BRINGING BSM TECHNOLOGY TO THE WORLD

TECHNOLOGY UPDATE: RECYCLING TECHNOLOGY/BITUMEN STABILISATION

Mix Design of Bitumen Stabilised Materials

Kim Jenkins

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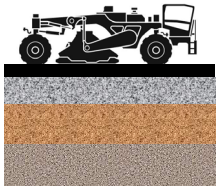
WHAT CAN YOU EXPECT AS A TAKE AWAY?

- **Classification of Materials Quality from Pavement Evaluation**
- **Mix Design Components**
  - Classes
  - Dealing with RA (= RAP)
  - Specimen Compaction (**New**)
  - Test Methods (**New**)
  - Revised Limits (**New**)
- **Link to Structural Design**



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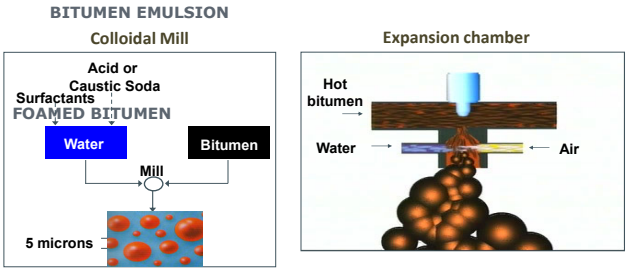
BITUMEN STABILISATION AGENTS



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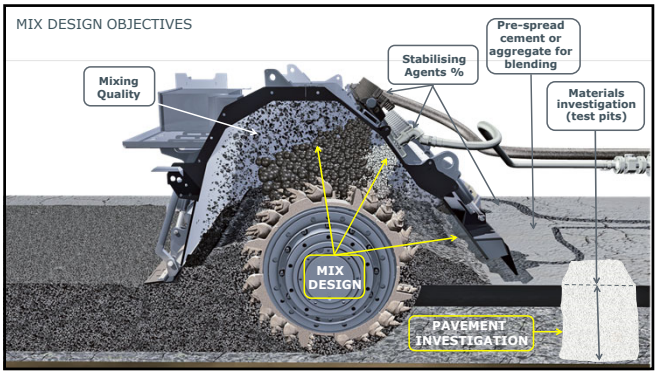
MIX DESIGN OBJECTIVES



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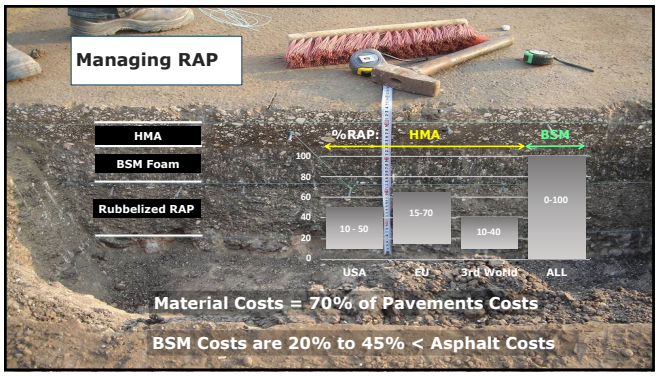

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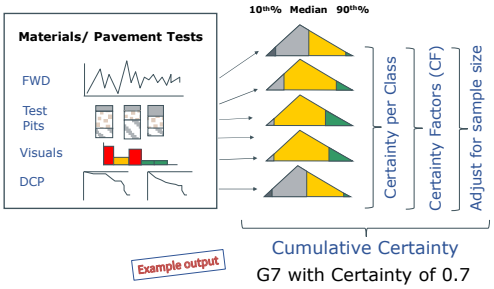
MATERIAL CLASSIFICATION FROM DIVERSE TESTING



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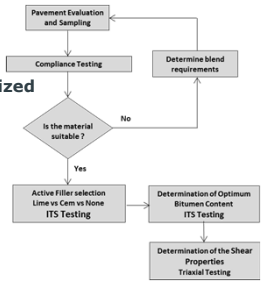
MIX DESIGN IMPROVEMENTS

Unstabilized Material

ITS

Triaxial



Class	ITS Limits	
	ITS_{DRY} (kPa)	ITS_{WET} (kPa)
BSM1	> 225	> 125
BSM2	> 175	> 100

