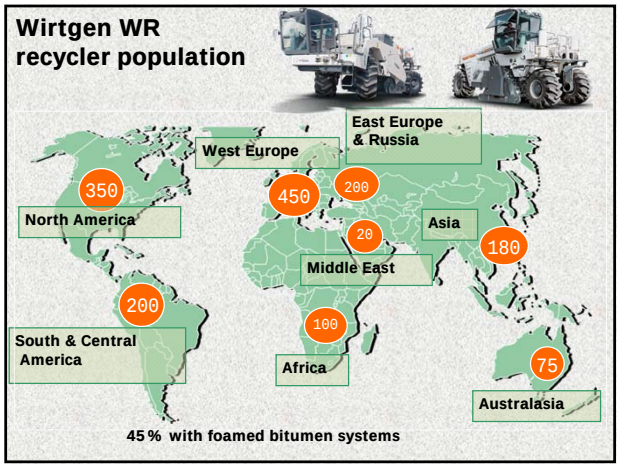
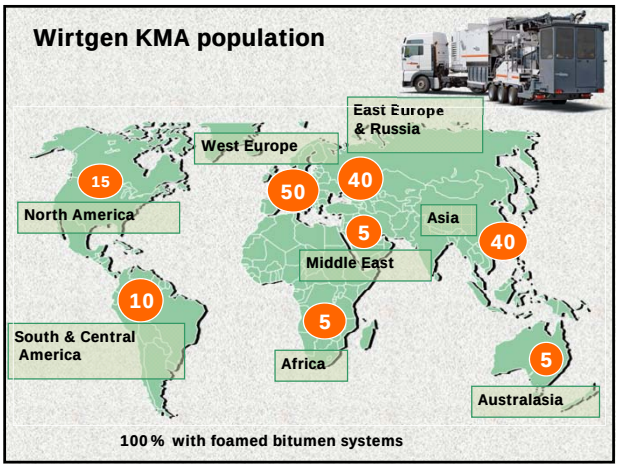
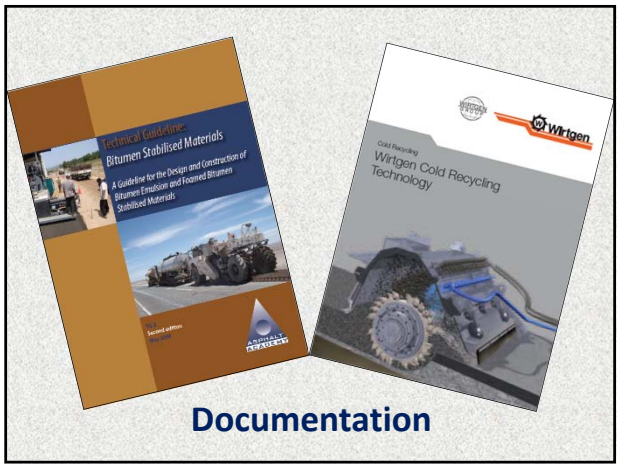
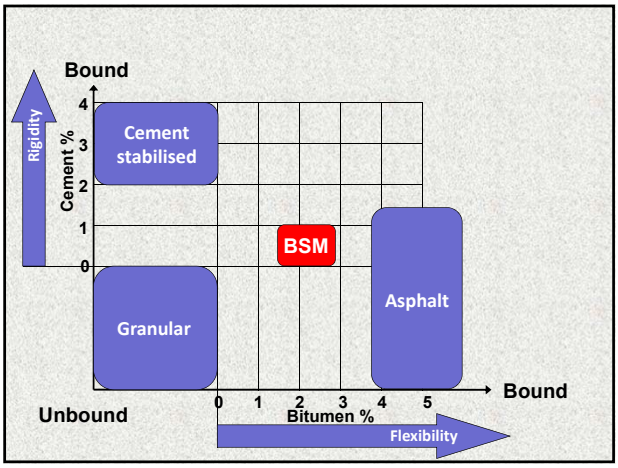
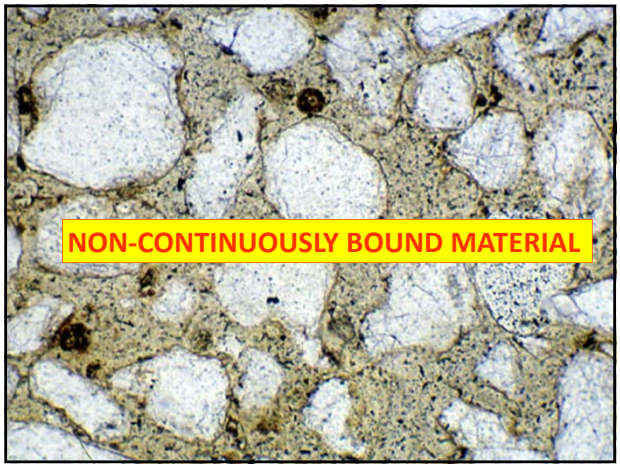

DESIGNING PROJECTS
(Recycling RAP)
FREMIX
ISAP WG2 meeting
Fortaleza, Brazil
Sunday 30th September 2012
Dave Collings
LOUDON INTERNATIONAL
SOUTH AFRICA

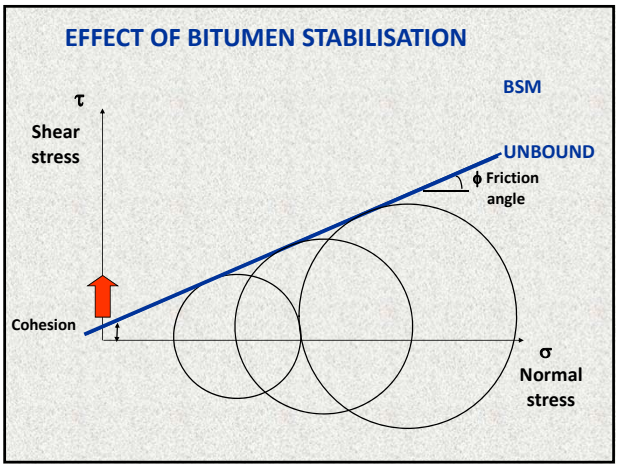

Wirtgen WR recycler population
East Europe & Russia
West Europe
350
North America
450
200
20
Asia
180
Middle East
200
South & Central America
100
Africa
75
Australasia
45 % with foamed bitumen systems

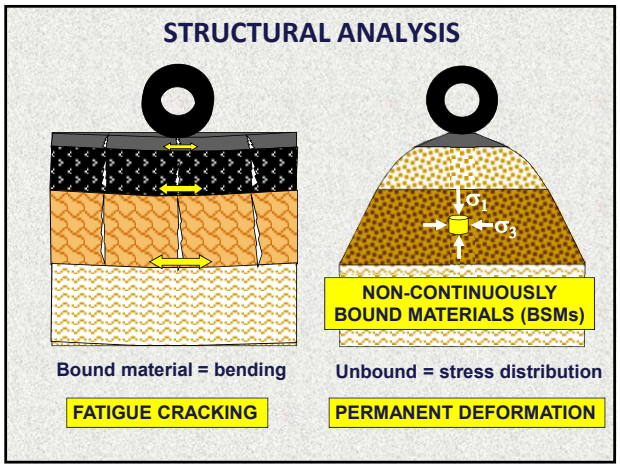

Wirtgen KMA population
East Europe & Russia
West Europe
15
50
40
North America
Asia
5
40
Middle East
10
5
South & Central America
Africa
5
Australasia
100 % with foamed bitumen systems


