Guidelines for the Manufacture and Construction of Asphalt

Manual 5 – October 2020

sabita

excellence in bituminous products

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Manual 11	(Withdrawn)
Manual 12	Labour Absorptive methods in road construction using bituminous materials
Manual 13	LAMBs – The design and use of large aggregate mixes for bases
Manual 14	(Superseded by TG2)
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Manual 36	Use of Reclaimed Asphalt in the Production of Asphalt
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CONTENTS

PREFACE

This 6th edition of Manual 5 of October 2020 has been revised to take account of recent developments in the design of asphalt as reflected in Sabita Manuals 35 and 24, which will impact on the management and execution of the construction of asphalt layers.

Also included is a troubleshooting guide for identifying problems, finding reasons for their occurrence and means of avoiding them or rectifying the consequences. This is a comprehensive guide, which was compiled by the late Julian Wise and generously shared by Martin & East (Pty) Ltd.

While it is not practicable to cover the extensive field of asphalt manufacture and construction comprehensively, the content has been expanded to present a section on legal requirements and prescriptions to ensure sustainable practice and safety in the production of asphalt roads and airfields.

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INTRODUCTION

The purpose of this manual is to define and describe, from a practical perspective, the principles and best practice procedures applicable to the production and placement of asphalt. The manual is prepared specifically for use by site engineers, asphalt manufacturers, asphalt paving contractors, design engineers and technical personnel engaged in quality assurance programs.

While effectiveness in the design of asphalt is covered extensively in Sabita Manuals 35 and 24, these newly developed procedures would be of limited benefit unless asphalt layers are constructed with due care to ensure that, after completion of construction, the layer is of adequate thickness, sufficiently dense, true to line and level and proportioned correctly in terms of its component materials. The focus of this manual is to assemble and disseminate knowledge and experience of involved personnel to achieve these goals.

ASPHALT DEFINED

The term asphalt is generally used to describe a variety of mixtures of aggregate, bitumen and mineral filler produced at an elevated temperature in an asphalt plant. Asphalt layers are designed to contribute to the structural capacity of the pavement, and / or improve functionality (e.g. riding surface texture, evenness) and ensuring durability of the layer so as to perform satisfactorily over an extended period. Asphalt mixes are primarily classified into two main categories based on aggregate packing:

- Sand-skeleton; or
- Stone-skeleton types

In *sand-skeleton* mixes, the loads are mainly carried by a mastic consisting of the finer aggregate fraction and bituminous binder, with the larger fractions providing bulk and replacing a proportion of the finer aggregate fraction.

In *stone skeleton* mixes the loads on the layer are carried by an interlocking matrix of the coarser aggregate fraction. For this matrix to be achieved, the voids between the coarser aggregate fractions are not over-filled by the mastic so as not to push the coarser aggregates apart.

Establishing the aggregate packing characteristics of the mix is a critical choice to be made for mix type selection.

In Manual 35 the practice of mix selection on the basis of particular grading envelopes has been discontinued and replaced by the adoption of a particular mix type (as described above). The reason for doing so is that gradings *per se* do not necessarily assure optimal aggregate proportioning. *Aggregate gradings* are, however, useful where mix designs are established and standardised for particular source materials and applications. Hence, gradings (together with aggregates shape and texture) are key to *quality assurance procedures* to ensure that mixes being laid on roads are representative of the materials used during the laboratory design process in the correct proportions and, consequently, can be expected to meet performance requirements.

Some mix types, classified in terms of grading characteristics are shown in Figure 1.

Continuous-graded (or dense-graded) mixes can be further subdivided into stone-skeleton (coarse) and sand-skeleton (fine) mixes, where the load is carried on the stone matrix and sand matrix respectively.

Open-graded mixes have high void contents and permit free drainage of surface water and have good road noise absorbing properties. Ultra-thin and thin friction courses are included in this category.

Gap-graded mixes comprise both conventional gap-graded asphalt mixes and stone-mastic asphalt (SMA) mixes. SMA's are typically stone skeleton mixes, whereas conventional gap-graded mixes are of the sand-skeleton type.

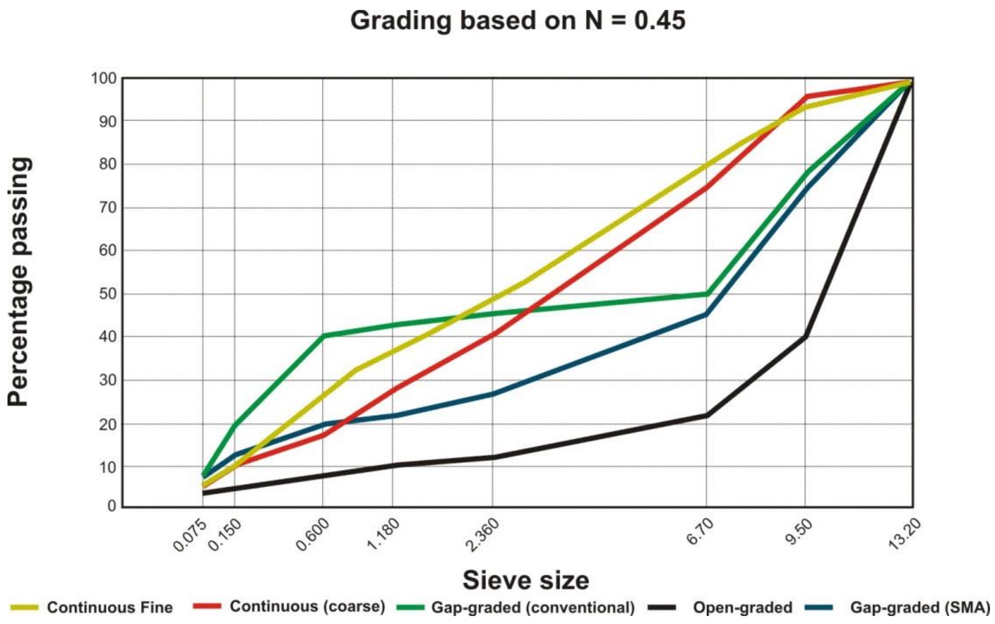


Figure 1: Grading Descriptions

MANUAL LAYOUT

This Manual comprises the following sections:

- Section A – Mix design process;
- Section B – Component materials
- Section C: Quality systems and specialised manufacturing and construction topics
- Section D – Materials handling
- Section E – Procedural and legal requirements for asphalt manufacture
- Section F – Construction management
- Section G – Paving
- Section H – Compaction
- Section I – Quality assurance

In each section guidance is given on procedures, techniques, plant and equipment to optimise the process of ensuring that correct and safe practices are carried out with the ultimate aim of providing an asphalt layer that will perform as expected.

SECTION A – MIX DESIGN PROCESS

A1 MIX OPTIMISATION AND APPROVAL PROCESS

The aim of all asphalt design procedures is to establish the mix in terms of composition, behaviour and performance characteristics to ensure that specified functional and structural performance criteria can be realised during the manufacturing and paving process. In order to ensure that a mix can endure the rigours of its service life-cycle, it goes through a mix design optimisation process. This mix design process comprises a staged approach of optimisation and approvals which eventually will culminate in the production of an asphalt mix that meets the established performance expectations.

Through this process of design and optimisation, the mix is considered for staged approval/acceptance at various steps in the process.

A1.1 PRINCIPLES OF MIX DESIGN

The principles of asphalt mix design are covered in various manuals, notably Sabita Manual 35. The first phase of the design process is the development of performance and specification requirements that are determined by the pavement engineer to meet the pavement structural design criteria.

The first iteration of the mix design to meet the stated requirements is done in a laboratory in a manner that endeavours to simulate project-specific manufacturing, transport, construction and service conditions, which include geographic locations and seasonal climatic variation and the plant type, setup and functionality. However, simulated laboratory conditions will not emulate actual project-specific circumstances completely and this aspect needs to be addressed in the mix optimisation process.

It is essential for asphalt manufacturers to have knowledge of the engineering demands on the performance of asphalt products and how compositional and volumetric mix principles are mobilised to meet performance characteristics implied in exacting engineering specifications. Equally, it is essential for asphalt manufacturers to be familiar with the workings of asphalt plants particularly in respect of how mechanical, thermal and hydraulic characteristics impact on the mixing of the asphalt as well as its mixed properties and service life performance.

Current asphalt design methods make use of a range of aggregate and binder specifications, in conjunction with a range of volumetric or spatial composition principles (e.g. those derived from Gyratory compaction procedures or the Bailey Method) to facilitate the attainment of the desired engineering properties and performance characteristics. Key to this optimisation process is a clear understanding of the packing characteristics of the mix components as well as the simulation, in the laboratory, of compaction initially attained under suitable field compaction procedures. It is also necessary to understand the equilibrium density attained under the influence of traffic. Ultimately the design process should culminate in the development of a *project mix design* which will determine the composition of the mix to be laid on the project.

Various degrees of complexity as regards mix properties or performance criteria are specified for various applications. Typical properties employed for dense mixes to ensure adequate product performance, durability and constructability are dealt with in Sabita Manual 24: *User Guide for the Design of Asphalt* Mixes and covered comprehensively in Sabita Manual 35: *Design and Use of Asphalt in Road Pavements.*

A1.2 PRODUCTION MIX DESIGN AND APPROVAL PROCESS

A comprehensive production mix design process ensures that target engineering properties and performance characteristics are consistently met with raw materials that are representative of those used in the approved mix design.

If at any time it becomes evident that the asphalt being produced consists of component materials no longer representative of those used in the current project mix design, a review of the mix design should follow without delay. Such a review process may result in the adjustment of the relative proportions of the components to meet the predetermined engineering properties and / or mix performance characteristics. Continually ensuring that the mix produced meets the specification and performance parameters, is of critical importance in the overall quality management process.

The process of optimisation and finalising a project mix design to meet contractual obligations can be summarised in the following steps:

- The asphalt mix designer meets with the pavement engineer, client (as may be represented on a particular site), asphalt manufacturer and asphalt paver to fully understand the pavement design, scope of works, specifications, materials to be used, asphalt plant set-up and capabilities, mix economics as well as the paving and of compaction equipment array.
- The asphalt mix designer undertakes the laboratory mix design with these inputs and guided by the relevant manuals such as Sabita Manual 35, as may be applicable.
- The laboratory mix design is proposed by the asphalt mix designer for consideration by the asphalt manufacturer and asphalt paver for consideration, optimisation and acceptance.
- The latest edition of SABITA Manual 35 must be consulted when carrying out the design and plant trial of the mix. It is noted that Manual 35-linked D3 Asphalt Mix Design form has been updated to provide for the incorporation of Performance Grade (PG) classification and the Bailey Method of aggregate packing.
- The accepted laboratory mix design is then proposed by the legally obligated party to the client / pavement engineer for acceptance.
- Following consideration and addressing of queries from the pavement engineer by the proposer, and acceptance of matters addressed, the pavement engineer may accept the laboratory mix design that the asphalt manufacturer may consider for trial mix manufacturing.
- Before production of the trial plant mix, the manufacturing plant has to be checked, calibrated and accepted for mechanical, thermal, safety, environmental, electrical and electronic compliance. During this stage of plant calibration, a dry aggregate run is followed by a mix manufactured at optimum bitumen content following which tests of aggregate grading and bituminous binder content and properties are carried out.
- Following calibration of the plant and acceptable material components and quality, full-scale plant trials are undertaken. The plant trial is essential for demonstrating that the asphalt plant can produce a consistent mix as per the agreed design
- In full-scale plant trials, batches of 10 to 20 tonnes of asphalt are manufactured with bitumen contents being at optimum plus and minus 0.5% for testing. The efficient operation of the plant is also assessed.
- The plant mix and its components are tested to check for comparison with the laboratory mix design and specification compliance criteria. Transport and construction needs are also assessed.
- The optimum target binder content is then analysed against the laboratory mix design optimum and adjusted to take into considerations conditions that the mix are exposed to in the plant.
- Should the lab mix design optimum target binder content be adjusted based on the above analysis, the mix should be run at this adjusted target and then tested for mix compliance with the specifications.
- The plant may also be checked and calibrated again.
- After all is found in compliance with the specification, the mix design with the possibility of adjusted target binder content, is proposed for the paving trial.
- Before the paving trial can be undertaken, the plant and equipment have to be checked for compliance and the paving team for competence.
- A paving trial is to assess the workability of the mix, compliance of the paved mat with expectations in terms of functionality, thickness, joints, texture and to establish a quality reference. Furthermore, it should be

established whether transport of the mix proceeds smoothly, that the paving crew is experienced and capable of paving to specification and that all plant is reliable and in good condition. Any problems relating to the construction and constructability of the layer must be immediately rectified. A high level of monitoring, including photographic records, visual assessments and data recording and testing will be required to ensure that the process can be replicated to meet the project specification. Once the paving trial has been successfully completed, there must be no deviations from the procedures or changes in plant, unless there is full agreement from the employer and / or the engineer. A paving trial flow chart is presented below in Figure 2.

- A minimum of 50 tonnes of paving trial mix per binder content, at optimum binder content plus and minus 0.3%, is manufactured, transported and paved.
- The mix is observed during transport for properties like coating, bitumen drain down, mix segregation, rate of cooling, differential cooling (outside crust) and mix balling.
- The paved mat is monitored during paving for possible drag shear cracking, knitted uniformity of surface, segregation, balling both over the cross-section and area as well as rate of cooling.
- The mix is observed during rolling for shear cracking (by incorrect rolling) mat creep, mix tenderness, bitumen migration, mix segregation as well as the rate of cooling.
- The paved mix is then tested for compliance with plant mix parameters as well as specifications.
- Following an analysis of the observations the paving train arrangement and operations are adjusted, if necessary.
- The target binder content is also reviewed for possible adjustment for the start of routine production.
- Once all issues have been resolved, this mix is proposed by the obligated contracting party to the client for acceptance.
- This mix is then produced for 3 to 4 days, checked for consistency of compliance with the specifications.
- The mean values of properties of mixes complying with the specifications are then used to set the working mix targets and tolerances. The revised tolerances windows are tested for specification compliance using laboratory mix design trend analysis and projections
- Following possible adjustments for consistency, the mix design is proposed for final acceptance.
- Following this, the mix is ready for routine production.

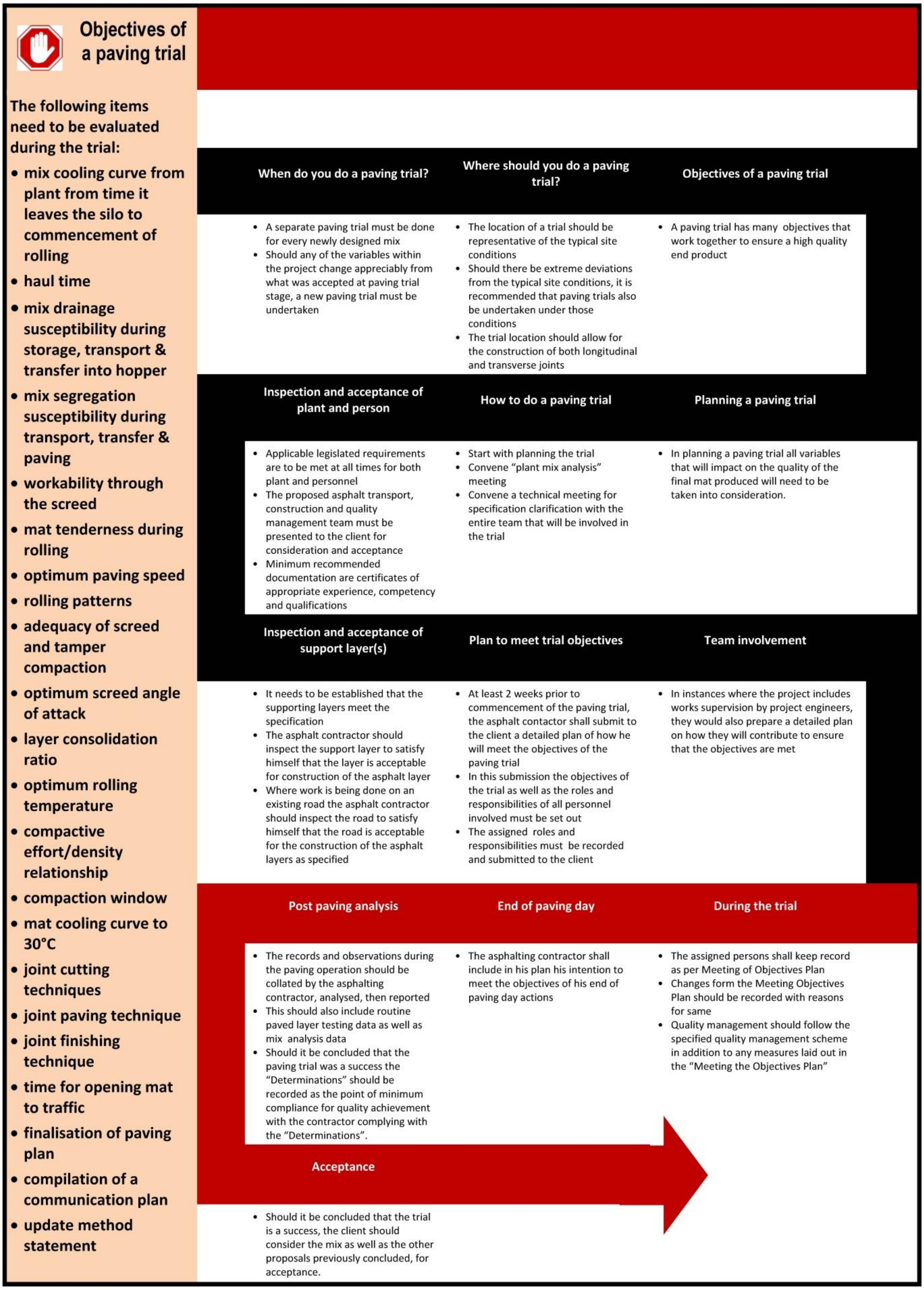


Figure 2: Paving Trial Flow Chart

The 3-page Check List, given in Table 11 of Chapter 12, Section 4 of SAPEM, ***must*** be completed by the engineer, together with the contractor, at the paving trial. Any deviations are to be corrected and if there is doubt regarding any aspect of the trial, a fresh trial may be called for. Check 1: Paver, as well as Checks 9 to 12 relating to the rollers, hand tools and haulage vehicles, must be used for each day's production and signed off by the contractor and the engineer's representative. A typical process flow diagram with timetable and responsible parties is detailed in Figure 3.

Suggested Timetable (Duration)	Process	Parties to be consulted by Supplier
Within two weeks of contract award	**Mix design meeting:** • Assess specifications, available resources and test facilities; • Determine provisional aggregate sources, binder, grading proportions and volumetric properties.	Contractor & Contract Engineer
Five weeks before start of production (2 weeks)	**Assessment of volumetric properties** • Perform laboratory assessments of volumetric properties on selected alternatives; • Select optimum mix composition based on initial laboratory assessment; • Fine-tune mix composition and volumetrics and test with a production run; • Adjust mix composition based on the production run outputs and set targets (e.g. voids, binder content and grading) for performance assessment.	Contract Engineer & Design Laboratory
Five weeks before start of production (2 weeks)	**Performance assessment** • Evaluate compliance with specified performance characteristics of plant samples; • Optimise or redesign mix based on outcomes; • Submit mix design for approval.	Contract Engineer & Specialised Testing Laboratory
One week before start of production (4 days)	**Trial section assessment** • Assess constructability (40 tons run, minimum); • Check performance related properties of field samples; • Establish compaction effort required and appropriate rolling pattern; • Compare and, if necessary, resolve differences between results on field and laboratory samples.	Contractor & Contract Engineers
At least three days before start of production	**Finalisation of production mix properties** • Select volumetric and compositional targets for production; • Set tolerances for process and acceptance control; • Submit process and acceptance control statement on production and construction temperatures, rolling techniques and plan; • Submit final mix parameters for acceptance control to the client's representative.	Contractor & Contract Engineers
First three production lots	**Initial production assessment:** • Examine the results of three lots; re-assess mix composition and establish whether any fine-tuning of mix proportions or properties is needed; • If necessary, re-submit these for process- and acceptance control purposes.	Contractor
Throughout production	**Production Control:** • Monitor volumetric and compositional properties of the mix on a daily basis for compliance with the project mix tolerances; • Frequently monitor binder properties and performance characteristics of the mix to ensure that design objectives are consistently being met; • If meaningful changes in mix characteristics are evident, reassess performance characteristics and make the necessary adjustments to the composition and volumetric properties of the mix.	Contractor, Engineer & Employer

Figure 3: Flow Diagram for Optimal Mix Design Process

SECTION B – COMPONENT MATERIALS

B1 MATERIALS USAGE AND CONTROL AT THE PLANT

Raw materials used in asphalt manufacture include aggregate (usually crushed stone, although natural sand is sometimes used), inert or active filler (cement, hydrated lime, PFA) and a bituminous binder. Sometimes bitumen may contain additives and / or modified (with e.g. rubber crumbs, hydrocarbons and polymers). Increasingly manufactured aggregate (steel and chrome slag) as well as reclaimed asphalt from existing road pavements are used.

B1.1 AGGREGATES

The selection process and specification of aggregates is thoroughly discussed in Sabita Manual 35*: Design and Use of Asphalt in Road Pavements*. In considering suitable sources of aggregate there are a number of factors to take into account, other than those pertaining to the quality and cost of the aggregate, such as:

- Consistency at source before and during production.
- Capacity to supply the required quantities during full production.
- Distance from asphalt plant.
- Community effect on Quarry or source.
- Capability and capacity to supply the appropriate class of aggregate.

Once a source that can comply with above requirements has been identified, certain measures can be taken to prevent disruptions such as:

- Entering into supply agreements with guaranteed volume and quality targets.
- Regular communication meetings to ensure suppliers are kept informed on supply requirements.
- Performing back up designs with alternative aggregates for high demand periods where aggregate shortages may occur.

(a) Stockpiles

The process of quality control of asphalt begins with the aggregate stockpiles, irrespective of the type of manufacturing plant. Proper receiving and stockpiling procedures are crucially important to limit variation in aggregate and, hence, consistency of mix quality.

Stockpiling management should incorporate the following practices to ensure uniformity and to minimise segregation and contamination:

- The stockpile base should be clean, dry and stable, and should not be allowed to become contaminated with dust, mud or grass. The base should be sloped to allow free drainage;
- The stockpile should be built in horizontal (or gently sloping) layers. It may be cost-effective in terms of energy savings to protect the materials in the stockpiles from excess moisture by means of covers or a roof especially the finer fractions like crushed dust and sands;
- Stockpiles of the various aggregate sizes or types should be kept separate at all times, by barriers if necessary;
- Care should be taken to minimise segregation during both the stockpiling and loading processes. Loading should take place on the entire face of the stockpile, perpendicular to the direction of aggregate flow.

All sampling and testing of materials should be performed by technicians suitably qualified to carry out the required testing correctly, and at the required frequency. Test reports should be submitted to the responsible person on completion.

B1.2 RECLAIMED ASPHALT

In the interests of sustainable practice, reclaimed asphalt (RA) is becoming an increasingly valuable resource for the production of asphalt. RA contains both aggregates and bitumen, and its use can lead to cost savings and reduced reliance on non-renewable material resources. The use of RA is thoroughly explained in Sabita Manual 36 / TRH 21: *Use of Reclaimed Asphalt in the Production of Asphalt*.

B1.3 BITUMINOUS BINDERS

Bitumen must comply with the current edition of SANS 4001:BT1: *Penetration grade bitumens*. While the current specifications listed are still relevant, some clients may specify a performance graded (PG) binder for the manufacture of asphalt, as set out in the SABS technical specification SATS 3208: *Performance Grade (PG) specifications for bitumen in South Africa*.

(a) Handing

Guidance on legal compliance in the transport of bituminous binders is covered comprehensively in Sabita Manual 34: *Guidelines to legislation on the transportation of bitumen and Bitumen spill protocol*.

For modified binders the reader is referred to TG1, *Technical Guideline*: *The use of modified bituminous binders in road construction* which stipulates that some form of mixing and circulation is necessary to maintain homogeneity of all modified binder types while stored. In addition, to prevent the development of any "hot spots" within the product or possible segregation, a circulation/stirring system should be in place, even for short periods of storage on site.

Safety procedures during loading and offloading of bituminous binders are presented in Sabita Manual 25: *Code of Practice: Transportation, off-loading and storage of bitumen and bituminous products.*

The Occupational, Health and Safety Act (Act No. 85 of 1993) lists the responsibilities of employers and employees to safeguard the health and safety of employees in the workplace, and those likely to be affected by their activities. The chief executive officer of the company has overall responsibility and accountability for health and safety on the terrains or sites occupied by the company. (See Section E1.14 OCCUPATIONAL HEALTH AND SAFETY ACT

(b) Sampling and testing

As the responsibility for product quality passes from the haulier or consignor to the consignee at the point of offloading, correct sampling techniques and testing are essential components of the quality management process.

SANS specifications require that sampling of bitumen and bitumen emulsions be carried out in accordance with ASTM Method D140. Additional aspects of sampling procedures are covered in TMH5: *Sampling methods for road construction materials.* The procedures for sampling at various operational situations are comprehensively covered in the Sabita Manual 25: *Code of practice: Transportation, off-loading and storage of bitumen and bituminous products*.

Samples should be collected in new or clean containers and marked with an indelible marker with all the relevant information pertaining to the source of the binder, transaction information, temperature and the name of the person taking the sample.

The sample volume should be such so as to retain at least 1 litre of the binder after testing. This will enable further testing should that become necessary. It is recommended that retained samples be kept for at least six months in a manner that will enable rapid retrieval when required.

In the interests of safety, sampling should only take place through a sampling valve between the discharge pump and the receiving tank or, if this is not available, through a sampling valve situated on the tanker and **NOT** from the top of the tanker or delivery hoses.

B1.4 ACTIVE FILLERS

Fillers used in the manufacture of asphalt (such as rock dust, cement, lime) must comply with the current editions of the relevant SABS specifications.

(a) Storage

Since filler must be kept dry, storage silos should be adequately sealed. Bagged filler must be protected from the elements.

The filler delivery system to the mixing plant must be adequately sealed and checked for ingress of moisture and escape of filler into the air.

b) Sampling and testing

Each delivery of filler should be accompanied by a certificate of compliance with the relevant SANS specification for grading.

B1.5 BINDER MODIFIERS

Modifiers have varying storage and handling requirements. Recommended handling and storage procedures and temperature to ensure product compliance with the specification should be provided by the manufacturer.

Granulated rubber for use in asphalt mixes is usually supplied in bags. Storage and sampling is covered in Sabita Manual 19: *Technical guidelines for bitumen-rubber asphalt*.

For other binder modifiers see details provided in the Sabita publication TG1, *Technical Guideline: The use of modified bituminous binders in road construction*. It is also recommended that storage and sampling be carried out in accordance with supplier's specifications and generally acceptable engineering practice.

SECTION C – ASPHALT MANUFACTURE

C1 PLANT TYPES AND OPERATION

An asphalt plant typically comprises a factory-like layout of various installations and operations that merge to manufacture asphalt. The broad operations include processing and storage of raw materials, transfer and feed of raw materials in prescribed proportions, heating of materials, mixing of materials, storage of manufactured asphalt and dispatch of manufactured asphalt.

Emissions management, although carried out separately during a number of operations, times and locations can also be considered as an extensive, separate operation of an asphalt plant.

Support operations like quality management laboratories, control mechanisms, mechanical workshops, administration and dispatch are equally important and also form part of the factory. Each operation uses components of plant (mechanical, electrical), labour and materials.

Traditionally, asphalt plants have been primarily differentiated by the raw materials mixing processes, these being batch mixing and continuous mixing. These have endured, however, other differentiators have gained prominence as technologies have improved and widened the scope of operations. These now include the proportion of and manner in which RA can be accommodated, heating and heat energy management abilities, level of mobility (from stationary or fixed to completely mobile and further differentiation by the speed of collapsing and re-erection).

Plants vary in size and may be *mobile* or *stationary*. A mobile plant is one which can readily be detached into components and transported to another site where it can be re-erected. Differentiation in the past between the capabilities of stationary and mobile plants has all but disappeared with both now having similar capabilities.

Operational elements common to all types of asphalt plants are:

- drying and heating of aggregate
- proportioning the components (aggregate, filler and binder)
- blending of components

C1.1 MIXING PLANT TYPES

Two of the main types, differentiated by the mixing processes and procedures will be discussed being:

- Batch type – components (aggregate, mineral filler) are dried, heated and weigh-batched per size fraction and then added into a 'pug mill" where the appropriate mass of binder is introduced and all components mixed to form a batch;
- Continuous or drum mix type – components (aggregate, mineral filler) are dried, heated and mixed with binder continuously in a drum.

(a) Batch mix plant

The basic process by which the component materials flow in and the product flows out of a typical batch can be described as follows:

- Aggregates are dawn from storage or stockpiles into cold feed bins of individual aggregate fractions.
- From the cold feed bins, the aggregates, in the correct proportions, are transported into a rotary drier, by a speed calibrated conveyor belt. Generally, the rate of feed of the aggregates and the amount of fuel that is burnt in the drier are variable and is adjusted based on aggregate temperature and moisture content as well as the energy that the fuel contains.

- In the rotating the drier, a series of metal flights circulate the aggregates, through lifting and releasing it through the burner flame and hot gasses, thereby drying and heating the aggregates to the required temperature.
- The heated aggregates are fed into a hot elevator, and then onto a screening unit which separates the aggregates into different sized fractions and stored into hot bins. The dust and hot gas from the aggregate drying process are vented into the dust extraction system. Certain modern plants are recirculating the exhausted hot gas back within the system or using it to heat other component materials including reclaimed asphalt.
- The aggregates and mineral filler (when used) are drawn from each hot bin to match the job-mix formula, and fed into the weigh hopper. Generally, in a batch plant, the aggregate proportioning is controlled at hot bins, although it should be noted that correct proportioning at the cold feed system, is critically important to achieving balanced proportioning in the hot bins.
- Bitumen, heated to the requisite temperature, is stored in tanks and the required amount is pumped into "weigh-pot" through heat-insulated pipes. The amount of bitumen stored in the weigh-pot before being released into the pug-mill is relative to the required binder content of the mix. It is essential to keep the binder within the specified temperature range for storage, pumping and manufacturing to ensure proper delivery and coating of the aggregates.
- The aggregates are transferred into pug mill in a controlled amount and mixed, following which the binder is introduced to the pug mill and thoroughly mixed with aggregates.
- After mixing each batch, the product is transferred by a conveyor belt to hot storage silos, or loaded directly into a truck and hauled to the paving site.

Figure 4 illustrates the sequence of the operation of a typical batch plant. Also shown is the typical conversion detail used to feed reclaimed asphalt, by adding the material to be recycled (RA) into the weigh hopper. Details of the mix tower are depicted in Figure 5.

Where aggregate gradations are consistent and the cold feed calibration system is in good order, the screening unit may be bypassed. In this case the mix composition is controlled directly from the cold feed, as for a drum mixer.

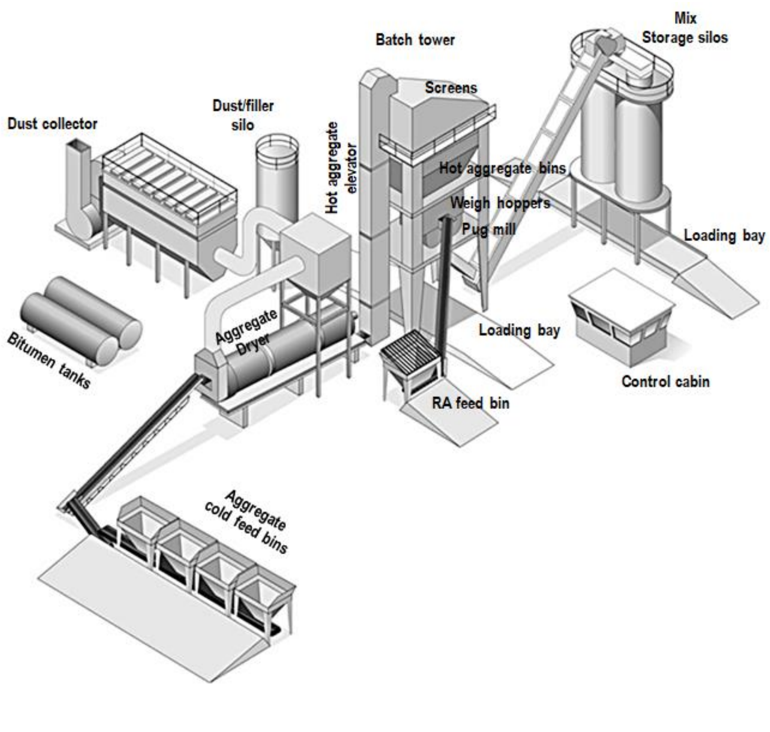


Figure 4: Batch Plant with RA Hopper

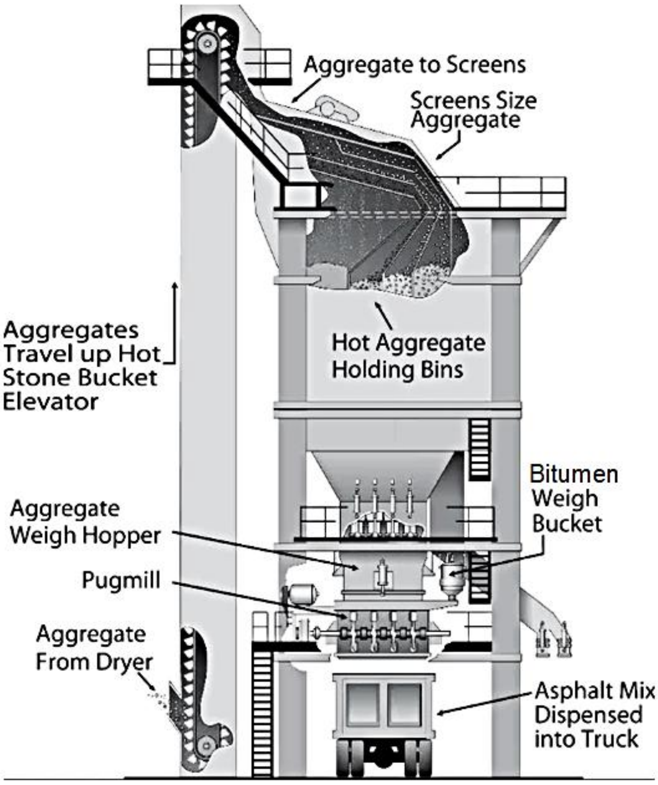


Figure 5: Batch Mix Plant Tower Detail

(b) Continuous or drum mix plant

A typical continuous mixing plant, the drum mixer, relies on volumetrically proportioned delivery of aggregate and other additives from the cold feed unit and volumetric delivery of binder. These materials then combine in the heating drum to give the specified products.

