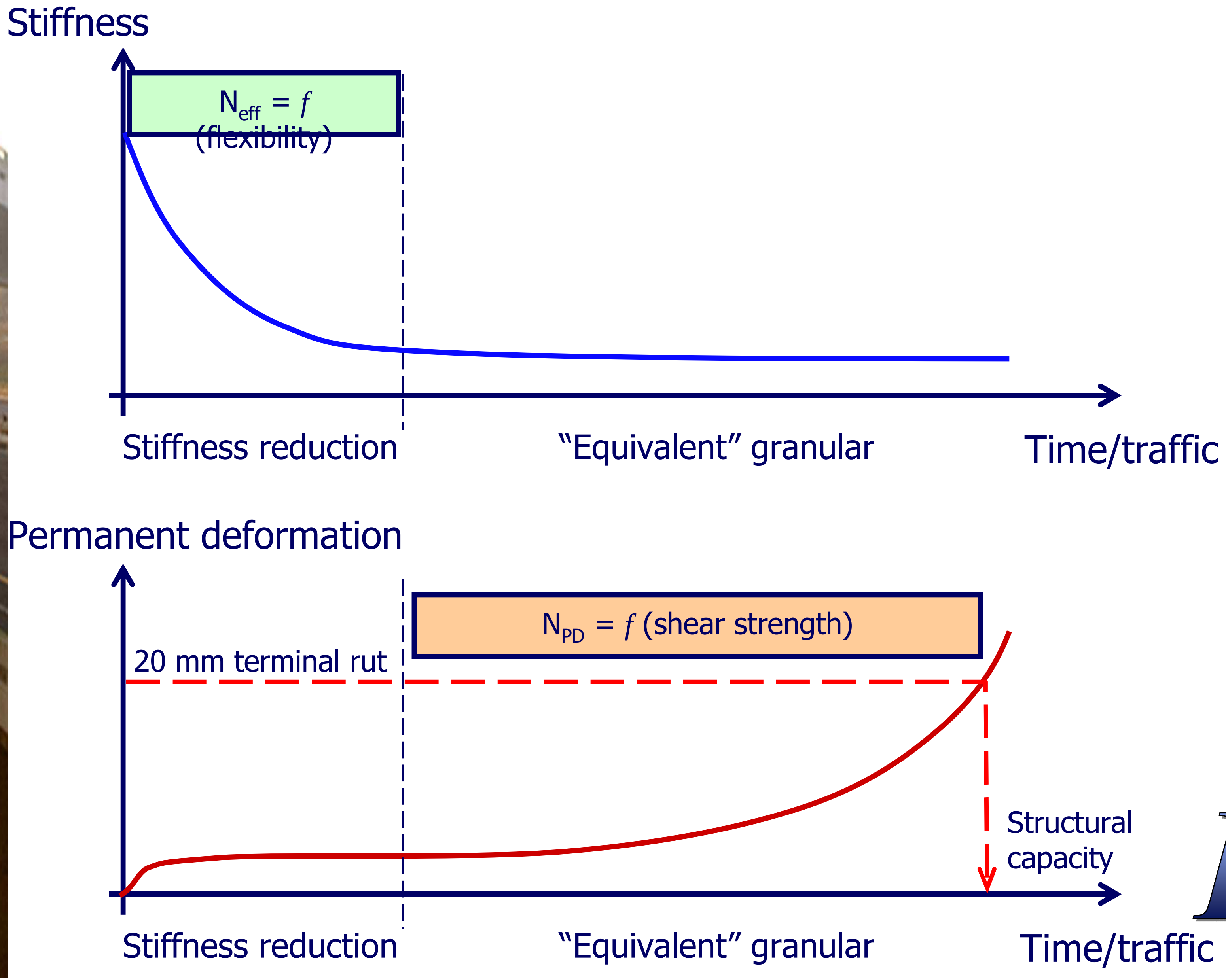


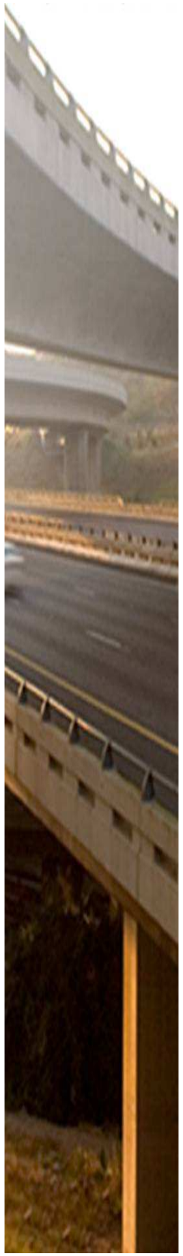
TG2 2002 structural design: Post-mortem

- CAPSA 2004 “knife-in-the-back” paper
  - Data from P504 Cliffdale Road used to refute stiffness reduction
- TG2 2nd edition
  - Pavement Number design method introduced
    - Material classification system with Design Equivalent Material Class (DEMAC) and Effective Long-Term Stiffness (ELTS)
- … but what was the real problem that prevented FB designs from achieving structural capacities higher than 3 miSA?

TG2 2002 ME-design procedure







TG2 2002 ME-design procedure

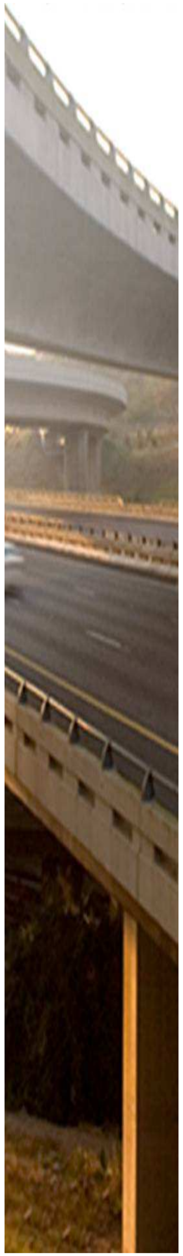
- Structural capacity of stabilised material

SC = $N_{eff} = f$ (flexibility) **+** $N_{PD} = f$ (shear strength)

- Structural capacity of crushed stone

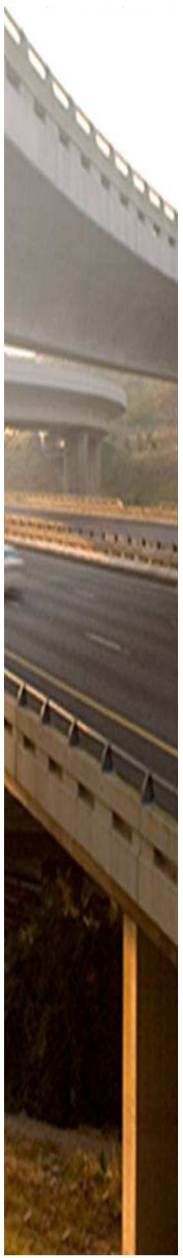
SC = $N_{PD} = f$ (shear strength)

- Crushed stone outperformed stabilised material and specifically foamed bitumen in terms of permanent deformation i.e. shear strength