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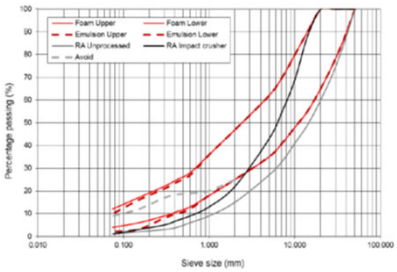
GRADING



$$P_x(\%) = \left[\frac{d_x}{D_{max}}\right]^n$$

n = 0.5 Fuller
n = 0.45 Nijboer

(tightest packing)

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GRADINGS – KEY FEATURES

Table 4.7 Recommended Grading for BSM-Foam and BSM-Emulsion

Sieve size (mm)	Percentage passing each sieve size (%)			
	Target gradings BSM-Foam	Target gradings BSM-Emulsion	Grading for BSM-Foam and BSM-Emulsion, with > 50% RA	
	Upper & Lower Limits	Upper & Lower Limits	Unprocessed	Impact crushed
50	100	100 – 100	100	100
37.5	87 – 100	87 – 100	85	100
28	76 – 100	76 – 100	72	100
20	65 – 100	65 – 100	60	100
14	55 – 100	55 – 100	49	88
10	47 – 89	48 – 89	41	69
7.1	40 – 78	41 – 78	33	55
5.0	34 – 68	35 – 68	27	43
2.0	22 – 48	25 – 48	15	22
1.0	15 – 37	18 – 37	9	13
0.6	11 – 30	12 – 30	6	9
0.425	9 – 26	10 – 26	4	7
0.3	7 – 22	8 – 22	3	5
0.15	5 – 17	3 – 15	2	3
0.075	4 – 14	2 – 10	1	1

Don't dry RAP >40°C

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GRADING – DRY AND WET

Dry = Unwashed grading on air dried material

Wet = Washed grading on air dried material

Comparison of washed and unwashed grading tests provides insight into filler properties:

- Dry grading indicates available filler for BSM
- Wet grading indicates extra cohesive filler might not be released during mixing e.g. sticking to large aggregate

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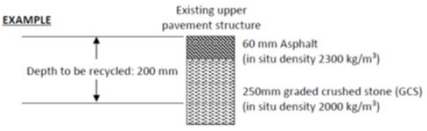
BLENDING OF MATERIALS

EXAMPLE



Blend the materials in proportion to layer thickness and in situ density as follows:

Material	Mass / m² (kg)	Proportion by mass	Per 10kg sample (g)
Asphalt (60mm at 2300 kg/m³)	0.06 x 2300 = 138	138/418 = 0.33	0.33 x 10000 = 3300
GCS (140mm at 2000 kg/m³)	0.14 x 2000 = 280	280/418 = 0.67	0.67 x 10000 = 6700
Total	418	1.00	10000

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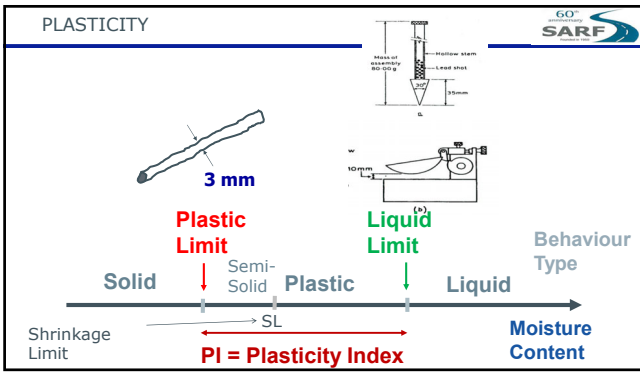
PLASTICITY



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BSM COMPONENT REQUIREMENTS

Table 4.10 BSM Component Requirements for Classification

BSM Class	BSM 1		BSM 2	
Binder type	Foam	Emulsion	Foam	Emulsion
Class (untreated)	G4 (A or B)		G5 (A or B) and G6*	
Grading for BSM	See Table 4.7			
P0.075 (%) [Granular > 50%]	> 4%	> 2%	> 4%	> 2%
P0.075 (%) [RA > 50%]	> 1%	> 1%	> 1%	> 1%
P0.075 (%) [Maximum for all]	< 10%			
Durability DMI	See Table 4.2			
Plasticity Index PI (%)	< 6%		< 8%	
Aggregate Mixing Temperature (°C)	> 15	> 10	> 15	> 10
Target Density (kg/m³)	100% MDD		98% MDD	
Bitumen requirements	Expansion Ratio > 8		Half-life > 6 secs	
Active filler requirements	Cem II (32.5) or hydrated lime			