A simplified diagram of a typical continuous mixing plant is shown in Figure 6. Also illustrated in this figure are the modifications for reclaimed asphalt (RA) feeding. The key modules include:

- A burner situated at the cold feed end of the dryer-drum;
- Binder feed from the back end of the dryer-drum mixer;
- Feed for RA into the midpoint of the dryer-drum mixer.

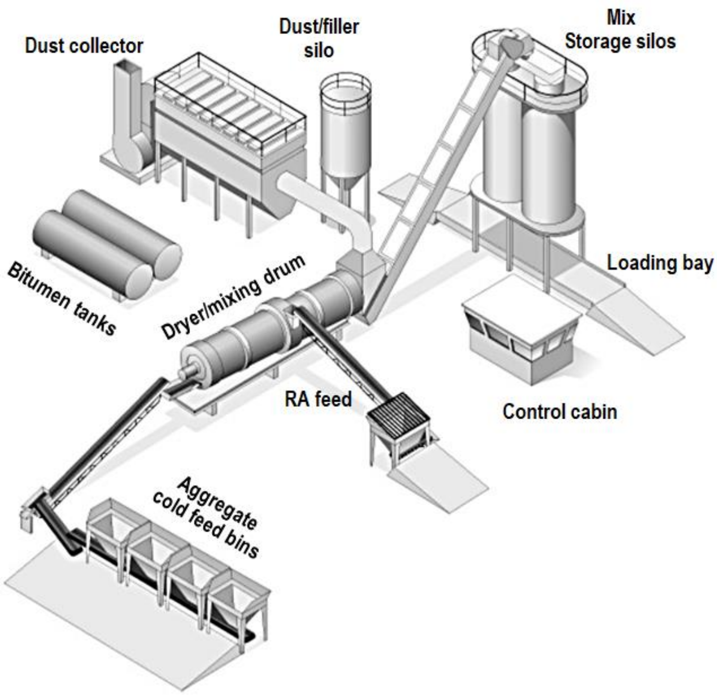


Figure 6: Continuous / Drum Mixer

Various specially adapted continuous mixers exist worldwide. One such type is the counter flow drum, where the burner is positioned at the end of the drum opposite the aggregate entry point. The aggregate is dried and heated in the drying drum section. Mixing with binder and filler takes place in the separate mixing drum section. Another variation, called the double drum plant, combines these two actions in one drum, with the inside drum used for heating and the outside for mixing.

C1.2 PLANT COMPONENTS AND THEIR FUNCTIONS

Details of the various components of asphalt plant types and their functions are described below:

(a) Cold feed system

For all plant types to yield a uniformly acceptable end product, all input materials need to be accurately proportioned. The importance of feeding each aggregate size to the dryer at the correct rate of flow cannot, therefore, be over-emphasised. For this purpose, plants are equipped with cold feed units capable of correct proportioning of the cold (and usually moist) aggregate fractions being fed to the dryer. A typical unit is shown in Figure 7.

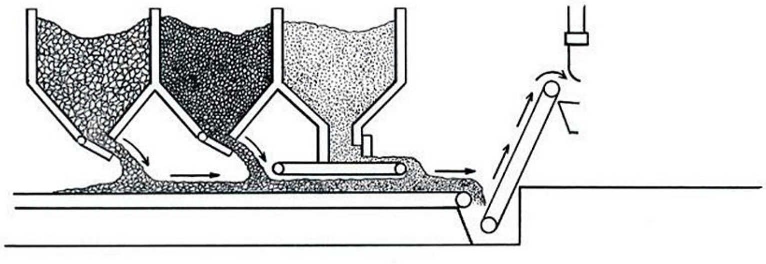


Figure 7: Typical Cold Feed Unit

Cold feed bins are generally fed by means of front-end loaders from the stockpiles. Segregation should be prevented at all times.

Feed units are placed under each cold feed compartment. These units are designed to give a uniform flow of material on to the conveyor belt. Units are calibrated so that the flow rate can be controlled.

There are various types of feeders, the most popular being the continuous belt feeder shown in Figure 8.

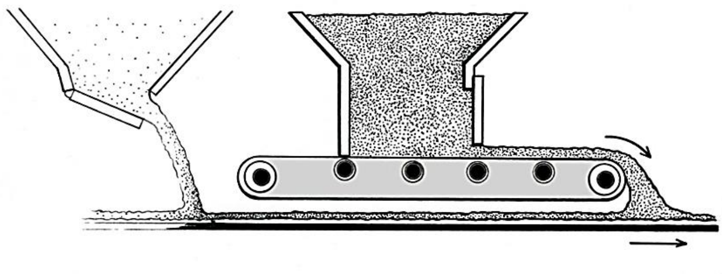


Figure 8: Typical Cold Feed Belt Feeder

In batch plants excessive feed can overload the screens (if used), causing carry-over of finer aggregate into the coarser aggregate bins. Erratic feeding causes some hot bins to overfill while starving others, leading to:

- Aggregate layers of varying size in the hot bins, especially the fine aggregate bins, resulting in alternating rich and lean batches;
- Overloaded dust collection systems;
- Reduced dryer draught.

In drum mix plants, aggregate is weighed before drying. Since the material may contain an appreciable amount of moisture that will influence the aggregate mass, accurate measurement of aggregate moisture content is important. From the measurement, adjustments can be made to the automatic binder metering system to ensure that the amount of binder delivered to the drum is correct for the amount of dry aggregate.

To ensure a uniform flow of material from well-managed stockpiles, the following points should be adhered to:

- Feeder gates should be accurately calibrated and correctly set;
- Gates should be kept free of obstructions. Use of a grizzly over the cold feed compartments will reduce the likelihood of large stones causing obstructions;
- Prevent arching or packing of fine aggregate in the compartments. Correct use of vibrators will eliminate this problem.

(b) The dryer

The conventional dryer shown in Figure 9 is a revolving cylinder 1-3m in diameter and 4.5-12m long, in which aggregate is dried and heated by a burner and, in the case of drum mixers, mixed with binders.

Inside the dryer steel lifters called “flights” are arranged to ensure circulation and proper drying of the aggregate. As the dryer rotates these flights lift the aggregate and drop it through the burner flame and hot gases as illustrated in Figure 10.

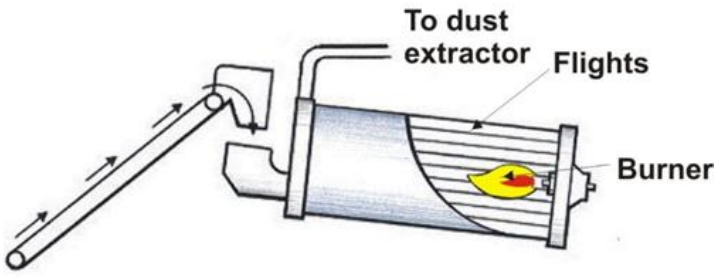


Figure 9: Dryer

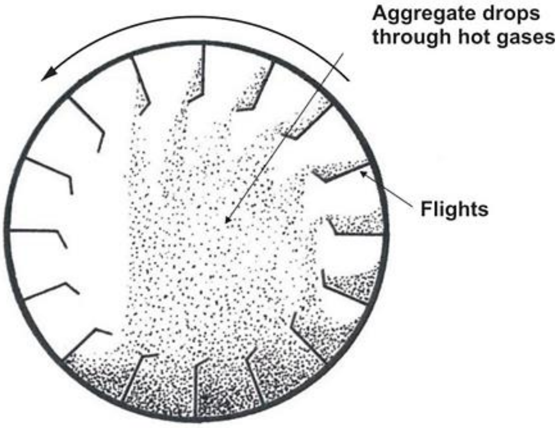


Figure 10: Flights in Dryer

The slope of the dryer drum, its speed of rotation, diameter and length, together with the way the flights are arranged, all combine to control how long the aggregate takes to pass through the drum.

The dryer performs two functions:

- It vaporises and removes any moisture in the aggregate;
- It heats the aggregate to the required mixing temperature.

(d) RA split feed system

To counter undesirable emissions, split-feed systems – in which the RA is fed to the drum mixer separately from the new aggregate – are now commonly employed to produce asphalt mixes containing reclaimed asphalt.

With a split-feed system the virgin aggregate is delivered to the burner end of the drum-mix plant in a conventional manner. The RA is delivered into a separate entry point near the midpoint of the drum length, as shown earlier in Figure 11.

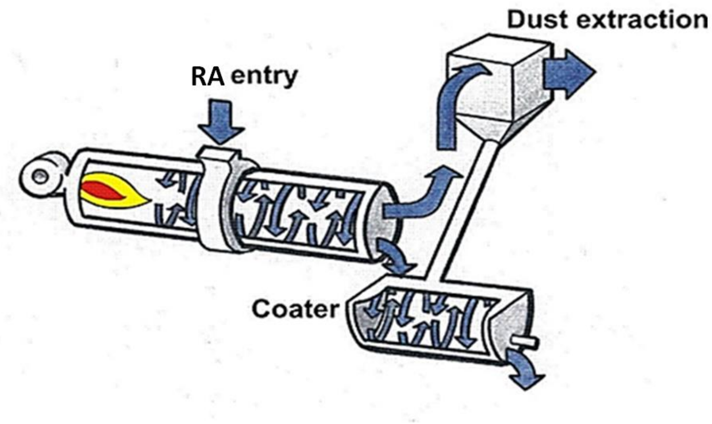


Figure 11: Drum Mix Plant with RA Feed and Coater

A variety of designs are employed for the intake system used to introduce the RA into the drum. Typically, the drum has a series of ports, or entry chutes, cut into the shell to allow the RA to be introduced from the charging conveyor as the drum turns. At the point at which the RA enters the shell, a short length of the flights is often removed or configured so that the asphalt-coated material can easily be blended with the virgin aggregate. Heating of the RA begins as soon as it enters the port and as the combined aggregate is picked up by the flights, heating and drying of the blend continues.

When RA is charged into the drum at its midpoint, the feed of virgin aggregate at the burner end is lessened, thereby reducing the concentration of aggregate in the veil upstream of the RA entry point. Consequently, the amount of heat transfer to the virgin aggregate is decreased. As a result, the temperature of the gases at the contact point with the RA is higher, and there is an increased probability of damaging the asphalt coating on the RA. This problem increases in severity as the proportion of RA used in the recycled mix increases and the amount of new aggregate decreases accordingly. Methods for reducing the exhaust gas temperature involve increasing the concentration of virgin aggregates in the veil upstream of the RA entry point, as well as raising the temperature of the RA before it comes into contact with the heated new aggregate.

Normally, for asphalt mixes with RA binder replacement proportions of more than 15%, a split-feed system is used to minimise hydrocarbon emissions, depending on the adequacy of the veil of new aggregate inside the drum and the discharge temperature of the mix. As the percentage of RA rises and the moisture content of the RA increases, there is a greater potential for emission problems. When the amount of RA used exceeds 30% RA binder replacement, special consideration needs to be given to the plant type to ensure adequate heat transfer from the exhaust gases to the virgin aggregate before those gases come in contact with the RA.

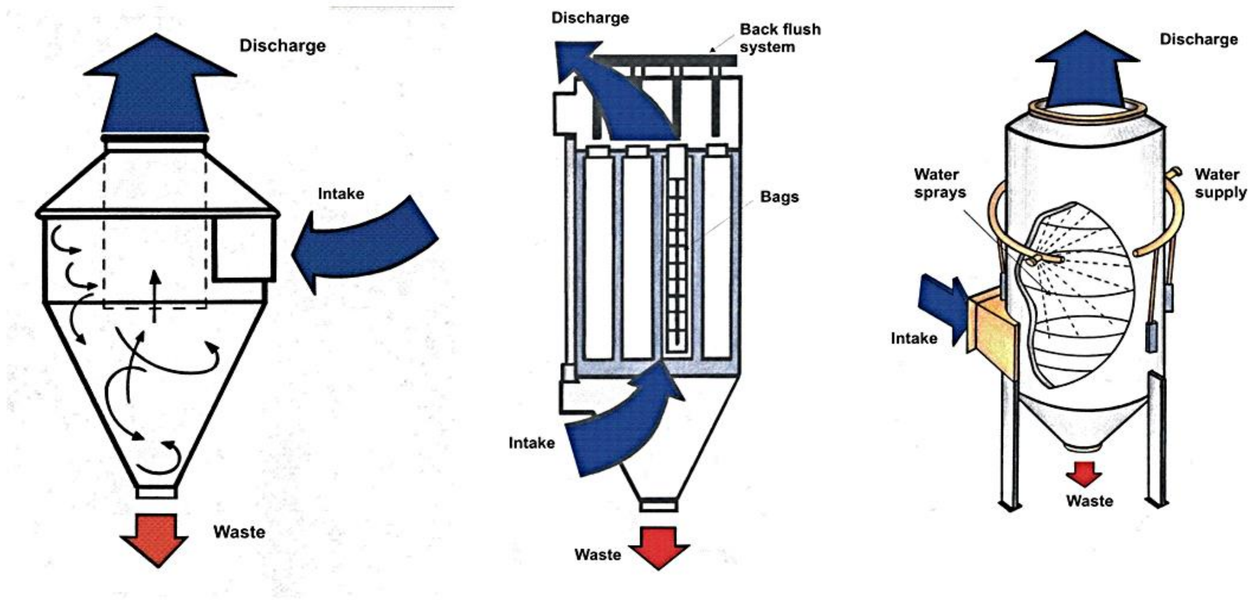
(c) Dust extractors and collectors

All plants must conform to the applicable environmental protection laws, specifically the National Environmental Management: Air Quality Act No 39 of 2004. Although most plant operators do not have the sophisticated equipment to monitor emissions daily, specialist consultants are available to do so.

Dust collection equipment is connected to the dryer unit to meet anti-air-pollution requirements, and, in some cases, to provide filler for use in the asphalt being produced.

Stack emission other than a plume of steam is an indication that the burner is set incorrectly and unburned fuel is causing smoke emissions from the stack, or dust collection is inefficient, in which case dust is discharged from the stack. Such deficiencies should be attended to as a matter of urgency.

Three types of dust collectors are commonly used – cyclones, wet scrubbers and filler bag houses as shown in Figure 12.



1 Cyclone dust collector 2 Bag house 3 Wet scrubber

Figure 12: Dust Collection Systems

Cyclone dust collector

Cyclone dust collectors operate on the principle of centrifugal separation. The exhaust gas and dust from the dryer is sucked into the cyclone where it spirals, throwing the dust particles against the wall of the container from where they slide downwards to the collection point (see Figure 12 #1 above).

Bag houses

A bag house is a large metal housing containing hundreds of synthetic, heat-resistant fabric bags, usually silicone-treated to increase their ability to collect very fine particles of dust. A typical installation, shown in Figure 12 #2, functions much in the same way as a vacuum cleaner. A large fan creates suction within the housing, which draws in dirty gas and filters it through the fabric of the bags.

Wet scrubbers

A wet scrubber entraps dust particles in water droplets and removes them from the exhaust gases. This is done by breaking up the water into small droplets and bringing them into a direct contact with the dust-laden gases. As Figure 12 #3 illustrates, gases from the dryer are introduced into a chamber through one inlet while water is sprayed into the chamber from nozzles around the periphery. Most wet scrubbers are used in combination with a centrifugal collector which collects coarser material while the wet scrubber removes the fines.

(d) Screens (batch plants only)

Screens are sometimes used in batch mixing plants. Aggregates, having been heated and dried, are carried by the hot elevator – usually an enclosed bucket conveyor – to the screen unit where vibrating screens separate the aggregates into specific sizes. To perform this function properly, the total screen area should be large enough to handle the total amount of feed delivered, and must be in balance with the capacity of both dryer and pug mill. The use of this system in modern-day production in South African practice is reserved for highly variable aggregate sources.

(e) Hot bins (batch plants only)

Hot bins are used for the temporary storage, prior to introduction into the weigh hopper, of the heated and screened aggregates in the various sizes required. Each bin is an individual compartment or a segment of a large compartment. The partitions between the compartments must be tight, free from wear holes and high enough to prevent aggregate spillage into an adjacent compartment.

A properly sized hot-bin installation should be large enough to hold enough material of each size to permit the mixer to operate at full capacity.

(f) Weigh hopper (batch plants only)

Aggregates are withdrawn from the hot bins and deposited into the weigh hopper, which is suspended from scale beams that weigh the cumulative amounts of aggregate contained. Figure 13 illustrates how the cumulative scale settings are used to control the proportion of aggregates drawn from each bin.

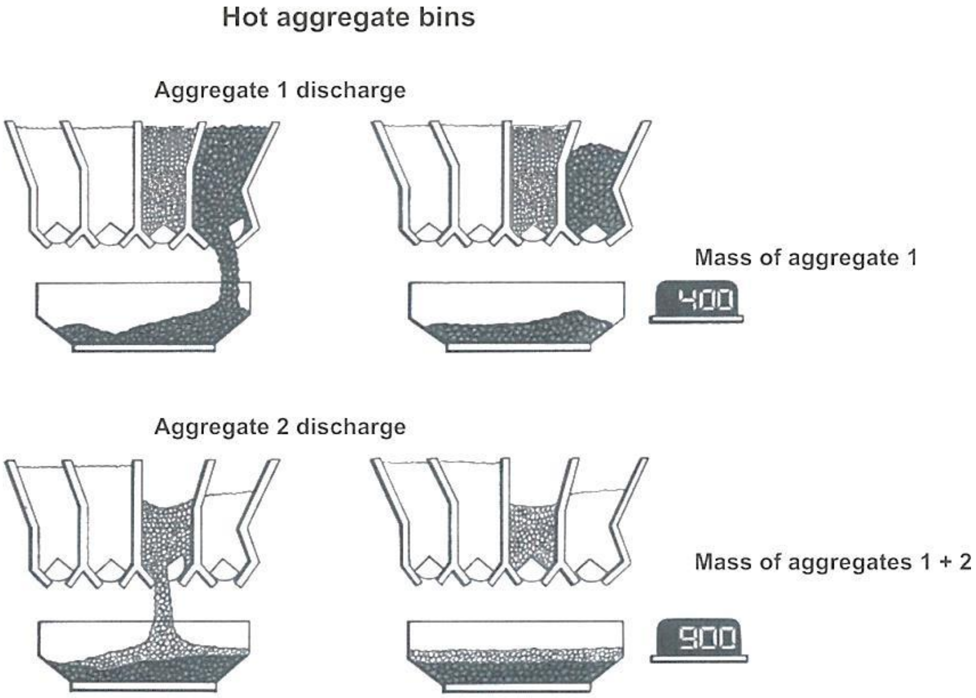


Figure 13: Cumulative Weighing of Aggregate

The overall efficiency of the mixing process depends on the accuracy of the scales. Hence, they should be checked daily and serviced regularly.

(g) Binder meters

Batch plants

Aggregate deposited into the plant's pug mill from the weigh hopper is blended with the correct proportion of binder. In a typical plant system, the quantity of binder to be introduced is weighed separately in a weigh pot before being introduced into the pug mill. When the required mass of binder has been pumped into the weigh pot, a three-way valve in the ring-line bitumen feed system closes off the link to the weigh pot (See Figure 14). The binder in the weigh pot is then pumped through spray bars into the pug mill.

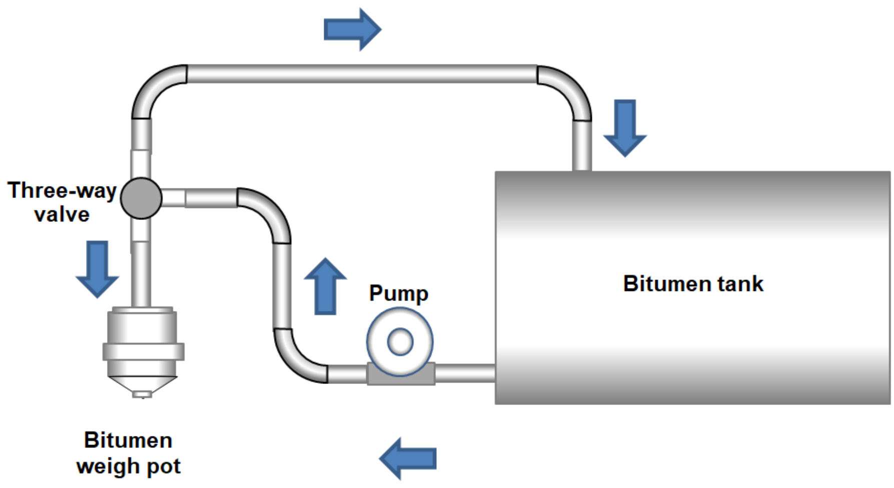


Figure 14: Binder Metering

Since binder accumulates on the sides of the weigh pot during operation, the tare mass should be checked regularly for accuracy.

Drum mixers

In a drum mixer, the binder is added to the aggregate inside the dryer drum.

Binder metering and delivery is a continuous mechanical proportioning system locked with the aggregate weigh system to ensure the correct binder content of the mix. The mass of aggregate being transported into the dryer/mixer, as measured by a sensor under the aggregate conveyor, determines the quantity of binder delivered into the drum (see Figure 15).

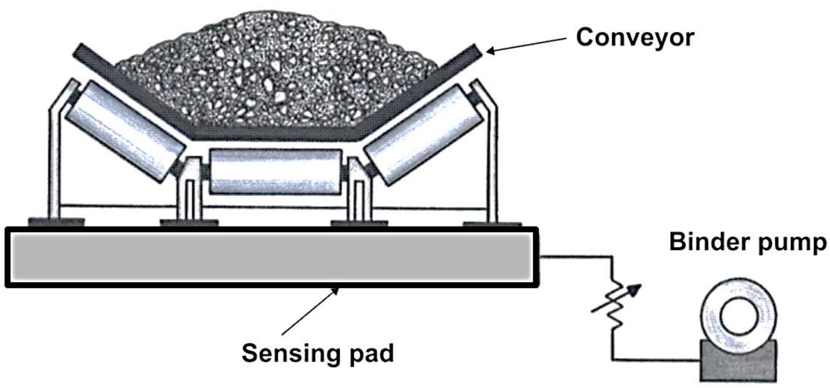


Figure 15: Binder Metering System (drum mixer)

(h) Pug mill (batch plants only)

The chamber in which the binder and aggregates are mixed in a batch plant is called pug mill. A twin-shaft mixer is used in virtually all modern asphalt plants, consisting of a lined mixing chamber with two horizontal shafts on which several paddle shanks, each with two paddle tips, are mounted. The paddle tips are adjustable and easily replaced.

The paddles must be set to ensure that there are no “dead areas”, i.e. zones where material can accumulate out of reach of the paddles and thus not be thoroughly mixed. Worn or broken paddles should be adjusted or replaced before the plant start-up.

Figure 16 shows an over-filled pug mill, an under-filled pug mill (both of which will prevent compliance with specification) and a pug mill filled correctly.

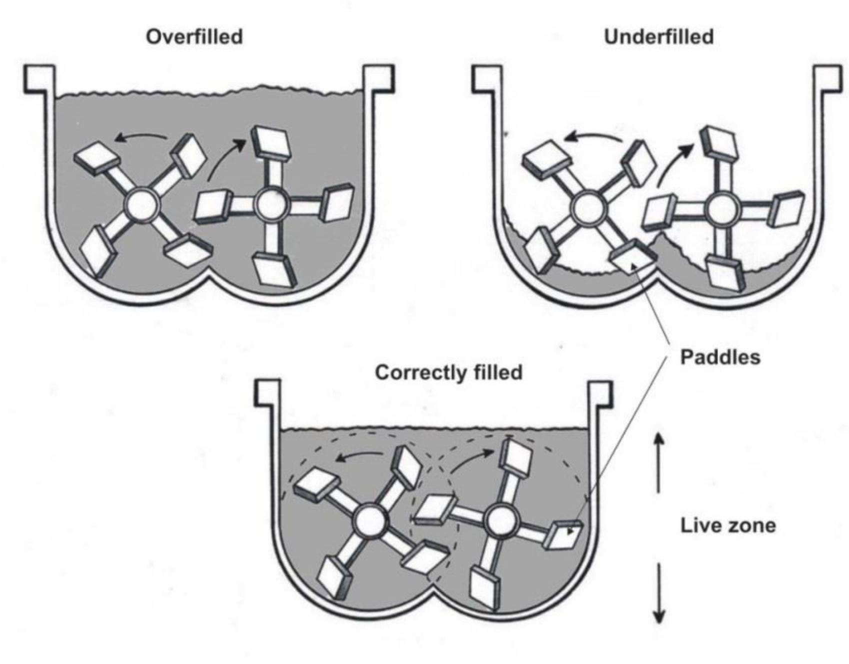


Figure 16: Pug Mill Capacity

(i) Control cabin

The control cabin normally contains all controls necessary to activate, shut-down or adjust plant operations, and all the dials and indicators necessary to monitor the manufacturing process.

The cabin should afford the operator a clear view of the entire plant and ancillary operations.

(j) Introduction of filler and other additives:

Filler

Mineral filler, either extracted from the heated, dried aggregate, or active filler, or a combination of the two, can be fed back to the aggregate blend, in controlled proportions in the following ways or combinations thereof:

- Directly to the mix, in which case the active filler portion would require weighing;
- Directly from the primary collector (full amount);
- From secondary collector (e.g. baghouse) by metered amount as required.

Filler addition methods for extracted and imported filler (lime, cement, rock flour) for various plant types are as follows:

- **Batch Plants:** weighed and fed into pug mill;

- **Drum Plants:** blown into mixing section of drum i.e. the binder addition zone, in such a way as to prevent loss thereof in the exhaust gas stream.[1]

Additives

Lighter additives, such as cellulose fibre and polyamine introduced as follows:

- **Batch Plants: pre-packed and introduced into the pug mill at the start of the dry-mix cycle;**
- **Drum** Plant: continuous feed (similar as for filler above).

Binder modifiers

See section B1.5 BINDER MODIFIERS.

C1.3 PLANT OPERATION

Asphalt plant operations differ significantly between batch plants and continuous mix plants.

(a) Batch plants

Modern batch plants can be operated in three modes:

- Manual;
- Semi-Automatic;
- Automatic.

In manual mode, each phase of batching is performed by manipulating an electric switch or button. These activate pneumatic, hydraulic or electric power systems for weighing, mixing and discharge.

In semi-automatic mode, several batching functions are accomplished automatically. These generally include the operation of the weigh hopper discharge gate, binder weigh bucket, wet mixing and the pug mill discharge gate in the correct sequence.

In fully automatic mode the plant is almost completely self-acting. Once mix proportions and timers have been set and plant operation begun, the plant machinery repeats the weighing and mixing cycle until the operator stops it or until the shortage of material or some other unforeseen event causes the plant controls to halt operation.

A typical batch plant cycle is illustrated in Figure 17.

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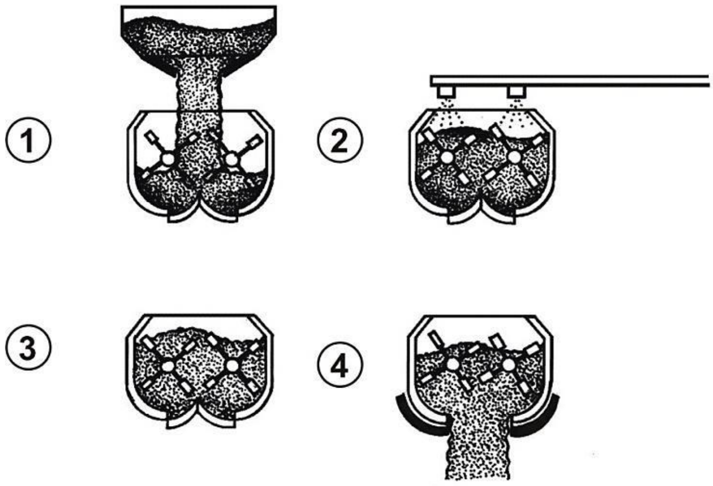
[1] Significant quantities of dust are entrapped in the mixture during the coating process. The coating zone is essentially a primary collector and can significantly reduce the dust in the system gas.



1 - Introduction of mineral-aggregate blend
2 - Introduction of binder
3 - Wet mixing
4 - Discharge

Figure 17: Batch Plant Cycle

Optimal mixing cycles are between 45 – 50 seconds, of which the wet mixing times are 30 – 35 seconds to ensure adequate coating of the aggregate. The mixing times may have to be increased if additives such as bitumen modifiers or cellulose fibres are added. Too long a mixing cycle can result in excessive binder ageing.

(b) Continuous mix plants

To ensure consistency of mix proportions that meet the specified requirements the following equipment controls are required:

- Separate cold feed controls for each aggregate size;
- Automatic continuous aggregate weighing system;
- Interlocking controls of aggregate cold feed and binder delivery to the drum;
- Automatic burner controls;
- A primary dust collector system capable of feeding collected material back into the system or to waste.

When operating a drum mixer, regular monitoring of aggregate grading and moisture content is extremely important. This is because the final mix grading is wholly determined by the grading of the individual fractions, and the specified binder content is based on the dry mass of aggregate while the sensors are measuring the mass of moist aggregate. Excess moisture in the aggregate can adversely affect the mix.

Excess moisture will also result in increased energy consumption - each percentage point increase in moisture content can increase heating fuel costs by up to 12%.

The plant should, therefore, be equipped with devices to obtain representative samples of each cold feed unit and the total cold feed. Such a device – a sampling chute fitted at the head of the cold feed conveyor belt is shown in Figure 18.

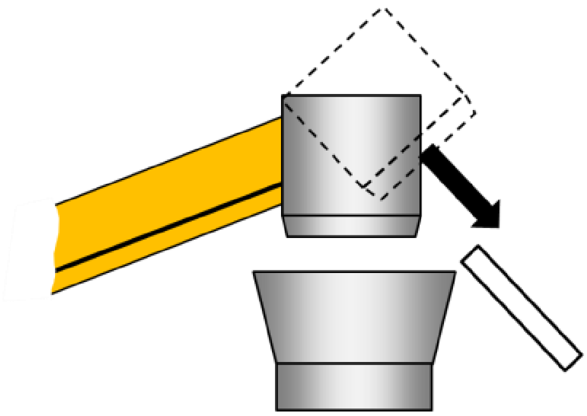


Figure 18: Cold Feed Sampling Device

(c) Temperature control

Since the aggregate makes up about 94% of the total mass of the mix, the temperature of the aggregate controls the temperature of the mixture. Normally a mixing temperature is determined by binder viscosity for adequate coating of the aggregates and to facilitate paving and compaction of the layer, on site. This temperature would naturally be affected by site conditions and the haul distance, as well as the composition of the mix.

The required temperature of the binder is determined by its temperature-viscosity characteristics, and should be such that the viscosity is in the range of 0.15 - 0.30 Pa.s for mix production. Compaction, however, can be carried out within a viscosity range as high as 20 Pa.s (see Figure 19). It is recommended that information on the temperature-viscosity relationship relevant to the bitumen in use be obtained from the bitumen supplier on a regular basis to ensure that appropriate temperatures are adopted for the various operations.

Note that the appropriate temperature range for compaction is derived from the temperature-viscosity relationship of the aged binder.

Modified binders require higher mixing temperatures, depending on the type and percentage of modifier introduced into the bitumen. For the appropriate ranges, the reader is referred to the Sabita publication TG1: *Technical Guideline: The use of modified bituminous binders in road construction*.

A "harsh" mix will need a lower binder viscosity to facilitate compaction, whereas other mixes may be compacted satisfactorily at higher binder viscosities (i.e. lower temperatures).

If the aggregate has a higher moisture content than normal, its temperature on discharge from the dryer drum will be lower unless the cold feed rate has been reduced or the burner fuel and air rates increased. This temperature should be monitored carefully to ensure that the mix temperature is adequate for satisfactory compaction, and not so high as to have an adverse effect on the binder quality.

Conditions in the pug mill are such that the binder will harden excessively if the aggregate temperature is too high. The large mass of stone holds heat which could rapidly overheat the thin film of binder coating it; the action of the paddles in the pug mill allows air to come in contact with these thin films and hardening through oxidation takes place. This, in turn, reduces the flexibility and durability of the asphalt, shortening its effective life. Mixing should, therefore, take place at as low a temperature and short a cycle as will provide a complete coating of the aggregate particles.

