

SOUTH AFRICAN PAVEMENT ENGINEERING MANUAL

Chapter 12

Construction Equipment and Method Guidelines



**AN INITIATIVE OF THE SOUTH
AFRICAN NATIONAL ROADS AGENCY SOC LTD**

Date of Issue: October 2014

Second Edition

South African Pavement Engineering Manual
Chapter 12: Construction Equipment and Method Guidelines

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Chapter 12

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AFRICAN NATIONAL ROADS AGENCY SOC LTD**

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BACKGROUND

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SCOPE

The South African Pavement Engineering Manual (SAPEM) is a reference manual for all aspects of pavement engineering. SAPEM is a best practice guide. There are many relevant manuals and guidelines available for pavement engineering, which SAPEM does not replace. Rather, SAPEM provides details on these references, and where necessary, provides guidelines on their appropriate use. Where a topic is adequately covered in another guideline, the reference is provided. SAPEM strives to provide explanations of the basic concepts and terminology used in pavement engineering, and provides background information to the concepts and theories commonly used. SAPEM is appropriate for use at National, Provincial and Municipal level, as well as in the Metros. SAPEM is a valuable education and training tool, and is recommended reading for all entry level engineers, technologists and technicians involved in the pavement engineering industry. SAPEM is also useful for practising engineers who would like to access the latest appropriate reference guideline.

SAPEM consists of 14 chapters covering all aspects of pavement engineering. A brief description of each chapter is given below to provide the context for this chapter, Chapter 12.

Chapter 1: Introduction discusses the application of this SAPEM manual, and the institutional responsibilities, statutory requirements, basic principles of roads, the road design life cycle, and planning and time scheduling for pavement engineering projects. A glossary of terms and abbreviations used in all the SAPEM chapters is included in Appendix A. A list of the major references and guidelines for pavement engineering is given in Appendix B.

Chapter 2: Pavement Composition and Behaviour includes typical pavement structures, material characteristics and pavement types, including both flexible and rigid pavements, and surfacings. Typical materials and pavement behaviour are explained. The development of pavement distress, and the functional performance of pavements are discussed. As an introduction, and background for reference with other chapters, the basic principles of mechanics of materials and material science are outlined.

Chapter 3: Materials Testing presents the tests used for all material types used in pavement structures. The tests are briefly described, and reference is made to the test number and where to obtain the full test method. Where possible and applicable, interesting observations or experiences with the tests are mentioned. Chapters 3 and 4 are complementary.

Chapter 4: Standards follows the same format as Chapter 3, but discusses the standards used for the various tests. This includes applicable limits (minimum and maximum values) for test results. Material classification systems are given, as are guidelines on mix and materials composition.

Chapter 5: Laboratory Management covers laboratory quality management, testing personnel, test methods, and the testing environment and equipment. Quality assurance issues, and health, safety and the environment are also discussed.

Chapter 6: Road Prism and Pavement Investigation discusses all aspects of the road prism and pavement investigations, including legal and environmental requirements, materials testing, and reporting on the investigations. The road pavement investigations include discussions on the investigation stages, and field testing and sampling (both intrusively and non-intrusively), and the interpretation of the pavement investigations. Chapters 6 and 7 are complementary.

Chapter 7: Geotechnical Investigations and Design Considerations covers the investigations into fills, cuts, structures and tunnels, and includes discussion on geophysical methods, drilling and probing, and stability assessments. Guidelines for the reporting of the investigations are provided.

Chapter 8: Material Sources provides information for sourcing materials from project quarries and borrow pits, commercial materials sources and alternative sources. The legal and environmental requirements for sourcing materials are given. Alternative sources of potential pavement materials are discussed, including recycled pavement materials, construction and demolition waste, slag, fly ash and mine waste.

Chapter 9: Materials Utilisation and Design discusses materials in the roadbed, earthworks (including cuts and fills) and all the pavement layers, including soils and gravels, crushed stones, cementitious materials, primes, stone precoat fluids and tack coats, bituminous binders, bitumen stabilized materials, asphalt, spray seals and micro surfacings, concrete, proprietary and certified products and block paving. The mix designs of all materials are discussed.

Chapter 10: Pavement Design presents the philosophy of pavement design, methods of estimating design traffic and the pavement design process. Methods of structural capacity estimation for flexible, rigid and concrete block pavements are discussed.