Technical Guideline
Bitumen Stabilised Materials
A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials
Wirtgen
Cold Recycling
Wirtgen Cold Recycling Technology
Documentation


Bound
Rigidity
Cement %
4
3
2
1
0
Cement stabilised
BSM
Asphalt
Granular
Unbound
0 1 2 3 4 5
Bitumen %
Bound
Flexibility


NON-CONTINUOUSLY BOUND MATERIAL


EFFECT OF BITUMEN STABILISATION
BSM
τ
Shear stress
UNBOUND
ϕ Friction angle
Cohesion
σ
Normal stress


STRUCTURAL ANALYSIS
σ1
σ3
NON-CONTINUOUSLY BOUND MATERIALS (BSMs)
Bound material = bending
Unbound = stress distribution
FATIGUE CRACKING
PERMANENT DEFORMATION

CRACK PROPAGATION (Collings/ Jenkins CAPSA 2011 Paper)

(Fracture mechanics)

CONTINUOUSLY BOUND MATERIAL

CRACK "TIP" — STRESS CONCENTRATION

Paris' Law: $\frac{d_c}{d_N} = A.K^n$

- K: Stress intensity factor at crack tip
- d_c / d_N: Increase in crack length / load cycle

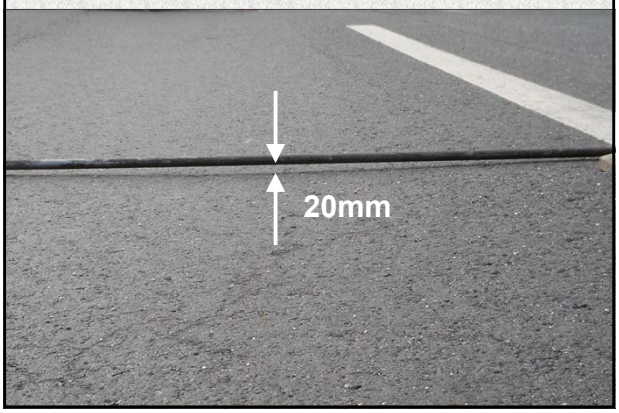
NON-CONTINUOUSLY BOUND MATERIAL

CRACK "TIP" CANNOT FORM

- Localised bond breaks / localised shear
- Localised bond re-establishes

Similar to unbound granular materials

FAILURE CONDITION



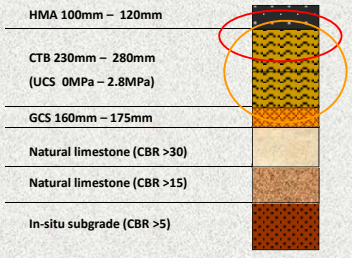
PAVEMENT CONDITION AT FAILURE

Bound materials	Unbound materials
	Non-continuously bound materials
"Broken"	Not "broken"
Fatigue cracking	Permanent deformation

PAVEMENT REHABILITATION DESIGN

Pavement Composition
Distress Mechanism

Example



Failure zone

Upper CTB failure (crushing)

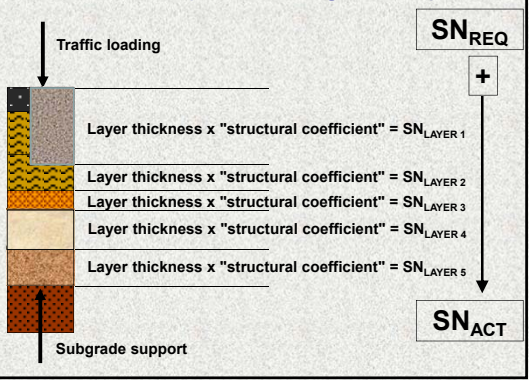
Non-uniformity

Variations in

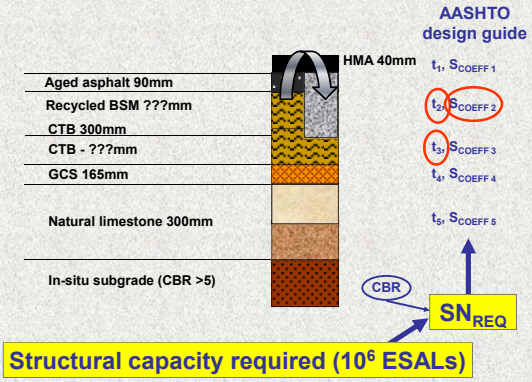
- number of layers
- thickness of layers
- strength (UCS)

ESTIMATING THE RECYCLING DEPTH

Structural numbers "SN" (AASHTO design method)



ESTIMATING THE RECYCLING DEPTH (EXAMPLE)



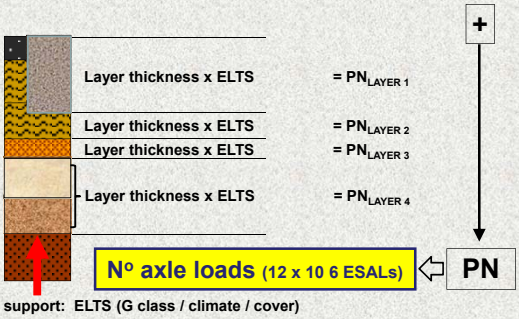
Wirtgen Cold Recycling Technology Manual

SUGGESTED STRUCTURAL LAYER COEFFICIENTS FOR BITUMEN STABILISED MATERIAL (BSM)

STRUCTURAL LAYER COEFFICIENT (per inch)	0.18	0.23	0.28	max 0.35
TG2 (2009) CLASSIFICATION	BSM3	BSM2	BSM1	
MATERIAL PROPERTIES AFTER STABILISATION				
100mm dia briquettes ITS_{DRY} (kPa)	125	175	225	
150mm dia specimens ITS_{EQUIL} (kPa)	95	135	175	
150mm Triaxial specimens				
Cohesion (kPa)	50	100	250	
Angle of Friction ( )	25	30	40	
MATERIAL CBR VALUE BEFORE STABILISATION (at 100% compaction)				
Materials with CBR < 20% not recommended	20	40	80	
ANTICIPATED APPLICATION RATE OF BITUMEN FOR STABILISATION (% by mass)				
	BSM3 2.5 - 4.0	BSM2 2.3 - 3.0	BSM1 2.0 - 2.5	