LABORATORY PROPERTIES

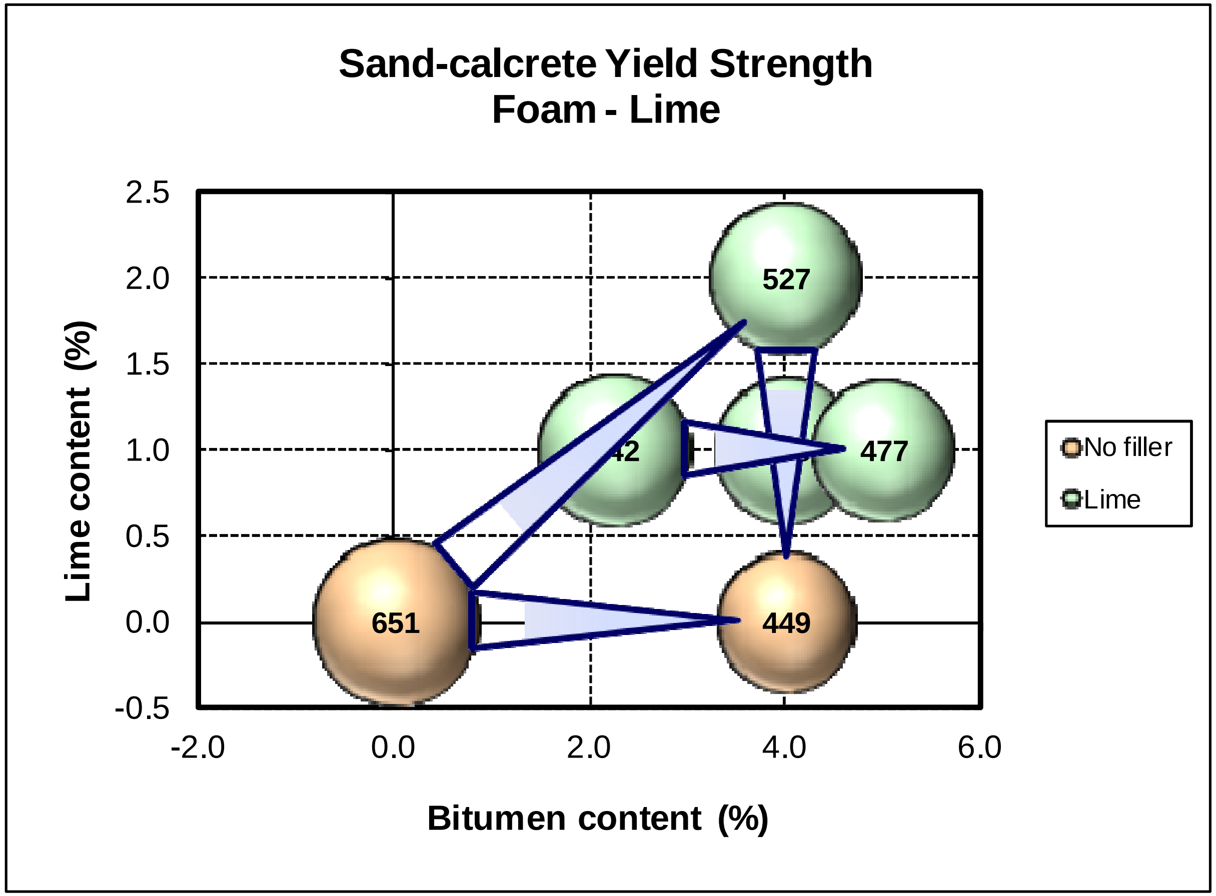
The shear strength of stabilised material



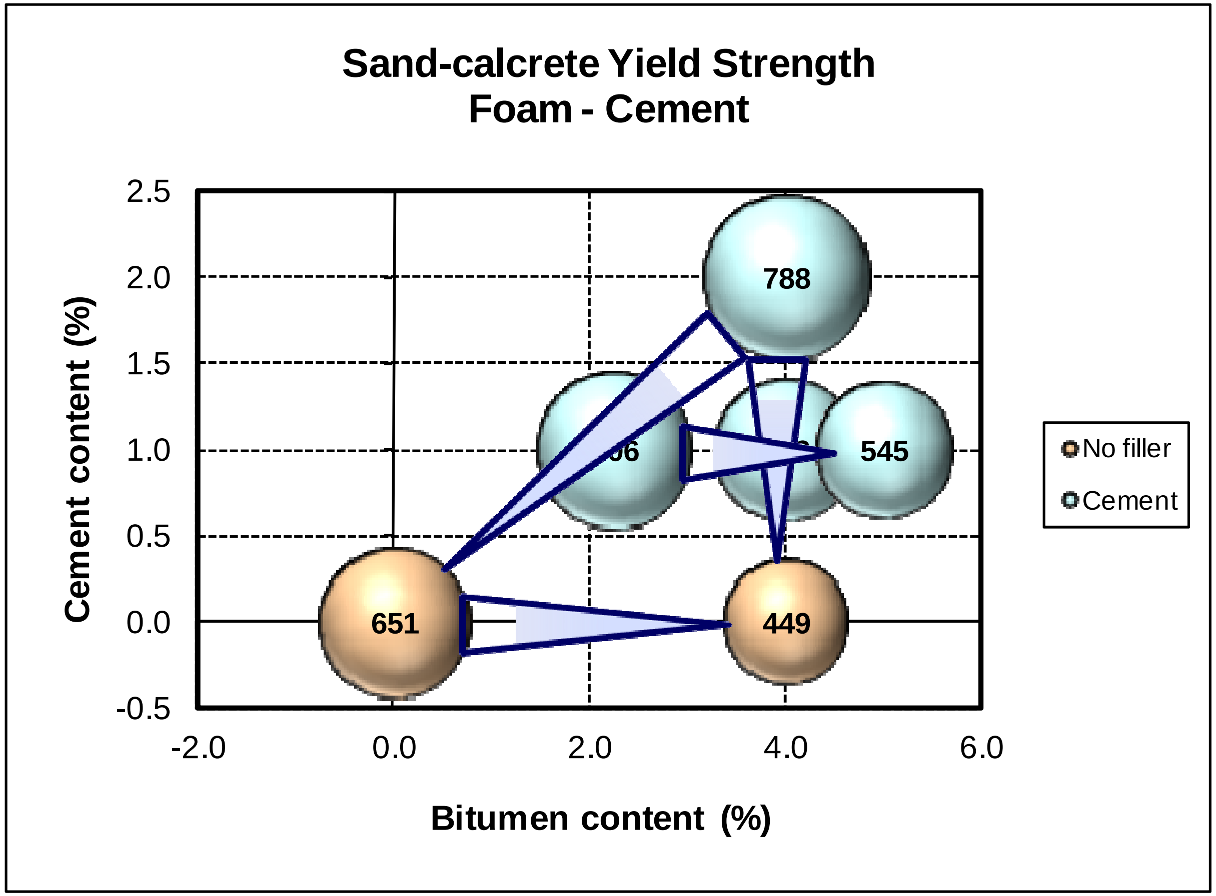
Laboratory projects associated with Gautrans HVS programme

- Range of materials
  - Sand and calcrete mixture from northern KZN
  - Recycled, previously cement treated base and subbase from Gauteng
  - Recycled crushed stone base and subbase from Western Cape
- Experimental design
  - Range of volumetric densities
  - Range of saturation levels
  - Range of confinement pressures (0 – 200 kPa)
- Monotonic tri-axial tests
  - Average strength results

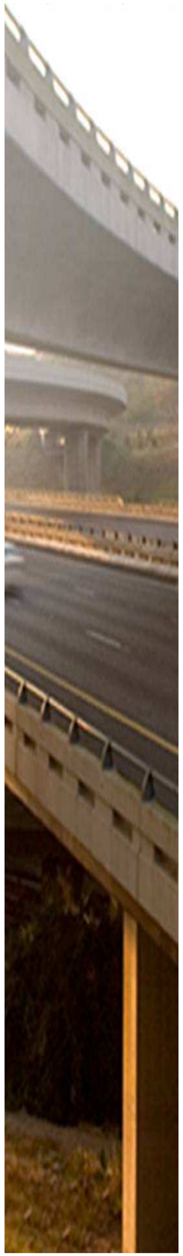
Sand and calcrete mixture – Foam and lime treatment

