Compaction of hot mix asphalt

Presented by John Onraet

1

“Paving is an art, compaction is a science”

Julian Wise

2

"The trouble with compaction <u>isn't</u> that there is no answer

. . . .

it's that there are so many answers !!!"

Julian Wise

3

But first, what is asphalt?

- A mixture of aggregates, bitumen and filler
- All heated up and mixed together
- Very precise "recipes" to achieve required design standards

4

…… or visually

Bitumen

Modifiers

✚

Crushed stone aggregates

✚

Filler

5

Where and how is it manufactured or "mixed"

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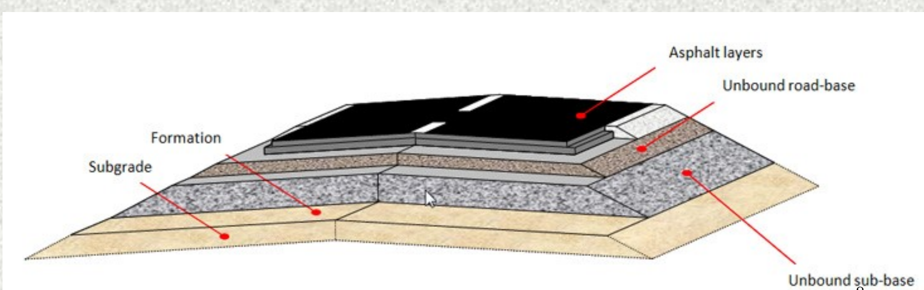
Three main parts

7

Where is it used?

- There are many uses for asphalt, but in Southern Africa it is mostly used in Transportation (e.g. roads, airport runways, taxiways, etc.)



8

Now off to the site……….

9

10

…………. and into the paver

11

And then…. the need for compaction

12

Why the need for compaction?

Achieving uniform density means:

- more rut resistance
- less permeability
- less oxidation
- less fatigue cracking
- more durable
- lasts longer

13

Consider the opposite, i.e. insufficient density

- Rutting
- Permeability and oxidation
- Premature cracking or raveling
- Shorter life

  Life of asphalt reduces by 10% for every 1% decrease in density (below 92%), i.e. 30% less life @ 90% than at 93% MTD

14

To summarise.....

1. Strength and stability of the mix

2. Closes passages through which water and air would otherwise penetrate

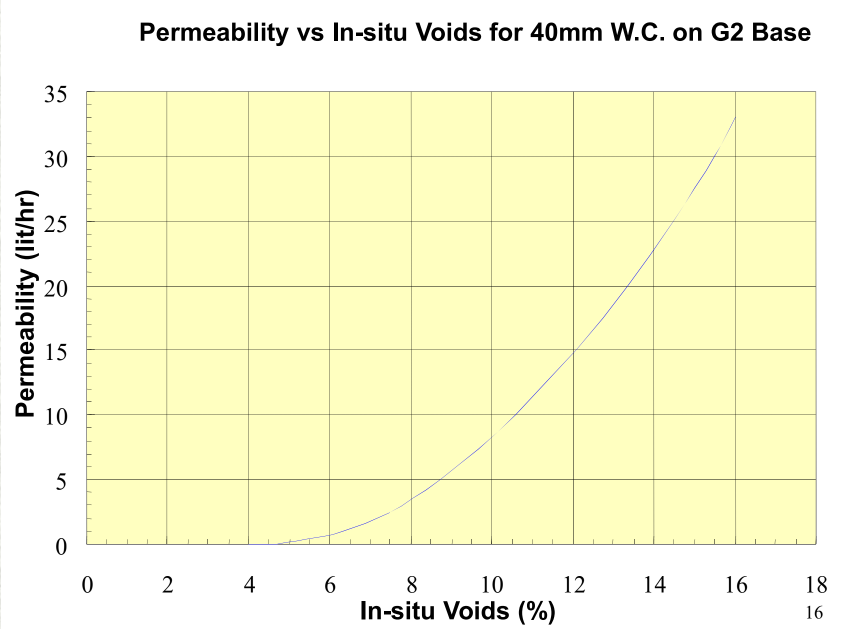
Voids in an *under* compacted mix tend to be interconnected. Air and water penetrate, oxidise the bitumen, causing it to turn brittle.

This is called “ageing”, and can lead to premature failure.

In an *over* compacted mix, there are insufficient voids.

Here the traffic may close these up completely, causing “flushing” or “bleeding”

15



16

Main risks to compaction

- Base compaction and preparation
- Difficult-to-compact mixes
- Rapid cooling (of thin layers)
- Rollers and rolling
- “Shoving”

17

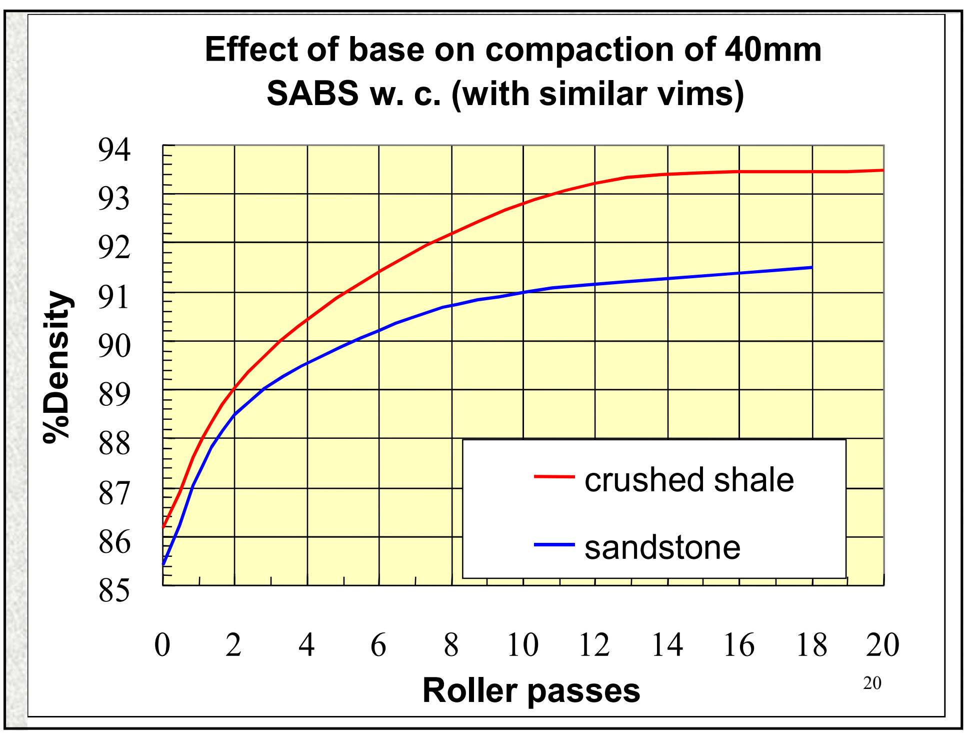
Base condition and surface

- The base should be an “anvil”
- Compactive effort must be absorbed by the asphalt, not the base!!

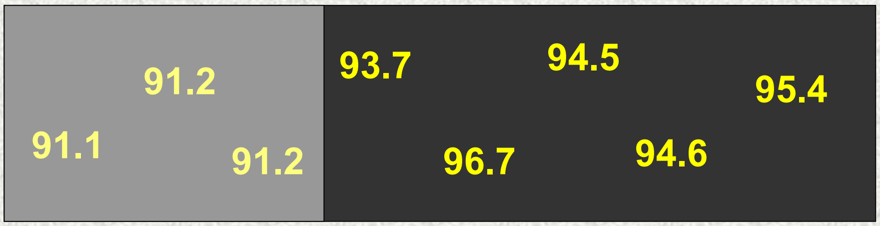
TIP: before paving, check for visible deflection and indentations in the base by proof rolling with a *pneumatic roller* or fully *laden water truck*.

18


19


Effect of base on compaction of 40mm
SABS w. c. (with similar vims)
%Density
94
93
92
91
90
89
88
87
86
85
0
2
4
6
8
10
12
14
16
18
20
Roller passes
crushed shale
sandstone
20

Guess where moisture content of base was too high ?



