Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV)
German Road and Transportation Research Association

Asphalt Pavements Working Group

FGSV

Guide to the production of asphalt pavements

Guidance for ensuring that smoothness meets requirements

H VAE

W 1

Edition 2019
Translation 2020

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Processing group: Smoothness when paving roller-compacted asphalt

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Preliminary remark

The Guide to the production of asphalt traffic area pavements – Notes for ensuring that smoothness meets requirements (“H VAE”), edition 2019, was prepared by the FGSV German Road and Transportation Research Association’s “Smoothness when paving roller-compacted asphalt” task group and completed by its “Construction Technology” committee (led by Dipl.-Ing. Lars Keller).

Table of Contents

1 General

The demands placed on road quality have risen further in recent years as a result of increased traffic volumes and higher axle loads. For roller-compacted asphalts, special importance is attached not only to compaction but also to smoothness. Achieving a level surface that meets the requirements requires process knowledge as well as care during the preparation and execution phases. Smoothness is a fundamental prerequisite for long service life of asphalt road pavements. For this reason, the "Guide to the production of asphalt pavements – Guidance for ensuring that smoothness meets requirements" (H VAE) summarises practical experience as well as findings and conclusions from research studies.

Such guidance is not, according to its (primary) intended purpose, suitable either as a basis for contracting or as a standard. According to its secondary purpose, however, it may also be used in excerpts or modified as an integral part of construction, supply and engineering contracts (see ARS no. 26/1980 "Grundsätze für das Aufstellen Technischer Regelwerke für das Straßenwesen – Arten und Inhalt" [Principles for compiling technical regulations for road engineering – categories and content]).

2 Area of application

The "H VAE" guide is applicable to all hot-paved roller-compacted asphalts produced for asphalt base, binder and surface courses and for asphalt combined base and surface courses in accordance with the Additional Technical Conditions of Contract and Directives, as well as to special surface coverings.

The measures described in the guide are unique in nature. It contains guidance on how new asphalt road pavements can be executed, and existing ones maintained,in line with requirements, as well as considering ongoing developments in machine technology.

The "H VAE" guide was created on the basis of many years of practical experience, and is therefore targeted especially at those directly involved in road-building. It can also be distributed in parts to staff involved in specific processes. Some repetition across the various sections is unavoidable, but has been kept to a minimum.

3 Significance and evaluation of smoothness

3.1 Significance of smoothness

Smoothness is of key significance in terms of road safety, ride comfort and the durability of asphalt pavements. Any roughness in the road surface will generate mechanical vibration in the vehicle, which is also transmitted to the vehicle's occupants and cargo. The vibration of the vehicle and its load in turn place additional stress on the road.

The complexity of constructing smooth asphalt pavements is evidenced in publications such as [23] and [24]. The surface geometry of the road is influenced by several factors simultaneously, interacting with each other and with the surface. It should be noted that the long-term behaviour of a road structure follows a certain pattern, the essential foundations of which are established during construction. The resulting longitudinal roughness results primarily from

- the initial roughness of the base,
- the variability in the plant-produced asphalt mix, and
- inconsistency of construction operations.

These inconsistencies in the construction process lead to localised fluctuations in the deformation modulus of the various pavement layers over time. During the service life of the road, an accumulation of factors linked to

– weather (temperature),
– ageing of the asphalt mixes, and
– traffic load

occurs. All in all, this also leads to permanent deformation at different locations, and to varying degrees over time [23, 24, 27].

It should be noted that minor irregularities with a general roughness ("AUN") between 0.3 and 1 cm^3 have little influence in terms of road damage [25, 26]. The general roughness value (abbreviated as "AUN") is one of the road condition criteria under the "Smoothness in longitudinal profile" category of the Additional technical conditions of contract and directives on the assessment and evaluation of the condition of roads ("ZTV ZEB-StB"). Conversely, very uneven roads (AUN ≥ 27 cm^3) indicate on average a 30 to 40% increase in road stress, and in isolated cases even double it. The local stresses are up to seven times higher under unfavourable circumstances.

3.2 Evaluation of smoothness in Germany

The smoothness requirements for acceptance under the building contract are regulated in the Additional technical conditions of contract and directives for the construction of traffic area pavements made of asphalt ("ZTV Asphalt-StB") and the Additional technical conditions of contract and directives for the structural maintenance of traffic areas – asphalt pavements ("ZTV BEA-StB"). Under those standards, measurement is carried out according to the principle of the 4 metre smoothness (measuring straightedge, planograph, profilograph). The smoothness measuring methods cited are detailed in the Technical testing regulations for smoothness measurements on pavement surfaces in longitudinal and transverse directions: Measurements with contact ("TP Eben Berührende Messungen").

In assessment and evaluation of road surfaces, the high-speed road monitor (HRM) is used to record the longitudinal elevation profile of a road. This evenness measuring method is detailed in the Technical testing regulations for evenness measurements on pavement surfaces in longitudinal and transverse directions: Measurements without contact ("TP Eben – Berührungslose Messungen"). The evaluation of longitudinal profiles under the "ZTV ZEB-StB" terms is currently based on the AUN value.

The AUN value is a geometric quantity that does not take into account the effects of roughness on the road user, the cargo or the wheel load. The BLP ("Bewertetes Längsprofil"; longitudinal profile evaluation) method was developed as an alternative which combines purely geometric evaluation with the effect component [29].

3.3 Constraints on evaluation

There is a general consensus that the measurement methods based on the 4 metre straightedge are not appropriate as means of assessing longitudinal smoothness. Roughness with a wavelength greater than 4 metres, as well as periodic undulations, cannot be detected by these measurement methods, even though both are crucial to evaluation. Periodic undulations are recorded with the planograph, but are not given further consideration due to the evaluation algorithm and the requirements of "ZTV Asphalt-StB" and of the Additional technical conditions of contract and directives for the construction of base courses with hydraulic binders and concrete pavements ("ZTV Beton-StB").

It also needs to be considered that when using the measurement methods cited it is necessary to close the road to traffic in order make smoothness measurements. According to the "TP Eben" contact measurement rules, the measurements must always be carried out at walking speed (using the planograph).

The measurements under the "ZTV ZEB-StB" terms by non-contact methods can be carried out with little impact on traffic flow by means of fast-moving systems. On this basis, both roughness with linear expansion greater than 4 metres and periodic roughness can be recorded ("AUN" value) and their effects on driving dynamics evaluated ("BLP").

3.4 Economic analysis of smoothness

The roughness of a road surface causes vehicles to vibrate depending on their speed, which, according to [14], also changes the driving resistances and thus the energy required to move a vehicle. As can be seen from Figure 2, human beings react to the roughness by subjective perception of vibration, which can result in their health being negatively impacted.

The body of the road is also subjected to greater stress by additional vertical loads.

In 1971, the Guidelines for comparative economic analysis in road-building ("RWS") [19] represented the first

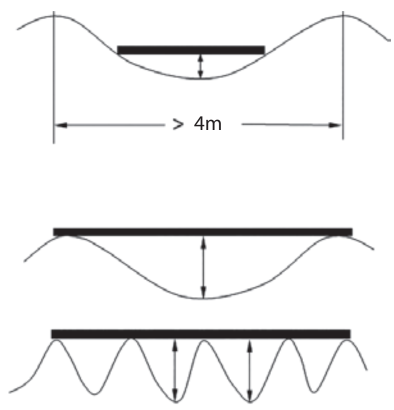


Figure 1: Illustration of the measurement problem when using a 4 metre straightedge [30]

attempt in Germany to take into account the influence of road condition on vehicle operating costs [28]. A dependence of the fuel consumption on the vehicle speed, road-holding and quality of the road surface was established on a theoretical basis in 1976 [17]. The first basic calculations of road user costs were made in the late 1980s [18, 21].

According to [28], road user costs can be depicted as a function of the general roughness ("AUN") in longitudinal direction and can be reduced by maintenance measures through savings on vehicle operating and accident repair costs. It is shown that [quote taken from the original German] "from an economic point of view, a higher level of intervention (...) in terms of maintenance of federal motorways would be justified for the sake of improving general longitudinal roughness". The annual economic losses resulting from all additional fuel costs are estimated at € 24,000 per kilometre of motorway. Increasing intervention would lead to lower additional road stress due to fluctuating axle loads and, as a result, a longer service life with less depreciation of roads.

In 1997, a study was carried out in the USA [22] to investigate the effect of the smoothness of the road surface achieved during the production of a new asphaltic concrete surface course on the behaviour of the road over its total service life. It was found that the subsequent smoothness depends heavily – but not solely – on the initial smoothness of the asphalt surface course, the service life of which can be significantly increased by a minor improvement in smoothness during production, leading to positive general economic effects. A 9% extension of the service life can be achieved through improving the smoothness by 25%. A 50% improvement in smoothness can be expected to extend useful life by at least 15%.

Thus, based on [26], it can be stated that roads should be constructed at the highest possible level of smoothness [quote taken from the original German] "in order to counteract the increasingly accelerating deterioration of the road superstructure due to roughness".

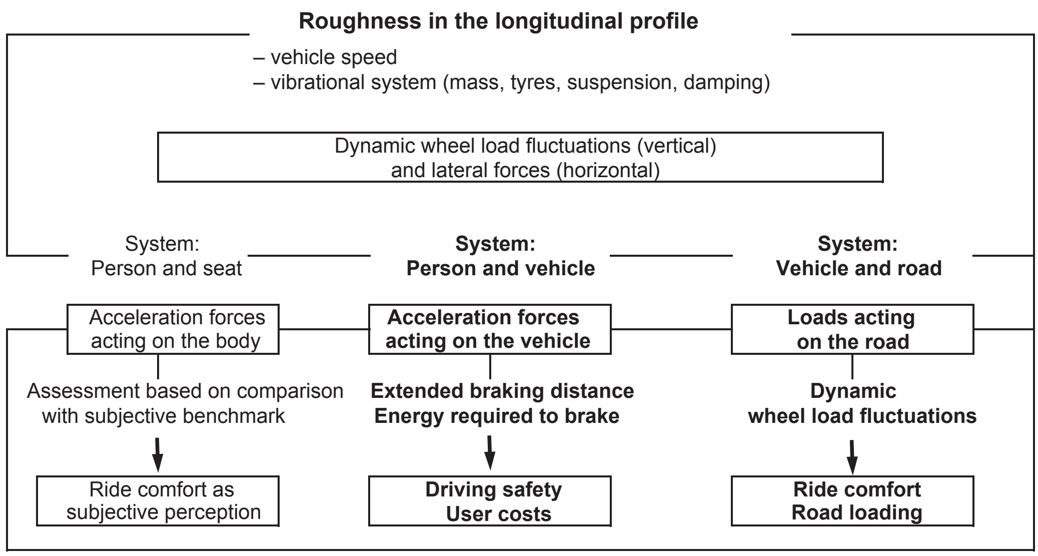


Figure 2: Effects of road roughness [14]

4 Asphalt paver terminology

Road pavers are used for paving roller-compacted asphalt. They are designed as tracked or wheeled tractors, comprising the two main elements of the tractor and the screed. The paving material is fed from the material hopper (5) by two independent-running conveyors (6) to the augers (9) mounted on the rear, as shown in Figures 3 to 5. The augers can also be independently controlled and distribute the material in front of the paving screed.

Note that the options shown in Figure 6 for adjusting the inner working angle of the screed with the aid of the turnbuckle (17) and for increasing the auger tunnel by selecting the front articulation point (16) of the basic screed (15) on the tow arm (12) are implemented in different ways by the manufacturers. The way in which component units providing higher compaction are used also varies significantly: double tampers, post-compaction pressure plates (32, 33) or single and double row press bars.

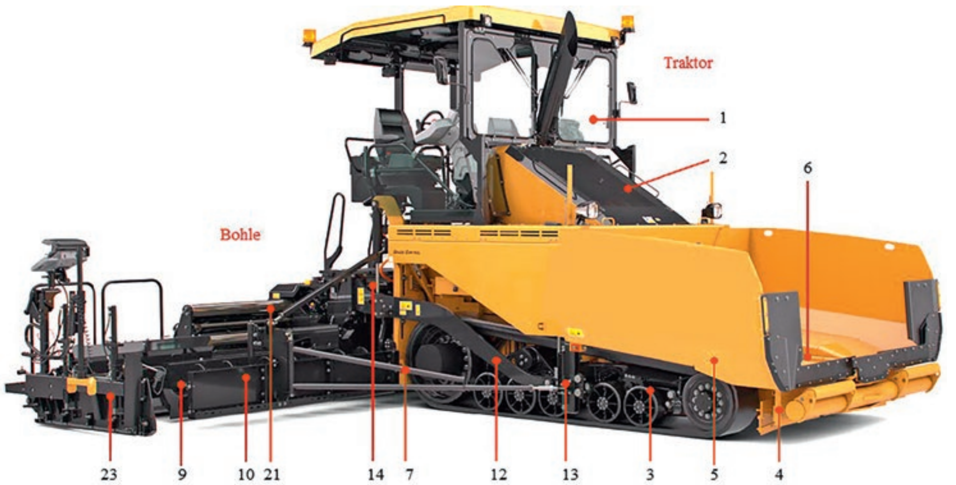


Figure 3: Asphalt paver with variable-width screed [8]; see Table 1 for reference symbols

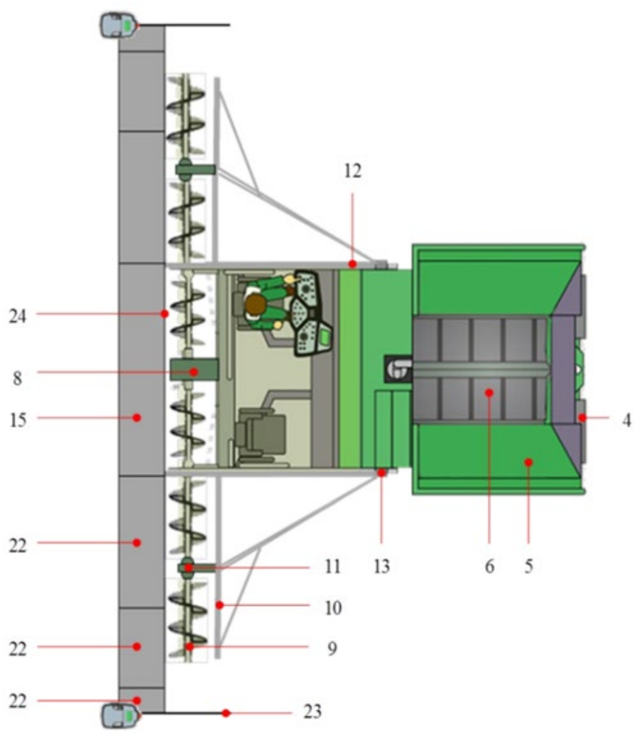


Figure 4: Top view of an asphalt paver with fixed-width screed [34]; see Table 1 for reference symbols

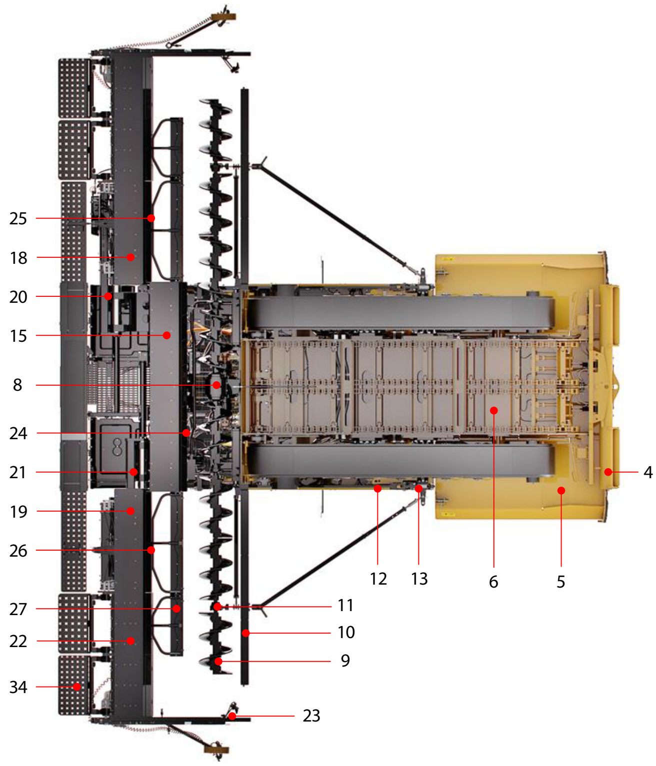


Figure 5: Bottom view of an asphalt paver with variable-width screed [8]; see Table 1 for reference symbols

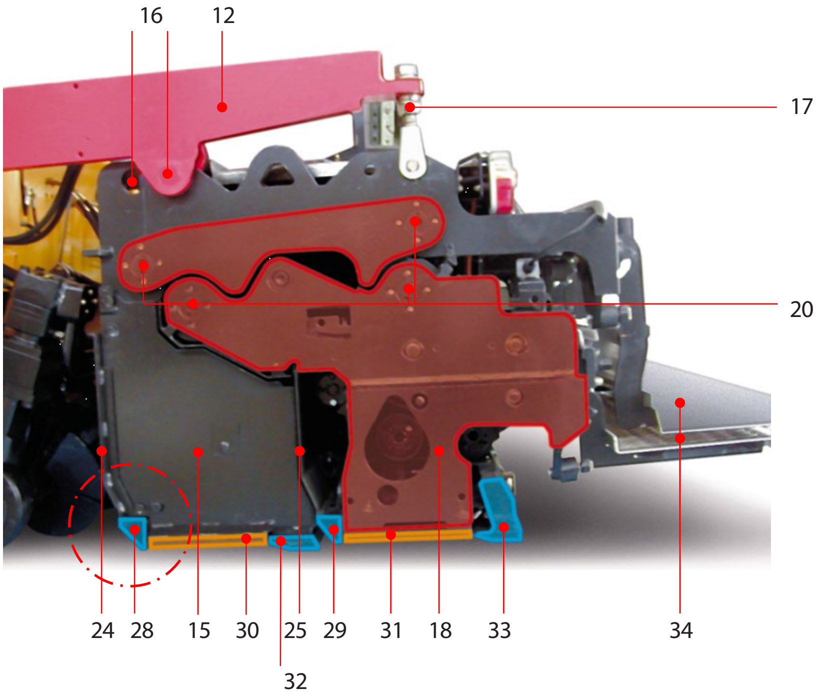


Figure 6: Higher-compaction screed [10] with red dotted base; see Table 1 for reference symbols

Table 1: Reference symbols for Figures 3 to 6

No.	Reference symbol	No.	Reference symbol
1	Operator's platform	18	Left extender
2	Drive unit	19	Right extender
3	Track unit	20	Guiding system, left side
4	Push-roller bar	21	Guiding system, right side
5	Material hopper	22	Attachment part (varying sizes)
6	Conveyor/slatted frame	23	Screed limiter plate/side plate/end gate
7	Asphalt paver rear panel	24	Tamper shield of basic screed
8	Auger gear	25	Tamper shield of left extender
9	Auger	26	Tamper shield of right extender
10	Material guide plate/chute	27	Pre-strike off plate/deflector in front of crawler track
11	Auger bearings	28	Basic screed tamper
12	Tow arm	29	Tamper of left extender
13	Screed tow point and tow point cylinder	30	Basic screed plate
14	Screed lifting cylinder	31	Screed plate of left pusher
15	Basic screed	32	Basic screed pressure plate
16	Pivot point of basic screed on left tow arm	33	Pressure plate of left extender
17	Turnbuckle between left tow arm and basic screed	34	Walkway

5 The principle of the “free-floating” screed

According to [2], changes in the tow point position (“vertical step raising”) affect the movement of a screed when in self-levelling mode, as shown in Figure 7.

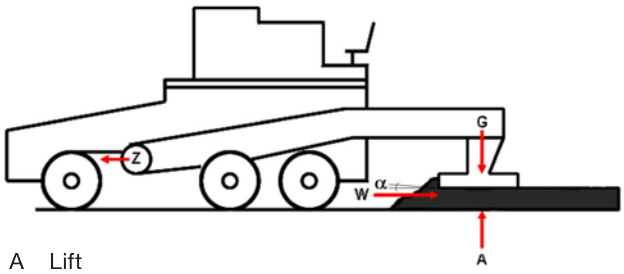
The correction of the screed correlates with the length of the tow arm (levelling arm) L and the distance covered. After completing one tow arm length (1 L), 63% of the new paving thickness is achieved; after two lengths 87%; after three length 95%; after four length 98%; and after five lengths 99%.

In [31] it is indicated that the timing of the change in height is affected by other influences, such as the compaction of the material or the material flow under the screed, and so the grade and slope control is not determined solely by a height correction at the screed tow points.

According to [3], the dynamic lift A is in equilibrium with the weight G of the paving element. Other forces indicated in Figure 8 are the resistance of the material W and the tractive power Z at the pivot point of the tow arm. The function of the freely suspended screed therefore depends on a force system which must be balanced during paving in order to ensure the smoothness of the asphalt mix laid. The screed will inevitably respond to an uncontrolled change in any system force by a height correction.

The correlation depicted about 30 years after the market launch of the first paver with a floating screed [2] with regard to the equilibrium of forces acting on the paving screed [3] is no longer in line with the latest state of the art.

New findings [32] show that the movement behaviour of the paving screed is not solely dependent on the pressure of the aggregate material against the tamper shield, but is also influenced by the flow properties of the asphalt mix and the stress conditions in the area of the screed base. Short-time fluctuations in the height of the material feed lead to more pronounced changes in tractive force relative to the distance covered and – contrary to the usual assumption – the paving thickness increases as the asphalt mix temperature rises.



A Lift
G Weight of the paving element
W Material resistance
Z Tractive power
The author has added the angle of attack α

Figure 8: Asphalt paver with floating beam according to [3]

Figure 9 shows a simplified application of the forces and moments acting on a tamper-vibrating screed.

To simplify matters, it may be assumed that, due to the acute angle of attack α, the front and rear edges of the screed plate are at the same height, and the friction force on its tamper shield can be ignored if part of the sheared material flows upwards and is returned to the auger tunnels.

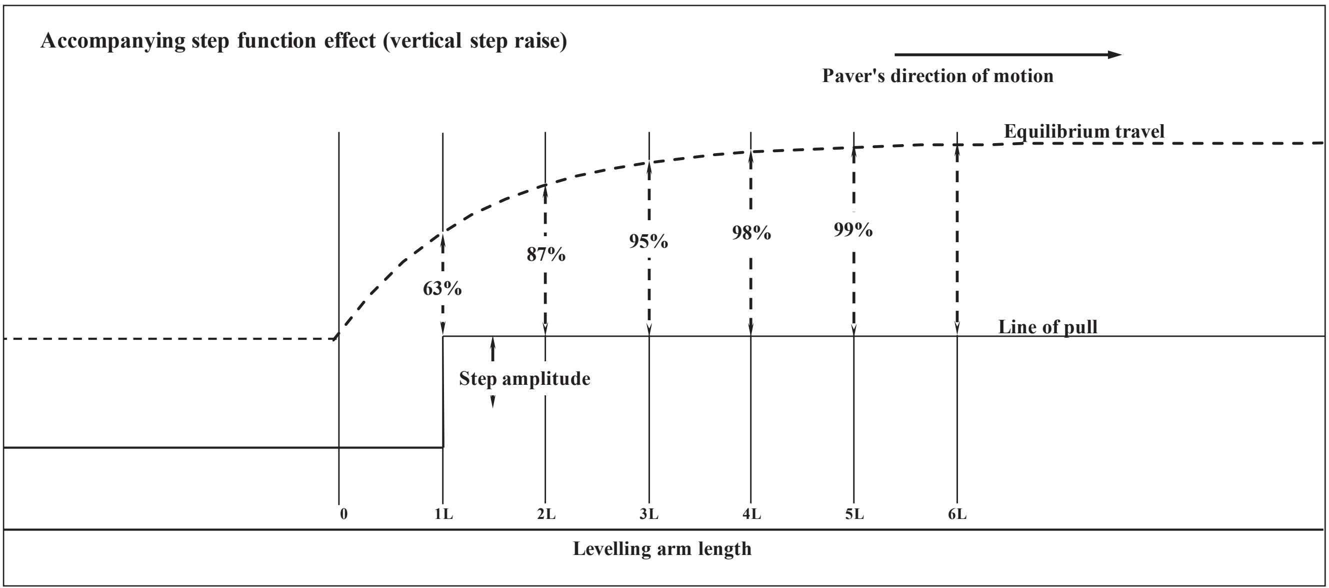
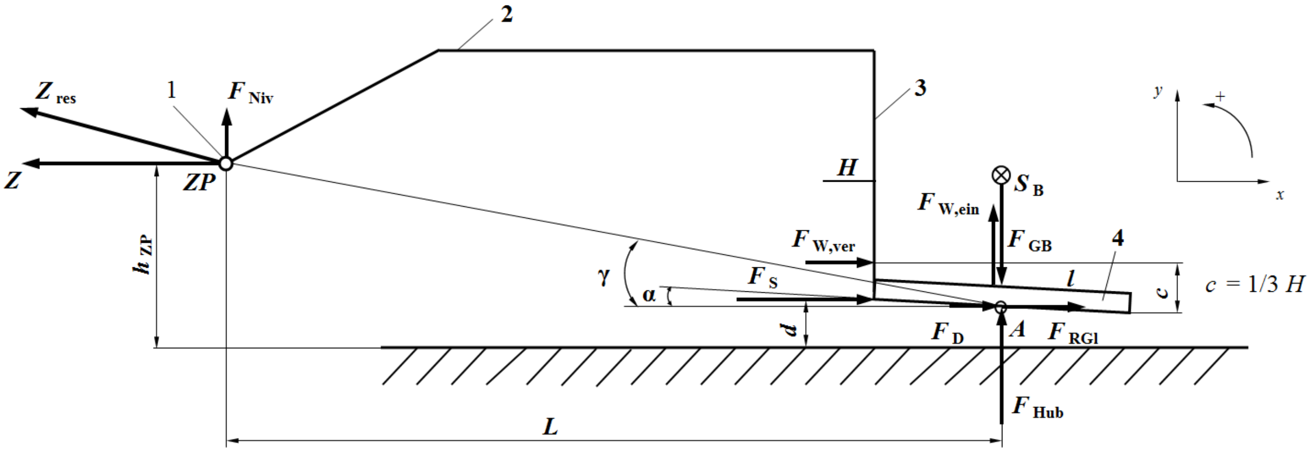


Figure 7: Screed reaction of the floating screed according to [2]; percentages rounded



1	Pivot point	H	Head of material
2	Tow arm	L	Distance between tow point and regulating point
3	Screed tamper shield	S_B	Centre of gravity of screed
4	Screed plate	Z	Tractive force
A	Position	ZP	Screed tow point
F_D	Compressive strength	Z_{res}	Resultant tractive force
F_{GB}	Weight of the screed	c	Lower third point of head of material H
F_{Hub}	Hydrodynamic lifting force	d	thickness
F_{Niv}	Force on tow point cylinder	h_{ZP}	Position of tow point
F_{RGl}	Friction force on bottom of screed plate	l	Length of screed plate
F_S	Shear force	x, y	Cartesian coordinates
$F_{W,ein}$	Resistive force of mix supporting the screed	α	Screed equilibrium angle of attack
$F_{W,ver}$	Resistive force of asphalt mix	γ	Working angle

Figure 9: Simplified schematic of the forces and moments acting on a tamper vibrating screed [32]

The horizontal forces F_S and F_{RGl} act at the height of the positioning location A at the distance d from the base. F_{RGl} is subject to only minor fluctuations and can therefore be regarded as a virtually constant quantity.

In order to understand the movement behaviour of the free-floating screed, it is important to consider above all the effective moments resulting from the acting forces and the associated moment arms (h_{zp} – d), (h_{ZP} – c – d) and L.