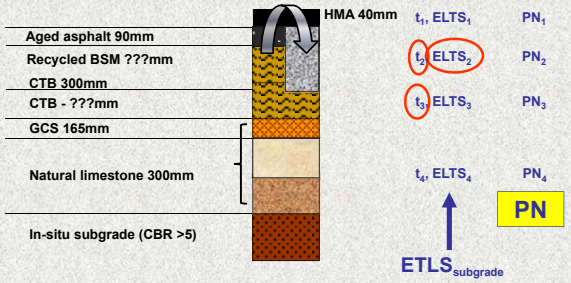
ESTIMATING THE RECYCLING DEPTH

Pavement numbers "PN" (TG2 (2009) design method)



ESTIMATING THE RECYCLING DEPTH (EXAMPLE)

TG2 (2009)



t_1, $ELTS_1$ — PN_1

t_2, $ELTS_2$ — PN_2

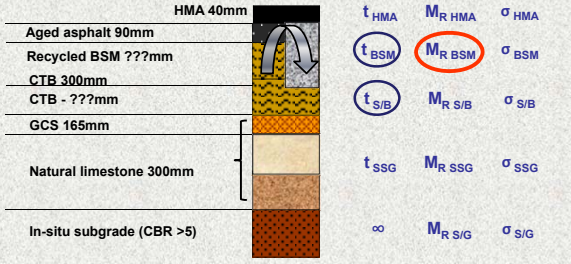
t_3, $ELTS_3$ — PN_3

t_4, $ELTS_4$ — PN_4

PN

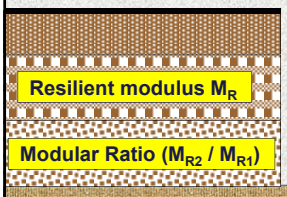
$ETLS_{subgrade}$

MODELLING (Multi-layer linear elastic theory)



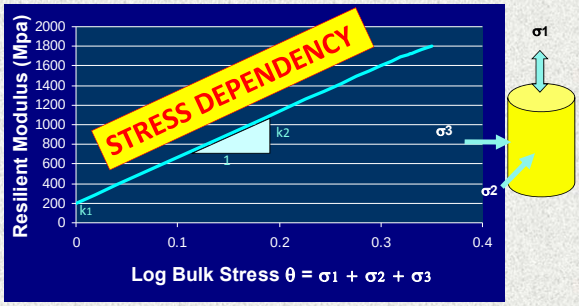
t_{HMA}	$M_{R\ HMA}$	σ_{HMA}
t_{BSM}	$M_{R\ BSM}$	σ_{BSM}
$t_{S/B}$	$M_{R\ S/B}$	$\sigma_{S/B}$
t_{SSG}	$M_{R\ SSG}$	σ_{SSG}
∞	$M_{R\ S/G}$	$\sigma_{S/G}$

PAVEMENT LAYERS



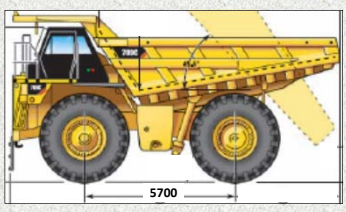
	Max M_R (Mpa)	Modular ratio M_{R2} / M_{R1}
HMA	2000 – 5000	3 – 5
BSM	500 – 1200	2 – 4
CTB	200 – 400	2 – 4
GCS	300 – 500	1.7 – 2
Gravel	150 – 250	1.5 – 1.8

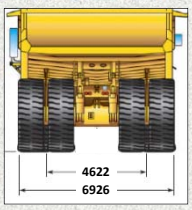
Resilient Modulus for Coarse Granular Materials and BSMs

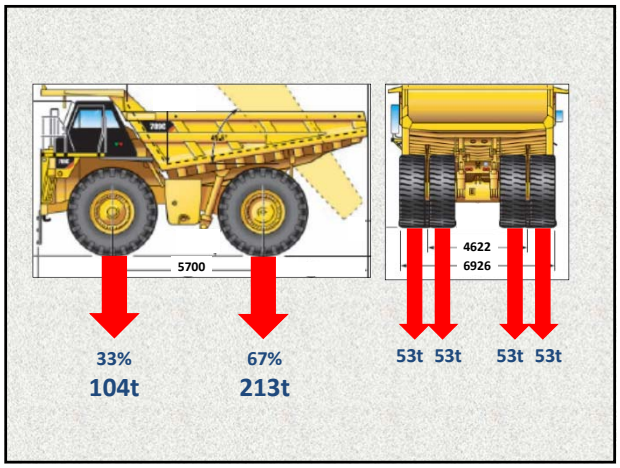


Cat 789C

Gross operating weight: 318t

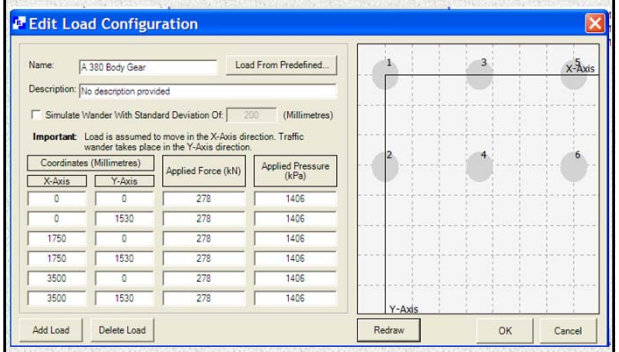




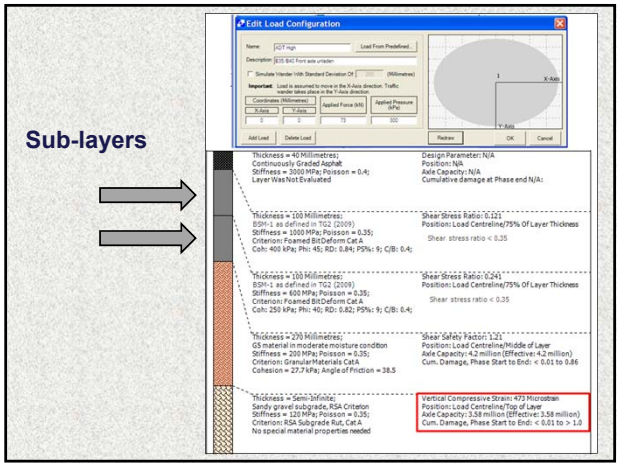


Runways / taxiways

A380F – Body Gear
(167 tons at MTOW)

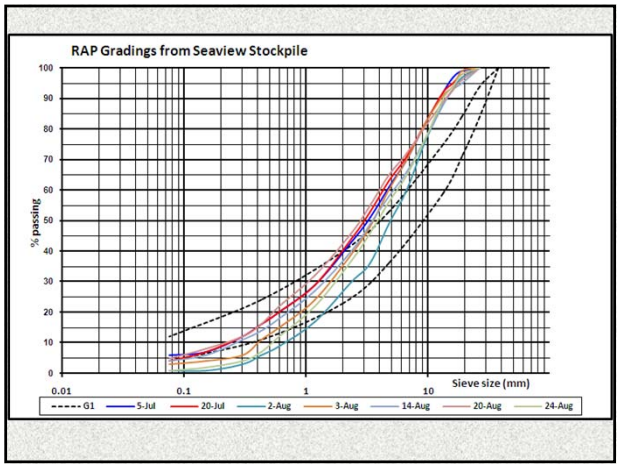


Sub-layers



BSM STABILISATION DESIGN

Sample Preparation	Scalping / crushing
Preliminary tests	Gradings Atterberg Limits MDD/OMC