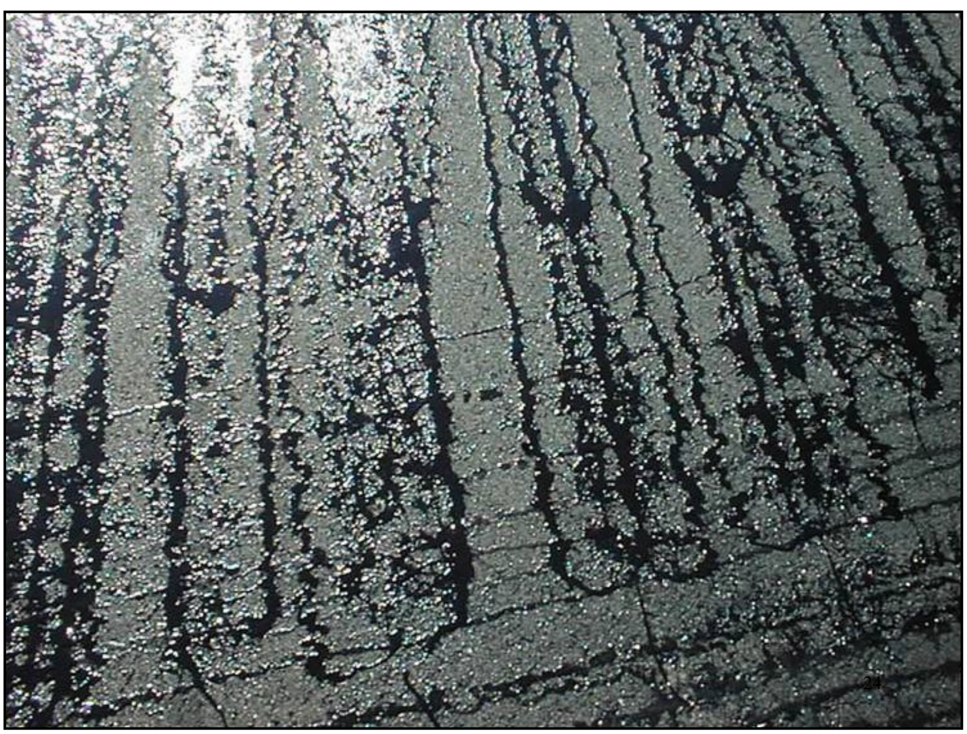
- 35 mm SABS w.c. on new base

21

What is Tack and why apply it?

- **Definition:**
  - Very light spray of diluted emulsion
- **Purpose?**
  - To provide a bond
- **Is it important?**
  - Bonded structure has longer life
  - "Always apply even on a new surface"
- ***Prime is not a tack !***

22



25

Difficult-to compact mixes

- Aggregate shape and texture
- Grading
- Voids in mix
- Filler/binder ratio
- Bitumen viscosity & film thickness
- Max stone size vs layer thickness

26

What else affects compaction?

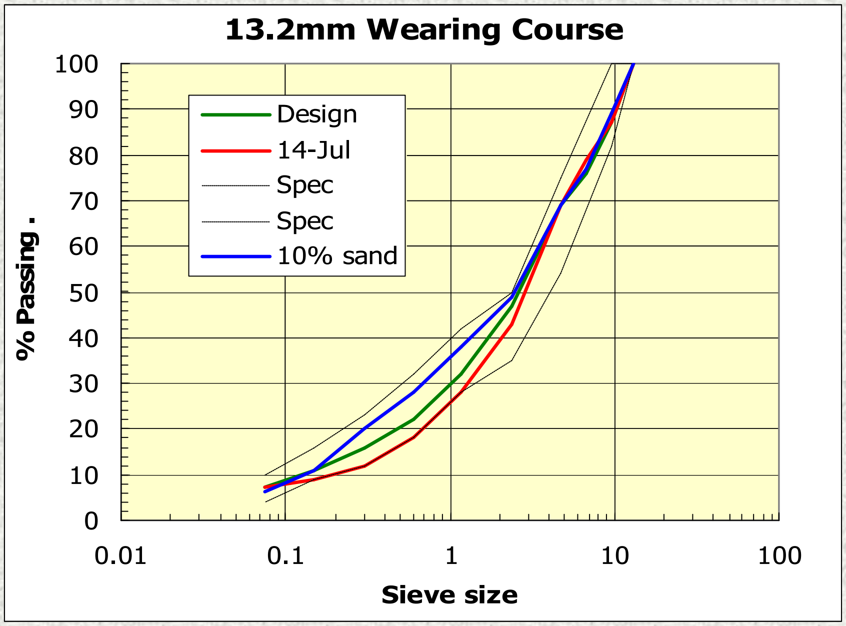
- Stiff rut-resistant mixes have high internal friction
- Needs greater compactive effort
- Hot bitumen is the only lubricant.
- Don't maximise stability at the cost of compactibility.
- If you aren't able to get density, the objective is defeated.
- Natural rounded sands can cause mix to become more tender and easier to compact.

27

- Grading can also affect whether a mix is harsh or tender, e.g. semi gap graded harder to compact than flat continuously graded
- Relationship between Vim's and achievable compaction
- Filler (0.075 fraction) content and type has a big impact on compactibility.
- Particularly if there is a high percentage of super-fines (< 10 microns).
- Bitumen viscosity and content also affect compactibility.
- Max size stone vs mat thickness affects the compactibility

28

How grading can affect it



Compare Marshall test (lab) to the site

Marshall:

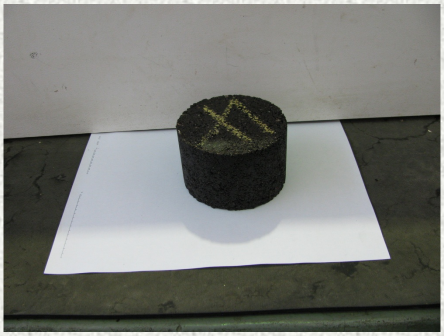
- 63.5mm cookie
- 140^0C
- Impact comp.
- Confined
- Vim's calculated

Site:

- 25mm to 100mm
- $140 – 80^0C$
- Never impact
- Low confinement
- Max. voids spec

30

Lab Briquette



Site Core

31

Lab

Site

32

Lab versus Site

- **MTD (Rice) = voidless mix = 2530**
- **Marshall = compacted mix = 2410**
- **Vim's = $\frac{\text{diff x 100}}{\text{Rice}}$ = 4.7%**

- **Colto spec = 97% Rice – Vim's (Vim's 4% to 6%)**
- **Some specs = 93% Rice (with Vim's at 4% to 5%)**

33

Site compaction

For thicker mats it's easy to achieve the minimum

but, **for thinner mats it's more difficult.**

Site experience shows that based on Marshall designs:

- It's easy to get >95% densities on thick BTB or LAMBS
- More difficult to get >92% on 40mm COLTO medium
- Even more difficult when COLTO medium is 35mm thick

34

Why then 97%?

- 97% Rice – Vim's is a relationship
- Thick mats it's easy
- Thin mats it's difficult
- Wearing courses are getting thinner
- But specified densities are rising
- Therefore greater effort required.
- But shorter compaction window available due to thinness.
- 93% Rice with 5.0% Vim's,VERY DIFFICULT unless thickness is at least 45mm

35

Checking compaction

36

Effect of filler/binder ratio

Colto Medium on G2

binder	filler	f/b	vims	dens.
5.2	8.1	1.56	4.6	90.8
5.5	7.3	1.33	4.5	93.6

37

Filler / binder ratio

38

Upper limit to filler/binder ratios

- There is a limit to be able to achieve compaction, and the ratio depends on:
  - Max size of aggregate
  - Layer
- Compactibility is also indicated by the Marshall Stability/Flow ratio

39

Bitumen

- Changes from lubricant to binder as it cools
- Compaction window ends at $\pm 80^0$C for 50/70 pen
- 10^0C difference between 35/50 & 50/70 pen for mixing & placing
- >Film thickness improves compactibility

40

Bitumen – penetration Grade

- 100 gram mass

- 5.0 seconds into bitumen

- At 25 deg Celsius

Measured in 1/10 mm

41

Layer thickness & max size stone

Thick mats compact easier than thin?

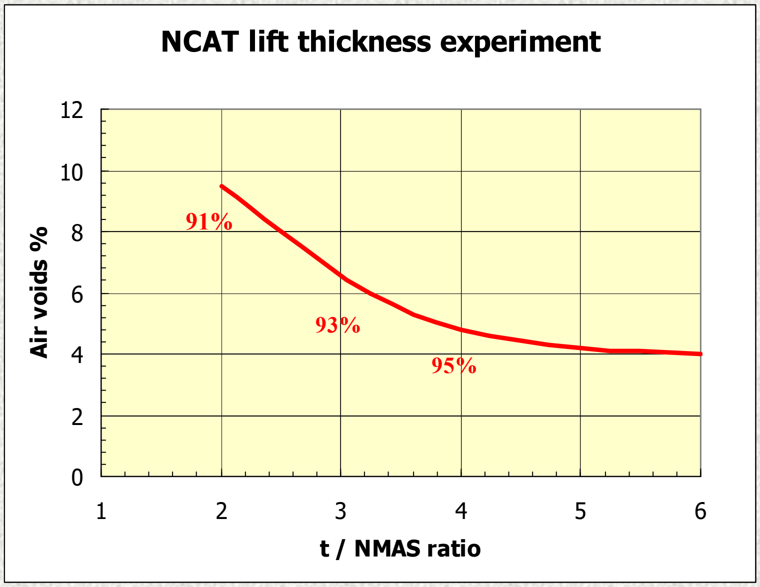
- Retain heat longer
- Less internal friction

What is recommended thickness?

- At least 3 x maximum aggregate size, **although……………….!**

42

Effect of thickness/aggregate ratio on density



43

CAPSA 07 paper recommendations

MAX mix mm	Min. dens. % Rice	Min. thickness mm
9.5	92.5	25
13.2	93	40
19.0	93	50
26.5	93	50
37.5	94	75

44

Paving temperatures

- Thin mats cool rapidly
  - Mixing & delivery temps critical
  - Big drop in temperature between truck and mat
  - Delivery temperature determines the start of the compaction window
- Thick mats cool slowly
- For 60/70 pen bitumen, upper limit for mixing = 175 deg.

45

- Typically when it is mixed at 160^{0}C, it arrives at 150^{0}C.
- But directly behind the paver it drops to 135^{0}C.
- Compaction should be completed by the time the mat cools to about 80^{0}C deg (never below 70^{0}C).