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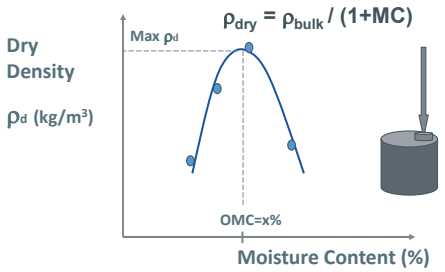
COMPACTION: MAXIMUM DRY DENSITY



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AGGREGATE DURABILITY DURING COMPACTION

Table 4.1 Breakdown Coefficient

Sieve Size (mm)	Passing Sieve Size (%)		Change (%)
	Before Compaction	After Compaction	
5	42	51	9
2	31	35	4
0.425	14	19	5
0.075	8	12	4
		Breakdown Coefficient	22

Maximum Breakdown Coefficient = 20

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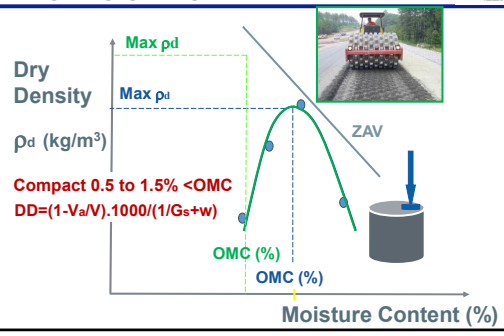
COMPACTING GRANULAR MATERIAL



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FOAMING CHARACTERISTICS

Purpose
Specifications
Bitumen Type (70/100)
Testing
- Different water contents
- Different temperatures
- Measurement
  - Expansion
  - Half Life

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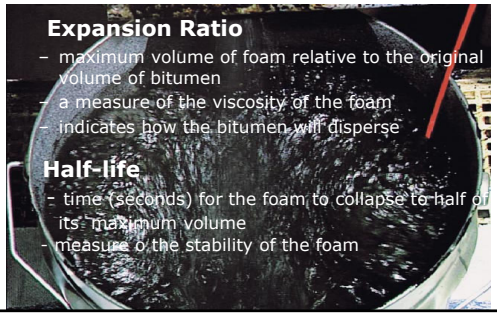
FOAMED BITUMEN CHARACTERISTICS



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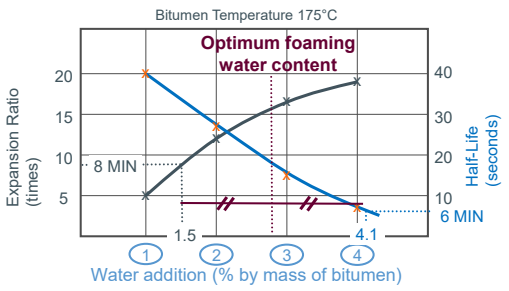
FOAMING CHARACTERISTICS



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MIXING PROCESS BSM-foam Mixing

1. Prepare WLM 30
2. Material Temperature
   - Binder at selected temp
   - Aggregate at 25^{0}C

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MIXING PROCESS BSM-foam Mixing

1. Prepare WLM 30
2. Material Temperature
3. Add Filler
   - Mix for 30 secs dry

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MIXING PROCESS BSM-foam Mixing

1. Prepare WLM 30
2. Material Temperature
3. Add Filler
4. Add Water to Achieve Fluff Point
   - 60% of OMC for mixing

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MIXING PROCESS BSM-foam Mixing

1. Prepare WLM 30
2. Material Temperature
3. Add Filler
4. Add Water to Achieve Fluff Point
5. Add Foamed Bitumen WLB 10S
   - Set mass bitumen %
   - Start mixer
   - Add foamed bitumen
   - Mix for 45 secs

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MIXING PROCESS BSM-foam Mixing

1. Prepare WLM 30
2. Material Temperature
3. Add Filler
4. Add Water to Achieve Fluff Point
5. Add Foamed Bitumen WLB 10S
6. Add Water to OMC
   - Mix for 30 secs

Nozzle: 2.5mm jet for 100g/s 2.0mm jet for 50g/s
Fan nozzle: 60/40 for WLM30 (70/30 is too wide) **Check!**
Extension nozzle for foaming into bucket

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MIXING PROCESS — BSM-foam Mixing

1. Prepare WLM 30
2. Material Temperature
3. Add Filler
4. Add Water to Achieve Fluff Point
5. Add Foamed Bitumen WLB 10S
6. Add Water to OMC
7. Ready for Compaction

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Stabilisation Mix Designs

How many ITS tests come from one mix?