BSM STABILISATION DESIGN

Sample Preparation	Scalping / crushing
Preliminary tests	Gradings Atterberg Limits MDD/OMC
1. Effect of active filler	ITS_{DRY} / ITS_{WET}
2. Optimum bitumen addition	ITS_{EQUIL} / ITS_{SOAK}
3. Shear properties	Cohesion / ϕ

ACTIVE FILLER EFFECT ON FOAMED BITUMEN TREATMENT

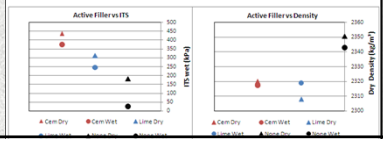
MATERIAL TO BE STABILISED	Aggregates	Bitumen	Filler
Description	10% RA + 75% Base + 15% Subbase	70/100	As shown
Location / Source:	Slot 1, km0+400	Colas	-
Mod AASHTO (kg/m³)	2319	Optimum moisture content (%)	4.4

FOAMED BITUMEN STABILISED MATERIAL SPECIMENS

Compactive effort	Vibratory Hammer : TG2(2009) Method 8(2)	150mm		diameter
Date moulded	24.08.2012			
Foamed Bitumen added (%)	2.2	2.2	2.2	
Type & Percent filler added (%)	1% Cement	1% Lime	None	
Moulding moisture content (%)	4.4	4.5	4.8	

TEST RESULTS

ITS dry (kPa)	438	313	181	
Moisture content at break (%)	2.0	1.8	1.0	
Dry Density (kg/m³)	2320	2308	2351	
Temperature at break (°C)	25.5	25.4	24.9	
Displacement (mm)	1.6	1.9	2.2	
ITS wet (kPa)	375	245	25	
Moisture content at break (%)	4.1	4.3	4.0	
Dry Density (kg/m³)	2317	2319	2343	
Temperature at break (°C)	24.6	24.7	24.8	
Displacement (mm)	1.6	2.5	2.1	
Tensile Strength Retained (%)	86	78	14	



FOAMED BITUMEN MIX DESIGN REPORT - LEVEL 2

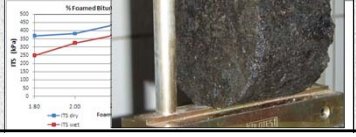
MATERIAL TO BE STABILISED	Aggregates	Bitumen	Filler
Description	10% RA + 75% Base + 15% Subbase	70/100	Cem ii 32.5N
Location / Source:	Slot 1, km0+400	Colas	NPC
Maximum Dry Density (kg/m³)	2319	Optimum moisture content (%)	4.4

FOAMED BITUMEN STABILISED MATERIAL SPECIMENS

Compactive effort	Vibratory Hammer : TG2(2009) Method 8(2)	150mm		diameter
Date moulded	24.08.2012			
Foamed Bitumen added (%)	1.80	2.00	2.20	2.40
Type and percent filler added (%)	1% Cement	1% Cement	1% Cement	1% Cement
Moulding moisture content (%)	4.6	4.3	4.4	4.4

TEST RESULTS

ITS equilibrium (kPa)	368	383	438	432
Moisture content at break (%)	2.5	2.4	2.0	2.4
Dry Density (kg/m³)	2308	2331	2311	2320
Temperature at break (°C)	25.7	25.7	25.5	25.2
Displacement (mm)	1.3	1.7	1.6	1.8
ITS soaked (kPa)	247	324	375	369
Moisture content at break (%)				
Dry Density (kg/m³)				
Temperature at break (°C)				
Displacement (mm)				
Tensile Strength Retained (%)				
TG2 (2009) Material Classification BASED ON ITS_{DRY} AND ITS_{WET}				



FOAMED BITUMEN MIX DESIGN REPORT - LEVEL 3 TRIAXIAL

MATERIAL TO BE STABILISED	Aggregates	Bitumen	Filler
Location / Source:	Slot 1, km0+400	Colas	NPC
Description	10% RA + 75% Base + 15% Subbase	70/100	Cem ii 32.5 N
Maximum Dry Density (kg/m³)	2319	Optimum moisture content (%)	4.4

BITUMEN FOAMING CONDITIONS

Foaming water added (%)	2.5	Bitumen temperature (°C)	160

FOAMED BITUMEN STABILISED MATERIAL CHARACTERISTICS

Compactive effort	Vibrating Hammer TG 2 2009			
Date moulded	30.08.2012			
Foamed bitumen added (%)	2.0			
Type and percent filler added (%)	1% Cement			
Average Diameter (mm)	152	152	152	152
Average Height (mm)	291.1	292.6	296.5	293.3
Moulding moisture content (%)	4.4	5.0	3.8	4.4
Dry Density kg/m³	2335	2346	2356	2354

TEST RESULTS

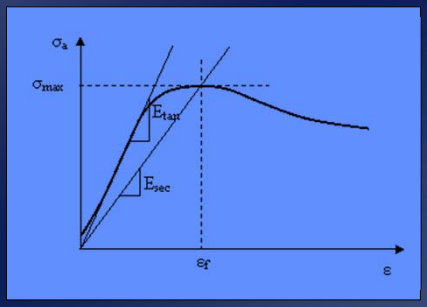
Applied Confining Stress (σ_3) (kPa)	0	50	100	200
Applied Failure Load (kN)	58.2	65.8	70.1	82.1
Moisture Content at break (%)	2.4	2.2	2.4	2.4
Temperature at break (°C)	25.0	25.3	25.5	24.8
Displacement (mm)	3.9	3.9	7.6	5.3

CALCULATIONS

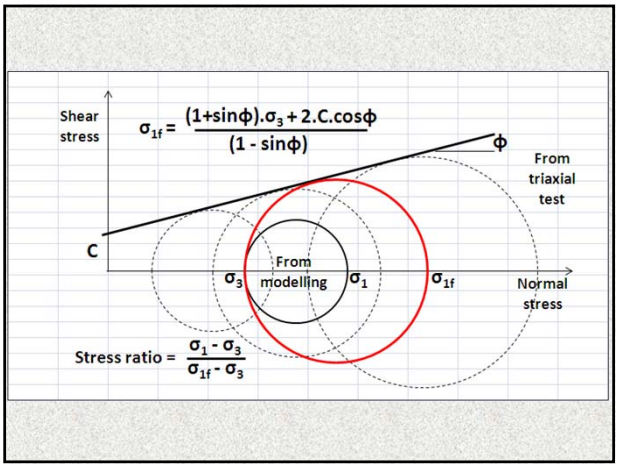
Applied Failure Stress (kPa)	3209	3628	3863	4522
Mass of dead loads (kg)	5.1			
Stress due to dead loads (kPa)	2.8			
Major Principle Stress at failure ($\sigma_{1,f}$) (kPa)	3212	3630	3866	4522