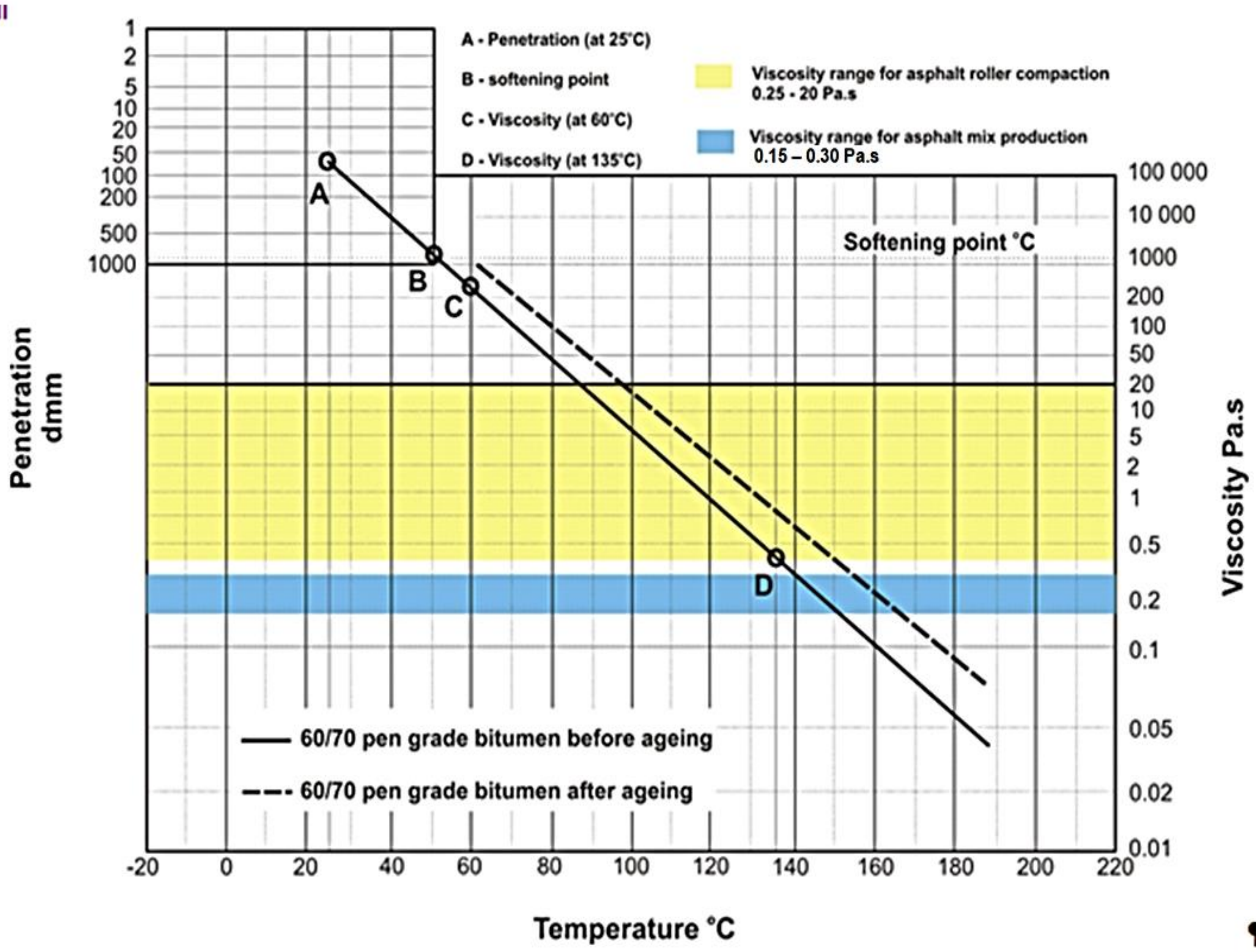


Figure 19: Typical Temperature / Viscosity Chart for a 60/70 Penetration Grade Bitumen

SECTION D – MATERIALS HANDLING

D1 HOT STORAGE AT PLANT AND TRANSPORT TO SITE

D1.1 HOT STORAGE

To prevent plant shutdown through temporary interruptions of paving operations or shortages of trucks to haul the material from the plant to the paving site, asphalt plants are generally equipped with storage silos for temporary storage of hot asphalt. See Figure 20.

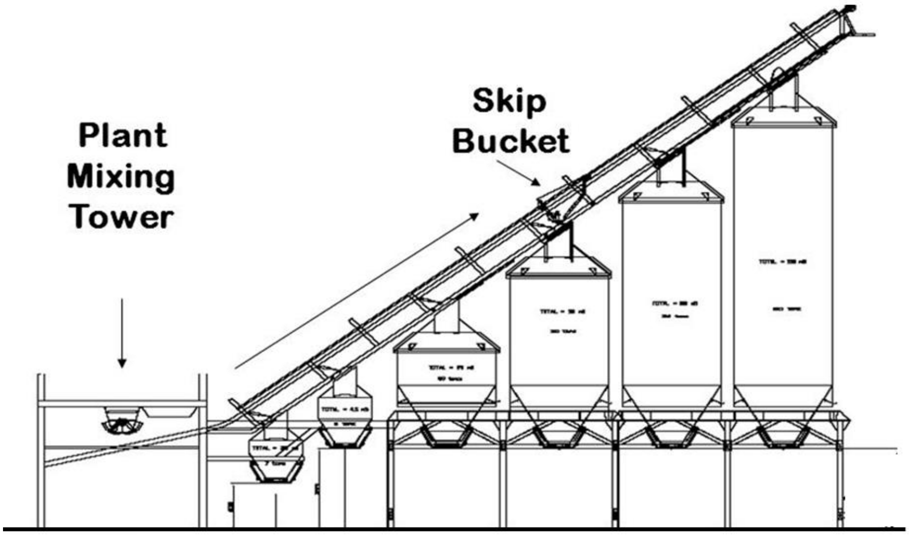


Figure 20: Hot Storage Silo

Storage bins are insulated to cater for storage periods up to 12 hours or longer. Longer storage periods require specialised planning and storage bin systems to prevent ageing. Hot storage capacity varies and may be several hundred tons.

These bins are charged from the top using a variety of conveying systems, for example belt conveyors, bucket elevators or skip hoists. Most storage bins are cylindrical with a conical outlet at the bottom.

In cases where asphalt plants have multiple silos or produce multiple types of asphalt mixes, the silos should be clearly and uniquely identified to ensure the loading of the correct type of asphalt for specific sites.

D1.2 TRANSPORT TO SITE

Mix segregation and temperature segregation are two of the most common phenomena encountered during the transport of asphalt. Temperature segregation can be minimized by properly loading the mix at the asphalt plant and suitably covering the asphalt mix with a tarpaulin or similar heat covering device. While this is simple to do, mix segregation is a little more complicated to address since it is affected by the condition of the trucks and, to a large extent, by driver behaviour. To ensure that mix segregation is minimized during the asphalt transport cycle, asphalt suppliers should ensure that trucks they use for transporting asphalt are in good condition and truck drivers adopt good driving habits.

(a) Haul trucks

Truck bins must be inspected at the start of each shift, to ensure that they are clean and sponged or sprayed down with release fluid to stop the asphalt from sticking to the sides and that the tailgates are secure and closed properly. The trucks should preferably not be used for any other purpose than for carting asphalt.

Dimensions

Trucks to haul hot mix from the plant to the paving site can be rigid or articulated tipping vehicles. To facilitate discharging asphalt into the paver hopper, trucks must have an elongated tailpiece to prevent spillage around the paving unit. The overhang of the body should be at least 750mm, preferably 800mm.

An absolutely minimum clearance of the chassis and / or springs of 650mm should be maintained when fully loaded, and brake boosters must not extend past the tyres if they have less than 650mm clearance from the ground when fully loaded.

These measurements should be taken as a guideline and confirmed with the actual plant equipment on site as a multitude of pavers and asphalt transfer vehicles are used.

The truck must also not have a back bumper bar and mud flaps as it will interfere with tipping.

The chute height above the ground in the tipped position should be not less than 850mm, preferably 900mm.

The distance that the asphalt can be transported ranges from a few kilometres to a few hundred kilometres. This is dependent on weather/seasonal/climactic conditions and the type of asphalt and its temperature. For example, the Stone Mastic Asphalt mixes cannot be transported far due to drain down of the mastic, whereas warm mix asphalt can generally be transported the furthest. Acceptable loss of temperature and binder drain-down will dictate the distance.

Release agents

To prevent asphalt adhering to the truck body, an approved or acceptable release agent, e.g. a silicone emulsion, or biodegradable vegetable oil emulsion, should be used. Whichever release agent is used, it should not be allowed to pool in the truck bin. This can be dealt with by tipping the bin after the release agent is applied to drain any excess, before loading.

***Note**: Oil-based materials such as engine oil, paraffin or diesel fuel should not be used.*

Vehicle condition

All trucks delivering asphalt must be in good working order, able to carry and tip loads efficiently, and be issued with a valid roadworthy certificate.

Specific items to be checked are:

1. Complete absence of oil and diesel leaks;
2. Fully functional brakes;
3. Good idling and tipping capability, with no hydraulic leaks;
4. Tail-gate suitable for tipping into paver hopper and must be able to lock properly during transport to avoid spilling asphalt on the route;
5. Adequate uphill pull-away capability.

Covers

Asphalt in trucks should be covered with a tarpaulin or other suitable thermal insulation sheeting. In winter a thermal blanket (duvet) must be used. The canvas must then go over the thermal blanket to secure it during travel.

***Note**: Hessian covers are not acceptable.*

The truck bin sides can also be insulated by bolting shutter plank to the inside of the bin.

The sheeting should cover the entire surface of the asphalt and be well tied or weighted down and kept in place until tipping.

Although the drop in temperature over short haul distances may not adversely affect the paving and compaction operations, covering of the load will minimise both heat loss and hardening of the binder film as a result of exposure to air flow.

Loading

Measures should be in place to minimise segregation of the material in the truck body: the asphalt mix should be discharged continually in bulk and evenly distributed in the bin taking into account axle loads and tipping capability. For instance, if the truck bin is loaded too heavily in front it might not be able to tip the load. Care should be taken not to load step by step from the hot storage onto the truck bin as this would cause segregation.

(a) Loaded trucks

Trucks loaded with asphalt must be weighed on a scale with a valid calibration certificate and issued with the relevant weigh bridge tickets. Weighbridge tickets must show the date, time of batching, asphalt type, tonnage, cumulative tonnage and batch temperature. The person receiving the tickets on site must be able to fully understand the contents on the ticket, as well as what the required mix is. Every ticket must be checked to ensure that the correct mix has been delivered.

The loaded truck should comply with the legal requirements in respect of maximum axle load and gross vehicle mass. The number of trucks and their load capacities should be balanced to plant output and haul distance to ensure a continuous supply of asphalt to the paver. The following components of truck turnaround time should be taken into account:

1. Distance between plant and site
2. Average travel speed between plant and site
3. Waiting time at plant
4. Loading time at plant
5. Minimum headway between truck arrivals at site
6. Waiting time at paver site
7. Unloading time at site
8. Quantity of asphalt to be transported per hour

To ensure a continuous supply at the paver, the reader is referred to APPENDIX 1 where fleet demand calculations are given to assist in achieving this.

(b) Driver Requirements

Drivers should be experienced and able and willing to carry out instructions correctly. They should be aware of company policy and standing instructions regarding the cleaning of the truck body and disposal of excess material. Drivers must be in possession of a valid Professional Driving Permit (PDP) and must have undergone site-specific induction and be medically fit. Drivers are also expected not to stop unnecessarily en route to site or mixing plant for whatever reason in view of the negative effect on load cycle time or temperature of the load.

Essential driver skills include:

1. Ability to manoeuvre in confined areas;
2. Straight and brisk reverse over long distances;
3. Avoidance of damage to works, e.g. kerbs and edges of fresh mats;
4. Ability to connect smoothly with the paver and correct release of breaks;
5. Controlled tipping without spillage.

(c) Communication

It is of the utmost importance that there is constant communication between the asphalt plant and the site, so that either the manufacturing or the paving rate can be adjusted if there are delays at either end. The person in charge of the paving team must estimate at what time the trucks are required to arrive on site, so that they don't end up standing for hours cooling down, and that the rate of supply is commensurate with the paving speed.

(d) Delivery to site

The time between batching and tipping should be planned to ensure that the trucks are tipped in the same order as they are batched.

To ensure that the paver does not have to stop unnecessarily, the asphalt should be delivered to site at a rate similar to that of paving.

SECTION E – PROCEDURAL AND LEGAL REQUIREMENTS FOR ASPHALT MANUFACTURE

This section will cover:

- An outline of the suite of national environmental legal frameworks (NEMA, etc.), including other frameworks that may apply in certain cases to the manufacture and construction of asphalt products.
- A guideline on environmental regulatory compliance as generally applicable to asphalt manufacture and road construction. Various asphalt manufacture and road construction activities would require cognizance of specific legislation and the main relevant aspects of the outlined legislative framework will be presented as applicable to these activities, including:
  - Asphalt manufacture;
  - Asphalt transport (basic coverage as handled by SABITA Safety Manual 8);
  - Road maintenance; and
  - Road construction and borrow pit development.

As the subject cannot be covered in detail in this document, the reader is referred to the Sabita Website to access details as presented in the document: *Environmental Legislation Guideline Document for Asphalt Manufacture and Road Construction*, August 2015.

E1 RELEVANT LEGISLATIVE FRAMEWORK

E1.1 CONSTITUTION OF THE REPUBLIC OF SOUTH AFRICA ACT

The Constitution of the Republic of South Africa Act (Act No. 108 of 1996) incorporates the Bill of Rights, which covers various human rights as enshrined in this piece of legislation. It stipulates the right to an environment that is not harmful to human health and the protection of the environment for present and future generations.

E1.2 CONSERVATION OF AGRICULTURAL RESOURCES ACT

The Conservation of Agricultural Resources Act (Act No. 43 of 1983) provides the legislative framework for control of the use of natural agricultural resources in the Republic, and aims to promote conservation of the soil, water sources and vegetation as well as combating weeds and invasive plants.

E1.3 ENVIRONMENTAL CONSERVATION ACT

Most of the provisions of the Environment Conservation Act (ECA) (No. 73 of 1989) have been superseded by the National Environmental Management Act (NEMA). However the noise management stipulations of this act still have particular relevance. The specified day time residential threshold noise level is 55dBA.

Noise control regulations have been published and revised in Government Gazette 13717 (dated 10 January 1992) and Government Gazette 15446 (14 January 1994) - GN. No R. 55. These regulations make it the responsibility of all local authorities to apply the regulations.

Subsequently in terms of Schedule 5 of the Constitution of the Republic of South Africa Act (Act No. 108 of 1996), legislative responsibility of administering the noise control regulations (NCR) was devolved to provincial and local authorities. Provincial NCR only exist in the Free State, Gauteng, Mpumalanga and Western Cape Provinces.

E1.4 EXPLOSIVES ACT

The Explosives Act (Act No. 15 of 2003) outlines the requirements with regard to the keeping, storage, possession or transportation of explosives as highlighted in Section 10 of the Act.

Explosives storage and transportation permits are issued by the Minister of Police.

E1.5 MINERAL AND PETROLEUM RESOURCES DEVELOPMENT ACT

The Mineral and Petroleum Resources Development Act (MPRDA) (Act No. 28 of 2002), as amended provides the framework legislation for equitable access and sustainable development of the country's mineral and petroleum resources.

In addition to the relevant legislative aspects highlighted above the MPRDA stipulates the following:

- The holder of a mining right/permit (e.g.: aggregate mining firm) remains liable for any site pollution or ecological degradation, as well as the management thereof, until a closure certificate has been issued for the respective site.
- Financial provision must be made for the closure or sudden termination of work in terms of site rehabilitation and re-vegetation work.

E1.6 NATIONAL ENVIRONMENTAL MANAGEMENT ACT (NEMA)

The National Environmental Management Act (NEMA) (No. 107 of 1998), as amended advocates that the principles of Integrated Environmental Management (IEM) should be adhered to.

There are also a set of regulations promulgated in terms of the Act which specify when project specific environmental impact assessments are required, as well as outlining the minimum requirements for such assessments.

E1.7 NEM: AIR QUALITY ACT

The National Environmental Management: Air Quality Act (No. 39 of 2004), as amended in 2014 forms the framework for the control of air pollution. Manufacture of asphalt for road surfacing at permanent facilities and mobile plants requires an Atmospheric Emission Licence (AEL). Metropolitan and district municipalities are charged with issuing Atmospheric Emission Licences. The defined emission limits (taken as daily averages) for macadam preparation plants are as follows (as defined in GG 37054 of 22 November 2013 – GN 893). (See Table 1).

The requirements in terms of compliance timeframes regarding these emission limits for asphalt manufacturing plants are as follows:

- New plant is required to comply with the new plant minimum emission standards as contained in Part 3 of the Act from 01 April 2010.
- Existing plant must comply with minimum emission standards for existing plant as contained in Part 3 of the Act by 01 April 2015, unless where specified.
- Existing plant must comply with minimum emission standards for new plant as contained in Part 3 of the Act by 01 April 2020, unless where specified.

Table 1: Atmospheric Emission Limits for Asphalt Manufacturing Plants

Substance or Mixture of Substances		Plant Status	Emission Limit - mg/Nm³ (273K and 101.3 kPa)
Common Name	**Chemical symbol**		
Particular matter	N/A	New	50
		Existing	120
Sulphur dioxide	SO_2	New	1 000
		Existing	1 000
Total volatile organic compounds from vapour recovery / destruction units	N/A	New	150
		Existing	150

E1.8 NEM: BIODIVERSITY ACT

The NEM: Biodiversity Act (No. 10 of 2004) guides the management and conservation of biodiversity, with particular focus on species and ecosystems that warrant national protection, and the sustainable use of indigenous biological resources.

A comprehensive national list of ecosystems that are threatened and in need of protection is currently being finalised.

E1.9 NEM: INTEGRATED COASTAL MANAGEMENT ACT

The NEM: Integrated Coastal Management Act (Act 24 of 2008) was amended by the Integrated Coastal Management Amendment Act (Act 36 of 2014) and promotes the conservation of the coastal environment, ensuring development (including transport infrastructure) and natural resource use within the coastal zone is socially and economically justifiable and ecologically sustainable.

E1.10 NEM: PROTECTED AREAS ACT

The NEM: Protected Areas Act (No. 57 of 2003) allows for protection, conservation and management of ecologically viable areas of biological diversity (natural landscapes and seascapes).

E1.11 NEM: WASTE ACT

The NEM: Waste Act (Act 59 of 2008) provides regulations in terms of the responsible and safe transportation of waste materials, preventing spillage of waste onto transport infrastructure (roads, railways) and ultimate dispersion into the environment. This act was recently amended by the NEM: Waste Amendment Act (Act 26 of 2014).

E1.12 NATIONAL ROAD TRAFFIC ACT

The National Road Traffic Act (No. 93 of 1996) applies to transport activities and provide definitions regarding road infrastructure. A noteworthy clause is the one related to the prohibition of the transportation of dangerous goods.

E1.13 NATIONAL WATER ACT

The National Water Act (No. 36 of 1998), as amended on 02 June 2014 governs the interactions between water resources and proposed developments. The Act incorporates the regulations regarding the prevention of pollution and the responsibility of polluters of water bodies to remedy pollution effects.

E1.14 OCCUPATIONAL HEALTH AND SAFETY ACT

The Occupational Health and Safety Act (No. 85 of 1993) governs the protection of workers from work hazards, and applies to all types of work. The Act was amended again in 1993 as the Occupational Health and Safety Amendment Act (No. 181 of 1993).

Government gazette 16596 (25 August 1995) - GN No R 1179, as amended by GN No R930 of 25 June 2003, outlines the hazardous chemical substances regulations stipulating various occupational exposure limits (OEL) as defined below:

- "OEL" means a limit value for a stress factor in the workplace as revised from time to time by notice in the Government Gazette;
- "OEL-CL" or "occupational exposure limit - control limit" means the occupational exposure limit for a hazardous chemical substance as listed in Table 1 of Annexure 1 hereby; and "control limit" has a corresponding meaning;
- "OEL-RL" or "occupational exposure limit - recommended limit" means the occupational exposure limit for a hazardous chemical substance as listed in Table 2 of Annexure 1 *of the notice (own insertion)* hereby and "recommended limit" has a corresponding meaning.

Specific hazardous chemical substances and OEL which pertain to SABITA operations are provided as follows:

- Asphalt – petroleum fumes are stated to be a suspected human carcinogen (classified in the carcinogenic compounds list) and require special care to prevent / limit exposure to fumes.
- Occupational exposure control limits are provided for some of the raw materials of asphalt and modified binders and stipulations for rubber fume and rubber process dust (as highlighted in Annexure 6 of the government notice).
- Occupational exposure recommended limits are provided for asphalt and solvents exposure in laboratories.

Regulations promulgated in terms of this act are:

- Major Hazard Installation Regulations (GN R 692 of 30 July 2001).
- General Machinery Regulations (GN R 1521 of 05 August 1988).
- Construction Regulations, 2014 (GN R 84 of 07 February 2014).

These regulations are applicable to all persons involved in construction work and provide guidelines on the permits required, the responsibilities of all role-players during construction work, the management of construction work, risk assessment as well as various methodologies for aspects such as excavation, fall protection, demolition, etc.

E2 LEGISLATIVE COMPLIANCE GUIDELINE

The document: *Environmental Legislation Guideline Document for Asphalt Manufacture and Road Construction*, August 2015, which can be accessed on the Sabita website at http://www.sabita.co.za/other-publications/ gives a comprehensive summary of the applicability of the above legislated requirements in respect of:

- Existing and planned asphalt mixing plants
- Asphalt transport
- Road maintenance
- Road construction and road upgrades

Additionally, the reader is referred to Sabita Manual 34: *Guidelines to legislation on the transportation of bitumen and Bitumen spill protocol*.

E3 OCCUPATIONAL HEALTH AND SAFETY

E3.1 GENERAL INTRODUCTION

There are several hazards associated with the manufacture of hot mix asphalt. Elevated temperatures associated with asphalt and its components (bituminous binders and aggregates), noise, moving machinery and manoeuvring earthmoving equipment and trucks at the stockpiles and loading zones, constitute conditions that require due care to control employees' exposure to associated hazards, thereby preventing serious injury, damage or even loss of life. Solvents and cleaning aids used in asphalt laboratories pose a threat to good health. Laboratories, including those on construction sites, should therefore be equipped with the necessary extraction and ventilation systems to limit exposure to toxic fumes.

At the paving site tally-clerks, screed operators, rake men, laboratory staff taking samples and haul truck assistants are all exposed to the hazards of passing traffic and moving plant.

Proper induction of new employees into the company's safety programmes, as well as ongoing training in the safe handling of materials and proper operation of plant and equipment, is therefore essential.

The processes associated with the manufacture and paving of asphalt, by their very nature also impact on the environment. Waste products which may contain pollutants, emissions and noise are generated, and non-renewable natural resources and energy are consumed. Manufacturers have an obligation to minimise the impact of their operations on the environment and this can be achieved through innovations that will, e.g., lower manufacturing temperatures, increase the use of reclaimed asphalt in new mixes, and reduce emissions and noise. Pavers could be equipped with scavengers in the auger boxes to dispel fumes at a level that will not affect the breathing of paving staff.

It is therefore essential that employers and employees be conversant with the relevant sections of the Act and regulations made under the Act, and that they are understood and followed by each person involved in the project.

E3.2 SPECIFIC HEALTH, SAFETY AND ENVIRONMENTAL REQUIREMENTS

The Occupational Health and Safety Act of South Africa (Act No. 85 of 1993) and relevant Regulations made under the Act, prescribe the minimum requirements for Health and Safety in the workplace, and of those likely to be affected by their activities. In terms of this Act the "employer" and "employee" have distinct responsibilities and duties to ensure health and safety in the workplace. In particular employers and employees must take cognisance of the following requirements of the Act:

- Section 8. General duties of employers to their employees.
- Section 9. General duties of employers and self-employed persons to persons other than their employees.

- Section 10. General duties of manufacturers and others regarding articles and substances for use at work.
- Section 13. Duty to inform.
- Section 14 General duties of employees at work.

E3.3 RELEVANT REGULATIONS

A number of Regulations have been made under the Act and several of these may be relevant and applicable to the operations and activities discussed in this Manual. Operators must ensure that they are conversant with the relevant requirements and especially the requirements of the Construction Regulations 2014 where road construction activities are included in a project.

E3.4 BEST PRACTICE GUIDANCE

A number of Manuals, Training Courses, DVD's, Posters and other Health and Safety Communication Notes have been developed by Sabita to assist with managing the risks associated with the storage and handling of bituminous products, as well as first aid treatment of injuries and the prevention and fighting of fires. Guidance provided includes the development of an occupational health and safety policy, the principles governing company commitment to the health and safety of its employees, general duties of employees at work and the appointment and functions of those employees with responsibility for implementing the company's health and safety plan. In addition, some documents address recommended risk assessment procedures designed specifically for operating plant and equipment directly related to the application of bituminous products.

The following SABITA publications have specific relevance for the operations discussed in this Manual and can be accessed via the SABITA website www.sabita.co.za or printed copies can be ordered from the SABITA offices:

- SABITA Manual 8 - Guidelines for the safe and responsible handling of bituminous products;
- SABITA Manual 25 - Code of Practice: Transportation, off-loading and storage of bitumen and bituminous products;
- SABITA Manual 29 - Guide to the safe handling of solvents in a bituminous products laboratory;
- SABITA Manual 34 (34a and 34b) - Guideline to legislation on the transportation of bitumen and Bitumen spill protocol;
- DVD410 - The safe handling of bitumen;
- DVD420 - Treatment of bitumen burns;
- DVD430 - Working Safely with Bitumen;
- DVD440 - Firefighting in the bituminous industry;
- DVD450 - Safe loading and off-loading of Bitumen;
- Environmental Legislation Guideline Document for Asphalt Manufacture and Road Construction;
- An industry best practice guide for the storage of reclaimed asphalt (RA) at asphalt plants;
- Operating best practice for Temporary Asphalt Plants;
- Sabita bitumen spill protocol;
- HSE Communications Note 02/2014 - Design of facilities for the storage and distribution of bitumen and bituminous products in above-ground tanks;
- HSE Communication Note 01/2017 – Silica Dust Control.

E3.5 CONCLUDING REMARKS

Caring for employees and the environment is an obligation and not simply an option that may or may not be exercised. Excellence in health, safety and environment management can justifiably be seen as license to operate in a harshly unforgiving modern business and social environment. In addition, the legal consequences of non-compliance could be extremely costly if plant operators choose to ignore requirements. The Occupational Health and Safety Act is currently under revision and when the amended Act takes effect harsh penalties, including administrative or so-called “spot” fines, could severely punish offenders. Therefore, plant operators are urged to “do the right thing” and conform as far as is reasonably practicable. Make use of the advice available to achieve the desired excellence in order to prove proper “due diligence” should this ever be required.

SECTION F –
CONSTRUCTION MANAGEMENT

F1 SITE AND PLANT PREPARATION

Quality asphalt paving requires thorough preparation and checking to ensure that:

- Haul roads are in good condition, well maintained and properly drained.
- Enough suitable machines are available to carry out the paving and compaction correctly.
- Enough skilled operators and labourers are on site to carry out the work correctly.
- The supply capability of the asphalt plant and truck fleet is sufficient to keep the paver moving without interruption.
- All plant and tools are clean and in good condition.
- All road appurtenances such as manhole and valve covers have been reset to new levels if necessary.
- All personnel and implements required to accommodate traffic and render the work zone safe are in place.
- The base or substrate on which the asphalt is to be laid is correctly prepared and clean and that the effect of base levels on the final finish and quantities are clearly understood.
- Weather conditions to be expected during paving operations are assessed.
- Quality Control plans are in place and approved, including sampling locations and procedures.
- Where Enrobé à Module Élevé (EME) is being laid, special considerations given in Sabita Manual 33 should be followed.

F2 PROJECT PLANNING

Good planning is essential to ensure optimal productivity while maintaining high quality standards. To achieve these goals consistently, all phases of the job must be incorporated in the planning process. Some of the issues vital to the planning process are listed below:

By identifying the specific project parameters, the contractor can effectively plan each phase of the project to achieve the optimum balance between production rates, cost-effective operations and profitability, while ensuring quality hot mix asphalt layers. Typical planning areas are listed below:

F2.1 SITE MEASUREMENT AND CHECKING OF EXISTING GRADE CONDITIONS TO INCLUDE:

- Identify low/high areas, vertical alignment aspects (i.e. transitions) and other areas requiring special paving planning, hand corrections, levelling or repair;
- Check that there are adequate falls for drainage;
- Calculate tons required based on actual average thicknesses (usually determined by a grid of dips);
- Check that adequate substrate construction support exists;
- Check for the encroachment of tree roots which can distort the pavement layer;
- Deal with street furniture that requires adjustment (e.g. manhole covers etc.);
- Decide on applicable bond coat application.

F2.2 CONFIGURATION OF THE PAVER AND LEVEL CONTROL SYSTEM:

- Check required paving width and whether the use of screed, auger and auger tunnel extensions is required;
- Check which level control system is most applicable for each side of the paver (i.e., averaging beams, fixed string line, joint-matching shoe or constant cross-fall).

F2.3 OTHER PLANT REQUIREMENTS:

- Select suitable rolling train, sequence and passes;
- Provide standby paver or rollers if required.

F2.4 MATERIAL DELIVERY TO THE PAVER:

- Check asphalt plant capabilities and required delivery in tons per hour;
- Examine the type, suitability and number of trucks for a particular haul distance and the availability of tarpaulins;
- Check on traffic conditions, haul routes, access to paving site and traffic control measures.

F2.5 PROJECT REQUIREMENTS:

- Establish the sequence of paving, the paving lanes and handwork required;
- Determine the location of longitudinal and transverse joints and the required treatment of joints;
- Take note of project requirements applicable to mix parameters, compliance limits, finish, compaction (density) and surface texture.

F2.6 QUALITY ASSURANCE:

- Establish a system for recording site data;
- Agree on the responsibility for and timing of site coring and/or nuclear gauge testing;
- Establish a laboratory testing and reporting system;
- Establish a sampling and storing system;
- Agree on a procedure for dealing with any defects.

F2.7 PAVING SITE CONDITIONS:

- Establish channels of communication on site between engineer, contractor, supplier and paving crew;
- Agree on a protocol for weather limitations;
- Determine acceptable asphalt mixing and delivery temperature ranges;
- Check surface preparation and weather influences on various surface types;
- Assess trial section outcomes;
- Carry out other inspection and assessment routines;
- When paving adjacent to traffic, ensure that the minimum requirements in terms of a “safety zone” is maintained;
- Keep local traffic authorities informed of operations, especially in the event of break downs on busy roads.

F2.8 DAILY CHECKS ON PLANT

- Checks # 9 (paver) and #9 to 12 (rollers) as per Table 11 of Chapter 12, section 4 of SAPEM should be completed by the engineer and contractor daily before paving commences.

F3 BOND COAT, PRIME AND OTHER SUBSTRATE/SURFACE PREPARATIONS

The performance of asphalt is directly dependent on the condition of the support layer(s). For a full-depth asphalt pavement, if the condition of the granular sub-base and/or lower sub-grade soil is poor, the ultimate life of the roadway may be significantly reduced. For asphalt layers placed on top of a new, untreated granular base course, the base material should be stable and the surface firm and dry - it should not be distorted or ravelled by construction traffic. Where asphalt is laid on top of existing asphalt layers, the surface should be properly prepared – potholes filled, cracks sealed, distress repaired and the surface cleaned. A bond coat should also be used to ensure a bond between the existing pavement surface and the new asphalt overlay.

F3.1 SURFACE PREPARATION OPERATIONS

The following operations are essential to ensure that the substratum is properly prepared for paving:

- New granular bases should be well constructed. This requires:
  - Material of suitable quality, that is adequately compacted and sufficiently dry;
  - Finishing to correct levels;
  - A good, uniform surface texture free of excess fines.
- The base should be primed, with a bond coat applied and cleaned. If there is any doubt as to whether both prime and bond coat are required, it is advisable to err on the side of caution and to apply both. Unless a very thick overlay is being constructed it is advisable that all distressed areas in the underlying layer be either removed or repaired before paving commences.
- If the bond coat is applied immediately in front of the asphalt using a "self-tacking" paver, it is essential to have at least one full-time worker cleaning up any asphalt spillage from the trucks, otherwise there will be a lack of bond at such areas. The truck operators must be instructed not to bang their tailgates to remove excess asphalt onto the road from within the bin.
- If there are cracks in an existing asphalt pavement surface, they should be sealed individually, or some type of surface treatment should be applied to the whole roadway area. Joints in concrete pavement that are poorly sealed should be routed out and sealed. Rocking concrete slabs should be seated.
- Should existing road marking paint prevent proper surface preparation, consideration should be given to have it water-jetted off to ensure proper adhesion and / or penetration.
- Before paving, the area should be measured and a grid of dip measurements taken to determine:
  - Average thickness;
  - High and low areas (for possible repairs or corrections);
  - Asphalt volume requirements.

  It is important to note that paver screeds are inflexible and a substrate with a varying profile across its width will almost certainly result in variable thickness of the paved layer.

- Slopes should be checked to ensure surface drainage. A minimum slope of 1% to a runoff escape point is necessary. The potential for ponding should be established, particularly at intersections and bell mouths.
- A rough, uneven existing asphalt surface should be levelled with asphalt mix, preferably using a paver to fill in the low spots in the surface. Alternatively, it should be milled with a precision milling machine to remove the high spots.
- Once the required repairs have been completed, the pavement surface should be cleaned of all dust, dirt and other debris using multiple passes of a mechanical broom. If brooming does not remove all accumulated dirt, the use of compressed air or water may be necessary.
- If the aggregate surface appears smooth or polished, precautions should be taken to prevent slippage of the newly paved layer. Trial areas should be paved to identify problems and solutions, and roughening by planing or the use of a specialised bond coat may be necessary.

F3.2 PRIMING OF SUBSTRATE

The priming of granular layers or substrate serves to bind the upper zone (10mm approx.) to provide protection against the scuffing effects of construction traffic for a limited period, and to prevent the ingress of water. It will not provide adequate adhesion between the base and an asphalt layer placed on top of such a granular base as its purpose is to penetrate and condition the top zone of the base. Similarly, it is not possible to prime a base using a bond coat, as penetration will not take place. Hence the application of a bond coat is always recommended. For more details regarding the use and application of prime coats the reader is referred to Sabita Manual 26: *Interim guidelines for primes and stone precoating fluids.*

F3.3 BOND COAT

As mentioned above, application of a bond coat should precede paving operations to ensure a bond between the existing primed pavement surface and the new asphalt overlay, both during the construction and in-service phases of the asphalt layer. If a good bond is not formed between the existing surface and the new overlay, slippage during rolling or thereafter may occur, leading to the layer being shoved in a longitudinal direction, particularly at zones where the traffic accelerates or brakes.

To optimise the effectiveness of the bond coat the pavement surface must be free from anything that might cause slippage, and must be thoroughly cleaned before the bond coat is applied. All dust and dirt should be removed by mechanical brooming, washing or blowing.

Generally, a diluted bitumen emulsion (anionic or cationic stable mix emulsion, diluted 1:1 with water) is used to provide a complete coverage of the surface with a thin residual binder film on the surface. Typically, residual bitumen application rates of approximately 0.15 to 0.25 ℓ/m^2 are aimed at, depending on the condition of the surface to which the bond coat is applied. An open-textured surface requires more bond coat than a surface that is tight or dense, and a dry, aged surface requires more bond coat than a surface that is rich or flushed.