  "Compaction window" is the time available until this lower temperature is reached.
- Thin mats cool rapidly – thus mix at as high a temperature as possible
- e.g. 40mm mat: mix 160^{0}C, deliver 150^{0}C, start rolling 135^{0}C

46

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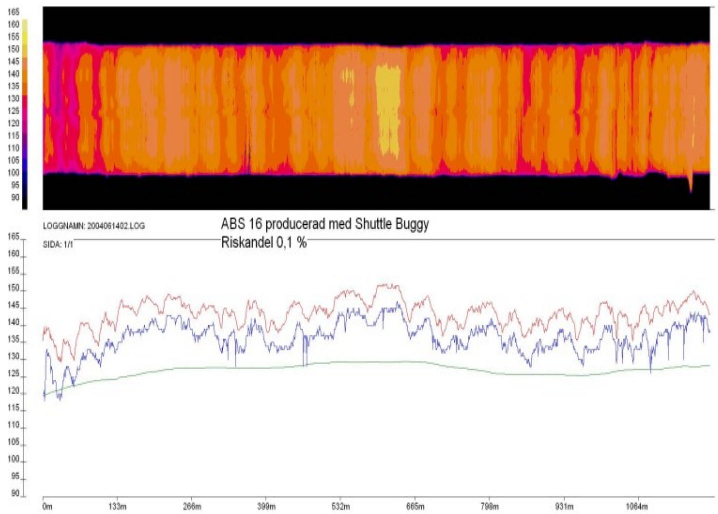
Temperature segregation



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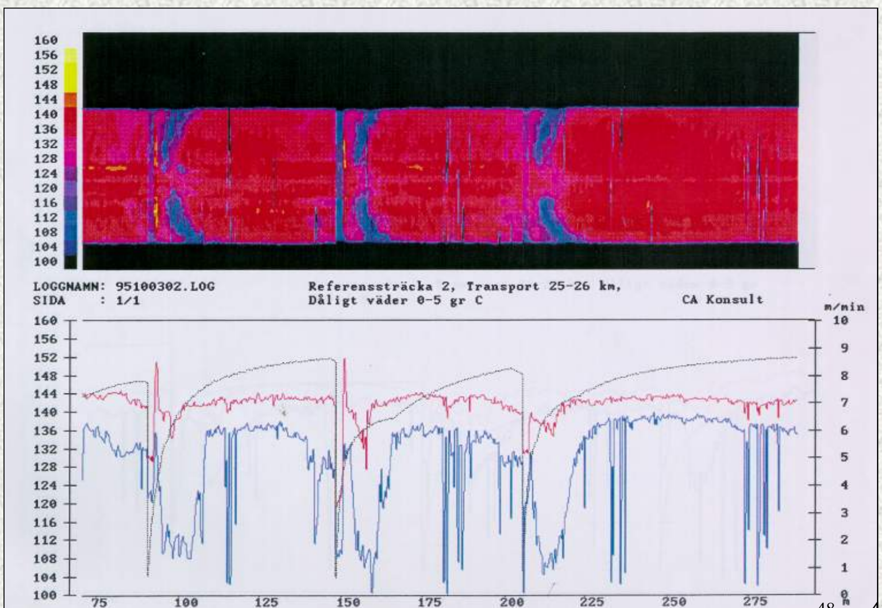
Temperature segregation



48 48

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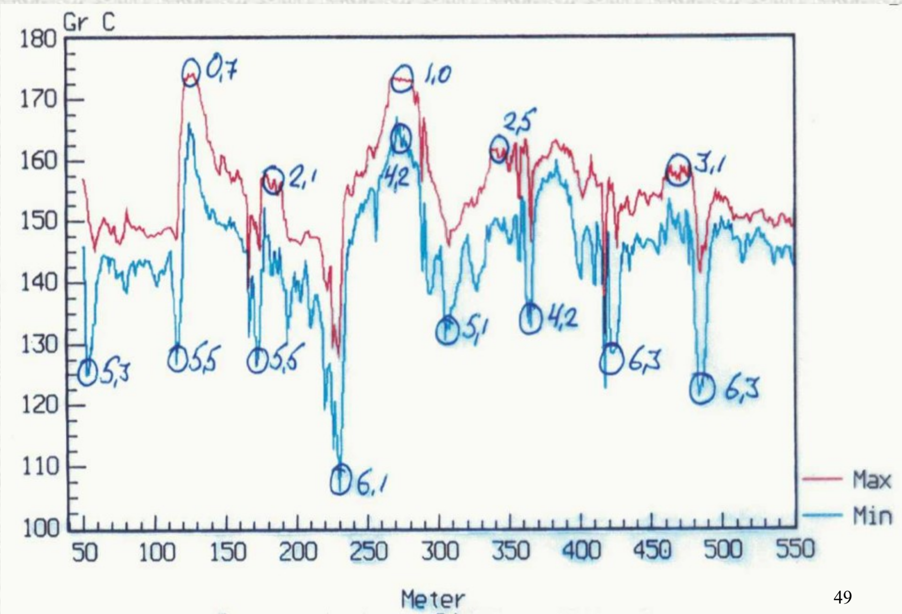
Air void content vs temperature



49

Weather conditions affect how fast the mat cools

Thinner the mat, the faster it cools:

- Base temperature
- Air temperature
- Wind speed
- Solar radiation
- Rain?

50

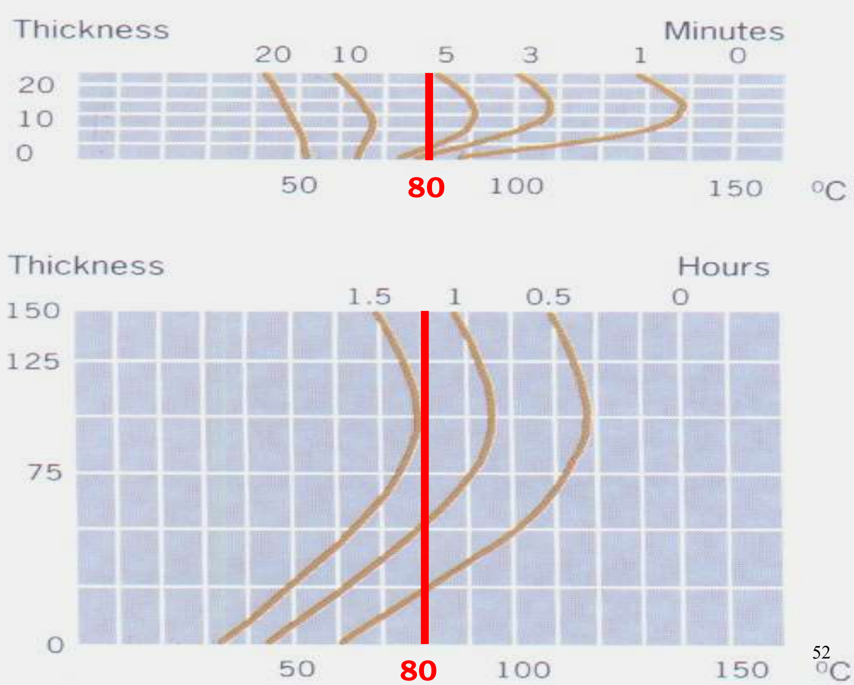
Cold wet weather

- Rapid cooling
- Rapid cooling + wet base
- Rapid cooling + trapped water

- Specifications do not address unsuitable weather conditions adequately.
- Usually no distinction is made for thin to thick layers or the different types of base.

SABITA MANUAL NO. 22 Adverse Weather

51



52

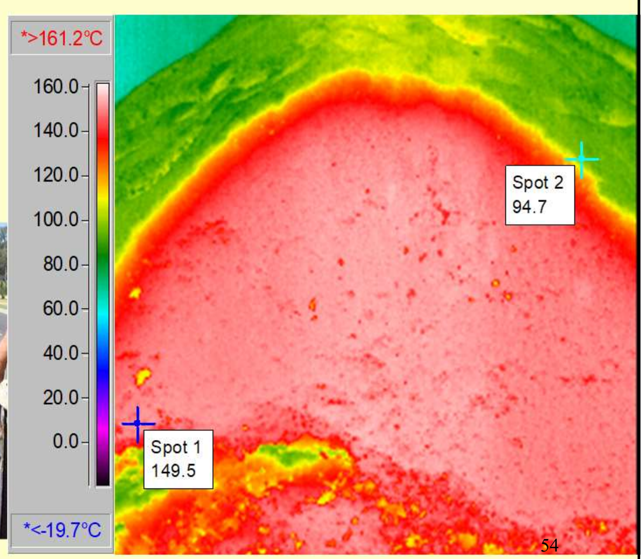
Some very basic observations

- Heat transfer from mat to base is greater than from mat to air – basic physics
- Surface is about 10 deg lower than inside the mat
- 20mm mat can easily cool from 150 to 80 deg in about 5 mins – we'll see this later
- 150mm mat cools fro 140 to 80 deg in > 1 hr