COHESION (C) (kPa)	642	INTERNAL ANGLE OF FRICTION (φ)	46.9

More information from monotonic test

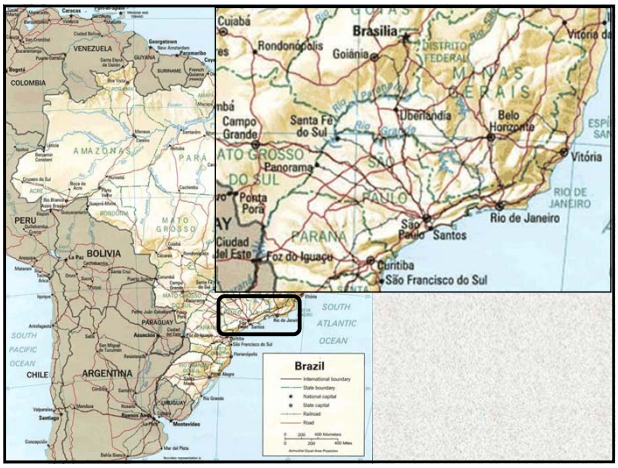


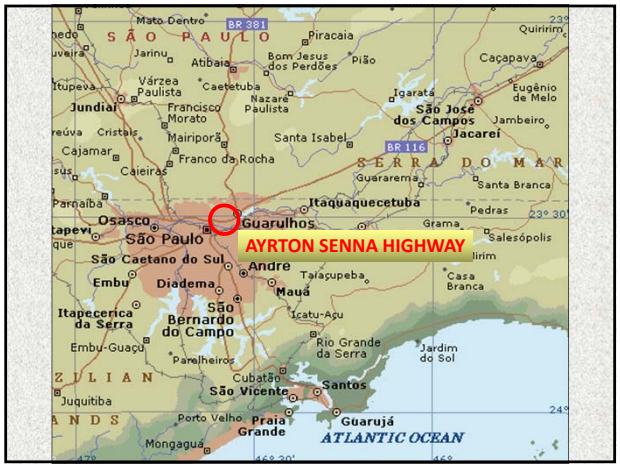
Ebels



Classification Parameters and Certainty Factors: BSMs

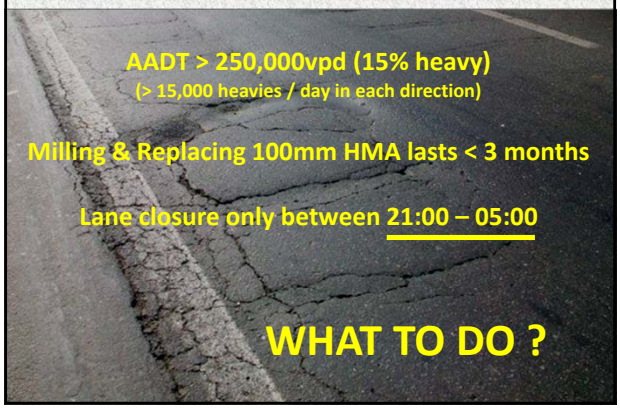
- Treated Material (from Mix Design)
  - *Triaxial tests*
    - Cohesion (0.45)
    - Friction Angle (0.4)
    - Tangent Modulus (0.1)
    - Retained Cohesion (MIST) (0.45)
  - *ITS dry, equil,wet (100 & 150 mm) (0.1, 0.15)*
  - *UCS (0.1)*





8-lane divided facility
Brazil's most heavily trafficked highway

SCARY STATISTICS



PAVEMENT INVESTIGATIONS

(500m TRIAL SECTION – SLOW LANE ONLY)

Deflections (FWD & Benkelman Beam)

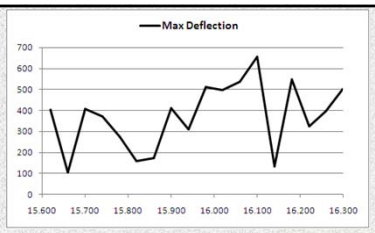
Visual assessment

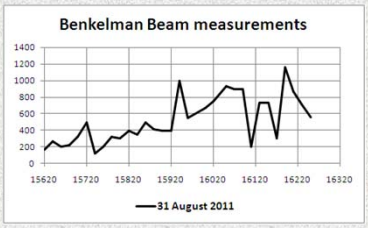
4 x Test pits

10 x Core extractions

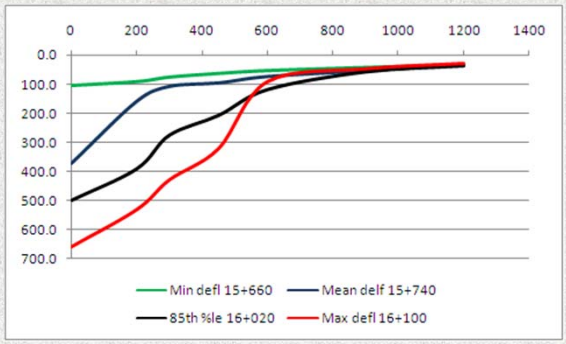
10 x DCP probes (through core holes)

FWD



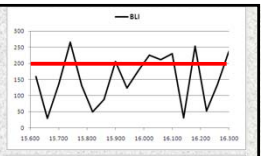


FWD – Deflection Bowls

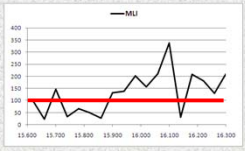


DEFLECTION INDICES

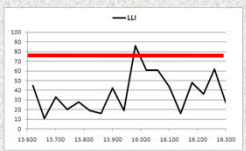
$BLI = D_0 - D_{300}$



$BLI = D_{300} - D_{600}$



$BLI = D_{600} - D_{900}$



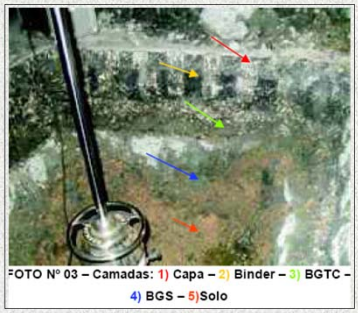
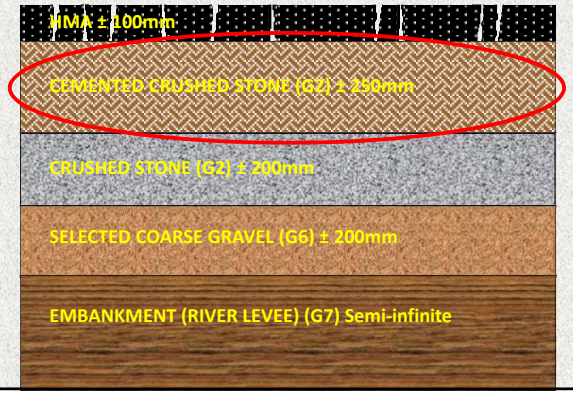