The following key factors should be further considered:

- The binder distributor used to apply the bond coat should be certified to carry out the operation, and should be checked on site to ensure that all the nozzles are fully functional and set at the correct angle and height above the pavement surface.
- Where the bond coat application is to take place by hand, an experienced operator using sound equipment and employing correct spray practices is essential.
- The application rate for the bond coat should be based on the target residual application rates of net bitumen, which should generally range from 0.15 to 0.25 ℓ/m^2 for normal surfaces.
- Milled pavements may require higher rates of application. A residual net rate of bitumen as high as 0.35 l/m^2 of binder may be needed to ensure a proper bond because of the increased surface area. On the other hand, too much bond coat may promote slippage of the new overlay on the old pavement, or may even cause bleeding of the bond material through thin overlays.

- Whenever possible, it is good practice to spray bond coat well in advance of paving (but not more than about 18 hours). This enables the bond coat to "set up" and reduce pick-up on supply truck tyres and the paver.
- Bond coats should not be exposed to traffic for any length of time. If this is inevitable, proper precautions should be taken, such as reducing the posted speed limit on the roadway and sanding the surface.
- It is prudent always to apply a bond coat between successive layers of new, fresh asphalt. However, in such cases the net binder application rate should be reduced by up to 50% if the layers are placed soon after one another.
- On rough or uneven surfaces, any small "pools" of bond should be spread by sweeping with a broom, to reduce the likelihood of fatty spots developing on the paved asphalt surface.
- When in doubt as to whether or not to bond, always err on the side of applying a bond coat.
- Reversing trucks onto the bond coat to tip, or the use of a MTV, can cause the bond coat to lift and thus create a loss of bond. In addition, if the adjacent layer has already been surfaced, the tyre tracks can create unsightly marks. The use of "non-tracking" bond coats should therefore be seriously considered.
- Applying the bond coat to the edges using a brush is more effective than by spraying and there is less likelihood of overspray onto the adjacent layer.

F4 RECORDING OF INFORMATION

Details of every load of asphalt dispatched from the asphalt plant to the paving site need to be recorded on a delivery note, which usually includes the following information:

- Project information and date;
- Truck registration and load size;
- Temperature and time of load leaving plant;
- Mix details and cumulative tons delivered.

The site worksheet should capture these details and, in addition, record:

- Arrival time and time tipped into the paver;
- Arrival temperature and temperature when tipped into the paver;
- Base and air temperatures, weather, and wind conditions and the times these were recorded;
- Stake values where each load is paved;
- Paved width and thickness of each load and running average thickness;
- Conversion factor used for determining thickness [*thickness mm = (tons* x *1000) / (area m2 x factor)*.

F5 PRODUCT QUALITY ENHANCING EQUIPMENT AND METHODS

Various new manufacturing and construction technologies have recently become available, which are suitable on high performance contracts to optimise final product quality or reduce costs.

F5.1 MATERIAL TRANSFER-VEHICLE

The material transfer vehicle (MTV) (Figure 21) is designed to act as a shuttle between the asphalt haul truck and paver. Some machines have storage capacity, allowing the contractor to even out the truck cycles and reduce haul costs. Thermal as well as aggregate segregation is significantly reduced or even eliminated by the machine's remixing action. The MTV therefore permits non-stop paving and improves uniformity, all of which leads to a much improved finished surface.

Figure 21: Material Transfer Vehicle

F5.2 *IN-SITU* ASPHALT HEATING DEVICES

Various asphalt-reheating devices are available which can be utilised to either repair areas of insufficient compaction or to prepare cold joints without costly and time consuming cut or removal operations. The older generation type with direct flame heating, which will damage the asphalt binder significantly, is not recommended. New types of infrared heating devices, used in conjunction with rejuvenator additives, have proved to be acceptable in terms of limiting binder ageing damage. These devices can greatly accelerate production in work zones with restricted occupation, but should be used in conjunction with sound engineering judgement. Nevertheless, mix ageing and its effect on durability should be thoroughly assessed and controlled.

F5.3 PLANT OPERATING SYSTEMS

The following manufacturing system enhancements can be utilised to increase product quality:

- **High accuracy binder control system** – The use of accurate load cell systems, bulk feed followed by dribble feed injection, and electronic controls increase the accuracy of binder addition up to 1 kg/batch (±0.05%);
- **Aggregate control systems** – Advanced weighing and controlled feed systems enable higher levels of mix consistency (typically 10 kg/batch or to ±0.75% accuracy);
- **Automatic plant systems** – Full automatic controls enable consistent mixes and early detection and shut down of defective mix compositions.

F5.4 PAVER & ROLLER OPERATION SYSTEMS

Recent advances which can be used to increase product end-quality include:

- Laser guided paving systems for improved riding quality precision (level control set to predetermined levels relative to a fixed reference system), screed-assist, screed-lock, slope control, etc.;
- Double-layer paving – a capability to pave two mixes or layers in one pass. The benefits of this type of paving include savings in the application of bond coats, superior interlocking of the two layers, reduced compaction cost, reduced occupation and closure times and reduced paving costs;
- "Self-tacking" pavers – this enables the placement of specialised layers like (ultra) thin friction courses while avoiding bond coat pick-up and the additional cost of employing binder distributors
- GPS and IR systems on rollers allowing operator to see rolling patterns, number of passes and mat temperatures on a screen while rolling.

SECTION G – PAVING

Placing and compacting asphalt is the operation to which all the other processes are directed. The asphalt is brought to the paving site in trucks and usually deposited directly into the paver. The paver then spreads the mix at a set width and thickness as it moves forward. In doing so the paver partially compacts the material by means of its own weight (static) and its tamping-bar as well as vibration of the screed.

The full length of road to be paved must be carefully inspected and the substrate checked for visual defects to ensure a clean, hard and level surface. Special care should be given to joints and there must be sufficient space for the compaction equipment on the outside edges next to structures.

Immediately, if required for gap-graded and semi gap-graded asphalt and while the mix is still hot, pre-coated chippings can be spread on the freshly paved mat. Steel-wheeled (static and / or vibratory) and rubber-tyred rollers are driven over the (chipped) mat, further compacting the mix until the required density is achieved.

The use of rolled-in-chips on continuously graded asphalt is suspect in view of the possible adverse effect on mix performance in terms of durability and permeability, and should only be prescribed by experienced practitioners after due consideration of these effects.

After a pavement layer has been compacted and allowed to cool, it is ready to accommodate traffic loads. Thick layers of asphalt cool at a slower rate than thinner layers, and care must be taken to avoid opening to traffic too soon. If more than one lift is to be paved in the day's production, the lower lift must be allowed to cool down to a maximum temperature of 50°C before applying a bond coat and paving the next layer. Similarly, paving subsequent layers on the same day should be avoided wherever possible unless sufficient cooling time is available.

G1 FUNDAMENTAL PAVER FUNCTIONING

G1.1 THE PAVER

A typical paver comprises two basic units - a tractor unit and a screed unit as shown in Figure 22.

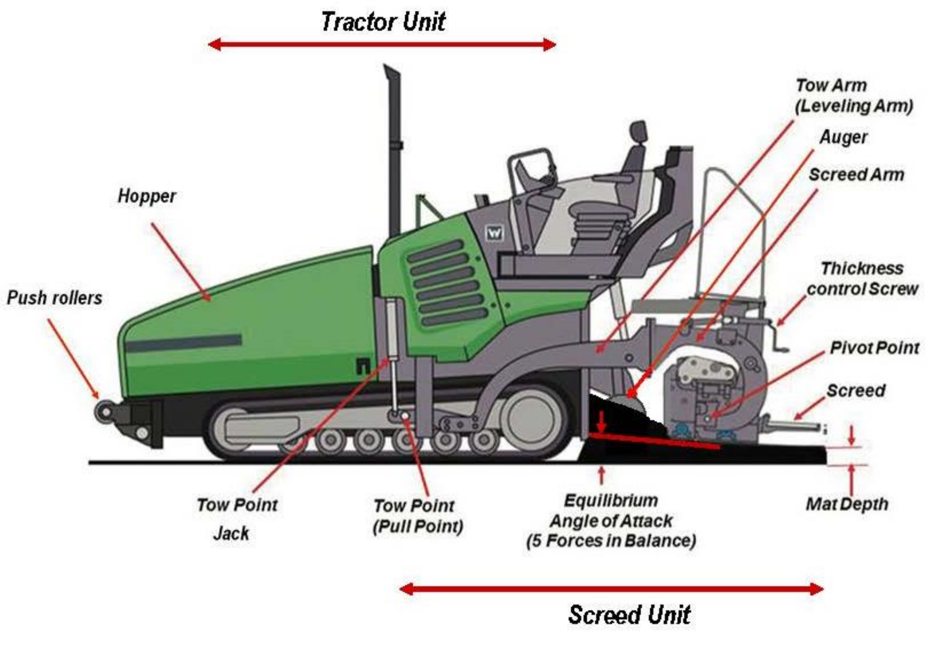


Figure 22: The Paver

Paver tractor units are driven either by wheels or tracks, each type with its advantages and disadvantages. Paved thicknesses can vary from thin to very thick e.g. 12 mm to 200 mm. Paving speeds can vary from 4m/min to up to 15 m/min and are determined by the paving width, rate of supply and roller coverage. The minimum screed width is usually either 2.4 m or 3 m, but the minimum width required for paving may be larger, as some of the screed components are outside the screed width. Maximum width, without extensions, is usually 5m or 6m and extension boxes can be added in multiples of 0.5 or 0.75 m. The wider the screed, the more traction is required and the faster the rate of material supply required.

Paving widths of greater than 6 m require very good traction and pavers with tracks are usually recommended in such cases, as well as when steep slopes are encountered.

Screed widths of greater than 8 m will usually require special stabiliser bars, and twisting of the screed on undulating sections can become an issue.

The main two paver units comprise the following components:

- The tractor unit has:
  - A mechanical drive system carried on wheels or tracks;
  - Push rollers at the front to make contact with the loading truck tyres;
  - Folding hopper and conveyors to receive and direct the asphalt back towards the screed;
  - Augers that distribute the material laterally in front of the screed;
  - Mechanical and hydraulic mechanisms for the functioning of the augers, tow arms and screed.
- The screed unit:
  - The screed unit essentially consists of hardened steel plates attached to a frame. Heaters for the plates are set into the screed frame. These heaters are either electrical or gas-powered. Tamper bars are set in front of the screed plates, and tamper shields protect the tampers from filling with material and also act as a backing wall, allowing the augers to transport the mix along the front of the screed (see Figure 23 & Figure 24);
  - This unit is attached to the tractor *tow points* by the tow arms;
  - Hydraulic jacks at the tow points can raise or lower the tow arms to change the “angle of attack” of the screed unit relative to the paved surface (see Figure 22);
  - Hydraulic jacks, attached to the rear of the tractor lift the screed clear of the ground. However, during paving these jacks are disconnected to allow the screed to float on the asphalt mat being paved.

G1.2 PAVER OPERATION

Automatic feed system

Figure 23: Asphalt Paver Feed System

Figure 23 illustrates how material is tipped from the truck into the paver hopper ① onto the slats of the conveyor system②, which transports the material into the paver tunnel from where it falls onto and in front of the augers③, which feed the material to the front of the tamper bar as illustrated in Figure 24.

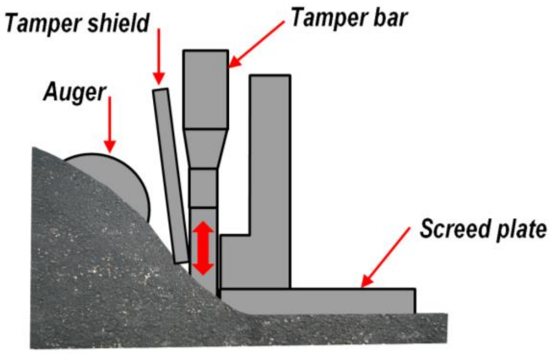


Figure 24: Screed Plate and Tamper Bar

Sensors in the conveyor tunnels and above the augers are linked to regulate the flow of material to ensure that the augers are correctly charged with an appropriate, constant head of material in front of the screed.

The augers should be set at a height of 50 to 70 mm clear above the finished level of the mat being laid. If the augers are too high the mix will not be transferred evenly across the screed and segregation can take place. Augers that are set too low will cause blemishes in the mat.

The screed unit is attached to the side arms in two places to make angle of attack adjustments possible.

In modern pavers:

- The conveyor and auger on one side of the paver work independently from those on the other side;
- Sensors mounted on the outside of the screed read the amount of material in the auger tunnel, and activate the movement of the conveyors and augers;
- The system should be adjusted so that the augers ideally operate 100% of the time;
- These automatic controls aim to maintain a constant depth of material ahead of the screed (25 - 50% of the auger depth should be visible);

- Augers can also be reversed so that all asphalt is guided to one side of the screed (for paving narrower widths);
- Extension augers must be used when the screed is extended to ensure that the material is distributed evenly along the full length of the screed.

Modern screeds have:

- Tampers to tuck and partially compact the material under the leading edge;
- Vibrators to carry out the partial compaction and to promote even spreading;
- Hydraulic extensions for widening from 2.4 to 4.8 m. Extension boxes can then be added;
- Screed lock that fixes the hydraulics to prevent the screed from settling when the paver stops;
- Screed memory settings which allow for faster paver set-up at the start of a paving day.
- Crown adjustment to crank the screed for a camber or valley fit;
- Thermostatically controlled heaters (gas or electric) to maintain screed plate temperature and prevent material from sticking to the screed plate.

Floating screed operation

The floating screed principal works as follows:

- The heavy steel plate at the bottom of the screed is set to a small “angle of attack”, i.e. upwards in the direction of paving. This angle is set before paving by manual adjustment on the screed cranks to factory recommendations;
- The screed unit is attached to the tractor unit at the tow points by the tow arms. Raising the tow points while paving will increase the angle of attack of the screed unit relative to the paved surface, thus causing the screed to rise, increasing mat thickness;
- Lowering the tow points will have the opposite effect, decreasing mat thickness;
- The tow points are situated near the centre of the paver to ensure that their vertical movement as a result of surface unevenness is kept to a minimum;
- There are a number of forces at work as the screed is pulled forward. A state of equilibrium of these forces is illustrated in Figure 25:

  P – Pull on the screed, i.e. the traction exerted by the tractor;
  W– Weight of the screed;
  M, F – Resistance of the material against and under the screed;
  R – Reaction supporting the screed, perpendicular to the inclined screed plate.

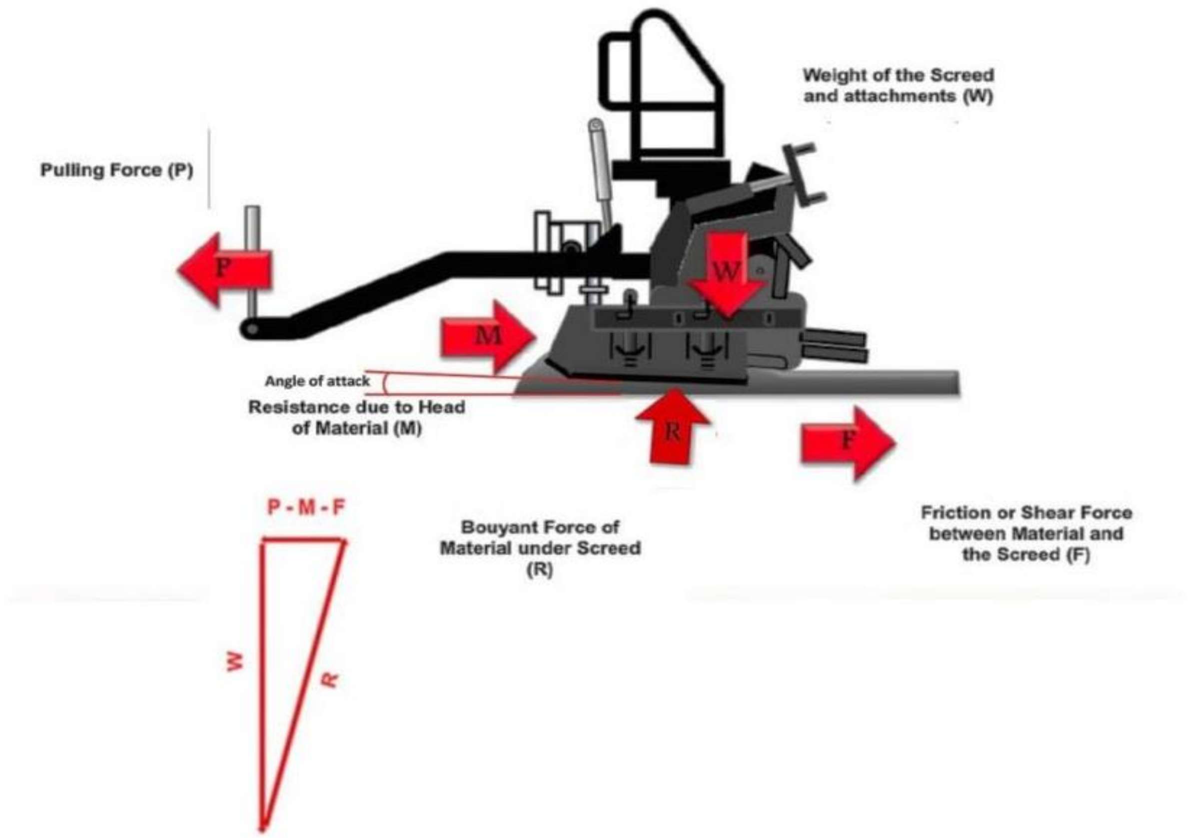


Figure 25: Floating Sreed Unit

Thus the screed floats on the material at the level where the forces are in equilibrium (similar to water-skiing). Any change in forces P, W, M and F will cause R to change, resulting in the level of the screed changing.

Factors that will cause the screed to rise and fall during paving are:

- Changes to the head of material in front of the screed;
- Changes in paver speed and stop/start paving operations;
- Changes to the angle of attack induced by raising and lowering of the tow points;
- Excessive variations in mix temperature causing M & F to change;
- Excessive changes in mix composition, for example percentage of large aggregate and binder content;
- Changes to the weight of the screed (e.g. personnel getting on and off the screed plate).

In order to maintain a constant mat thickness for a change in paver speed or material head in front of the screed, the natural equilibrium of forces on the screed cannot be relied upon and the screed angle (angle of attack) must be manually adjusted using a thickness control screw or depth crank. Screed angle adjustments do not immediately change mat thickness but rather require a finite amount of time and tow distance to take effect. Figure 26 shows that it typically takes five tow lengths (the length between the tow point and the screed) after a desired level is input for a screed to arrive at the new level.

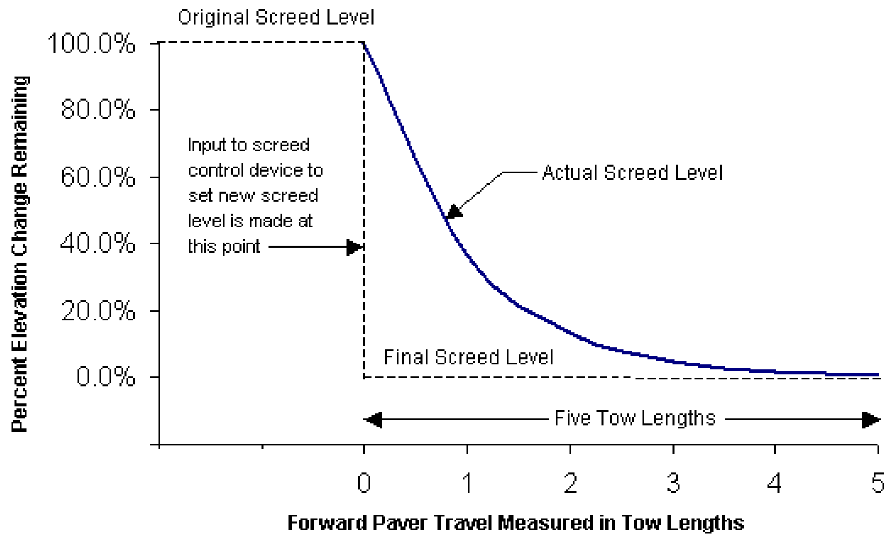


Figure 26: Screed Response to Adjustment of Angle of Attack

In addition to changes in the forces acting on the screed, undulations in the base will also cause the tractor and thus the tow points to move up and down. Automatic screed level control (see section G2.1 Automatic screed level controls) is designed to counter this undesired vertical screed movement to ensure a smooth mat.

Other screed operation functions and checks

The screed unit strikes off, partially compacts and irons the surface of the mat as it is pulled forward over the material. At the same time the tamper bars, shown in Figure 24, oscillate up and down to tuck the asphalt smoothly under the leading edge of the screed plate. Tamper bar projection below the level of the screed plates and tamper bar condition are critical. Worn tampers must be replaced.

Most screeds also have vibrators mounted on the unit to continue the partial compaction and ironing action.

Tamper and vibrator speeds are adjustable and are set for paving speed and type of mix.

The screed unit is usually equipped with heaters to prevent the mix sticking to the screed plate. They are used to heat the screed at the start of paving operations and to keep it at a constant temperature when paving.

Raising or lowering the tow points changes the thickness of the mat. Typically a change in tow point level takes one tow arm length 70% of the change to the screed level, and up to 5 tow arm lengths to effect the full change.

Before paving the following items should be checked:

- The bottom surface of the screed plates should be checked for evenness, cleanliness and excessive wear. Extension plates should be pre-set at the same angle and in the same plane as the bottom surface of the main screed plate;
- Tampers should be checked for excessive wear, adjustment and proper operation. Excessive wear causes a pitted surface in the mat and improper adjustment will lead to the mat having a scuffed appearance. The limit of the bottom stroke of the tamper bar should extend approximately 0.4 mm below the bottom of the screed plate or as per manufacturers instruction;
- If the screed is of the vibrating type, the vibrators should be started with the screed in a raised position to ensure their proper functioning;
- The heating unit should also be checked for proper operation by lighting the burner and allowing it to burn for a few minutes, or by observing the temperature on the control panel if electric heating is fitted.

At the end of paving shifts it is important that the paver be properly cleaned. While the machine is still warm, the hopper, conveyors, augers, tamper bars and screed plates should be cleaned and given a light spray of release agent to ensure a smooth start the next day. Special attention to tamper bar cleaning is essential to ensure proper functioning.

Cleaning of pavers should take place on a surface where the cleaning materials can be captured and disposed of.

G2 LEVEL AND FINISH CONTROLS

G2.1 AUTOMATIC SCREED LEVEL CONTROLS

Most pavers have tow point controls which can be set by manual or automatic means. As mentioned above, it is not good practice to continually adjust tow point elevation manually. Pavers normally operate using an automatic screed level control whereby tow point elevation is adjusted to a level datum other than the tractor body.

Automatic screed controls have three main components:

- Sensor;
- Control box;
- Hydraulic cylinders to change the tow point settings.

The sensors feed electric impulses to a control box which activates the hydraulic cylinders to change the tow point setting up or down to achieve the required screed tilt.

Automatic screed level control operates on the principle that if the screed is made to follow a smooth reference datum, regardless of irregularities in the surface or the variable forces on the screed, a more even surface will result.

Thus, base undulations will be ignored and varying forces acting on the screed will be adjusted for by the constant adjustment of the elevation of the tow points in relation to a datum other than the wheelbase of the paver.

Automatic level control results in a more even finish than can be accomplished by the paver with its wheel base as a reference, or by manual adjustment by the screed operator.

The sequence at the start of paving is as follows:

- Set the tow points for the desired mat thickness;
- Pave the first load, checking mat depth manually and correcting the tow point settings if necessary;
- Once the tow points are set correctly for the desired depth of spread, the automatic system is activated;
- The system takes over the settings to produce an even mat.

G2.2 AUTOMATIC PAVE LEVEL CONTROL EQUIPMENT

The equipment and functioning of automatic level control equipment are listed below.

Level or grade sensors (mechanical or sonic)

These sensors are normally attached to the side of the screed and extending forwards.

Averaging beams

The purpose of averaging beams is to even out deviations from a true line in the substrate surface over a distance greater than the wheelbase of the tractor unit.

Articulated averaging beams (shown in Figure 27 and Figure 28) have two or three levels of averaging skid sets that can each rotate without meaningfully changing the elevation of the whole beam. For three-level beams nearly 90% of undulation under any one skid is removed.

Continuous spring-mounted skid foot beams average out most of the surface undulations, except where these undulations have very long wavelengths.

For articulated averaging beams, a cable, stretched from end to end of the beam, is essential in averaging out vertical movement in the beam. The cable provides a moving datum for the sensor. Theoretically, the least vertical movement of the cable takes place at the mid-point of the cable.

The best position for the sensors is opposite the augers, i.e. one-third within the middle third of the length of the tow arm. This position accommodates both the changes in datum level and changes to forces on the screed. (See Figure 29)

Where averaging beams are used on both sides of the paver, the sensors adjust the height of the tow points on either side of the paver.

While tow points react immediately to sensor signals, the screed takes some time to react fully. This translates into 3 to 6 meters of travel for most of the change to be effected and up to 10m for the full change.

Figure 27: Mechanical Sensor on Articulated Averaging Beam

Figure 28: Two-Level Articulated Averaging Beam

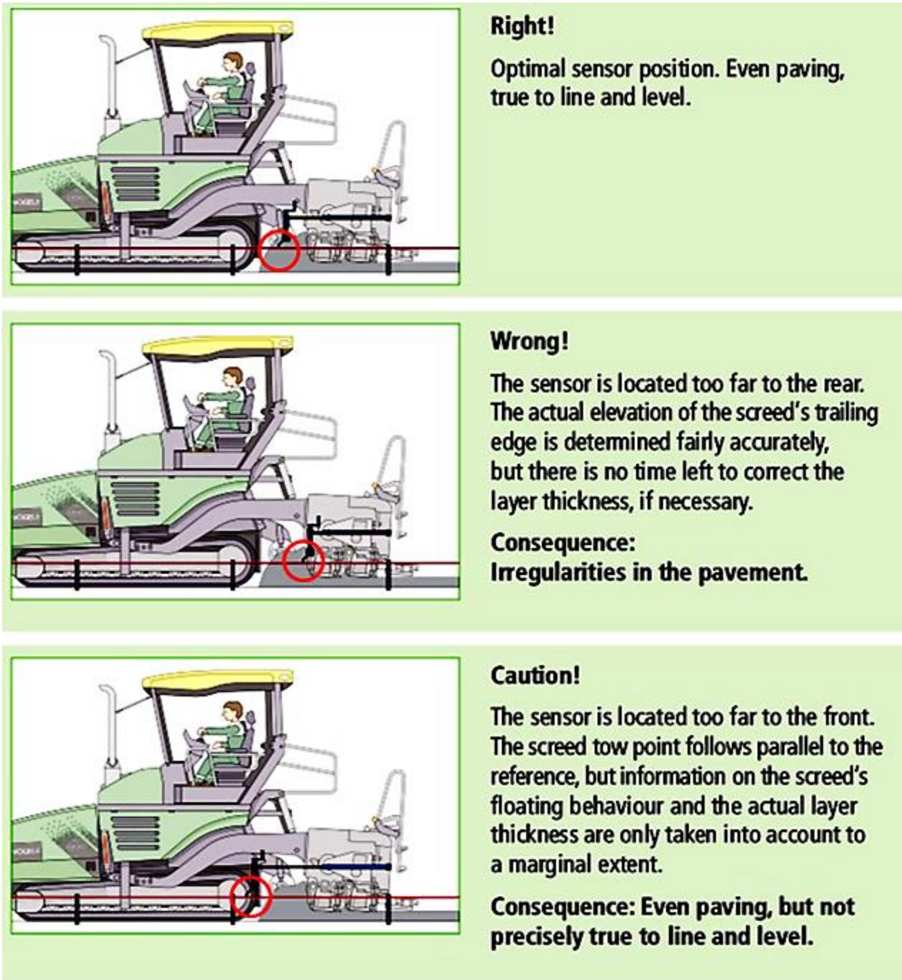


Figure 29: Positions of Sensor on Averaging Beam

Source: NAPA

Joint matching shoe:

Joint matching sensors consist either of a contact type (usually a small shoe or ski attached to the paver that slides on an existing surface, near the paved edge as shown in Figure 30), or a non-contact sensor as shown in Figure 31. These sensors are mostly used to track the adjacent mat at a longitudinal joint to ensure matching levels across the joint. The best position for this device is as close to the tow point as possible to reduce the lag effect of the screed after tow point adjustment.

Figure 30: Joint Matching Shoe (contact type)

Figure 31: Joint Matching Shoe (non-contact type)

Erected stringline or straightedge system

This system consists of a stringline or series of straightedges or strings erected to a specific elevation which is independent of the existing base or substrate elevation (See Figure 32 and Figure 33). This system is often used for paving asphalt base, since sub-base levels are seldom accurate enough for an averaging beam to be effective. The system will also ensure accurate finished asphalt base levels for maintaining a constant wearing course thickness.

In general the system comprises the following:

- Adjustable pedestals are set to actual design levels, spaced 5 – 10 metres apart to avoid any sag in the line;
- Thick line (nylon or cord) is stretched tightly across pedestals, or straightedges put on top of pedestals to provide a reference or datum for the sensor arm.

Stringlines can be set up on both sides of paver, but require good truck driver skills to avoid damage by reversing trucks. A straightedge system may be easier in some cases as individual sections can be removed without disturbing the entire system.

Figure 32: Stringline Setup

Figure 33: Non-contact Stringline Sensor

Constant Cross-fall Sensor:

Typically, a joint matcher on a kerb and channel on one side of the paver in conjunction with a cross-fall sensor on the screed unit will ensure a constant cross fall, e.g. 2% from the channel to the opposite paved edge, regardless of base levels.

G2.3 SELECTION OF SENSOR TYPE

Automatic level control should be used on both sides of the paver wherever possible. However, the level control priority may be different on each side, necessitating the use of different equipment. For example: on one side a joint matcher may be used to track the channel, while on the other side an averaging beam may be used to achieve a target mean thickness.

Automatic level control is more effective than manual control, provided that good paving practices are maintained. However, roughly 50% of the dips and humps in the base will still reflect through due to:

- The floating action and lag time of the screed; and
- Differential compaction due to varying depth of the layer.

Therefore, where finishes of existing layers are poor, the use of correction (levelling) layers is a very important consideration for good rideability. In such cases multiple layers will improve final evenness by reducing the unevenness of successive layers.

Level control equipment should be selected on the basis of the main paving priority on each side of the paver:

- To average out the levels of the base and thus achieve a desired average mat thickness e.g. wearing course on base – use the **Averaging Beam**;
- To pave to a design level, e.g. where there are no kerbs or channels – use a **Stringline on Pedestals**;
- To tie in to an existing level e.g. pave against an adjacent mat – use a **Joint Matcher**. However, if the finished profile of the existing mat is poor, an averaging beam should be considered;
- To achieve a constant cross fall e.g. from a channel to a crown – use an Averaging Beam, Joint Matcher or String-line one side with the **Constant Cross-fall Sensor**.

The range of sensor types for various uses is listed in Table 2 below with comments on their efficacy.

Table 2: Sensor Types

Description	Use	Advantages	Disadvantages	Comments
Joint Matcher (contact sensor)	Ensuring consistent level at joint between paving lanes, paving to channels etc.	Good for inconspicuous joints	Will copy a bad riding quality from one lane to the next	Reliable, proven and simple
Joint Matcher (non-contact sensor)	Same but with no mechanical contact	Same, but less prone to mechanical interference	Will copy a bad riding quality from one lane to the next	Requires a single non-contact sensor
Averaging Beam (contact sensors)	Provides an average reference level over a longer distance to even out shorter bumps.	Proves better riding quality	Many mechanical components, can lead to thickness issues if not controlled correctly.	Reliable, proven and simple
Averaging Beam (non-contact sensors)	Same but with no mechanical contact	Same, but can be made even longer to provide an even smoother average result	More expensive than mechanical system	Simple to use and integrated into most modern paving systems.
Stringline or Beams with Pedestals (non-contact sensors)	Use when paving to design levels	Provides a line referenced to surveyed levels	Truck access can be difficult, can give problems with differential compaction if base levels are not accurate. Takes time to set up.	Often the best compromise between level accuracy and simplicity, provided that layer thicknesses are fairly constant and base levels are correct.
3-d Levelling	Large areas where electronic design data is available	Provides a virtual final level in 3 dimensional space.	Accuracy claims can be inflated. Expensive, and takes time to set up.	Generally either uses GPS or Ground Stations. Useful on large areas, is airports etc.

G2.4 LOOSE VERSUS COMPACTED MAT THICKNESS AND DIFFERENTIAL COMPACTION

The uncompacted mat behind the screed must be paved thicker than the final required thickness as compaction reduces the paved, "loose" thickness. The degree of reduction in thickness differs for various asphalt mixes, and typical examples are:

Material	Reduction
Base	25 to 30%
Dense graded wearing course	17 to 20%
Open-graded, UTFC	8 to 10%

At the start of paving, the screed is lowered onto blocks (see Figure 34 A) of the correct loose mat thickness. For example, adjacent to a previously completed 40 mm mat the paver screed should rest on 8 mm blocks placed on the completed mat.

The thickness of the loose mat must be checked regularly across the full width, to ensure that the specified minimum layer thickness is being achieved.

Due to the varying thickness of the mat arising from unevenness of the base or substrate layer, consolidation of the paved thickness by, say, 20 % during compaction results in some of the undulations of the underlying layer being reflected in the finished surface paved to the correct profile. This is illustrated in Figure 34 B with:

- Top – uncompacted mat:
  - Upper line is top of mat behind paver;
  - Bottom line is top of base.
- Bottom Picture – after compaction:
  - Upper line is no longer flat; the mat has gone down by 20%;
  - Final surface now undulates, following base, but less pronounced.