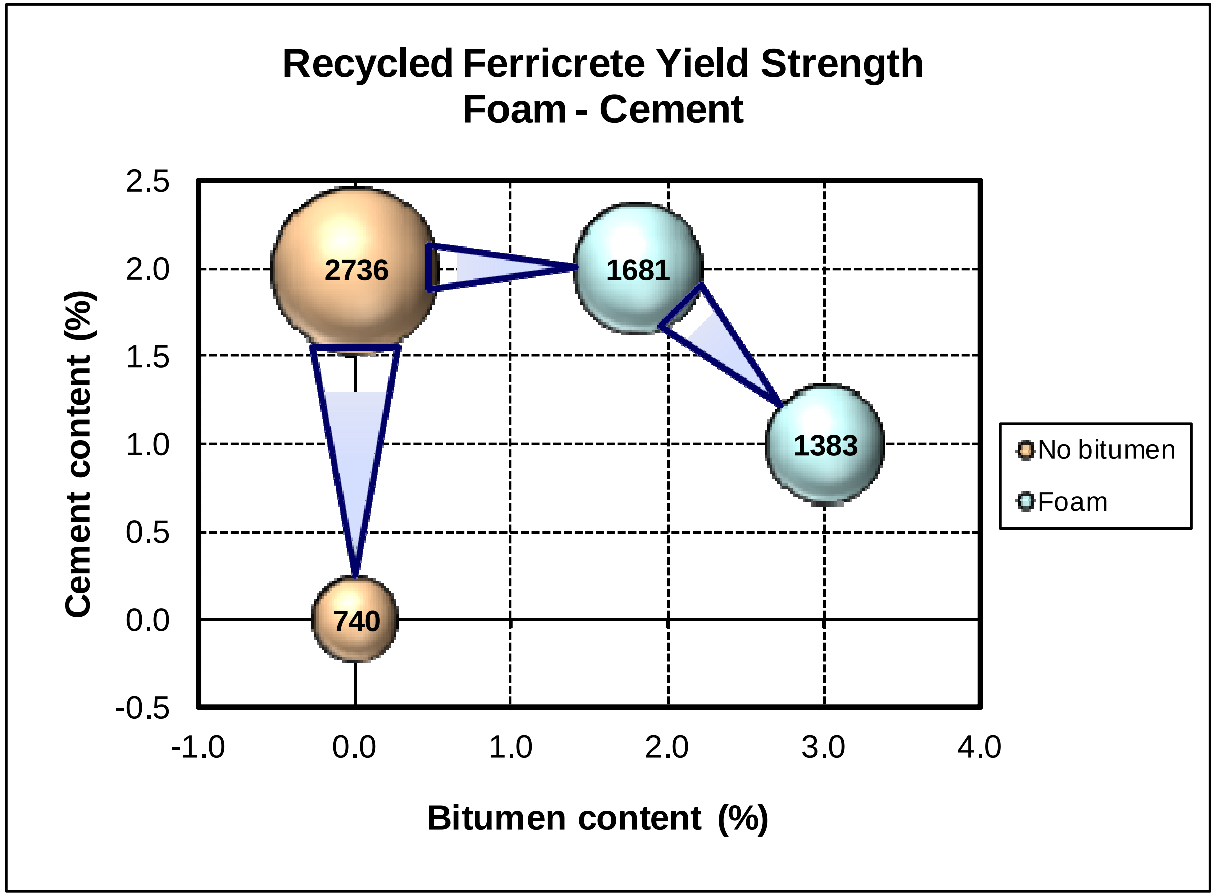


Sand and calcrete mixture – Foam and cement treatment

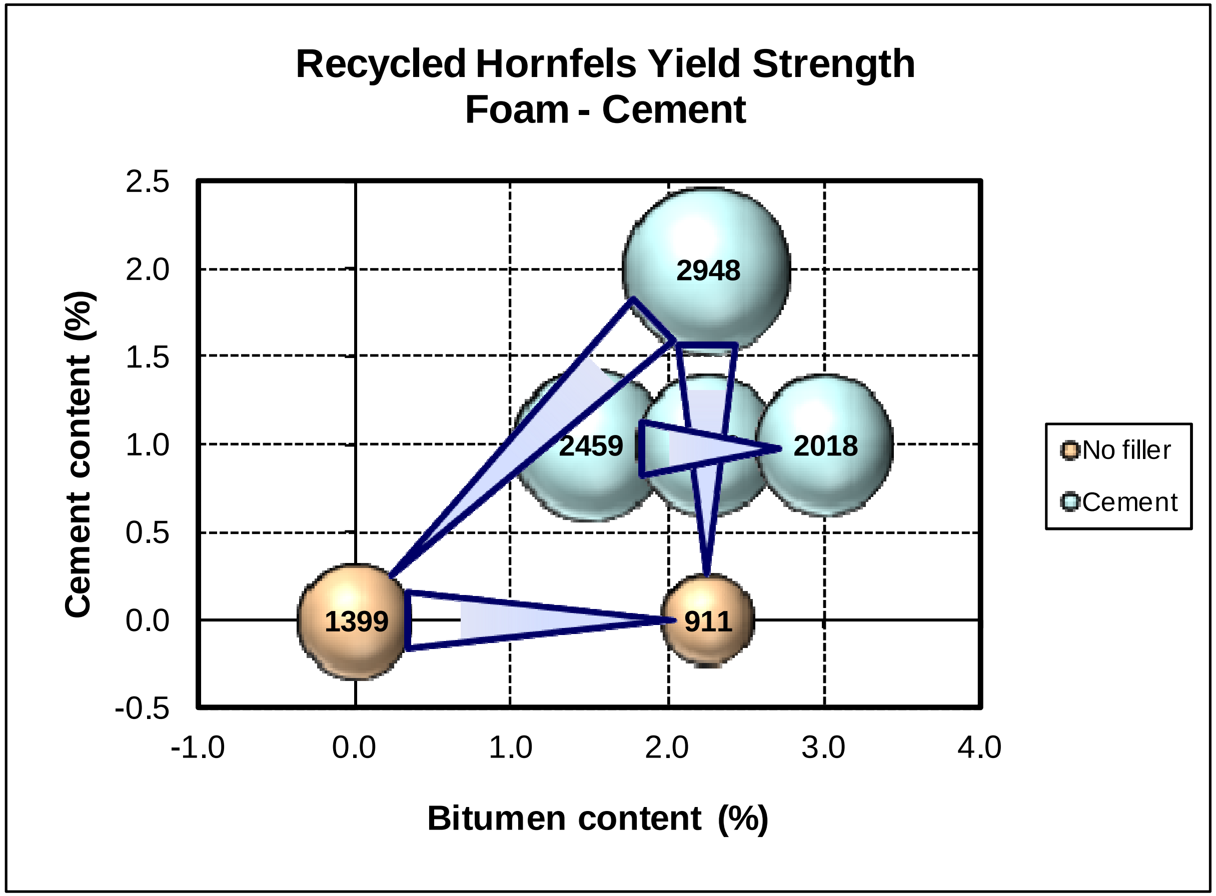


Recycled ferricrete – Foam and cement treatment

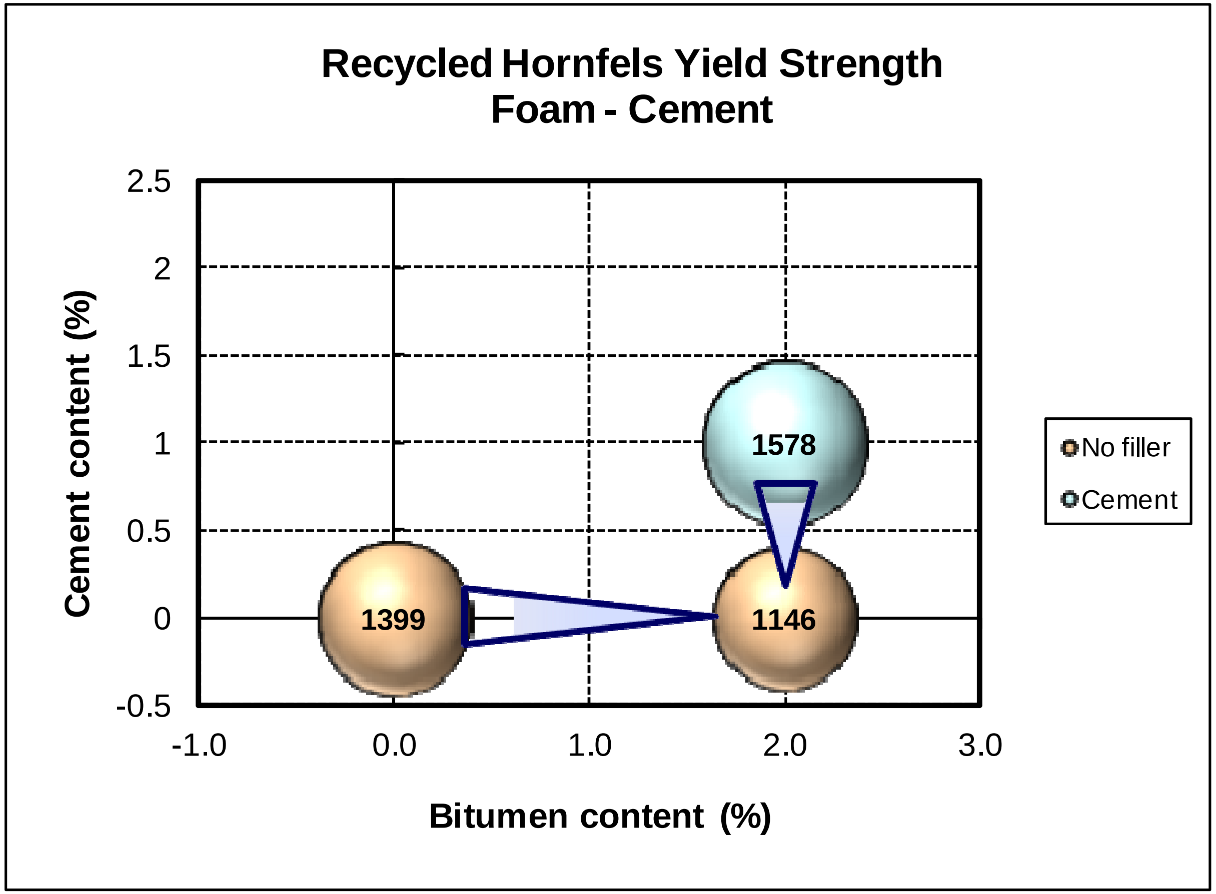


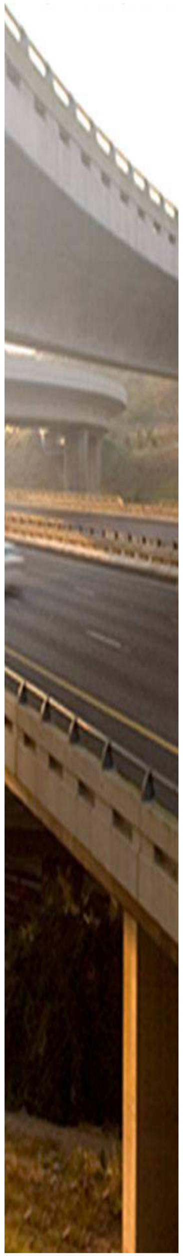


Recycled crushed stone – Foam and cement treatment



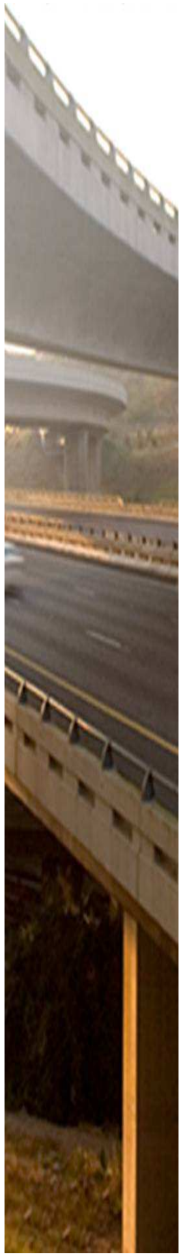
US recycled crushed stone – Foam and cement treatment





Laboratory shear strength results

- Shear strength of stabilised material
  - Trends shown for selected material – treatment combinations
  - Same trends hold for other materials and combinations of cement and emulsion
- Basic rules
  - Shear strength determines resistance to permanent deformation
    - The addition of binder alone or binder with incorrect filler type negatively affects the shear strength of the material
    - Increasing binder content at a constant level of cement reduces the shear strength of the mix
    - Increasing cement content at a constant level of binder increases the shear strength of the mix

