

Compaction of hot mix asphalt



Presented by **John Onraet**

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**“Paving is an art,
compaction is a
science”**

Julian Wise

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**“The trouble with compaction
isn’t that there is no answer**

.....

**it’s that there are so many
answers !!!”**

Julian Wise



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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



Filler



Crushed stone aggregates

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Where and how is it
manufactured or “mixed”



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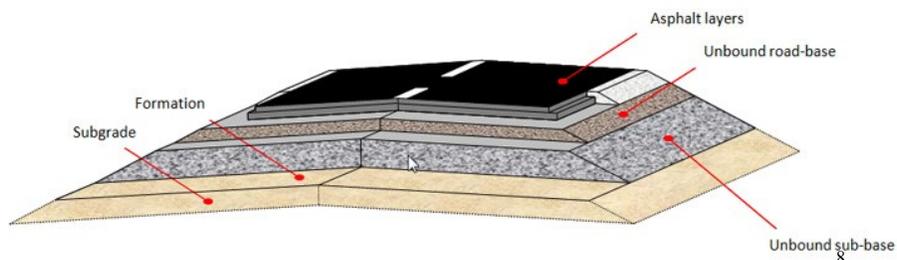
Three main parts



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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.)



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Now off to the site.....



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..... and into the paver



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And then.... the need for compaction



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Why the need for compaction?

Achieving uniform density means:

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

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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

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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.

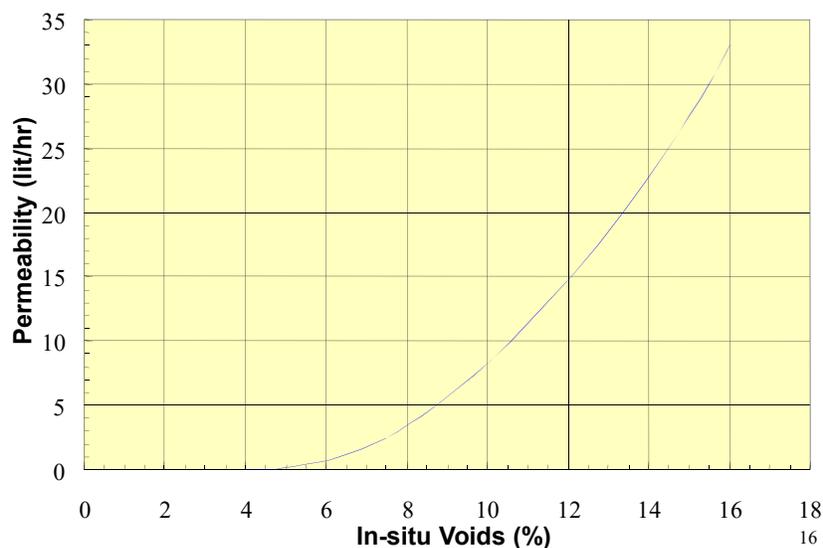
This is called “ageing”, and can lead to premature failure.

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

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

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Permeability vs In-situ Voids for 40mm W.C. on G2 Base



Main risks to compaction

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

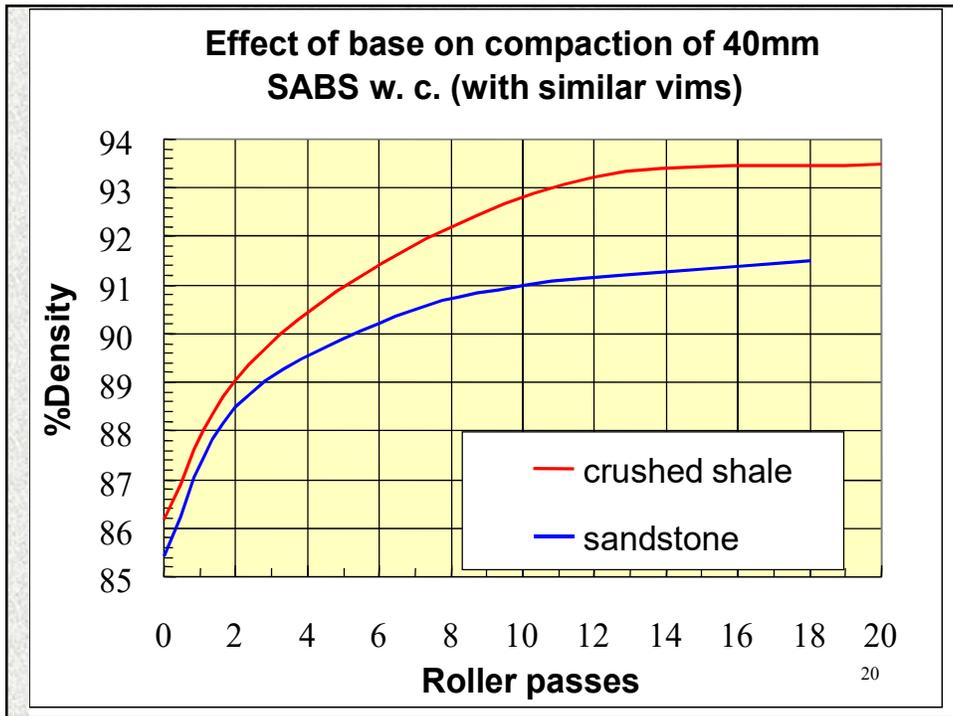
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Base condition and surface

- 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*.

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Guess where moisture content of base was too high ?

	91.2	93.7	94.5	95.4
91.1	91.2	96.7	94.6	

- 35 mm SABS w.c. on new base

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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 !***

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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**

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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.**

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- **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 Vm'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**

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How grading can affect it



Compare Marshall test (lab) to the site

Marshall:

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

Site:

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

Lab Briquette



Site Core



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Lab



Site



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Lab versus Site

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

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

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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

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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

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Filler / binder ratio



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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

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Bitumen

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

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Bitumen – penetration Grade



- 100 gram mass
- 5.0 seconds into bitumen
- At 25 deg Celsius

Measured in 1/10 mm

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Layer thickness & max size stone

Thick mats compact easier than thin?