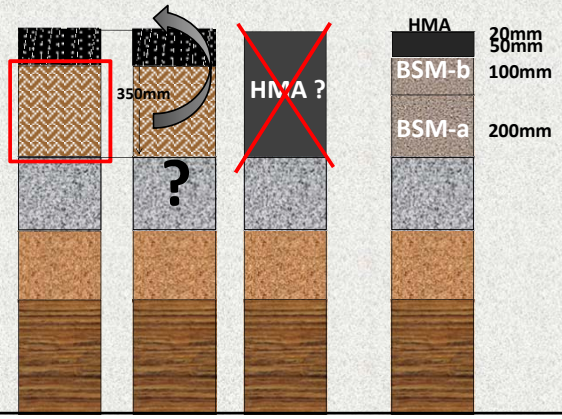
FOTO Nº 03 – Camadas: 1) Capa – 2) Binder – 3) BGTC – 4) BGS – 5)Solo

	FURO	01	02	03	04	05	06	07	08	09	10	Média
Espessura (cm)	CAPA	7,0	7,0	3,0	5,8	5,0	4,9	4,8	5,2	5,2	5,1	5,3
	BINDER	-	2,9	3,3	-	-	7,3	7,9	-	-	-	5,4

RESULTS OF PAVEMENT INVESTIGATIONS



REHABILITATION OPTIONS ?? (8-hour working window)



DESIGN ASPECTS

Superior BSM parent material (selected RA blend)

Drainage, drainage, drainage, drainage, drainage, drainage, drainage

Support (undercut / rockfill / outlet drain)

DESIGN ASPECTS

Superior BSM parent material (selected RA blend)

Drainage, drainage, drainage, drainage, drainage, drainage, drainage

Support (undercut / rockfill / outlet drain)

Stability (density / moisture content)

Early trafficking (sacrificial layer of HMA)

HMA surfacing to be delayed (after curing)

8-hour working window (short sections)

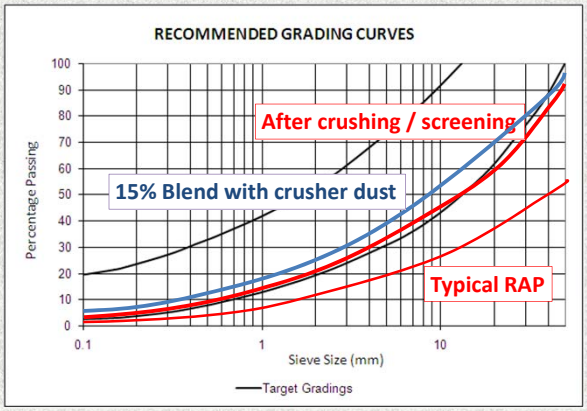
LABORATORY PROCEDURES

Sample preparation

Sieve analyses (gradings)

Sample blends with -5mm crusher dust

Bitumen stabilisation designs



STABILISATION DESIGNS

BSM LABORATORIES (PTY) LTD
Bitumen Stabilised Materials Testing Laboratories
REG. NO. 2009/023623/07
25 WESTMEAD ROAD, WESTMEAD, KWAZULU-NATAL, SOUTH AFRICA
+27(0)31 7001333 +27(0)31 7001009

Client:	Ukheza Services	Job Card No:	-
Project:	Ayrton Senna Highway, Sao Paulo, Brazil	Date Received:	27.10.2011
Sample Number:	Design 1	Date Tested:	01.11.2011
Sample Delivered By:	Ukheza Services	Date Reported:	02.11.2011

ACTIVE FILLER EFFECT ON FOAMED BITUMEN TREATMENT

MATERIAL TO BE STABILISED		Aggregates		Bitumen	Filler
Description		85% Reclaimed Asphalt + 15% -4.75 Dust		80/100	As shown
Location / Source:		Reclaimed Asphalt Stockpile		Fremix	-
Mod AASHTO	(kg/m³)	2028	Optimum moisture content (%):		6.8

FOAMED BITUMEN STABILISED MATERIAL SPECIMENS					
Compactive effort		Vibratory Hammer : TG2(2009) Method 8(2)		100mm	diameter
Date moulded		28.10.2011			
Foamed Bitumen added	(%)	2.5	2.5		
Type and percent filler added	(%)	1% Cement	1% Lime		
Moulding moisture content	(%)	5.9	5.3		
TEST RESULTS					
ITS dry	(kPa)	662	414		
Moisture content at break	(%)	6.3	6.9		
Dry Density	kg/m³	2124	2101		
Temperature at break	(oC)	N/A	N/A		
ITS wet	(kPa)	517	396		
Moisture content at break	(%)	6.7	6.9		
Dry Density	kg/m³	2097	2092		
Temperature at break	(oC)	N/A	N/A		
Tensile Strength Retained	(%)	78	81		

BSM LABORATORIES (PTY) LTD

Bitumen Stabilised Materials Testing Laboratories

REG. NO. 2009/023623/07

25 WESTMEAD ROAD, WESTMEAD, KWAZULU-NATAL, SOUTH AFRICA

+27(0)317001333 +27(0)317001909

Client:	Unibeza Serucos	Job Card No:	-
Project:	Ayrton Senna Highway , Sao Paulo, Brazil	Date Received:	27.10.2011
Sample Number:	Design 1	Date Tested:	01.11.2011
Sample Delivered By:	Unibeza Serucos	Date Reported:	03.11.2011

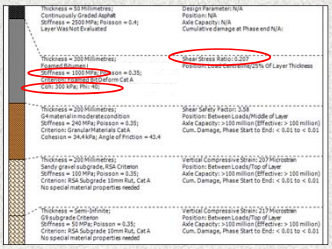
FOAMED BITUMEN MIX DESIGN REPORT - LEVEL 1

MATERIAL TO BE STABILISED	Aggregates		Bitumen	Filler
Description	85% Reclaimed Asphalt + 15% -4.75 Dust		80/100	Cement
Location / Source:	Reclaimed Asphalt Stockpile		Fremix	-
Maximum Dry Density (kg/m3)	2028	Optimum moisture content (%):		6.8

FOAMED BITUMEN STABILISED MATERIAL SPECIMENS				
Compactive effort	Vibratory Hammer : TG2(2009) Method 6(2)		100mm	diameter
Date moulded	27.10.2011			
Foamed Bitumen added (%)	1.75	2.00	2.25	2.50
Type and percent filler added (%)	1% Cement	1% Cement	1% Cement	1% Cement
Moulding moisture content (%)		5.7	4.1	5.9
TEST RESULTS				
ITS dry (kPa)		432	535	662
Moisture content at break (%)		0.3	0.8	0.3
Dry Density kg/m³		2129	2142	2122
Temperature at break (oC)		N/A	N/A	N/A
ITS wet (kPa)		306	379	517
Moisture content at break (%)		1.3	1.0	0.7
Dry Density kg/m³		2142	2142	2095
Temperature at break (oC)		N/A	N/A	N/A
Tensile Strength Retained (%)		71	71	78
TG2 (2009) Material Classification BASED ON ITS_{DRY} AND ITS_{WET}		BSM 1	BSM 1	BSM 1