Since fluctuations of the forces $F_{W,ver}$ and F_S cannot be completely avoided even with the most careful paving practices, the disturbances to their moments $F_{W,ver}$ (h_{ZP} – c – d) and F_S (h_{zp} – d) must be kept to a minimum by way of small lever arms h_{ZP}. For this reason, the lowest possible tow point height h_{ZP} should be selected for paving.

6 Factors influencing smoothness

6.1 Guidance on planning and drafting work specification

For the construction of new classified traffic routes, the Guidelines for the design of motorways ("RAA") and Guidelines for the design of rural roads ("RAL") specify a minimum ramping on the winding stretches in order to minimise zones with inadequate water run-off.

From a machine technology perspective, this minimum ramping provides a useful distance-dependent variation in slope of 2.5% over a 25 metre displacement length.

Practical experience in paving shows that greater ramping (> 0.15 ≙ 3.75% over 25m) can lead to roughness. This fact is not taken into account in "ZTV Asphalt-StB", as no objection can be made to the design-based influences of grade and slope on smoothness.

When carrying out structural maintenance of traffic routes, in the course of work preparation the profile of the existing road surface in longitudinal and transverse directions should be surveyed. Where condition assessment data according to "ZTV ZEB-StB" is available, reference can be made to it.

Table 2: Recommended measures for milling the base to achieve the required smoothness of the asphalt surface course in accordance with "ZTV Asphalt-StB 07/13"

<table>
<tr><td rowspan="21">Specified unevenness on the new road surface ≤ 4mm</td><td>ZTV Asphalt-StB 07/13</td><td colspan="7">Course to be removed</td></tr>
<tr><td rowspan="2">Course to be paved</td><td colspan="2">No removal*)</td><td colspan="2">Asphalt surface course</td><td colspan="2">Asphalt surface and binder course or asphalt surface and base course1)</td><td rowspan="2">Complete removal</td></tr>
<tr><td>Existing smoothness</td><td>Measure</td><td>Existing smoothness</td><td>Measure</td><td>Existing smoothness</td><td>Measure</td></tr>
<tr><td rowspan="4">Asphalt surface course or construction of compact asphalt pavements</td><td rowspan="2">≤ 6mm</td><td rowspan="2">No measures</td><td rowspan="2">≤ 6mm</td><td rowspan="2">Contour milling</td><td colspan="2">Layered milling2)</td><td rowspan="4"></td></tr>
<tr><td>≤ 6mm</td><td>Contour milling</td></tr>
<tr><td>> 6mm and ≤ 18mm</td><td>Fine milling with averaging ski or paving with profile equalisation</td><td>> 6mm and ≤ 18mm</td><td>Milling with averaging ski</td><td>> 6mm and ≤ 18mm</td><td>Milling with averaging ski</td></tr>
<tr><td>> 18mm</td><td>Milling with contact wire/3D or paving with profile equalisation</td><td>> 18mm</td><td>Milling with contact wire/3D</td><td>> 18mm</td><td>Milling with contact wire/3D</td></tr>
<tr><td rowspan="7">Asphalt surface and binder course or asphalt surface and base course</td><td rowspan="2">≤ 10mm</td><td rowspan="2">No measures</td><td rowspan="2">≤ 10mm</td><td rowspan="2">Contour milling</td><td>≤ 10mm</td><td>Contour milling</td><td rowspan="7">New build**)</td></tr>
<tr><td colspan="2">Layered milling</td></tr>
<tr><td rowspan="2">> 10mm and ≤ 30mm</td><td rowspan="2">Fine milling with averaging ski or paving with profile equalisation</td><td rowspan="2">> 10mm and ≤ 30mm</td><td rowspan="2">Milling with averaging ski</td><td>> 10mm and ≤ 90mm</td><td>Milling with averaging ski</td></tr>
<tr><td>> 90mm</td><td>Milling with contact wire/3D</td></tr>
<tr><td rowspan="3">> 30mm</td><td rowspan="3">Milling with contact wire/3D or paving with profile equalisation</td><td rowspan="3">> 30mm</td><td rowspan="3">Milling with contact wire/3D</td><td colspan="2">Mill both courses together</td></tr>
<tr><td>> 10mm and ≤ 30mm</td><td>Milling with averaging ski</td></tr>
<tr><td>> 30mm</td><td>Milling with contact wire/3D</td></tr>
<tr><td rowspan="7">Asphalt surface, binder and base course or asphalt surface course and two-layer asphalt base course</td><td rowspan="2">≤ 20mm</td><td rowspan="2">No measures</td><td rowspan="2">≤ 20mm</td><td rowspan="2">Contour milling</td><td>≤ 20mm</td><td>Contour milling</td><td rowspan="7">New build**)</td></tr>
<tr><td colspan="2">Layered milling</td></tr>
<tr><td rowspan="2">> 20mm and ≤ 60mm</td><td rowspan="2">Milling with averaging ski</td><td rowspan="2">> 20mm and ≤ 60mm</td><td rowspan="2">Milling with averaging ski</td><td>> 20mm and ≤ 90mm</td><td>Milling with averaging ski</td></tr>
<tr><td>> 90mm</td><td>Milling with contact wire/3D</td></tr>
<tr><td rowspan="3">> 60mm</td><td rowspan="3">Removal of the asphalt surface course</td><td rowspan="3">> 60mm</td><td rowspan="3">Milling with contact wire/3D</td><td colspan="2">Mill both courses together</td></tr>
<tr><td>> 20mm and ≤ 60mm</td><td>Milling with averaging ski</td></tr>
<tr><td>> 60mm</td><td>Milling with contact wire/3D</td></tr>
</table>

1) If necessary, optimisation of the profile based on survey; milling with contact wire.
2) Applies to the construction of compact asphalt pavements.
*) Check whether milling of the asphalt surface course is more suitable.
Surface treatments and thin asphalt surface layers (DSK, DSH or DSH-V) must be removed beforehand by fine milling.
**) New build: The requirements set out in Table 25 of "ZTV Asphalt-StB 07/13" apply.

The existing road surfaces should be checked for

– longitudinal and transverse roughness,
– super-elevation in the winding section,
– longitudinal and transverse cross-slopes and
– roughness at road junctions and road fittings.

In the event of major deviations from the smoothness requirements or parameters relevant to the planning procedure, milling of the base or paving of a suitable asphalt mix should be specified in order to improve the profile in accordance with “ZTV BEA-StB 07/13”. In this, it appears useful to define a new profile or super-elevation and specify controlled milling (contact wire or comparable technology such as 3D) (see Tables 2 and 3).

The averaging ski method can compensate for roughness up to 2/3. An existing roughness of 12mm results in a roughness of 4mm after milling [37, p. 126 ff.].

Porous asphalt is neither finely milled nor paved over and is therefore ignored.

Table 3: Recommended measures for milling the base to achieve the required smoothness of the asphalt surface course in accordance with “ZTV BEA-StB 09/13”

ZTV BEA-StB 09/13	No removal	
Course to be paved		
DSK DSH DSH-V	Specified roughness on the new road surface upper edge ≤ 6mm	
	Existing roughness	Measure
	≤ 6mm	No measures*)
	> 6mm and ≤ 18mm	Fine milling with averaging ski
	> 18mm	Fine milling with contact wire/3D
	Specified roughness on the new road surface upper edge ≤ 4mm	
	Existing roughness	Measure
	≤ 4mm	No measures*)
	> 4mm and ≤ 12mm	Fine milling with averaging ski
	> 12mm	Fine milling with contact wire/3D

*) Surface treatments should be removed beforehand by fine milling. The milling, fine milling and ultra-fine milling processes are explained in the Guidance on milling asphalt pavements and pavements with components typical of tar/pitch (“H FA”).

The cause of the major deviations should be investigated. Possible influencing factors are:

– deformation of the individual asphalt courses (including underlying courses),
– heaving due to frost, roots,
– collapse due to sinkholes, collapsed utility pipelines, engineering structures, and
– weak load-bearing capacity in the road base.

The results of the preliminary investigation must be included with the tender documents, in particular

– the documentation of the existing grades and slopes,
– the documentation of longitudinal and transverse roughness,
– the material properties of the asphalt layers to be removed, and
– the material properties of the asphalt course on which the milling will take place.

To achieve optimal smoothness, profile and cross-slope corrections should be made during the milling process.

As milling process, smoothness should be measured on each layer before paving the next layer on top.

6.2 Planning paving operations

Asphalt paving and compaction must be carefully planned. This planning includes not only determining the sequence of the sections to be paved and compacted, but also the selection and deployment of paving and compacting equipment. Delivery, paving and compaction operations must be coordinated.

As a rule, the planning of asphalt paving is limited to the capacity of the asphalt mixing plant and the time required for delivery vehicles to reach the construction site. This means that asphalt mix logistics determine the paving speed, which in practical execution of the paving concept often leads to interruptions that have a significant impact on the success of paving, and thus also negatively affect the evenness of the course being laid. It must be emphasised that **mixing capacity does not mean the same as laydown rate!**

The paving speed should be selected in such a way that interruptions are avoided as much as possible, taking into account the performance of the rollers used.

6.2.1 Paving and compaction equipment

6.2.1.1 General

The paving and compaction equipment must be designed so that the specified compaction, slope and smoothness parameters are met when the equipment is used correctly. In addition, particular attention must be paid to placing the surface layer with a uniform texture. Further information can be found in the Information sheet on the compaction of asphalt (“M VA”).

6.2.1.2 Material transfer vehicles (MTV)

The use of material transfer vehicles (MTVs) entails process advantages which have a positive effect on the performance attributes of the asphalt course:

- if the site is supplied with sufficient asphalt mix,
  - non-stop paving;
  - continuous material flow from the hopper of the MTV to the auger chamber at the screed;
  - higher utilization of paving equipment per hour;
  - higher production rates;
- more uniform temperature of the asphalt mix,
- avoiding of contact between the truck and paver, and
- avoiding traction problems with the paver.

However, segregation of the mix may occur if the mix level in the hopper or hopper insert spills over the edges of the hopper. Further information on the use of material transfer vehicles is given in [16].

6.2.1.3 Asphalt pavers

When using a paver, the goal should always be to pave the mix with a sufficient pre-compaction level that is uniform across the entire paving width. A **high pre-compaction** has a positive effect on the smoothness and reduces the required compactive effort.

A distinction is made between pavers equipped with a steel or rubber tracks (track pavers) and those with a wheeled chassis (wheeled pavers).

Track pavers are essentially characterised by

- very good traction on loose and firm ground,
- high stability at wider working widths (> 8m),
- easy pushing of trucks, and
- flexibility to be used for any type of paving.

Figure 10: Track paver with material scraper shoe [11]

Using a steel or rubber track paver also makes for more even and smooth paver movement.

Wheeled pavers have advantages

- when driving in tight bends and
- thanks to their good self-levelling properties based on their pendulum axles and consequent very smooth running.

The front axle(s) should preferentially be equipped with all-wheel drive and anti-slip control (traction control).

The paving screeds available are fixed-width or variable-width (Vario) screeds. The screeds can be equipped with tampers, vibrators and high compaction components (double tampers, pressure plates, pressure bars).

Fixed-width screeds can be used to achieve more uniform pre-compaction across the full paving width and better smoothness and structuring of the asphalt surface. Compared to the optional method of working in echelon with wide paving widths, operation of the fixed-width screed and control of the material flow is easier. However, fixed-width screeds have the disadvantage compared to variable screeds that adjusting to a change in paving width is only possible with hydraulically extending attachment parts.

When paving asphalt mix with no confined edges (curbs etc.), minimal compaction can be achieved by the use of edgers. Edge attachments (see Figure 11) confine the asphalt mix laterally under the screed so that it is evenly compacted out to the outer edge. Thus, the formation of a shoulder (see Figure 72) when the asphalt mix is easily compacted is prevented by rolling. This applies particularly when laying to greater paving thicknesses, or with easily compacted and very hot asphalt mix.

To control the paving thickness and slope, pavers should be equipped with appropriate levelling units (see section 6.6).

Figure 11: Paving screed equipped with an edge attachment [35

6.2.1.4 Rollers

Modern rollers are well-designed to enable gentle deceleration and acceleration as well as smooth steering. Steering movements should be reduced to a minimum, especially when compacting asphalt surface courses. The roller operator must also ensure that at least one machine length is available for the roller to run out beyond the reversing point when stopping to reverse and change direction.

A particularly important factor in terms of smoothness is close the relationship between the linear load to the drum diameter and the contact pressure to wheel diameter (Nijboer factor C: 0.20 ≤ C ≤ 0.25kg/cm², see Figure 12).

The closer C is to 0.20kg/cm², the more favourable the rolling behaviour of the roller drum will be (smaller bow wave, see Figure 13).

The static linear load LL_{stat} and the Nijboer factor C are calculated as follows:

$$LL_{stat} = \frac{G}{b} \left[\frac{kg}{cm}\right], \quad (1)$$

$$C = \frac{G}{b \cdot d} \left[\frac{kg}{cm^2}\right]. \quad (2)$$

Due to the unfavourable Nijboer factor, the asphalt mix is builds up in front of this drum, and this can lead to cracking and bumps after rolling.

Note: The service weights/axle loads specified by the roller manufacturers usually refer to a full fuel tank and a half-full water tank (CECE [12]). Edge pressing and cutting equipment, and especially chip spreaders, can considerably change the static linear load.

In tight curves, split drums are advantageous as they reduce material displacement due to the different drum rotational speeds on the inside and outside edges of the drum (see Figure 14).

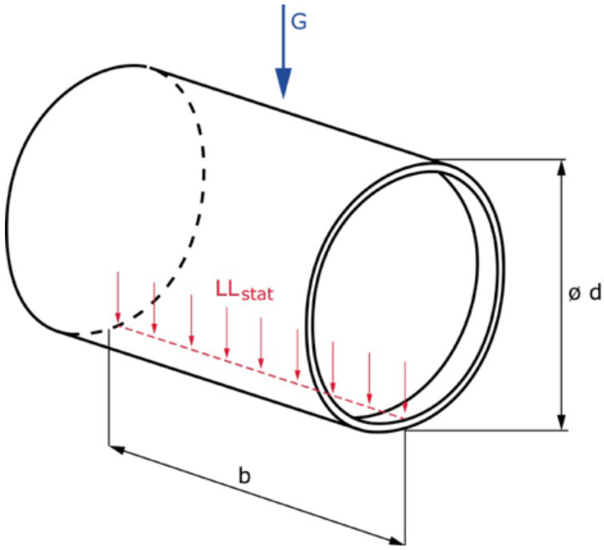


Figure 12: Correlation between axle load G, drum width b and drum diameter d to explain the static linear load LL_{stat} and the Nijboer factor C [13]

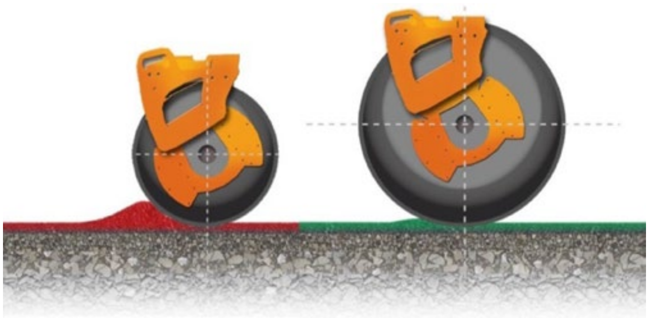


Figure 13: Schematic representation of the influence of the Nijboer factor C [13] on the formation of the bow wave in rolling direction due to different drum diameters with the same static linear load

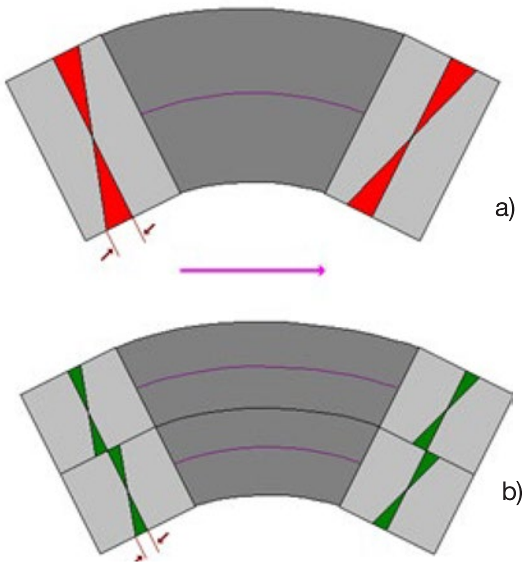


Figure 14: Schematic representation of the material displacement due to different drum speeds of a solid drum (a) and split drum (b) while cornering [1]

By splitting the drum, lateral sliding can be reduced by half.

The use of tandem rollers with lateral offsetting of the drums (crab steering) is advantageous for rolling the edges of courses with no edge confinement which are susceptible to deformation.

To avoid unevenness, the rollers used for chip spreading should not be operated with vibration.

Types of rollers

The following roller types are available for compacting asphalt courses:

– static three-wheeled rollers,
– pneumatic-tyre rollers,
– combination rollers, and
– tandem rollers with different vibratory systems.

The operating principles of the rollers are described in detail in the “M VA” information sheet, which is why only aspects relevant to smoothness are addressed here.

For **static three-wheeled rollers** equipped with drums of different linear loads, a special rolling pattern is strictly speaking required for the main compaction in order to ensure uniform compaction across the paving width. In this case, the rolled strips must be offset in parallel by the amount of the rear drum width.

If the static three-wheeled rollers are equipped with drums of the same linear load, the full width of all drums can be offset (virtually the full width of the roller).

In both cases, an overlap of approximately 10cm must also be taken into account.

If possible, a **pneumatic-tyre roller** should be used in combination with a smooth-drum roller. The use of a pneumatic-tyre roller directly behind the paver with hot tyres and no water spray applied (hot and dry) has proved its worth in continuous paving.

The tyres can be warmed up by driving slowly on the asphalt already compacted by the smooth-drum roller; only after the tyres have warm up sufficiently does the pneumatic-tyre roller switch to the front position.

All tyres must have the same tyre pressure. Tyre pressures should be adjustable so as to allow the compactive effort to be adapted to different paving conditions.

The tyre pressure must be adjusted in accordance with the roller manufacturer’s recommendations. The tyre track left behind must not have any elevations or depressions, which can be easily checked with a straightedge as shown in Figure 15.

A track overlap of the front and rear wheels must exist with the curve radii common in road construction.

Tandem vibratory rollers compact the asphalt mix by the interaction of static linear load, amplitude, frequency, drum diameter and roller speed.

Their compactive effort must be adjustable in order to adapt them to the respective paving thickness and to the asphalt mixes of differing compactability.

Combination rollers compact the asphalt mix by a combination of dynamic and kneading compaction.

They should be designed in such a way that the distance between the tyres is significantly less than the width of the tyre, so that the strips not covered by the tyres can be rolled over in the next pass by appropriate lateral offsetting of the roller with sufficient overlap.

As with the pneumatic-tyre rollers, care must be taken to ensure uniform tyre pressure. When selecting the tyre pressure, it should be kept in mind that the tyre pressure also increases as the temperature rises.

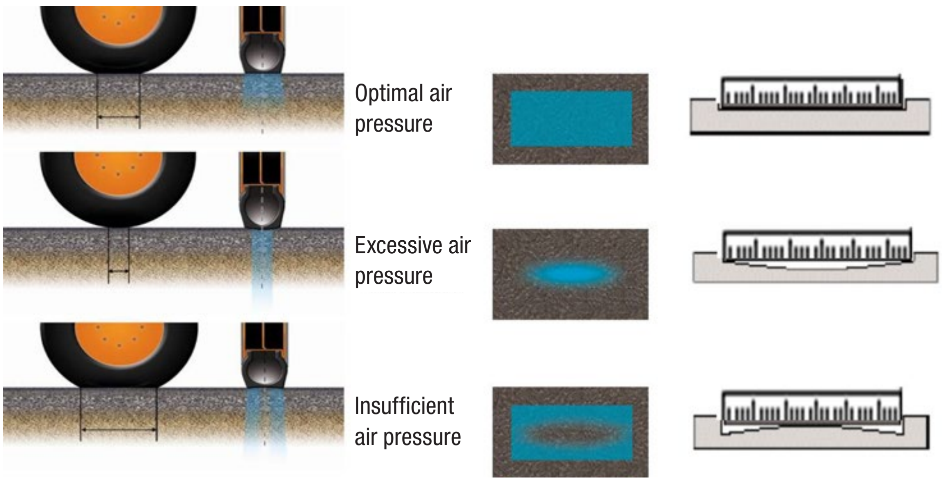


Figure 15: Effects of pressure on the surface profile [13]

As compaction progresses, the contribution of pneumatic tyres to further compaction decreases, which is why more roller passes are required than with a tandem vibratory roller. The pneumatic tyres should be aligned with the paver when rolling.

6.2.2 Equipment selection

Use of the following machinery is recommended for the paving of roller-compacted asphalts with smoothness conforming to requirements:

– wheel loader with clamshell bucket,
– material transfer vehicle with large-capacity hopper insert for the paver,
– a paver that meets the constructional requirements,
– rollers with a static linear load of max. 25kg/cm for initial static rolling of the pavement,
– rollers with a static linear load in the range of 25 to 30kg/cm for the breakdown compaction,
– rollers for spreading the pavement with grit.

To avoid or shorten interruptions of paving due to improper feeding of the paving equipment (see Figure 16), each asphalt paving site must have a wheel loader with a clamshell bucket positioned in front of the material transfer vehicle/paver, wherever possible.

When selecting a paver, the radii and grade to be paved are of particular importance in addition to the planned laydown rate.

Roughness often occurs during paving on steep stretches due to traction problems: When the paver cannot push the truck (often a semi-trailer) smoothly; slip occurs under the track unit, and in extreme cases the paver slides sideways. When selecting the paver, therefore, the relationship between the paver, truck and paving width should always be considered. In the present case there are three possibilities to avoid slip, and thus bumps and roughness:

– use a more powerful paver to push the semi-trailers, or
– use the existing paver and smaller trucks, or
– use the existing paver with a leading material transfer vehicle in front together with semi-trailers.

Figure 16: Paver stop due to improper material transfer to the paver [35]

To ensure uniformity of material transport and traceability of the road paving process, similar paving widths should be specified with “hot to hot” working in echelon with two or more pavers wherever possible.

Table 4 provides information on the suitability of the roller types for different conditions, and as such serves as a guide for appropriate use on different courses. The figures relate to the influence of the compaction equipment used as well as to both the longitudinal smoothness and the compaction performance; this explains the deviations from Table 5 of “M VA”. This is a combined evaluation assessing compaction **and** smoothness after rolling as well as permanent smoothness measured some time after the pavement has been open to traffic. The compaction is rated by means of four symbols, while the smoothness is rated by four colours. If the compaction is rated as unsuitable, the rating of the smoothness is irrelevant (“unrated”) because it is permanently at risk.

These figures relate solely to the main compaction, and require uniform and adequate pre-compaction by the paver, or pressing down of the asphalt course being paved prior to the roller compaction if asphalt mix prone to deformation is used or if the asphalt course is to be placed in thick layers. The overall complexity of rolling cannot be recorded in a single table. Consequently, roller applications depicted as unfavourable in Table 4 may well come into play if appropriate combinations of multiple compacting systems as well as different rollers are selected in the three compaction stages breakdown, intermediate and finish rolling. The relevant information set out in sections 6.2.3 “Planning guidance” and 6.9.1 “General rolling rules to achieve required smoothness” must be observed.

When using oscillation and controlled compaction in the case of porous asphalt courses (PA) according to the Information sheet on asphalt surface courses made of porous asphalt (“M OPA”), Hot mix for thin courses (“DSH”) and Hot mix for thin courses on spray seal (“DSH-V”) according to “ZTV BEA-StB 09/13”, specific knowledge is required which cannot generally be assumed as existing. For that reason, the “unsuitable” rating was chosen for the “Oscillation plus vibration” category.

According to “ZTV BEA-StB 09/13”, static or oscillating smooth-drum rollers are to be used as a rule for hot mix for thin courses (“DSH”) and for hot mix for thin courses on spray seal (“DSH-V”). According to the state of the art, it is also possible to use high-frequency (70Hz) smooth-drum rollers or smooth-drum rollers equipped with an automatic compactor without the risk of crushing aggregates and making waves in the mat. The recommendations of the roller manufacturers must also be observed (see notes in Table 4). Roller operators should be familiar with operation of the different compacting equipment, ideally based on a manufacturer’s training course.

Rollers with oscillation or controlled compaction can support the objective of compacting asphalt courses more evenly, thus more effectively ensuring the required permanent smoothness. However, this does essentially require thorough work preparation by the paving foreman and professional application of the technology by the paving team (coordination and communication by the paving team and roller operator). For this reason, the paving screed must pre-compact an asphalt course as uniformly as possible, and to the appropriate level, both in the paver’s direction of travel and across the full paving width. Particular attention must be paid to ensure a consistent temperature of the delivered asphalt mix.

In order to achieve the required compaction as well as a level and close-textured surface, appropriate combinations of multiple compacting systems and different rollers are advantageous.

6.2.3 Planning guidance

Paver manufacturers recommend the following paving speeds:

– Asphalt base course 2 to 8m/min
– Asphalt binder course 4 to 10m/min
– Asphalt surface course 3.5 to 8m/min

Taking into account the paving width and thickness as well as the transport logistics, lower effective paving speeds in a range of 2.5 to 4.0m/min are often achieved in practice.

Table 4: Suitability of different compaction methods for main compaction

Compaction	Evenness
++ Particularly suitable	Particularly suitable
+ Suitable	Suitable
– Conditionally suitable	Conditionally suitable
0 Unsuitable	Unsuitable
	Unrated

	Nijboer factor C kg/cm²	Static linear load LL kg/cm	Operating weight BG t	Asphalt base course ≤ 14cm	Asphalt base course > 14cm	Asphalt binder course 6 to 8cm	Asphalt binder course > 8cm	Asphalt concrete surface course	Stone mastic asphalt	Combined base and surface course	Porous asphalt	DSH/DSH-V	Surface course made of reduced-temperature asphalt
Static three-wheeled roller (same linear load, same drum diameter)				–	–	+	–	+	++	–	+	+	+
Pneumatic tyre roller				++	+	++	+	++	0	++	0	0	0
Tandem roller	0.20 ≤ C ≤ 0.25	**Static**											
		20 < LL ≤ 25	4 ≤ BG ≤ 7	–	0	–	0	–	0	0	+	+	+
		25 < LL ≤ 29	7 < BG ≤ 10	–	0	+	–	+	+	–	++	++	+
		29 < LL ≤ 32	10 < BG ≤ 14	++	+	++	++	–	+	–	++	++	+
		32 < LL	BG > 14	++	+	++	++	0	+	0	+	++	–
		Dynamic											
		Vibration											
			4 ≤ BG ≤ 7	+	0	+	–	++	+	+	0	0	+
			7 < BG ≤ 10	++	++	++	++	++	++	++	0	0	++
			10 < BG ≤ 14	+	+	+	+	–	+	–	0	0	–
			BG > 14	+[1]	+[1]	–	+	0	+	0	0	0	0
		Oscillation plus vibration[3]											
			4 ≤ BG ≤ 7	–	0	+	–	++	++	+	0	++[4]	+
			7 < BG ≤ 10	+	+	++	++	++	++	++	0	+[4]	+
			10 < BG ≤ 14	+[1]	+[1]	++	+	–	+	–	0	+[4]	–
		Controlled compaction											
			BG > 7	++	++	++	++	++	++	++	0	+[2]	++
Combination roller			BG > 7	+	–	+	+	++	0	+	0	0	0

[1] With high pre-compaction
[2] With the directional oscillator “OSCIL” and the circular oscillator, manually set the smallest required amplitude or select static mode
[3] Oscillation technology is generally combined with vibration technology
[4] Oscillation only

It should be strongly emphasised that the paving performance must be in line with the available mixing capacity of the supplying plant and the asphalt mix logistics and must be adapted to the required rolling work. This is the only way to ensure uninterrupted paving and uniform pre-compaction by the paver.