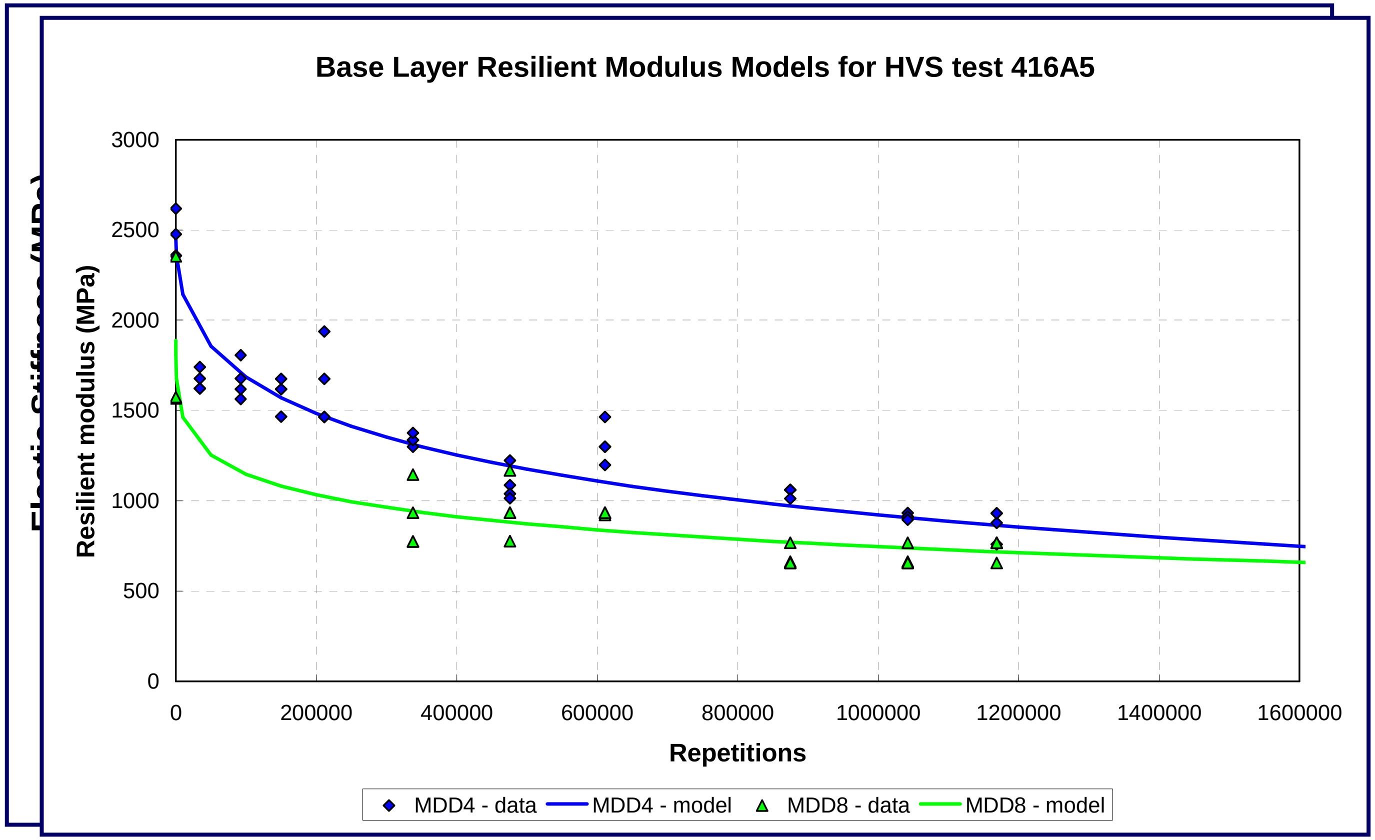


FIELD BEHAVIOUR AND PERFORMANCE

Stiffness reduction and permanent deformation

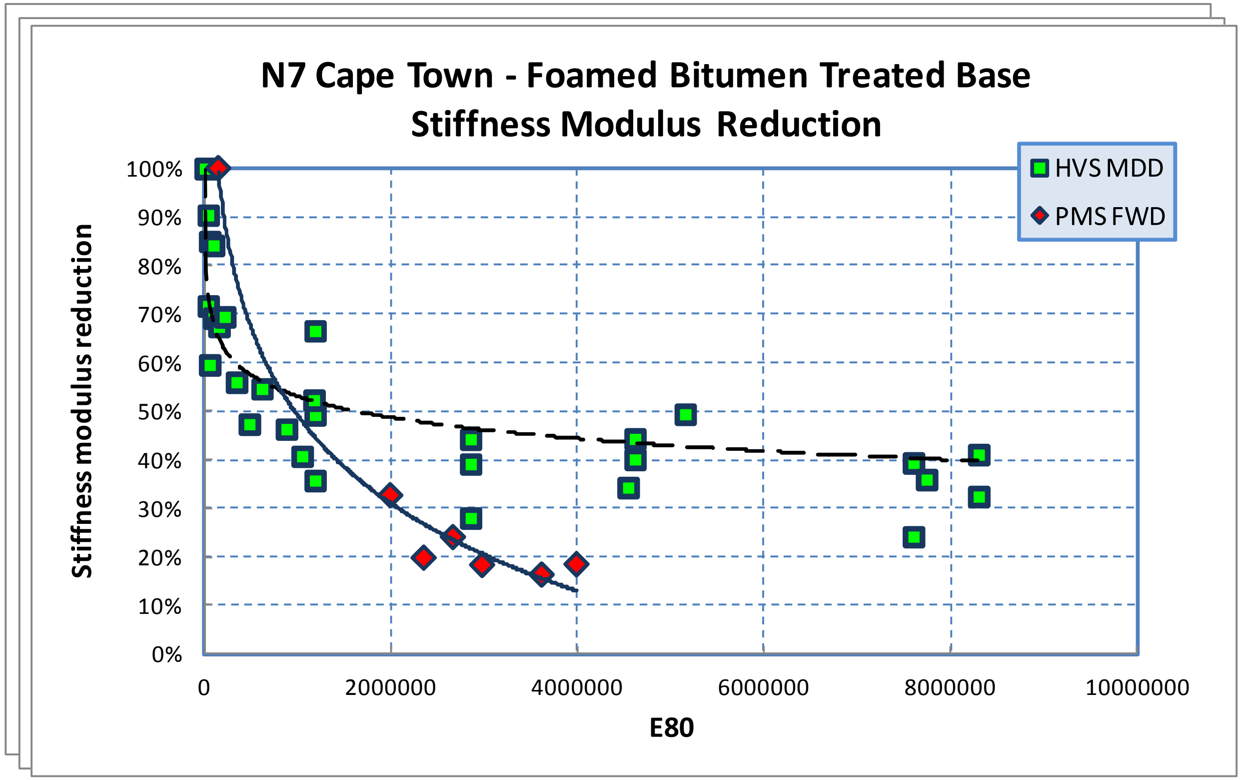
Origin of stiffness reduction

- MDD back-calculated stiffness for HVS tests
  - P243 Vereeniging
  - N7 Cape Town



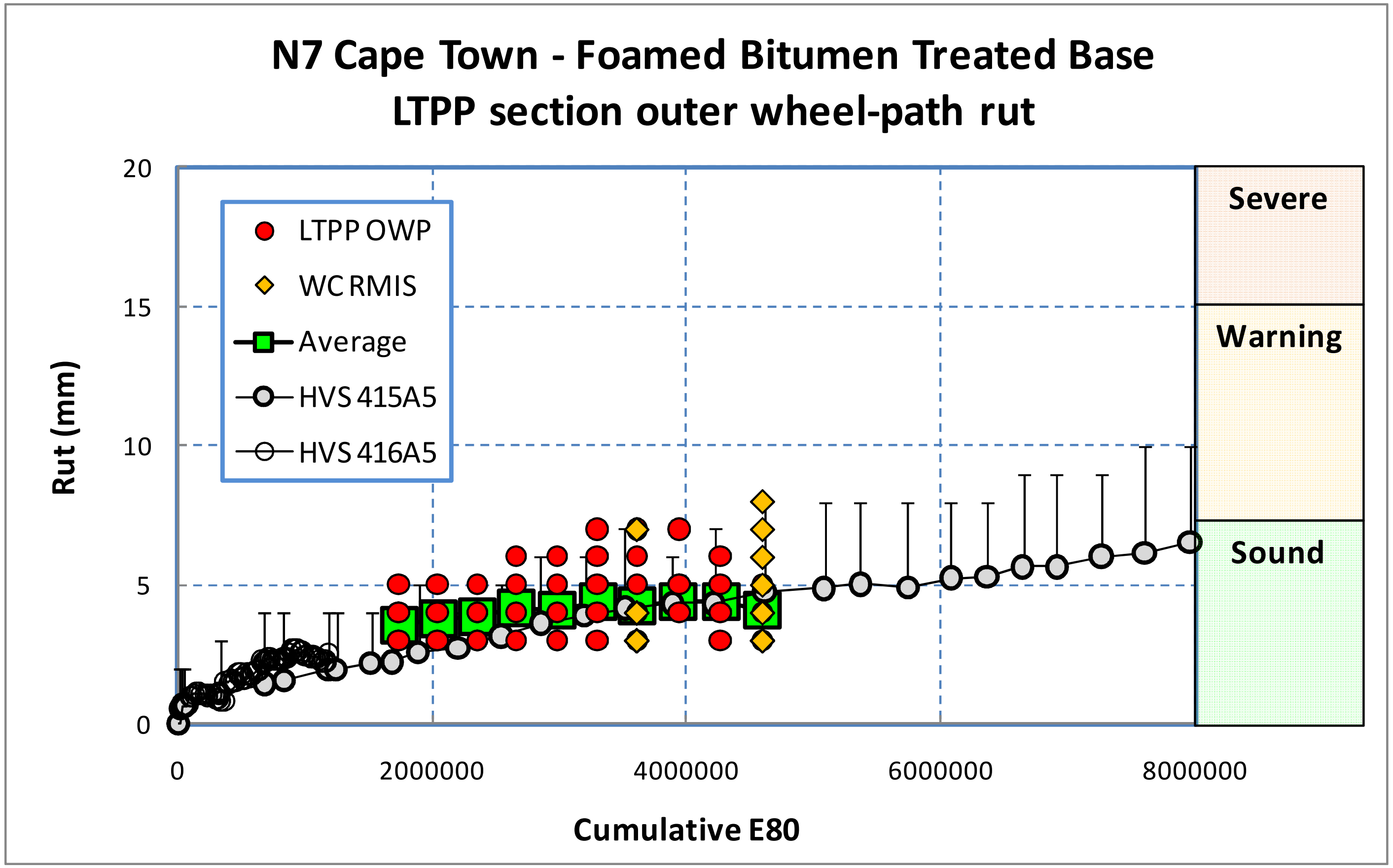
Confirmation of stiffness reduction

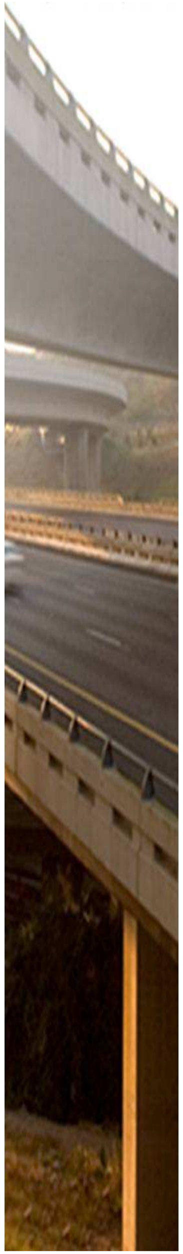
- FWD back-calculated stiffness for in-service roads
  - P243 Vereeniging
  - N7 Cape Town