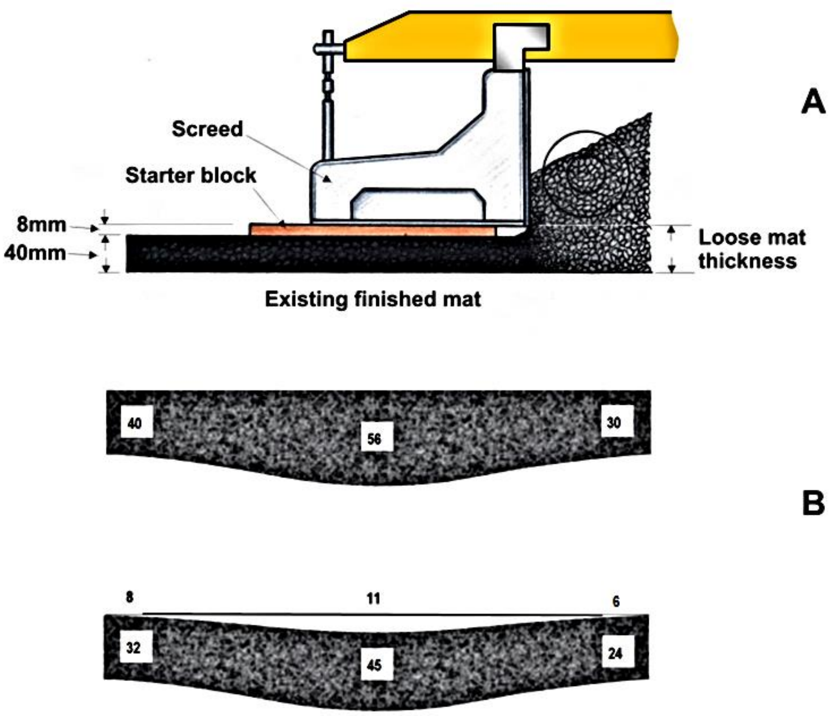


Figure 34: Starter Block (A) and Differential Compaction (B)

G2.5 GENERAL GUIDELINES

- Every truck load should be checked to ensure that the temperature of the asphalt tipped into the paver hopper is within an acceptable temperature range;
- Care should be taken to *ensure that the truck does not reverse directly on to the push-rollers* on the front of the paver, as this will cause the paver, and thus the screed, to jerk. This will cause an indentation in the mat surface that will adversely affect rideability;
- Once the tow points have been correctly set and the automatic level control activated, the following good paving practices should be adhered to as they have a major effect on the final finish:
  - Paving at a constant speed, selected to suit the compaction effort;
  - A constant supply of material to the paver to reduce start/stop activity to an absolute minimum.
- Other good paving practices:
  - Before paving, the screed plates should be cleaned, checked for wear and then heated to suit the mix type;
  - Tow-points should be set correctly for the required mat thickness;
  - Paving should always start on starter blocks under the screed;
  - Paving lines should be marked out each side of the paver for guidance;
  - Extension augers should be attached to suit the paving width;
  - Forward movement should only commence once auger boxes are filled over their full width;
  - A constant head of asphalt across the entire width of the screed should be maintained;
  - The hopper should not be emptied between loads. The new load should be added to the hopper so as to heat up what's left from the old load;
  - The tipping of trucks must be well controlled to avoid spillage in front of the paver;
  - Paving thickness should be checked regularly by calculations and with a dip rod and adjustments made gradually and evenly;
  - Excessive manual adjustment of the tow points should not be allowed;
  - Frequently check the mat finish between the paver and the rollers with a straight-edge and visually to identify any problems;
  - Walking on the unrolled mat should be avoided;
  - Handwork should be limited to areas inaccessible to the paver or for correcting deficiencies.

G3 HAND PAVING

For the successful laying of asphalt by hand the following precautions should be taken into account:

- Deliveries to site should be staggered according to production capacity to ensure that material is always at a workable temperature;
- Keep the stockpile covered with a tarpaulin to reduce heat loss;
- For large areas the use of a rubber-wheeled front-end loader (instead of wheelbarrows) will improve efficiency of distribution from stockpile to working area;
- Dump and spread for short distances only to avoid segregation;

- A lute or the flat-edged, reverse side of a metal rake should be used to spread the asphalt to the correct depth. The surface should then be smoothed with a straight-edge to achieve an even surface, before starting compaction;
- An even thickness of asphalt may be achieved by working to pegs and a builder's line pre-set to the required thickness, or by using pre-set rails;
- The supervisor should monitor the asphalt temperature at all times to detect asphalt which has cooled to **the critical cut-off point below which it can no longer be successfully compacted** (for example, this temperature is typically 80°C);
- Tight corners and catch pit/gulley surrounds need the skill of an experienced finishing hand, who may apply the hot mix asphalt using a shovel and roller, and complete the compaction using a hand-stamper or "pogo" compactor.

G4 DETAILS OF SUBSTRATE PREPARATIONS FOR ASPHALT PAVING

G4.1 GRANULAR LAYER PREPARATION FOR NEW ASPHALT PAVEMENTS

(a) Gravel Sub-base or Sub-grade Soil

If the asphalt pavement is to be placed directly onto gravel sub-base or sub-grade soil, this support material should meet all requirements in respect of moisture content, density, support strength, and evenness. The layer should provide a firm foundation for the paved asphalt layer.

(b) Granular or Crushed Stone Base Courses

If the asphalt layer is to be constructed on a new or existing untreated granular or crushed stone base layer, this support material should meet all the specified project requirements for moisture content, density, structural strength, and evenness. Proof rolling of the granular base should be done before priming, and any noticeable excessive deflections of the base or indentation of truck wheels in the granular base course material should be evaluated to assess whether the support layer has sufficient stability to ensure adequate compaction of the asphalt layer.

If the condition of the granular support layer material is deemed not to be satisfactory, the layer should be reworked or stabilised to render it suitable for overlaying.

In all cases the construction of a "biscuit" layer of fines at the surface of the layer should be avoided. Any excess fines should be broomed off the surface before priming and applying a bond coat.

G4.2 PREPARATION OF EXISTING ASPHALT SURFACING FOR OVERLAYS

The degree of preparation needed for an existing asphalt pavement depends on the condition of that surface. At a minimum, distressed areas should be removed and replaced; potholes properly patched, cracks cleaned out and sealed, and ruts filled in or, preferably, removed by precision cold milling.

(a) Pavement Replacement and Patching

It is generally inadvisable to attempt to bridge failed areas with new overlay material unless a very thick overlay is to be constructed. Removal and replacement should be carried out on all existing pavement areas where severe load-related distress has occurred. All asphalt and granular base materials that have failed should be excavated or milled to spoil, or *in-situ* recycled. Granular sub-base or sub-grade distortion should be repaired by undercutting and replacement with suitable backfill material. Proper subsurface drainage should be installed as necessary where water moisture problems exist. New granular base course material, stabilised base course layers, or asphalt mix should be placed to bring the strength of the pavement structure in each failed area to the same level as the surrounding good pavement layers. If asphalt is used to patch a large area, it should be placed with a paver and compacted with suitable heavy rollers.

Localised distressed areas should be patched properly. Each area should be cut back to sound pavement and squared up, with the sides as vertical as possible, the loose material and water in the hole removed, a bond coat applied to the sides and bottom of the hole, the mix placed in the hole, and the new material adequately compacted, preferably with a roller. If the pothole or failure area is deeper than 100 mm, the mix should be placed in more than one layer and each layer compacted properly.

(b) Crack Filling

The benefits of filling cracks other than those that are patterned and associated with severely distressed areas, depend, in part, on the width of the cracks. If the cracks are narrow (less than 5 mm in width), special cold emulsion type filler is needed. Cracks that are too narrow to be filled with a hot sealing material should be widened with a mechanical router before sealing is attempted. Alternatively, they should be bridged with strain absorbing materials e.g. grids or geotextiles. If wider cracks are present, they should be cleaned of debris with blown air. The crack-sealing material should only be inserted when the cracks are clean and dry. The level of the crack-filling material should be slightly lower than that of the surrounding pavement surface and should not spill over the top of the crack, where it could create a bump in the new pavement layer during the rolling process.

(c) Levelling Courses

To improve final rideability, it is good practice before paving an overlay, to place a levelling course to take up slacks on the existing pavement surface. This will reduce the effect of differential compaction of the overlay. This levelling course, sometimes called a correction layer or scratch coat, is designed to fill in the low spots on the pavement surface. This levelling action is accomplished by paving to predetermined levels (string-line etc.), set to ensure evenness after compaction.

(d) Milling

Milling can be used to remove the high points in the existing surface in lieu of placing a levelling course (filling in the low spots). Milling can be accomplished over a range of widths typically from 150 mm to 2m with one pass of the milling machine. They are normally set to mill to a fixed depth from zero to 300mm. If equipped with automatic grade and slope controls similar to those used on an asphalt paver, the precision milling machine is capable of producing a level surface in one pass over the existing surface. In addition, if the milled surface is properly cleaned, its texture can enhance the bond between the new and old layers, and may reduce the possibility of slippage of the overlay over the existing surface.

A pavement surface that has been milled is typically very dusty and dirty. Multiple sweepings by hand or passes of a mechanical broom are usually needed to remove all of the residual grit from the milled surface. In some cases it may be necessary to dampen the milled surface before sweeping, or to air blow or flush the milled surface with water to remove dust and very fine material completely. Any dust and dirt left on the milled surface will have a severely adverse effect on the bond between the existing course and the new asphalt overlay.

G4.3 PREPARATION OF CONCRETE SURFACINGS FOR ASPHALT OVERLAYS

When asphalt is placed over a concrete pavement the surface should likewise be properly prepared. Any severely distressed areas in the concrete slabs should be cut out, removed and replaced. Corrective work should also be completed on the underlying sub-base or sub-grade material, where necessary. Any severely spalled areas at joints should be repaired using partial-depth slab replacement methods. Rocking slabs should also be stabilised and consideration should also be given to the use of a crack-relief layer between the existing concrete pavement and the new overlay.

For joints that are poorly sealed, the existing seal material should be removed and the joints cleaned. When dry, the joints should be resealed with appropriate joint-sealing material. Care should be taken not to overfill the joints, particularly in cool weather when they are widely opened. In all cases the joint-sealing material should be below the top of the surrounding pavement surface. Once the patching and resealing has been completed, the surface of the concrete pavement should be cleaned completely using mechanical brooms and air blowing or water flushing or both, as required.

G4.4 PAVING FOR GOOD RIDING QUALITY

A number of factors influencing final finish for good riding quality will require attention during paving and compaction. These are:

- Substrate quality and layer thickness;
- Paving procedures;
- Tipping into the paver hopper; and
- Selection of rollers and rolling procedures.

(a) Substrate quality and layer thickness

Evenness of the underlying layer is a prerequisite for achieving good riding quality in the final paved layer, as even the best paving practice will result in roughly 50% of undulations in the underlying layer being reflected to the surface. Therefore if good riding quality is a priority, the use of correction layers should be given serious consideration.

Generally it follows that where multiple *thin* layers are paved, each layer successively improves the rideability. On the other hand, it may be more difficult to achieve good riding quality on a thicker mat, due to:

- Differential compaction of the mat;
- Movement and squeeze-out of the mat under the rollers.

With the above in mind, it has been noted that considerably better riding quality will be achieved by using two layers of 40 mm asphalt followed by a 20 mm friction course, than by using 90mm asphalt base followed by a 40 mm wearing course.

(b) Paving procedures

To achieve an even mat with good riding quality the following paving procedures are recommended:

- Automatic auger feed control should be employed at all times to maintain a constant head of asphalt in front of the screed unit. A fluctuating head changes the forces acting on the screed, causing the screed to rise or fall which will have a seriously adverse effect on the riding quality;
- The sensors should be set so that ideally the augers are continuously turning slowly. This means that asphalt is being fed at a continuous rate across the front of the screed;
- As mentioned before, paving should proceed at a constant speed to maintain a consistent equilibrium of forces acting on the screed and, hence, the evenness of the mat. Stoppages should be avoided at all costs, which requires a consistent supply of material to the paver;
- Automatic level control should be used on both sides of the paver at all times, each type being selected to suit the site requirements as previously described in the manual.
- Averaging beams should be at least 7 m long and should preferably consist of:
  - Adjustable pedestals set to actual design levels plus adjustments for differential lift thickness (if any), spaced 5 – 10 metres apart to avoid any sag in the line;
  - a three-level articulated averaging system with a free spanning wire between ends; or
  - an in-line spring mounted multi-skid system; or
  - a paver-mounted beam with sonic sensors.
- Level control using a Joint Matcher should only be used on an adjacent completed layer provided it has a good finish. If not, an averaging beam should be used;
- In exceptional circumstances, when automatic level control cannot be used, manual adjustment of tow points should be carried out – an operation that requires considerable skill. During such manual adjustment the following precautions are necessary:

- Adjustable pedestals are set to actual design levels, spaced 5 – 10 metres apart to avoid any sag in the line;
- Excessive adjustment should be avoided;
- Any adjustment should be conservatively done and in small increments. (Typically a change in tow point level takes 3 to 6 m to make 70% of the change to the screed level and up to 10 m to effect the full change).

- The paver should be equipped with a "screed-lock" hydraulic system that prevents the screed from sinking when a stop is unavoidable. The hydraulic pressure must be checked and set before paving.

(c) Tipping into the paver hopper

In addition the following processes related to asphalt supply to the paver should be followed to achieve an end product of uniformity and evenness:

- Reversing haul trucks should stop just short of the moving paver and wait with the brakes released. Moving forward, the paver will smoothly make contact with the truck and push it ahead, i.e. the paver should impart movement to the truck instead of the truck backing into the paver. Only then must the truck start tipping into the hopper. When raised, the body of the haul truck should not come into contact with any portion of the paver;
- As mentioned before, trucks should have a long enough overhang to tip well into the hopper and not spill in front of the paver. Spillage can compromise final quality in terms of finish and compaction for the following reasons:
  - The paver has to stop while the spillage is cleared thus affecting the screed level;
  - A short length of mat behind the paver will start cooling before being covered by the rollers;
  - Asphalt in the paver will start cooling.

When a paver is forced to stop for a short time to await the next truck, it should be stopped as quickly and smoothly as possible. Enough mix should remain in the paver hopper to retain its heat and a tarpaulin cover over the hopper will improve heat retention. Alternatively, only the hopper should be completely emptied, while the auger box is kept full at the same head of asphalt in front of the screed. This is an operation which takes considerable skill and should be avoided wherever possible.

(d) Selection of rollers

The choice of rollers and rolling techniques will also affect rideability.

Steel-drum rollers should be used as breakdown rollers. PTR's, if used as breakdown rollers, tend to form tyre ruts in the fresh asphalt surface that the subsequent rollers may not be able to completely eliminate.

As the rut depth increases with lift thickness, it is less likely that a good finish will be achieved when using PTR's on thicker lifts. To assure a good finish, the following precautions should be taken:

- Rollers should not:
  - Change lanes on the hot mat;
  - be stationary on the hot mat;
  - vibrate while stationary;
  - start, stop or change direction suddenly.
- Rollers should:
  - Stagger and angle stop positions on the hot mat;
  - Avoid excessive shoving of the mat.

SECTION H – COMPACTION

Achieving adequate compaction is a critically important aspect of the construction of asphalt to ensure satisfactory performance of the layer.

Compaction is the process of compressing the asphalt material to:

- Provide good interlock of the particles; and
- Reduce air voids to an acceptable level.

Compaction accomplishes two important goals:

1. To develop strength and stability of the layer; and
2. To close the passages through which water and air would otherwise pass.

Good compaction will therefore ensure satisfactory structural performance, durability and protection of underlying layers against the ingress of water, and prevent the asphalt from oxidative hardening (ageing).

If adequate density is not achieved, the following adverse effects may arise:

- Excessive permeability and oxidation may cause premature ageing, which may lead to premature cracking or ravelling. This will shorten the service life of the pavement;
- Rutting in the wheel tracks may occur due to further compaction by traffic;
- Insufficient long-term traffic compaction and kneading due to premature ageing which is likely to result in high permeability and brittle distress.

***Note*: In South Africa asphalt layers are frequently thin wearing courses, a situation which presents challenges to achieving a sufficiently impermeable asphalt layer. While permeability is a design criterion, care needs to be taken during paving and compaction operations to obtain an adequately dense mat. Distress and failures associated with excessive permeability usually manifests itself after the defects liability period – often 3 or 4 wet seasons later. Hence the process control associated with compaction should focus on the achievement of an impermeable asphalt layer and diligent testing programmes should be in place to assure that asphalt mixes are adequately compacted to avert mats with interconnected voids presenting passages for water**.

H1 ROLLERS AND ROLLING TECHNIQUES

The most commonly used rollers for compaction of asphalt in roads are:

- Steel drum rollers
  - Static: 10 – 14 tons.
  - Vibratory: 4 – 17tons.
- Pneumatic tyre roller (PTR) - minimum of 10 – 25 tons.

Rolling is carried out in three stages:

H1.1 BREAKDOWN ROLLING (140°C – 110°C RANGE)*

This stage takes place immediately behind the paver where the mat temperature is highest. Most of the compaction is achieved during this stage, e.g. an increase in density from about 84% Maximum Voidless Density (MVD) behind the screed, to about 91% MVD.

H1.2 INTERMEDIATE ROLLING (120°C – 80°C RANGE)*

This stage follows directly after breakdown rolling while the mat is still plastic and at a temperature that will permit further compaction. This stage of compaction should continue until the required compaction is achieved and the density is increased to the specified requirement e.g. from 91% to 93% MVD and the surface is knitted.

H1.3 FINISH ROLLING (90°C – 60°C RANGE)*

During this final stage irregularities in the surface are smoothed over to remove roller marks with little further densification of the layer. Final kneading of the surface is achieved.

A paver and typical and compaction train is shown in Figure 35.

Figure 35: Paver and Compaction Train

H2 ROLLER CHOICE

It is essential to use the correct roller combinations during the various rolling stages.

H2.1 BREAKDOWN ROLLING

Rollers with the highest compactive effort are used to reach adequate density rapidly on mats where the temperature is typically in excess of 135°C for continuously graded asphalt. This is best accomplished by steel wheel rollers. Three-wheel rollers are at their most effective here. Vibratory rollers have a wider compaction temperature range than static rollers and achieve density in fewer passes and are therefore also very effective. PTR's can achieve the required density, but on a very hot mat may give rise to problems as regards an even finish.

H2.2 INTERMEDIATE ROLLING

Intermediate rolling should follow breakdown rolling closely, while the mat is still plastic and at a temperature that will permit further compaction. This phase of rolling should continue until all the asphalt placed has been thoroughly compacted.

This stage is best accomplished by rollers effective at lower temperatures i.e. generally in the range of 95 - 135°C. Vibratory and PTR's are suitable for this stage, the latter being effective at temperatures as low as 70^0C, and where knitting of the surface is required.

** These are general temperature ranges applicable to dense graded mixes and actual values would depend on layer thickness, mix type, binder type and grade as well as weather conditions.*

H2.3 FINISH ROLLING

Heavy steel wheel static or vibratory rollers at very low amplitude vibration are employed to iron out any roller marks. This stage should be completed before the mat reaches a temperature of about 80°C, although evening out of the surface may be achieved at temperatures as low as 70°C.

H2.4 SPECIAL SITUATIONS

The following roller combinations are recommended for various situations:

(a) Thin continuously graded mats – 25 to 40 mm

Due to rapid heat loss of these thin layers in conjunction with relatively high internal friction, only a short compaction window is available. The following equipment is recommended:

- Two breakdown rollers plus one PTR;
- Under unfavourable weather conditions an additional intermediate roller can be added due to the very short compaction window, i.e. two breakdown rollers plus two PTR's (intermediate rollers). Wider rollers are preferred to effect more rapid coverage of the mat.

(b) Thick mats – 60 to 100 mm

Heat retention of a thicker layer provides a longer compaction window. Equipment recommended includes:

- One breakdown plus two intermediate rollers;
- Vibratory rollers should have variable amplitude control as it is preferable to commence rolling at high amplitudes, reducing these as rolling of a section of mat progresses.

(c) Over bridge decks and underground services

A 12 ton static steel wheel roller plus two PTR's are recommended. (***Note: Vibratory rollers should not be used)***

(d) UTFC and open-graded mixes

- Steel wheel static rollers or heavy vibratory rollers in static mode;
- The wider the roller the better due to very rapid cooling of these mixes.

(e) When "shoving" is likely

On steep inclines or when paving on old polished surfaces:

- Limit rolling with steel wheel rollers to minimum;
- Pave and roll in uphill direction;
- Increase the use of PTR's.

H3 ROLLING PATTERNS

To ensure full, uniform coverage of the paved mat it is essential that a regular rolling pattern is adopted. Rollers vary in width and a particular pattern would not apply to all rollers. For this reason, the best rolling pattern for each roller being used should be established and followed to obtain the most uniform compaction of the paved width.

Figure 36 below illustrates a typical rolling pattern, with the roller covering the width of the mat in three lanes. The sequence is:

- Start at low side of mat – lane 1 – up to paver and back;
- Change direction on cool mat;
- Roll lane 2 up to paver and a bit further than lane 1, and back;

- Change direction on cool mat;
- Roll lane 3, again a bit further than lane 2, and back;
- Start again on lane 1 and repeat.

Each forward pass of the roller should overlap the previous one, generally by 200 mm. Positions where the direction of rolling is reversed should be staggered to reduce unevenness. Rolling patterns must be systematic, consistent and disciplined to ensure uniform compaction.

H4 GOOD ROLLING PRACTICES

Before carrying out roller compaction, it should be established that:

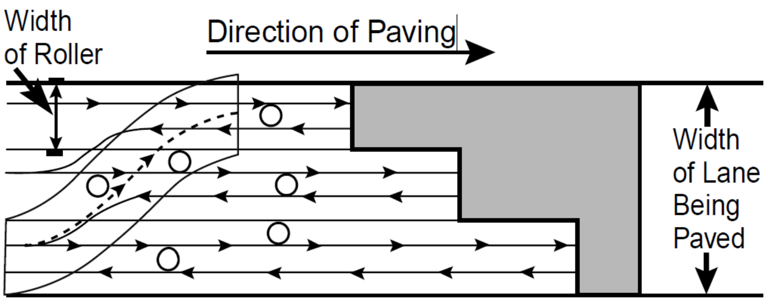
- A sufficient number of mechanically sound rollers, including stand-by plant, are on site to carry out the compaction correctly;
- Skilled operators are available;
- Steel wheel rollers are free from backlash when reversing direction;
- No rollers have oil or grease leaks;
- Pneumatic tyres on rollers are inflated to the appropriate pressure; and
- All sprinkler systems, mats and scrapers are in good operating condition.

To avoid surface blemishes and adverse ride quality, the following practices should be adhered to (see Figure 36):

- Rollers should not turn, change direction or be stationary on the hot mat;
- Rollers should not vibrate while standing still or reversing direction;
- Starts, stops and changes in the direction of rolling (i.e. forward and reverse) should be made evenly;
- To prevent excessive cooling of the mat, rollers should not spray excessive water onto the drums.

In general, rollers should:

- Roll as close to the paver as possible, particularly for thin mats due to the short compaction window;
- Roll as a team with a predetermined rolling pattern.



Source: NAPA **Figure 36: Paving Strip Rolling Techniques**

When rolling at corners such as are encountered at intersections, sharp turns that may result in tearing of the mat should be avoided by using multiple passes as illustrated in Figure 37.

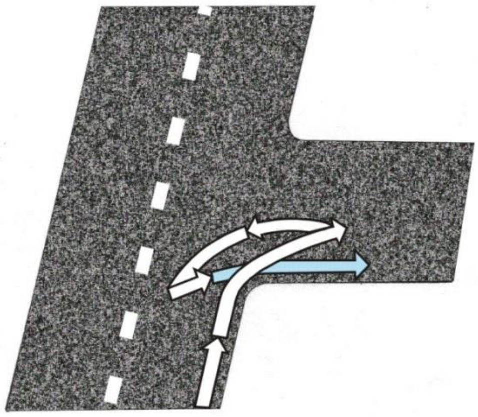


Figure 37: Rolling Techniques at Intersections

Steel drum rollers, both static and vibratory types, should normally be operated with the drive drum(s) forward, i.e. in the direction of paving, especially during break-down rolling. This will ensure that the material is tucked under the drive drum by the turning force before it is compacted and not shoved into a bow-wave by the steering drum (see Figure 38).

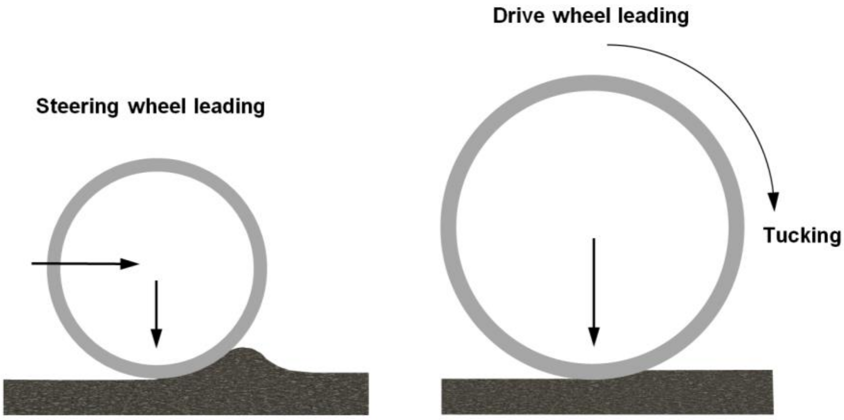


Figure 38: Pushing and Tucking Resulting from Direction of Rolling

There are exceptions to this practice which normally occur on steep grades or cross falls where the drive drum of the roller could "chatter" on the mat, causing displacement of the mat and an uneven surface. With the steering drum forward, partial compaction of the asphalt will be achieved before the heavier drive drum passes over it.

H5 JOINT CONSTRUCTION AND EDGE FORMING

As poorly constructed and compacted joints lead to a reduction in both riding quality and pavement performance, their construction needs special attention. It is estimated that as much as 50% of pavement defects can be ascribed to joint and other low-density zones.

Based on research as well as the findings of experienced practicing engineers, the following basic principles for longitudinal joint construction are proposed:

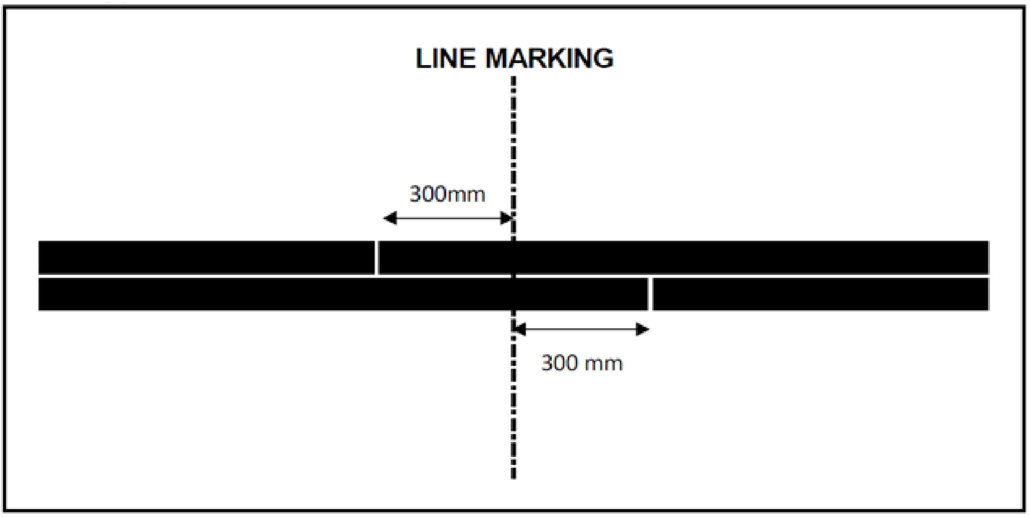
- Cracking and ravelling, the two main distress conditions at joints, are caused by relative low density and or surface irregularities at the joints. Field densities of at least 91% MVD are required at joints; permeability (Marvil test) of less than 5 ℓ/h is preferable;

- Joints falling within wheel tracks should ideally be constructed as hot, echelon-paved joints whenever feasible. If this is not possible or economically justifiable, paver widths that will ensure the joints are located at positions where the potential for traffic damage is minimised need to be employed, or such joints should receive special joint sealing treatment;
- A low-density zone along the unconfined edge(s) of the mat, caused by "squeeze-out" during rolling, generally extends from 75 mm for thin mats to up to 400 mm from the edge for very thick mats e.g.100 mm thick. (Squeeze-out depends on layer thicknesses, mix stiffness, base roughness, roller action etc.);
- The permeability in this low-density zone, especially on the vertical interface, can be 10 times higher than on the layer itself (Marvil permeabilities of 30 ℓ/h to 250 ℓ/h are typically measured on untreated joints). Also, density along this unconfined edge can be in the order of 5% lower than the rest of the mat;
- In contrast, the density along the confined edge of a well-constructed mat can be in the order of 2% higher than the rest of the mat;
- A rolling technique to reduce the "squeeze-out" of the unconfined edge is:
  - The edge of the first roller pass should be 100 – 150mm away from the edge, leaving an unrolled slight ridge along the edge;
  - The reverse pass takes place over the ridge during which the roller is supported by the partially compacted material, thereby reducing "squeeze-out".
- Treatment of joints to achieve a well-sealed, dense and bonded interface must include the removal of the uncompacted cold-side edge, special compaction of the hot-side edge and sealing of the interface using suitable raking techniques and / or sealing additives;
- Successive asphalt layers require stepped longitudinal edges and thus straddled joints with at least 150 mm offsets to ensure discontinuous joints and to reduce water infiltration.

H6 CONSTRUCTION OF LONGITUDINAL JOINTS FOR DENSE GRADED ASPHALT

Note: This section does not apply to open-graded or UTFC mixes

If paving more than one layer against existing asphalt, the longitudinal joints of the top and bottom layers shall be offset by 150 mm. This will improve compaction by creating a lip for the roller operator to properly compact into the bottom corner, as well as lengthening the water path.



For winter paving, heaters can be attached to the edge of the paver to heat the joint and prevent excessive cooling down of the new layer.

Longitudinal joints are formed between adjacent paving lanes and are zones where, because of lack of edge support and more rapid cooling, the joint face of the first lane may be insufficiently compacted.

Longitudinal joints can be classified as either ***hot joints*** or ***cold joints***.

Hot joints occur where pavers operate close together in echelon. The lane paved first does not cool significantly before placement of the second lane adjacent to it and the joint gets compacted only after placing of the second lane. Consequently the edge of the first lane does not require any special treatment.

Cold joints occur where the first lane has cooled significantly (e.g. to below 80°C) and was compacted and finished before paving of the adjacent lane. Where this mat will be exposed to traffic the edge should be rolled with a pneumatic roller to ensure compaction and traffic safety. Thicker layers should not be rolled-over without edge restraint (e.g. timber boards) due to the detrimental effect of the lateral squeezing-out of the mix on mat evenness.

The joint face of cold joints (the first lane side) requires special treatment to remove under-compacted and rounded-off material, and to produce a stable, interlocking face. A roller-mounted cutting wheel as shown in Figure 39, which leaves a sloping or vertical face, is recommended for this purpose. After cutting, the trimmings should be removed and a thick (1 l/m^2 net) bond coat of bitumen emulsion (preferably filler-enriched) should be applied to the face.

Proprietary bitumen-impregnated tapes can provide a rich bitumen coating to seal the joint. This is particularly effective in winter and should be seriously considered when paving at temperatures below 15ºC. However, if used they should be firmly attached to the edges of the layer to be paved against using a staple-gun and they must be constantly checked to ensure that they haven't become dislodged during the paving, especially by truck wheels being driven over them. This type of tape is not readily available and will need to be ordered.

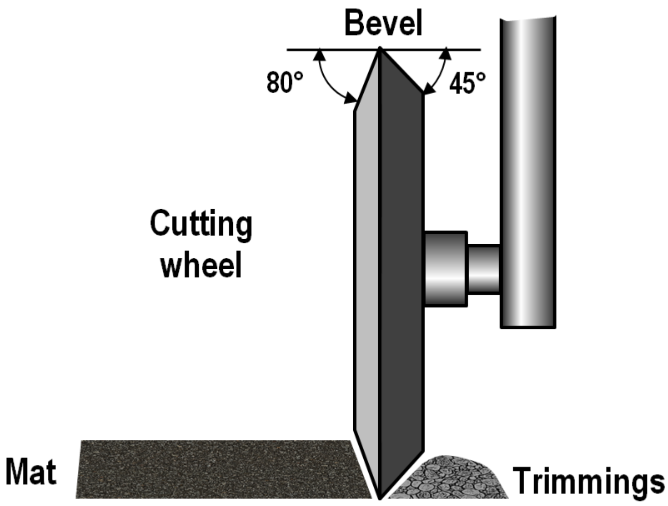


Figure 39: Roller Mounted Cutter

In paving the subsequent lane, the paver should be operated to overlap the adjacent rolled mat by 25 to 50 mm (See Figure 40A).

The overlapping material should be pushed back or bumped using the flat edge of a rake, leaving a bump as shown in Figure 40B. It may be necessary to adjust the overlap to achieve a smooth, properly constructed joint. Rolling should proceed immediately after the joint has been formed.

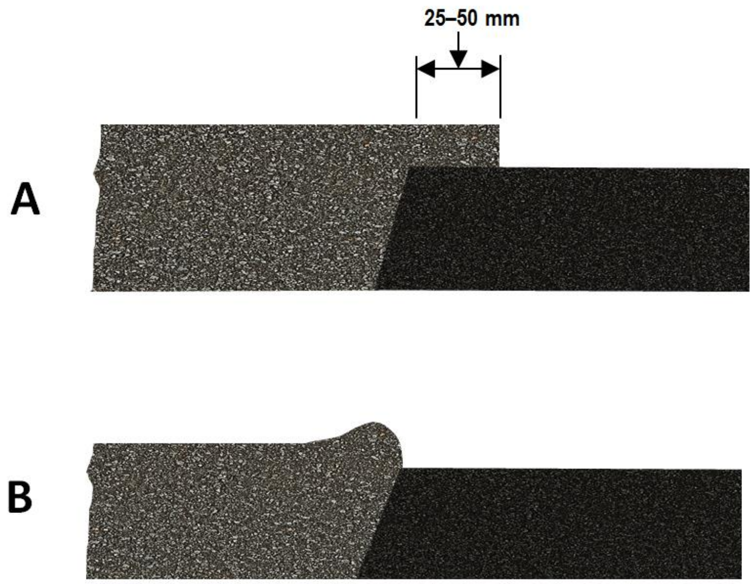


Figure 40: Options for Rolling Longitudinal Joints

One accepted method of compaction is for the roller to be placed on the first lane overlapping the second lane by 150 mm as shown in Figure 41A. The roller position is gradually shifted transversely until a thoroughly compacted, neat joint is obtained. Steel static rollers suit this rolling method.