Chapter 11: Documentation and Tendering covers the different forms of contracts typical for road pavement projects; the design, contract and tender documentation; the tender process; and the contract documentation from the tender award to the close-out of the Works.

Chapter 12: Construction Equipment and Method Guidelines presents construction equipment and controls, construction process guidelines, and the construction of trial sections. The construction equipment section includes discussion on crushing and screening plant, asphalt production plant, concrete mixing plant, bituminous binder distributors, cementitious agent tankers, milling machines, recycling machines, paving equipment, compaction equipment and nuclear testing apparatus. The construction process guidelines cover roadbed preparation, compaction of soils and gravels, cementitious stabilization, bitumen stabilization, modification of materials, cold recycling, crushed stone base, waterbound macadam base, surfacing seals, asphalt, concrete and block pavements, and proprietary products. Guidelines for the construction of trial sections for almost all layer types are also given. Chapters 12 and 13 are complementary, with Chapter 12 covering the proactive components of road construction, i.e., the method of construction. Chapter 13 covers the reactive components, i.e., checking the construction is done correctly.

Chapter 13: Quality Management includes acceptance control processes, and quality plans. All the pavement layers and the road prism are discussed. The documentation involved in quality management is also discussed, and where applicable, provided.

Chapter 14: Post-Construction incorporates the monitoring of pavements during the service life, the causes and mechanisms of distress, and the concepts of maintenance, rehabilitation and reconstruction.

FEEDBACK

SAPeM is a "living document". The first edition was made available in electronic format in January 2013, and a second edition in October 2014. Feedback from all interested parties in industry is appreciated, as this will keep SAPeM relevant.

To provide feedback on SAPeM, please email sapem@nra.co.za.

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1. INTRODUCTION

This chapter deals with typical construction plant used in road building, including aspects of the equipment that need to be checked during construction to ensure a good finished product. The construction processes, and related control factors to ensure quality, are also discussed.

The discussion focuses on typical generic equipment that is widely used at the date of publication of this document. It is meant for general information, rather than as a manual on how to use specific equipment. The intention is not to replace any specification and related requirements, but to assist practitioners to expand their knowledge and ensure that specified requirements are met.

The chapter is divided into three sections:

- Construction equipment and controls
- Construction process guidelines
- Trial sections

The appendix contains all the checklists included in the chapter, and a few extras, in a ready to print format.



Standard Specifications

Note that when this chapter was written and updated, the 1998 version of the COLTO Standard Specifications was being used. However, these specifications are currently being reviewed. A revised version of the Standard Specifications is likely to be published in 2015 and is likely to be issued either by SANS or COTO.

In this chapter, reference is only made to the Standard Specifications, which currently refers to the 1998 COLTO version.

2. CONSTRUCTION EQUIPMENT AND CONTROLS

The section provides useful information, tips and checklists on construction equipment in general use, to ensure the equipment operates correctly and effectively. The information is intended to supplement the plant manufacturers' guidelines that are not always available on site, and to assist in identifying and solving problems.

2.1 Crushing and Screening

A crushing plant is used to crush rock or gravel to produce material broken down to specific sizes and shapes to be used in granular layers, concrete, asphalt and surfacing seals. Normally a set of screens accompany the crushing plant to enable the stone sizes to be separated into the various fractions and gradings required for different material types. A typical crushing and screening plant is shown in Figure 1. Crushing is also discussed in Chapter 8: 3.2.2 and Chapter 9: 5.3 with respect to the utilisation of materials.

There are 3 stages in most crushing operations:

- **Primary crushing**, which is generally the first stage in any crushing operation. Mass reduction in rock fragment size takes place during this stage.
- **Secondary crushing**, during which the size of the crushed rock is reduced to the required size.
- **Tertiary crushing**, during which the shape of the aggregate is improved.



Figure 1. Crushing Operation

2.1.1 Types of Crushers

The following 3 main types of crushers are used to process solid rock masses into usable aggregate sizes, for all three stages of crushing:

- Jaw crusher
- Impact crusher
- Cone crusher

2.1.1.1 Jaw Crusher

The jaw crusher is used to crush most rock fragments into smaller sizes, which are then crushed in other types of crushers. It is not cost effective to crush very hard rock with a jaw crusher. In simple terms, the crusher operates like a human jaw. These crushers have a high volume throughput and generally produce an average quality shaped aggregate, which tends to be elongated. This crusher type is sensitive to the maximum size of the rock to be crushed.