This requires:

– reserving one half of the road for material feeding when working in echelon,

– avoiding backing up the trucks over long distances, and

– setting up clean out and turning areas (see Figure 41).

The time the truck stays with the paver depends on the paving speed and must therefore be harmonised with the overall planning.

The high take-off speed and the buffering of the asphalt mix make the use of a material transfer vehicle key to consistency during the paving process. Here too, however, it is important to select the paving speed, taking into account the material buffer, in such a way that paving is not interrupted.

With regard to the longitudinal smoothness of asphalt courses, practical experience has shown that it is better to reduce the paving speed and pave without stopping.

In the case of easily compacted asphalt mix or low pre-compaction by the paver, rollers with a low linear load and/or with a large drum diameter should be used for initial compaction. When compacting asphaltic concrete surface courses, small rollers can also be used for pre-compaction in order to introduce compaction into the layer as early as possible without causing cracking in the surface.

Guide values for the main compaction of different asphalt courses can be found in Table 5.

The passes with and without vibration take place in two phases, between which, depending on the asphalt mix, it may be necessary to pause compaction in order to guarantee expulsion of the trapped air.

In the case of easily compacted asphalt mix types, it has proved successful to use rollers with a lower service weight (values in Table 5 in brackets) in the first phase of main compaction in order to avoid roughness in the layer being compacted. In any case, the settings of the **compaction parameters** and the actual number of roller passes required must be determined **in situ**.

Based on practical experience, the following average roller speeds can be recommended[1]:

– 70 to 90m/min (4.2 to 5.4km/h) for seating the mix (static)

– 60 to 90m/min (3.6 to 5.4km/h)[*)] for two-stage main compaction (static)

– 50 to 80m/min (3.0 to 4.8km/h)[**)] for two-stage main compaction (vibration)

– 60 to 100m/min (3.6 to 6.0km/h)[***)] for two-stage main compaction (pneumatic-tyre roller)

– 70 to 100m/min (4.2 to 6.0km/h) for finishing (static)

– 80 to 120m/min (4.8 to 7.2km/h) for finishing (pneumatic-tyre roller)

Note: The “M VA” specifies roller speeds slightly differing from this:
[*)] 4.0 to 6.0km/h
[**)] 2.0 to 4.0km/h
[***)] 3.0 to 4.0km/h
for thick courses and 6.0 to 10.0km/h for thin courses.

Any increase in the roller speed will reduce the compaction effect.

High roller speeds can also lead to roughness when using vibratory rollers, due to the resulting wide impact spacing. The impact spacing should be 2 to 4cm (see Figure 17).

The number of rollers required is determined by the area output, the compactability of the asphalt mix and

[1] In the USA, roller compaction is divided into the stages seating, breakdown, intermediate and finishing. Seating is rarely used. In Europe, depending on the thickness of the asphalt layer and the deformation resistance of the asphalt mix, seating, usually a two-stage main compaction (see Table 5) and finishing are used. The two-stage main compaction can be regarded as breakdown and intermediate, following the North American approach.

Table 5: Compaction parameters and workflow in main compaction of roller-compacted asphalt with tandem vibratory rollers (guide values)

Type of roller-compacted asphalt	AC T		AC B		AC D		SMA	
Frequency	Low		Low/high		High		High	
Amplitude	High		High/low		Low		Low	
Roller speed for main compaction	4.0km/h ≈ 65m/min		5cm = 4.0km/h ≈ 65m/min 8cm = 3.5km/h ≈ 60m/min		4cm = 4.0km/h ≈ 65m/min		4cm = 4.2km/h ≈ 70m/min	
Number of passes with and without vibration	1 x without 3 x with	9 t (6t) 9 t (6t)	1 x without 3 x with	9 t (6t) 9 t (6t)	1 x without 3 x with	9 t (6t) 9 t (6t)	1 x without 3 x with	9 t (12 t) 9 t (12 t)
	2 x with 2 x without	9 t 9 t	2 x with 2 x without	9 t 9 t	2 x with 2 x without	9 t 9 t	1 x with 1 x without	9 t 9 t

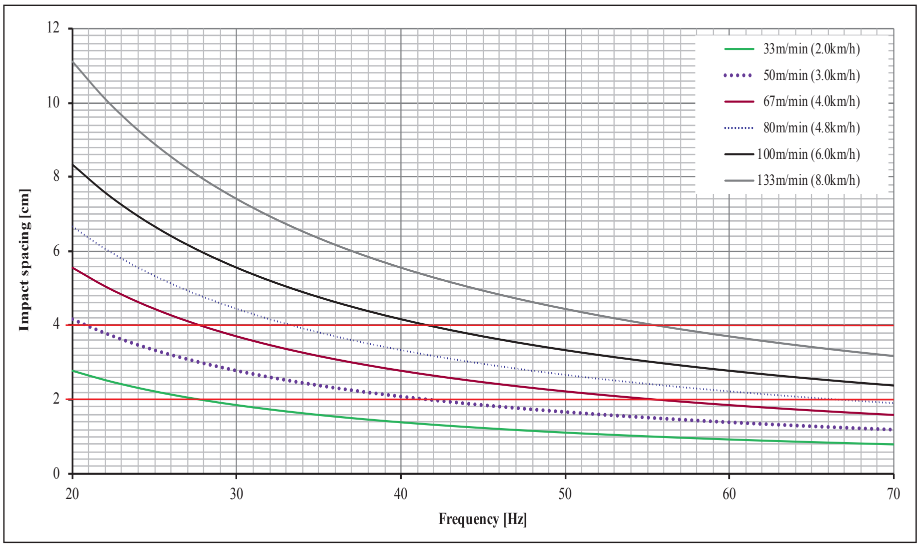


Figure 17: Correlation between roller speed and impact spacing; red lines indicate the optimal range; illustration according to [1]

the weather conditions. For calculation of the required number of rollers, refer to Appendix B and to the "M VA" information sheet.

For a sufficiently high and uniform compaction, the objective should be to achieve the most uniform possible distribution of rolled strips and roller passes, both across the paving width and over the length of the rolling area.

For a sufficiently high and uniform compaction, the aim should be to achieve the most uniform possible distribution of rolled strips and roller passes, both across the paving width and over the length of the rolling area. For large paving widths, rollers delivering the same compaction properties should be operated in parallel.

For the control of rolling work on federal trunk roads, full-area controlled compaction systems are recommended.

For rollers used to press down joints and edges and to spread the asphalt surface course, the roller production rate may be significantly lower – especially with narrow paving widths.

When operating multiple rollers, the area output must be calculated for each roller. The sum of the area outputs of the rollers used in each application area must be greater than the area output in paving (for calculation see Appendix B).

At paving widths in excess of 5.0 metres, two or more rollers should normally be used in parallel for each application area.

The required rolling time must be less than the time available for compaction. The time available for compaction is a result of the cooling the asphalt mix from the paving temperature down to a viscosity-dependent minimum temperature below which effective compaction is no longer possible without the risk of crushing aggregate.

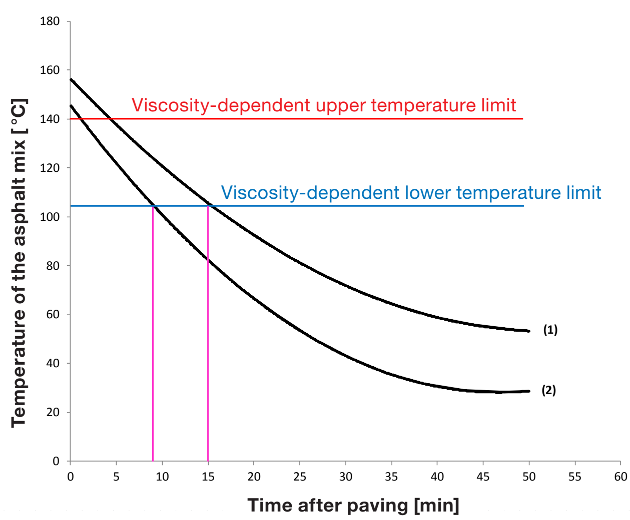
The paving thickness has a huge influence on the time available for effective roller compaction.

Asphalt mix paved in a thin layer cools down very quickly and therefore requires favourable weather conditions, high paving temperatures and rapid deployment of rollers. Asphalt mix paved in thick layers cools down relatively slowly (see Figure 18) and is therefore less sensitive to weather conditions.

At paving thicknesses of around 8cm and more, and at sufficiently high paving temperatures, the time available for effective roller compaction is practically always sufficient.

The compaction conditions can be improved by appropriately higher pre-compaction, intensifying the deployment of rollers and raising the temperature of the asphalt mix within the permitted range.

It should be emphasised, however, that an unlimited number of rollers cannot be deployed to ensure com-



(1) Favourable weather conditions: dry, warm, no wind
(2) Unfavourable weather conditions: damp, cool, windy

Figure 18: Schematic representation of the time available for compaction of an asphalt surface based on weather conditions; illustration according to [38]

paction in unfavourable weather conditions. Too many rollers will shorten the strip length, which should normally be 40 to 60 metres. Shorter rolled strips will mean more reversing points due to changes in direction of travel, which can lead to more uneven pavement surfaces.

6.2.4 Production and paving plan

Before the start of construction (2 to 3 weeks prior), the contractor should provide the client with a detailed production/paving plan and a plan for the removal and production of all superstructure layers, including a detailed description of the machine technology and transport logistics to be deployed, in traceable form.

The paving concept should include as a minimum:

- information on the execution of the milling work (milling profile, method of milling levelling),
- information on the production of transverse joints,
- information on the construction of the individual asphalt pavement courses (paving speed),
- information on the formation of joints, transitions and tie-ins,
- the required paving and compacting technology specified in accordance with “M VA”,
- information on the delivery of the asphalt mix:
  - specification of the asphalt mixing plant(s) (operator, location, initial test number, proof of certification, planned daily delivery quantity);
  - circulation plan for delivery of the asphalt mix;
  - where appropriate, identification of the delivery vehicles;
  - information on the thermal insulation of dump boxes and documentation of temperature measurement;
  - indication of the person responsible for coordination during execution (name; availability and contact information should be ensured).

The information on the paving process, transverse joints, joints and tie-ins for the individual courses should also be set out in plans and detailed views on a suitable scale.

If necessary, the paving concept should also specify the following:

- Information on the production of the bituminous interlayer (SAMI)
- Information on the production of bridge approaches including mastic asphalt paving.

The trucking plan for delivery of the asphalt mix should include the following information as a minimum:

- simple transport route(s) from the asphalt mixing plant to the construction site and back,
- planned laydown rate per type of asphalt mix per time unit,
- number of vehicles,
- number of planned rounds,
- planned cycle time of the transport vehicles from loading (at the asphalt mixing plant) to unloading (at the construction site) taking into account the lower limit values for the asphalt mix temperature on delivery to the site in accordance with the “ZTV Asphalt-StB”,
- assurance of the permitted temperature ranges (see sections 5 and 6.4),
- planned measures to maintain a continuous paving process in the event of disruptions to the logistics plan.

6.3 Quality of the base

The rigidity and evenness of the base are key to the achievable degree of density of the asphalt course being paved. Inadequate base support can make it impossible to compact in accordance with the contract. Therefore, when asphalt courses are being laid on unbound courses, the requirements for the deformation modulus of the base (E_{V2} values) specified in the Additional technical conditions of contract and directives for the construction of unbound granular layers in road construction (“ZTV SoB-StB”) must be met prior to the start of paving. According to the “M VA” information sheet, the smoothness of the base influences the smoothness and uniformity of compaction of the asphalt course being laid on it due to differing paving thicknesses.

Before the subsequent layer/course is laid, the base must be visually inspected to assess its general condition and its longitudinal smoothness and transverse profile must be checked by means of levelling, cord measurement, a 4 metre straightedge and measuring wedge. If necessary, appropriate improvement measures must be taken in short order. **The paving foreman must be able to inspect the construction site at least one day before the start of paving!**

Bases with insufficient

- load-bearing capacity,
- smoothness and
- bonding
- as well those at the incorrect height, or exhibiting
- deformation,
- cracking,
- excessive moisture,
- potholes and
- contamination

are not suitable for surfacing without preparatory measures. Depending on the characteristics identified on the base, both the client and the contractor may be responsible.

As far as possible, the homogeneity of the load-bearing capacity of unbound bases should be determined using test methods according to the Information sheet on comprehensive dynamic procedures for testing

Figure 19: Alligator cracking on a surfaced base [11]

Figure 20: Height equalisation of longitudinal roughness [11]

the compaction of earthworks (“M FDVK E”). Alligator cracking on the surface of an asphalt course which is being reconditioned can be an indication of inadequate load-bearing capacity of the underlaying base materials (see Figure 19). The actual cause of the alligator cracking must be repaired before the asphalt mix is applied.

Longitudinal unevenness of the base not exceeding two-thirds of the track unit length of the paver deployed is usually covered over by the screed during paving, without the screed significantly changing its height (see Figure 20). However, in these short sections there is less compaction after the screed due to the greater paving thickness. When the roller runs over these initially still even sections, owing to the lower density a greater degree of slump than in the other sections will result, and thus a longitudinal roughness (depression). At a high point on the surface, exactly the opposite happens.

If the longitudinal unevenness of the base exceeds the track unit length, the existing depression is fully smoothed.

With automated grade and slope control, the screed in this section will almost fully maintain its position relative to the reference. Owing to the thicker paving, the pre-compaction declines, and the slump increases due to the rolling work.

The resulting uneven surface of the newly laid layer/course reflects the inadequate smoothness of the base. The roughness of the base is transmitted in weakened form until the end of compaction by the rollers.

When paving with no automated grade and slope control system, the screed will change its angle of attack due to the change in the tow point position (lower tow point) and pave at a lower level: the profile of the depression moves in weakened form in the paver’s direction of travel; the pre-compaction remains virtually the same.

For this reason, before the asphalt pavement is laid rough base must be eliminated by means of suitable profile improvement measures, for which mechanical methods, such as face milling or the laying of an asphalt levelling course with the paver, should be done.

6.3.1 Elevation of roadway appurtenances

When paving on a bound base, the height of manholes and other appurtenances must be checked (see Figure 21) and adjusted if necessary.

In the example shown in Figure 22, the height of the manhole has not been adjusted. When paving the asphalt mix, the screed was probably centred on the top of the manhole.

The optimal solution for smoothness and compaction would have been to adjust the height of the manhole to the paving thickness in order to avoid a difference in height.

Alternatively, it would have been possible to lay down a prolonged elevation and, if necessary, install it on one side only.

If roadway appurtenances are located in the shoulder areas of the new pavement, they should be installed on

Figure 21: Checking the height of a manhole [7]

Figure 22: Incorrect overlaying of a manhole which is not at the same height [11]

one side only if possible, because any height correction on the screed inevitably results in less change in height on the opposite side of the screed.

This can lead to problems when paving a crowned asphalt course.

6.3.2 Profile improvements on the base

Depending on the characteristics of the roughness and on economic aspects, the required profile improvement can be achieved both by milling and by levelling with asphalt mix.

High points on a base being surfaced (see Figure 23) can only be removed by milling.

The layer thickness to maximum aggregate size ratio must be adapted to the levelling depth.

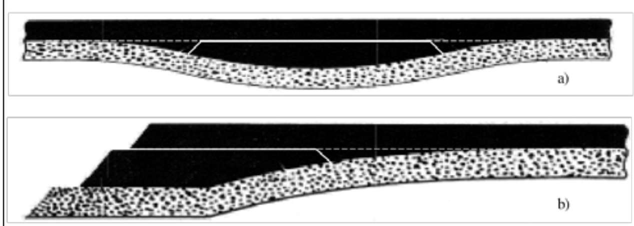
The asphalt mix is paved in a separate pass to compensate for roughness in a bound base. As a rule, paving is carried out with a paver; small areas are worked manually.

Figure 23: Marked high points on a laid asphalt base course [11]

The pre-profiling must be compacted particularly carefully. Figures 24 and 25 show how to pre-profile depressions in the longitudinal direction of the road and shoulders.

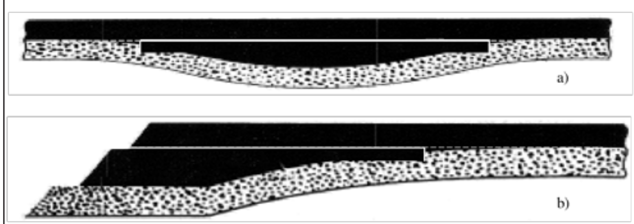
The procedure that has been customary in practice up to now, but is **unsuitable**, is shown in Figure 24. While maintaining the minimum paving thickness of the level regulating layer being applied in the compacted state (2.5 times the maximum grain size), the uneven longitudinal or transverse profile is adapted as far as possible to the required elevation profile being surfaced (dashed lines). Because the asphalt mix cannot be paved to “zero”, the outside edges are not covered by pre-profiling and lead to greater paving thickness and lower densities after rolling. The pavement laid on the pre-profiled base can react to this by deformation.

It is recommended to mill the uneven base in the tapered areas in such a way that excessive differences in layer thickness are avoided while adhering to the minimum paving thickness (see Figure 25). The maximum permissible deviations from the required elevation profile of the base being surfaced, considering Table 2, should be 10mm or 6mm respectively, depending on whether an asphalt base course or asphalt binder course is being pre-profiled.



a) Pre-profiling a depression
b) Elevating a shoulder

Figure 24: Preparation of a bound base for paving by pre-profiling; supplemented illustration according to [38]



a) Milling and pre-profiling a depression
b) Milling and elevating a shoulder

Figure 25: Preparation of a bound base for paving by milling and pre-profiling; supplemented illustration according to [38]

It is in no way recommended to operate the paving screed with a negative crown for the purpose of elevating shoulders on both sides in order to pave to a greater thickness in the areas concerned and so avoid the essential careful pre-profiling. Due to the resulting different degrees of slump, the required longitudinal and transverse smoothness cannot be easily achieved.

6.3.3 Milling the base

Detailed guidance on milling asphalt pavements can be found in "H FA".

Like the paver, the milling machine can also be guided by any reference (wire, averaging ski, 3D, slope sensor, ...) in order to meet the project design requirements and contact specifications (see Figures 26 and 27).

The production of a crown profile and its modification during paving place increased demands on the paving team when working on existing pavements. If the milling does not meet the design requirements, crowned paving and slopes on one side will produce different paving thicknesses, resulting in different degrees of compaction, which can lead to considerable roughness.

So, the course being re-constructed should be milled to the plan profile wherever possible. This has the following advantages:

– same layer thickness everywhere,
– saving on asphalt mix,
– easier measurement,
– same degree of compaction.

If the base is not milled to design, the layer thicknesses will vary widely, the consumption of asphalt mix laid will be higher, and the measuring process will be time-consuming and very complicated. The continual corrections needing to be carried out affect both sides of the screed and have an unfavourable effect on its floating behaviour. Widely varying degrees of thickness not only impair the achievable smoothness, but also have an unfavourable effect on the uniformity of compaction.

The milling work to be performed must be specified as comprehensively as possible by the client. Provision of the condition assessment and evaluation ("ZEB") data as well as the results of layer thickness measurements, core samples and planograph measurements are regarded as useful. Unusual roughness of the surface being milled, and the adjoining areas should also be indicated.

In preparing tenders, it is advisable for the bidder to visit the construction site prior to submitting the tender in order to gain an impression of

– the concrete curbs and gutters,
– the degree of cleanliness of the finished surface and the milled edges,
– the milling depth and the possible milling speed, and
– other special features (road obstacles in the milled area).

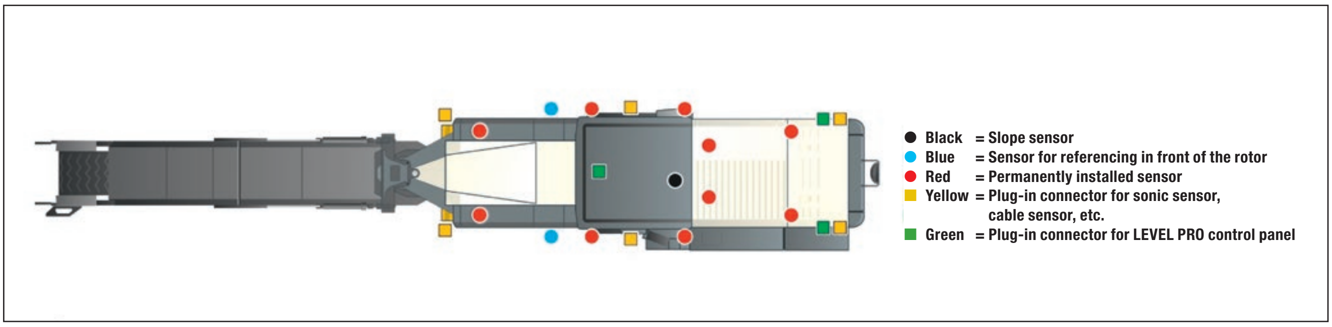


Figure 26: Schematic of a fully upgraded milling machine [37]

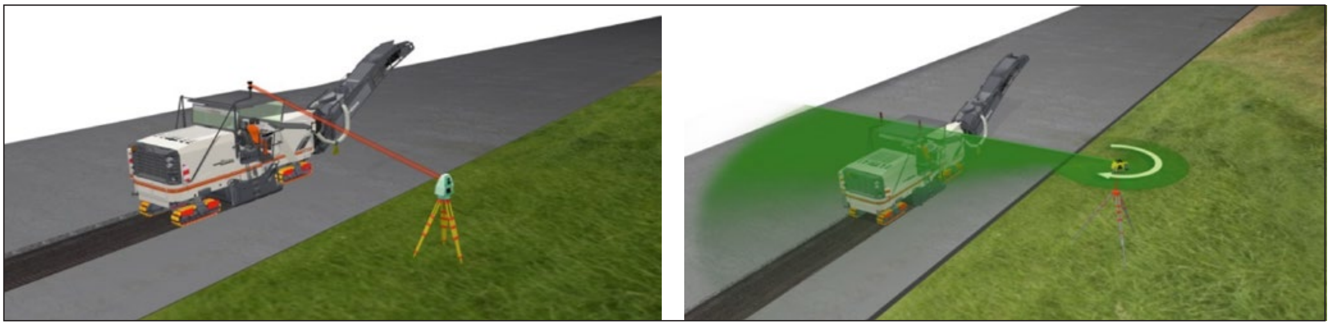


Figure 27: Schematic representation of milling machine control using 3D or laser technology (right) [37]

When carrying out milling work, it has proved beneficial to consider the following points, which may have to be agreed with the client:

– clean/expose the base and its edges,
– remove loose components (e.g. in case of clodding),

Figure 28: Scabbing and delamination on a milled base [11]

Figure 29: Cleaning a milled surface with a high-pressure rotary jet washer-suction unit [20]

Figure 30: Cleaning an asphalt base with an unsuitable high-pressure flat-jet water spray device with upstream extraction, with clearly visible dirt remaining on the base [20]

– mill down to uniform layers,
– if necessary, level course with suitable asphalt mix,
– install tie-ins by milling; as much as possible, do not accumulate the laid asphalt mix in the connecting areas,
– chamfer the connections vertically on the existing structure,
– as far as possible, define connections outside areas of transverse roughness (ruts),
– mill transitions on surface courses generously,
– in the case of multi-layer surface courses, mill transverse joints in a “sawtooth” pattern, i.e. inserting each layer, and
– determine the length of the connecting surfaces by cord measurement (gradient).

When milling, a responsible member of staff from the contractor (milling service provider’s client) should be on-site to give instructions on how to mill (profile, depth, reference) and also to monitor the work. Accordingly, the excerpts from the work specification and bill of quantities relevant to milling should be kept available at the construction site.

Note: If clods are built over, there may be problems with the longitudinal smoothness (varying height of the tow points and/or differing degrees of thickness) and the interlocking bonding between layers. Layer residues (see Figure 28) should be removed prior to surfacing. Such aspects must be taken into account in the paving plan.

The client must be informed of the scheduled milling date so that it can respond promptly to any problems that arise.

The operating personnel must be familiar with the milling machine (intensive training required).

In the event of major warping, controlled milling is required (based on contact wire or comparable technology).

The milled area must be checked and documented prior to tack coat as part of the self-monitoring process – see Guidance for ensuring that bonding on asphalt pavements meets requirements (“H SVA”). The client should be consulted if necessary (such as in the event of clodding and deep cracks). The following points should be noted in this regard:

– The milled base should meet the design requirements and even and clean (not as in Figure 31).
– The milled area must have a uniformly structured surface with regard to the distance between the cutting lines/height of the ridge.
– Within and between the milled strips, the transitions in the transverse pavement profile and the joints should be produced at the same height (not as in Figure 32).
– The start and end of the milled area should be cross-milled or cut in order to form a proper connection (not as in Figure 33).

– The milled area should be free of nests, open transverse joints, wide cracks (> 4mm), potholes and break-outs.

To prevent the dust particles on the milled surface from being carried away by site traffic, cleaning of the milled surface must be started immediately after milling. It must be ensured not only that the loose particles are completely captured, but above all that penetration of the cleaning water into the asphalt base is prevented. This will prevent bubbling when laying the new asphalt course. For the first cleaning cycle, it is sufficient if this is carried out with a self-collecting sweeping and suction machine. As the final stage, cleaning with high-pressure water and immediate subsequent extraction of the sludge/water mixture, for example by rotary jet mounted on a self-collecting sweeping and suction machine, has proved particularly effective in completely removing the residual dust. Thanks to the very short exposure time, using this technology ensures that the water can only act to loosen dirt from the surface, and no water penetrates into the base. After the water has been suctioned off, only a slightly damp surface remains, which is dry after a short time.

Figure 31: Imperfect surface and existing asphalt course after milling the asphalt surface course [7]

Figure 32: Joints between the milled strips and start of paving despite unbroken bitumen emulsion [35]

Figure 33: “Circular” connection point which was not milled or cut straight prior to subsequent laying of the asphalt base course [7]

High-pressure flat-jet water spray devices with upstream extraction are not suitable for the final cleaning of asphalt surfaces, however. If such equipment is used, there is a risk that the flat-spraying high-pressure jets will force water into the base in an uncontrolled manner. The deeper lying dirt in the texture will also not be captured. Moreover, the water is inadequately suctioned off by the upstream extractor, so that the water can also act for too long on the base, and as a result bubbling can occur when the next asphalt course is laid.

6.3.4 Tack coat application

If rain sets in immediately after application of the tack coat, it may be necessary to repeat the procedure! Uneven spraying or uneven distribution of the tack coat, dosing errors or sudden rain shortly before the start of the paving phase (see Figure 34) can result in a very slippery surface, which significantly reduces the static friction between the base and the track unit pads or drive wheels.

The paver has a certain tractive force to overcome the movement and working resistance (rolling, ascending and accelerating resistance, screed). In addition, the movement resistances of the trucks during material transfer must be overcome at periodic intervals.

Figure 34: Base wetted by rain shortly prior to laying an asphalt surface course [11]

If the static friction decreases, the existing tractive force is reduced, as the paver can no longer get traction the base. Due to the imbalance between the driving tractive force and frictional tractive force, and because the existing tractive force is less than the required tractive force, the paving speed decreases.

Since the settings of all other units (augers, conveyor chains, compacting systems, etc.) remain the same, the reduced paving speed changes the balance of forces and moments on the screed, which can react by changing the paving thickness. Changing the paving thickness or pre-compaction while maintaining the same paving thickness has a negative effect on the asphalt course produced.

When an automatic grade and slope control system is used, the screed will maintain its position almost completely. But since the pre-compaction changes, the resulting different degrees of thickness also leads to roughness.