Permanent deformation

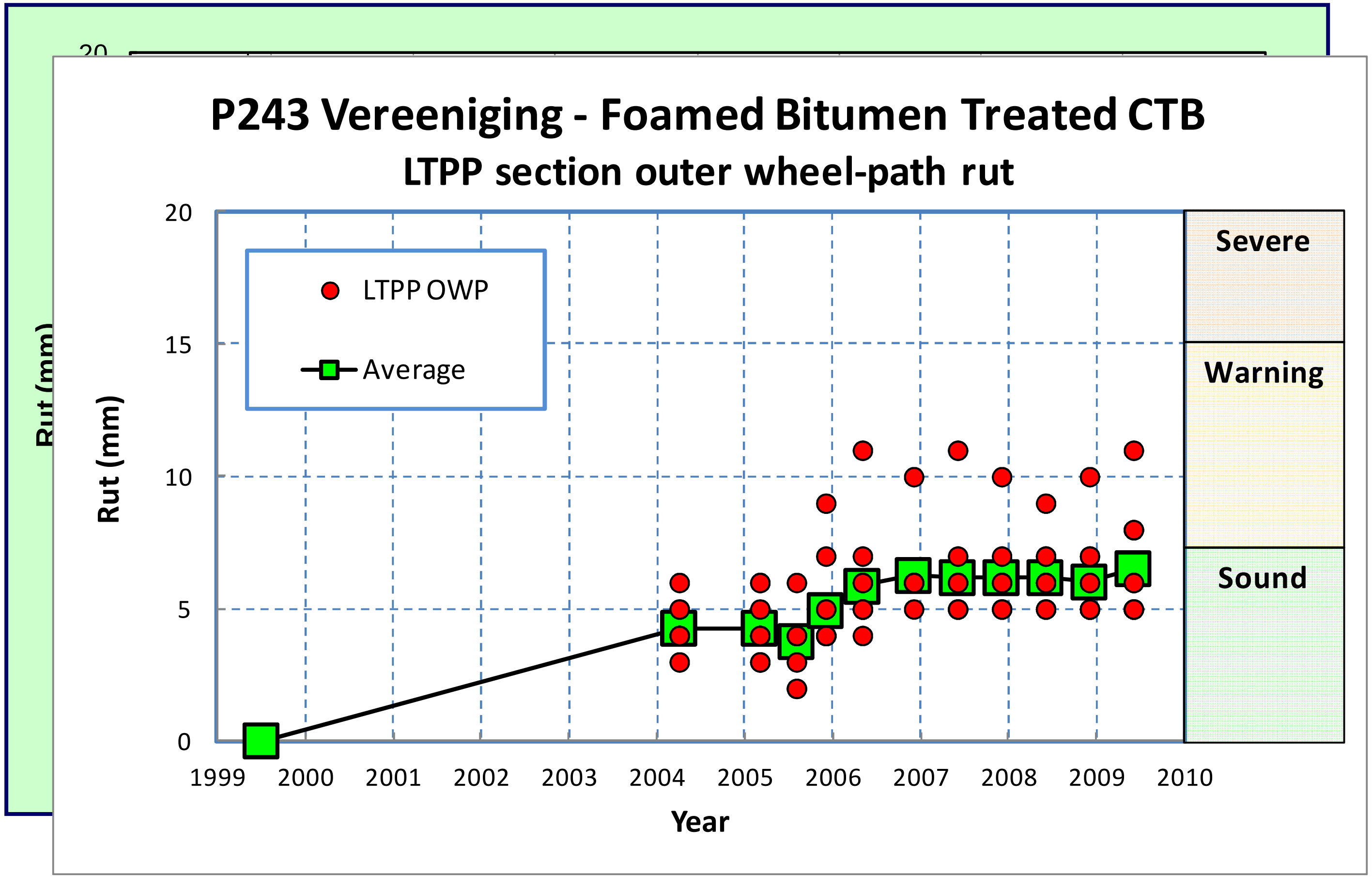
- Comparison between HVS and in-service rutting





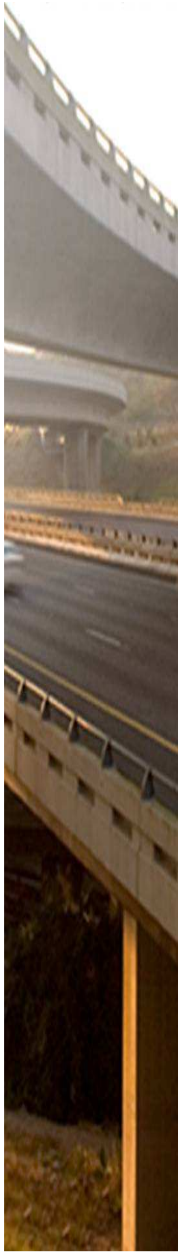
Permanent deformation

- Rutting on P243 HVS test section 411A5
  - Foam treated section with 2 % cement



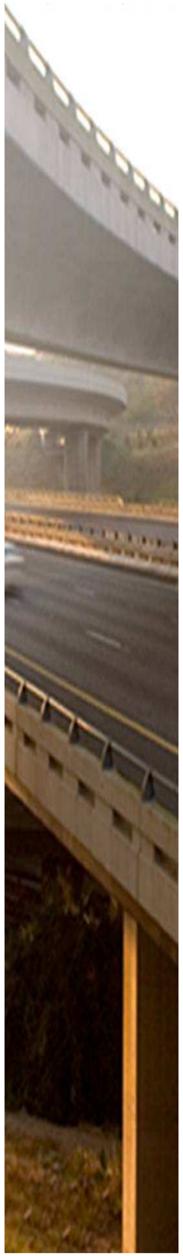
Rutting on in-service sections

- R22 Mseleni – Phelendaba
  - 250 mm sand and calcrete mixture
  - 4 % binder, 2 % lime
  - Constructed 2002 - rut survey 2008
    - 90th percentile rut = 18 mm
- MR 466 Mbazwana – Sodwana
  - Aeolian sand
  - 4 – 5 % binder
  - 2 % cement
  - Constructed in 1994
  - No rut in 1997
  - Lots of timber trucks



Rutting on in-service sections

- N11-08 Hendrina
- P243 Vereeniging
- N7-1 Cape Town



Permanent deformation

- Summary of in-service rutting

Summary of the nominal construction details of the foamed bitumen treated sections

Section	Construction year	Base aggregate	Base thickness (mm)	Binder content (%)	Filler	
					Type	Content (%)
R22/04	2002	50 % calcrete - 50 % sand	250	4	Lime	2
P504	1995	Granite	175	3.5	Lime	1
P243/1	1999	Recycled ferricrete	250	1.8	Cement	2
R27/8	2003	Natural gravel	200	2.5	Cement	1
N11/08	2003	Natural gravel	180	1.5	Cement	1
N7/01	2002	Crushed hornfels	250	2.3	Cement	1

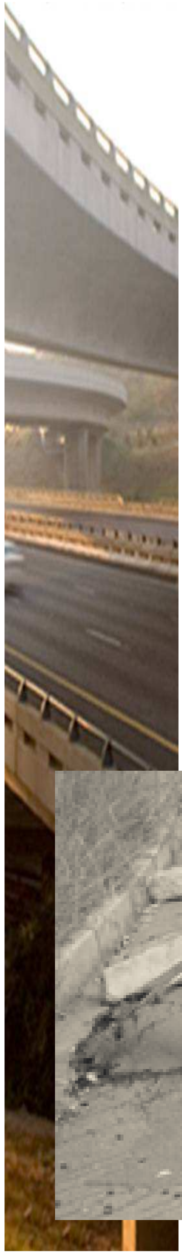
Summary of the 90th percentile rut data of the foamed bitumen treated sections