The crusher consists of a fixed jaw plate and a moving jaw plate that is coupled to an eccentric shaft. The moving jaw plate moves up and down through the rotation of the eccentric shaft, resulting in the opening size between the fixed and moving jaw plate continuously changing. This action results in the rock fragments being crushed in the crushing chamber to a smaller size, and discharged through the outlet at the bottom of the crusher. This process is schematically illustrated in Figure 2.



Aggregate Shapes Produced

- Jaw crushers produce **elongated** shaped aggregates.
- Impact crushers produce **cubical** shaped aggregates.
- Cone crushers produce **elongated** shaped aggregates.

The elongation of the particles can be reduced by good operating processes.

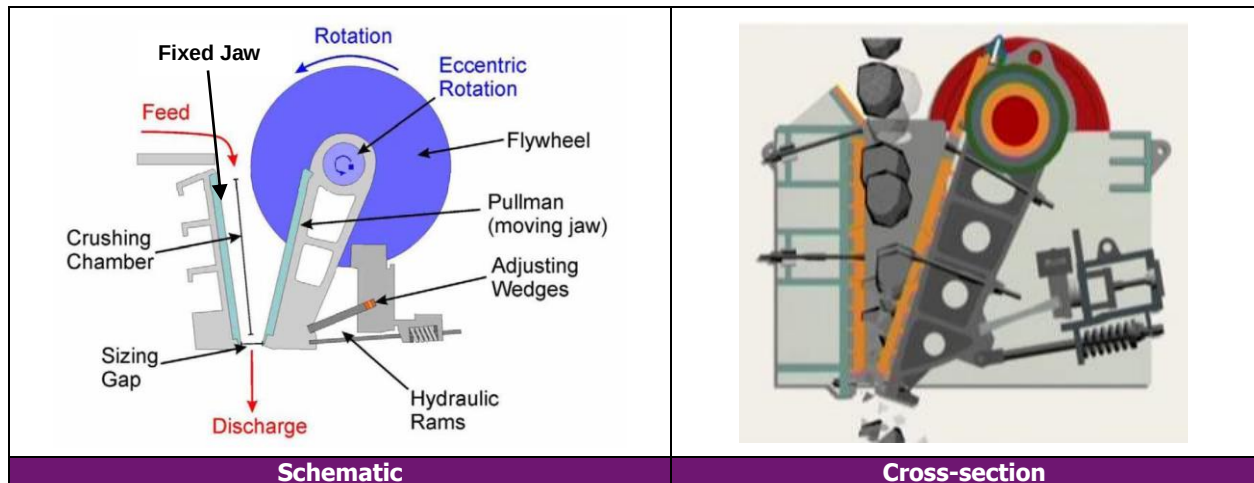


Figure 2. Jaw Crusher

2.1.1.2 Impact Crusher

The impact crusher is used to process high volumes of raw aggregate that are close to the final size. This type of crusher utilises impact energy to crush the aggregate. The crusher generally produces a cubical shaped aggregate. There are two different types of impact crushers; vertical and horizontal impacters, depending on whether the rotor is vertical or horizontal.

- In the **vertical impacter**, the material is fed from the top of the machine and centrifugal forces cause the material to thrust outwards. The aggregate particles crush against each other. This process is also known as attrition crushing.
- In the **horizontal impacter**, illustrated in Figure 3, the material is fed from the front of the machine. The horizontal shaft with blow bars rotates at a speed, which reduces the size of the aggregate, with a further reduction in the aggregate size through particle collision.

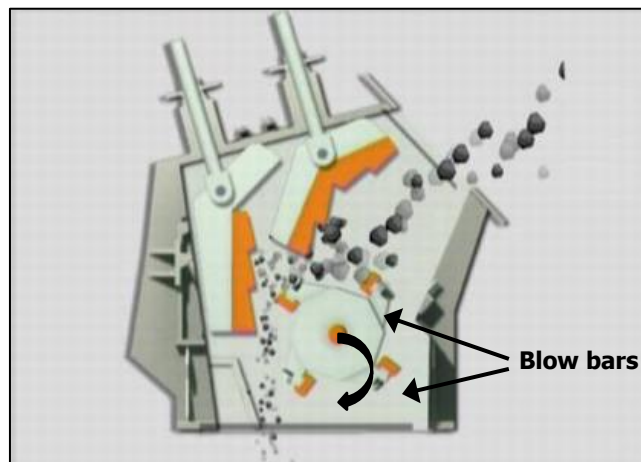


Figure 3. Cross Section Through a Horizontal Impact Crusher

2.1.1.3 Cone Crusher

The cone crusher relies on cone shaped liners in the machine to reduce the size of the aggregate. The aggregate is crushed between the working surfaces of the fixed and moving cones. This type of crusher is more advanced and efficient than the jaw crusher.