Alternatively, rolling may start on the second lane (as shown in Figure 41B) with the roll edge some 100 mm from the joint and moved transversely towards it, pinching the material on to the joint. Vibrating rollers suit this method.

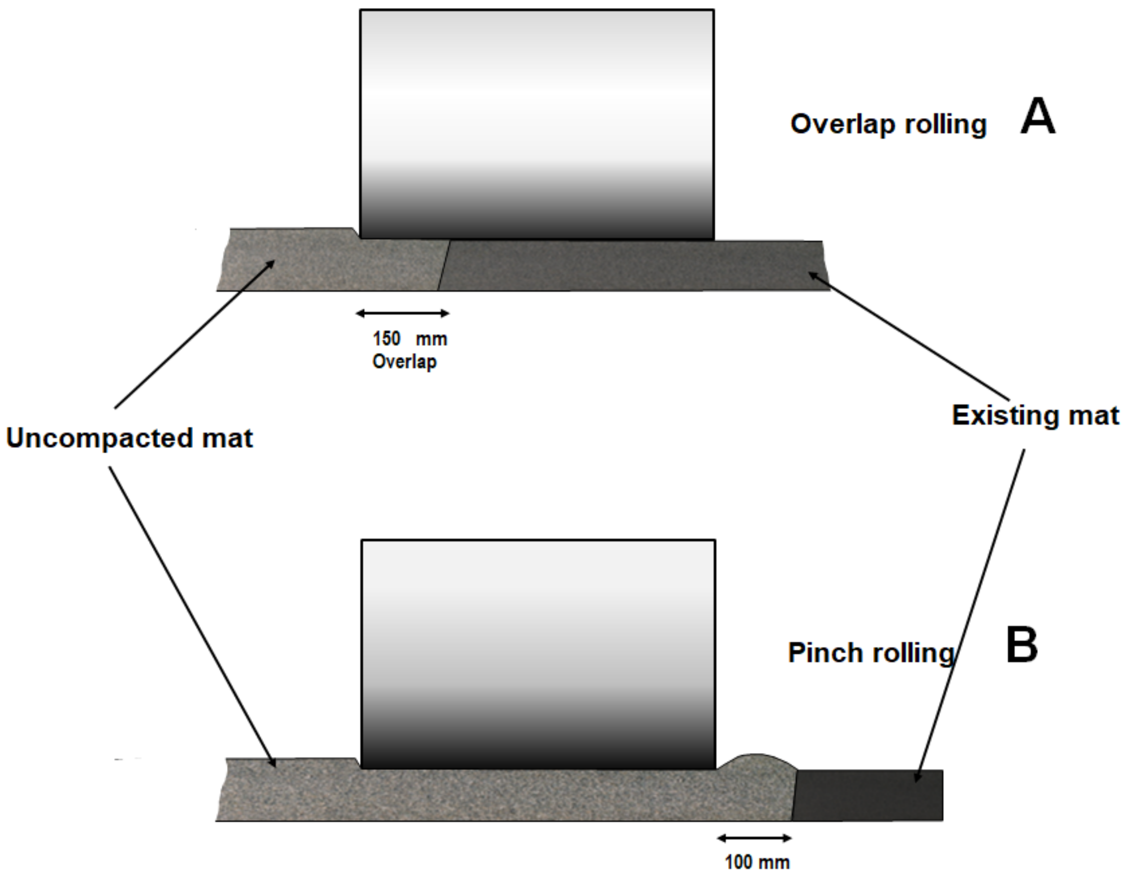


Figure 41: Two examples of Initial Rolling of Longitudinal Joints

H7 MILLING AND PAVING DURING REHABILITATION OF EXISTING ROAD

The reader is referred to Figure 42.

Mark out the section to be milled and paved - 150 mm wider than the final lane width.

Stage 1

Mill down to half of the pavement depth and to the marked width, being 150 outside the final width. The selected milling depth must consider the maximum and minimum permissible paving thicknesses for the EME type to be paved back.

Stage 2

Mill down to the full depth of the layer, but 150 mm in from the first cut.

Stage 3

Pave back bottom layer and allow the rollers to ride on the available lip and performing the “pinch” method to ensure full compaction into the corner.

Stage 4

Pave back top layer to the full milled width, also using the “pinch” method to achieve compaction into the corner.

Stage 5

Mill down to half of the pavement depth, 150 mm the other side of the final width. This will entail milling out 300 mm of the newly paved top layer.

Stage 6

Mill down to the full depth of the layer, ensuring that the newly paved asphalt on the adjacent lane is exposed and that no old asphalt is left in place.

Stage 7

Pave back the bottom layer in the same manner as was carried out on the adjacent lane.

Stage 8

Pave back the top layer in the same manner as was carried out on the adjacent lane.

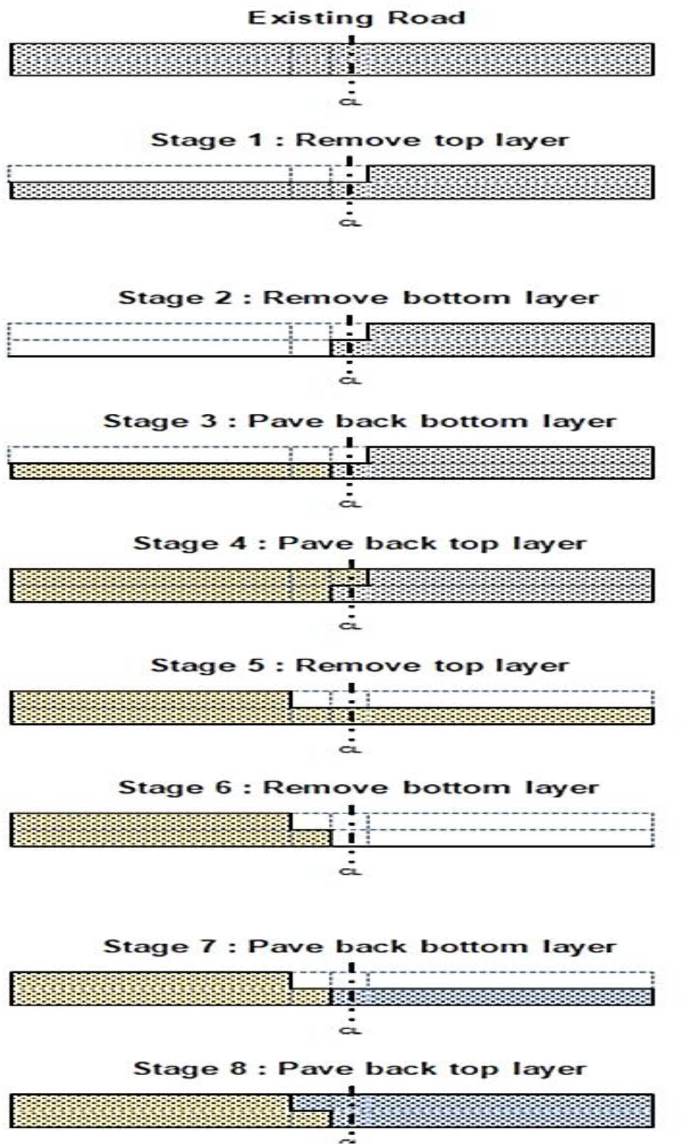


Figure 42: Milling and Paving Sequence

H8 LONGITUDINAL JOINTS FOR OPEN-GRADED AND UTFC MIXES

A characteristic of these mixes is to allow water to flow into and through them horizontally and longitudinal joints should in no way prevent this. Therefore:

- The unconfined edge should never be cut back as this tends to close up the face;
- No tack should be applied to the cold mat edge;
- The hot mat should be paved to butt against the cold mat, and should not overlap it.

H9 TRANSVERSE JOINT CONSTRUCTION

A transverse joint is formed at a point where work is resumed after a stoppage or at the end of the day's work. The techniques used at the "night" joint position differ depending on traffic requirements and the type of substrate.

Since a poorly constructed transverse joint will cause a noticeable bump and/or durability problems, particular care should be taken to ensure a smooth riding surface.

Achieving good compaction in the joint area can be difficult and special care should be taken by:

- Frstly, cutting back the cold mat sufficiently to remove all poorly compacted and uneven areas;
- Secondly, using good rolling techniques when compacting the new joint.

It is sometimes suggested that transverse joints be constructed at an angle to reduce the possibility of creating a bump for passing traffic.

As the end of the screed is at right angles to the direction of paving it is suggested that a slight angle of up to 15 degrees can be accommodated. Angles of the order of say 30 degrees will require extensive hand-work to fill a wedge not reached by the paver. This is most undesirable as it will compromise rideability and possibly compaction.

***Note*: To ensure a uniform thickness of mat at a transverse joint it is important for the paver to continue in the normal fashion right up to the point where the joint is to be formed. This implies that the head of material in front of the screed remains at a consistent level up to the location of the joint to ensure that the forces acting on the screed remain in equilibrium with a constant angle of attack.**

The paver should not be allowed to run empty when a transverse joint is to be formed (often done to limit the amount of asphalt for disposal).

Four situations at transverse joints are described:

- Finishing against an existing mat;
- Finishing on the substrate with a tapered joint;
- Preparation of the joint before resuming paving;
- Resuming paving at a prepared transverse joint.

H9.1 FINISHING OF THE PAVED LANE AGAINST AN EXISTING MAT (UNSTEPPED)

Paving up to the existing prepared joint should be done as follows:

- Approach the joint at the normal paver speed;
- Don't allow the auger box head to drop ahead of the screed as it approaches the joint;
- Switch off the level sensors as the paver starts climbing onto the existing mat;
- Stop the paver as the screed reaches the joint;
- Raise the screed, move the paver away, and remove excess asphalt;
- Check with a straight edge and correct the levels where necessary;
- Roll and complete the joint as discussed below.

H9.2 FINISHING OFF THE PAVED LANE WITH A TAPER

Where it is required that traffic will traverse the position of the joint, a temporary taper should be constructed. The length of taper is usually dependent on traffic speed and volume. Nevertheless, the paving routine for the last load of the day is the same:

- Normal paving speed should be maintained with no slowing down;
- Stop the paver when the hopper is empty but the auger box still has a full head of material in it (If the auger box is allowed to empty, the screed will drop and affect the thickness and riding quality at the joint);
- The screed is raised and the paver is moved away;
- This leaves excess material at the joint position that is used to form the taper.

There are two methods of constructing such a joint:

Method 1

The material ahead of the marked joint position is temporarily pushed away in a longitudinal direction and a vertical edge is formed on the face of the mat. To facilitate removal of the taper before paving continues, treated release paper or similar material to which asphalt will not adhere is placed ahead of the joint directly on the face of the mat and on the existing pavement surface. (See Figure 43A)

Before subsequent paving starts the loose material is simply removed to the prepared face and a bond coat of bitumen emulsion applied to the face.

Method 2

After the paver has moved away surplus material is formed into a ramp and compaction proceeds as shown in Figure 43B. Before subsequent paving starts, a saw cut is made into material of uniform thickness near the screed position to leave only a fully compacted mat with a true surface. The material ahead of the cut is then removed and a bond coat of bitumen emulsion applied to the face.

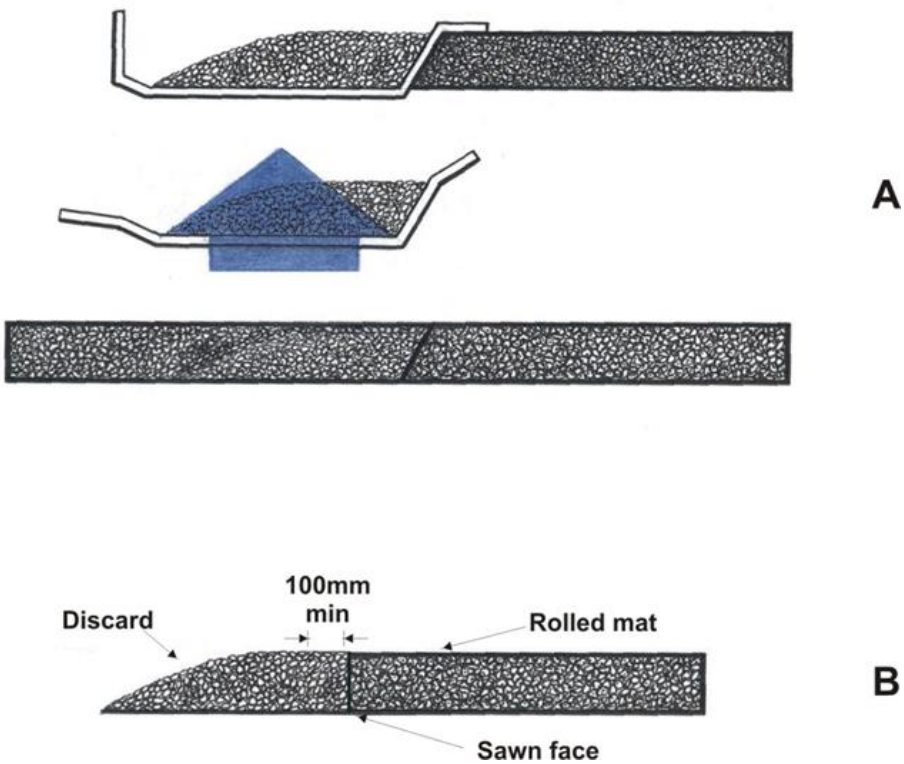


Figure 43: Transverse Joint using a Paper Interlayer (A) and with Sawn Vertical Face (B)

H9.3 PREPARATION OF THE JOINT BEFORE PAVING

The joint should be prepared as follows (illustrated in the figure below):

- Remove the temporary taper;
- Check the area of mat just behind the proposed joint position with a straight edge, for any unevenness in the surface that could cause rideability problems;
- Also visually check the same area for poor surface finish and possible poor compaction;
- If there are any doubtful areas, move the joint position back to remove these areas and mark the new position on the mat;
- Cut the mat back to the (new) joint position;
- The removal of the taper and the possible cutting back of the mat may result in some hollows and roughness in the surface of the underlying layer. These must be levelled with asphalt and compacted before paving restarts to avoid any differential compaction that could later affect rideability;
- Tack the base area where needed;
- Tack the edge of the joint to assist sealing.

Care must be taken to ensure that there is proper compaction right into the bottom corner of the transverse joints when in a box. Milling back into the new work gives a compactable curved face at the bottom. The top shall be cut vertically to 3 times the maximum stone size, to prevent feathering. The steps are shown on the adjacent sketches.

If space does not allow for the use of a milling machine, the joint must be cut while the mix is still fresh, since the alternatives would be to cut it with a diamond saw and use a jackhammer which is not recommended.

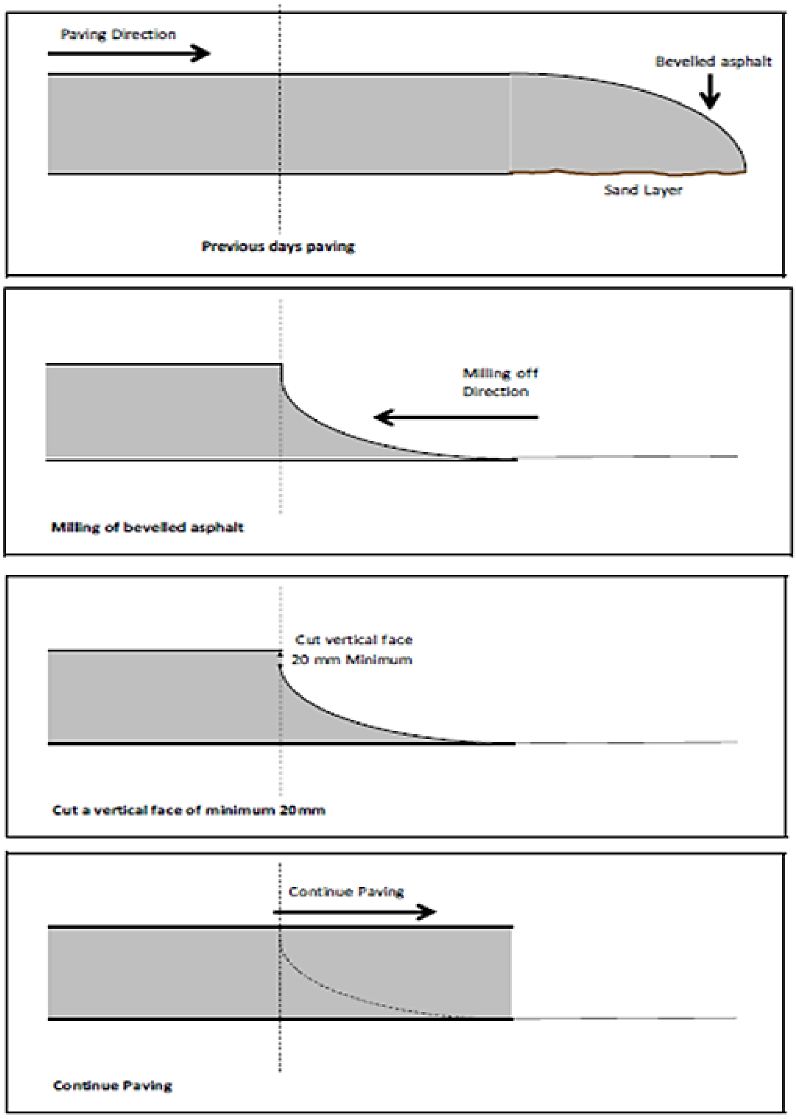


Figure 44: Joint Preparation Prior to Paving

H9.4 RESUMING PAVING AT A PREPARED TRANSFER JOINT

- Lower the screed onto the correct size starter blocks to suit the loose thickness of the mat;
- Set the tow points to suit the mat thickness;
- Carry out all the correct starting procedures and pull away;
- Stop the paver after about 10m to attend to the joint. (Although this is start/stop paving, it is necessary to get the joint right before continuing);
- Check and prepare the joint for rolling by;
  - Removing excess material off the old mat; and
  - Checking the level of the hot mat across the joint with a straightedge.
  - During this operation handwork should be kept to a minimum and any repairs should be carried out quickly.
- Rolling
  - Start rolling transversely across the mat with just a small overlap (100mm) across the joint onto the hot mat;

- Where there is no adjacent mat for the roller to move onto, use boards against the edge of the mat (see Figure 45);
- Increase the overlap with each pass until the full drum width is on the hot mat;
- During this rolling, continually check the joint with a straightedge, especially in the wheel tracks, and repair where necessary;

- When the joint is satisfactory, re-start paving and revert to normal longitudinal rolling.

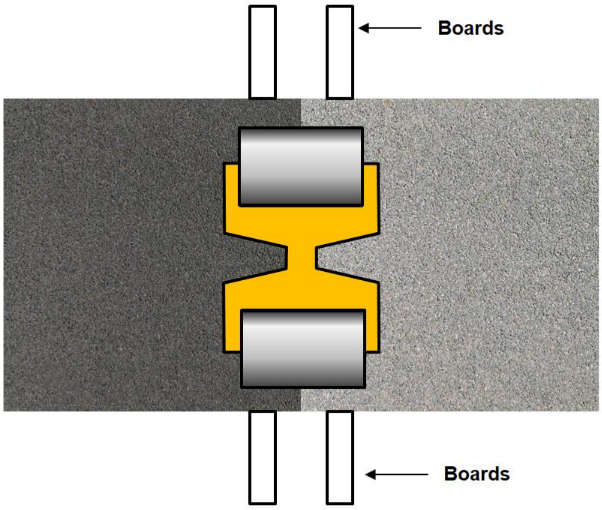


Figure 45: Edge Protection when Rolling Transverse Joint

H10 EDGES

The outside (exposed) edges of the mat should be rolled concurrently with the longitudinal joints. In rolling edges, roller wheels are extended 50 mm to 100 mm beyond the mat edge. A combination of edge raking to produce a 1:4 gradient, and rounding-off rolling using a PTR, is recommended to ensure a safe, neat, uniformly shaped finished layer edge. Tie-in milling in combination with the above rolling is needed where new overlays need to be tied-in flush with existing kerb, channel or concrete edging restraints.

H11 CLEANING-UP AND FINISHING INSPECTIONS

H11.1 SURFACE FINISH

The mat behind the paver should be frequently examined for uniformity, i.e. there should be no areas of evident excess or deficiency of binder or segregation of aggregates. Unsatisfactory material in affected areas should be removed to the full depth of the layer and replaced with new asphalt - even after compaction should deficiencies only become evident at that stage.

H11.2 SURFACE TOLERANCES

The importance achieving acceptable surface tolerances and evenness for acceptable riding quality on modern high-speed roads cannot be over-emphasised. Measured in terms of the International Roughness Index (IRI) algorithm over, say, an average of 100 m moving area, average IRI measurements of less than 2, and preferable below 1.4, should be aimed at. The use of three-level averaging beams (or beams with spring mounted type ski-feet) and various other methods are essential for riding quality improvement of asphalt layers. Also, correct paving procedures are essential to achieving good riding quality.

Various types of profile measuring equipment e.g. the ARRB walk-behind profilometer, laser meters, and ARAN are generally used. Any irregularities, based on the mean or other statistical measures – e.g. maximum or 90th

percentile worst value, measured over a fixed or moving length (say 100 m) that varies more than the specified tolerance for each layer - should be corrected before the next layer is placed.

In the lower courses, these can usually be corrected by removal; by milling to the correct level- or by placing levelling layers of material. In the final layer, however, the entire affected area should be removed promptly and sufficient new material placed to form a true and even surface. If the required evenness is obtained in the first course of asphalt laid, the subsequent courses can usually be placed uniformly by simply setting the paver for the thickness desired. It is however preferable on high profile projects to enhance the riding quality of the finished pavement by employing full averaging beams both sides of the paver where possible.

H11.3 OPENING TO TRAFFIC

Various factors need to be taken into account to establish an appropriate time for a newly laid layer to “set-up” before being exposed to traffic loading. These are:

- Ambient temperatures;
- Type and volume of traffic;
- Layer properties, i.e. mix type and thickness;
- Grade and type of binder.

Typically, a one-hour to eight-hour period may be required to allow the layer to have sufficient bearing capacity without undue deformation. Thicker asphalt base layers require a longer time.

H12 ROLLER TYPE CHARACTERISTICS AND OPERATIONAL ASPECTS

H12.1 STATIC STEEL DRUM ROLLERS

While the three-wheel type is most commonly used, tandem rollers are also available. Characteristically the three-wheel type has two large, heavy rear drive wheels that can be ballasted with water for extra weight and pressure, and a single small, lighter tiller wheel at the front, which is usually not ballasted.

Compaction with static steel drum rollers is achieved through top-down, high surface pressures causing the consolidation of asphalt particles into a tightly knit configuration. This action requires good lubrication, thus these rollers are most effective where the mat is at its hottest i.e. normally in the breakdown zone. Thus they are normally used as breakdown rollers

Rolling speeds are typically 4 - 8 km/hr. Steel drum rollers should normally be operated with the drive drums forward, i.e. in the direction of paving. This will ensure that the material is tucked under the drive drum by the turning force before it is compacted and not shoved into a bow-wave by the steering drum.

H12.2 VIBRATORY TANDEM ROLLERS

Typically, vibratory rollers for road construction weigh between 4 and 17 tons, with the loading usually equally distributed between two tandem drums. Vibration can be set on either or both drums. Both drums are drive drums.

Vibratory rollers are versatile in their application provided that the amplitude and frequency are adjustable and appropriate settings selected in conjunction with the speed of rolling.

Vibratory rollers impart a rapid succession of impacts on the surface, which gives rise to pressure waves that reduce the internal friction of the material and set the particles in motion to be rearranged into a denser configuration.

Factors affecting the compactive action of vibratory rollers are (see Figure 46):

- Linear drum loading;
- Amplitude and frequency of vibration; and
- Rolling speed.

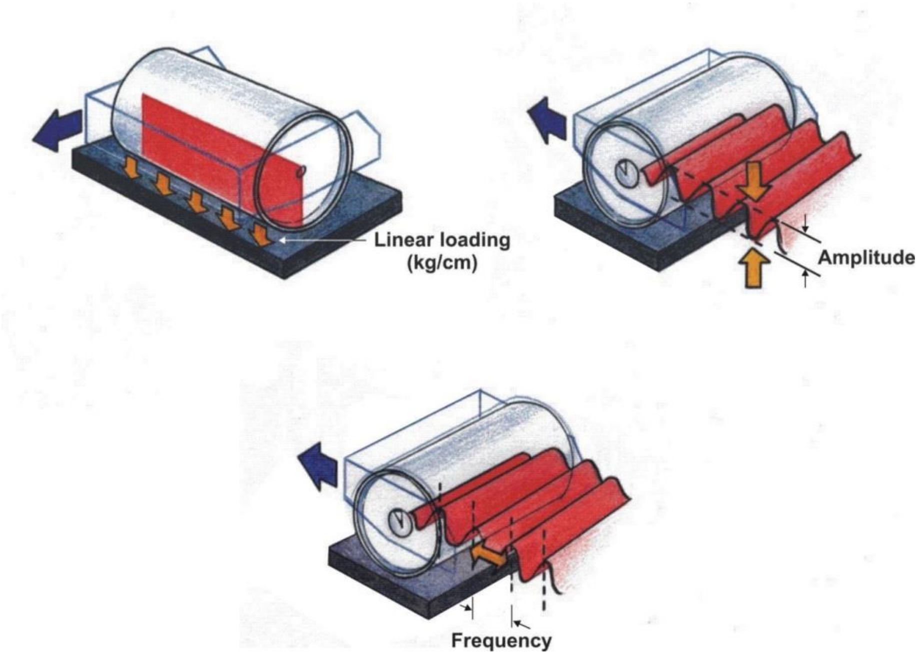


Figure 46: Compactive Action of Vibratory Rollers

The higher the drum loading, the greater is the compactive effort during vibration. Drum loadings vary from about 40 kg/cm for the very heavy rollers down to 15 kg/cm for the 4 ton rollers.

These rollers compact effectively when used in vibratory mode, and should not be used in static mode for the purpose of increasing density.

Vibrating rollers generally achieve density in fewer passes than do static rollers of similar size.

The rolling speed of vibratory rollers determines the spacing of impacts on the mat. For optimum spacing, the speed for a roller that vibrates at 3 000 cycles per second would be in the order of 5 km/hr. For wearing course asphalt low amplitude vibrations, typically 0.3 to 0.4 mm, is appropriate. For thick asphalt bases, rolling can start at higher amplitudes e.g. 0.7 to 0.8 mm, and as density increases, reduced to the lower amplitude.

Advanced operator skills are required for vibratory rollers. To provide versatility, most vibratory rollers require that the operator coordinate the frequency, amplitude and speed to produce an acceptable surface and density. Also, the vibrations must be cut off prior to stopping or reversing directions. All modern rollers have this facility. Failure to observe the cut-off precautions will produce a very poor surface.

H12.3 OSCILLATORY ROLLERS

Oscillatory rollers are a particular type of vibratory rollers which allow the plane of vibration to be varied from the vertical to the horizontal, or any angle between the two. The mechanism by which compaction is achieved is therefore adjustable between pure vertical impact and horizontal manipulation, and appears to allow for greater movement and orientation of aggregates. Some of the benefits of oscillatory rollers include the following:

- Fewer passes may be required – this should be confirmed by trial sections.
- Less likelihood of over-compaction or aggregate crushing.
- Dynamic compaction even in vibration-sensitive areas such as bridge decks.
- Some systems are self-regulating and require no adjustments.
- Environment-friendly thanks to lower noise levels and reduced vibration energy.

H12.4 PNEUMATIC TYRE ROLLERS (PTR'S)

Pneumatic tyre rollers range from 10 to 25 ton in mass and are capable of increasing density at lower mat temperatures than steel drum rollers. The rear tyres of PTR's are offset from the front ones to ensure complete coverage of the mat in a pass. The wheel loadings are usually the same on all wheels, these being 200mm wide for 10 – 14 rollers with heavier ones having 300mm wide tyres.

Compaction with PTR's is achieved through manipulation and kneading of the mat, causing consolidation. The confining action of adjacent tyres limits lateral movement during rolling, making these roller types less likely to shove the mat than steel drum rollers. This makes PTRs preferable for tender mixes to avoid shoving.

Also, PTR's provide a more uniform degree of compaction by compacting areas bridged by steel drum rollers, and also offer a kneading action that tends to close up the surface and provide a tighter finish.

The compaction effort is determined by three factors:

- Load per wheel.
- Ground contact pressure which is determined by:
  - Tyre pressure;
  - Tyre contact area; and
- Roller speed.

If the load is kept constant and tyre pressure is increased, the tyre contact area is reduced and the contact pressure increased.

The correct rolling speed is 4 to 5.5 km/hr to ensure that the kneading action effectively increases the density of the mat.

PTR's should preferably not to be used for breakdown rolling or at mat temperatures in excess of 110°C due to:

- The tyre ruts possible causing final rideability problems;
- Unsightly blemishes on the surface due to "pick-up".

PTRs are effective down to about 70^0 or 60^0C, depending on the mix type. To prevent pick-up by the pneumatic tyres on hot mats it is good practice to warm up the tyres before covering a fresh mat, and to use a release agent on the tyres.

H13 TYPICAL ROLLER PATTERNS FOR VARIOUS CONDITIONS

As guidance, Table 3 below gives recommended roller patterns and estimated production rates for mixes, in terms of their compactability characteristics i.e. tender, average and harsh.

Table 3 Recommended Roller Patterns and Production Rate

Compactability of mix	Recommended rolling effort#		
	25 mm thick	40 mm thick	>60 mm thick
Tender mix	2 Roller Team	2 Roller Team	2 Roller Team
	60 tons/h max	100 tons/h max	120 tons/h max
Average mix	3 Roller Team	3 Roller Team	2 to 3* Roller Team
	60 tons/h max	80 tons/h max	120 tons/h max
Harsh mix	N/A	3 to 4 Roller Team	2 to 3Roller Team*
	N/A	60 tons/h max	100 tons/h max

Note

At appropriate mat temperature; excluding adverse conditions where increased effort will be essential

* Three rollers maybe necessary up to 90 mm thickness; for two rollers reduce production slightly.

H14 COMPACTION WINDOW UNDER ADVERSE CONDITIONS (WINTER)

Most specifications restrict paving to "favourable weather conditions" and do not deal comprehensively with all the complexities associated with the laying of hot mix asphalt in adverse weather conditions such as:

- Rain, wind and low temperatures in winter rainfall areas.
- Thunderstorms and low winter temperatures in summer rain fall areas.

In the light of the above, Sabita Manual 22: *Hot Mix Paving in Adverse Weather* was developed to set out guidelines to assist site staff involved in the paving of asphalt as well as asphalt suppliers to deal with this issue. Users of this manual are encouraged to acquaint themselves with the content of Manual 22 in the interests of efficiency, decreasing wasteful practice, and reducing risk.

H14.1 PURPOSE OF MANUAL 22

To deal with risks of achieving adequate compaction when faced with rapid cooling (in association with wet base and trapped water), Manual 22 provides information and recommendations on:

- Good paving practices
- Risks involved
- Limiting conditions for paving
- Precautions required

H14.2 RAPID COOLING

Loss of heat from the asphalt mat through the effects of wind, water and low ambient temperatures causes the available paving and compaction time window to shrink. Additionally, where low temperatures are associated with weaknesses introduced by moisture in a granular base adequate compaction of the asphalt is difficult to achieve. Also, trapped water in the asphalt can cause a loss in durability or stripping of the bitumen from the aggregate, leading to premature distress.

Manual 22 sets out a number of factors affecting the cooling of asphalt and means of reducing exposure to risk:

- Mixing and transport
- Site conditions
- Layer / mat thickness
- Wind speed
- Trapped water
- Granular base moisture

An illustrative example of the combined effects of mat thickness, base temperature delivery temperature and wind speed is shown in Figure 47. Air temperature = base temperature, wind speed = 18 km/hr)

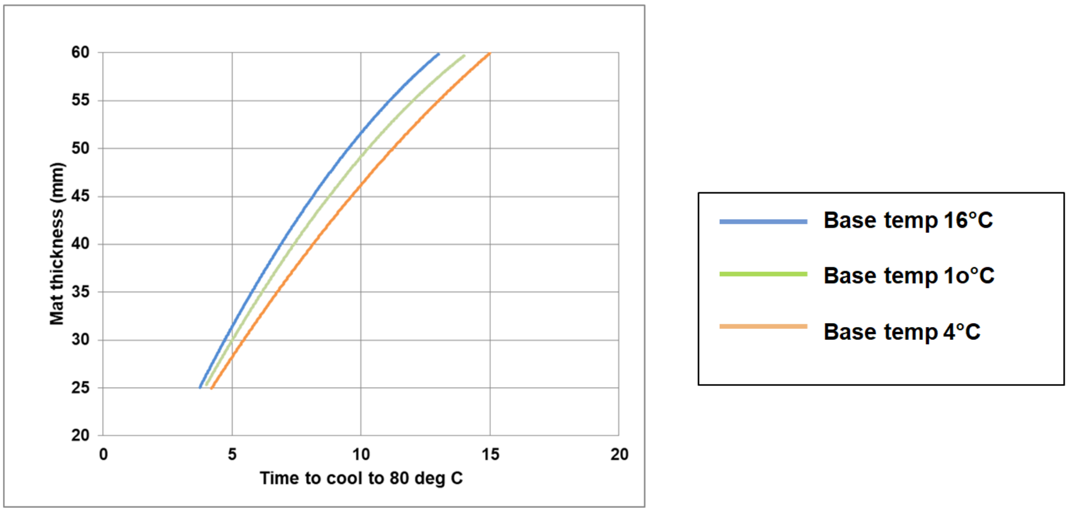


Figure 47: Time for Mat to Cool to 80°C

Source: NCHRP: Synthesis of Highway Practice 152

A single factor possibly not always taken into account with sufficient gravity is wind speed and its effect on the duration of the compaction window. Figure 48 illustrates the significant effect of wind speed on the reduction of the compaction window. What is described as a strong breeze (25 – 32 km speed, in which large branches sway) can reduce the time available to achieve sufficient compaction by no less than 30%.