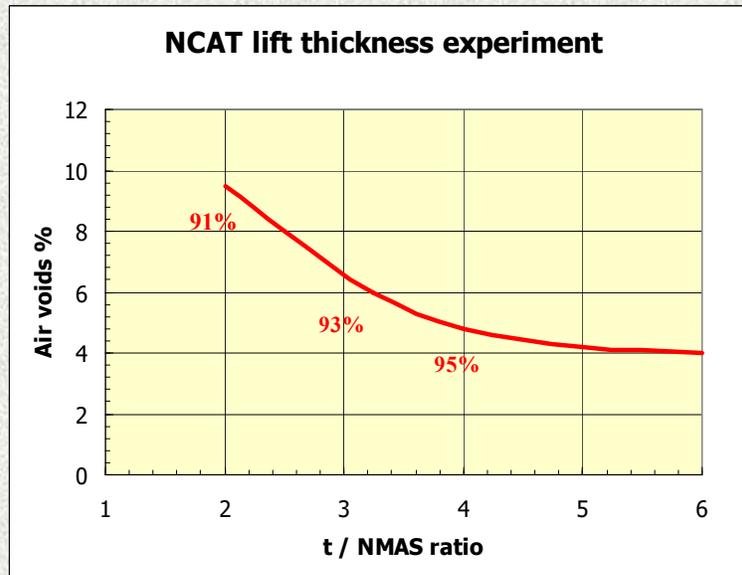
- Retain heat longer
- Less internal friction

What is recommended thickness?

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

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Effect of thickness/aggregate ratio on density



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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

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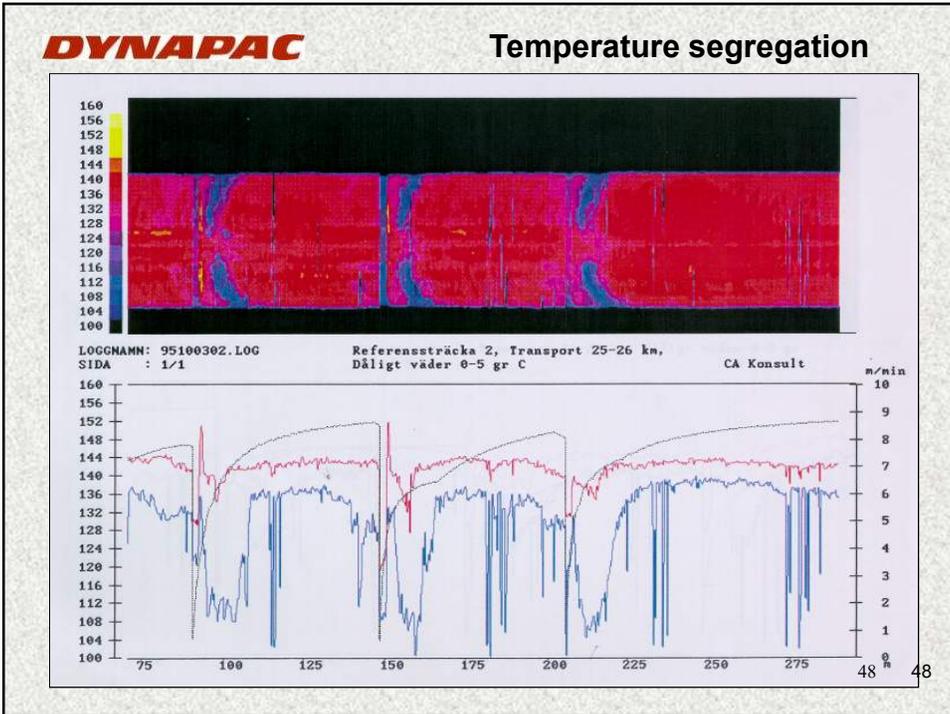
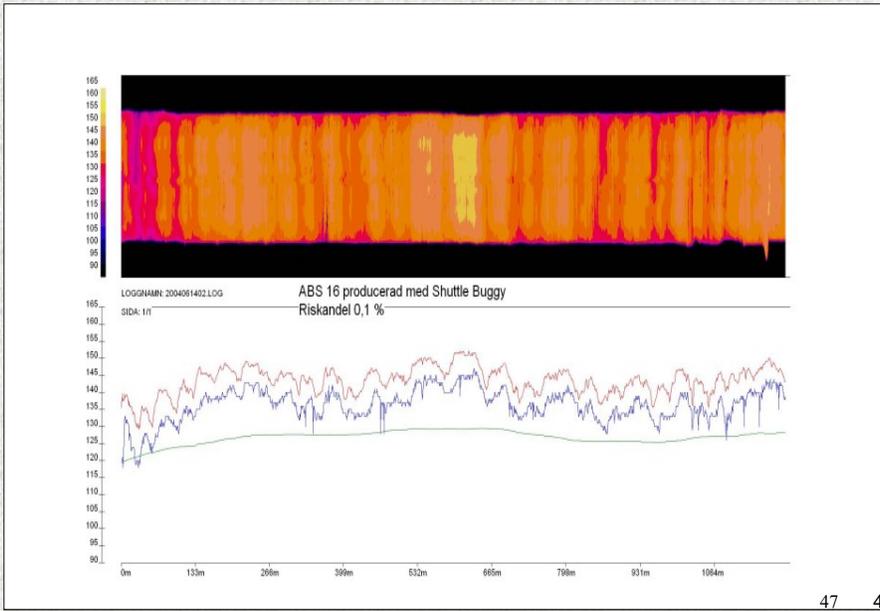
Paving temperatures

- **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.**

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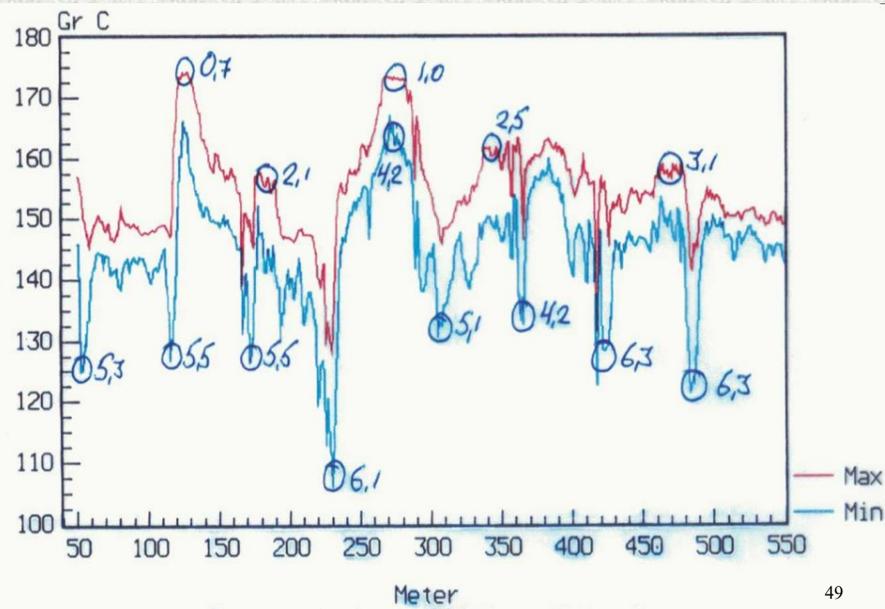
- **Typically when it is mixed at 160°C, it arrives at 150°C.**
- **But directly behind the paver it drops to 135°C.**
- **Compaction should be completed by the time the mat cools to about 80°C deg (never below 70°C).**
“Compaction window” is the time available until this lower temperature is reached.
- **Thin mats cool rapidly – thus mix at as high a temperature as possible**
- **e.g. 40mm mat: mix 160°C, deliver 150°C, start rolling 135°C**