The crusher, shown in Figure 4, consists of a cone shaped bowl liner that crushes the aggregate against the mantel liner. The mantel liner has a pre-set closed side gap setting, to control the size of the aggregate produced. The head of the shaft is positioned eccentrically from the vertical plane, which results in one face being against the mantel at all times, while the aggregate is fed from above. As the cone shaped bowl liner moves to the mantel liner, the aggregate is crushed. As the bowl liner moves away from the mantel liner, the aggregate is discharged from the outlet.

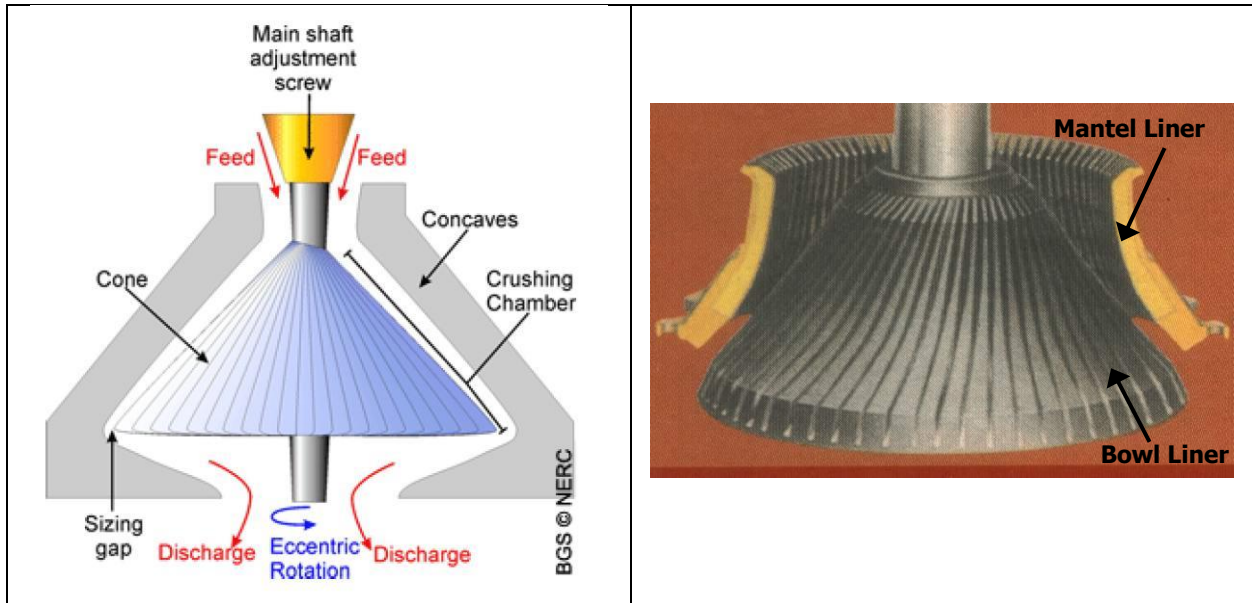


Figure 4. Schematic Diagram of Cone Crusher

2.1.2 Screening and Washing Operation

Screening of the crushed aggregate is an essential part of the production process of graded crushed stone, to ensure a quality product is obtained.

From the primary crusher, the crushed rock material is normally transported to a screen that removes the minus 50 mm fraction. The oversized material is returned to the crusher for re-crushing. The screen vibrates for the particles to move upward and forward, which greatly increases the output rate. The crushed material moves down the screen on a covered screen deck, with screen mesh of a desired aperture. A screening plant can have as many as three different screen decks to extract three different aggregate sizes. An example of a set of screens is shown in Figure 5.



Figure 5. Aggregate Screens

Screening efficiency depends on how well the materials are fed onto the screen, and how quickly it passes over the screen mesh. When the material feeding process is inadequate, pegging and blinding reduce the effectiveness of the screen, which is reflected in the grading achieved.

- **Pegging** occurs when aggregate becomes stuck in the woven mesh due to slow movement of the particles.
- **Blinding** occurs when too many moist fines stick together and clog the screens.