53

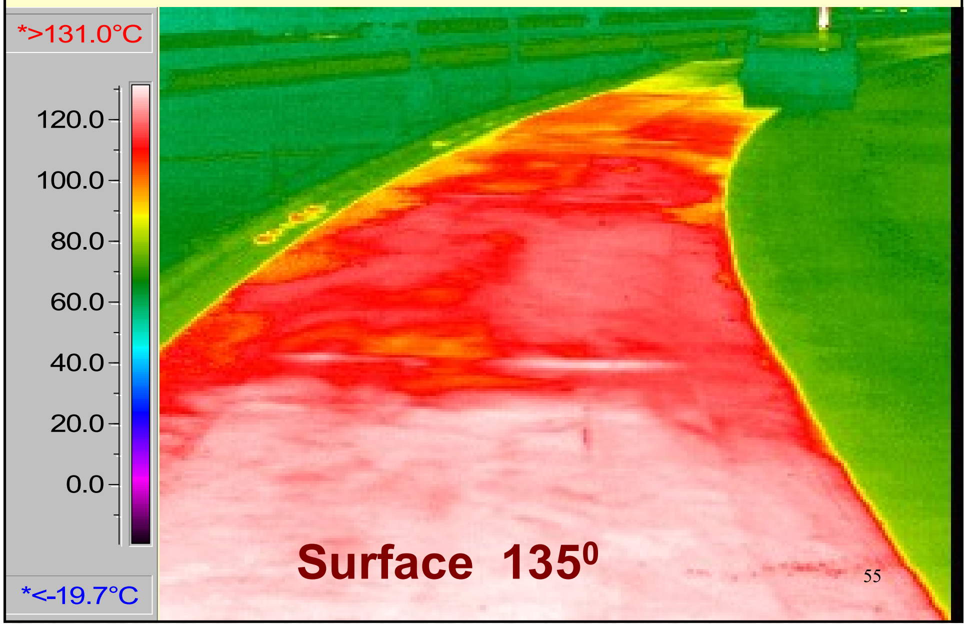
Temperature in truck

- Surface 90^0
- Inside 150^0

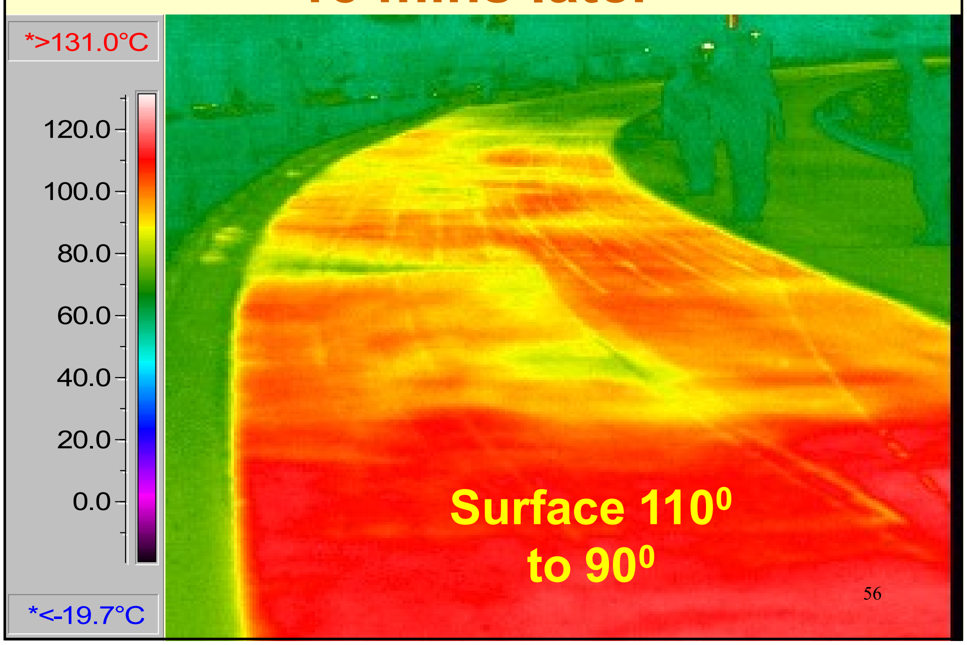


54

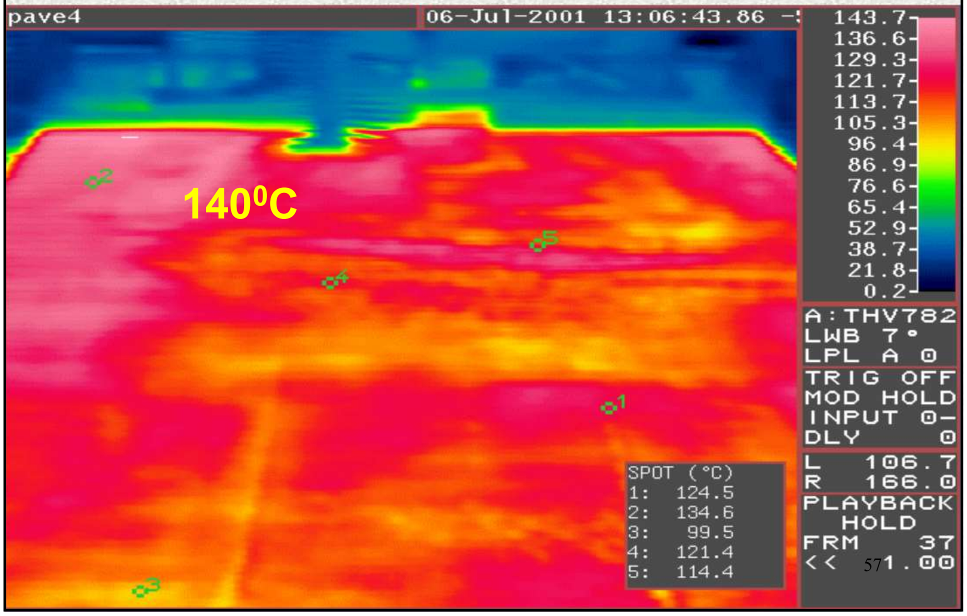
40mm Mat directly behind paver



15 mins later

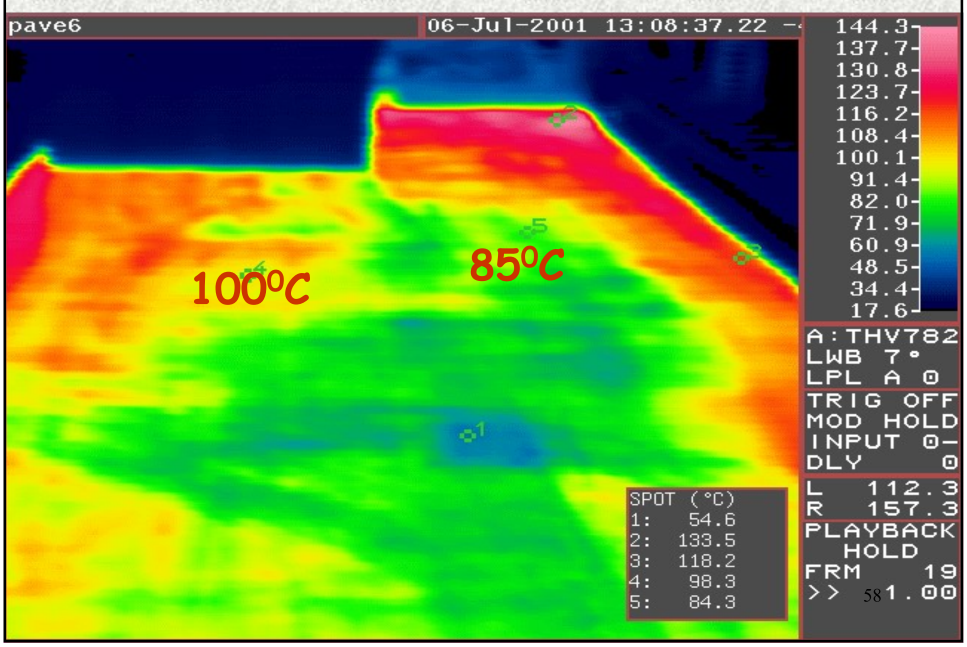


25mm mat directly behind paver



57

± 2 mins later



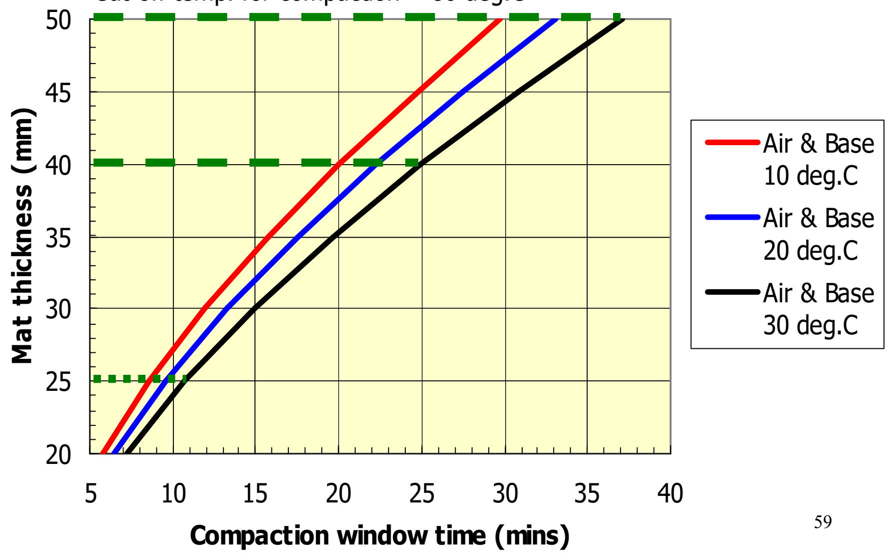
58

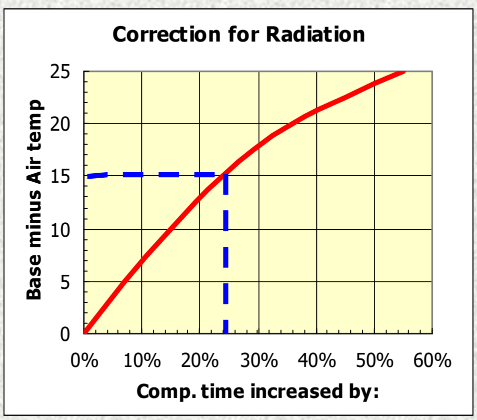
Cooling rate of C. G. HMA mats for:

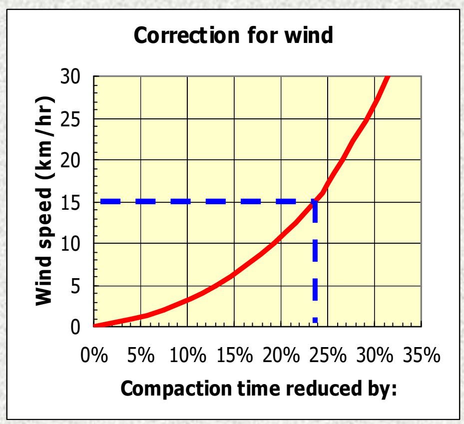
Wind speed = zero

Temp. of mat behind paver = 135 deg.C

Cut-off temp. for compaction = 80 deg.C







Recommended min compaction time required is:
- 10 mins for user-friendly mixes
- 13 to 14 mins for harsh mixes

Compaction windows in winter

Example:

air	base	wind	del.temp
13^0	18^0	20 k/h	150^0

Mat mm	Time to cool to 80^0 (mins)	OK?
25	7	NO
40	16	Tight
50	24	Yes

61

Suggestions to ease the problem

1. Increase thickness if possible

- better density and lower permeability
- protecting the base and producing a longer life road
- especially where handwork is necessary e.g. bell-mouths etc.

62

…or Alternatively:

2. Design the mix for reduced internal friction so that compaction is achieved with fewer passes

- increase bitumen for better lubrication and slightly lower voids (for light traffic roads)
- reduce maximum stone size e.g. from 13.2mm to 9.5mm

63

It's all about temperature!!

64

65

“To achieve compaction, the mat must go down, not sideways.”

66

Adhesion problems

- Smooth surface
- No tack
- Separation layer formed by
  - Dust, biscuit layer
  - Faulty prime or tack
- Old polished surface
- Steep slopes, crossfalls

67

68

Could also be due to:

- Tender mix overstressed
- Contamination of the bitumen
- Choice of rollers and number of passes

But, POOR ADHESION is the most common cause

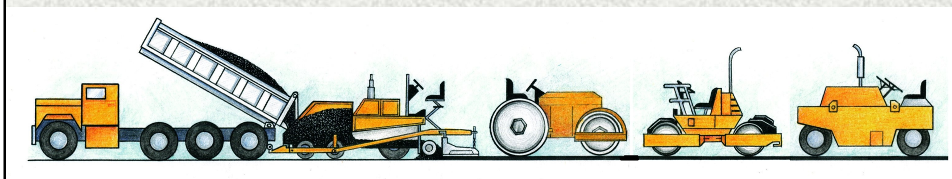
69

"Must remember" fundamentals

- Base must be an "anvil"
- Tack is very important
- Thin mats cool rapidly
- Thick mats compact easier than thin
- Min 3:1 ratio for
  mat thickness : nom max size agg….

70

Compaction equipment



- **Steel drum rollers**
  - **Static**
  - **Vibratory**
- **Pneumatic tyred rollers**

71

Four different types of compaction:

- Pressure – steel statics
- Vibration – tandem vibratory
- Manipulation – pneumatics
- Impact

72

3 Phases of rolling

- Breakdown
  - Achieves most compaction
- Intermediate
  - Adds further compaction
  - Consistent overall compaction
  - Closes surface
- Finish
  - Irons out surface

73

At what temp range do I use

- Steel static ?
  - When mat is hottest, >120^0
- Vibratory ?
  - When mat is hottest, and down to 80^0
- PTR ?
  - Best from 120^0 to 100^0

74

Static steel drum rollers

75

Static rollers

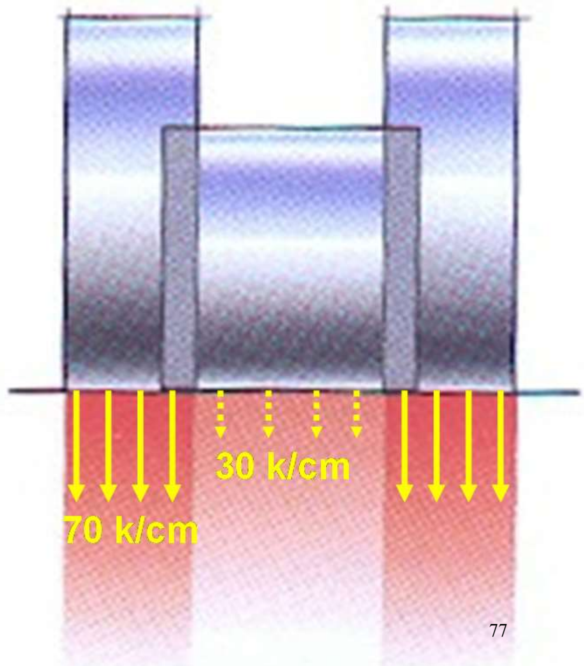
- Use static dead weight and squeeze
- Good lubrication needed
- Compact from top down

Compaction influenced by:

- Drum diameter (1500mm)
- Drum loading (60 to 80kg/cm)