Mechanistic Analyses (Rubicon Toolbox)

M_r (MPa)	C (kPa)	Φ (°)	Stress ratio



Critical stress ratio = 0.35 **> 100 million ESALs**

CONSTRUCTION SEQUENCE

1. 21:00 Close off slow lane and shoulder
2. Mill out HMA – haul RAP to stockpile
3. Mill out CTB – remove from site
4. Proof roll with 18t PTR
   Undercut where necessary + install outlet
5. Import BSM-foam (KMA treated RAP blend)
   (RAP passed thru impact crusher & screen)
6. Spread 200mm & compact with 19t padfoot
7. Level / light spray / smooth drum roller
8. Import & pave 130mm BSM-foam
   (Crushed RAP blended with 15% crusher dust)
9. Compact (12t tandem & PTR)
10. Apply 20mm HMA
11. Open to traffic by 05:00 / Pray

TRIAL SECTION CONSTRUCTION (500m Slow Lane)

Monday 14th to Friday 18th November 2011

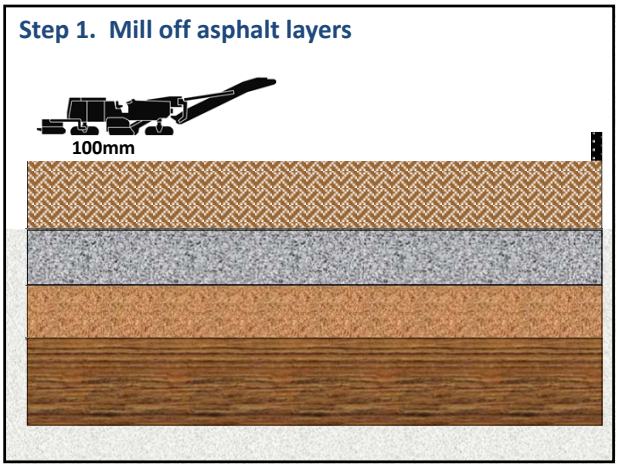
All work done at night

1st night – 100m (nearly a disaster)

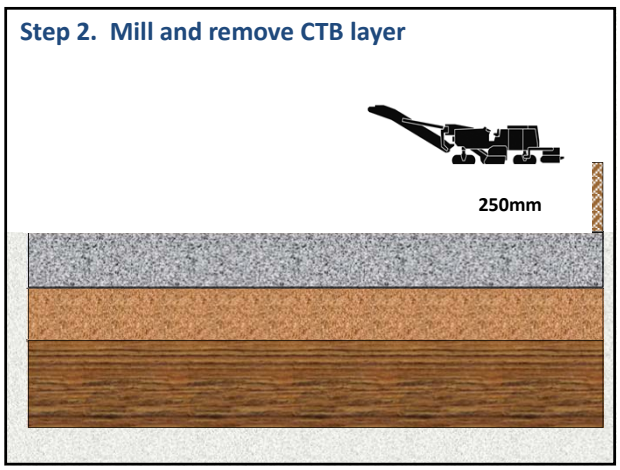
2nd night – 100m (much better)

3rd night – 300m (perfect, including undercut)

Step 1. Mill off asphalt layers



Step 2. Mill and remove CTB layer

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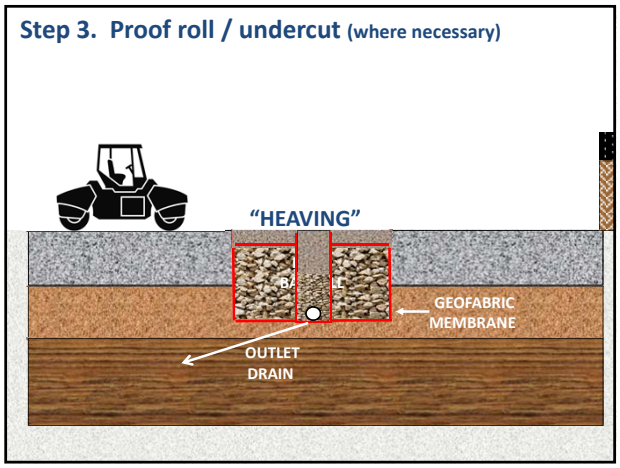
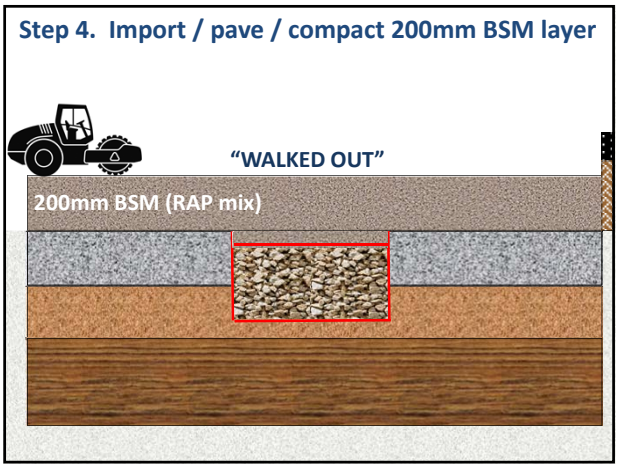
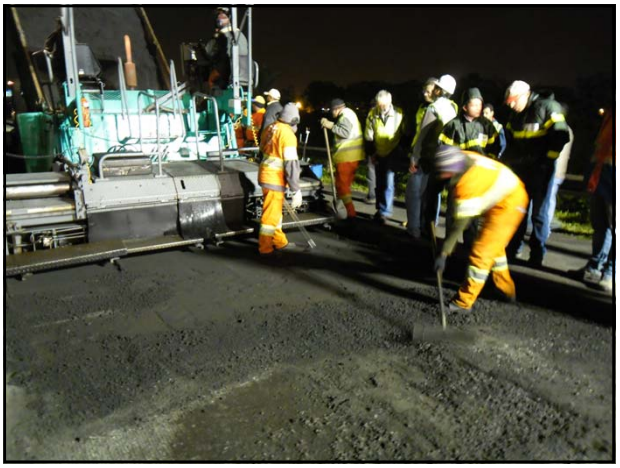

Step 3. Proof roll / undercut (where necessary)
"HEAVING"
GEOFABRIC MEMBRANE
OUTLET DRAIN