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DYNAPAC

Air void content vs temperature



Weather conditions affect how fast the mat cools

Thinner the mat, the faster it cools:

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

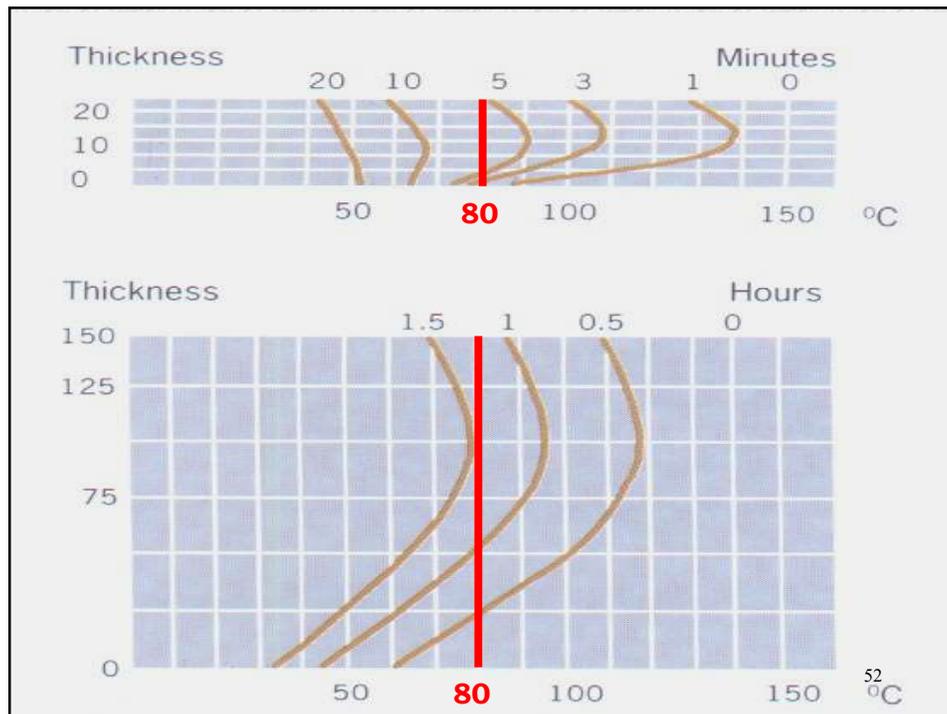
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Cold wet weather

- 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

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Some very basic observations

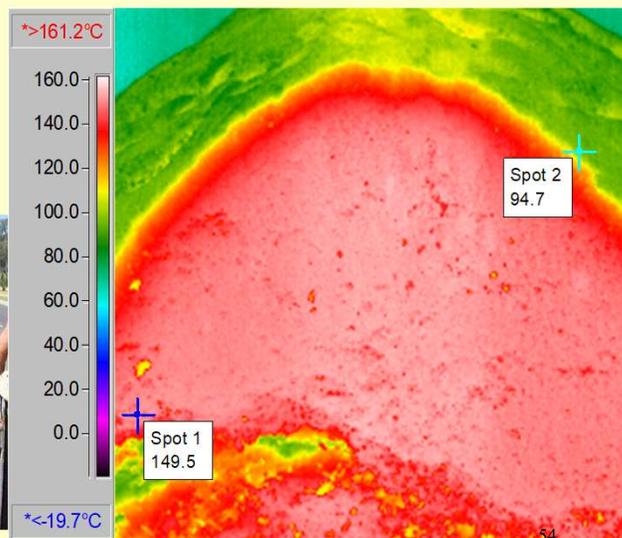
- Heat transfer from mat to base is greater than from mat to air – basic physics
- Surface is about 10 deg lower than inside the mat
- 20mm mat can easily cool from 150 to 80 deg in about 5 mins – we'll see this later
- 150mm mat cools from 140 to 80 deg in > 1 hr