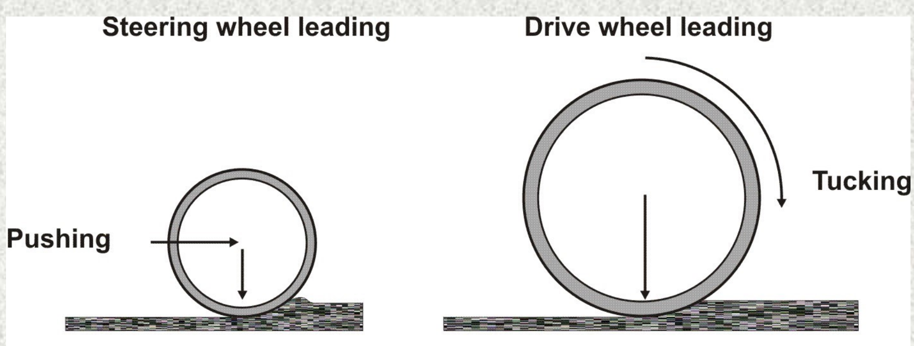
76

Drum loading of a 3 wheel roller



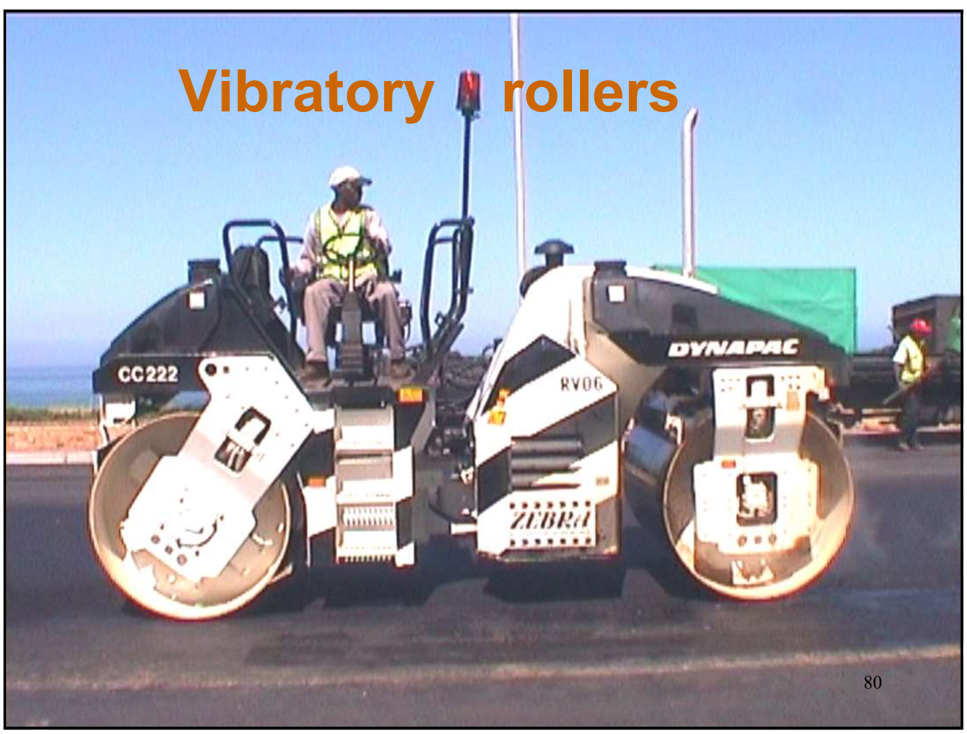
77

Rolling direction for 3 wheelers



78


DYNAPAC
DYNAPAC
79


Vibratory rollers
CC222
DYNAPAC
RV06
ZEBRA
80

81

Vibratory rollers

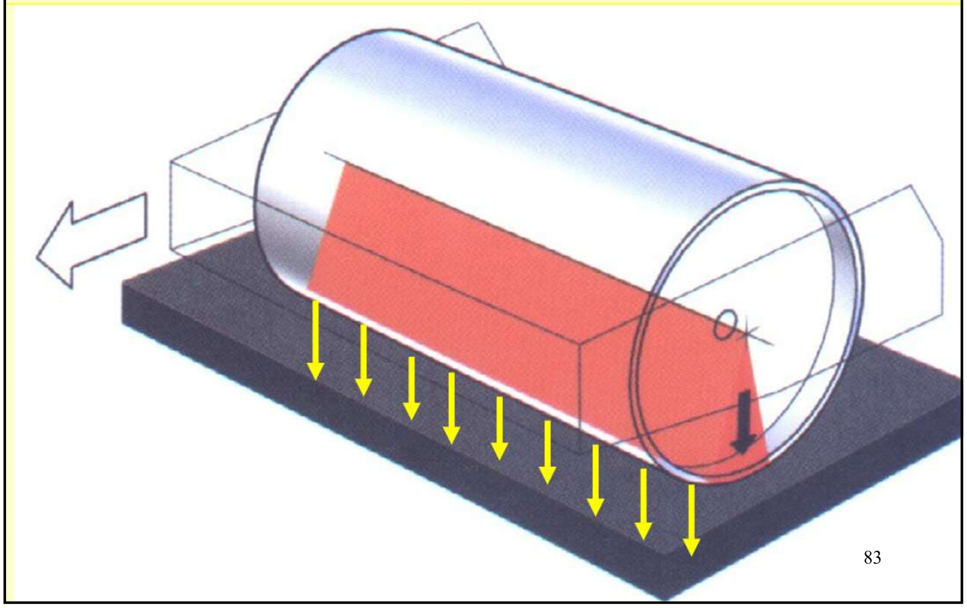
- Rapid succession of impacts
- Reduces internal friction
- Compacts from bottom up

Compaction effort influenced by:

- Drum loading
- Amplitude & frequency
- Speed
- Centrifugal force ?

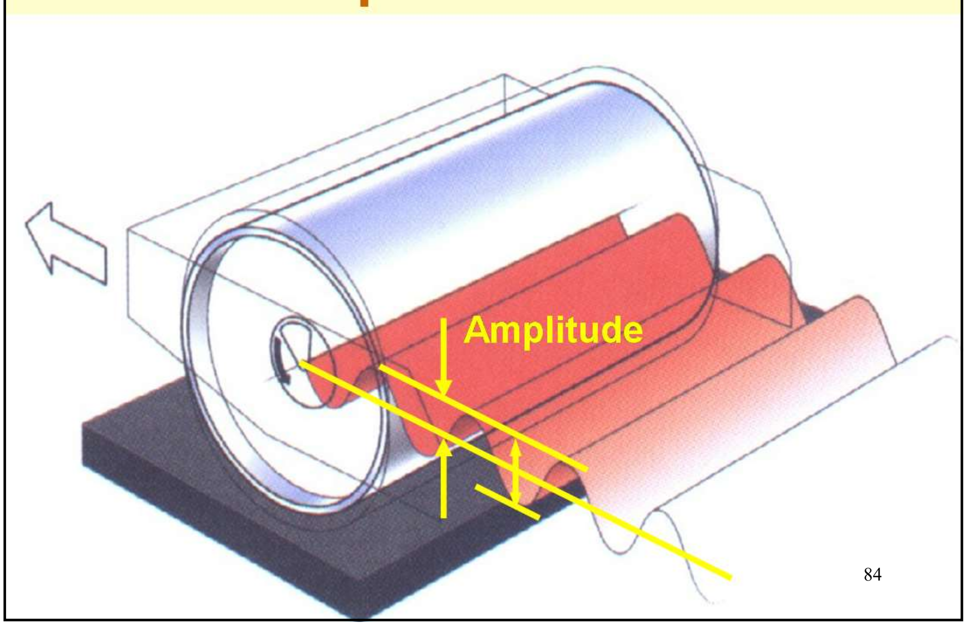
82

Drum loading – kg/cm



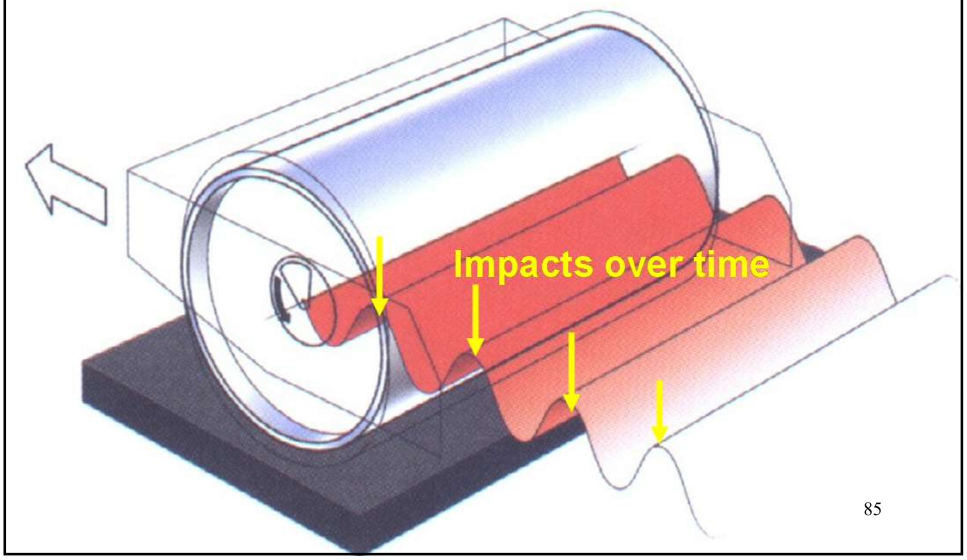
83

Amplitude - mm



84

Frequency – vpm (hz)



85

Rolling speed

- **Speed determines impact spacing**
- **Impact spacing depends on**
  - **Frequency + amplitude**
  - **Drum diameter**

Recommended impact spacing for different drum diameters

- •25mm, 900 to 1300 diameter
- •30mm, 1300 to 1400
- •35mm, > 1400mm

86

- Calculation of speed is then simple = frequency x impact spacing

i.e. Speed = 3000vpm x 25mm

= 75m/min

- Correct speed critical – why?
- Normally works out at about 5 km/hr

87

- Centrifugal force can be misleading as a guide to compactive effort
  CF = mass x ampl x freq^2.
  Reduce freq & CF reduces
  but reduce speed so that impacts are still 30mm apart
  – back to same compactive effort

Speed too slow:

- Excessive reduction in internal friction – mat starts shoving

Speed too fast:

- Impacts too far apart – not enough reduction in internal friction

88

Typical vibrating rollers

Roller mass tons	Drum loading kg/cm	Frequency v.p.m.	Amplitude mm
10	31	3000	0.4 & 0.8
7	25	4250 / 3000	0.3 & 0.7
2.5	13	4000	0.3

89

- Big difference in drum loading between the 3 rollers
- Compare with drum loading of steel static roller (75 kg/cm)
- Compactive effort only effective when they are vibrating - don't use as static
- Don't expect good compaction from 2.5 ton
- Low amplitude for most wearing course mats.
- Can increase amplitude for thicker mats (say 75mm and greater) or use a combination of high followed by low.