The problem can be exacerbated by the friction between the base and the asphalt mix under the screed:

When the screed slides **on the asphalt mix**, a frictional force is exerted in the paver's direction of travel. The screed's driving force is counteracted by the **frictional force of the material laid on the base**, which is influenced both by the material properties of the asphalt mix and by the structure and characteristics of the surface of the base being paved over.

The friction between the asphalt mix and the base must be greater than the friction between the asphalt mix and the screed. This is the only way to prevent the screed from pushing the asphalt mix. Further compaction by the rollers is now necessary. Otherwise the paving thickness will change. A dirty, dusty base will produce the same effects.

The quantity of bitumen emulsion stipulated in the bill of quantities serves only as a basis for calculation and may have to be adjusted in line with the job site conditions! The bitumen emulsion should as far as possible be applied evenly and over the entire area using an emulsion spray truck, based on the principle of "as much as necessary, as little as possible"!

The spray rate must be set on the distributor (tack truck or spray paver). The spray quantity can be checked by overspraying and check-weighing known flat bodies (tiles, metal discs used for layer thickness measurement) in accordance with [DIN] EN 12272-1: "Surface dressing – Test methods – Part 1: Rate of spread and accuracy of spread of binder and chippings".

As there are clear differences in quality, for large-scale construction projects a sufficient number of hermetically sealed samples should be taken from the bitumen emulsion and tested. Laboratory testing must begin within 7 calendar days.

The cleaned base must be dry and free of any loose, organic and foreign components. The duration of the curing process is heavily influenced by the weather, so the base can be dried with the aid of heaters if necessary. The bitumen emulsion must be completely cured before the asphalt mix is laid (exception: hot mix for thin courses on spray seal ("DSH-V"). This state is reached as soon as the water has completely evaporated or run off and the previously brownish colour has become completely black. In Figure 35, the bitumen emulsion on the milled base had not yet been completely cured when a stone mastic asphalt (SMA) was laid. The effects can be seen in Figure 36: Partial structural changes of the laid course due to sudden evaporation of the water from the bitumen emulsion still present on the base.

Figure 35: Paving an SMA on an incompletely cured bitumen emulsion [11]

Figure 36: Condition of the SMA pavement as shown in Figure 35 after the incompletely cured bitumen emulsion has been paved over [11]

Particularly when laying asphalt mix on a milled base that has not been sufficiently cleaned, or where the bitumen emulsion sprayed on it has not yet broken completely (see Figures 32 and 35), there is a risk of asphalt cement residue accumulating on individual track unit pads. Material builds up on the tracks or tyres (wheeled-paver) and clumps fall of the trucks in line with the screed's tow point during the paving process. When laying an asphalt pavement with no automatic grade and slope control system, the position of the tow point is thus shifted upwards, allowing the screed to react by changing the paving thickness. When an automatic grade and slope control system is used, this effect is somewhat mitigated, though it cannot be completely avoided. The result is periodically recurring roughness, which is usually only detected by the roller operators. For this reason, the screed operators must continually check the cleanliness of the rubber pads or tyres on the paver. Countermeasures should be taken as necessary:

– use material scraper shoes,

– remove large accumulations of material in front of the material scraper shoes on both sides,

– spray the rubber pads with release agent, or

– mechanically clean the rubber pads.

To protect against abrasion and dirt, the pre-sprayed surfaces may **only** be driven over for the purpose of laying the asphalt mix.

At high ambient temperatures, there is a risk that hot truck tyres will carry off the bitumen, so cooling zones should be set up for the truck tyres.

6.4 Producing asphalt mix

Asphalt mixes – and in particular roller-compacted asphalt mixes – are nowadays produced almost exclusively in state-of-the-art asphalt mixing plants. In Germany, batch mixers are mainly used for production. In isolated cases continuous mixers are also used, especially as on-site machinery.

In the asphalt mixers, the components of the asphalt, such as bitumen, aggregates, fillers and possibly asphalt granulates, are homogeneously mixed to produce asphalt mix after specified initial testing. The asphalt mixers are computer-controlled and have a large number of measuring and weighing units by which the relevant parameters for production of the asphalt mix are monitored. Intensive laboratory monitoring of both the building materials used and the finished asphalt mix ensures that the delivered material complies with the specifications of the initial test within very narrow tolerance limits. These standards are detailed in [DIN] EN 13108-21: "Bituminous mixtures – Material specifications – Part 21: Factory production control". The factory production control not only relates to the previously described testing of the building materials and the finished product, but also monitors and calibrates the individual components of the asphalt mixer, such as weighing and temperature units, in a specific cycle as part of the monitoring of the entire plant, thereby guaranteeing a safe manufacturing process.

Fluctuating asphalt mix temperatures have a very great influence on the smoothness of the paved course.

In the current applicable "ZTV Asphalt-StB 07/13", in section 2.3.4 relating to the transporting of asphalt mix, the lowest and highest temperature of the asphalt mix is specified depending on the type of asphalt and the type and grade of binder according to Table 6.

The differences between the lowest and highest temperature are between 30 and 40°C. These temperature specifications do **not** relate to the production temperature alone.

Fluctuations in the temperature of the asphalt mix at the lower end of the permitted temperature range have a more negative effect on the smoothness of the surface. It is therefore advisable to produce the asphalt mix at the upper ends of the temperature ranges, taking into account the respective transport distance.

With today's state-of-the-art mixer control, mixer technology and temperature monitoring, it is possible to produce asphalt mix within narrow temperature limits. This statement is based on the fact that in the continuous production of an asphalt type or grade, the parameters of the asphalt mixer that influence the temperature can be set very precisely.

Table 6: Lowest and highest temperature of asphalt mix in °C*) according to "ZTV Asphalt-StB 07/13", Table 5

Type and grade of binder in the asphalt mix	Asphaltic concrete for asphalt surface courses, asphalt binder, asphalt base course mix, asphalt combined base and surface course	Stone mastic asphalt	Mastic asphalt	Porous asphalt
20/30	–	–	210 to 230	–
30/45	155 to 195	–	200 to 230	–
50/70	140 to 180	150 to 190	–	–
70/100	140 to 180	140 to 180	–	–
40/100 – 65**)	–	–	–	140 to 170
10/40 – 65	160 to 190	–	210 to 230	–
25/55 – 55	150 to 190	150 to 190	200 to 230	–

*) The lower limit values apply to the asphalt mix on delivery to the construction site; the upper limit values apply to the asphalt mix during production and on exiting the asphalt mixer/silo.

**) The manufacturer's specifications must additionally be observed.

The temperature of large quantities of asphalt mixes produced in a continuous process, such as one type of asphalt, can thus be produced within a specific temperature range coordinated with the construction site. The key point in terms of temperature fluctuations, however, is the post-mixing of residual quantities or the production of small quantities of asphalt mix. By combining "similar" types of asphalt mix, temperature fluctuations when producing small quantities can be minimised.

This prerequisite for a limited temperature range is rarely encountered in view of the current demands placed on asphalt mixers. The following influences on the mixer result in fluctuating asphalt mix temperatures that exceed the technically achievable level:

– production of small quantities of asphalt mix, e.g. when reordering residual quantities,

– changing the type and grade of asphalt mix,

– differing moisture content of the aggregates used,

– differing asphalt granulate feed volumes on changing grade.

In order to ensure a uniform temperature, it is imperative that the asphalt mixing plant receives exact information from the paving contractor about the residual quantity to be produced as early as possible (see section 6.5). Only if this information is available can unnecessary restarting of the asphalt mixer to produce residual quantities be avoided.

As part of the internal communications at the asphalt mixing plant, it must be ensured that all parties involved are informed of any change of grade or asphalt granulate change, or fluctuations in the moisture content of the aggregates used.

Only if all the information on the building materials being used is available can the employee operating the asphalt mixer control system optimally control the production process and so produce the asphalt mix with little fluctuation in temperature.

The response to the implementation of the information concerning the raw materials being used must be determined individually on each asphalt mixer, as each one requires different procedures.

6.5 Transport logistics and ordering of asphalt mix

Before planning materials and the paving process, the types of asphalt mix to be laid according to the contract must be identified and checked. If, after the order has been placed, asphalt mix grades change based on the client's instruction, such as following submission of concerns on the part of the contractor or the like, this must be taken into account.

When determining the asphalt mix quantities, the areas or quantities specified in the tender must be checked with regard to the location. If the areas to be asphalted are not clearly defined by plans or the like, they must be defined together with the client. In addition, the edges – especially where there are curbs – should be checked with regard to paving thicknesses. The actual areas and quantities should be determined on that basis.

Asphalt mixes should be ordered at an early stage so as to assure the supply of raw materials.

6.5.1 Planning guidance

In order to ensure site and traffic safety, it must be ensured in advance that the measures approved by the transport authorities are implemented and that they are fully operational by the start of work at the latest.

If, due to local conditions, it should be necessary for machinery and equipment to be parked solely in the construction area, all necessary barriers must also be in place at the time of machine delivery. The space required for machinery after completion of the work must also be determined in advance and prepared as necessary.

Diligent work preparation helps to avoid downtimes and promotes continuous paving. The provision of sufficient clean water and spreading material – possibly at multiple storage locations – is of particular importance. This should also take into account that necessary pumps, standpipes, loading equipment etc. be available in sufficient quantities and kept in the right places.

Any necessary upgrading of the paver to a wider paving width should as far as possible be completed the day before paving begins.

When determining the scheduled start of work, parameters such as the distance from storage areas to the work site, the condition of the equipment, the number of pavers and rollers to be used, etc. must be taken into account. Particularly in the cold season, air temperatures must be taken into account in addition to sunrise and sunset times. If temperatures are expected to be too low early in the morning, the start of paving must be postponed.

When planning the paver's direction of travel and speed, the on-site conditions also play a role. For the sake of optimal work preparation, it is advantageous to involve paving foremen in the decision-making process as early as possible, in view of their comprehensive practical experience. The daily or hourly output should be determined depending on lengths, widths, intersections, traffic islands and construction phases.

Depending on the circumstances, it may be necessary to adjust the hourly output during the day, for example by changing the paver if necessary, as a result of constraint points or widely varying paving widths, and not least also by manual paving. Such dependencies should also be determined as far in advance as possible, taken into account and communicated to the asphalt mixing plant.

The situation at the start of paving must also be considered in good time. If the transition areas cannot be paved at the same speed as mainline paving, the asphalt mixing plant must also be informed so that an appropriate adjustment can be made in the delivery schedule of the asphalt mix.

Unfortunately, the planning of asphalt paving is usually limited to the capacity of the asphalt mixing plant and the time required for delivery vehicles to reach the construction site. This inevitably causes interruptions to paving operations in real-work practice.

They can have a major influence on the success of paving, and so also negatively impact on the smoothness of the course being laid. This also applies to the consistency of paving speed, especially with regard to the interaction of the paving and compacting equipment used and the resultant smoothness of the asphalt layer. For that reason, the laydown rate must be matched to the roller compaction, taking into account the truck logistics. As already mentioned in section 6.2, it should be explicitly stated once again that **mixing capacity does not mean the same as laydown rate!**

6.5.2 Asphalt mix logistics

6.5.2.1 General

Continuous material flow is a key factor influencing smoothness in the production of asphalt pavements.

The paving speed, which depends on the material flow, influences not only the degree of pre-compaction and the angle of attack. Continuous, non-stop paving counteracts the tendency of the asphalt mix to segregate and aids the laying of a smooth asphalt pavement. The longer paving is interrupted, the greater risk of bumps and roughness in the paver's direction of travel after it has restarted.

6.5.2.2 Calculating the hourly asphalt mix rate

A basic prerequisite to achieve smooth pavements is a consistent paving speed. The quantity of asphalt mix required for paving is roughly calculated as follows:

$$M = v_e \cdot t_e \cdot B \cdot \rho \cdot d \qquad (3)$$

where:

B = paving width [m]

M = asphalt mix rate [t/h]

d = paving thickness [m]

t_e = paving time (usually 45 to 50min/h when paving with no material transfer vehicle and 55 to 60min/h when paving with a MTV)

v_e = paving speed [m/min]

ρ = density [t/m³].

6.5.2.3 Transport logistics

In transport logistics, merely considering transport distances and times and potential delivery delays is not sufficient. Other considerations are:

– The required **vehicle type** (size, weight, loading space) must be adapted to local conditions. Any necessary changes of vehicle type in the course of the day must be included in planning.

– Notwithstanding the requirement to use thermally insulated vehicles for construction works on federal highways in Germany above a certain area of asphalt being laid (circular on road construction dated 13 December 2016 from the Federal Ministry of Transport and Digital Infrastructure (BMVI) with reference to the circular dated 16 December 2015) [4], vehicles with an insulated circular dump box are generally to be preferred for transporting asphalt mix.
– The **truck cycle time –** including weighing and loading, driving to the construction site, preparation for unloading, unloading, cleaning and return to the asphalt mixing plant – must be determined.
– The continuously required **number of delivery vehicles** depends on the planned laydown rate (quantity of asphalt mix) and is determined according to equation (4).
– **Truck break times** must be taken into account and scheduled as far as possible. This is an important factor in considering the **driving start time** for each driver.
– To ensure a consistent paving speed throughout the day, the possibility of deploying standby trucks should be investigated. If this is not possible, the logistics processes must be planned so that the paving speed is deliberately reduced, and the screed parameters and rolling pattern adjusted at the same time, in order to guarantee truck breaks for a defined period of time.
– In the event of unforeseeable and ongoing disruptions to material logistics which cannot be compensated by a longer-term reduction in paving speed, paving must be stopped and a transverse joint installed. "Stop-and-go" paving with sudden, irregular changes in paving speed inevitably leads to inconsistent density and must therefore be avoided.

The number of trucks required is calculated as follows:

$$n_{truck} = \frac{M \cdot t_u}{M_l} \quad (4)$$

where:
M = asphalt mix rate [t/h],
M_l = loading capacity of a truck [t],
t_u = truck cycle time [h],
n_{truck} = number of trucks [–].

The number of trucks required should be rounded up.

For example, with a planned laydown rate of 160t/h, a truck cycle time of 60 minutes and a loading quantity of 27 tonnes per truck, at least 6 vehicles must be deployed. This does not factor-in the legally prescribed breaks for drivers. Figure 37 shows an interruption of the paving process due to inadequately planned asphalt mix logistics.

Figure 37: Prolonged interruption of paving due to inadequately planned asphalt mix logistics [11]

It is also wrong for too many trucks to have to wait on-site for the material to be delivered to the MTV or paver. If no defect has occurred on the paving train, the condition shown in Figure 38 is an unmistakable sign that the logistics have been poorly planned, or that the specified loading intervals are not being observed and the drivers are driving in convoys to the site.

Figure 38: Long truck queues in front of paver due to inadequate transport logistics [35]

The delivery quantity per hour must be specified in detail and must be brought to the site as specified. Based on the previous example, this means that with a laydown rate of 160t/h, around 2.7 tonnes of asphalt mix per minute is required. If truck semi-trailers with a loading capacity of 27 tonnes are deployed, one vehicle is needed on the construction site every 10 minutes and not – as is unfortunately often the case – all 6 trucks at once. This aspect must be considered when ordering asphalt mix.

6.5.2.4 Logistical requirements for the asphalt mixing plant and the construction site

Third-party transport contractors must be checked in terms of their vehicles' equipment and their drivers' knowledge of asphalt paving. All vehicle drivers must be informed of many details before their first trip to the construction site regarding directions, stipulated routes where applicable, site access roads, contact personnel on-site, etc.

When working in echelon and where deliveries come from more than one asphalt mixing plant, it is recommended that the asphalt mixing plants/vehicles be assigned to the respective paver. The same applies when laying different types of asphalt mix with one or two pavers (compact asphalt pavements, see Figure 39).

The following information is important to ensure uniform paving.

At the asphalt mixing plant, the cleanliness of the loading areas, the careful handling of the cleaning and release agents provided (no diesel or water) and the wind-proof covering of the loading area must be checked.

It is essential to ensure that the specified loading times and intervals are observed, and that the drivers drive to the construction site directly upon leaving the mixing plant site and not in convoys. As a rule, the loading process (loading, covering, collecting the delivery ticket) takes about 10 to 15 minutes.

In order to determine the required travel time from the asphalt mixing plant to the construction site and back, the planned route can be driven as part of work preparation procedures. From a practical point of view, however, an estimate with the aid of a route planner is sufficient. The average speed of the trucks should be estimated at 60km/h on motorways and trunk roads, and approximately 45km/h on rural and local roads.

In order to minimise the time spent reversing trucks **on-site**, additional turning facilities may need to be planned in the construction site area, taking into account the reversing distance and duration. The distance between the next waiting truck and the paver should be kept as short as possible.

The time between releasing the emptied truck and filling the next truck (truck loading cycle) is normally 2 to 3 minutes.

Drivers should clean the truck loading sill as necessary before returning to the asphalt mixing plant. To avoid spreading residual mix across the construction site or in front of the paver (see Figure 40), a suitable area and appropriate containers (see Figure 41) should be provided for cleaning.

Truck drivers should be informed accordingly. Experience has shown that regular checks must be carried out in order to ensure that the areas and containers provided are actually used. Up to 10 minutes should be allowed within the delivery cycle for cleaning the loading sill and exiting the construction site.

Figure 39: Identification of the vehicles delivering the asphalt mix for the surface course when laying a compact asphalt pavement [11]

Figure 40: Negative example: Residual mix spread across the construction site after cleaning the truck loading rims [35]

Figure 41: Good example of cleaning a truck's loading sill on-site [35]

6.5.3 Ordering asphalt mix

Asphalt mix should be ordered by the site construction manager using a form adapted to the organisation of the contractor and provide for input of the following information as a minimum:

- essential information about the construction site (location, access route, if necessary with plan),
- office-based administrator, including phone number,
- paving foreman, including mobile phone number,
- day of paving work,
- start of paving,
- asphalt mix type and quantity,
- targeted hourly output,
- transport distance (to set the optimal asphalt mix loading temperature), and
- desired vehicle type (details of local conditions or stipulation of specific vehicle type): 3-axle, 4-axle, truck semi-trailer).

Sufficient space should be provided for other relevant information.

Appendix D shows an example of such a form, which must be distributed in advance to all parties involved in the paving process (asphalt mixing plant, truck dispatcher/transport contractor and site foreman). This ensures that the personnel involved all have the same information, and that no discrepancies occur before and during paving.

The following tasks relating to asphalt mix ordering must be performed by the foreman during paving:

- Continuous monitoring of paving progress and
- of deliveries (sufficient cargo space, continuous delivery, traffic problems).
- Continuous monitoring of the quantities of asphalt mix laid in relation to the area being paved (surplus or shortfall).
- Timely initiation of orders for extra load(s) of asphalt mix in order to avoid stoppages of the paving crew(s).

The primary goal must always be continuous paving, so constant dialogue between the asphalt mixing plant and the site foreman is the key!

6.6 Grade and slope control method and reference

6.6.1 Task of grade and slope control

The free-floating screed has self-levelling properties by design. When all the forces involved are in balance and there are no changes to the effective paving parameters, the screed maintains its level and ensures a level surface. Changes in paving speed, asphalt composition, asphalt mix temperature etc. lead to changes in paving thickness.

The task of the grade and slope control system is to compensate for the changes by means of the tow point cylinders with the aim of complying with the geometric specifications such as layer thickness, profile, targeted slope, and longitudinal smoothness. Deploying the automatic grade and slope control system compensates for irregularities in the base. It should be noted that this can result in different paving thicknesses with different degrees of pre-compaction. Rolling produces different degrees of compacted thickness and consequently, roughness.

6.6.2 Functional principle of automated grade and slope control and references

The grade sensor is mounted either on the tow arm or on the end gate of the screed, while the slope sensor is attached to the cross-member connecting the two tow arms. At the start of paving, the sensor reading is calibrated to the reference or zeroed. If the grade sensor detects a change in the screed's height during paving relative to the reference, the screed tow point is adjusted until the grade sensor has returned to its starting position. When using a slope sensor, in the event of a deviation from the target value the tow point cylinder assigned to the sensor is adjusted until the specified slope on the cross-member is reached again.

References for grade and slope control

A physical reference which can be scanned by a sensor is essential to the deployment of any automatic grade and slope control system. Possible references are:

Base

The base can be scanned with a contact or sonic sensor. The smoothness and finish of the base is particularly important here, as any defects will be transmitted to the top layer.

Curbs, gutters

Curbs and gutters can be used as references with contact or sonic sensors when it is desired for the paved surface to match the curb and gutter to some relative thickness. Owing to the natural roughness of curbs, the use of a mechanical ski or an averaging sonic sensor is recommended. Lowered curbs can be bridged by stretching a tensioned wire (stringline) over them or by temporarily switching off the automatics on the grade and slope control system. When connecting to uneven gutters and troughed gutters, make sure that the front curb face (directly connecting to the asphalt course) is used as a reference. In addition, on uneven curbs, the contact or sonic sensor can be placed at various positions along the middle 2/3 distance of the tow arm to reduce the joint-matching performance of the screed.

The automated grade and slope control system must be switched on and off at intervals of approximately 1 metre before and after drains in the gutter.

Stringline

The stringline is used for paving according to the job site specification and can be scanned with both contact and sonic sensors. It is important to tension with a high tensile force (approximately 150kN) so as to avoid sagging of the wire. Nylon or wire ropes with a minimum diameter of 2mm are used. If older generations of sensors are used, wire ropes with a diameter of 3mm are required. It is important that the base is at the correct grade per specifications in order to prevent the paving thickness from falling below the minimum or excessive asphalt mix being consumed.

Laser

Laser technology is used for surfacing with constant longitudinal and transverse profiles. It should be noted that the accuracy of the laser beam decreases with increasing distance from the laser device, due to light diffraction in the air. Applications must therefore be limited to a maximum of 200 metres.

3D control

The 3D control system – also referred to as a virtual stringline – is used to ensure paving is in accordance with the design and the digital job site specification. The references are survey points in the site coordinates system. The advantages are that no stringlines are needed and it is easier to generate complex geometries with many gradient changes. It is important that the base is at the correct grade in order to prevent the paving thickness from falling below the minimum or excessive asphalt mix being consumed.

A selection of suitable grade and slope controls for the paving of asphalt base and binder courses in selected road pavements is set out in Table 7.

6.6.3 Types of sensors and selection of suitable grade and slope controls

Slope sensor

Application: Paving projects with specified slopes.

The slope sensor works like an electronic spirit level, with the aid of a liquid sensor for example. Its working range is typically between ± 10% slope. The sensor is mounted on the traverse beam between the screed tow arms, and continuously measures the slope. Its accuracy is < 0.1%, which corresponds to an error of about 1mm per metre. In paving practice, it has proved useful to set a medium sensitivity in order to avoid over-reaction by the slope sensor.

Depending on the task and screed type, the slope sensor can be used on paving widths to a maximum of 6 to 7 metres, in accordance with the manufacturers' recommendations. The slope sensor should generally not be used for paving asphalt surface courses (except when paving on commercial job sites).

Mechanical grade sensor

Application: Mechanical referencing with high accuracy.

The measurement error is between ± 0.1 and 0.2mm. A reference line, which may be the base itself or a stringline, is copied. Depending on the manufacturer, the mechanical grade sensor has a limited working range between ± 10mm and ± 50mm. For this reason, the height of the sensor is adjusted via a spindle during set-up.

It can be equipped with skis in lengths of 0.3m, 1m and 2m, with a wand for referencing in stringline mode or an averaging beam with a tensioned wire for referencing by direct contact. The mechanical grade sensor can also be used for direct referencing of curbs or parallel lanes by means of skis.

Variable mechanical grade sensor

Application: Direct referencing of curbs or parallel lanes.

The variable mechanical grade sensor combines the advantages of the sonic grade sensor with the high accuracy of mechanical sensors. It has a wide working range of ± 10cm with a measurement error of just ± 0.5mm. It can likewise be equipped with skis, a wand for referencing in stringline mode or an averaging beam with a tensioned wire for referencing by direct contact. It is particularly suitable for direct referencing of curbs or parallel lanes by means of skis.

Sonic sensor

Application: Non-contact scanning of base, curbs and stringline.

The sonic sensor can be used to scan either the base directly or a stringline. Its variable working range is between 250 and 600mm with a measurement error of less than ± 2.0mm. The screed operator can choose whether the sonic sensor is used to reference the base or a stringline. When referencing the base, the sonic sensor is aligned parallel to the working direction. To reference the stringline or a stringline, the sonic sensor is positioned at right angles to the working direction.

Note: The correction values determined within the sonic sensor are influenced by the ambient conditions, especially by the temperature of the base. In particular, non-contact referencing of a hot surface can lead to erratic behaviour and thus roughness in gusty winds and/or varying humidity.

Remedies are a shorter distance between the sensor and the base or use of a mechanical sensor.

Laser receiver

Application: Non-contact referencing over greater distances when paving surfaces with constant longitudinal and transverse gradients.

The standard working range is between 200 and 650mm, depending on the design of the laser receiver. A laser device with a fast-rotating laser beam, which forms a reference plane, serves as a height reference. It should be noted that the accuracy of the laser beam decreases with increasing distance from the laser device, due to light diffraction in the air. Applications must therefore be limited to a maximum of 200 metres. Fog, rain and sunlight also sets limits on application.

Ski with multiple sensors

Application: Compensation for uneven of the base or reference.

The reference is scanned at several points and the result averaged by sequencing multiple sonic sensors. The sensors are mounted on a mechanical beam and can cover an area of up to 13 metres. The advantage is correction of extensive roughness, such as undulations on the unbound base, and levelling of minor localised roughness.

The beam is attached to the tow arm above the screed, so allowing the base to be referenced within the paving area parallel to the paver's direction of travel. Mechanical averaging beams (also known as drag skis) must always be mounted outside the screed.

It must be ensured that the sensors are mounted symmetrically at the same distance to each other, to compensate for fluctuations of the beam. The rear grade sensor can be positioned over the freshly-laid mat. This setting stabilises the measured value, and therefore produces a more even paving result.

3D sensor

Application: When paving motorways, roads and other areas.

A digital job site specification serves as a virtual reference – or virtual stringline – for 3D control of the asphalt paver. A high-precision surveying device – usually an auto-tracking total station or a combination of laser receiver and GPS system – delivers 3D data and information on non-conformity to the job site specification in real time as a measurement variable for grade and slope control. The screed is controlled in height and slope according to the job site specification. Depending on the manufacturer, automatic direction and screed width control is also available as an option.

The prerequisites for this are a well-defined smooth design of the surface to be paved, especially in areas with variations in slope, and a sufficient number of highly accurate survey points along the paving surface. It should be noted that accuracy decreases with increasing distance from the total station, due to light diffraction in the air. The shot distance of total stations is therefore limited to radii between 100 and 150 metres, depending on weather and the specific application conditions. A total station can cover an area of up to 300m before control needs to be passed over to a next total station. This technique is referenced as leap frogging or hot swapping to guarantee continuous paving.

The advantages of stringless paving are cost savings based on the elimination of the stringline, the avoidance of channelling of truck traffic, and high-precision paving with no physical reference.

It is important that the base is at the correct level in regard to design in order to prevent the paving thickness from falling below the minimum and avoid excessive paving material being consumed.

Position of sensors

The slope sensor is mounted on the traverse beam between the tow arms above the auger on the bracket provided by the manufacturer.

The grade sensor must be installed between the auger and the paver's rear panel so as to ensure that the paving is precisely to design.

Rule of thumb: Position a single grade sensor at 1/3 of total tow arm length (= tow point to screed rear edge) from screed rear edge. It should be approximately between auger and rear panel of the paver. Depending on the manufacturer, this results in a position closer to the auger or closer to the tow point.

If the grade sensor is too far behind the auger, the current height of the rear edge of the screed is determined relatively accurately, but the reaction time is no longer sufficient to correct the screed properly. The result is an unevenness in the surface, i.e. a short-wave undulating paving due to over-reaction of the screed.