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Temperature in truck

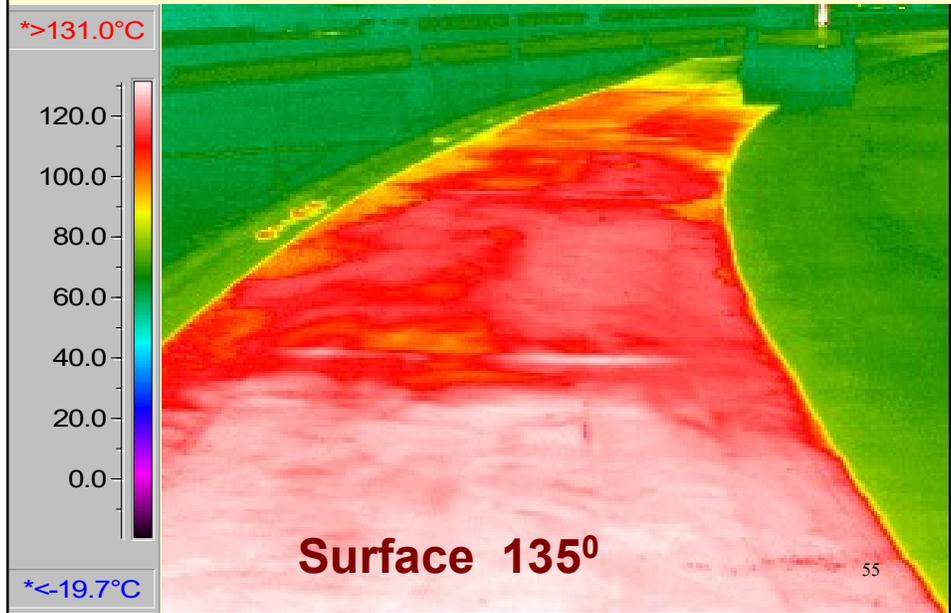
➤ Surface 90°

➤ Inside 150°

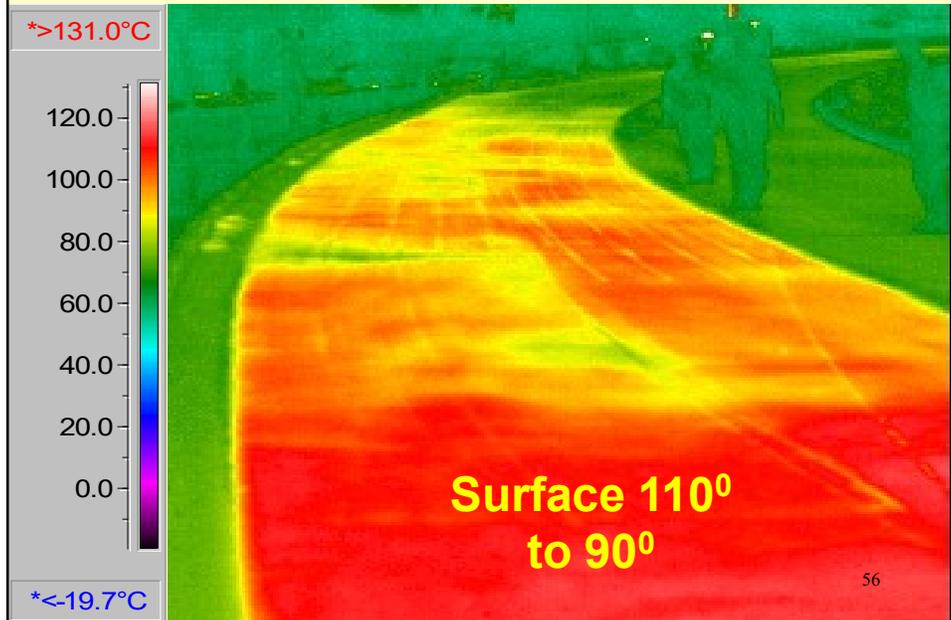


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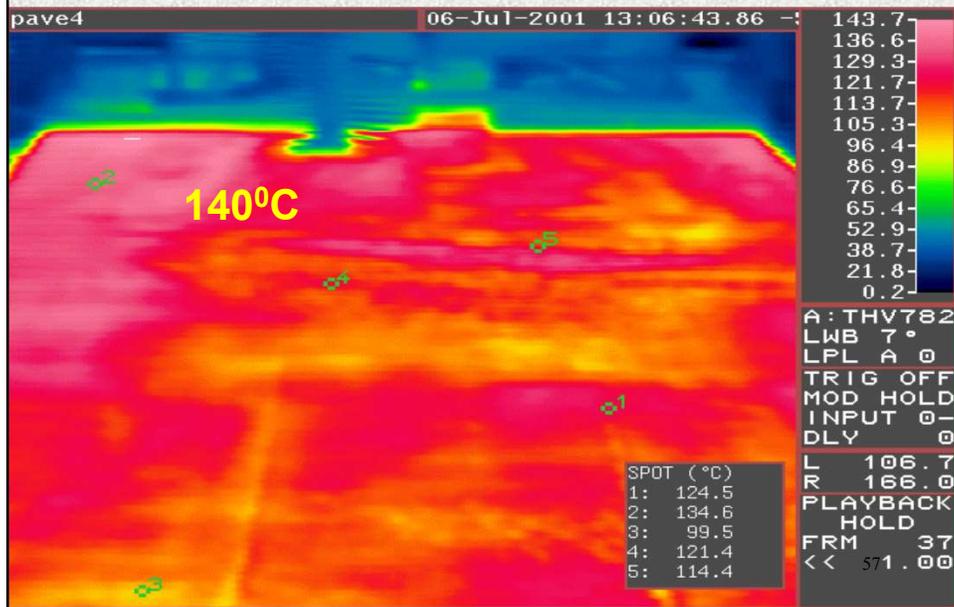
40mm Mat directly behind paver



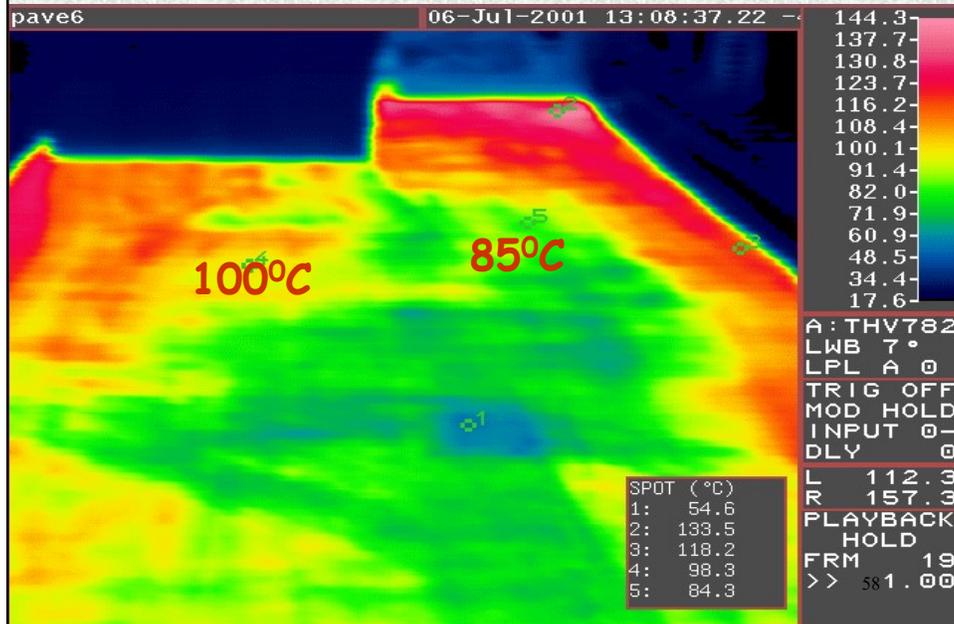
15 mins later



25mm mat directly behind paver

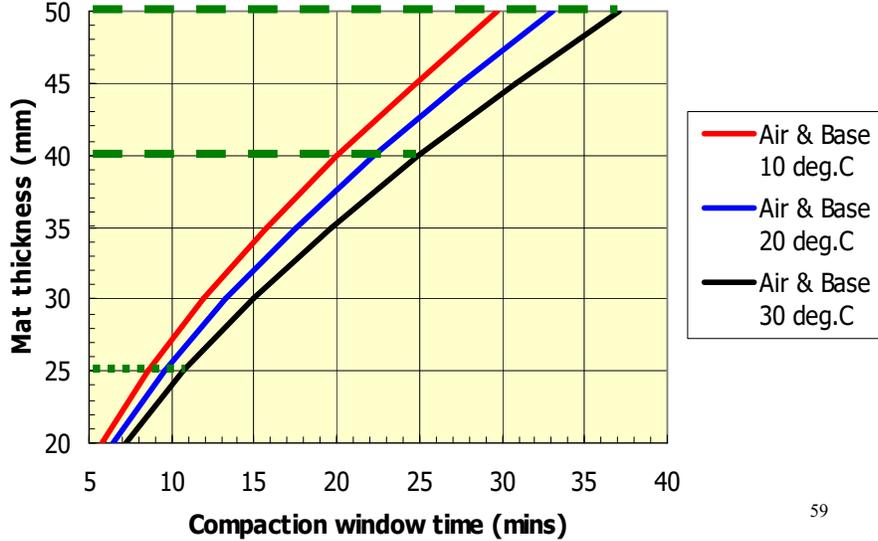


± 2 mins later



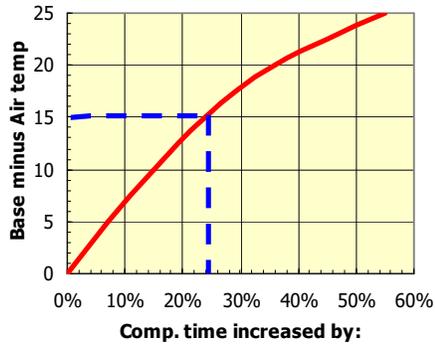
Cooling rate of C. G. HMA mats for:

Wind speed = zero
 Temp. of mat behind paver = 135 deg.C
 Cut-off temp. for compaction = 80 deg.C

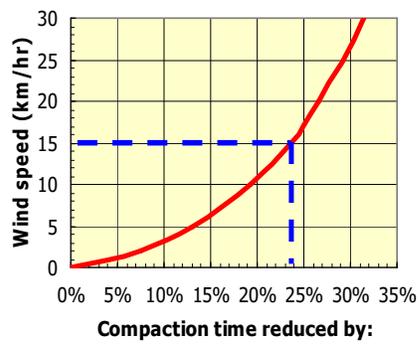


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Correction for Radiation



Correction for wind



Recommended min compaction time required is:

- 10 mins for user-friendly mixes
- 13 to 14 mins for harsh mixes

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Compaction windows in winter

Example:

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

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

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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.

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...or Alternatively:

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

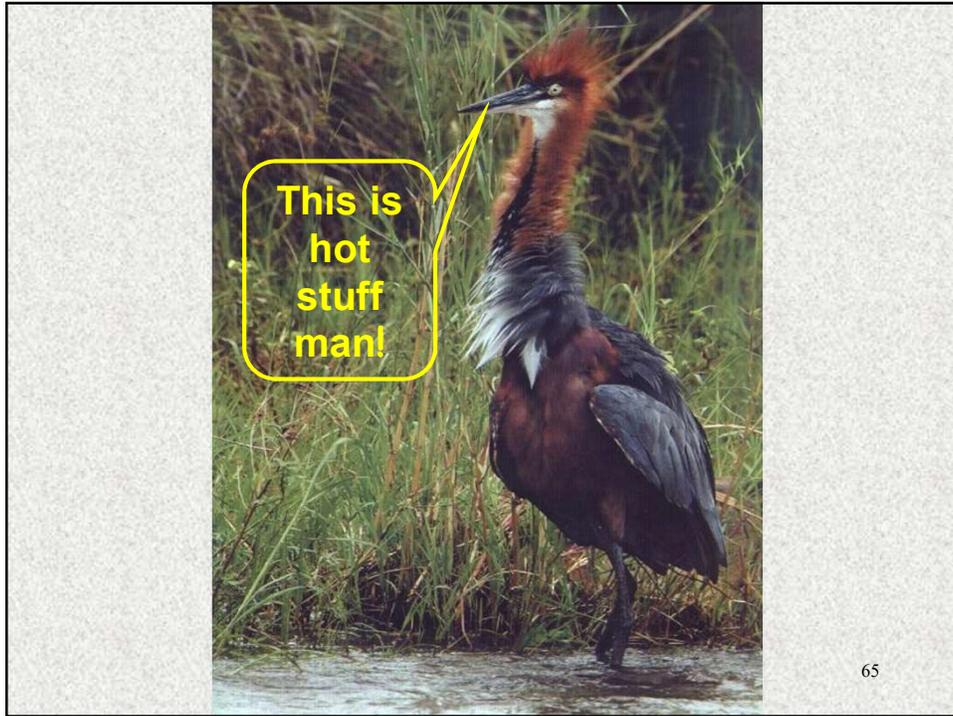
- increase bitumen for better lubrication and slightly lower voids (for light traffic roads)
- reduce maximum stone size e.g. from 13.2mm to 9.5mm

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It's all about temperature!!



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

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Adhesion problems

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

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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

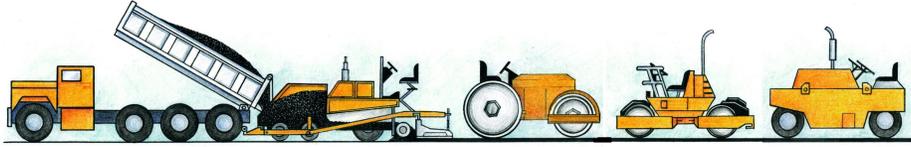
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“Must remember” fundamentals

- 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....

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Compaction equipment



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

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Four different types of compaction:

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

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3 Phases of rolling

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

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At what temp range do I use

- **Steel static ?**
 - When mat is hottest, $>120^{\circ}$
- **Vibratory ?**
 - When mat is hottest, and down to 80°
- **PTR ?**
 - Best from 120° to 100°

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Static rollers

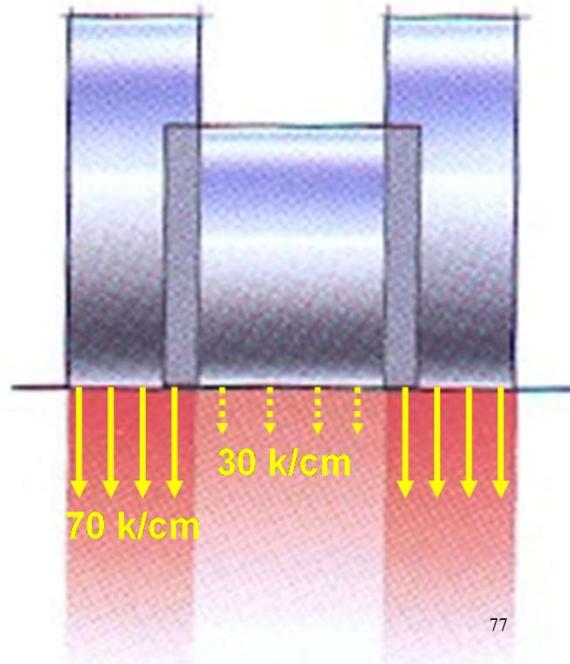
- Use static dead weight and squeeze
- Good lubrication needed
- Compact from top down

Compaction influenced by:

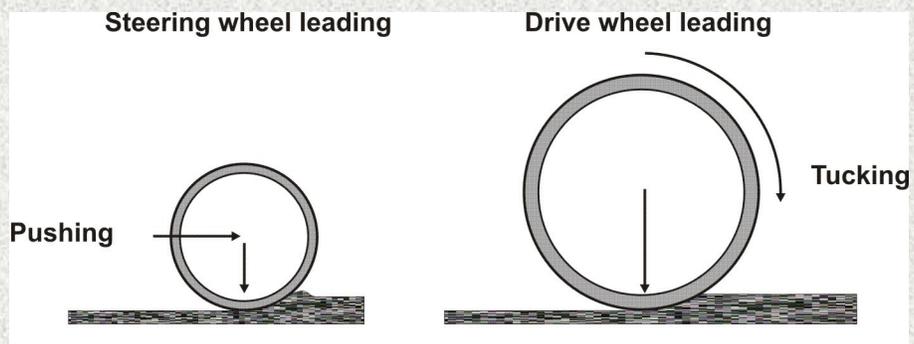
- Drum diameter (1500mm)
- Drum loading (60 to 80kg/cm)

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Drum loading of a 3 wheel roller



Rolling direction for 3 wheelers



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Vibratory rollers

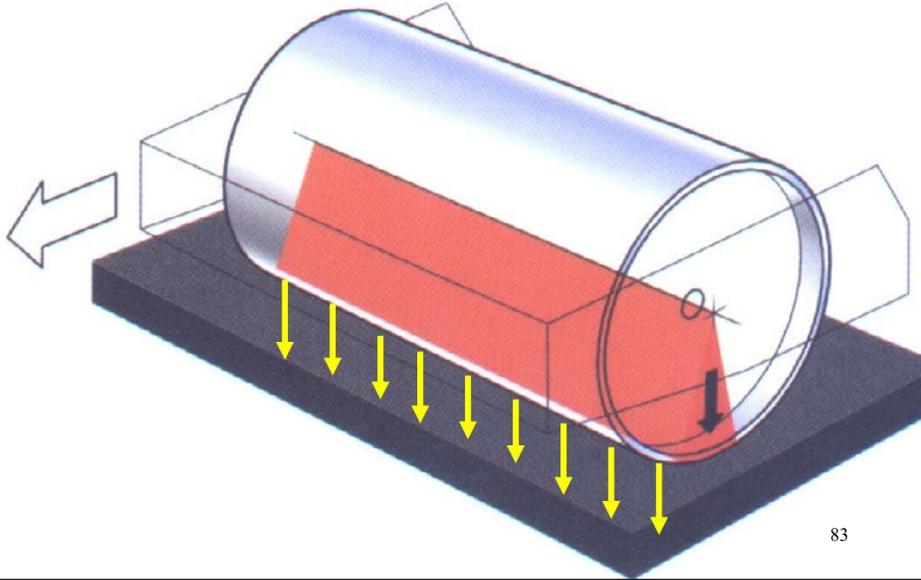
- Rapid succession of impacts
- Reduces internal friction
- Compacts from bottom up

Compaction effort influenced by:

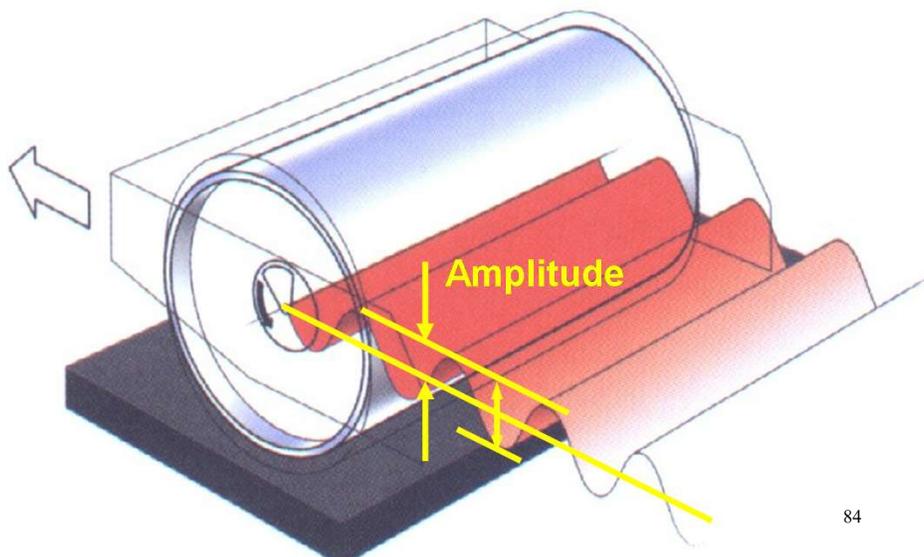
- Drum loading
- Amplitude & frequency
- Speed
- Centrifugal force ?

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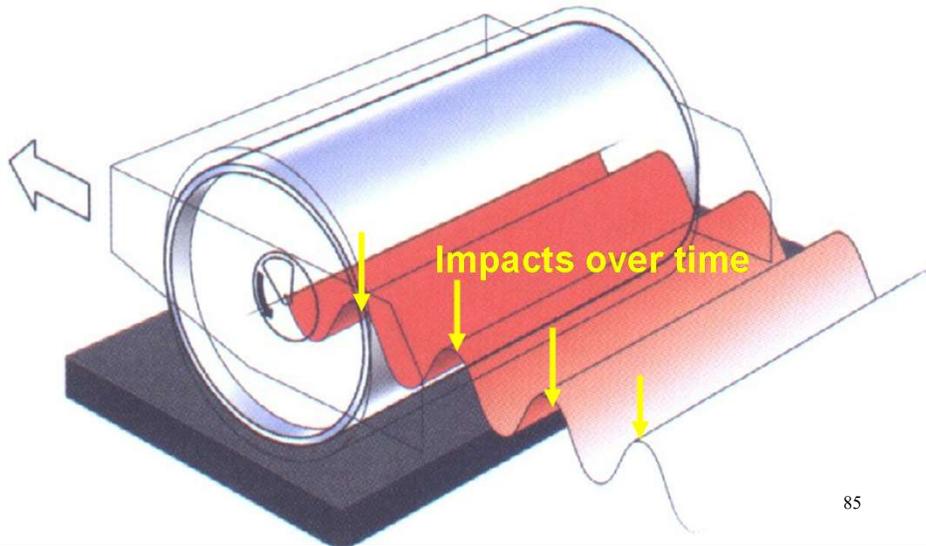
Drum loading – kg/cm



Amplitude - mm



Frequency – vpm (hz)



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

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- 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

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- Centrifugal force can be misleading as a guide to compactive effort
 $CF = \text{mass} \times \text{ampl} \times \text{freq}^2$.
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

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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

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- 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.