If the crushed material has a high dust content, washing of the aggregate is required to remove any inherent dust clinging to the particles. Special screens are used to wash the aggregate in its final stages.

Classifiers are also used to separate different particle sizes in the crushed material. This is a wet process where the material is drenched with pressurised water. The classifier creates an upward flow enabling the lighter finer particles to be extracted at the top. The heavier coarser particles move to the lowest end for extraction. The wet finer particles (sand) need to be de-watered by allowing it to drain freely, or is processed through a de-watering plant.

Another example of a classifier is based on an inclined Archimedean Screw device, as illustrated in Figure 6. The material is forced upward by the screw, while being washed. The screw has a gap setting, allowing coarser particles to move up and out for re-processing.



Figure 6. Screw Classifiers

A cyclone can also be used to wash the aggregate. In a cyclone, shown in Figure 7, the material is subjected to centrifugal forces to remove the water.



Figure 7. Cyclone Crusher Plant

2.1.3 Combined Crushing and Screening

Combined mobile crushing and screening plants have the capacity to crush, screen and recycle material. They are, unfortunately, not as accurate in screening as a fixed plant, but provide high production rates. The process is illustrated in the schematic diagram and photograph of a mobile crusher in Figure 8.



Figure 8. Mobile Jaw & Cone Crusher with Screens

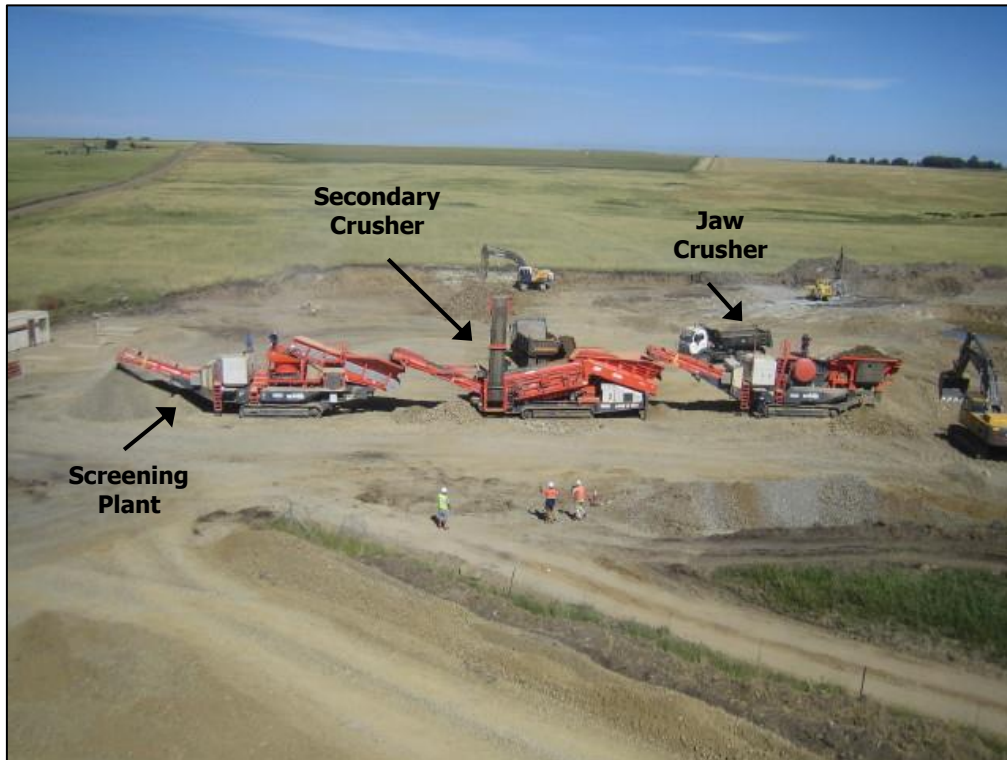


Figure 9. Mobile Crushing and Screening Plant

2.1.4 Stockpiling and Loading

Typical aggregate stockpiles are shown in Figure 10. When stockpiling and loading aggregates, the following guidelines should be followed:

- Choose **an area for stockpiles** where material is close to where it will be used, but not exposed to excessive dust.
- **Clear the area** to ensure that no debris, grass, mud or dirt contaminates the aggregate.
- Provide a **hard clean platform**, by compacting the in situ material.
- **Slope the area** slightly to allow for drainage.
- Keep **access roads to stockpiles** clean, so that equipment such as front-end loaders do not track dirt into the stockpile.
- Provide **ample separation between stockpiles** or bays to avoid intermingling.
- If slight **segregation** occurred during transporting aggregate to site, remix before stockpiling.
- Use **signboards** to clearly identify aggregate product to assist in loading correct materials for various applications, such as concrete.
- **Build up stockpiles in layers**, and do not over-tip, i.e., avoid aggregate rolling down long slopes and segregating.
- **Mixing and correct stockpiling** for base materials is essential to ensure a homogenous product. The crushed aggregate should be offloaded on the stockpile and shaped in layers. The base of the stockpile should be large enough to prevent new material being dumped on the stockpile too close to the edge of the stockpile. If material is dumped and falls beyond the edge of the stockpile, it segregates and the coarse material accumulates along the perimeter at the bottom of the stockpile.
- The loading shall be done with a front end loader. The material shall be loaded from the bottom upwards to ensure that the different material layers in the stockpile are sampled to ensure remixing of the material and to minimizing segregation. During loading there should be no **undercutting of the stockpiles platforms**, which leads to contamination of the material with the underlying soil.

Building the Stockpile in Horizontal Layers	
Completed Stockpiles	
Labelled Stockpiles	

Figure 10. Aggregate Stockpiles

2.1.5 Sampling and Testing

To ensure that the aggregate in the stockpiles or bins is within specification, the laboratory should take and test representative samples. The relevant specification for aggregate compliance determines the tests required. The sample size is affected by the aggregate type and the number of tests to be conducted. SANS method 825 describes sampling methods to give a reasonable probability that the sample obtained is representative of the lot sampled.

Sampling is done from either a stockpile or conveyor belt. The following guidelines should be followed:

- **From Stockpiles.** Take at least ten increments from different parts of the stockpile, working from the base of the stockpile upwards, as shown in Figure 11. Avoid sampling in segregated areas, or from the surface of the stockpile.
- **From Belts.** Stop the conveyor and remove a one meter length of aggregate along the length of the belt using the special apparatus shown in Figure 12.



Figure 11. Sampling from Stockpile



Figure 12. Belt Sampling

Some of the most common laboratory tests carried out on crushed aggregate are listed below. Many of these tests, and the associated standards, are discussed in Chapter 3: 3 and Chapter 4: 3.

- 10% Fines aggregate crushing value (10% FACT)
- Aggregate crushing value (ACV)
- Alkali aggregate (silica) reaction (ASR)
- Average least dimension (ALD)

- California Bearing Ratio (CBR)
- Clay particle indicator using the Methylene Blue test
- Shrinkage of aggregates (SABS SM 836: Effect of fine and coarse aggregate on the shrinkage and expansion of cement: aggregate mixes (mortar prism method))
- Dust content, i.e., the percent passing the 0.075 mm fraction
- Fines modulus (FM)
- Flakiness index (FI)
- Gradings, i.e., the particle size distribution
- Grading modulus (GM), calculated from the gradings
- Linear shrinkage (LS)
- Liquid limits (LL)
- Organic impurities. Important as it can lead to retardation of setting time and staining of concrete.
- Plasticity Index (PI)
- Polished stone value (PSV)
- Presence of sulphates and sulphides, which can lead to expansion and efflorescence, resulting in reduced density of the concrete.
- Soundness, i.e., chemical durability
- Voids content, determined by the shape of material and grading
- Water absorption (WA)

All aggregates are tested for compliance with either the SANS specifications, the Standard Specifications or contractual specifications.

2.1.6 Crushing Problem Solving

Crushing is a robust operation, and is generally done by the aggregate producer. Therefore, problem solving is not discussed in this chapter.

2.2 Asphalt Production Plants

Asphalt production plants are used to mix hot aggregates and hot bituminous binders, to provide a homogeneous hot asphalt mix. There are two main types of plant facilities in use in South Africa for producing hot mix asphalt (HMA) paving mixtures: batch plants and drum plants. In each type of facility, the aggregates are proportioned according to the requirements of the mix formula, dried and heated, and then mixed with the required asphalt binder. With both types of facilities, fine aggregate can be supplemented, liquid additives can be added, and reclaimed asphalt (RA) can substitute a portion of the aggregate fractions to make recycled mixes.