Active Filler Addition

Standard % Bitumen e.g. 2.2%

6 x 3.3= 20 kg +extras = 26 kg

1 mix = 26 kg

1 mix = 26 kg

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Active Filler Selection

Bitumen addition	(%)	2.2	2.2	2.2
Type / amount of active filler	(%)	1% Lime	None	1% Cement
Moulding moisture content	(%)	8.5	8.4	8.5
TEST RESULTS				
ITS_{DRY}	(kPa)	**267**	**243**	**259**
Moisture content at break	(%)	2.5	2.4	2.5
Dry density	(kg/m^3)	2248	2257	2248
Temperature at break	(°C)	24.9	25.1	24.9
Displacement	(mm)	2.3	2.1	1.7
ITS_{WET}	(kPa)	**184**	**58**	**126**
Moisture content at break	(%)	6.1	6.3	6.1
Dry density	(kg/m^3)	2247	2254	2247
Temperature at break	(°C)	25.0	24.9	25.0
Displacement	(mm)	3.1	2.8	2.3

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Select bitumen addition range

1.8 | 2.0 | 2.2 | 2.4

Guidelines for estimating Optimum Bitumen Addition

Fraction < 0.075mm (%)	Bitumen addition (% by mass of dry aggregate) Fraction < 4.75mm		Typical material
	< 50%	>50%	
< 4	**1.8**	**2.0**	Recycled asphalt (RA)
4 – 7	**2.2**	**2.4**	RA / Graded crushed stone / Natural gravel / blends
7 – 10	**2.4**	**2.6**	
> 10	**2.6**	**3.0**	Gravels / sands

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Stabilisation Mix Designs

How much bitumen should be added for effective stabilisation ?

i.e. a "Mix Design"

Test specimens with varying bitumen quantities

Specimens "cured" for 3 days (moisture loss)

Soak half the specimens in water for 24 hours

Indirect Tensile Strength (ITS)

Bitumen addition

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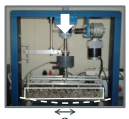
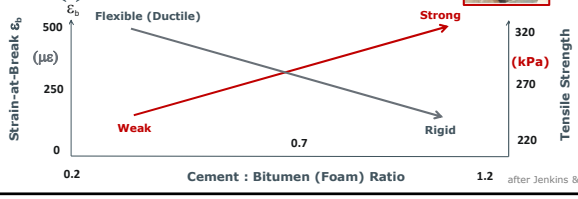
INFLUENCE OF ACTIVE FILLER



STRENGTH VS FLEXIBILITY

ITS



after Jenkins & CSIR

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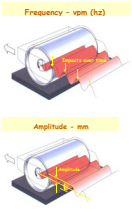
MIX DESIGN: SPECIMEN IMPROVEMENTS



Padfoot
Dynamic Roller

Drop Weight
Hammer

	Field (Vibro)
Frequency (Hz)	50 – 65
Amplitude (mm)	0.4 – 1

Lab (Mod.Proc)
1
457.2

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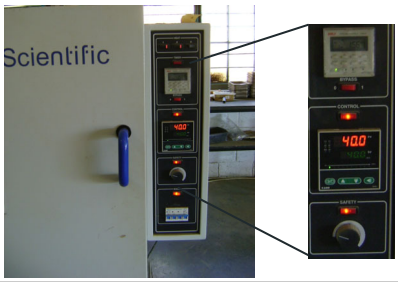
Conditioning test specimens

OVEN CURING



CRITICAL

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OVEN CURING

ITS Specimens

1. Place in a forced draft oven for 72 hours at 40°C
   Minimum spacing of 25mm between specimens
2. After 72 hours, remove one specimen from the oven and weigh it
3. Place back in the oven for a further 4 hours
4. After 4 hours, re-weigh the same specimen
5. If the mass is the same, take all specimens out of the oven
   Allow to cool to 25°C in a temperature controlled room
6. If the mass reduces, place back in oven for a further 4 hours
   Continue from Step 4 until mass remains constant
7. Place half the specimens (3) in a water bath at 25°C for 24 hours
   Submerge the specimens under 25mm of water