If the grade sensor is too close to the screed tow point, the tow point will follow the reference in parallel. Information on the floating behaviour of the screed and the current paving thickness is only taken into account to a minor extent. The consequence is a paving result that is relatively smooth, but not to design.

The effects of the different sensor positions on the longitudinal smoothness and longitudinal profile are shown in Figure 42. As the recommended positions of the grade sensor may vary depending on the manufacturer, the asphalt paver and automated grade and slope control system manufacturers' instructions must be observed!

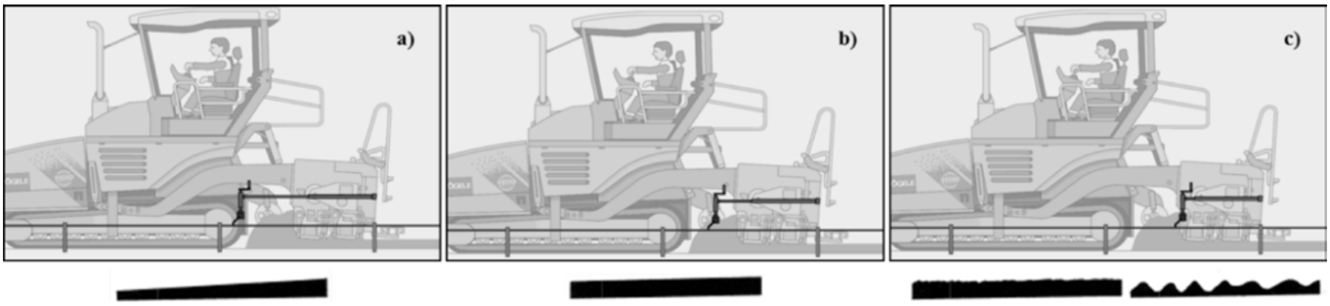


Figure 42: Effect of the grade sensor position on the longitudinal smoothness and profile [33]

In the view a), the sensor is too close to the tow point. Changes in the distance to the reference – such as due to extending a depression – are detected too early. Conversely, information about a change in screed height due to fluctuations in the material feed height or asphalt mix temperatures reaches the sensor only in weakened form. Paving is smooth, but not to design.

If the sensor is too close to the centre of gravity of the screed, as shown in view c), the opposite happens: Changes in the distance to the reference are detected too late and changes due to material fluctuations are detected directly. The result is uneven paving.

If, however, the sensor is positioned in line with the tamper blade of the basic screed, the paving is precisely true to existing grade, but not absolutely even. This is the sensor position required for joint matching or paving for yield (precise thickness control).

In its optimal position (for a Vögele paver) the sensor is between the auger and the rear panel of the paver, as shown in view b). The asphalt mix can be paved smooth and to design because the position of the grade sensor in the area between the auger and the tow point of the paver results in a balance between the reaction time of the screed to changes in its position and the detection of these grade deviations relative to the reference.

6.6.4 Significance of the base

The base should ideally have no defects. In the case of an unbound base such as for frost protection or a crushed-stone base, care must be taken to ensure that the load-bearing capacity is sufficient, and that the course is at the design elevation and that its longitudinal and transverse profile is correct to the design.

Milled areas should as far as possible have no scabbing or clods, as these reflect up to the surface. This is especially true if the base is used as a reference by the grade and slope control system. Machine or manual levelling course may be necessary to ensure sufficient base conditions and to avoid inaccuracies in the referencing.

The possibilities for the paver to compensate for extreme variation of the base are fundamentally limited. As already described, roughnesses in the base leads to different layer thicknesses when the paving is to design. Due to the resultant differing degrees of slump, the irregularities in the base are reflected in the new pavement and negative affect smoothness. Effective compensation for roughness can only be achieved by paving multiple layers.

6.6.5 Preparatory work

Reference for grade and slope control

- Road base, curbs: Pay attention to cleanliness, evenness and constructing to meet design requirements.
- **Stringline:** No slack, taut, pin spacing 5 to 7 metres, in curves 3 to 5 metres, visually check the levelness and tautness of the line.
- When using nylon ropes: Pay attention to the influence of temperature (day/night: accumulation of moisture will cause the rope to lengthen; drying at the start of the day increases this effect). A visual check for rope sag before and during paving is essential, tightening the rope as necessary.
- **Laser:** Check the inclination in 2 axis directions; observe maximum distance of 150 to 200m, in case of strong solar radiation reduce to < 100m due to increasing instability and inaccuracy of the laser beam. Consider other influences:
  - Rain, fog, possible reflection from (coated) glass panes.
  - Position the laser transmitter at the side in front of the paver in the paver's direction of travel.
  - Install protected from vibration at a sufficient distance from the vibratory rollers and on a firm surface.
  - The connection between the transmitter and receiver must not be disturbed by the material feeding process.
- **3D:** Check control points for accuracy and integrity. Check the job site specification. Check the measuring instruments. Paint the boundary lines for paving.

Machine preparation

- Select suitable sensors for the application.
- Ensure correct positioning of the grade sensors.
- Check the control parameters of the control unit. Check the sensitivity setting and the reaction of the tow point cylinders (according to the recommendations of the paver manufacturer).

  Note: When using the same grade and slope control system for different types of pavers, it is essential to observe the relevant manufacturer's instructions (changes of setting).

6.6.6 Paving with automated grade and slope control

During the paving process

- Sonic sensor as grade and slope control:
  - Make sure that the distance to the reference is correct and observe the manufacturer's recommended optimal distance to the reference.
  - When referencing on a hot surface, the measured value may be impaired by wind – including that caused by fast passing vehicles – and lead to unstable grade and slope control. Important when paving "hot to hot": If the base is sufficiently level, it may be possible to dispense with referencing of the laid strip and pave only according to layer thickness.
- Averaging ski as grade and slope control:
  - Be sure to observe the manufacturer's instructions.
  - Ensure equal distance between the sensors, with symmetrical mounting.
  - Ensure that the distance to the reference is correct.
  - In curves or radii, pay attention to the correct positioning of the sensors above the reference. In tight curves, it has been shown in practice that the position of the two outer sensors should not exceed the length of the paver.
  - Widen the control window and adjust the sensitivity as necessary.
  - Application is recommended for short roughness and roughness exceeding two-thirds of the track unit length.
- As a rule, the standard sensitivity setting on the controller recommended by the respective manufacturer is sufficient. In the event of short undulations in the paving result, excessively aggressive control may be the cause. The sensitivity should then be reduced. Inadequate sensitivity can result in long wavelengths because the reaction is too slow.

Paving control

- When paving with a stringline or a fixed height reference (such as a gutter), regularly measure off the stringline and check that it is in accordance to design.
- Regularly check longitudinal and transverse smoothness with a 4 metre straightedge.
- When paving with a slope sensor, the specified slope must be checked with a 4 metre straightedge and bubble level (1 m) or digital smart level.
- Check the bubble level by measuring in two directions (turning over).
- When paving with 3D, regularly check that the mat meets thickness and design requirements using a second total station.
- In the case of deviations from the design, carry out corrections on the controller only in steps. The screed requires a half to one paver length before height correction is fully effective.
- Avoid correcting too frequently.
- Perform multiple control measurements and average the results before making a correction.

Paving asphalt surface courses

- Do not use slope control (except when paving squares).
- Pave constant thickness while following existing grade.
- The **asphalt surface course** should **always be paved without automated grade and slope control**, as the roughness of the base is spread out over a longer paving distance (3 tow arm lengths = 1.5 paver lengths).
- If it is necessary to tie into an existing asphalt lane or other structure when paving surface course, the use of a suitable grade sensor is recommended. If, in exceptional cases, the smoothness of the base being paved over (e.g. an asphalt binder course) cannot be improved, a suitable reference becomes necessary for paving with automated grade and slope control.

6.7 Preparing the asphalt paver and rollers for operation

The prerequisites for achieving the specified smoothness are homogeneous conditions behind the screed with regard to the temperature of the asphalt mix, and adequately high pre-compaction and paving thickness both longitudinally and transverse to the paver's direction of travel. Rolling cannot be used to correct any errors caused by paving with the paver.

6.7.1 Basic equipment of a paving crew

All paving crews should have the following basic equipment:

- wood and metal starting blocks for the paving screed,
- cut-off shoes for manhole covers and catch basin inlets,
- wooden beams for the rollers to park/run on,
- shovels and rakes,
- sampling shovel and sufficient buckets for sampling,
- trowel,

- pouring can[1]),
- folding rules,
- cord,
- bubble levels (1 m),
- 4m measuring straightedge,
- spray paint or marking chalk,
- layer thickness measuring devices (rulers or measuring tape),
- fast-reacting probe thermometers for measurements on the asphalt mix,
- infrared thermometer for measurements on the base,
- motorised or manual tamper,
- cutters,
- jackhammer,
- small vibrating plate compactor with water sprinkling system.

6.7.2 Preparing the asphalt paver for operation

To be able to set up all the necessary machines ready for use by the planned start of paving, it is necessary for the personnel to start work with **sufficient lead time**. The construction manager and/or foreman should give a briefing on the construction site, indicating in particular any change of paving material and paver(s), as well as any bottleneck spots or the like.

The following procedure has proved successful in preparing the paver for use (see check list in Appendix E):

1. Check the engine oil level and operating fluids, and visually inspect the machine for hydraulic leaks and other defects.
2. Adjust the screed width to the paving conditions and joint profile; use an edge attachment and material scraper shoe if necessary.

[1]) To wet the asphalt course when using a larger vibration plate

Table 7: Selection of suitable grade and slope controls for the paving of asphalt base and binder courses in selected road pavements

++ Particularly suitable + Suitable – Conditionally suitable x Not suitable Asphalt base and binder courses in selected road pavements / Sensor type	Paving on an-unbound base	Paving on a bound base	Rural roads	Municipal roads	Plots of land	Roundabouts	Airfields
Mechanical							
Mechanical grade sensor							
Stringline mode	++	++	++	++	++	–	++
Ground mode (mechanical ski < 1 m)	x	Mchanical ski 0.3m only in tight bends				+	x
Ground mode (mechanical ski 1 to 2m)	x	+	+	+	+	x	x
Averaging beam (> 2m)	+	+	+	+	–	x	+
Slope sensor ≤ 6.5m	++	++	++	++	++	x	++
Non-contact, ultrasonic							
Single-cell sonic sensor							
Stringline mode	+	+	+	+	+	+	–
Ground mode	x	+	+	+	+	+	–
Multiple sensor							
Stringline mode	++	++	++	++	++	++	++
Ground mode	x	+	+	+	+	+	+
Averaging Beam/Big Ski	+	++	++	++	++	x	++
Non-contact, optical							
Laser receiver	++	++	x	x	++	x	+
3D control							
3D sensor	++	++	+	+	++	–	++

3. Adjust the transverse auger to the paving conditions.
4. Set the distance between the auger and screed tamper shield.
5. Determine the levelling method; install and connect external control stations and check the function of the automated grade and slope control system.
6. Start the engine, warm it up and bring the hydraulic oil to operating temperature.
7. Test the function of the conveyor.
8. Heat the screed, and to heat up faster preferably hold it a few centimetres above the ground or place it on wooden beams.
9. Run the tamper manually when the screed is heated up and increase the speed in steps up to the maximum so as to ensure proper operation when paving begins.
10. Position the paver, lower the screed, taking into account the compaction thickness; adjust the auger height and screed tow point cylinders.
11. Set the conveyor, auger and compaction system modes to automatic; set the values required for paving and for working in echelon adjust the pre-compaction. The compaction performance of all screeds must be adjusted to the level of the screed with the lowest performance in order to achieve uniform pre-compaction across the entire paving width.
12. Fill the conveyor and auger tunnel with asphalt mix, set the conveyor and auger sensors, and wait about 5 minutes for the asphalt mix to heat up the parts in contact with it.
13. Set the paving speed and start paving.

Depending on the paving situation (paving thickness and width, type and grade of asphalt mix, screed type), the factors listed below can influence both the density and the thickness of the laid and finally compacted course via the movement behaviour of the screed:

In general **condition monitoring** of the paver, particular attention must be paid to the condition of the track unit pads and the material conveying and compacting systems.

The **screed width** and the **auger** must be adapted to the paving conditions. To do so, for the selected **paving width** the necessary accessories recommended by the paver manufacturers (tunnel extensions, auger extensions including external bearings, pre-strike offs/dosing plates) must be fitted in their entirety so as to avoid inconsistent material levels in the auger tunnel and segregation in the outer area of the screed (see Figure 43).

Figure 43: High material level in the left outer area of the screed and material segregation due to missing tunnel extensions and auger shaft extensions [11]

The resultant fluctuating conveyor and auger speeds influence pre-compaction. Different densities of asphalt mix in front of the paving screed lead to differing degrees of compaction and thus to roughness.

Large material accumulations not only increase paving thickness, they also influence the floating behaviour of the screed in the extender area, which as a result tends to periodically go “nose-down” (negative angle of attack).

Due to the measuring position of the material fill level in front of the screed, its fluctuations increase with increasing auger speeds. This fact must be taken into account when setting the paving speed.

Fluctuating material pressure against the tamper shield of the basic screed caused by insufficient adjustment of the conveyor speed, as well as fluctuating auger speeds, will result in a permanent change in the density (pre-compaction) of the asphalt mix subsequently laid and – depending on the duration of the fluctuations – also in a change of paving thickness.

The distance between the end plate and the end of the auger shaft should as far as possible not exceed 65cm. If the distance between the outer auger flight and the end gate is too large, the pressure of the material against the tamper shield of the extender or attachment part concerned will also increase. When working in echelon with two or more pavers, similar paving widths should be specified wherever possible, taking into account material transport considerations and the traceability of the laid asphalt mix.

To be able to react to changing paving widths, and to limit the pressure of the material against the end plate, a minimum distance of 25cm should be maintained.

On short stretches of wider road (such as parking bays or acceleration and slowing lanes), the paver can only be set to the width of the continuous lane. The resultant accumulations in the outer areas of the screed must be kept at an acceptable level by the deployment of additional personnel (temporary shovelling). On longer stretches of widened road, paving must be stopped, and the paver must be reset to the new permanent paving width or laid by the addition of a second paver working in echelon. It is also possible to pave somewhat wider, cut back the asphalt course and pave the widened stretch “hot to cold”.

Edge attachments confine the asphalt mix laterally under the screed (see Figure 11) so that the energy of the compacting systems is not dissipated. Thus, the formation of a shoulder (see Figure 72) when the asphalt mix is easily compacted is prevented by rolling. This option occurs particularly when laying to greater paving thicknesses, or with easily compacted and very hot asphalt mix.

Any material in front of the track unit changes the height of the screed tow point when the track unit passes over it, resulting in a bump. This cannot always be prevented by using **material scraper shoes** in front of the track units (see Figure 47). Notwithstanding this, it must be ensured – especially when paving on a milled base – that no material adheres to the rubber pads of the track unit, causing periodic roughness. This problem is exacerbated by the use of polymer-modified emulsions. It must generally be ensured that the track unit pads are worn more or less evenly.

In order to prevent segregation and roughness (see Figure 44), an increased **distance between the auger and screed tamper shield** has proved to be the best solution for large paving thicknesses and widths and when laying critical materials (e.g. AC 22 B S). This increases the performance required of the paver, though it can also have a negative effect on smoothness if the ratio of machine output to paving width is unfavourable.

Before starting paving, the **hydraulic oil** must be brought to operating temperature. The high viscosity of hydraulic oil that is too cold causes sluggish levelling in particular. The tamper and vibration speeds as well as the output power of the high compaction systems also change if the oil heats up slowly only after paving has begun.

An auger set too high can cause traction problems and material overflow; if set too low it can lead to increased pre-compaction and waviness.

Figure 44: Segregation in an asphalt base course AC 32 T S due to inadequate distance between auger and screed tamper shield [11]

Both these misadjustments affect the density and the smoothness of the laid asphalt course. The **minimum distance between the lower edge of the auger wing and the base** depends essentially on the diameter of the largest aggregate of the asphalt mix:

– Maximum aggregate size ≤ 16mm: Paving thickness + 5cm

– Maximum aggregate size > 16mm: Paving thickness + 8cm

Depending on the manufacturer, it may be necessary to pull the auger even higher at the start of paving, especially when laying an asphalt surface course. This promotes heat-up of the auger gear and the screed tamper shield in order to avoid adhesion of asphalt mix and to ensure the smooth flow of material at this narrow point. About 10 minutes after the start of paving, the auger can be lowered gradually to the above-listed positions.

With regard to the values to be set for tampers, vibration and high compaction, the relationships listed in Table 8 generally apply.

These are guide values which must always be adapted to the actual paving conditions, taking into account the paver manufacturer’s recommendations!

When setting the compacting systems, their wear conditions must be taken into account, and when selecting the tamper speed, the pre-set tamper stroke must be considered. With a higher tamper stroke, it is possible to work with a comparatively lower tamper speed.

Table 8: General screed parameters for paving different courses of roller-compacted asphalt

Pavement type	Asphalt mix	Layer thickness (cm)	Pave speed (m/min)	Tamper stroke (mm)	Tamper speed (U/min)	Vibrator speed (U/min)
Asphalt surface course	SMA	≤ 3	3 to 6	2 to 4	600 to 900	1000 to 1500
		> 3	3 to 6	4	600 to 900	1000 to 1500
	AC	≤ 4	3 to 6	2 to 4	600 to 900	1000 to 1500
		> 4	3 to 6	4	600 to 900	1000 to 1500
Asphalt binder course	AC	≤ 6	4 to 6	4	900 to 1200	2400 to 2800
		> 6	2 to 4	4	900 to 1200	2400 to 2800
Asphalt combined base and surface course	AC	5 to 10	2 to 5	4	1100 to 1400	2400 to 2800
Asphalt base course	AC	≤ 10	2 to 5	4 to 7	1100 to 1400	2400 to 2800
		> 10	2 to 4	4 to 7	1200 to 1600	2600 to 3000

Note: Frequencies for setting tamper and vibration are specified on a case-by-case basis. To calculate the system speeds, multiply the frequencies by 60 s (e.g. f = 20 Hz: 20 Hz · 60 s = 1200 rpm).

6.7.3 Preparing the rollers for operation

Rolling must not be interrupted due to inadequate equipment maintenance. To prepare a roller for operation, the following procedure must be applied:

1. Fill up the roller with fuel.
2. Check the coolant level.
3. Check the oil levels.
4. Visually inspect the hydraulic system.
5. Grease lubrication points as necessary.
6. Fill water tanks and, where applicable, release agent tanks.
7. Check the functionality of the water spray system (spray nozzles, filters).
8. Check the drums/pneumatic tyres for damage and to make sure they are clean.
9. Check the functionality and wear of the scrapers.
10. Select the edge pressing and cutting equipment/ cutting disc and check its functionality.
11. Check the tyre pressure on rollers with pneumatic tyres.
12. Check the compacting systems.
13. Check connections for tight fit.
14. Check the functionality of the chip spreader and load it as necessary.
15. Bring the hydraulic oil to operating temperature.
16. Then place the roller ready for operation at the location where paving is to start.

6.8 Paving with an asphalt paver

6.8.1 General instructions

Asphalt should generally be paved on a **dry and frost-free base**, as laying asphalt on a frozen or wet base result in uneven heat dissipation in the asphalt mix. Uneven heat dissipation leads to different degrees of uncompacted thickness and compaction in the asphalt course, which in turn leads to roughness on the surface.

A wet base reduces friction between the asphalt mix and the base so that the paving screed does not scrape the asphalt mix but pulls it along with it. Wet bases also cause the pavement to slide and crack during rolling.

After rain, the water must run off or be removed from the base before starting or resuming paving.

Since the problem of heat loss increases with decreasing layer thickness, asphalt surface courses should not be laid at all when it is raining. If rain does set in, paving must be stopped until the base has dried again.

An asphalt paver usually works **against the longitudinal gradient** (uphill). When paving downhill, the material pressure against the screed's tamper shield decreases, which not only results in less pre-compaction of the asphalt mix, but also in more frequent changes to the screed's position. Because the truck driver has to continually brake, the equilibrium of forces and moments are further disturbed (see Figure 9). Also, asphalt mix is more likely to spill leak out of the material hopper.

At **intersections**, the main roadway should preferably be paved first. The adjoining stretches of road can then be tied in at the same height, taking into account the compaction thickness. Miscellaneous areas, bullnoses, islands etc. should be paved by machine wherever possible.

6.8.2 Positioning of the screed

If the screed was extended to the required height the day before, in order to produce the construction joint the point at which the layer thickness corresponds to the specified value – seen in the paver's direction of travel – must be determined using a 4 metre measuring straightedge. The transverse joint must be cut back to where it is level as determined by using a 4m straightedge to guarantee a construction joint at the same height.

Figure 45: Improperly executed transverse joint due to insufficient cut-back of the old pavement [11]

Figure 46: Use of flat steel to set the screed before paving [7]

Taking into account the **degree of rolldown** for roller compaction, the screed can in principle be laid on an extensively and properly laid asphalt base. The much safer way to achieve the correct paving height is to support the screed at multiple points with suitable wood or flat steel supports (see Figure 46).

The following methods have proved useful in achieving a greater angle of attack and so prevent the screed from dropping at the start of paving:

- Pulling the second or third truck forward in order to feed the paver with sufficient hot asphalt mix.
- Positioning both tow points one scale point higher.
- Setting a higher material feed rate.
- Starting off slowly.
- Guiding the screed by a reference (e.g. contact wire) and, when laying an asphalt surface course, switching off the automated grade and slope control system after about 20 to 25 metres.

6.8.3 Transferring the asphalt mix from the truck to the asphalt paver

The staff receiving asphalt mix deliveries need to be **authoritative in dealing with the truck drivers!**

So that the paver operator can be sure that the delivered asphalt mix does not exhibit any segregation, crust formation or thermal damage, the truck tarps must be removed immediately before the asphalt mix is transferred to the material MTV/paver.

Unskilled truck drivers can negatively influence smoothness during paving:

- If the truck does not line up in the middle of the paver hopper, or docks at an angle, the paver will follow the truck, causing the screed to swing out and pave unevenly.
- If the truck backs into the paver and makes contact, the screed can be pressed backwards into the already laid pavement.
- Repeated braking of the truck not only leads to traction problems for the paver. If the truck driver stays on the brake during the material feeding process, this will affect the behaviour of the screed. As the frequencies of the compacting systems do not change, the reduction in paving speed shortens the impact spacing of the tamper and the vibration, and the screed tends to lay thicker. The same applies generally to the higher-compacting component units.
- To avoid segregation, the trucks should dump asphalt mix types with a maximum aggregate size of ≥ 16mm slowly.

As investigations have shown when paving SMA with a TV screed [32], the temperature of the asphalt mix has the greatest influence on the screed's self-levelling behaviour. Fluctuating asphalt mix temperatures cause longitudinal and transverse roughness.

If the screed is levelled automatically, temperature differences in the asphalt mix result in different densities after paving, both in the paver's direction of travel and transverse to it. This results in different degrees of roll-down. The auger height of the screed is maintained virtually the same.

If and the screed's self-levelling system is used, the paving thickness increases as the temperature of the asphalt mix rises, with otherwise identical paving parameters. The pre-compaction behind the screed barely changes, however.

Depending on the levelling method, the screed characteristics and the flow behaviour of the asphalt mix underneath the screed, deviations from the target temperature towards lower asphalt mix temperatures in particular can lead to a significant reduction in layer thickness or density after paving. For this reason, it is recommended that measures be taken, in consultation with the asphalt mixing plant, to avoid temperature fluctuations as far as possible (logistics, use of material transfer vehicles, consistent production temperature).

The temperature of the asphalt mix must be checked before transfer to the paver. Deliveries should be rejected where appropriate.

Any asphalt mix that has been spilled in front of the MTV or the paver during material feed must be removed immediately, because this residual mix cools down very quickly and will lead to areas of insufficient compaction. When paving on a bound base, it is necessary to use the material scraper shoes on both the feeder transfer vehicle and the paver in order to prevent asphalt mix residues from getting under the track units. If asphalt mix residues get under the MTV track units, they will solidify, and the paver's material scraper shoes will no longer be able to push them aside (see Figure 47).

Figure 47: Paver track unit running over cold spilled asphalt mix [11]

When cleaning the truck beds on-site, mix chunks that have fallen off and not been removed (see Figure 40) will cool down, and can no longer be pushed aside by the paver's material scraper shoes. It is therefore important to ensure a clean base during the paving process.

It has proved useful to set up clean out area(s) for the trucks (see Figure 41). The truck drivers should be instructed to use the cleanout area(s) and monitored by the paving foreman.

6.8.4 Flow of material in the asphalt paver

The asphalt mix transferred from the truck to the paver is conveyed into the auger tunnel by the conveyors, where it is spread in front of the paving screed by the augers. The condition of the asphalt mix and the way in which the material is fed in front of the screed have a significant influence on the quality of the paving.

Figure 48: Material segregation and exposed tunnel due to hopper wings being folded too late [11]

The level of material in the paver hopper decreases continuously after the material has been transferred by the truck. The **hopper wings** must be operated in such a way that neither cooling nor segregation of the asphalt mix is promoted. The following measures are recommended:

It is essential to ensure that there is always sufficient asphalt mix in front of the conveyor tunnel to cover the tunnel entrance. This prevents the chimney effect and cooling of the asphalt mix in the tunnel and auger area (see Figure 48).

The hopper wings should be closed briefly after each truck exchange so that the partially cooled/segregated material is conveyed inwards as quickly as possible. The hopper wings should move as smoothly as possible on both sides when doing so.

Figure 49: Cause and effect – Defective pre-strike offs cause an open structure of the asphalt course [7]

– If there is a temporary interruption of mix delivery, the hopper should be closed in order to avoid temperature losses. A further intermediate section can be installed if necessary, depending on the waiting time until the next truck arrives.

The asphalt mix should be transported consistently and smoothly from the hopper to the auger tunnel. Fluctuating conveyor speeds result in uneven pressure of the asphalt mix against the tamper shield of the screed. It has been proven that longitudinal material transport is supported by sensors, and preferably runs on two separately controlled **conveyors** so as to be able to supply each auger with material differently (such as on tight bends). It must be ensured that sufficient material is fed under the auger gear box. The relevant instructions of the machine manufacturers must be observed.

It has also proved useful to start paving with **augers** at a higher level, so that the tamper shield of the screed can warm up quickly in the area behind the auger gear. This prevents the asphalt mix from sticking. Approximately 10 minutes after the start of paving, the auger can be slowly lowered to the recommended distance from the base (see section 6.7.2). It is essential to observe the surface structure of the mat immediately behind the screed when doing so. The conveyor control should be set so that there is a slight overfill in the transfer area to the auger tunnel. The auger not only conveys the asphalt mix towards the screed end gate; the rotating auger also compacts it. Depending on the auger geometry, the material fill level and the auger speed, the density of the asphalt mix in front of the screed can be increased by as much as 5%. The forces acting on the screed's tamper shield change, and influence paving thickness.

Even if the screed maintains its position following only a brief fluctuation in auger speed, the degree of roll-down changes in every case.

At a constant asphalt mix temperature and with the same paving parameters, the paving thickness increases as the material feed level rises. For this reason, it is essential to ensure an even flow of material in the auger tunnel.

Incorrectly set or defective **pre-strike offs** (see Figure 49) cause an unfavourably high material level in front of the extenders of a variable width screed. This results in major cooling of the excess asphalt mix. The sharp increase in the displacement resistance of the cooled asphalt mix exacerbates the unfavourable effects of a high material level on the screed's movement behaviour. The screed's extenders may react by twisting, which increases in the direction of the screed end gate. This can often be identified by the open texture of the pavement surface. Only a correct setting of the material tunnel extensions and pre-strike offs ensures that the asphalt mix is continuously consumed in front the screed's extenders and attachment parts, thus ensuring that the asphalt mix is laid evenly and with a uniform surface structure.