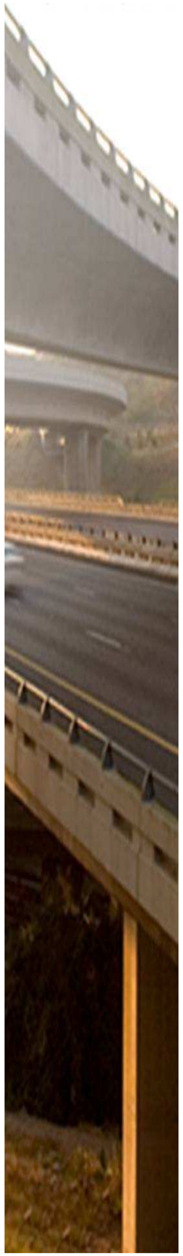
Section	Construction year	Rut survey year	Years since construction	90th percentile rut (mm)	Rut rate (mm/year)
R22/04	2002	2008	6	17.9	2.98 [a]
P504 B1 (LHS)	1995	1997	2	12.0	6.00 [a]
P504 B2 (LHS)	1995	1997	2	12.2	6.10 [a]
P504 C (LHS)	1995	1997	2	4.0	2.00 [a]
P243/1	1999	2009	10	8.0	0.80 [b]
R27/8	2003	2010	7	4.5	0.64 [b]
N11/08	2003	2010	7	6.3	0.90 [b]
N7/01	2002	2010	8	6.3	0.79 [b]

Note: a – Lime
b – Cement

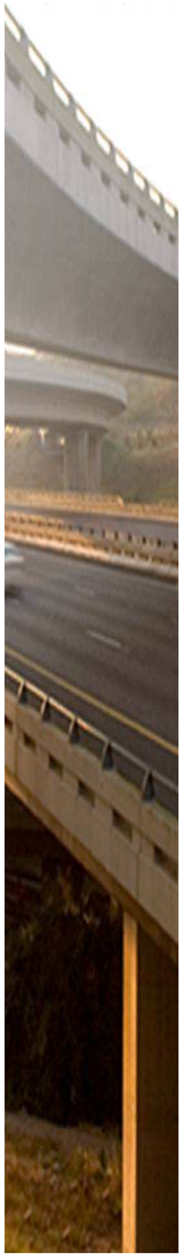
Permanent deformation: Moisture sensitivity

- P504 Cliffdale Road
- N11-08 Hendrina
- P243 Vereeniging



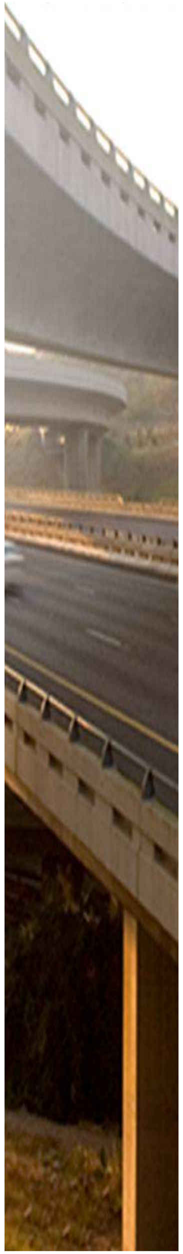


DESIGN PROCEDURES REVISITED



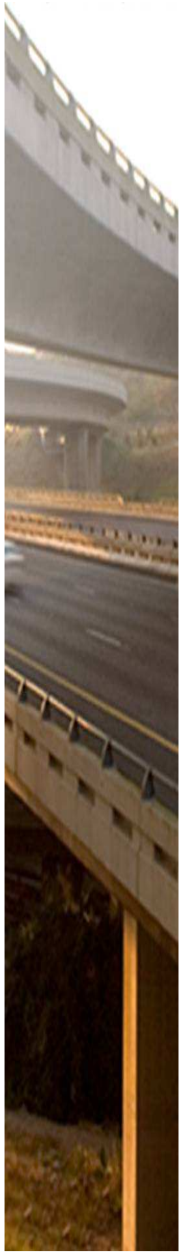
CAPSA 2004 "knife-in-the-back" paper revisited

- "*The two different materials treated with foamed bitumen on MR 505 appear to be performing beyond initial expectations. Predictions for structural capacity … with the SAMDM appear to be amiss.*"
- 1997 two years after construction
  - Left-hand side lane (low traffic)
    - 95% rut on two sections of treated decomposed granite 12.0 and 12.2mm
    - Rut rate - 6 mm per year
- Collings only reports rut data from 2004 after a 30 mm AC overlay in 1998
  - At that stage additional 8 mm rut on RHS



CAPSA 2004 "knife-in-the-back" paper revisited

- "*The traffic loading pattern carried by this pavement presented an ideal opportunity to check one of the theories postulated by HVS test results: The resilient modulus of foamed bitumen treated material reduces when subjected to repeated loads*."
  - Stiffness reduction confirmed from FWD data on in-service roads
  - The whole stiffness reduction debate is almost irrelevant in determining the structural capacity of foam treated material
  - Stiffness reduction is actually beneficial to the layer

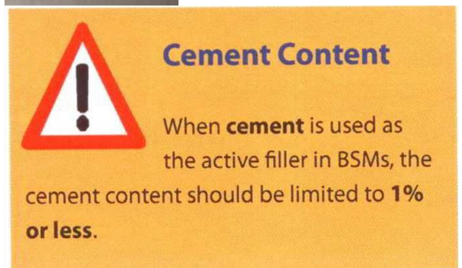


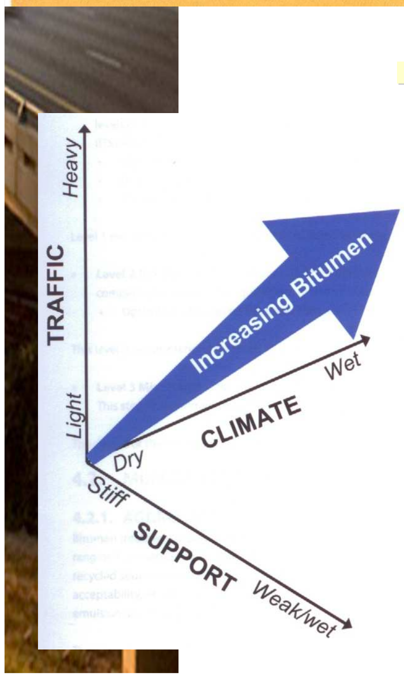
Subsequent correspondence

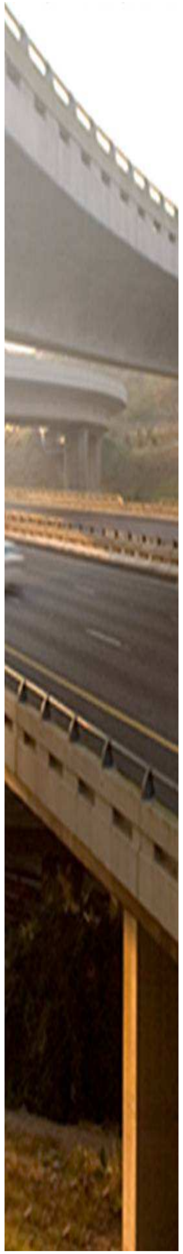
- P243-1 Vereeniging
  - *"As previously discussed, this section of road is NOT representative of a foamed bitumen stabilised base. … 1.8% foamed bitumen with 2% cement added. The results were not entirely surprising since the amount of cement in the mix exceeded the bitumen. I could launch into a diatribe here on TG2 First Edition vs TG2 Second Edition, but will refrain. The bottom line is that the models coming out of the trials carried out on this section of road are wrong.."*
- Are the results/models wrong or don't they agree with a preconceived definition of foamed bitumen treatment?
  - Laboratory results show improved shear strength with 2% cement
  - HVS and in LTPP show about 5 mm rut after 0.8 meSA and 10 years service respectively
  - HVS and LTPP show slight stiffness reduction, less than N7
  - No surface cracks after 10 years

TG2 2009 Design Philosophy

- Mix design
  - Less cement – more bitumen
    - Volumes of tri-axial data collected by the CSIR show
      - No other filler contribute to shear strength gain to the same degree as cement
      - For any given binder content there is a significant and consistent increase in shear strength when the cement is increased from 0 to 1 to 2 %
    - CAPSA'11
      - Xu et al (China)
        - Optimum rut resistance and peak bending strength at 1.5 % cement
        - Increasing cement content improves moisture resistance
      - A Browne (New Zealand)
        - Reduction in UCS with increasing binder content
        - 1 – 1.5 % cement for early strength
        - Cement reduces moisture susceptibility