90

Oscillatory roller

91

Oscillatory roller

92


EVIB 200 MN qm
0 50 150 250 350
0,3 mm
104 °C
3,7 km/h
43 Hz
F1
F2
F3
F4
F5
F6
F7
F8
F9
F10
F11
F12
F13
F14
A
B
C
ESC
P1
P2
P3
93


ZEBRA
HAMM
ZEBRA
HAMM
Pneumatic rollers
94

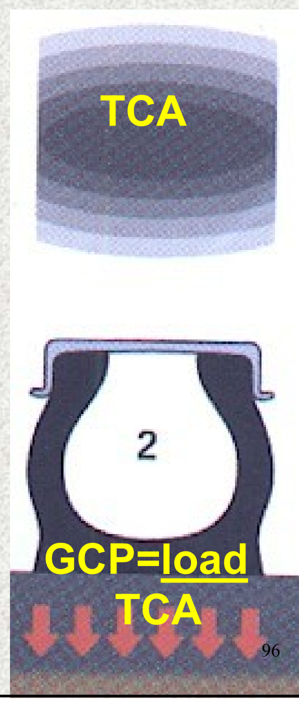
Pneumatic rollers

- Manipulates and kneads
- Rearranges particles differently
- Seals the surface well

- Compaction effort influenced by:
- Wheel load
- Ground contact pressure (G.C.P.)
  - Tyre pressure
  - Tyre contact area
- Speed

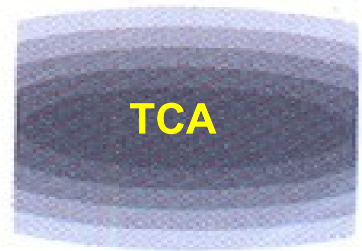
95

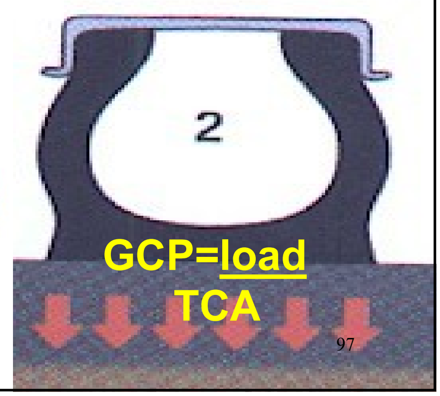
200 mm tyres



96

300 mm tyres





97

Typical PTR's

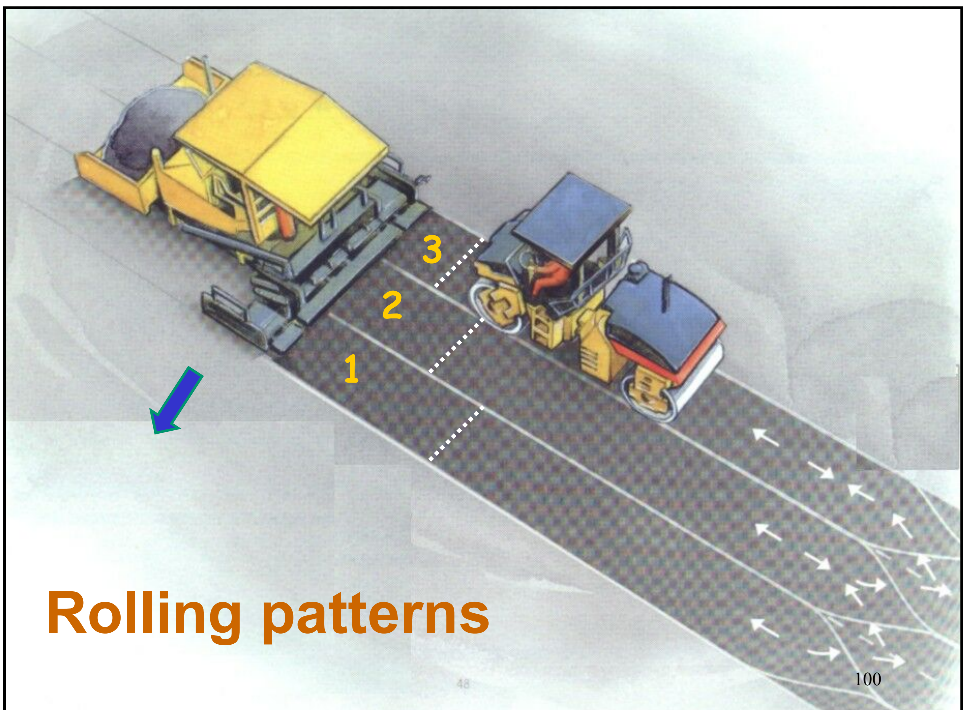
Tyre width mm	Wheel load kg	Tyre press kg/cm²	G.C.P. kg/cm²	T.C.A. cm²
200	1400	7.0	5.7	240
300	2500	6.3	5.7	430

98

PTR's – where, when, how

- OK for breakdown & intermediate
  - but if used as breakdown --?
- Best from 120⁰C down
- Work better on tender mix than steel drums
- Speed critical – roll slowly
- 5.6 to 6.2 kg/cm² G.C.P.

99



Rolling patterns

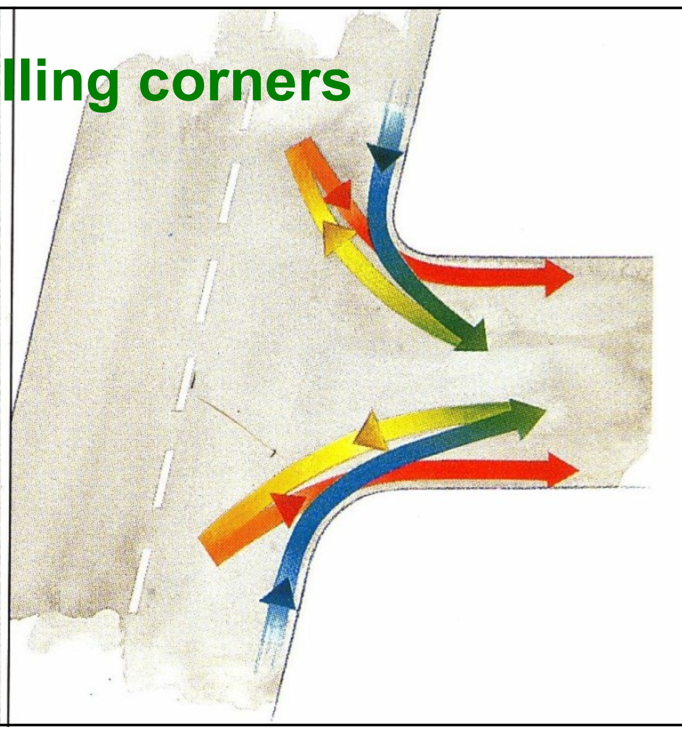
100

Length of b/down rolling zone

Mat thickness	25	25	40	40	50	50
Mat width	3.2	4.8	4.8	6.0	4.8	6.0
Roller lanes	2	3	3	4	3	4
Passes reqd.	6	6	8	8	8	8
B/down time	5	5	11	11	17	17
Rolling zone m	26	17	30	23	45	34

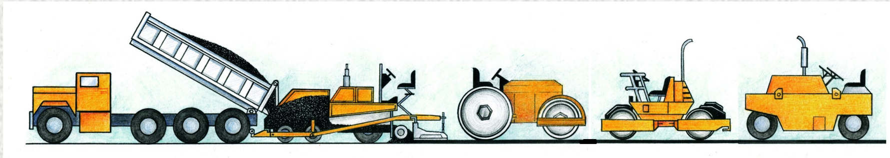
101

Rolling corners



102

Roller combinations



- Thin mats – 25 to 40mm
  - in cold weather
- Thick mats – 60 to 100mm
- Static rolling
- UTFC / Popcorn
- In shoving situations

103

General good practise

- Rollers should not
  - Turn on hot mat
  - Stand still on hot mat
  - Vibrate standing still
  - Start or stop suddenly
  - Spray excessive water on drums

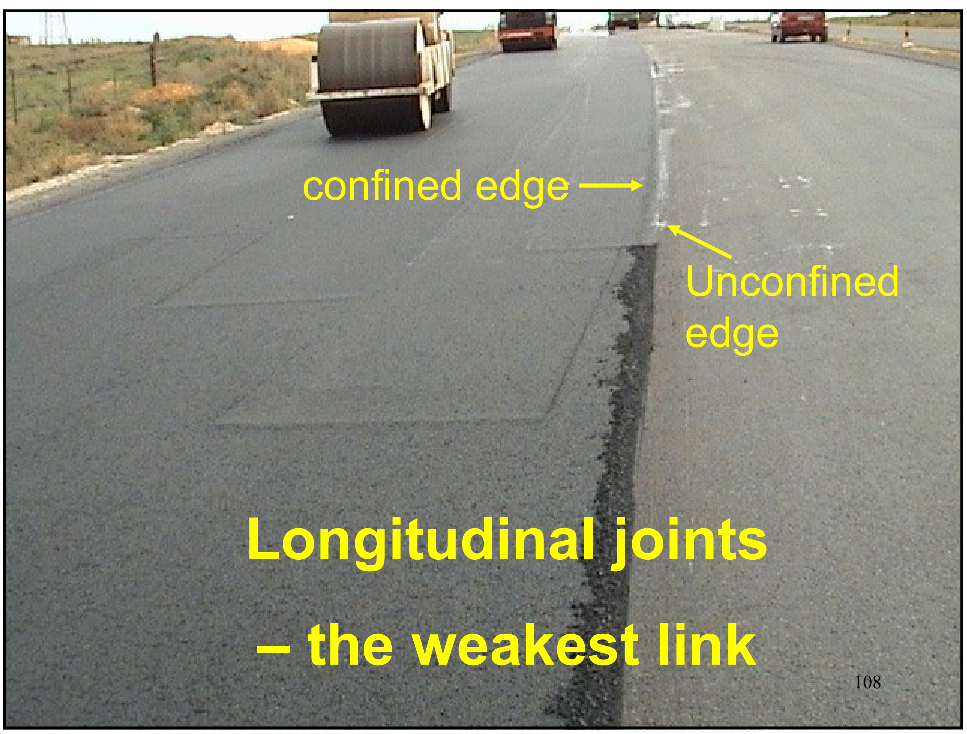
  (Rideability)
- Rollers should
  - Roll "aggressively"
  - Roll as a team