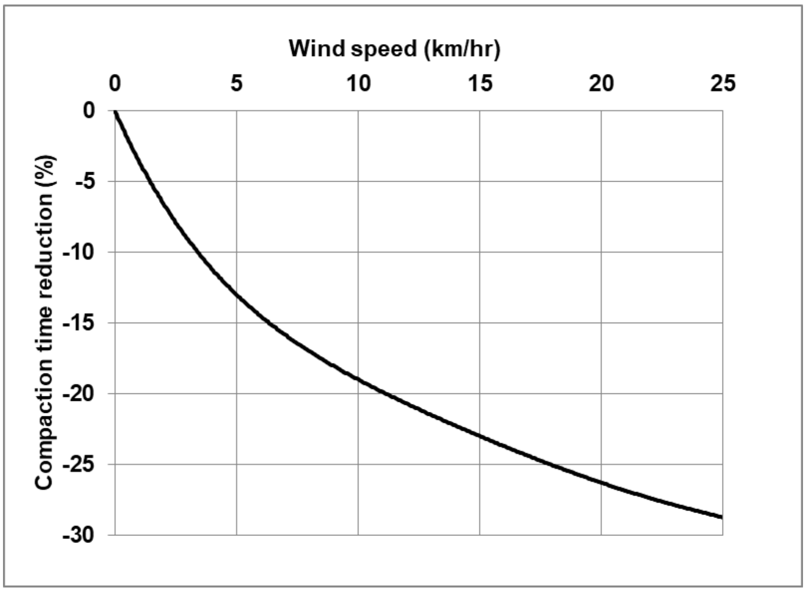


Figure 48: Effect of Wind Speed on Compaction Time

Source: National Asphalt Pavement Association

An example of recommended minimum base and air temperatures in relation to wind speed is shown in Table 4.

Table 4: Recommended Min Base and Air Temperatures in Relation to Wind Speed

Wind speed (km/hr)	Mat thickness (mm)	25	40 - 60	> 60
	Base temperature (°C)	18	10	4
0 - 10	Air temperature (°C)	15	10	4
> 10		18	13	10

H14.3 RECOMMENDED PRACTICE

Practical recommendations to deal with risk associated with inclement weather conditions are given in Manual 22. It is not the intention here to cover these matters in detail; rather it is recommended that the reader familiarises him/herself with the recommendations:

Ground rules

- Working in adverse weather conditions requires close cooperation, good planning and a well organised site team to ensure that quality standards are maintained.
- Prime, bond coat, bitumen and mixing temperatures.
- The bond coat should be applied before the rain. If it is not applied and "broken" before any rain, paving should be postponed. Limitations on dynamic viscosity of the binder and, as a result, suitable mixing temperatures are also suggested.
- Managing the effects of rain on granular bases.
- Moisture in the base layer should be less than 50% OMC before priming or paving commences.
- Minimum base and air temperatures (in relation to wind strength).
- Recommended minimum base and air temperatures are given for prevailing wind strength.

- Minimum lay-down temperatures.
- Guidance is given on minimum delivery temperatures and mat temperatures before rolling.
- Transporting the hot asphalt.
- Good communication between the paving contractor and the asphalt supplier should be maintained at all times so that allowance can be made for supply interruptions.
- Compaction management.
- Consider narrower paving widths for more rapid roller coverage with due consideration of the location of longitudinal joints in relation to wheel tracks.
- Procedures for paving when caught in rainy conditions.
- A number of emergency measures are suggested, including reducing water on roller drums to a minimum.
- Factors to be considered when assessing overall risk:
  - Type and amount of rain
  - Mat thickness, wind speed and base temperature
  - Base condition and sensitivity to water
  - Prevailing temperatures
  - Asphalt delivery temperatures
  - Level of supervision

Risk assessment

Four levels of risk are identified in Manual 22 together with precautions to be adopted:

- Nil (N) – still employ good paving practice.
- Low (L) – precautionary measures need to be taken.
- Medium (M) – avoid paving unless absolutely necessary.
- High (H) – paving should not take place.

A matrix of assessing risk levels are given in Manual 22 in cases where paving takes place on:

- Water resistant substrates (e.g. asphalt, cementitious layers); or
- Layers susceptible to moisture damage (unstabilised, granular).

An example of determining levels of risk when paving on ***granular layers*** is given in Table 5.

Table 5: Risk Assessment Paving on Granular Substrate

Mat thickness (mm)	25		40		60	
Weather conditions	Wind speed		Wind speed		Wind speed	
	Nil	> 10 km/hr	Nil	> 10 km/hr	Nil	> 10 km/hr
Air temp: > 24°C Drizzle Light rain Moderate rain	 L M H	 M H H	 L L M	 L M H	 L L M	 L L M
Air temp: 18 – 23°C Drizzle Light rain Moderate rain	 M H H	 H H H	 L M H	 M H H	 L L M	 L M H
Air temp: <18°C Drizzle Light rain Moderate rain	 H H H	 H H H	 M H H	 H H H	 L M H	 M H H

Mix compactability

The compactability characteristics of a mix, ranging from "tender" to "harsh" would also influence the compaction window. The adverse effect thereof for a set of inclement weather conditions is illustrated in Table 6.

Table 6: Compaction Windows under Adverse Conditions

Compactibility of mix	Compaction window (time) for various layer types#		
	40 mm thick	30 mm thick	20 - 25 mm thick
Tender mix	20 min	13 min	9 min
Average mix	15 min	10 min	7 min
Harsh mix	10 min	N/A	N/A

Note # At air temperatures of approx. 10°C, wind speed of approx. 10 km/h, road surface temperatures of 5 – 10°C.

SECTION I – QUALITY ASSURANCE

In the broadest sense quality can be described as the extent to which something is fit for its purpose. More specifically, product quality is defined as conformance with requirements, freedom from defects and the sum of its characteristics reflecting its ability to satisfy stated or implied performance requirements.

Quality assurance entails all those planned and systematic actions necessary to provide confidence that a product will perform satisfactorily in service. It deals with the overarching issue of procurement by the most efficient, economical and satisfactory means available, and involves the continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction procedures and processes and the various interactions of these activities.

The principles of formal quality assurance can be applied with considerable benefit to the manufacture of asphalt. It is therefore recommended that the manufacturer has a quality assurance system in place in accordance with ISO 9000 and meeting the requirements of ISO 9001. In the South African context the Construction Industry Development Board (CIDB) is the industry regulator responsible for public sector construction. Any contractors operating in the public sector must be registered in terms of the Construction Industry Development Board Act (Act No. 38 of 2000). The CIDB also administer the *Construction Management System SANS 1393* standard, which is based on, and forms an acceptable alternative to, the ISO 9000 approach.

Seven quality management principles form the basis of ISO 9000, being:

- QMP 1 – Customer focus
- QMP 2 – Leadership
- QMP 3 – Engagement of people
- QMP 4 – Process approach
- QMP 5 – Improvement
- QMP 6 – Evidence-based decision making
- QMP 7 – Relationship management

It is generally accepted that the term quality assurance encompasses three elements:

- process control
- acceptance control
- independent assurance

Generally accepted definitions of these elements are given below.

PROCESS CONTROL

Process control comprises those actions and considerations necessary to assess production and construction processes in order to control the level of quality of the end product. It includes sampling and testing to monitor the process, but usually does not include acceptance sampling and testing. Process control is the express responsibility of the asphalt producer / contractor, and its purpose is to ensure confidence in the processes undertaken.

ACCEPTANCE CONTROL

Sampling, testing and the assessment of test results to determine whether or not the quality of the constructed product is acceptable in terms of the specifications. Acceptance control is normally the responsibility of the employer, his agent or the contractor, or it may even be a shared responsibility. Financial obligations flow from the acceptance control process in terms of payment for work performed to an acceptable standard.

INDEPENDENT ASSURANCE

A management tool that requires a third party, not directly responsible for process or acceptance control, to provide an independent assessment of the product and/or the reliability of test results obtained during process and acceptance control. The results of independent assurance tests are not used as a basis for product acceptance.

Process control is closely associated with QA procedures during manufacture and construction This aspect is amplified below.

I1 PROCESS CONTROL

As part of a process control procedure it is essential that the manufacturer ensures that the raw materials used in the manufacture of asphalt i.e. bituminous binders, aggregates and filler, comply with his stated requirements in supply agreements, and do not differ significantly in quality from those materials used in project designs. Having assurance that the raw materials comply with his requirements, the manufacturer must then take the necessary steps to measure and record the composition of the mix being manufactured to ensure that the proportions of component material fall within targeted ranges determined during the project mix design stage.

Aggregates

Design objectives are the main considerations when selecting aggregates for a project mix formula. The initial selection of aggregates to be used is based on test data supplied by the source before delivery to the plant stockpiles. The general characteristics and physical properties of aggregates for asphalt are defined in various specifications, although some clients may have their own standards. The raw aggregates should come from sources approved by the employers (or their agents) and should be tested for compliance with designated quality standards.

A critical element of this process is the regular monitoring of aggregate stockpiles to ensure that materials being mixed are representative of those used in the project mix design. If at any time it is evident that this condition is not being met, a new design based on materials currently available should be submitted

Binders

General considerations for quality assurance of bituminous binders throughout the supply chain are presented in Sabita manual 25: *Code of Practice: Transportation, off-loading and storage of bitumen and bituminous products*, with some aspects of the sampling and testing as well as safety precautions dealt with in section 1.5.1 of the document.

It is also advisable that the viscosity temperature relationships are affirmed from time to time to ensure that appropriate mixing and lay down temperatures are being maintained.

Mixtures

Sabita Manual 35 sets out the procedures to be followed to run plant mix trials as well as compliance limits for key components of the mix composition.

On completion of plant mix trials, plant control of asphalt mixtures covers a series of interrelated elements. The basic elements that require process control testing are:

- Mix design:
  - Selection of binder, aggregate and compositional design;

- Selection of aggregates;
- Selection of a mixing temperature and lab compaction temperatures.

- Day-to-day plant control and tests:
  - Stockpile and cold-feed aggregate quality;
  - Hot-bin gradations (for batch plants);
  - Cold-feed proportioning adjustments;
  - Hot-bin weight adjustments (for batch plants);
  - Binder content tests;
  - Gradation of aggregate in mix;
  - Adjustments of mixing time and temperature;
  - Preparation of laboratory specimens for the relevant testing of compositional or strength parameters.

Field Control of Placement

Process control during placing and compaction should focus on pre-empting the laying of defective product and enabling corrective action to be taken. It is recommended that a paving trial section of sufficient scope to be representative of the processes which will be undertaken, during which a *modus operandi* can be established that will ensure the construction of a properly compacted layer to the required finish. The construction and monitoring processes required for this phase of construction is dealt with in A1.2 PRODUCTION MIX DESIGN AND APPROVAL PROCESS above as well as Sabita Manual 35.

It is considered sound practice for the contractor to address the following controls, which will entail the keeping of detailed records, during construction:

- Application of a bond coat;
- Adequate rate of delivery of asphalt to the paver;
- Paver speed and paver adjustments;
- Level and thickness of the mat;
- Weather conditions as they affect achievement of compaction, roller types, rolling patterns, coverage and speed;
- Control of yield thickness of layer(s) and pavement evenness.

To assist practitioners in assuring the quality of the laid asphalt as well as to identify and pre-empt defective product, a comprehensive troubleshooting guide for asphalt paving is presented in APPENDIX 2. The reader would be well advised to familiarise himself with this content, as, not only is valuable guidance given in avoiding many pitfalls, corrective and pre-emptive actions are also presented.

Risks

On most contracts specifications call for end-result assessment of quality which incorporates Process Control and Acceptance Control procedures. To limit bias, the system requires the implementation of random sampling plans to procure samples. The guiding principle of such schemes is to incentivise the contractor to produce a quality product, complying with the specified product standards, including required compaction levels and finish.

In cases where marginal material or finished product deviations are encountered, protocols for reassessment or corrective action exist which may lead to conditional acceptance in conjunction with reduced payment offered to the contractor.

Two types of risks are associated with the judgement of compliance schemes: the contractor's risk and the employer's risk. The contractor's risk is the probability of rejection of a lot of material while it is acceptable – termed α-risk. The employer's risk is the probability of accepting a lot when the lot is unacceptable – termed β-risk. Typically a contractor who has been assigned to carry out a project should not run an unduly high risk of wrongful rejection; consequently his risk should be consistently low, say 5%. On the other hand the employer may have to be prepared to run a higher risk of wrongful acceptance, which will vary considerably, depending on the number of samples assessed to establish compliance.

An important question is: how large should a sample be in any specific situation? If a sample is used which is larger than necessary, resources are wasted; if the sample is smaller than required, the risk of wrongful decisions may be increased and the objectives of the analysis not be achieved.

With the use of conventional probability theory these risks can be quantified and built into the judgement of compliance procedures.

Consistency and representativity of sampling methods, as well as the accuracy and repeatability of testing procedures, should be considered in any approved quality plan in relation to the risk of an element of construction not complying with a specification.

Another important practical consideration in the selection of a sampling plan is cost. This problem is largely economic in nature; ultimately the cost of sampling should be weighed against the potential losses or damages of wrongful acceptance of a defective lot.

Figure 49 illustrates the effect of sample (or lot) size on the risk of wrongful acceptance of defective product. In this example a statistical acceptance plan for compaction based, typically, on an acceptable percentage of defectives of 10% (below an arbitrary 95% minimum compaction requirement) with a fixed α-risk of 5 % to the producer. For a sample size of 3, the client would be faced with a β-risk (of accepting defective material) of 72.2%, which is very high. When the sample size is increased to 8, the β risk is reduced to only 6.4% which is quite acceptable. Thus the principle of "safety in numbers" should be given due consideration in developing sampling plans.

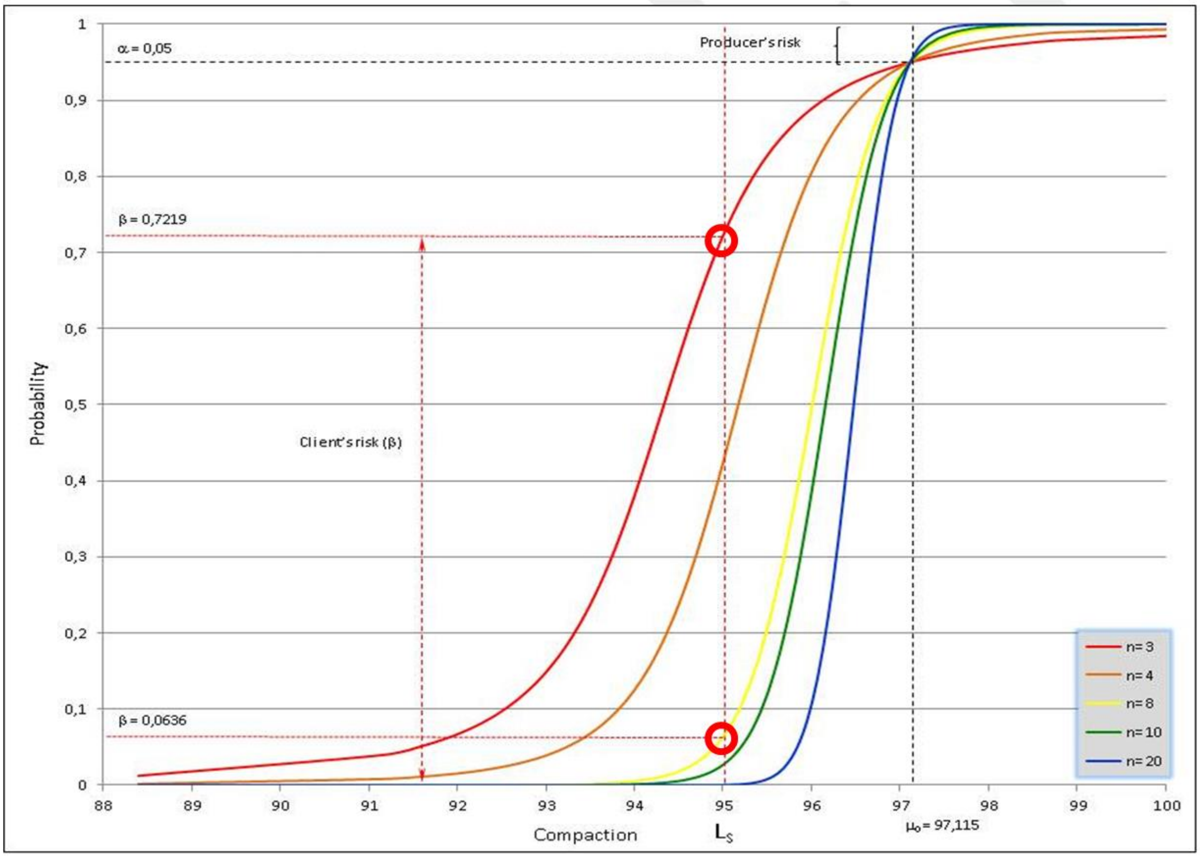


Figure 49: Comparative Risks of Producer and Client

I2 QUALITY CONTROL PLAN

To assist with quality assurance, the above should be comprehended in a quality control plan (QCP) for a specific contract with the intent to monitor and improve construction quality.

The QCP should address the elements of key quality control personnel, their responsibilities and their qualifications as well as procedures to be used in order to control quality during construction.

APPENDIX 1

Ensuring a continuous supply of asphalt to the construction site

Truck logistics, paving and compaction are all interconnected and interdependent processes and should be coordinated to ensure a high-quality asphalt pavement. The highest quality pavements are produced when uniform, continuous operations are present during the construction process.

For instance, no advantage is gained from the paver speeds that extend plant production rates beyond the reasonable capacity to ensure quality. Such situations would result in frequent stops of the paver to wait for arriving trucks at the construction site. If this waiting is too long (e.g. a few minutes on a cool day), the evenness of the paved layer will be negatively affected. It should be borne in mind that the mix will be cooling off during paver stop and so will the paver hopper. A long paver stop will result in temperature differences between cooled off mix and fresh, hotter mix. These temperature differentials may result in density differentials and ultimately, affect the riding quality of the paved layer.

It is therefore critical that plant production and paving operations be closely coordinated to ensure that the paver train is continuously supplied with enough asphalt and, equally important, the trucks should not have to wait to discharge the asphalt into the paver hopper. From a productivity perspective the number of trucks used in the asphalt paving cycle is critical to ensure continuous supply. Achievement of this situation will result in efficient and continuous asphalt paving operations and superior quality of the constructed layer, with a consequent reduction unnecessary construction joints, inconsistent material density and low pavement smoothness.

The amount of asphalt to be delivered in a period is a function of the number of trucks, their capacities and the cycle times of the trucks. More importantly, the delivery productivity is determined solely by the cycle times of the trucks since the truck capacities are more or less fixed. However, when the cycle times change, the rate of material delivery changes and this mostly affects paving and compaction operations in a negative manner with a resultant drop in overall asphalt quality.

To ensure that the paver does not stop during construction for lack of supply, the supplier and contractor an estimate should be made of the number of trucks required in the asphalt paving cycle. The number of trucks needed in the cycle from asphalt plant to construction site can easily be determined using basic *fleet demand calculations*. These calculations give the supplier and contractor an estimate of the minimum number of trucks that should be used for a particular project site, given the target production for the day, the number of working hours, the distance between plant and site and an approximation of waiting and loading times. However, the method does not consider the stochastic effect inherent in construction e.g. the effect of traffic on the travel and cycle times.

Fleet-Demand Principles

The cycle time between asphalt plant and the construction site can be calculated as a function of the distance plant - site, and the average waiting and loading times.

$$Cycle\ time = 2L\frac{60}{S} + [W_p + L_p + W_s + U_s]$$

Where:

L = distance between plant and site

S *= average speed between plant and site*

W_p *= waiting time at the plant*

L_p *= loading time at the plant*

W_s *= waiting time at the site*

U_s *= unloading time at the site*

The number of trucks needed can be calculated as a function of the vehicle capacity and the quantity of material to be transported per hour. Given the target production for the day and the number of working hours in the day, the minimum headway for truck arrivals on the site and the minimum number of trucks required can be calculated.

$$H_m = \frac{60C}{D}$$

Where:

H_m *= Minimum headway between truck arrivals*

C *= average truck capacity*

D *= quantity of asphalt to be transported per hour*

The number of trucks can then be calculated using the formula:

$$Number\ of\ trucks\ needed = \left[\frac{2LD}{SC}\right] + \left[\frac{D(W_p + L_p)(W_s + U_s)}{60C}\right]$$

The above formulae can easily be transferred into a spreadsheet for ease of calculation and interpretation. Also, an estimator/planner can perform sensitivity analyses to check the effect of traffic, the effect of alternative routes on cycle times or make more accurate estimates of the cycle times if trucks with different capacities are used for the supply of asphalt.

Track and trace systems on the market

Several software-based process management solutions are available on the market that enable planners and estimators to better plan and manage construction process including logistics. These range from productivity calculators, pure track and trace systems that enable site managers to track where asphalt trucks are in the logistics cycle and, more process management solutions that attempt to provide better control of the entire process. The latter includes integrated solutions that enable asphalt construction site planning, scenario planning, mix transport and process control during actual construction site activities. Some of the current available software solutions include the following:

https://www.cat.com/en_US/articles/solutions/paving/paving-calculator-app.html

https://volzconsulting.de/en/bpo/bpo-asphalt/

https://www.thunderbuild.com/

https://www.kws.nl/nl/over-ons/werkwijze/asfaltproces/pavelink

https://www.q-point.com/en/

https://www.wirtgen-group.com/ocs/en-nl/voegele/witos-paving-plus-257-p/

APPENDIX 2

A Trouble Shooting Guide for Hot Mix Asphalt Paving

INTRODUCTION

Pavements are assessed for quality by considering their:

- Riding quality - lack of smooth riding, bumps, depressions.
- Surface appearance – bleeding, rough texture, cracks, segregation, poor joints and other imperfections.
- Thickness and level - excessive variation in thickness, and not paved to correct levels.
- Compaction and permeability - low density resulting in deformation, shorter life.
- Mix properties compared to the design mix.

PROBLEMS encountered during paving and under traffic are described in this guide, together with possible causes and suggested solutions.

Not every asphalt problem is covered in this guide, but those covered are the most well-known and experienced by the contributors to this troubleshooting guide. Our suggestion is to use this guide for assistance, and to perhaps get a second opinion from an experienced practitioner.

CAUSES are grouped for simple identification.

Keep in mind that problems can be caused by a combination of two or more factors. Thus it is often difficult to pinpoint the cause to a single factor. For example: Flushing (see BLEEDING, FLUSHING) can happen for a number of reasons. One situation could be when high ambient temperatures are combined with immediate opening of the road to heavy traffic. If one or the other does not happen, there may be no problem.

Look for the root cause of the problem, remembering that other “causes” may just be aggravations.

SOLUTIONS given are mainly preventative, not corrective. For example, once “bleeding” has occurred, usually the only corrective solution is to remove and replace the section. The solutions given are steps to take to prevent it recurring.

The ***Probability (Pr)*** of the problems’ occurrence is indicated: High (H), Medium (M), Low (L)

The ***Impact (Im)*** on final product is also indicated: High (H), Medium (M), Low (L)

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
MAT TEARS BEHIND SCREED WHILE PAVING (ALSO KNOWN AS "DRAGGING")	1. BASE or OLD SURFACE			1. BASE
	a. High spots on surface of base or old surface, resulting in sections of mat paved too thin	L	M	a. Check base levels before paving and trim off high spots to ensure minimum mat thickness is achieved
	2. ASPHALT MIX			2. ASPHALT MIX
	a. Stone size too large for mat thickness	L	M	a. Reduce stone size and revise mix, or pave thicker mat
	b. Asphalt temperature too low	M	H	b. Raise delivery temperature if possible, keep loads covered at all times
	3. PAVER			3. PAVER
	a. Mat paved too thin	H	H	a. Use dip stick to check loose mat thickness; adjust screed level control
	b. Not enough asphalt feed to screed	L	L	b. Increase feed settings for conveyors and augers or use "automatic" control
	c. Paver speed too fast	M	M	c. Guess what?
	d. Worn screed plates	H	M	d. Replace
	e. Cold and or dirty paver screed	M	L	e. Heat screed to asphalt temperature and clean before paving
	f. Incorrect crown settings on cambered surface	M	M	f. Increase lead crown (should be slightly higher than trailing crown)
	g. Screed angle of attack out of adjustment	M	M	g. Set to factory recommendations – don't guess on site
	h. Tampers worn or damaged	M	M	h. Replace before it gets worse
	i. Tamper speed or tamper projection setting out	M	M	i. Important to set correctly to ensure tampers tuck asphalt under screed
	j. Screed vibrator speed incorrectly set	L	L	j. Set to manufacturers recommendations
	k. Pressure setting on screed incorrect	L	L	k. Set to manufacturers recommendations
SURFACE MARKS CAUSED BY PAVER SCREED	1 Play in screed suspension links (causes ripples)	L	H	1. Fix it or scrap it!
	2. Trucks bumping or not square to paver (forces screed back and down, leaving line indentations)	H	M	2. A specific team member should be controlling trucks and tipping. Truck should be stationary, parked square on, with brakes released, as paver approaches it.
	3. Incorrect operation of paver and screed controls	H	M	3. Screed Operator is a highly skilled job – train in good paving practices.
	4. Loss of traction causing paver to skid or slew (indentation one side or other, or waves in surface)	M	M	4. Reduce screed width and or reduce head of asphalt in auger box. Ensure truck brakes are off. Is base soft/loose? Use paver with greater traction capabilities.
	5. Surface tears caused by cold or dirty screed plates	H	M	5. Clean and heat screed to ±150 deg C before starting to pave
	6. Worn screed plates (surface tears)	H	M	6. Replace (whatever it costs!)
	7. Incorrect angle of attack settings on screed or extensions (surface tears)	H	L	7. Reset angle of attack on main and extention screeds to factory settings - don't guess on site.
	8. Sudden adjustments to hydraulic screed width will result in longitudinal ridges in the soft mat	H	L	8. Normally these will be flattened by the breakdown roller with no Adverse consequences
	9. Worn tampers or tampers not protruding enough	M	M	9. Replace and reset

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
SURFACE MARKS CAUSED BY ROLLERS	1. STEEL DRUM ROLLERS			1. STEEL DRUM ROLLERS
	a. Changing direction too abruptly (leaves indentation)	M	M	a. Smooth slow down to stop (no pause), reverse, smooth speed up
	b. Turning on hot mat (causes scuffing)	H	M	b. Avoid turning on the hot mat; where forced to, make wide radius turn
	c. Heavy roller standing or pausing too long on hot mat (can leave indentation)	M	M	c. This is a big NO-NO
	d. Rolling too fast followed by abrupt stops	M	M	d. Establish correct speed; then change direction as in 1.a. above
	e. Too much rolling resulting in shoving deformation or de-compaction (leaves dimpled surface)	H	H	e. Don't overdo steel drum roller passes. Limit them and then continue rolling with pneumatic rollers
	f. Whip in roller drives when changing direction (indentation)	L	M	f. This roller really needs fixing!
	g. Roller drum edge marks (common on tender mixes)	H	L	g. Iron out with steel drum roller at back of train while mat is still hot enough
	h. Vibrator on when roller is stationary (indentations)			h. Don't even think about it!
	i. Pick-up on steel drums (scars on mat)	L	M	i. Check sprinkler system. Use release agent in water. Drum surface may be too rough (e.g. from rolling granular base)
	j. Edge marks from weight shift when rolling super-elevations	H H	L L	j. Roll from low side up the slope, iron out marks with a lighter roller
	2. PNEUMATIC ROLLERS			2. PNEUMATIC ROLLERS
	a. Pick-up of fines on pneumatic tyres (leaves scars on surface)	H	L	a. Allow pneumatic tyres to heat up to mat temperature. Keep pneumatic roller off very hot mat. Use release agent on tyres.
	b. Tyres pick up bitumen and deposit it as blobs (cow pats!)	H	L	b. Reduce number of passes if possible, roll at slower speed (4 to 5 kph), use release agent on tyres.
	c. Incorrect or uneven tyre pressures can also cause marks as well as pick-up	L	L	c. Please do the obvious
	d. Tyre marks (slight grooves) especially when using rollers with 200mm wide tyres	M	L	d. Iron out with steel drum roller behind pneumatic, while mat is still hot enough
	e. Rollers parked on tacked area between rolling sessions will pick-up when they start re-rolling	M	L	e. Park on clean areas, clean tyres and warm tyres up before going on to the fresh mat

SURFACE IMPERFECTIONS CAUSED BY LAYER BELOW ASPHALT	1. Poor base surface finish and levels. About 50% of base imperfections will reflect through to the asphalt surface.	H	H	1. Do levelling layers to bring base to correct levels before paving final mat.
	2. Potholes, depressions not repaired correctly (will reflect through to surface)	H	M	2. Do repairs and correction layers to level before final mat
	3. Pitted surface from over-sweeping or traffic will reflect through as a dimpled surface on the asphalt.	H	H	3. Apply asphalt scratch coat before final mat

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
ROUGH, COARSE SURFACE TEXTURE. (IN SOME AREAS OF THE MAT COMPARED TO OTHERS)	1. ASPHALT			1. ASPHALT
	a. Asphalt not hot enough when paved. This is critical for thin layers (<50mm)	H	H	a. Are weather conditions causing rapid cooling? Raise delivery temperature if possible, cover loads during hauling and waiting, and don't delay paving. See SABITA Manual 22 for minimum delivery and paving temperatures.
	b. Asphalt overheated (burnt and brittle)	L	H	b. Usually visible while paving - remove and replace
	c. Segregation of the asphalt	L	M	c. Many causes for this. Check mix grading, paver auger height setting and raking techniques for a start. See Section on SEGREGATION
	d. Poor temperature control of mix causing some areas to be too cool to get a consistent quality finish	M	M	d. Particularly important to maintain consistent high delivery temperatures for thin layers (<50mm). See 1.a. above. Consider turning away trucks that are not hot enough
	e. Steel drum roller bridges over a strip of hot mat, usually onto adjacent cold mat	H	M	e. Thickness of hot mat against adjacent mat must allow for compaction. Always use pneumatic roller to ensure compaction of possible bridging
	2. HANDWORK			2. HANDWORK
	a. Poor workmanship	H	H	a. <u>Skills plus speed</u> are essential for good results with handwork
	b. Asphalt too coarse or max size stone too large for handwork	M	H	b. Dense graded mix with small max size stone is needed for good finish to handwork areas
	c. Asphalt not hot enough for handwork, especially for thin layers. Cools before compaction is complete.	H	H	c. Asphalt for handwork must be delivered at consistently high temperatures and kept hot with tarpaulin while working. Speed of spreading and compacting is essential in order to get density and finish. A common bad practice is to use the last bit in a truck for handwork. Use a full fresh truck.
	d. Mat cooling too rapidly for handwork	H	H	d. Are weather conditions too cold or windy for handwork?

	e. Too much raking f. Back-chipping	M H	M H	e. Use good handwork techniques. Load with shovels, dump in small stockpiles right at handwork areas, spread with rakes over as short a distance as possible. f. Paver should pave a perfect mat, with no back-chipping necessary. If not, something on the paver needs adjustment or repair

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
SEGREGATION IN AREAS OF THE MAT	1. ASPHALT PLANT			1. ASPHALT PLANT
	a. Stockpiling procedures	L	M	a. There are established methods for this – stick to them
	b. Aggregate grading operation	L	M	b. Repeat 1.a. above
	c. Condition of storage bins	L	H	c. Upgrade if necessary
	2. PAVER			2. PAVER
	a. Augers set too high – patches of segregation	L	M	a. Bottom of augers should be about 50mm above top of loose mat
	b. Worn auger flights	L	M	b. Replace them
	c. Lack of extension augers to match width of screed- can cause segregation at sides of mat	M	M	c. Always use extension augers and auger box plates to avoid overloading of screed as well as segregation
	d. Centre drive/pillar supporting augers – can cause segregation as a strip behind this pillar	H	M	d. Check if half augers each side of pillar can be reverse mounted to move asphalt around and behind the pillar.
	3. ASPHALT MIX			3. ASPHALT MIX
	a. The larger the max size stone, the greater the potential to segregate	H	M	a. Include smaller stone sizes to get continuous smooth grading curve
	b. Mat too thin for max size stone used	H	H	b. Usual rule is mat thickness approximately = 3 x maximum size stone
	c. Too high content of large aggregate	L	H	c. Include smaller stone sizes to get continuous smooth grading curve
	d. Mix too gap-graded or coarse	L	H	d. Repeat 3.c. above
	4. HANDWORK			4. HANDWORK
	a. Too much raking – fines left behind, larger stones end up at perimeter of raked area	H	H	a. Load with shovels, dump in small stockpiles right at handwork areas, spread with rakes over as short a distance as possible.
	b. Broadcasting by shovels (back-chipping) – same result as 4.a.	H	H	b. Don't back-chip! The big stones all spread further than the fine material.
	c. Pulling asphalt heaps by rake too far – same result as 4.a.	H	H	c. See 4.a. above.