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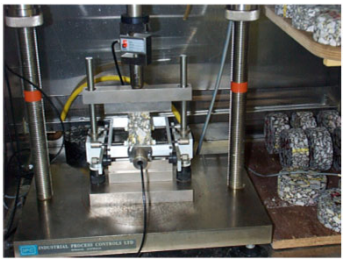
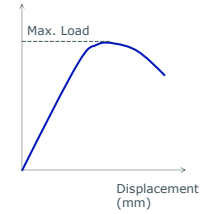
INDIRECT TENSION STRENGTH (ITS) TEST



Displacement Controlled (50±5 mm/min)



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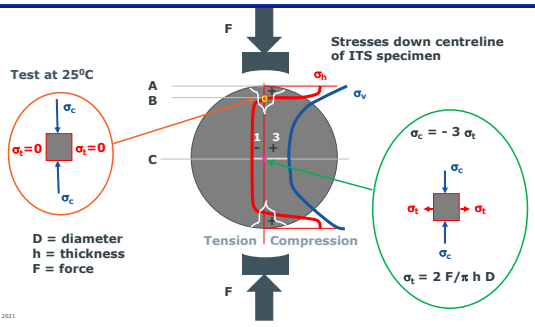
STRESS CONDITIONS FOR INDIRECT TENSION STRENGTH TEST



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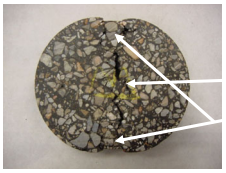
FAILURE IN AN INDIRECT TENSION STRENGTH TEST



Sample doesn't only fail in tension but also in shear and compression !

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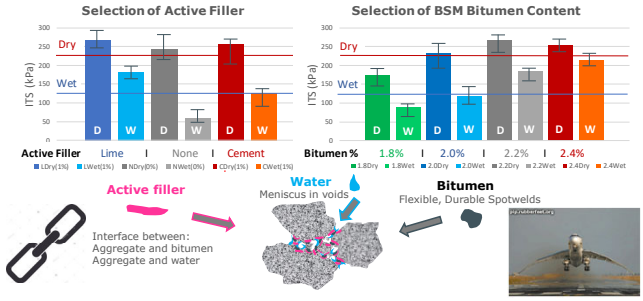
Slide 35

A2 Author, 2021/03/05

A3 Author, 2021/03/10

ITS – PRIMARY ANALYSIS OF BSM MIX



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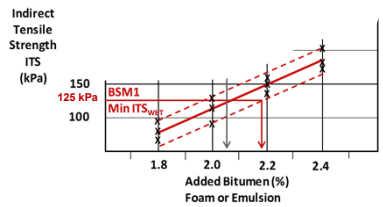
ITS TO TACKLE NUMEROUS VARIABLES



Notes

Active filler selected
Sensitivity analysis of BC
Plot 90th & 10th Percentile

Design BC = Highest BC for ITS ($_{WET}$ or $_{DRY}$)

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MIX DESIGN IMPROVEMENTS - TRIAXIAL TEST

Test at 25^{0}C

Confining Pressure
0 kPa 50 kPa
100 kPa 200kPa

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Conditioning test specimens

OVEN CURING

Triaxial Specimens

1. Place in a forced draft oven for 8 hours at 40°C
   Minimum spacing of 25mm between specimens
2. After 8 hours, wrap in cling wrap (or place in a sealed bag)
3. Place specimens back in oven for a further 48 hours
4. After 48 hours remove all the specimens from the oven
   Allow to cool to 25°C in a temperature controlled room for 24 hours
   Do not remove the wrapping from 8 specimens until immediately before testing
5. Remove the wrapping from 2 specimens and place under water
   Submerge under 25mm water in a bath at 25°C for 24 hours

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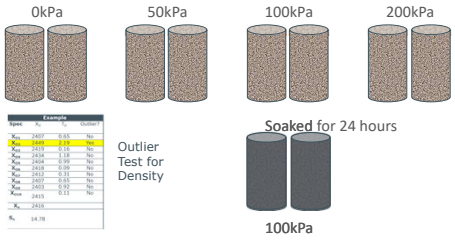
Stabilisation Mix Designs