104

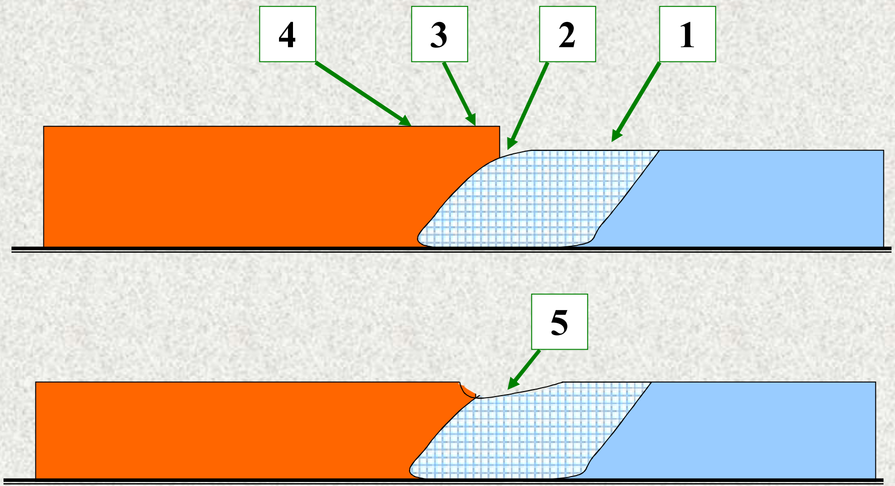

105


Have a standby roller
106


Longitudinal joints
Transverse joints
107


confined edge
Unconfined edge
Longitudinal joints
– the weakest link
108

Challenges of a longitudinal joint

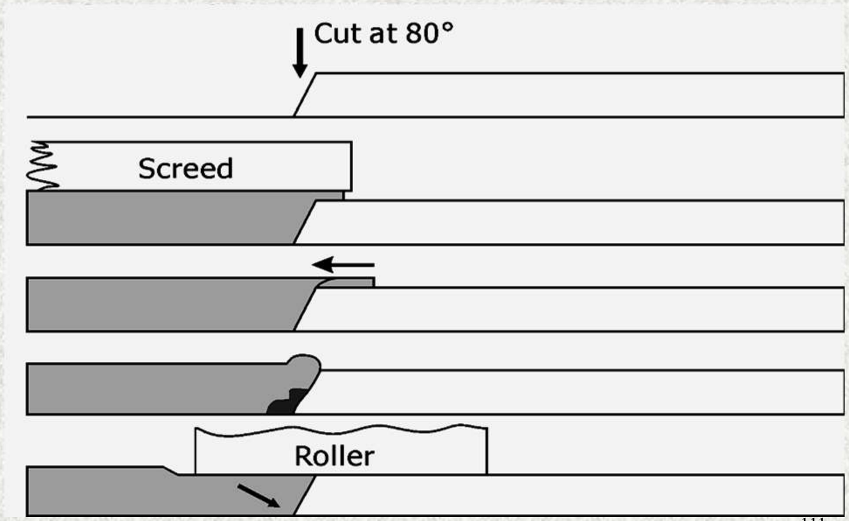


109

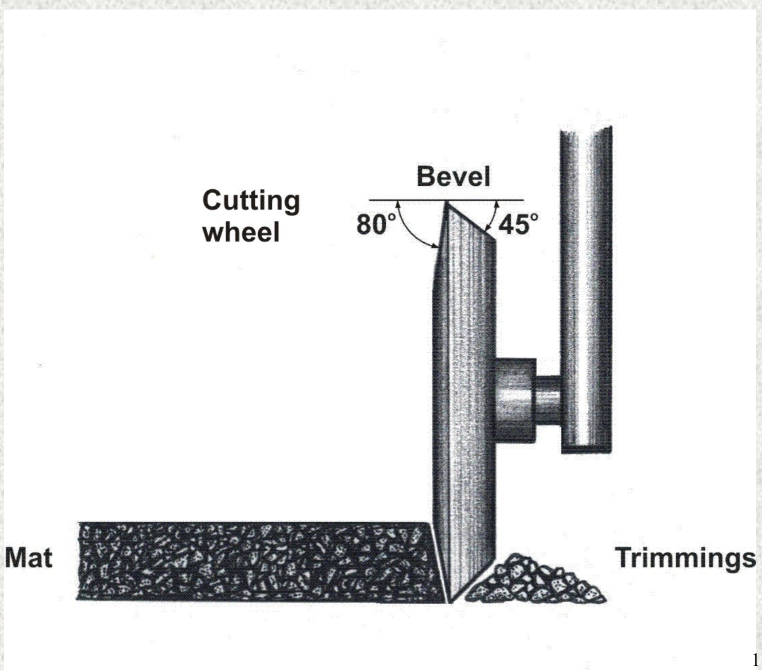
MTV – Transverse joints

110

Joint construction



111

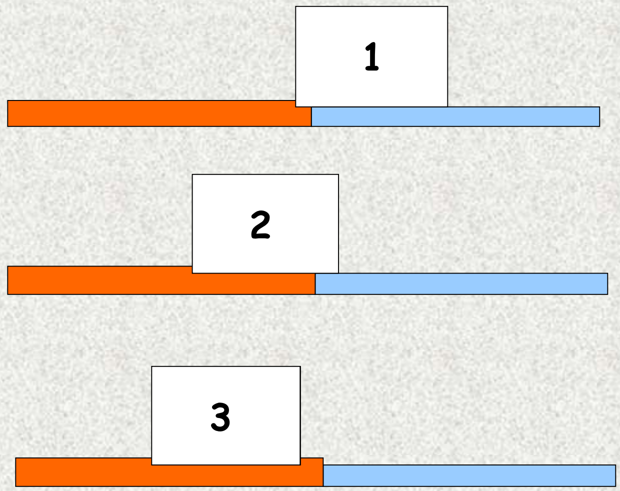


112


NEW LOGO. NICE.
113

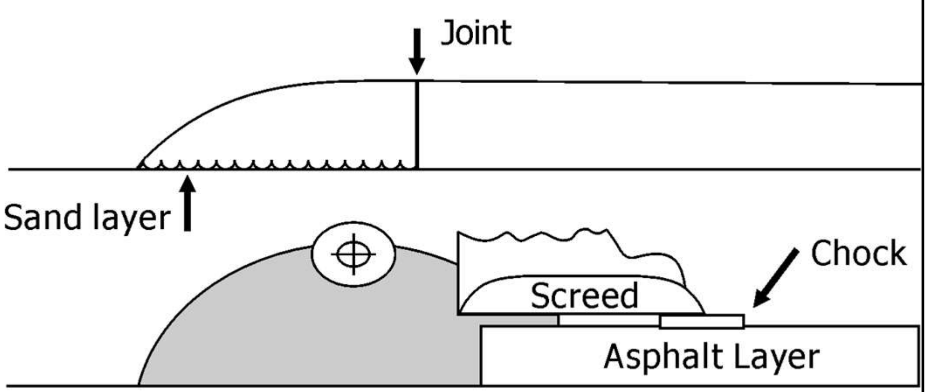

bumping the joint
114

Three methods to roll longitudinal joints



115

Transverse joints




Check mat for best position
117


Cut joint
-square
or angle
118


Clean and level
119


Tack
120


CONSTR
VEHICLE
Start paving on starter blocks
121


VEHICLE
“Bumped” joint ready for rolling !
122

Priorities for rideability?

- Flat, even base
- Constant head of material in front of screed
- Constant speed; no stop/start
- Automatic level control on
- Steel drum breakdown roller
- Too much adjustment of tow points?
- Loss of traction of paver caused by?

123

Continued …….

- What asphalt trucks do on the mat?
- Something wrong with the paver?
- Rollers, correct type and method?
- The type of asphalt mix
- The mat thickness and underlying conditions?
- Joints, where and how many?
- Is there a lot of handwork?

124

The significance of good rideability

Not only for the comfort of the driver!

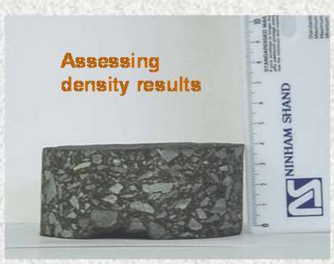
- Protection of goods in delivery vehicles and reduced maintenance cost of the vehicles themselves
- The lifespan of the road is significantly increased if the rideability is good
- New rideability specs have penalty / reward clauses based on profilometer readings and calculation of International Rideability Index (IRI, mm/m or m/km)
- Europe is moving away from IRI to WLP (weighted longitudinal profile) that takes into account different speeds

125

Asphalt Density Assessment

Density is determined from either:

- Cores – 100mm diameter for mixes with NMAS < 26mm 150mm for larger NMAS.
- Troxler (radio active density testing equipment)



126

Cores versus troxler ....

Cores are accurate, but are from a tiny area of mat

Troxler is useful conjunction with cores

Cores must be:

- Positioned representatively
- Drilled at a low surface temperature
- Drilled with skill and good equipment
- Examined for defects
- Cleaned, cut if necessary, and prepared well
- Tested accurately
- Assessed with good engineering judgement

NOTE: Cores across joints don't tell a clear story!
Cores each side of a joint do.....

127

Rolled in Chips

- Harmful to a thin layer
- Increases permeability
  - Water
  - Air
- Cools the mat
  - 15^0 Celsius at 13 kg/m^2
  - Rapid temperature reduction
- Reduces the compaction window

128

And now ……..

129

130

131