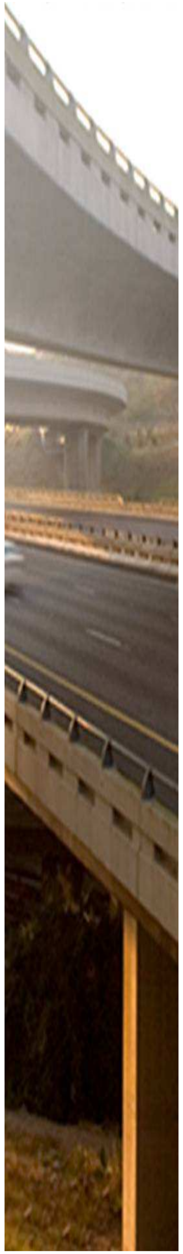




TG2 2009 Design Philosophy

- PN structural design
  - PN contribution of layers determined by
    - Effective Long-Term Stiffness
    - Base Confidence Factor
    - Thickness adjustment factor for cement stabilised layers

Type	Description	Class	ELTS	BCF	TAF
Bitumen stabilised	High strength	BSM1	600	1.0	1
	Medium strength	BSM2	450	0.7	1
Cement stabilised	Base quality	C3	550	0.6	1.0 @ 300 mm 0.4 @ 200 mm 0.2 @ 150 mm
	Subbase quality	C4	400	0.4	



TG2 2009 Design Philosophy

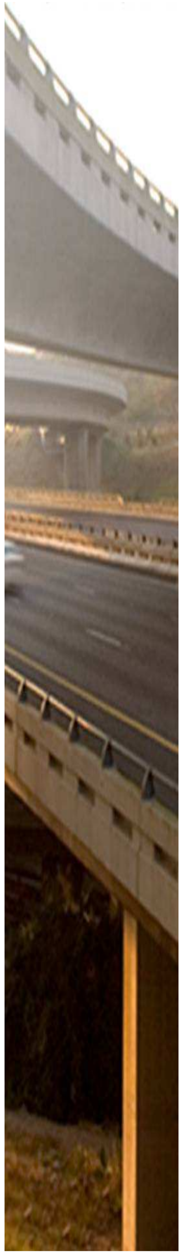
- TRH4 structures PN calculation examples

CTB-B-ES1

Material code	Thickness (mm)	PN contribution
S	5	0.4
C3	125	0.8
C4	150	0.8
G9	300	2.7
G10	-	-

CTB-A-ES3

Material code	Thickness (mm)	PN contribution
AC	30	8.3
C3	150	1.0
C4	200	2.2
G9	300	2.7
G10	-	-



TG2 2009 Design Philosophy

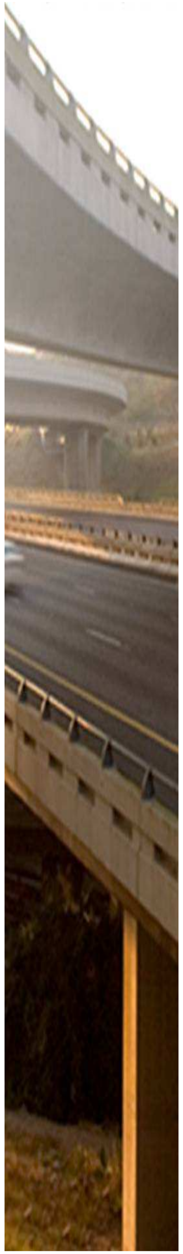
- PPIS structures PN calculation examples

PPIS6-P174/1

Material code	Thickness (mm)	PN contribution
S	5	0.4
C3	150	1.0
C4	150	1.2
G6	300	4.2
G9	-	-

PPIS22-N4/2

Material code	Thickness (mm)	PN contribution
AC	25	8.8
C2	100	2.4
G2	100	5.0
C3	100	1.1
G6	-	-



TG2 2009 Design Philosophy

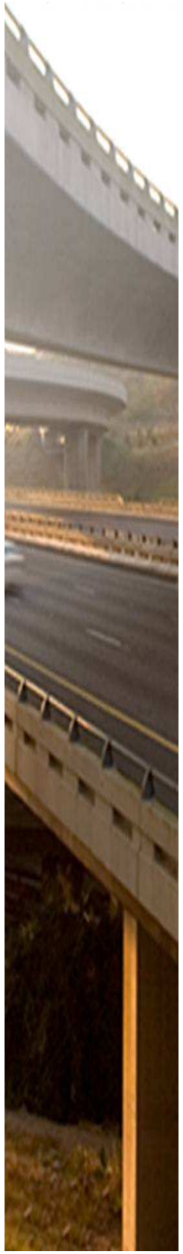
- PPIS structures PN calculation examples

PPIS6-P174/1

Material code	Thickness (mm)	PN contribution
S	5	0.4
C3	150	1.0
C4	150	1.2
G6	300	4.2
G9	-	-

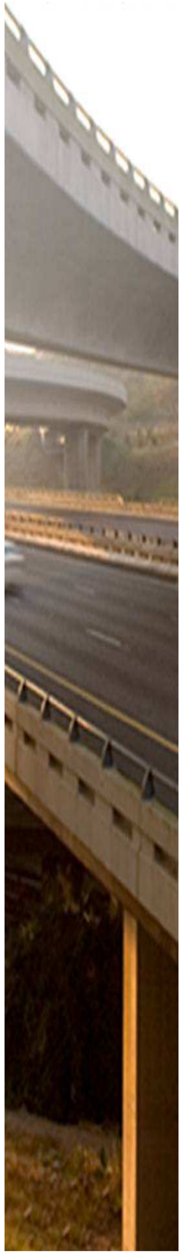
PPIS6-P174/1

Material code	Thickness (mm)	PN contribution
S	5	0.4
BSM2	150	4.7
BSM2	150	4.7
G6	300	4.2
G9	-	-



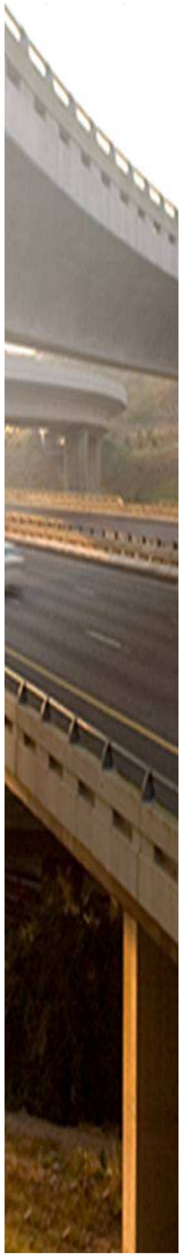
Closing remarks

- Stiffness reduction is a real phenomenon and not only a characteristic of HVS testing
  - Stiffness reduction is NOT A CRITICAL MODE OF DISTRESS THAT LIMITS STRUCTURAL CAPACITY
- The shear strength and permanent deformation of foamed bitumen treated material ultimately determines the structural capacity of this material
  - Increasing cement content up to 2 % increases shear strength
  - Increasing binder content reduces shear strength (lubricant)
- In service FBT sections with lime exhibit much higher initial rut rates than sections with cement filler
- Foam treated material is prone to shear failure under conditions of high moisture content



Closing remarks

- TG2 2nd edition
  - Mix design
    - No motivation could be found for limiting cement contents to 1 % other than to comply with a preconceived definition of foamed bitumen stabilisation
    - In fact, all the data and evidence points to the fact that 1 to 2 % cement significantly improves the properties of the mix
    - Below 2 % cement the ICS of most materials is hardly satisfied, strength gain is slow and shrinkage cracks should not be a problem
  - Structural design
    - The PN calculation rules appear to have a very strong negative bias towards cement stabilisation



Closing remarks

- Final remark
  - Allowing slightly higher cement contents (1 – 2 %) in foamed bitumen treated material depending on the design situation will make the material more competitive in terms of structural capacity