Specimen Pairs
Tested at 4 different confining pressures



Outlier Test for Density

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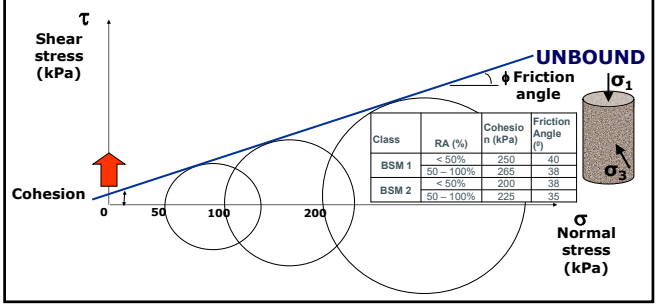
TRIAXIAL TEST @ EQUILIBRIUM MC – MOHR COULOMB PLOTS



Class	RA (%)	Cohesion (kPa)	Friction Angle (°)
BSM 1	< 50%	250	40
	50 – 100%	265	38
BSM 2	< 50%	200	38
	50 – 100%	225	35

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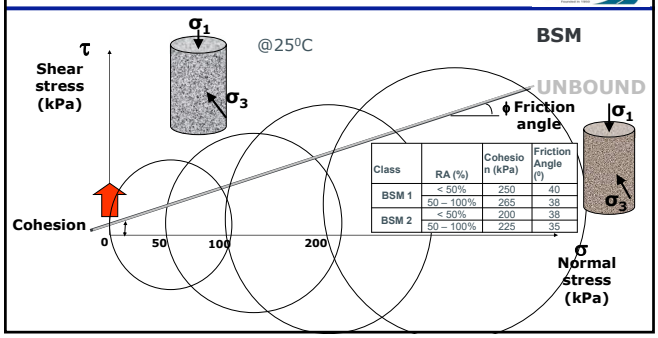
TRIAXIAL TEST @ EQUILIBRIUM MC – MOHR COULOMB PLOTS



Class	RA (%)	Cohesion (kPa)	Friction Angle (⁰)
BSM 1	< 50%	250	40
	50 – 100%	265	38
BSM 2	< 50%	200	38
	50 – 100%	225	35

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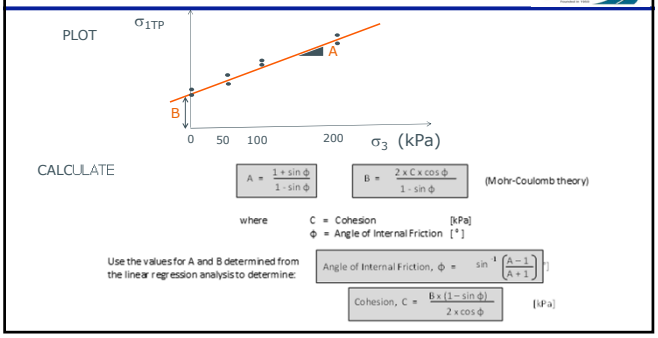
FAILURE ENVELOPE EQUATION



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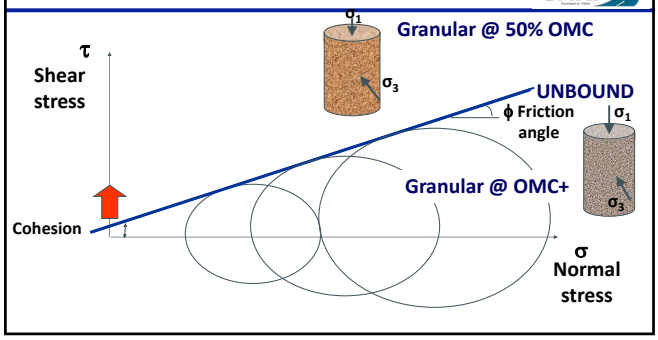
EFFECT OF MOISTURE REDUCTION (DRY BACK)