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Oscillatory roller



Oscillatory roller



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Pneumatic rollers

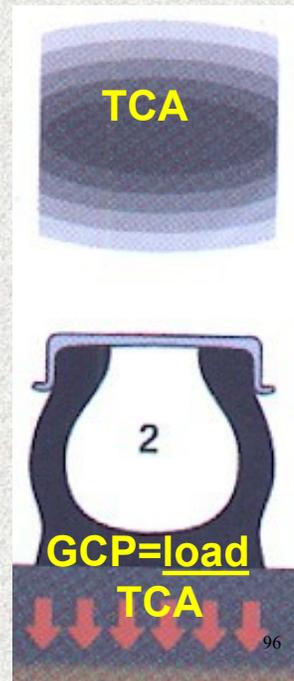
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Pneumatic rollers

- 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

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200 mm tyres





Typical PTR's

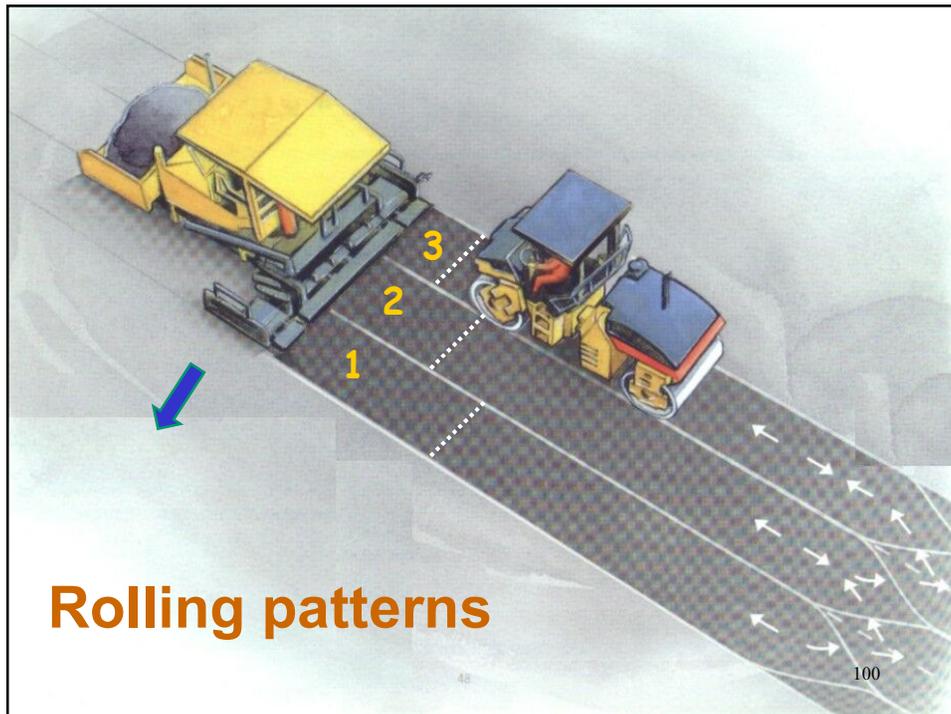
Tyre width mm	Wheel load kg	Tyre press kg/cm ²	G.C.P. kg/cm ²	T.C.A. cm ²
200	1400	7.0	5.7	240
300	2500	6.3	5.7	430

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PTR's – where, when, how

- OK for breakdown & intermediate
 - but if used as breakdown --?
- Best from 120°C down
- Work better on tender mix than steel drums
- Speed critical – roll slowly
- 5.6 to 6.2 kg/cm² G.C.P.

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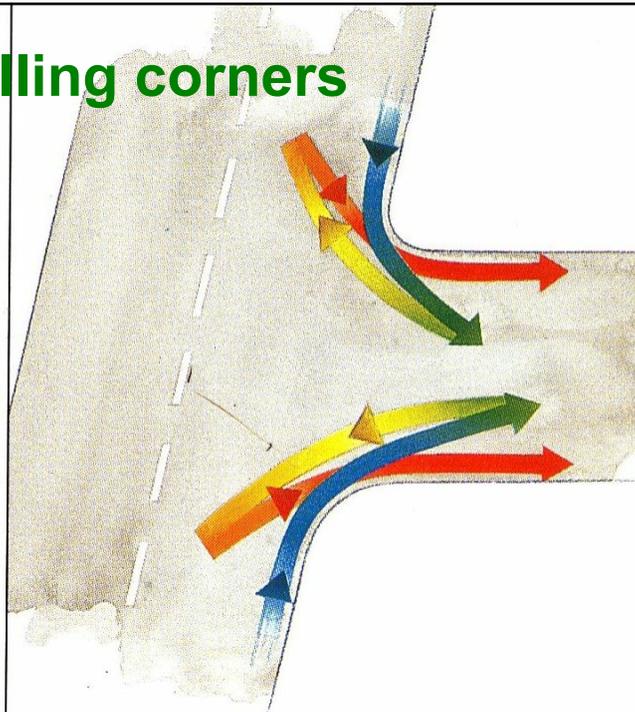


Length of b/down rolling zone

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

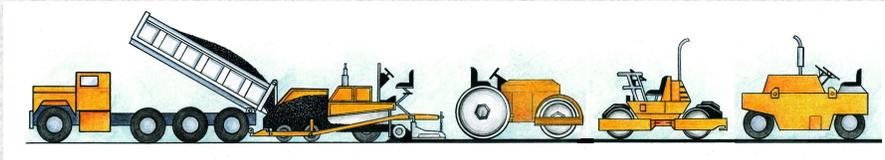
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Rolling corners



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Roller combinations



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

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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
- **Rollers should**
 - Roll “aggressively”
 - Roll as a team

} Rideability

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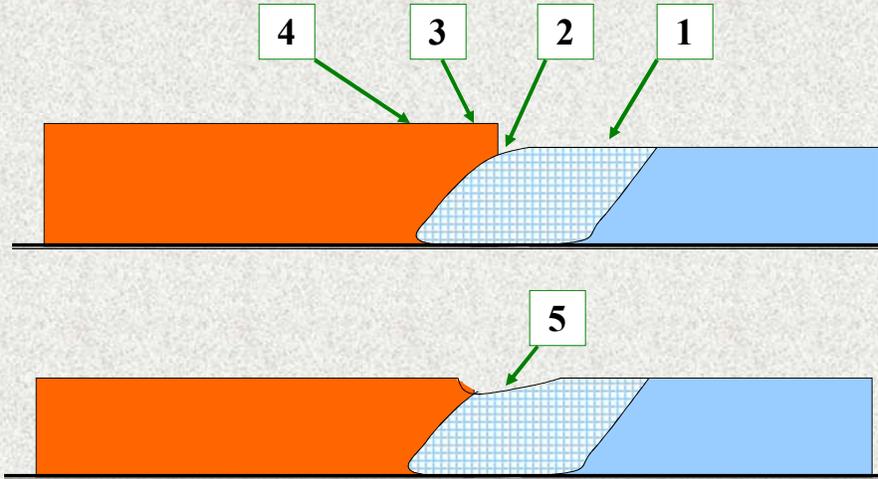
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Challenges of a longitudinal joint