6.8.5 Adjusting the compaction performance of the screed

When using a paver, the goal should always be to pave the asphalt mix with an **appropriately high pre-compaction level** which is also **uniform** across the entire paving width. High pre-compaction mitigates the formation of rolling cracks. It is recommended to optimise the screed's performance in the following order: Tamper – vibration – high compaction. The manufacturers' recommendations must be observed.

The required compaction performance of the screed varies from paving operation to paving operation, and depends on a number of different factors, such as the type and grade of asphalt mix, the paving thickness, width and speed, the type of base, and the weather conditions.

If the compaction performance is selected correctly, the screed's weight is supported uniformly on the screed plates over their entire area. The result is a very even asphalt layer with a uniform surface structure.

If the compaction performance is inadequate, the weight of the screed is shifted more to the rear of the screed plates. The resultant excessive angle of attack can cause roughness and high wear on the screed plates. This paving error is often detected too late, however, because the rear edges of the screed plates remove the laid pavement with a uniform structure.

If the compaction performance is too high, the screed's weight is supported more at the front of the screed plates. The resultant incorrect angle of attack likewise causes roughness and high wear on the trailing edges of the screed plates. This paving error can be identified by the fact that the screed is laying a pavement with short, periodically wavy undulations and a very open surface texture. The screed goes "nose-down" (see Figure 50, left side).

However, the higher the pre-compaction by the screed,

– the higher the resistance of the asphalt course to deformation,
– the earlier rolling can be carried out without endangering the smoothness, and
– the longer lasting the smoothness of the finished asphalt course will be.

Figure 50: Two-strip "hot to hot" paving of a 10cm thick asphalt base course AC 32 T S, 50/70 with unmatched screed output (view in opposite direction to paver's direction of travel) [7]

The constraints on the asphalt technology resulting from the larger volume of mix (mortar) during paving due to temperature and compaction must be considered, however. If pre-compaction is too intensive at high asphalt mix temperatures, the current voids content of the asphalt mix under the screed will approach zero and the rigidity of the pavement will be reduced. No increase in rigidity can be achieved by the roller compaction applied immediately after paving, because the large volumes of mix (mortar) and the lack of voids counteract further compaction and resultant inter-locking of the aggregate structure. Only constant-volume deformations occur.

Owing to the complex relationships between the

– asphalt mix type and grade,
– paving thickness,
– paving width,
– paving speed,
– weather,
– paving temperature of the asphalt mix and
– compaction performance of the different screed types,

no general recommendation can be given as to the suitable degree of pre-compaction. In any case, the manufacturers' recommendations must be observed. Their process engineering experts should be consulted if necessary.

When working in echelon "hot to hot" with two or more pavers, the compaction performance of all screeds must be adapted to the level of the screed with the lowest output in order to achieve uniform pre-compaction across the entire paving width (see section 6.7.2).

If this principle is not observed, the density of the laid asphalt mix may vary considerably, and widely differing degrees of rolldown and smoothness problems may occur, as can be seen clearly from Figure 50. The fast lane (right side in picture) was paved with a high-compaction screed and the truck lane with a screed without higher-compacting systems (TV screed). In an effort to also achieve the highest possible pre-compaction in the truck lane, at a paving speed of 3.5m/min a tamper speed of 1500 rpm was set on the TV screed. Due to the high compaction performance selected for this paving situation, there were periodically recurring short waves in the mat. On the left side of the fast lane, pre-compaction was well over 90%, while 89% Marshall density was measured across the entire width of the truck lane. This resulted in significantly differing degrees of rolldown, which were not taken into account during paving and led to the formation of a depression in the centre of the road (white line).

The surface texture of an asphalt course depends, among other factors, on the type of screed used. It is therefore advisable to use the same type of screed in each lane when working in echelon to pave an asphalt surface course.

In view of possible incorrect settings on the conveying and compacting systems, the surface of the laid pavement must be continuously monitored by the screed operators. If defects occur in smoothness, texture or pre-compaction, they must be **remedied immediately**. If this is not possible, paving must be stopped.

The roller drivers feel short waves very clearly and can also detect pronounced long waves. They must inform the paving team immediately if they do so.

Continuous communication between the paving foreman, the paver operators and the roller drivers is essential.

6.8.6 Corrections during the paving process

The following corrections to the paving width, depth and speed influence the screed's behaviour. If the screed is levelled using automatic grade and slope control, the effects may be less pronounced or, in some cases, completely different compared to the manual operating mode.

If the **paving width** changes due to widening or narrowing, a change in the paving thickness is likely. The weight of the screed is supported on the screed plates. In the case of hydraulically-extendable screeds, an increase in paving width means that the same weight force of the screed is distributed over a larger area of screed plate. The balance between the weight force of the paving screed and the lifting force is thus altered, and the screed reacts by increasing the paving thickness while maintaining the same asphalt mix temperature and paving parameters.

If it is necessary to correct the **paving thickness**, it is recommended that the position of the relevant tow point be changed in small steps (half scale points on the tow point cylinder). The correction of the screed correlates with the length of the tow arm and the distance covered. After a height correction in self-levelling mode, the paver must run about one and a half of its lengths before the screed operator checks the paving thickness again. When using the automated grade and slope control system, the screed reaction time is shortened to one paver length. Correcting the paving thickness on one side of the screed inevitably leads to a lesser change in paving thickness on the other side. The screed operators must therefore inform each other of planned corrections to the tow point positions if these are expected to reach or exceed 1 scale point in total.

If the **paving speed** is increased at the same tamper and vibration speeds, the impact distances between the compacting systems increase and the screed tends to lay a thinner mat. When an automated grade and slope control system is used, the screed maintains its height, but pre-compaction decreases.

If the rise in paving speed increases the tamper and vibration speeds in an appropriate manner, the impact distances remain approximately the same and the screed tends to lay a thicker mat, because the time the screed spends above a surface dwell time is shorter and so the influence of the weight force is less. Here, too, the screed maintains its paving height with automated grade and slope control. The pre-compaction decreases by less.

If, in **exceptional circumstances**, the paving speed is to be adapted to the material supply, this must be done in stages (maximum changes of 1m/min each time). At the same time, the tamper and vibration speeds and the output of the higher-compacting systems must be gradually adjusted accordingly. **The procedure is not recommended** because the relationships between tamper and vibration speed and paving speed are not linear. Any change in paving speed influences the rolling pattern and thus the consistency of roller compaction.

6.8.7 Localized bumps and roughness after paver stop

Bumps at start-up resulting from stops of on-site operations is caused by the asphalt mix properties as well as the paving and equipment parameters and is subject to the interaction of the individual influencing variables.

In terms of the asphalt mix, the temperature during paving, the aggregate size and the stability of the mix are important. Paving thickness, paving width, duration of stop and weather conditions are the significant paving parameters. For the paver, tamper lift, tamper speed, paving speed, screed rigidity, the head of material, as well as the manufacturer-specific possibilities of preventing the screed from sinking or floating up, play a role.

It is therefore important that the paving is continuous and non-stop as much as possible. The full range of construction site logistics is key in this.

6.8.8 Paving "hot to cold"

When paving "hot to cold", the screed must not contact the cold pavement. It has proved useful to lift the side plate in the contact area sufficiently so that enough asphalt mix can spill out to create an overlap of about 2cm. The excess material is pushed back into the joint area by the asphalt raker in order to create an excess of asphalt mix in the joint area so as to achieve the required density (see Figure 51).

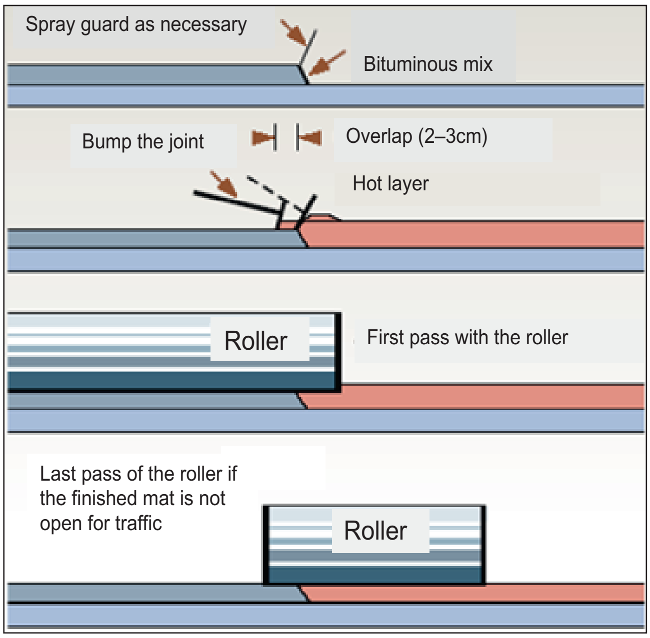


Figure 51: Producing the joint when paving "hot to cold" [9]

Figure 52: Variant of paving "hot to hot" with three pavers working in echelon [11]

6.8.9 Paving "hot to hot" with two or more pavers working in echelon

Generally, the paver with the larger paving width should be in front.

According to "ZTV Asphalt-StB", the distance between pavers must not exceed one paver length, in order to prevent cooling of the last joint area to be paved and the associated defects in surface texture and compaction.

When paving with more than two pavers, in order to avoid introducing defects across the entire paving width it has proved useful for either the outer pavers or the middle paver(s) to be guided and connected to the other paver(s) (see Figure 52). Grade sensors can also be used when paving asphalt surface courses to ensure a good longitudinal joint match. If the base is sufficiently smooth, the use of grade sensors can be dispensed with under certain circumstances. This also rules out the possibility of paving defects being transferred between two pavers.

Special attention should generally be paid to the overlap area. It is advantageous that the overlap should not be more than 5cm. In the wide range of applications 2cm is often sufficient.

Special care must be taken when working in echelon to pave asphalt binder and surface courses with organic additives (waxes) in unfavourable weather conditions. In the area of contact with the cold base, so much heat is drawn from the asphalt mix that the additive in the asphalt mix reaches its crystallisation limit. This can result in the tamper of the following screed hitting a compacted zone in the overlap area. Due to the resistance of the material, the screed periodically moves upwards. The short periodic roughness in the contact area between the two strips runs out to the opposite side of the screed.

When paving asphalt mix types with viscosity-changing organic additives in unfavourable weather conditions, product-specific characteristics must be taken into account.

6.8.10 Transverse joints

To form a proper transverse joint, the connecting edge should be formed at an angle of 90° and painted. Two ramps should be laid from the asphalt mix in the area of the track units over which the paver can gradually run onto the connecting structure (road, bridge). To achieve optimal integration of the structure into the road, it has proved useful in practice to pull a contact wire two to three paver lengths before and after the structure and to operate with automated grade and slope control (see Figure 53).

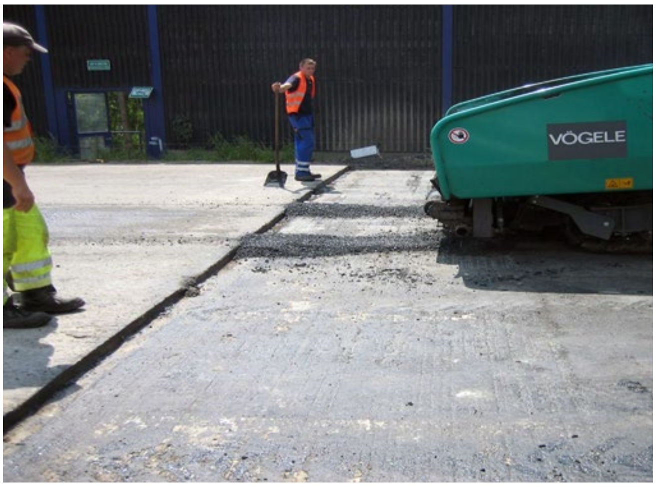


Figure 53: Connection prepared for paving [35]

In the case of skewed joints, the paver should be moved up to the joint and the paving of roller-compacted asphalt completed. After cutting back, the remaining paving area should be closed with mastic asphalt. According to “ZTV Asphalt-StB”, the connections are to be formed as transverse joints.

6.9 Roller compaction

6.9.1 General rolling rules to achieve required smoothness

It is recommended to always keep one roller more than is necessary available for the required compaction.

Paving can only begin when all rollers are ready for operation.

Roller compaction should be started as early as possible with rollers of sufficient weight. The paver must be approached as closely as possible even on the first roller pass. To avoid bumps, in the case of low pre-compaction, thick layers and easily compacted asphalt mix (e.g. asphaltic concrete for surface courses) rollers with a low linear load and a favourable Nijboer factor should be used for pressing down (static roller pass). When compacting stone mastic asphalt grades SMA 8 S and SMA 11 S, the first roller pass can be carried out dynamically with an available rolling time < 10min (see Appendix B).

Asphalt mixes with a harder binder and a high aggregates content > 2mm can be rolled hotter than asphalt mixes with round grains.

Due to the rapid cooling of thin pavements in unfavourable weather conditions, the roller should be moved closer to the screed.

A single rolling temperature for all applications cannot be defined, because different binder viscosities require different rolling temperatures.

The recommendations for application of the various roller types, as well as the compaction parameters and workflow processes, are set out in Tables 4 and 5 and in the relevant explanatory notes.

The roller speed in vibration mode should be selected so that the impact distance is 2 to 4cm (see Figure 17). Excessive impact distances due to excessively high rolling speed lead to washboard-like formations on the pavement surface (see Figure 54).

Rolling must always be carried out smoothly, with no sudden stops, starts or turns. Before reversing, vibration must be switched off in good time in order to avoid vibration or oscillation at a standstill resulting in roller marks which cannot be removed by the subsequent roller passes.

The smoothness and texture of the asphalt surface course must not be damaged by construction equipment driving on it.

The rollers used for spreading should not be operated with vibration. Drum sprinkling must be switched off in order to avoid accumulation and dripping of moist fine particles from the scraper. However, if spreading on the first roller pass is stipulated by contract, sprinkling must be used, otherwise asphalt may stick to the drum.

The chip spreaders **must never be overloaded**, as the enormous increase in the static linear load on the supporting drum during early rolling results in an increased bow wave, which can lead to roughness and roller cracking. With increasing compaction, rollers with overloaded chip spreaders tend to rock even in static operation, causing short ripples or waves in the pavement (see Figure 55).

On older rollers with only one driven drum, the drum should point in the direction of the paver in order to avoid pronounced bow waves and thus the occurrence of roller cracking (except when paving on steep stretches).

At locations where the paving has been stopped, the roller should not be reversed, in order to avoid putting bumps in the mat. It is advantageous to drive diagonally over the areas concerned. If a bump does occur at start up, the relevant section should be rolled as perpendicular as possible to the paver’s direction of travel (see Figure 56).

To achieve better smoothness on changing direction in the hot asphalt mix, reversing during rolling should be carried out in a slight curve so that the resulting bow wave can be eliminated with the subsequent parallel offset roller passes (see Figure 57). If the roller does not have an automatic reversing function, when reversing the rolling direction, it should be allowed to slow down gently and should be started up again immediately without a sudden motion.

Moving from strip to strip on the hot asphalt course should be avoided and must only be carried out on the cooled asphalt course at the end of the rolled strip (see section 6.9.3.4).

Under no circumstances may the roller be left standing on the freshly laid pavement (see Figure 58) or parked on the finally compacted and still hot course.

Once the necessary rolling work has been completed, the rollers must move off the newly-paved area and be parked outside diagonally to the paver’s direction of travel. Due to the heat still present in the drums, the rollers should be placed on the largest possible surfaces (e.g. wooden beams) when on existing asphalt surfaces too.

Figure 54: Formation of impact spacing marks due to excessive roller speed during vibration [11]

Figure 55: Short, periodic bumps in the asphalt surface course caused by an overloaded chip spreader [11]

Figure 56: Cross-rolled section to reduce bumps caused by paver stop [7]

Figure 57: Elimination of the bow wave in front of the paving screed caused by the previous roller pass by means of a slight curve at the end of the following parallel strip [11]

Figure 58: Trough-shaped depression in the pavement caused by a stationary roller [11]

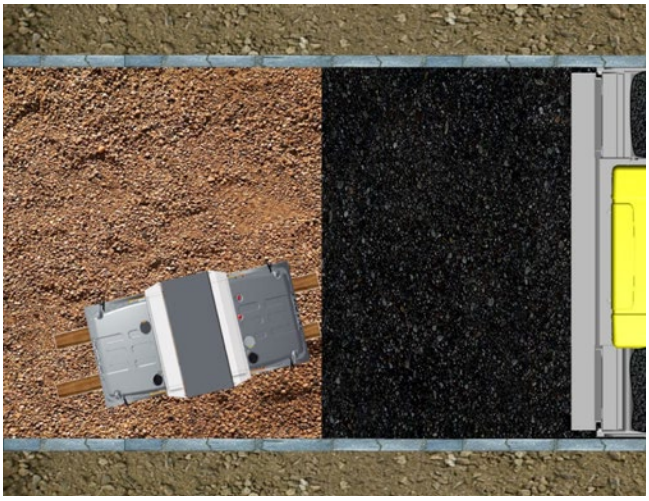


Figure 59: Use of wooden beam supports when driving the roller onto the unsupported asphalt course [13]

If the rollers are to be moved off the laid pavement to the side, boards or wooden beams should be placed in step formation at the relevant points to ensure that the drums roll off at the same height and so avoid deforming the edge.

The drum water spray system must be switched off in time prior to moving off the asphalt course, so as to prevent picking up dirty material of the drums. When driving back onto the surface being worked, the wooden supports should be long enough (at least one roller length) for the scrapers to be able to clean the drums before they reach the fresh pavement (see Figure 59).

In order to create confinement and lateral support for the following parallel roller passes, rolling should begin at the lower edge of the paver strip and move towards the middle or upwards as appropriate. The individual rolled strips must be **overlapped** by at least 10cm (see Figure 60).

On bends with a corresponding slope, rolling must begin on the inside. For tight radii, split drums are advantageous, because pushing of the asphalt being compacted is reduced by half (see Figure 14).

The roller drums and tyres should use as little water spray as possible.

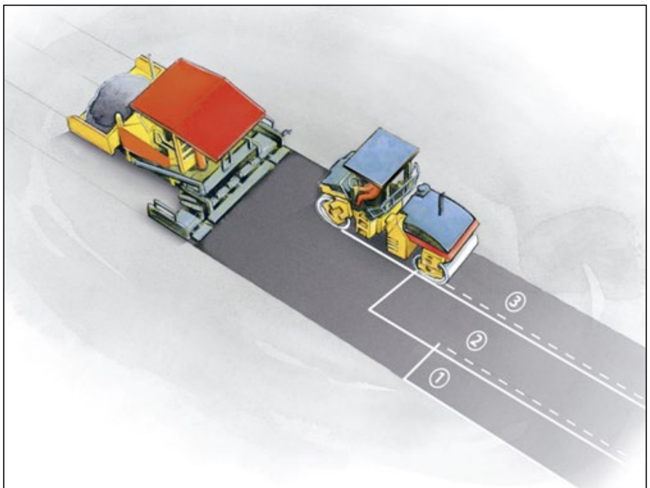


Figure 60: Sequence of rolled strips on a slope angled to the left in the paver's direction of travel [11]

6.9.2 Influence of weather

6.9.2.1 Warm weather

On hot, calm days with no wind, the asphalt mix cools down slowly. It might be necessary to wait a while before running heavy rollers on thick layers of easily compacted asphalt mix at high temperatures. Rollers with low linear loads should therefore be used for pressing down. In general, overly intensive working of the laid pavement with pneumatic-tyred or vibratory rollers can lead to asphalt cement build-up on the surface and so reduce friction. According to the "M VA" information sheet, the risk is particularly high in warm weather.

6.9.2.2 Cool weather

On cold days, the paved asphalt mix cools down rapidly, so that the temperature required for effective compaction may fall below the asphalt-specific minimum before compaction is complete.

By

– higher pre-compaction,
– the use of additional or more effective rollers,
– shortening the length of roller pass or making more roller passes while simultaneously reducing the paving speed,

the compaction process can be intensified.

Rollers with a high compactive effort should operate close behind the paver. Special attention must be paid to rapid rolling.

Shortening the roller pass increases the number of reversing points in the area, which can have a negative effect on the smoothness of the asphalt course.

If the rolling time to achieve the required compaction is longer than the time available due to weather and paving conditions, the paving process should be adjusted accordingly (reduce paving speed, increase roller area output) or terminated.

6.9.2.3 Wet conditions

When paving on a wet base, a great deal of heat is drawn from the hot asphalt mix, placing ideal compaction and solid aggregate interlock at risk.

If an asphalt mix with few voids is laid on a wet base, the water vapour is created and cannot escape. This can lead to bubbling and resultant circular cracks. During rolling, the newly laid pavement is often slides back and forth on the wet base under the action of the rollers. It is advisable to dry the base or to sweep or suction off the water.

Water on the surface of the laid asphalt mix (rain, too much free water) cools the asphalt course from above, and can impair the ability to achieve a tight, sealed surface and lead to roller cracking.

6.9.2.4 Wind

Wind accelerates the cooling of the asphalt course being compacted. On asphalt surface courses especially, sufficient compaction may no longer be achievable in strong winds even in warm weather conditions. This applies in particular to asphalt mix variants that are difficult to compact. This can be countered by the measures set out in section 6.9.2.2.

6.9.3 Rolling patterns

Taking into account the weather and paving conditions as well as the compaction technology available on-site, the roller drivers should be instructed to follow a suitable rolling pattern based on the parameters:

- roller type,
- roller speed,
- rolling pass length,
- sequence of roller passes,
- type and number of static and dynamic transitions.

For compacting asphaltic concrete layers, the use of pneumatic-tyred rollers has proved successful. When compacting asphalt base and binder courses, once the tyres are warm enough (at least 60 °C) the pneumatic-tyred roller works as the first roller after the paver. They can be used on asphaltic concrete surface courses to seal the surface by closing up any surface voids remaining after main compaction.

The most common use of pneumatic-tyred rollers is the compaction of asphalt base-surface courses.

A roller pass means running the roller in one direction. Forward and reverse motion is referred to as a roll.

The roller drivers should be assigned and instructed accordingly:

- define rolling areas (see Figure 61),
- the rollers are kept close together (see Figure 62),
- no changing positions in the rolling pattern,
- each roller remains in its rolling zone,
- coordinated procedure for filling up with water.

One roller driver must be designated to monitor compliance with the specified rolling pattern and intervene to coordinate the compaction process if necessary.

Figure 61: Adherence to the rolling areas specified by the rolling pattern [1]

Figure 62: Adherence to specified rolling areas and keeping close together [7]

6.9.3.1 Rolling transverse joints

Transverse joints should be rolled in stages with the aid of a 4 metre straightedge in parallel strips with a maximum spacing of 15cm, transverse to the roadway and without vibration, until the roller is positioned on the fresh pavement across its full drum width (see Figure 63). If this procedure is not possible due to space limitations, it is also possible to roll diagonal to the traffic lane in a fan-like manner (see Figure 64). Once the roller is fully positioned with both drums on the asphalt course being compacted, compaction should as far as possible be carried out by vibration transverse to the paver's direction of travel. The roller should then move diagonally into the joint for further compaction, if possible without vibration. On moving out, vibration must be turned off before reaching the joint.

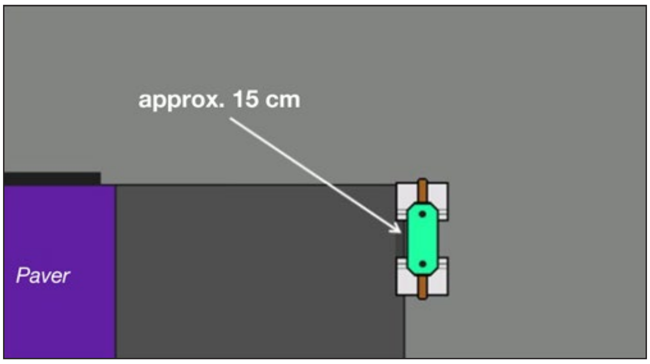


Figure 63: Rolling a transverse joint perpendicular to the paver's direction of travel [1]

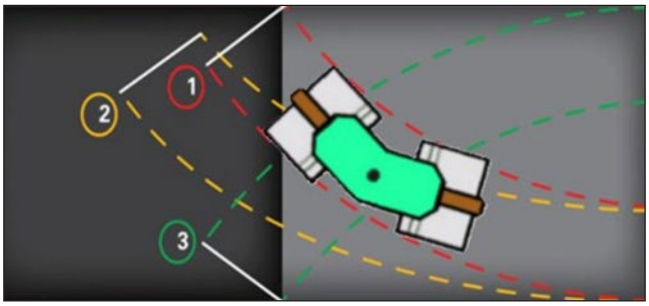


Figure 64: Rolling the joint at an angle to the paver's direction of travel [1, 6]

6.9.3.2 Rolling longitudinal joints

Cold joint

Rubber-tyred rollers are not suitable for rolling longitudinal joints in "hot to cold" paving!

Two basic design scenarios are employed, with differing effects on transverse smoothness.

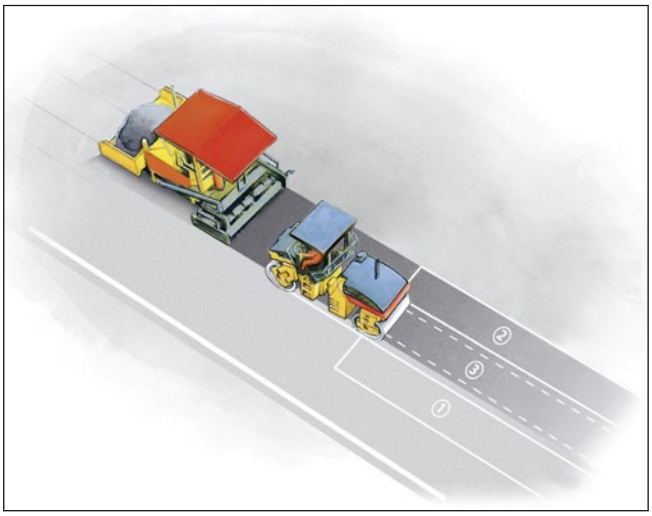


Figure 65: Sequence of rolled strips when rolling a cold joint based on scenario 1 [11]

Scenario 1

Compaction begins in the joint area and is then completed from the outside towards the joint (see Figure 66). This ensures a joint at consistent height. However, pressing the hot asphalt mix out of the joint area may have an unfavourable effect on compaction because there is a tendency to push mix away from the joint.

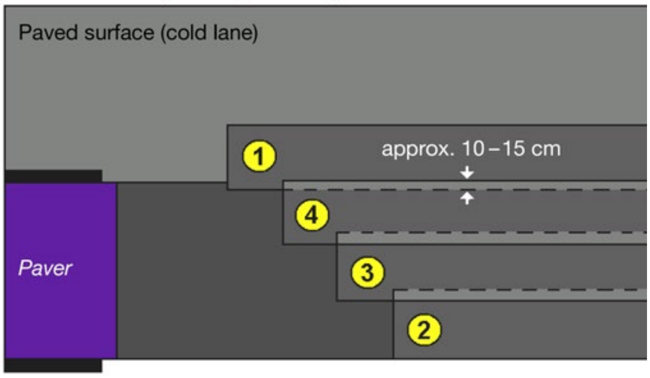


Figure 66: Compaction of the longitudinal joint based on scenario 1 [1]

Scenario 2

Compaction begins in the outer area of the paved strip. The joint is rolled last (see Figure 67), which produces a high contact pressure and compaction complying with requirements in this area. Connection at consistent height is only possible if the asphalt mix in the joint area is still sufficiently hot (roller passes in lane 4 without vibration!).