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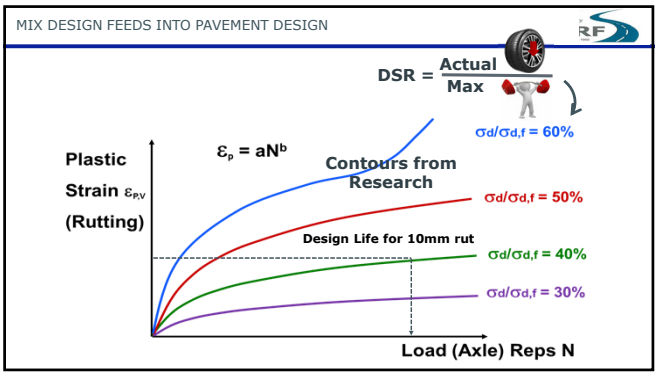
MIX DESIGN FEEDS INTO PAVEMENT DESIGN



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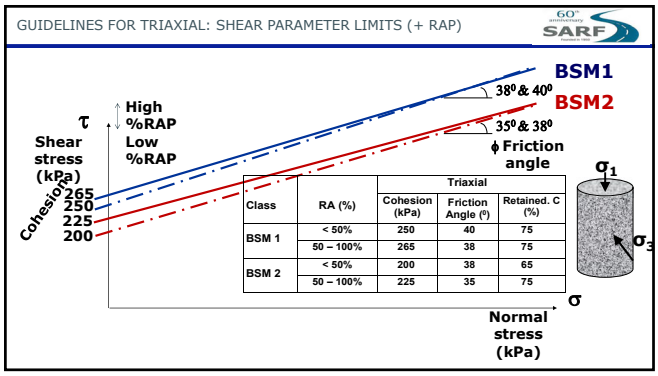
GUIDELINES FOR TRIAXIAL: SHEAR PARAMETER LIMITS (+ RAP)



Class	RA (%)	Triaxial Cohesion (kPa)	Triaxial Friction Angle (⁰)	Triaxial Retained. C (%)
BSM 1	< 50%	250	40	75
	50 – 100%	265	38	75
BSM 2	< 50%	200	38	65
	50 – 100%	225	35	75

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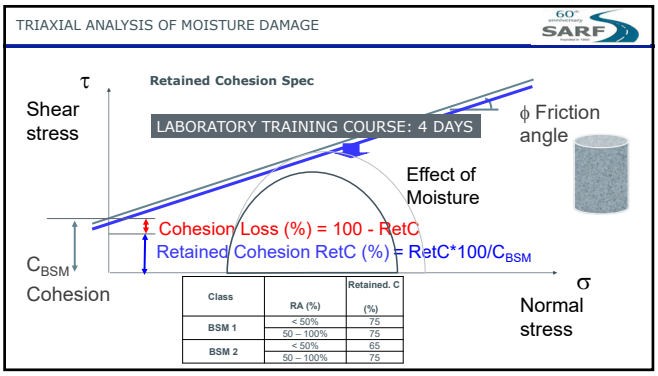
TRIAXIAL ANALYSIS OF MOISTURE DAMAGE



Class	RA (%)	Retained. C (%)
BSM 1	< 50%	75
	50 – 100%	75
BSM 2	< 50%	65
	50 – 100%	75

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SUMMARY (BASED ON > 350 MIX DESIGNS)

	BSM 1		BSM 2
Traffic:	High to Medium		Medium to Low
Aggregate:	CBR > 80%	Bearing Capacity	CBR > 40%
	GCS & RAP	Source	Crushed Gravel & some RAP
BSM mix:	High	C, ϕ and Ret.C	Moderate

Links to Structural Design

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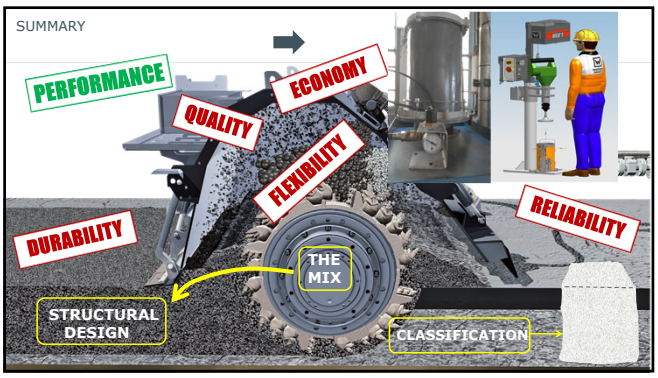
SUMMARY



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