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
MAT SHOVES UNDER ROLLER DRUMS (OFTEN RESULTING IN CLOSE, TRANSVERSE HAIR CRACKS I.E. "CHECKING")	1. SITE, BASE CONDITIONS Lack of adhesion with the base causes the mat to move laterally under the rollers. The reasons can be:			1. SITE, BASE CONDITIONS
	a. Granular base not primed and tacked, or asphalt base not tacked before paving	H	H	a. Always prime and tack a granular base, and always tack an asphalt base before paving. Only tack area that will be paved within 24 hrs.
	b. Granular base is primed only	H	M	b. Prime should not be regarded as a replacement for tack.
	c. Inadequate prime coat (has prime done its job?)	H	M	c. Check application, penetration and surface for consistency and cover
	d. Prime too fresh or too thick (causing slippage plane)	L	H	d. Wait till dry, or blind wet prime patches with dust and sweep off
	e. Too little tack (not enough "glue" action)	H	H	e. Adhesion with base is <u>very</u> important; apply tack correctly.
	f. Too much tack, or tack not broken (slippage plane)	L	H	f. Wait till dry, or blind wet tack patches with dust and sweep off
	g. Tack driven off by traffic in front of paving	H	M	g. Allow tack to "break" before allowing traffic on it. Don't let trucks or other plant park on a tacked area; to prevent pick-up
	h. Prime or tack containing strong solvents (penetrates and softens bitumen in asphalt)	L	H	h. Not easy to identify this. Try a different product to check if it solves the problem.
	i. Dusty or dirty base (causing a separation layer)	H	H	i. Sweep, clean and tack before paving.
	j. Biscuit layer in base (causing a separation plane, usually resulting in severe shoving and wide cracks)	M	H	j. Check for unswept base or base added to make up levels. Clue is when cores pick up the biscuit layer only. Remove biscuit layer.
	k. Very smooth granular base surface (not rough enough to create a good key)	H	H	k. Some suggestions for creating a good key are: roughen surface, tack coat, scratch coat, back-chip before paving (see 1.j. below)
	l. Very dense base (prime does not penetrate causing slippage plane)	L	M	l. Spray prime (and tack) light enough not to cause a slippage plane
	m. Old surface highly polished (e.g. old chip-seal or rolled-in-chip surface)	H	H	m. After tack coat, apply scratch coat or back-chip surface with asphalt and roll with pneumatic before paving to create a god key
	n. Rolling on steep grade or cross-fall (gravity will have its way!)	H	H	n. back-chip base & roll with PTR before paving to create a good key, use a harsher mix, pave uphill, limit steel drum roller passes, increase PTR passes, vibrate uphill only – static mode downhill
	o. Sudden change in base surface material e.g. granular base to concrete bridge deck	H	M	o. Again check correct use of tack and possibly use scratch coat
	2. ASPHALT MIX			2. ASPHALT MIX
	a. Bitumen too soft, causing mix to be tender	L	H	a. Check binder viscosity at 135°C. If close to 0.22, try a stiffer bitumen
	b. High binder, low filler contents causing tenderness	L	H	b. Stiffen mix: decrease binder, increase filler (but keep VIM correct. Ensure that the mix still conforms to the design requirements for the job
	c. Grading causing tender mix	L	M	c. Grading curve especially below 4.75 may need to be steeper
	d. Rounded or smooth aggregates causing tenderness	M	M	d. Change aggregates to rough, angular if possible.
	e. Tender mix combined with high air temperatures	H	H	

				e. Delay breakdown rolling (risky!), limit steel drum passes, increase pneumatics passes
	f. Excess moisture in asphalt from plant	L	H	f. Inform plant immediately, so they can take corrective action
	g. Mix too hot to support breakdown roller	L	H	g. Drop mixing temperature slightly, but remember this reduces compaction widow time
	h. Thick hot mat retains high temp and shoves easily)	H	M	h. Delay rolling. Specify a lower delivery temperature e.g. 1300C, but ensure proper coating of the aggregate.
	i. Contamination with solvents that soften the bitumen	L	H	i. Diesel may be the culprit; can often be detected by smell
	3. ROLLER For a mix that has a tendency to shove for whatever reason, the choice, sequence and control of rollers is critical.			3. ROLLER There is lesser tendency to shove under a vibrating roller than under a heavy steel static roller (e.g. 3 wheeler). But a PTR is by far the best to limit shoving. In these situations, skilled attention is needed on the compaction process.
	a. Excessive steel drum rolling	H	H	a. Limit steel drum passes, increase pneumatic passes
	b. Tender mix being over-rolled	H	H	b. As in 3.a. above.
	c. Roller too heavy on a tender mix	M	H	c. Put on a diet – see opening comment above under ROLLER
	d. Static roller steering drum ballasted (causes wave)	M	L	d. Steering drum to be light as possible to prevent “bow-wave”
	e. Small diameter steel drums (impart too much horizontal forces on mat)	M	L	e. Replace with roller with larger diameter drums(to impart mainly vertical forces)
	f. Changing direction too abruptly (localised shoving)	M	L	f. Smooth slow down to stop (no pause), reverse, smooth speed up
	g. Turning on hot mat (localised shoving)	M	L	g. Avoid turning on hot mat, or make wide radius turns

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
UNSATISFACTORY COMPACTION OF FINISHED MAT	1. BASE COURSE			1. BASE COURSE
	a. Base not sufficiently compacted overall	H	H	a. Base must be an "anvil" to obtain good asphalt compaction
	b. Specific areas not compacted e.g. trenches, patches	H	H	b. Test suspect or potential areas for density before paving
	c. Areas of base too high making mat too thin	H	H	c. Take dips on base before paving; take off excessively high spots
	d. Yielding/pumping base (often caused by moisture)	H	H	d. Don't pave before OMC < 50%. Check base for movement with PTR or full water truck before paving. Also check drainage of under layers. All this of course needs to be done before priming is done.
	e. Lack of adhesion with base, allowing mat to move laterally during compaction (“shoving”). This often compromises density.	H	H	e. See section on MAT SHOVES UNDER ROLLER DRUMS for solutions
	2. ASPHALT MIX			2. ASPHALT MIX
	a. Unsuitable bitumen viscosity	L	H	a. If a hard binder e.g. 40/50 pen, is used, increase mat thickness and temperature to ensure adequate compaction window.
	b. Variations in viscosity at construction temperatures between different batches or suppliers of bitumen	L	H	b. There can be large differences in viscosity at 1350C without the product being out of spec. This can make the difference between harsh and tender.
	c. Asphalt not hot enough (particularly applies to thin mats	H	H	c. Increase delivery temperature if possible, cover loads during hauling and waiting. See SABITA Manual 22 for recommended minimum temps.
	d. Mix not compactable enough (too harsh) at specified thickness and expected weather conditions (particularly applies to thin mats)	H	H	d. Increase mat thickness to suit conditions Check grading against specification, particularly from 2 mm sieve down, and most particularly the filler content – high fines can cause harshness. Mix may be too coarse or tending to be gap graded Check binder content – is there enough binder (lubrication) in the mix for workability? Check for high filler/binder ratios – indicate harshness. Is VIM high? This limits the achievable density. VIM should suit traffic loading – low traffic, reduce Vim’s and vice versa. Consider addition of natural sand to make mix less harsh BUT ensure that the mix still conforms to design requirements for the job.
	e. Out of spec asphalt	H	H	e. Check all of 2.d. above
	f. Mat designed too thin for maximum stone size	M	H	f. Mat thickness should ≈3 x max stone size; or pave thicker mat
	g. Mat placed too thin	M	H	

	h. Segregated areas on finished mat	L	M	g. Check for high spots on base, allow for correct "fluff factor" (loose to tight), and strictly control paving thickness h. See section on SEGREGATION
PROBLEM	**POSSIBLE CAUSES**	**Pr**	**Im**	**SUGGESTED SOLUTIONS**
UNSATISFACTORY COMPACTION OF FINISHED MAT / CONTINUED	3. WEATHER CONDITIONS			3. WEATHER CONDITIONS (use SABITA Manual No. 22 as a guide)
	a. Temperatures and weather conditions unsuitable	H	H	a. Check minimum recommended base & air temps and wind chill effect applicable to the mat thickness. Delay paving until suitable weather conditions prevail
	b. Rapid cooling of mat	H	H	b. Increase mat thickness if possible Increase delivery temperature if possible; Cover loads properly during hauling and waiting Reduce paver speed; Increase number of rollers and roll "aggressively" i.e. right behind paver; Reduce water sprayed onto drums Know your compaction window time and complete rolling within it
	4. ROLLERS			4. ROLLERS
	a. The breakdown roller is critical as it raises the density of the mat from loose to close to maximum	L	H	a. Choice and operation of this roller is vital. Steel drum rollers are normally used but pneumatics can also work (but beware poor rideability & pick-up)
	b. Steel drum roller too light	L	H	b. The higher the linear loading on the drum, the quicker density is achieved
	c. Vibrating roller has unsuitable amplitude or frequency	M	H	c. Check and adjust (e.g. typical frequency = 50 Hz, amplitude to suit mat thickness)
	d. Too few rollers	H	H	d. Use enough rollers to achieve density within compaction window time
	e. Rolling too fast (particularly applies to vibrating and pneumatic rollers)	M	H	e. Vibrating and pneumatic rollers optimum speed is usually about 5 km/hr. Vibrating roller speed depends on frequency and drum diameter.
	f. Not enough passes	M	H	f. Number of passes should be established and maintained
	g. Poor rolling pattern	M	H	g. Establish suitable pattern and maintain it
	h. Pneumatic roller wheel loading too light – check if sufficiently ballasted	M	H	h. Ground contact pressure of tyres should be about 5.5 to 6 kg/cm2 to assist with compaction
	i. Pneumatic tyre pressures too low causing too low ground contact pressure	M	M	i. Check manufacturers chart of wheel loading & tyre pressure versus ground contact pressure and do what you have to do to comply with 4.h. above.

	j. Delayed rolling (allowing mat to cool before rolling)	H	H	j. Work rollers as close to paver as possible and complete rolling within the compaction window time

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
EXCESSIVE PERMEABILITY OF MAT IN GENERAL	1. ASPHALT MIX			1. ASPHALT MIX
	a. Mix too coarse – grading not continuous enough	M	H	a. Use appropriate continuous grading curve and max size stone
	b. VIM's too high, causing high in-place voids	M	H	b. Revise mix design.
	c. Insufficient filler and or bitumen	M	M	c. Design mix to achieve suitable filler/binder ratio and VIM's
	d. Maximum size stone too large for layer thickness e.g. 40mm mat using 26mm stone mix	H	H	d. Rule of thumb is that layer thickness should be about 3 x max stone size. <u>The lower this figure, the more prone the layer is to being permeable</u>
	e. Mixing temperature not high enough to ensure bitumen is at the right viscosity for compaction	M	H	e. Permeability equates to inadequate compaction. Ensure mixing and delivery temperatures are high enough. (See SABITA Manual 22)
	f. Binder too stiff for application, resulting in under compaction e.g. when modifiers are added	M	H	f. Use appropriate binder to ensure design requirements for the job are met. The stiffer the binder the thicker the mat should be to allow enough time to ensure compaction before mat cools.
	g. Compaction specification too low	L	M	g. Consider 93% Rice for large aggregate mixes (BTB, LAMBS)
	2. CONSTRUCTION			2. CONSTRUCTION
	a. Inadequate compaction causing high insitu voids	H	H	a. See section on UNSATISFACTORY COMPACTION
	b. Segregation in mat	L	M	b. Sort out what's causing it. See SEGREGATION
	c Shear cracks formed from shoving or over-rolling	H	M	c. Seal the surface over the area
EXCESSIVE PERMEABILITY AT LONGITUDINAL JOINTS	1. CONSTRUCTION			1. CONSTRUCTION
	a. Poor joint construction techniques	H	H	a. Longitudinal joints are weakest link in mat; use good construction practices
	b. Joint not rolled adequately or soon enough	M	M	b. First pass of breakdown roller should be on the longitudinal joint
	c. Edge of first mat not cut back enough	H	H	c. Cut back enough to remove under-compacted edge of mat
	d. Cut edge of first mat not tacked adequately	H	H	d. Brush on a good application of <u>neat</u> tack against cut edge
	e. Segregation at edge of mat	M	H	e. Cut back enough to get rid of this

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
LOW DENSITY NEAR LONGITUDINAL JOINTS	1. BASE CONDITIONS			1. BASE CONDITIONS
	a. Poor mechanical key, or inadequate tack, allowing asphalt to shove sideways under rollers at mat edge.	H	H	a. Compaction will be compromised if mat moves sideways. See section on **Mat shoves under rollers** for ways to prevent this.
	b. Steep slope or cross fall causing same as above	H	H	b. As for 1.a. above
	c. No edge confinement – mat shoves sideways near the unconfined edge	H	H	c. Before paving the adjacent mat, cut back edge of mat enough to remove under-compacted strip
	2. ASPHALT			2. ASPHALT
	a. Tender mix unable to support rollers at edge of mat	H	H	a. As for 1.a, b & c. above
	b. Segregation at edge of mat	M	M	b. Cut back to remove segregation
	c. Mix too harsh to achieve density	M	H	c. See section **Unsatisfactory compaction**.
	3. CONSTRUCTION			3. CONSTRUCTION
	a. Edge of first paved mat not cut back enough	H	H	a. Suitable width of cut-back varies depending on 1) mat thickness 2) how much sideways movement occurred under rollers.
	b. Poor joint construction techniques	H	H	b. Pave straight to correct level, cut back edge where necessary and tack, overlap adjacent mat, bump up overlap and roll immediately
	c. Not rolling soon enough	L	M	c. First pass of breakdown roller must be on longitudinal joint

LEVEL DIFFERENCES AT LONGITUDINAL JOINTS	1. CONSTRUCTION a Mat not paved to correct thickness to allow for compaction b Fluctuating head of asphalt in front of screed causing waves in mat c Over-controlling of screed level adjustment causing waves in mat d Poor line and level matching and overlap by paver e Poor raking techniques when matching joint levels f Poor joint rolling techniques g Unconfined edge of first mat shoved sideways under roller, squeezing it thinner than required at the joint h Insufficient or too much overlap of second mat onto first	 M H H H M M M M	 M L M M L L M L	1. CONSTRUCTION a Second mat must be paved to match first mat allowing for compaction. Usually allow 18 to 20% for loose to compacted mat for wearing courses b Use good level control practices. See section UNSATISFACTORY RIDING QUALITY, Item 3 & 4 c As for 1.b. above d Important to pave a straight edge, to the correct level with a consistent overlap of the second mat onto the first (usually 30 – 40mm) e Only handwork that should be necessary is to bump the overlap back onto the fresh mat before rolling. Any other repair work needs skilled raking . f Joint should be rolled first with steel drum breakdown roller g If this can't be corrected with level control equipment, the thin edge may need to be cut back. h This causes the "bumped" back edge to vary in height and thickness. Roller may not be able to achieve matched levels. See 1.d. above for solution.

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
TRANSVERSE JOINTS: LEVEL DIFFERENCES AT RESULTING IN A BUMP	1. BASE CONDITION a. Joint not cut back to level (flat) area on old mat b. Base uneven at joint position (often caused by cutting and preparation for joint) 2. CONSTRUCTION a. Paver tow points not set correctly at start of paving b. Mat not paved to correct loose thickness to allow for compaction c. No or incorrect starter blocks used d. Poor raking and levelling techniques when matching levels across the joint	 H H H H H H	 H M M M H H	1. BASE CONDITION a. Check for best position for joint using a straightedge in all directions b. After cutting and removing the asphalt, level the area with a levelling course and roll it before paving 2. CONSTRUCTION a. Operators must know positions on tow point scale for different thicknesses b. Usually allow 18 to 20% for loose to compacted mat for wearing courses, 25 to 30% for asphalt bases, 10% for popcorn. c. Use 2 starter blocks under the screed – size to suit the mat as in 2.b. above. d. Minimal raking should be required if paver is doing its job properly.

	e. Poor joint rolling technique	H	H	Handwork and levelling at the joint requires skill and training. e. First roll joint transversely; 150mm onto fresh mat at a time, until drum is fully on fresh mat, then roll longitudinally with breakdown roller
TRANSVERSE JOINTS: ROUGH, UNEVEN FINISH	1. ASPHALT a. Mix not suited to handwork b. Segregation near joint 2. CONSTRUCTION a. Poor joint rolling technique b. Poor raking technique or excessive raking c. Back-chipping	 L L M H H	 H M H H H	1. ASPHALT a. Handwork is difficult with gap-graded and large aggregate mixes b. Segregation usually happens with gap-graded or large aggregate mixes. 2. CONSTRUCTION a. See 2.e. above for suggested rolling technique b. If handwork is necessary, keep to a minimum and use a straightedge for leveling the loose asphalt c. Back-chipping should only be used if levels need correcting. Use straightedge to level corrected area before rolling.

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
UNSATISFACTORY RIDING QUALITY DUE TO A WAVY OR BUMPY SURFACE	1. BASE			1. BASE
	a. Poorly graded surface of base or old surface (paver only reduces undulations by approximately 50%)	H	H	a. Place and roll correction layers before paving final mat. Use line-on-pedestals level control if exact finished levels are required. (Ensure the pedestals are spaced to eliminate sagging of the line.)
	b. Lack of correction courses	H	H	b. Identify where needed and do correction courses prior to paving final mat
	c. Yielding base. Use pneumatic roller to check suspect base before paving.	H	H	c. Look for heaving under rollers. Usually caused by moisture or under-compaction. Check drainage of under-layers.
	2. ASPHALT MIX			2. ASPHALT MIX
	a. Significant changes in temperature between loads (will cause the level of the screed to fluctuate)	L	M	a. Reject loads too hot or too cool. Use level control system on "automatic" for best results.
	b. Very thick mat e.g. 100mm (bow-waves and undulations form under rollers)	H	H	b. Pave mat in two layers, or delay rolling until mat is less prone to "bow-wave" in front of roller. Reduce mixing temperature (by say 200C.)
	3. PAVER			3. PAVER
	a. Insufficient traction causing paver to skid or slew (this causes screed to rise and fall)	M	M	a. Reduce screed width, reduce head of asphalt in auger box if possible, use paver with greater traction capabilities
	b. Truck brakes not released when in contact with paver causing loss of traction	M	M	b. Brakes must be released before paver picks up truc
	c. Paver stands too long a time between loads; asphalt cools just behind screed where rollers cannot reach	H	M	c. Form a transverse joint when paver must wait, but do it well so as not to form a "bump" at the joint
	d. Warped screed plates causing waviness in the mat	L	M	d. Replace screed plates
	e. Play in screed suspension points (causes ripples)	L	H	e. If the screed is this bad, scrap it
	f. Angle of attack differs from main screed to extension screeds	M	M	f. Set to manufactures instructions
	g. Auger box overloaded (screed bull-dozes asphalt ahead of it, causing screed to rise)	H	H	g. Adjust settings for conveyors and augers to achieve constant feed. Aim for head of asphalt in auger box to be 2/3rd way up augers
	h. Variable head of asphalt in front of screed (causes screed to rise and fall due to its floating action)	H	H	h. This is a most important factor for achieving good rideability. Use "automatic" feed control for conveyors and augers to keep head constant (see 3.f. above)
	i. Too much variation in paver speed or stop/start paving (causes screed to rise and fall with changes of speed and stop/start paving)	H	H	i. Keep speed as constant as possible, and use grade control equipment on "automatic" to achieve level requirements. Avoid stop/start paving.
	j. Excessive manual adjustment of screed level controls	H	H	j. Use grade control equipment on "automatic" mode for best results.

	k. Asphalt spillage in front of paver. Wheels climb over heaps causing screed to rise and fall l. Paver tyres under-inflated causing paver and thus screed to sway, which in turn affects mat levels	H L	M L	k. Spillage happens. When it does clear it away before paver wheels come into contact with it l. Inflate tyres to manufactures recommendations.
	4. LEVEL/GRADE CONTROL SYSTEM a. Level control system not set up or operating correctly, or non-existent b. Level control system faulty or too sensitive	 H M	 H H	4. LEVEL/GRADE CONTROL SYSTEM a. Use line-on-pedestals to achieve exact finished levels, beam for control of mat thickness, and foot to match adjacent mat or channel levels. b. Test on site for reaction to vertical movement; adjust sensitivity if required
	5. ROLLERS a. Rolling a very thick mat when it is too hot can cause waves and undulations b. PTR used as breakdown roller can make deep tyre indentations in the soft mat that the following roller might not be able to completely flatten c. Inconsistent rolling patterns	 H H M	 H M L	5. ROLLERS a. Delay rolling until mat is less prone to forming a "bow wave" at drums, or reduce mixing temperature (e.g. by say 200C) b. Use a heavy steel drum roller immediately behind the PTR, or change to a steel drum breakdown roller c. Establish suitable rolling pattern and stick to it
THICKNESS VARIATIONS IN PAVED MAT	1. BASE a. Poorly graded surface of base (making thickness variations inevitable) b. Lack of correction courses	 H H	 H H	1. BASE a. Use beam or line-on-pedestals for level control, depending on whether thickness or finished level of the mat is the priority b. Identify where needed and do correction courses prior to paving final mat
	2. PAVER a. Poor control of head of asphalt in front of screed, causing screed to rise and fall slightly b. Manual over-adjustment of screed level controls c. Excessive variation in paver speed causes screed to rise and fall which affects thickness	 H H L	 M M M	2. PAVER a. Adjust settings for conveyors and augers to achieve a constant feed. Use "automatic" control for best results. b. Manual tow point adjustment requires a skilled operator. Use grade control equipment on "automatic" to match thickness requirements c. Keep paver speed as constant as possible

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
CRACKS IN THE MAT DURING PAVING	1. DUE TO MAT SHOVING UNDER ROLLER DRUMS See MAT SHOVES UNDER ROLLER DRUMS			1. DUE TO MAT SHOVING UNDER ROLLER DRUMS See MAT SHOVES UNDER ROLLER DRUMS
	2. DUE TO TEARING WHILE PAVING See MAT TEARS BEHIND PAVER			2. DUE TO TEASRING WHILE PAVING See MAT TEARS BEHIND PAVER
	3. FINE CRACKS DURING ROLLING			3. FINE CRACKS DURING ROLLING
	a. Yielding base due to under compaction or high moisture content (check for movement under pneumatic roller)	H	H	a. Base must be an "anvil" and moisture content must be < 50% OMC to get good density in asphalt
	b. Tender mix (often shoves under steel roller drums)	H	H	b. Stiffen mix: decrease binder and increase filler to keep VIM's correct
	c. Too much steel drum rolling especially on a tender mix	H	H	c. Use one steel drum roller and limit the passes. Follow with two pneumatics
	d. Mix too hot	L	M	d. Check mixing temperature. Thick mats can be mixed at lower temps than thin
	e. Paving on steep slope or cross fall	H	H	e. See paving techniques for hills in MAT SHOVES UNDER ROLLER
CRACKS OCCURING IN SERVICE	1. CROCODILE CRACKS			1. CROCODILE CRACKS
	a Underlying layer failure	M	H	a Check density and quality of under layer
	b Excess moisture in underlying layer	M	H	b. Check moisture content and under layer drainage
	c Insufficient support of pavement layers	M	H	c. Check structural design of layers
	2. LONGITUDINAL OR TRANSVERSE CRACKS			2. LONGITUDINAL OR TRANSVERSE CRACKS
	a Reflected through from active cracks in layers below	H	M	a. Active cracks in under layer must reflect through eventually. The thinner the mat the sooner they will appear
	b Shrinkage cracks from over-stabilised layers below (block cracking)	H	M	b. Maybe necessary to reduce cement content for future work. NOTE: Seal open cracks and the pavement may still function for many years.
	c Shrinkage cracks from recycled layer below (often show up as longitudinal cracks)	H	L	c. Reduce moisture content at mixing to prevent drying shrinkage in base
	d Traffic induced separation of surface from layer below (often at intersection in areas where traffic brakes)	L	H	d. All you can do is repair using good tack coat and rut resistant (modified) mix
	3. LONGITUDINAL JOINTS OPENING UP			3. LONGITUDINAL JOINTS OPENING UP See section on LONGITUNIAL JOINTS
	a. Poor joint construction	H	L	
	4. RANDOM CRACKS			4. RANDOM CRACKS
	a Roots	H	M	a Repair
	b Settlement cracks	H	M	b Repair underlying layers and surfacing

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
BLISTERS OR UPHEAVALS	1. DURING CONSTRUCTION a. Moisture vapour pressure from trapped moisture b. Reaction with crack sealing materials below	 L M	 H H	1. DURING CONSTRUCTION a. Puncture blister and continue rolling, but do not treat this lightly. If moisture is trapped it can lead to stripping (see separate section). b. Puncture along crack position; use light roller over crack. NOTE: Crack sealing should be well aged before being paved over
	2. AFTER CONSTRUCTION a. Roots b. Trapped volatiles from cutback asphalt c. Movement due to fresh bandage crack-sealing on layer below	 H L H	 M H H	2. AFTER CONSTRUCTION a. Remove roots and patch b. Remove cutback asphalt and patch c. Allow bandage crack-sealing to age before overlaying
BLEEDING (free bitumen on surface), FLUSHING (mastic fills all surface voids – surface looks shiny)	1. BITUMEN a. Too soft for traffic loading at ambient temperatures b. Contaminated, causing softening c. Compositional balance of bitumen	 L L L	 H H H	1. BITUMEN a. Check viscosity at 600C. Is it close to lower spec limit? Use a suitable grade for the expected temperatures and traffic b. Check properties of samples from mixing plant c. Check for compliance with specs, but note that spec tolerances are wide. Can be big differences in viscosity in bitumen of the same pen.
	2. ASPHALT DESIGN a. Bitumen content and or filler content too high, causing VIM's to be too low b. Grading close to max density line causing surface to close up, with potential for flushing or bleeding c. Filler acting as bitumen extender (causing excess mastic) d. Lower bitumen absorption by aggregates than designed for	 H L M L	 H M M M	2. ASPHALT DESIGN a. Revise mix design to ensure adequate VIM's after compaction and at end of design life b. Revise grading towards coarser curve, but ensure enough fines to achieve the correct VIM's c. Check filler properties; does it contain high % super fines (10 micron)? Possibly reduce filler content and revise mix design d. Check aggregate absorption and revise design to accommodate it
	3. ASPHALT MIXING & TRANSPORT a. Poor control of mix proportions causing some areas to be too bitumen rich b. Contamination in plant e.g. unburnt fuel etc.	 M L	 H H	3. ASPHALT MIXING & TRANSPORT a. Accurate control of binder and filler is vital during mixing

	c. Excess release agent in hot bins causing contamination d. Excess release agent (diesel?) on trucks e. Small localised bleeding areas caused by mastic "droppings" from trucks	L L L	M M L	b. Review plant records for temperatures, air feed, burners, nozzles and fuel quality c. Consider use of non-oil-based release agent d. Consider use of non-oil-based release agent e. These "droppings" are usually visible and must be removed.
	4. PRIME & TACK a. Volatiles or diluents in prime or tack penetrating the asphalt mat causing contamination and softening b. Excessive application, (usually seen as small pools), so that it works through the mat as bleeding c. Prime/tack not dry before paving	 L L L	 M L L	4. PRIME & TACK a. Allow time for full evaporation prior to paving. This might prove too long, so consider changing to a faster curing emulsion b. Use correct application rate. Soak up excess with cement or crusher dust and remove. c. Is application rate too heavy? If not, wait until dry.
	5. CONSTRUCTION a. Excessive release agent (diesel?) in paver hopper b. Over-compaction (e.g. when mix Vim's are too low, or when very thick layer is too easily compacted) c. Fuel and oil spills onto asphalt during paving d. Very high ambient temperatures causing heat retention in mat, resulting in over-compaction	 L L L H	 L H M H	5. CONSTRUCTION a. Don't do it! Consider use of non oil-based release agent b. Rather revise the mix design than reduce compaction effort. For very thick layers, reduce the mixing temperature so as to reduce rolling temperature. c. Plant and trucks to be leak free. Take out areas and replace. d. Reduce mixing temperature. Consider using a stiffer bitumen
	6. GENERAL a. Heavy traffic on too soon after paving, especially combined with high ambient temperatures b. Fuel and oil spills from traffic <u>NOTE</u>: Bleeding/flushing can be caused by a combination of two or more of many of the above factors e.g. high ambient temps + traffic on too soon. Remove one, no problem.	 H H	 H M	6. GENERAL a. Preferably leave overnight before allowing traffic on fresh mat. b. Maybe it will improve over time with the traffic riding off the bleeding.

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
RUTTING Deformation in wheel tracks under traffic (often accompanied by BLEEDING)	1. BITUMEN			1. BITUMEN
	a. Too soft for the application	M	H	a. Use correct grade or modify for the ambient temperatures and traffic.
	b. Contaminated, causing softening	L	H	b. Check properties of samples from mixing plant
	c. Compositional balance of bitumen	L	H	c. Check for compliance with specs, but note that spec tolerances are wide. Can be big differences in properties of bitumen of the same pen.
	2. ASPHALT DESIGN			2. ASPHALT DESIGN NOTE: Any mix revisions suggested below must ensure design requirements for the job are still met.
	a. Too high bitumen content	H	H	a. Revise design for a stiffer mix
	b. Very rounded aggregates	L	M	b. Change aggregate source (although generally no control over this)
	c. Grading close to max density line	M	M	c. Revise grading curve to achieve a harsher mix
	d. High filler content acting as bitumen extender (causing excess mastic)	M	H	d. Check filler properties; redesign mix with reduced filler and suitable Vim's (see 2.e. below for the opposite effect of another type of filler)
	e. Filler/binder ratio too low causing tender mix	M	H	e. Increase filler content but beware of making the mix uncompactable (NOTE: This filler is doing the opposite of the filler in 2.d. above)
	3. ASPHALT MIXING & TRANSPORT			3. ASPHALT MIXING & TRANSPORT
	a. Contamination in plant e.g. unburnt fuel etc.	L	H	a. Check temperatures, air feed, burners, nozzles and fuel quality
	b. Excess release agent in hot bins	L	M	b. Consider use of non-oil-based release agent
	c. Excess release agent (diesel?) on trucks	L	M	c. Consider use of non-oil-based release agent
	4. CONSTRUCTION			4. CONSTRUCTION
	a. Excessive release agent (diesel?) in paver hopper	L	L	a. Consider use of non oil-based release agent
	b. Over-compaction (only if mix Vim's are too low)	L	H	b. Rather revise the mix design than reduce compaction effort
	c. Very high ambient temperatures	H	H	c. Consider using a stiffer or modified bitumen
	5. GENERAL			5. GENERAL
	a. Heavy traffic or accelerating/decelerating traffic (at intersections)	H	H	a. Redesign a rut resistant mix (maybe with stiffer or modified bitumen) but make sure it is still compactable
	b. Fuel & oil spills from traffic	H	M	b. Repair. Note that EVA modified asphalt is resistant to these spills.

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
RAVELING OF SURFACE (loss of stone on surface after traffic)	1. BASE			1. BASE
	a. Wet or under compacted base causing first crocodile cracking, followed by raveling.	H	H	a. Don't pave on under-compacted base or before OMC < 50%. Also check drainage of under layers.
	b. Sub-standard base causing crocodile cracking followed by raveling.	H	H	b. Base must be capable of supporting the design traffic and be a high quality "anvil" to obtain good asphalt compaction. <u>The asphalt can never compensate for poor base</u>.
	2. ASPHALT			2. ASPHALT
	a. Incorrect mix design for application	L	H	a. Check on mix properties for the situation and redesign if necessary
	b. Binder content too low or poor binder control	L	H	b. Check on target binder and variation allowed and compare with job results.
	c. Dirty or soft aggregate	H	M	c. Check for contamination in aggregates and ACV
	d. Mix not hot enough on delivery, resulting in under compaction	L	H	d. Check delivery temp and temp immediately behind paver. High enough? See SABITA Manual 22 for recommended temperatures.
	e. Bitumen overheated causing asphalt to become brittle. This can usually be seen on arrival.	L	H	e. Inform plant immediately. Discard overheated asphalt.
	f. Mix proportions or grading out of spec.	L	M	f. Check properties & grading target and tolerances. Compare with job results
	3. CONSTRUCTION			3. CONSTRUCTION
	a. Under-compaction of mat	H	H	a. Above all, GET COMPACTION, or you are in deep trouble
	b. Mat paved too thin	H	H	b. Get thickness right, or face more trouble
	c. Handwork areas not well compacted or finished	H	H	c. Handwork areas are usually a weak link due to rapid cooling of the mat and resulting under-compaction and coarse finish.
	4. TRAFFIC			4. TRAFFIC
	a. Fuel or oil spills causing softening of bitumen	H	M	a. You can’t prevent this; just repair the areas

PROBLEM	POSSIBLE CAUSES	Pr	Im	SUGGESTED SOLUTIONS
STRIPPING of bitumen off the aggregate under traffic. (Can occur in asphalt bases and at longitudinal joints under heavy traffic.)	1. SITE CONDITIONS			1. SITE CONDITIONS
	a. Water trapped in layers or ingress of water, both combined with heavy vehicle traffic	H	H	a. It's vital to avoid water being trapped in the asphalt layers as this causes stripping when pore pressure builds up under heavy traffic
	b. Inadequate surface or sub-soil drainage	H	H	b. As for 1.a. above
	c. Moisture trapped in pervious or cracked asphalt; this can happen during construction or under traffic	H	H	c. As for 1.a. above
	2. ASPHALT MIX			2. ASPHALT MIX
	a. Bitumen overheated (looks brown and brittle)	L	H	a. Max mixing temperature for 60/70 pen bitumen should be 165 – 1700C
	b. Field voids too high (avoid 9 to 15% voids range)	H	H	b. This allows water to permeate the layer and stay trapped. Voids <9% cause impermeability. Voids >15% don't allow pore pressure.
	c. Low film thickness caused by high proportion of super-fines in filler	L	M	c. Reduce filler content e.g. 6% vs 8%, or change to filler with less super-fines
	d. Hydrophilic aggregates	H	M	d. Use lime in mix (usually 1%) or other heat stable, anti-stripping agent to improve adhesion with aggregates
	e. Mix not designed for possible stripping conditions	H	M	e. Include lime or other heat stable, anti-stripping agents in design of mix
	3. CONSTRUCTION			3. CONSTRUCTION
	a. Inadequate compaction resulting in in-situ voids being between 9 and 15%	H	H	a. Voids in this range firstly cause permeability and secondly allow buildup of pore pressure under traffic. Water under pore pressure causes stripping. See 2.b. above
DELAMINATION OF WEARING COURSE (some time after construction)	1. POOR ADHESION			1. POOR ADHESION See MAT SHOVES UNDER ROLLER for more information on adhesion.
	a Dusty or dirty base	M	M	a. Clean thoroughly, even go as far as scabbling to get rid of oil, fuel spills. Apply tack before paving.
	b Biscuit layer in base	M	M	b. Remove biscuit layer and replace with asphalt leveling course
	c Insufficient tack or tack not broken before paving	M	M	c. Adhesion is very important – do it right
	2. TRAFFIC			2. TRAFFIC
	a At braking or turning areas	H	M	a. Adhesion is at fault – see above