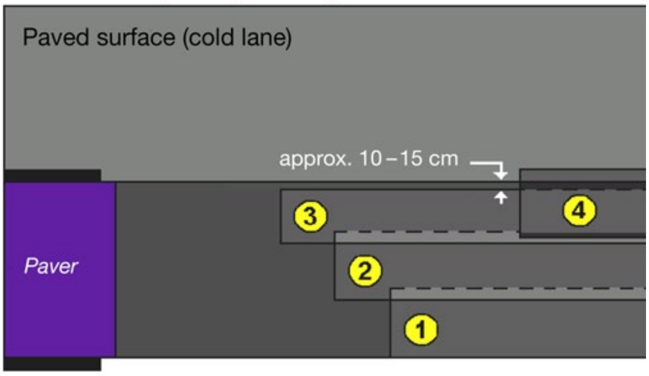


Figure 67: Compaction of the longitudinal joint based on scenario 2 [1]

Hot joint

When paving with two or more pavers working in echelon, ensure that rollers of the same weight class are deployed for breakdown compaction.

Compaction is usually started from the outside and moves towards the centre in such a way that a strip of approximately 15cm remains uncompacted on both sides of the joint when **paving with no crown** (see Figure 69). This strip is rolled immediately afterwards and, if properly executed, results in a tight and even joint between the two tracks.

Note: A different procedure is also possible. To make optimal use of the high temperatures prevailing in the asphalt course for compacting the joint area, and so achieve compaction in line with requirements, the hot joint is rolled first. The compaction of the paving areas behind the two pavers is then based on the rolling pattern shown in Figure 60, as when paving with one paver.

It is essential that the roller driver who is to close the joint area is designated in advance.

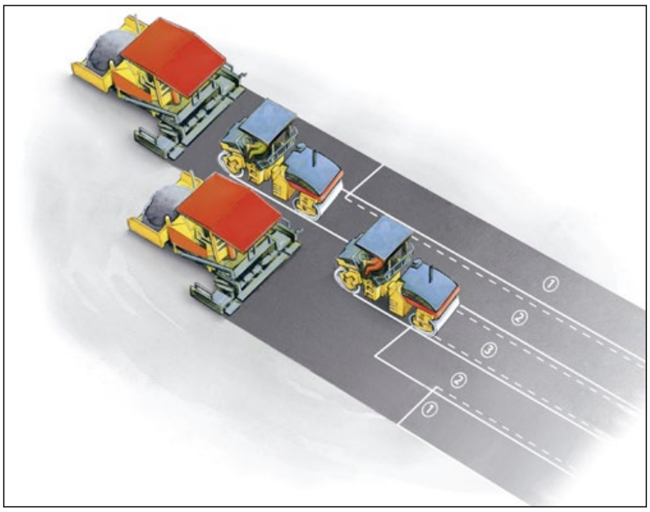


Figure 68: Sequence of roller passes when rolling a hot joint [11]

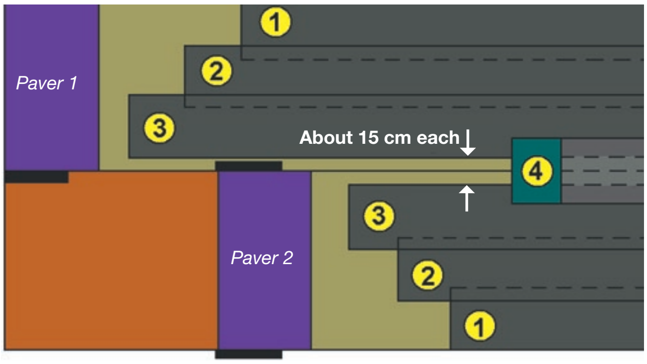


Figure 69: Rolling pattern when working in echelon with no crown [1]

If a crown is laid, the roller drivers must approach the crown from both sides (see Figure 70). The crown is not run over.

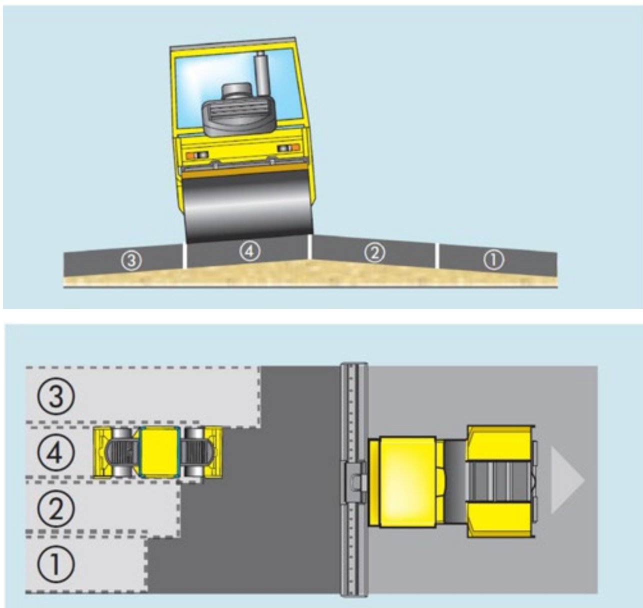


Figure 70: Rolling pattern when paving with a crown [5]

6.9.3.3 Compacting the edge of the road

Roadway edges with curbs

The drum at the front in the direction of travel runs on the curb (see Figure 71). Activating and deactivating the crab steering always starts with the rear drum, because this makes it easier to control the roller and so prevents roughness in the surface.

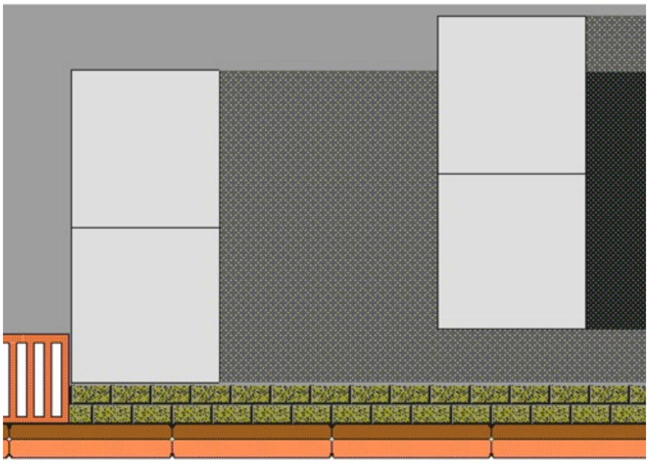


Figure 71: Running on the curb with crab steering [1]

Roadway edges without curbs

To prevent the rounding shown in Figure 72 in the area of the unconfined edge of the pavement being laid, the first roller pass should be carried out approximately 20 to 50cm from the outer edge, as shown in Figure 73. The initially uncompacted area must not be reworked too late, as there is a risk that the entire strip will be sheared off when the asphalt mix cools.

After rolling strips 2 and 3, the as yet uncompacted edge strips are compacted with the aid of the crab steering. The front drum runs on the inside when doing so. The rear drum can then be used to adjust the edge gently to the same height. The roller is supported on the full front drum and most of the rear drum on the already well compacted inner area of the road (see Figure 74). This effectively prevents the formation of a shoulder (see Figure 72).

Figure 72: Formation of a shoulder due to incorrect rolling on the outside of an asphalt course that is unsupported [11]

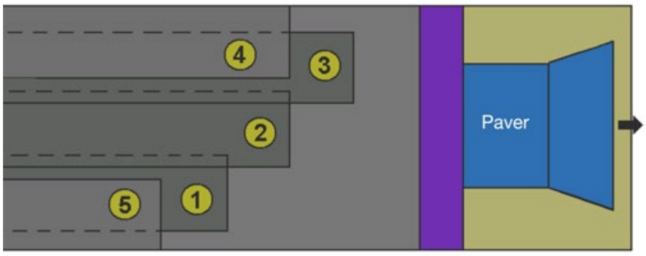


Figure 73: Sequence of the rolled strips when compacting the unsupported edges of an asphalt course [1]

Figure 74: Gentle compaction of the unsupported edge of a paved asphalt course with the aid of crab steering [11]

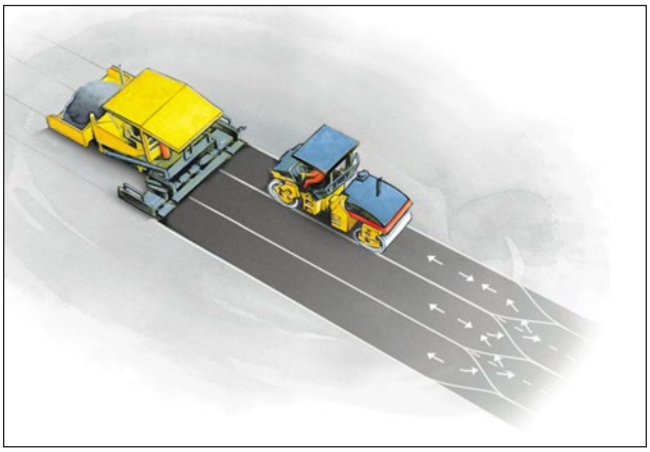


Figure 75: Lane changing in the compacted and cooled area [11]

Figure 76: Use of crab steering at the end of main compaction and start of final compaction with a heavy smooth-drum roller [11]

Figure 77: Final compaction with a tandem vibratory roller used for main compaction [7]

6.9.3.4 Lane changing

Moving from pass to pass (lane changing) must only be carried out on the cooled asphalt course at the end of the rolled strip farthest from the paver (see Figure 75). Lane changing or cornering on the hot asphalt course is not permitted. The individual rolled strips must be overlapped by at least 10cm.

6.9.3.5 Finishing main compaction and transition to final compaction

Roller tracks – which can impair transverse evenness in particular – can be removed at sufficiently high pavement temperatures at the end of the compaction process by using rollers with a high linear load.

Smoothing of the asphalt binder and surface courses should begin in the cooled area at a surface temperature of approximately 60°C. This temperature has been reached when one can place one's hand on the surface for about 5 to 6 seconds.

At the end of main (intermediate) compaction, the crab steering is employed in order to prevent the roller from tilting by increasing the contact width when running over transverse bump, thereby preventing the introduction of further unevenness (see Figure 76). If this roller is also used for final compaction, cross-track smoothing can be carried out in crab steering mode (see Figure 77). The static linear load for smoothing should be at least 25kg/cm. However, final compaction is made much easier by the use of smooth-drum rollers with linear loads of around 35kg/cm.

As opposed to main (breakdown and intermediate) compaction, final compaction usually starts from the high side. The rolled strips must be offset by at least 30cm. Smoothing should be carried out in the longest possible strips, in order to minimise the number of directional changes required.

6.9.4 Inadequate smoothness due to roller damage

The reaction of the asphalt surface to the operation of rollers gives indications as to the current compaction behaviour of the asphalt. From this, conclusions can be drawn for the appropriate selection of rollers.

If damage occurs due to rolling, its cause must be identified and eliminated as quickly as possible!

6.9.4.1 Adhesion of the asphalt mix to the roller drum

Adhesion of the asphalt mix to the roller drum is primarily due to excessively hot asphalt mix and/or inadequate water spray.

In the case of pneumatic-tyred rollers, the main causes are tyres and/or asphalt mixes that are too cold. It has proved beneficial to equip these compacting systems with a release agent spray system, a protective apron and, if necessary, a tyre heater. The asphalt can also adhere to the wheels if the internal tyre pressure is too low.

6.9.4.2 Tender mix

If compaction is started when the asphalt mix temperature is too high, there is a risk that a bow wave will form in front of the roller drum, especially if the asphalt mix is easily compacted. Sinkage is exacerbated by the use of rollers with high linear loads, insufficient pre-compaction by the paver or excessive paving thickness.

In addition, pushing can be caused by insufficient adhesion of the laid course to the base due to wet conditions, dirt contamination or excessive spraying.

As explained earlier, the Nijboer factor influences the rolling behaviour of the drum on the asphalt mix. Consequently, an unfavourable ratio of static linear load to drum diameter in combination with the aforementioned influencing variables can exacerbate the problem.

6.9.4.3 Bulging adjacent to the drum

In addition to unfavourable asphalt composition and insufficient pre-compaction, the main reasons for bulging adjacent to the drum are an excessively hot asphalt mix and exceeding of the specified paving thickness. Bulging adjacent to the drum may result in cracking.

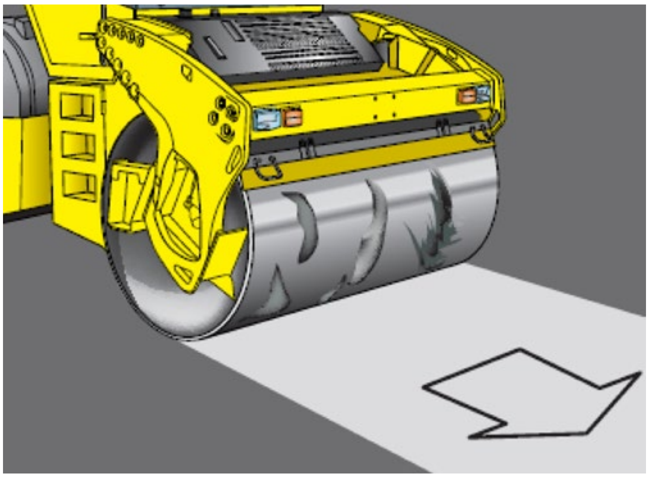


Figure 78: Adhesion of hot asphalt mix to the drum [5]

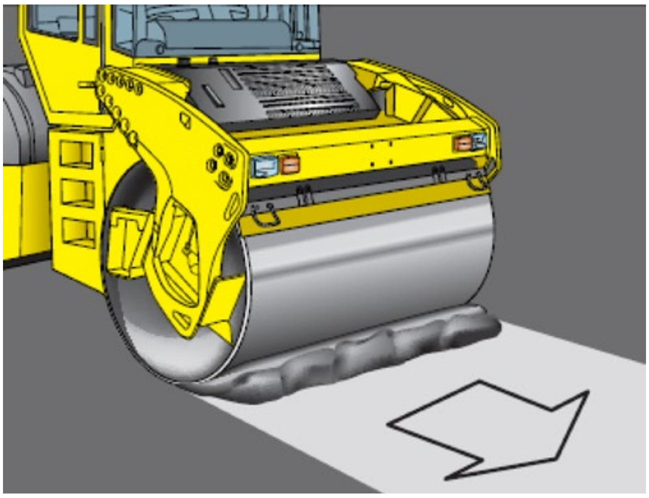


Figure 79: Sinkage of the drum and pushing of the asphalt course [5]

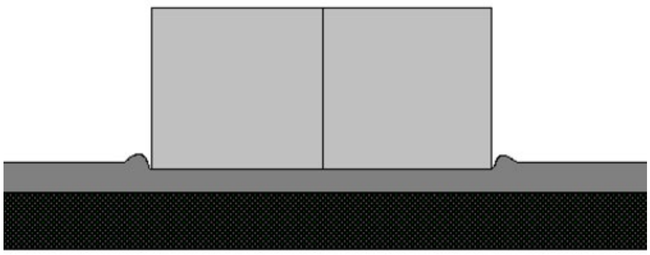


Figure 80: Bulging adjacent to the drum [38]

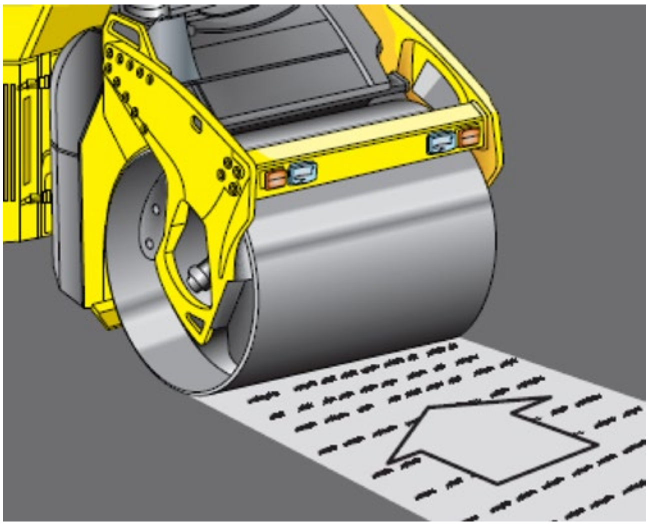


Figure 81: Transverse cracks occurring behind the drum [5]

Figure 82: Transverse cracking directly behind the drum due to using a roller that is too heavy [11]

6.9.4.4 Roller cracking

In addition to the causes already mentioned in section 6.9.4.2, too long a waiting period with the roller leads to the formation of transverse cracks behind the drum. The close-to-the-surface area of pavement being compacted cools down and the compaction resistance increases. At the same time, the hot zone in the middle of the layer causes a sharper increase in compaction. This causes the drum to literally tear into the pavement. Wind as well as cold and excessively wet drums produce comparable effects.

Additional defects in the base, excessive spraying of it and moisture, as well as the paving of thick asphalt courses on steep stretches, can lead to roller cracking in the pavement, as can excessively lean and sandy types of asphalt mix.

Transverse cracks occurring in the lower layers immediately after rolling are harmless. They usually do not extend deeper into the pavement than the maximum grain diameter of the rock used and are re-bonded with hot asphalt mix in the subsequent pavement layers. When paving asphaltic concrete, transverse cracks in the area of the asphalt surface course can be sealed with a pneumatic-tyred roller.

6.10 Acceptance

Acceptance procedures are subject to the “TP Eben” contact measurement rules.

An electronic planograph has proved to be the fastest and most effective method of documenting the evenness of asphalt courses in longitudinal direction.

Surface accuracy measurements in transverse direction are performed with a measuring straightedge or profilograph. This applies both to measurements taken during acceptance testing of the construction work and to measurements taken at the end of the limitation periods for claims based on defects. The profilograph enables reproducible, comparable measurements over the service life of the asphalt surface course.

Smoothness is measured as a control test by the client or by a test body accredited according to the Guidelines for the accreditation of test centres for construction materials and construction material mixtures in road construction (“RAP Stra”). If the contractor has to prove smoothness, the surface accuracy measurement must be carried out in the presence of the client. The accuracy of the measurement must be documented by signatures from both contract parties on the measurement report.

The aforementioned equipment can also be used for the contractor’s own monitoring. To build an experience database, additional surface accuracy measurements may be agreed in accordance with the “TP Eben” non-contact measurement rules.

The requirements of “ZTV Asphalt-StB” and “ZTV BEA-StB” apply to the smoothness of transverse joints and connections to existing structures. Road appurtenances such as manholes and water valves are subject to any requirements laid down in the work specification.

7 Special construction methods

7.1 Thin asphalt surface courses applied hot on spray seal

The hot paving of thin asphalt surface courses on spray seal ("DSH-V") is described in "ZTV BEA-StB 09/13".

The paving speed may be up to 16m/min. The tamper speed and – if possible – the tamper stroke should be adapted to the high paving speed. The asphalt paver manufacturers' recommendations must be observed.

7.2 Rubber-modified asphalt

Rubber-modified asphalt is subject to the Recommendations on rubber-modified bitumen and asphalt ("E GmBA").

No special equipment items or additional cleaning agents are required for paving. The paver's material feeder and hopper should be carefully wetted with a small amount of cleaning agent. Additional cleaning of the equipment may be necessary.

It has proved useful to support and optimise the paving and compaction process with a measuring probe.

No paving problems are to be expected if there is continuous delivery to the construction site, a homogeneous and reacted asphalt mix and a virtually constant asphalt mix temperature. Two-layer paving "hot to hot" is also possible.

No special requirements are placed on the rolling pattern, except that rubber-tyred rollers cannot be used for compaction. The rubber content influences the efficiency of rolling however. In some cases a spring-back effect can be observed.

7.3 Noise-optimised asphalt surface courses

The use of the noise-optimised asphalt mix types AC D LOA and SMA LA in accordance with the Recommendations for the planning and construction of noise-optimised asphalt surface courses made of AC D LOA and SMA LA ("E LA D") is not recommended for paving in intersection areas due to the particular stress caused by shear forces.

Paving "hot to hot" has proved useful in ensuring interlocking. Joints and connections should only be made with hot asphalt mix, and short paving fields should be avoided. Manually paved areas should be kept to a minimum.

7.4 Reduced-temperature roller-compacted asphalt

The use of viscosity-changed binders or viscosity-changing organic and mineral additives to reduce the production and processing temperatures of asphalt is described in the Information sheet on lowering the temperature of asphalt ("M TA"). Organic substances (fatty acid amide, Fischer-Tropsch wax, montan wax) are usually added to the asphalt mix. Mineral additives (zeolite) are rarely used.

Continuous delivery to the construction site is essential when paving. If paving has to be interrupted for more than 30 minutes, the paver should be emptied and the screed repositioned when delivery resumes.

The paving and compaction process should be supported by a measuring probe (isotope probe), in order to avoid over-compaction of the asphalt mix. Special attention must be paid to the development of and adherence to a suitable rolling pattern.

The surface should be blunted immediately after the first roller pass.

7.5 Asphalt surface courses made of porous asphalts

Asphalt surface courses made of porous asphalts are described in "ZTV Asphalt-StB" and in the "M OPA" information sheet, and may be executed by single-layer or two-layer methods.

7.6 Asphalt courses made of mastic asphalt with porous surface

The recommended paving temperature for mastic asphalt with a porous surface (PMA) according to the Working paper on the execution of asphalt surface courses made of PMA ("AP PMA") is between 180 and 190 °C. At temperatures > 195 °C, binder accumulations and streaks were observed on the surface of asphalt courses in the transition area between the basic screed and extender. If the paving temperature falls below 180 °C, depending on the mortar viscosity the desired pore system is no longer necessarily formed in the near-surface area of the course.

The asphalt mix can be ensilaged. The transport time should not exceed 2 hours. To enable uninterrupted paving as far as possible, the distances between the waiting vehicles should be kept as short as possible.

There are no requirements for the minimum air temperature when laying PMA.

The base must be clean and load-bearing. Pre-profiling is not necessary. No special requirements are imposed on drainage systems. No manual preparation is necessary, as the asphalt mix has self-compacting properties.

Operators are strongly recommended to set up a trial area approximately 100 metres length, in order to determine the optimal paving parameters for the current construction project and to avoid the occurrence of material flow-related binder accumulations on the pavement surface. Such a trial area can usually be billed as part of the delivery package if the results are good.

The use of a material transfer vehicle is also recommended.

The paving speed is often between 4 and 5m/min.

Particular importance should be attached to continuous transportation of asphalt mix within the paver. The position of the auger is slightly higher than usual. Nevertheless, excessive quantities of asphalt mix in front of the screed should be avoided. Larger auger diameters have a positive effect on the paving process.

The temperature on the screed plate should be as high and uniform as possible. A maximum of 5mm is sufficient for the press thickness; the roller does not press any more.

The tamper speed should be at the lower limit. True running of the tamper blades must be ensured.

The tamper speed should be precision-adjusted to the surface structure of the laid course.

After paving, no compaction takes place, only levelling of the pavement. Smooth-drum rollers with static linear loads of around 15kg/cm (approx. 3 to 4t) and 25 to 29kg/cm (8 to 10t) are used, generally operated without vibration.

The rollers with the low linear load should be used for early elimination of any transverse steps that may occur between the basic screed and the sliding parts. When the cross-steps can be smoothed depends on which viscosity-changing organic additives were used in production of the PMA. In the case of montan wax and fatty acid amide, the higher solidification point means that rolling can take place earlier (at approx. 130 °C) than is the case with Fischer-Tropsch wax (at approx. 110 °C).

A similar condition applies to levelling of the entire pavement by the rollers with the higher linear load. An appropriate distance from the paving screed must be maintained in consideration of weather conditions. Irrespective of the static linear load of the roller, the roller driver must ensure by visual inspection that the surface is not closed.

Asphalt courses made of PMA which have no curbs at the edge of the road are not at risk of deformation during rolling. The outer edge is pressed down with the bevel gear.

8 Need for training and further education

There are various education and career paths for operating road construction equipment (milling machines, asphalt pavers, rollers) in Germany. There is the classical route via apprenticeship to become a road builder or construction machine operator. But often direct entry is also chosen by way of other trades.

The law currently stipulates only a minimum age of 18 and the appropriate physical and mental capacity.

Road construction is a conventional trade. Road builder have to master many different aspects, and be able to build good roads on any site and under virtually any conditions. To do this, they must:

- be familiar with the general function of road construction equipment and be able to operate and maintain it,
- be able to select the appropriate screed and roller compaction technology,
- be able to set up road construction equipment independently,
- have a sound basic understanding of the latest milling technology, and know the possibilities and limits of modern-day milling,
- be familiar with, and master, the procedures for systematic preparation and post-work follow-up on construction sites (preparation with site markings for example; safety principles, staff induction; selection of suitable levelling equipment; quality control through to the final site inspection; and proper shutdown of equipment),
- master the principles of current materials science and logistics; and
- identify and respond to any problems that arise.

Road construction equipment manufacturers offer relevant technical and application engineering training courses covering both theory and practice. It is also recommended that the courses offered by the construction industry, the building trades, the industry's employers' liability insurance association and the road construction equipment manufacturers be used to obtain operating permits for asphalt pavers and rollers, including with a view to documenting professional qualifications to clients.

Training seminars should be attended every two years if possible, in order to refresh knowledge and learn about new innovations.

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10 List of images

Page

11 List of tables

Appendix A

Terms, abbreviations and symbols

Appendix A 1 Terminology

Smoothness

Smoothness is achieved when the shape or course of the actual profile, apart from its roughness, matches the target profile. It is independent of the design elevation and cross slope.

In this knowledge document, the term smoothness stands for "essentially a degree of smoothness that oscillating deviations of a given road surface produce relative to the corresponding target surface along selected profile sections". [36]

Roller compaction

Compaction of the asphalt mix by the rollers, including all phases of rolling and compaction from breakdown to finish rolling.

Screed base

Area in front of the tamper blade of a TV screed.

Hot and dry

Hot rolling without sprinkling onto the tyres.

Actual profile (longitudinal height profile)

The actual profile refers to the longitudinal section or cross-section through the actual surface of a course.

Roughness (irregularities)

Roughness is any deviation of the actual profile from the target profile that is not attributable to the layer surface texture.

The guidance provided relates to roughness in undulations of between 0.5 and 50.0 metres in length.

Pre-compaction

Compaction of the asphalt mix by the screed according to the "M VA" information sheet.