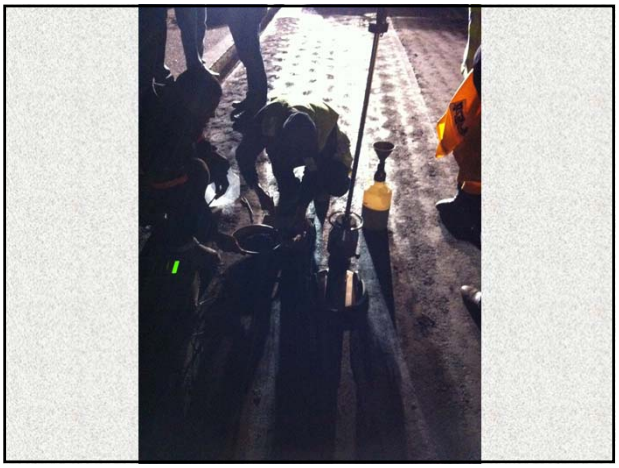

DYNAPAC

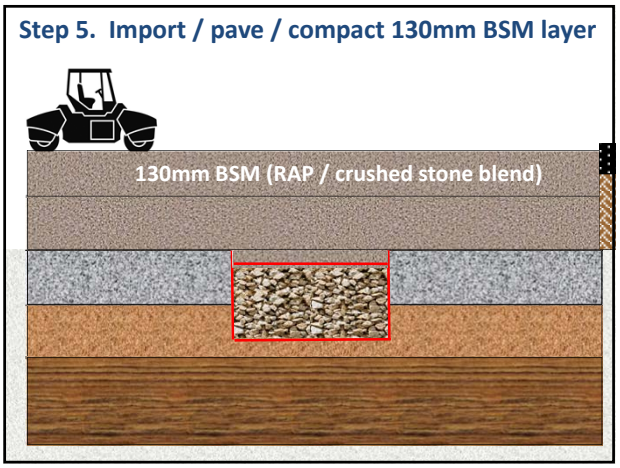

DYNAPAC

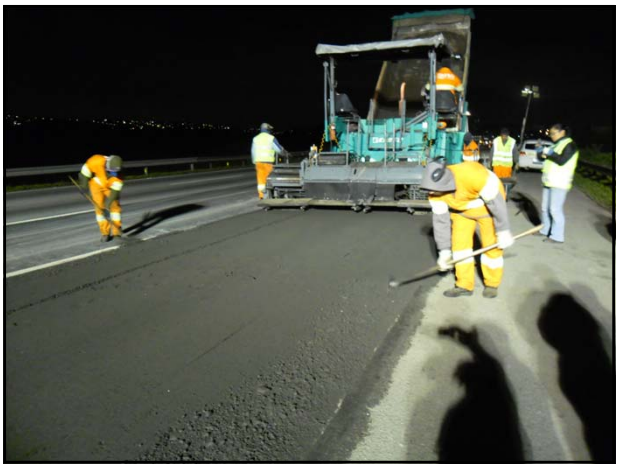

Step 4. Import / pave / compact 200mm BSM layer
"WALKED OUT"
200mm BSM (RAP mix)

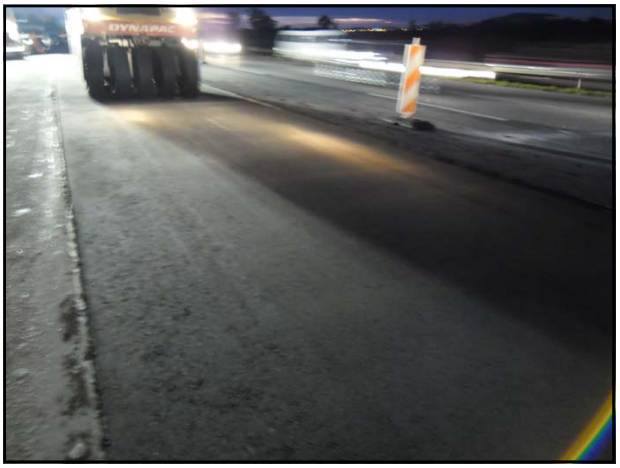

GEIBER

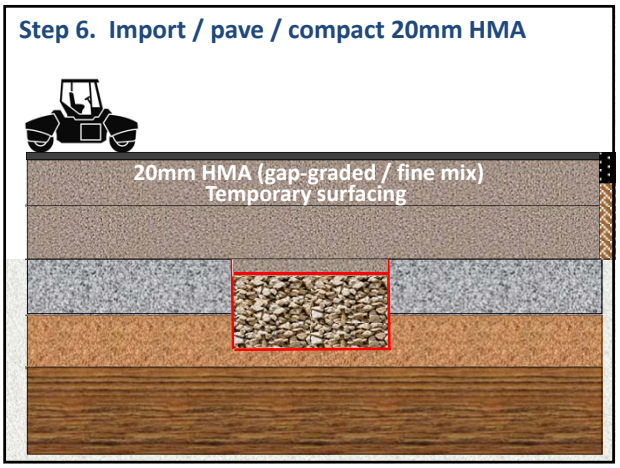





Step 5. Import / pave / compact 130mm BSM layer
130mm BSM (RAP / crushed stone blend)





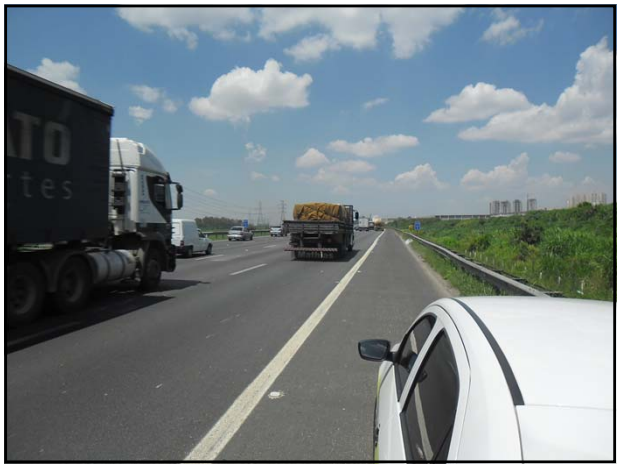

Step 6. Import / pave / compact 20mm HMA
20mm HMA (gap-graded / fine mix)
Temporary surfacing


VÖGELE


VÖGELE


18th November 2011


31ST January 2012




CONTROL SECTION: MILL & REPLACE 100mm


28th March 2012

SUMMARY

Early failures on Control Section "sold" the process

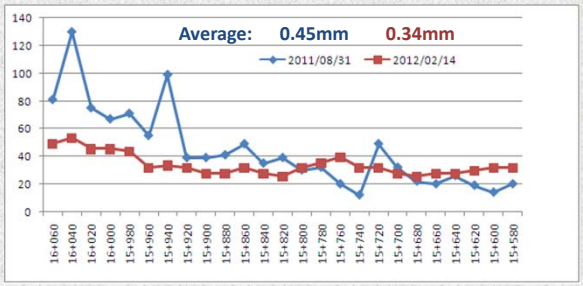
Concessionaire "delighted" with performance to date

Construction quality acknowledged as "the key"

20mm sacrificial HMA surfacing to remain in place
(The Trial Section has become a "Research Project")

Monitoring commenced in February 2012
(Average Benkelman Beam deflections < 0.4mm)

Benkelman Beam Deflections




And now....
10km Lane #4 currently being constructed
2103: 16km Lanes #3 and #4 planned