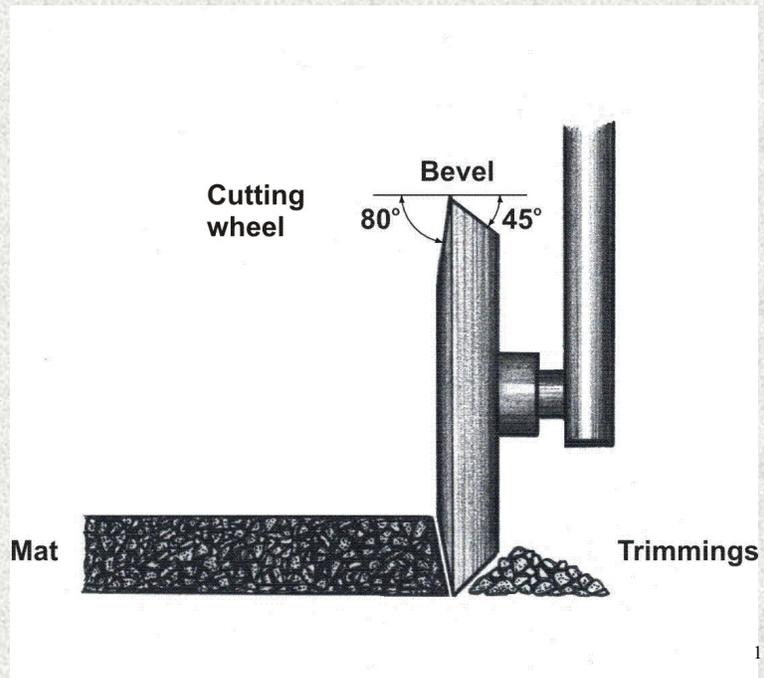
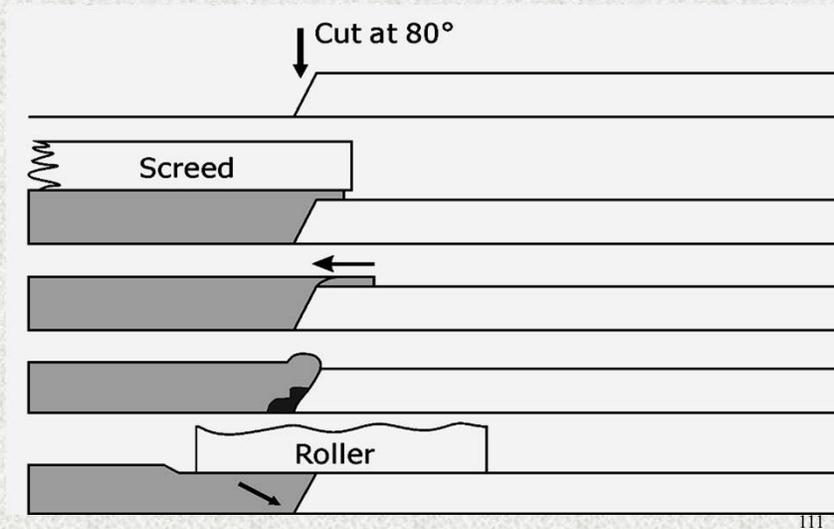
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MTV – Transverse joints

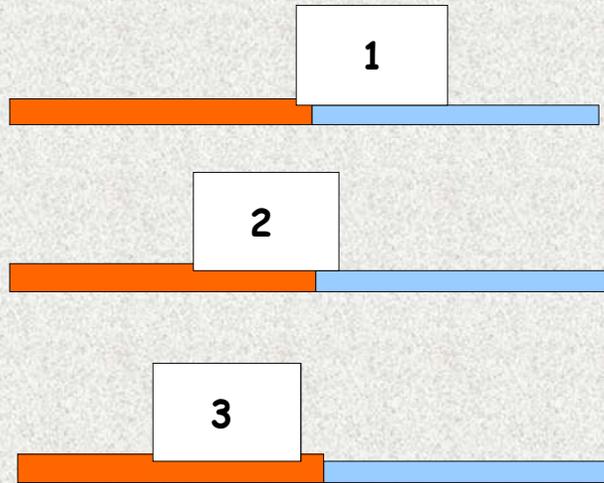
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Joint construction



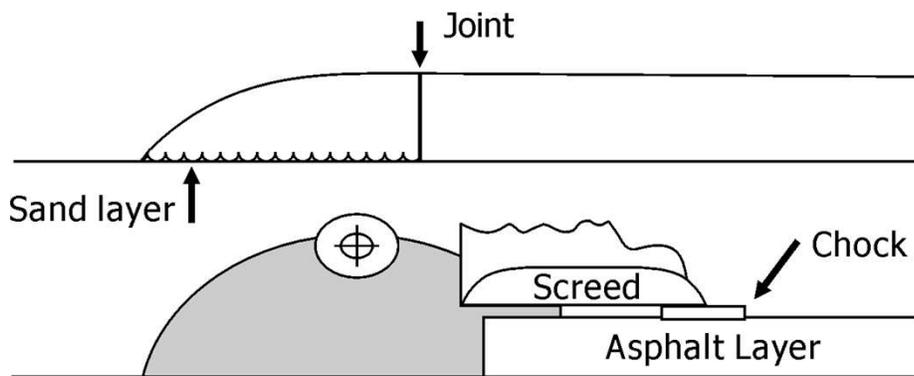


Three methods to roll longitudinal joints



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Transverse joints





Check mat for best position

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Cut joint
-square
or angle

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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?

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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?

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The significance of good rideability

Not only for the comfort of the driver!

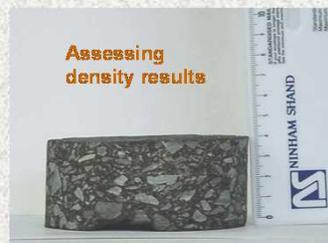
- Protection of goods in delivery vehicles and reduced maintenance cost of the vehicles themselves
- The lifespan of the road is significantly increased if the rideability is good
- New rideability specs have penalty / reward clauses based on profilometer readings and calculation of International Rideability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

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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)



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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.....

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Rolled in Chips

- Harmful to a thin layer
- Increases permeability
 - Water
 - Air
- Cools the mat
 - 15⁰ Celsius at 13 kg/m²
 - Rapid temperature reduction
- Reduces the compaction window



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And now

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