Appendix A 2 Abbreviations & Acronyms

AC	Asphalt concrete
AC B	Asphalt binder
AC D	Asphalt surface course
AC T	Asphalt base course
AUN	General roughness
BB	Work specification
BEA	Structural maintenance
BLP	Evaluated longitudinal profile
CECE	Committee for European Construction Equipment
DSH	Hot asphalt mix for thin courses
DSH-V	Thin asphalt surface courses applied hot on spray seal
DSK	Thin layers in cold paving
FDVK E	Comprehensive dynamic procedures for testing the compaction of earthworks
FGSV	Forschungsgesellschaft für Straßen- und Verkehrswesen e. V. [German Road and Transportation Research Association], Cologne
HRM	High Speed Road Monitor
inc.	incorporated
LV	Bill of quantities
MTV	Material transfer vehicle
PA	Porous asphalt
RWS	Guidelines for comparative economic analysis in road-building
RWTH	Rheinisch-Westfälische Technische Hochschule [University of Applied Sciences], Aachen
S	Special stressing, gritted mastic asphalt mix
SAMI	Stress-absorbing membrane interlayer
SMA	Stone mastic asphalt
StB	Road construction
TP	Technical testing regulations
TV screed	Tamper-vibratory screed
ZEB	Assessment and evaluation of the condition of roads
ZTV	Additional technical conditions of contract and directives

Appendix A 3 Symbols

A	Lift, position
B	Paving width
C	Nijboer factor
E_{V2}	Deformation modulus (reloading in plate load test)
F_D	Compressive strength
F_F	Area output of paver
F_{GB}	Weight of the screed
F_{Hub}	Hydrodynamic lifting force
F_{Niv}	Force on tow point cylinder
F_{RGl}	Friction force on bottom of screed plate
F_S	Shear force
F_W	Area output of roller
$F_{W,ein}$	Resistive force of mix supporting the screed
$F_{W,ver}$	Resistive force of asphalt mix
G	Axle load
	Weight of paving element
H	Head of material
L	Distance between tow point and position location pivot point
	Length of rolled strip
LL_{stat}	Static linear load
M	Asphalt mix rate
M_l	Loading capacity of a truck
N	Number of rolled strips
N'	Rounded number of parallel rolled strips
S_B	Centre of gravity of screed
$\ddot{U}$	Roll overlap (min. 10cm)
W	Material resistance, number of rollers
W'	Rounded number of rollers
Z	Tractive force
ZP	Screed tow point
Z_{res}	Resultant tractive force
b	Drum width
b_{eff}	Effective rolling width of the drum
c	Lower third point of head of material H
d	Drum diameter, paving thickness
f_n	Effective output factor (paving: 0.75; rolldown factor: 0.83)
g	Specific weight
h_{ZP}	Position of tow point
l	Length of screed plate
n	Number of roller passes
n_{truck}	Numbers of trucks
t_e	Paving window
t_{erf}	Required rolling time
t_u	Truck cycle time
t_{verf}	Available rolling time
v_e	Paving speed
v_w	Roller speed
x, y	Cartesian coordinates
Ψ	Fill level
α	Angle of attack
γ	Working angle
ρ	Density

Appendix B

Interaction between paving and compaction performance

The following example (for demonstration purposes only) illustrates the interaction between the paving performance with the paver and the compaction performance with the rollers (breakdown and intermediate compaction only, no finish rolling or transverse joint compaction) (for symbols see Appendix A).

Example

Paving an SMA 8 S, 25/55-55 A; paving thickness 4.0cm; specific paving weight 96kg/m^2; paving width 6.50m; paving length 2000m; available asphalt mix quantity 140t/h; tandem vibratory rollers with drum widths of 1.70m and 9.5t; compaction at low amplitude and high frequency (53Hz); temperature at start of rolling 140 °C; roller speed 65m/min; rolled strip length 50m; 6 roller passes (4 with vibration, 2 static)

Paving speed and area output of the paver

$$v_e = \frac{M}{f_n \cdot g \cdot B} = \frac{140\,t/h}{0.75 \cdot 96\,kg/m^2 \cdot 6.50\,m} = 5.0\,m/min \quad \text{(A 1)}$$

$$F_F = \frac{M}{g} = \frac{140\,t/h}{96\,kg/m^2} = 1458\,m^2/h \quad \text{(A 2)}$$

Rolling width

$$N = \frac{B}{b - Ü} = \frac{6.50\,m}{1.70\,m - 0.10\,m} = 4.06 \rightarrow N' = 5 \quad \text{(A 3)}$$

$$b_{eff} = \frac{B}{N'} = \frac{6.50\,m}{5} = 1.30\,m \quad \text{(A 4)}$$

Roller area output

$$F_W = \frac{b_{eff} \cdot v_W \cdot f_n}{n} = \frac{1.30\,m \cdot 65\,m/min \cdot 0.83}{6} = 701\,m^2/h \quad \text{(A 5)}$$

Number of rollers required for main compaction

$$W = \frac{F_F}{F_W} = \frac{1458\,m^2/h}{701\,m^2/h} = 2.08 \rightarrow W' = 3 \quad \text{(A 6)}$$

At a paving width of 6.50 metres, it is not possible to operate three rollers side by side. With six roller passes, it is also not possible to evenly divide the required rolling work into a combination of 2 + 1 rollers (two leaders and one follower). Consequently, it must first be examined whether the breakdown and intermediate compaction can also be achieved with **two rollers** if the area output of those two rollers is slightly increased. The roller speed would have to be increased accordingly for this. That also increases the required number of roller passes. Increasing the roller speed by 1km/h, for example, from 4 to 5km/h at a vibration frequency of 53Hz reduces the impacts per metre by 20%, which is why the number of roller passes with vibration now required is assumed to be 5 (a total of 7 passes).

Area output of a roller

$$F_W = \frac{F_F}{W} = \frac{1.458\,m^2/h}{2} = 729\,m^2/h \quad \text{(A 7)}$$

This results in an average **roller speed** of

$$v_W = \frac{F_W \cdot n}{b_{eff} \cdot f_n} = \frac{729\,m^2/h \cdot 7}{1.30\,m \cdot 0.83} = 79\,m/min = 4.7\,km/h \quad \text{(A 8)}$$

According to Figure 17, at a frequency of 53 Hz and a roller speed of 4.7 km/h the impact spacing is 2.5 cm, and is therefore within the optimal range. The question of whether the available time for roller compaction is sufficient is particularly important in this context.

Rolling time

$$t_{erf} = \frac{L \cdot n \cdot N'}{v_W} = \frac{50\,m \cdot 7 \cdot 5}{79\,m/min} = 22.2\,min \text{ (total)} \quad \text{(A 9)}$$

$$\rightarrow 11\,min \text{ per roller} = t_{erf} \leq t_{verf} \approx 12\,min \text{ (in good weather!)} \quad \text{(A 10)}$$

The required rolling time is in the limit range. If the weather deteriorates (e.g. sudden rain or the like), the required compaction can no longer be achieved due to the temperature. Then there might only be about 10 minutes available for roller compaction. In order to further improve the area output of the rollers, it would be necessary to increase the roller speed. The resultant greater impact spacing would in turn require more roller passes. In the available time window of around 12 minutes (or 10 minutes respectively), roller compaction would not be possible.

Consequently, it is only possible to reduce the laydown rate of the paver to such an extent that the time available for roller compaction is not exceeded, taking into account an efficiency factor of 25 % (overlaps, reversal times, weather conditions).

Rolling time

$$t_{verf} = 12\,min \cdot 75\% = 9\,min \rightarrow 18\,min \text{ for both rollers} \quad \text{(A 11)}$$

To be able to comply with the 25 % efficiency factor, the theoretical **area output of the asphalt paver** must change (2 rollers each at 75 % efficiency = 1.5 rollers):

$$F_F = F_W \cdot W = 729\,m^2/h \cdot 1.5 = 1094\,m^2/h. \quad \text{(A 12)}$$

With a specific paving weight of 96kg/m², the asphalt mix requirement for paving is therefore around 105t/h, which means a reduction in the **paving speed** from 5.0m/min to around 3.7m/min:

$$v_e = \frac{M}{f_n \cdot g \cdot B} = \frac{105\,t/h}{0.75 \cdot 96\,kg/m^2 \cdot 6.50\,m} = 3.7\,m/min \quad \text{(A 13)}$$

This results in a **roller speed** of

$$v_W = \frac{F_F \cdot n}{W \cdot b_{eff} \cdot f_n} = \frac{1094\,m^2/h \cdot 7}{2 \cdot 1.30\,m \cdot 0.83} = 59\,m/min = 3.5\,km/h \quad \text{(A 14)}$$

The impact spacing is approximately 2 cm, and is at the optimal range (see figure 17).

If a material transfer vehicle is placed ahead of the asphalt paver, the effective output factor can be increased to 95 to 100 % and paving carried out without interruption, provided the paver is continuously supplied with material. With the same asphalt mix quantity of 105t/h, paving could be executed at a **constant paving speed** of

$$v_e = const = \frac{M}{f_n \cdot g \cdot B} = \frac{105\,t/h}{1{,}00 \cdot 96\,kg/m^2 \cdot 6.50\,m} = 2.8\,m/min \quad \text{(A 15)}$$

Appendix C

Sample breakdown of a paving concept

The following example represents a possible paving scenario. The main items should be supplemented as necessary by meaningful sub-items..

1 Milling (machinery, milling direction)

2 Transverse joints (joint plan)

3 Asphalt mix

3.1 Asphalt mix supplier

3.2 Asphalt mix types to be used and their initial test report numbers

3.3 Asphalt mix parameters relevant for paving (determination of roller requirement according to “M VA”)

4 Paving of asphalt lifts (with detailed information on transport logistics, paving speed, on-site guidance for trucks, turning and cleaning stations, supply of operating materials)

4.1 Bituminous interlayer (SAMI layer)

4.2 Asphalt binder course

4.3 Mastic asphalt sealing/spray seal

4.4 Asphalt surface courses

4.5 Formation of joints and connections (depicted in layout diagram)

5 Self-monitoring/quality control

5.1 At the production site

5.2 On the construction site

6 Dealing with problems

6.1 Handling of transport vehicles when traffic delays occur

6.2 Handling of non-compliant asphalt mix

6.3 Dealing with problems arising on the construction site

6.4 Paving in unfavourable weather conditions

7 Responsible personnel/contacts (organisational chart with contact details)

8 Appendix: List of pavers and paving plans

Order form

Order form

By phone ☐ In writing ☐

Construction site: ____________ Site no.: ____________

Site location: ____________ Road/km: ____________

Order from: ____________

	Construction manager	Foreman
Admin clerk: ____________	Name: ____________	Name: ____________
Tel. no.: ____________	Tel. no.: ____________	Tel. no.: ____________
Fax no.: ____________	Fax no.: ____________	Fax no.: ____________
Mobile: ____________	Mobile: ____________	Mobile: ____________
E-Mail: ____________	E-Mail: ____________	E-Mail: ____________

Delivery subject to reservation Yes ☐ No ☐ Delivery date: ____________

Asphalt mix		Binder grade	Initial test no.	Quantity (total)	Delivery cycle	First delivery	Transport distance	Comments
Type	Grade			t	t/h	Time	km/min	
Asphalt combined base and surface course								
Asphalt base course								
Asphalt binder								
Asphalt surface course								

Special notes (e.g. route, vehicles, particular on-site conditions, detailed coordination)

Date Name

Figure D 1: Example of a form for ordering asphalt mix (based on [15])

Appendix E

Asphalt paving check lists

Appendix E 1 Tendering check list (client)

☐	Investigate smoothness of existing road surface in longitudinal and transverse direction → Tender document
☐	Identify causes of major deviations from parameters relevant to planning → Tender document
☐	Add results of preliminary investigation to tender documents, including relevant information on construction history → Tender document
☐	If necessary, arrange for profile improvement (define new gradient or new superelevation and specify controlled milling) → Part of work specification (BB) and bill of quantities (LV)
☐	Arrange the milling work and paving of the asphalt courses, preferably with the gradient → Part of work specification
☐	Document smoothness of milled base or of profile improvement and surface of asphalt courses before next asphalt course is laid → Part of bill of quantities (LV)
☐	Keep asphalt mix types tendered as part as one construction project as consistent as possible → Part of bill of quantities (LV)
☐	Request a detailed production and paving pian and a trucking plan for the machine technology and transport logistics to be deployed → Part of work specification (BB)

Appendix E 2 Bill of quantities check list (bidder)

☐	The bill of materials must be verified to comply with the latest regulations!
☐	Check paving limit values (paving thickness, paving weight, ...)!
☐	Results of preliminary investigation available?
☐	Indications of unusual roughness of the surface being milled and the adjoining areas also given?
☐	What processes can be included from a value-engineering perspective?
☐	If organic additives are tendered, check whether they can be used depending on weather conditions.
☐	In the event of any ambiguities identified in checking the work specification, and/or if documents are missing, written clarification must be requested from the tender issuing party in the course of preparing the bid.

Appendix E 3 Construction planning check list

Calculation of masses	
☐	The grades of asphalt mix to be laid according to the contract must be identified and checked.
☐	The asphalt mix must be ordered as early as possible.
Equipment planning	
☐	Vacuum sweeper (preferably self-propelled rotary jet cleaning machine)
☐	Ramp distributor truck
☐	Wheel loader with clamshell bucket
☐	Material transfer vehicle with large-capacity hopper insert for the paver
☐	An asphalt paver that meets the specification requirements and features the necessary equipment
☐	Determine the number of rollers required: – Observe the application recommendations for the various roller types. – The required rolling time must be less than the time available for compaction (for estimate see Appendix B). – Aim for even distribution of the lane widths and roller passes. – For large paving widths, rollers delivering the same compaction properties should be operated in echelon. – Provide a small roller for making the transverse joints. – Keep one roller as a back-up. – Do not use rollers designated for chip spreading for compaction.
☐	Water truck with pump and hose for refilling rollers and vacuum sweeper
☐	Auxiliary equipment (vibration plate with water spray system)

Planning paving operations	
☐	Allow for the season: – expected outside temperature and temperature of the base, – layer thicknesses in the cold season should be laid ≥ 3.5 cm, – possibly hot joints (echelon paving) or compact asphalt pavements, – if slow construction progress is to be expected, or if manual paving is to be carried out, postpone to a more favourable time of year, or alternatively use mastic asphalt, – use compaction aids if necessary.
☐	Agree schedule (weekday, day/night).
☐	Consider paving conditions: – local circumstances, – direction of paving (uphill or according to logistical possibilities), – longitudinal and transverse profiles, – formation of longitudinal and transverse joints, – in case of partial closure, keep traffic flowing via one half of the roadway for material feed, – avoiding bucking up trucks over long distances (provide turning areas).
Planning transport requirements	
☐	Adapt truck type to local circumstances.
☐	Include any necessary changes of truck type in the course of the day in planning.
☐	Preferentially deploy trucks with an insulated, rounded dump box.
☐	Define truck cycle times.
☐	Factor-in legally prescribed breaks.
☐	Consider paving speeds and directions.
☐	Determine the number of haul trucks.

Appendix E 4 Base check list

Producing the base	
☐	Keep a record of the quantity of millings removed from the construction site.
☐	Coordinate execution of the milling work with the client as necessary.
☐	Notify the construction supervisor and the asphalt mixing plant of the scheduled milling date.
☐	Specify the appropriate milling cutter type.
☐	**During milling, a contractor's representative should be on-site to give instructions on how to mill!**
☐	Mill under control in the event of major warping.
☐	Mill to the new profile whenever possible.
☐	Remove and clean scabbing or delaminated areas of milling before overlaying.
Checking the quality of the base	
☐	**The paving foreman must be able to inspect the construction site at least one day before the start of paving!**
☐	Determine the homogeneous load-bearing capacity of unbound bases using FDVK E procedures whenever possible.
☐	Repair the causes of cracking before starting paving.
☐	Ensure that the base is built to design and smooth.
☐	Before paving on a bound base, check the auger height of paver and adjust if necessary.
☐	As part of the self-monitoring process, check and document the milled base before tack coat; consult the client for assistance if necessary.
☐	Eliminate major roughness before laying the asphalt pavement by taking suitable measures to improve the profile.
Profile improvements on the base	
☐	Specify profile improvement by milling if necessary.
☐	Specify profile improvement by levelling with asphalt mix where appropriate: – Asphalt mix grade and aggregate size must be adapted to the levelling thickness to ensure a minimum of 2.5 :1 ratio of lift thickness to maximum grain size. 3 :1 is better. – Lay the asphalt mix in a separate pass to compensate for roughness in a bound base.
Spraying the base	
☐	Base must be cleaned and be free of any loose, organic and foreign components.
☐	Weather suitable for tack coat to allow sufficient curing time before paving?
☐	Adjust the quantity of bitumen emulsion specified in the bill of quantities as necessary.
☐	Adjust the spray quantity on the binder distributor truck by spraying over and check-weighing known flat bodies.
☐	Take a sufficient number of hermetically sealed retention samples from the bitumen emulsion and have them tested.
☐	Drive on tacked surfaces only to lay the asphalt mix.
☐	At high outside temperatures, set up cooling zones for truck tyres.

Appendix E 5 Paving and compaction check list

☐	By the day of paving, all questions relating to site preparation must have been clarified: – safety at work and on the road guaranteed, – access routes to the paver on the construction site clearly defined, – parking areas set up for equipment after end of paving, – results from a trial area regarding initial testing/compliance, asphalt mix production and paving implemented, – provide sufficient clean water and road grit material in the right places, – site introduction by the construction manager and/or foreman and notify changes of paving material and paver as well as bottlenecks or the like.
☐	The time staff begin work must be matched to the start of paving and local circumstances
☐	As a rule, pave uphill
☐	Pave onto a dry, frost-free base
☐	Bitumen emulsion must be completely cured before the asphalt mix is laid
☐	At intersections, preferably pave the main roadway first
☐	Pave miscellaneous areas such as bullnose, by machine wherever possible
Defining and checking the reference	
☐	Road base, curbs: Pay attention to cleanliness, smoothness and laying to design parameters
☐	Stringline: No slack, taut, pin spacing 5 to 7 metres, 3 to 5 metres. **Visually check the level and gradient of the line.**
☐	When using nylon ropes: Consider the influence of temperature
☐	Laser: Check the inclination in 2 axis directions, maximum distance 150 to 200m. Consider other influences.
☐	3D: Check reference points for accuracy and completeness. Check the job site specification. Check the measuring instruments. Spray paint guidance lines for paving.
Technical equipment of the paving crew	
☐	Provide wood and metal starting references for the paving screed
☐	Provide cut-off shoes for manhole covers and point drainage systems
☐	Provide wooden beams for the rollers to park/run on/off the mat
☐	Provide shovels and lutes
☐	Provide a sampling shovel and sufficient buckets for sampling (guide value: 4 buckets per 6,000 m^2 per asphalt course)
☐	Rake or lute
☐	Cleaning agent and hand-sprayer (no diesel). Use approved release agents.

Appendix E 5 (continued)

☐	Pouring can
☐	Folding rulers to measure mat thickness
☐	Stringline
☐	Bubble levels (1 m)
☐	4m straightedge
☐	Paint spray or marking chalk
☐	Layer thickness measuring pokers
☐	Fast-reacting probe thermometers for measuring mix temperature of the mat
☐	Infrared thermometer for measurements on the base
☐	Cutters
☐	Jackhammer
☐	Motorised or manual tamper
☐	Small vibration plate with water spray system
Equipment checking and matching to the paving operation	
☐	Carry out a general condition check of the paver, in particular: – establish cleanliness (no asphalt mix build-up), – check for any leaks of hydraulic fluids, etc., – check condition of track unit pads for excessive wear, – check condition of material conveying and tamper-vibratory systems.
☐	Where possible, specify similar paving widths for “hot to hot” paving with two or more pavers working in echelon.
☐	Where possible, complete upgrading of the paver to a wider paving width the day before paving begins.
☐	Check the material feed system settings
☐	Adjust the paving speed to the area output of the rollers (see Appendix B)
☐	Always keep a backup roller nearby
☐	Do not use rollers designed for chip spreading with vibration.
Preparing the asphalt paver for operation	
☐	Check engine oil level and operating fluids.
☐	Check emergency devices.
☐	Adjust the screed width to the paving conditions and joint profile; use an edge attachment and material scraper shoe if necessary
☐	Adapt the paver auger height to the paving conditions

Appendix E 5 (continued)

☐	Set the distance between the auger and screed tamper shield
☐	Determine the levelling method; install and connect external control stations and check the function of the automated grade and slope control system
☐	Start the engine, warm it up and bring the hydraulic oil to operating temperature
☐	Test the function of the conveyors
☐	Heat the screed, and to retain heat preferably hold it a few centimetres above the ground or place it on wooden beams
☐	Run the tamper manually when the screed is heated up, and increase the speed in steps up to the maximum so as to ensure proper operation when paving begins
☐	Position the paver, lower the screed, taking into account the slack; adjust the auger height and screed tow point cylinder.
☐	Set the conveyor, auger and compacting system modes to automatic; set the values required for paving and for working in echelon adjust the pre-compaction. The compaction performance of all screeds must be adjusted to the level of the screed with the lowest performance in order to achieve uniform pre-compaction across the entire paving width.
☐	Fill the conveyor and auger tunnel with asphalt mix, set the conveyor and auger sensors, and wait about 5 minutes for the asphalt mix to heat up the parts in contact with it. In consultation with the asphalt mixing plant, unload the truck with the hottest asphalt mix first.
☐	Set the paving speed and start paving
Preparing the roller(s) for operation	
☐	Check engine oil level and operating fluids
☐	Check emergency devices
☐	Visually inspect the hydraulic system
☐	Grease lubrication points as necessary
☐	Fill water tanks and, where applicable, cleaning agent tanks
☐	Check the functionality of the water spray system (spray nozzles, filters)
☐	Check the drums/pneumatic tyres for damage and to make sure they are clean
☐	Check the functionality and wear of the scrapers
☐	Select the edge pressing and cutting equipment/cutting disc and check its functionality
☐	Check the tyre pressure level on pneumatic tyre rollers and ensure all tyres are at the same pressure
☐	Check the vibration systems

Appendix E 5 (continued)

☐	Check connections for tight fit
☐	Check the functionality of the chip spreader and load it as necessary
☐	Bring the hydraulic oil to operating temperature
☐	Clean windows
☐	Adjust mirrors
☐	Place the roller ready for operation at the location where paving is to start
Pre-ordering asphalt mix (as early as possible!)	
☐	Coordinate delivery, paving and compaction: **Mixing capacity does not mean the same as laydown rate!**
☐	Stipulate the specific truck type
☐	Take account of local conditions (obstructions, traffic routing, mandatory paver's direction of travel, constraint points, changing paving widths, necessary interruptions of paving, change of paver)
☐	Agree driving and rest times
☐	Set out a detailed schedule for delivery tonnes per hour
☐	Arrange pre-ordering of asphalt mix by the construction manager using a defined form (see Appendix D)
☐	Send the completed form in good time to all parties involved (asphalt mixing plant, dispatcher, foreman, transport contractor where appropriate)
☐	Agree who provides the drivers with a comprehensive briefing before their first trip to the construction site!
Calling off asphalt mix	
☐	Weather conditions must meet minimum requirements
☐	Stipulate the start and end of paving time or location
☐	Take into account any changes required in the course of the day with regard to the type of trucks required
☐	Agree to driving and rest times in detail
☐	Agree the delivery tonnes per hour in detail
☐	Adjust the hourly output rate during the course of the day
☐	Coordinate remaining required quantities with the asphalt mixing plant in good time

Appendix E 5 (continued)

Distribution of work among the crew	
☐	Set up cleanout areas for the trucks, instruct the drivers accordingly and have them monitored by the paving foreman
☐	When working in echelon and where deliveries come from more than one asphalt mixing plant, assign the asphalt mixing plants/vehicles to the respective paver
☐	On short stretches of wider road, deploy additional personnel to relieve the strain on the screed (temporary shovelling)
☐	Specify and allot time for necessary manual paving areas in advance
☐	Brief personnel: – milling of small areas and tie-ins, – sweeping and tack coating of partial areas, – marking of the base for paving, – placement of adhesive films for layer thickness measurement, – sampling of materials, – check joint matching height immediately after paving, – direct trucks and asphalt mix receiving, – check temperature of asphalt mix before transfer to paver, – staff need to be authoritative in dealing with the truck drivers!
☐	Advise screed operators of correct working practice in joint areas when paving hot to cold (see Figure 51)
☐	Specification of a rolling pattern: – assign and instruct roller drivers accordingly (who, how, how often?), – designate a roller driver to be responsible for the construction joint, – designate one roller operator to monitor compliance with the specified rolling pattern and intervene to coordinate the compaction process if necessary (lead roller operator), – designate a roller operator to close the joint area. – When spreading is required, specify the spread rate of the road grip.
☐	Check the mat thickness after compaction
☐	Specify who is to move the water tank or water truck if required
☐	Enable continuous communication between the foreman and paver and roller personnel
☐	Monitor paving progress
☐	Monitor deliveries (sufficient cargo space, continuous delivery, traffic problems)
☐	Continuously monitor the mix quantity (tonnage) in relation to the area (surplus paving or shortfall)
☐	Maintain contact with the asphalt mixing plant on a regular basis

Appendix F

Selected paving and compaction defects

Table F 1: Selected paving and compaction errors

Cause/Effect	In paver's direction of travel							Transverse to paver's direction of travel				
	Uneven construction joint	Initial roughness	Irregularly recurring roughness	Periodically recurring long-waves in the mat	Short-waves in the mat	Periodically recurring short-waves in the mat	Sliding in front of the drum	Irregularly recurring rough spots	Transverse step formation	Roughness on the higher side	Shoulders	Bulging in front of the drum
Base												
Milling not true to design								x		x		
Residual of old layer still present on surface			x					x				
Varying adhesion of the asphalt mix to the base			x				x	x				
Asphalt mix												
Fluctuating composition of the asphalt mix			x				x		x			x
Variable mix temperatures				x			x	x				x
Paver												
Track ads worn				x								
Components incorrectly mounted		x			x							
Paving without edge attachment											x	
Missing or poorly adjusted pre-strike off plates		x	x									
Inadequate conveyor control						x						
Auger too low					x							
Paving												
Truck driver brakes irregularly			x									
Construction joint produced without using proper supports for the screed	x											
Variable auger speed			x									
Distance between pins too large				x								
Variable paving speed			x						x			
"Stop and go" paving		x	x									
Tamper speed too high		x				x						
Compaction												
Too large of impact spacing in vibratory compaction						x						
Heavy rollers deployed too soon			x				x					x
Spreader roller operated with vibration						x						
Exposed edge not compacted in crab steering mode											x	

Technical regulations

DIN	DIN EN 12272-1	Surface dressing – Test methods – Part 1: Rate of spread and accuracy of spread of binder and chippings	1)2)
	DIN EN 13108-21	Bituminous mixtures – Material specifications – Part 21: Factory production control	1)2)
FGSV	AP PMA	Working paper for the construction of PMA-asphalt surface courses (FGSV 738)	2)
	E GmBA	Recommendations on rubber-modified bitumen and asphalt (FGSV 724)	2)
	E LA D	Recommendations for the planning and construction of noise-optimised asphalt surface courses made of AC D LOA and SMA LA (FGSV 739)	2)
	H FA	Notes on the milling of asphalt pavements and pavements with components containing tar/pitch (FGSV 769)	2)
	H SVA	Notes on the realization of an requirement-meeting adhesion between layers in asphalt traffic area pavements (FGSV 731)	2)
	M FDVK E	Information sheet on comprehensive dynamic procedures for testing the compaction of earthworks (FGSV 547)	2)
	M OPA	Information sheet on asphalt surface courses made of porous asphalt (FGSV 750)	2)
	M TA	Information sheet on lowering the temperature of asphalt (FGSV 766)	2)
	M VA	Information sheet on the compaction of asphalt (FGSV 730)	2)
	RAA	Guidelines for the design of motorways (FGSV 202)	2)
	RAL	Guidelines for the design of highways (FGSV 201)	2)
	RAP Stra	Guidelines for accreditation of test centres for building materials and building material mixtures in road construction (FGSV 916)	2)
	TP Eben – Measurements with contact	Technical test specifications for smoothness measurements on road surfaces in longitudinal and transverse direction – Part: Measurements with contact (FGSV 404/1)	2)
	TP Eben – Measurements without contact	– Part: Measurements without contact (FGSV 404/2)	2)
	ZTV Asphalt-StB	Additional technical conditions of contract and directives for the construction of asphalt traffic area pavements (FGSV 799)	2)
	ZTV BEA-StB	Additional technical conditions of contract and directives for the structural maintenance of traffic areas – asphalt paving (FGSV 798)	2)
	ZTV Beton-StB	Additional technical conditions of contract and directives for the construction of base courses with hydraulic binders and concrete pavements (FGSV 899)	2)
	ZTV SoB-StB	Additional technical conditions of contract and directives for the construction of unbound granular layers in road construction (FGSV 698)	2)
	ZTV ZEB-StB	Additional technical conditions of contract and directives on the assessment and evaluation of the condition of roads (FGSV 489)	2)
BMVI	RS	Measures to improve the quality of asphalt paving. German Federal Ministry of Transport and Digital Infrastructure, Road Construction department, Circular on road construction dated 13.12.2016 (download from fgsv-verlag.de > Datenbanken (RS/ARS) > Date: 13.12.2016)	2)

Reference sources

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W stands for information documents:

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