2.2.1 Types of Production Plants

2.2.1.1 Batch Plants

Batch plant mixers involve conveying hot aggregate, heated in a rotating drum heater, and piping hot binder into a mixer, which mixes the two through the rotating action of a number of steel blades. These mixers were developed in the early 1900s and many are still in use today in South Africa. A typical batch plant layout is shown in Figure 13.

In the batch plant process, individual aggregates are proportioned from the cold feed bins onto a single collector belt, and sent to the dryer to be dried and heated through a hot gas stream. The dried and heated aggregates flow into a bucket elevator and are carried to the top of the batch tower. From there, it is deposited onto multiple screen decks, which separate the aggregate into different sizes and direct the fractionated aggregate into hot bins. The screens in the tower determine the size of the aggregates in the hot bins, and how the blended aggregate mixture is fractionated and readied for proportioning according to the specified asphalt mixture. The mixture is made by weighing the fractionated aggregates stored in the hot bins with an accumulative aggregate weigh hopper, positioned below the hot bins. Each predetermined material fraction is individually weighed in the aggregate weigh hopper, until the entire batch is weighed.

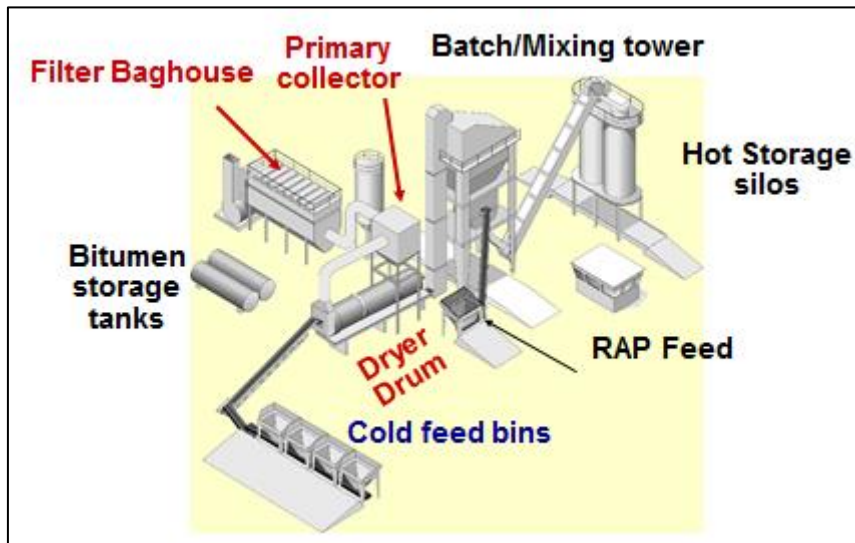


Figure 13. Batch Plant Layout

In a separate action, the bitumen binder is weighed in a weighing device, typically called a bitumen weigh bucket or bitumen scale.

After the aggregate and the binder are weighed, the aggregates are dropped into the pugmill mixer and blended together, in what is called a dry-mix cycle. This 2 to 5 second cycle blends the aggregates thoroughly, before the bitumen binder is **added**. When the dry-mix cycle is completed, the bitumen is dropped into the mixer and the wet-mix cycle starts. The wet-mix cycle lasts between 25 and 45 seconds. The cycle time is determined by the time required to produce a homogenous, well-coated mix. The uniform coating of large aggregate mixes typically takes longer than fine aggregate mixes. The time is usually determined subjectively by visual inspection.

Batch plants were originally designed to accept a combined crushed aggregate product and sand. The screens at the top of the batch tower were used to separate the aggregate into the individual fractions so that different mixes could be produced. Currently, mixes can also be produced utilising different percentages of sized aggregates, at ratios blended directly through the individual (single sized) cold feed bins. This eliminates some of the requirements of a batch tower. Therefore, in modern batch plant production, the aggregate proportions for the specified mixtures are usually first established/calibrated for the cold feed bins in order to obtain the target aggregate proportions for the mixture, just like a drum-mix plant. The determined ratios of the individual hot bins then become the proportions used to manufacture the final mix (job mix formula) with the batching plant.

2.2.1.2 Drum Mixers

In drum mixers, the aggregate heating drum is combined with a bitumen inlet, so it also acts as a mixer. These mixers consist of a large rotating drum, provided with a burner at the one end to heat aggregates loaded into the drum at that end. Bitumen is pumped into the drum nearer the other end, away from the burner, to avoid burning the binder. Mixing occurs from where the bitumen enters the drum, until the mix is poured out of the end of the drum. These mixers were introduced during the 1970s and are generally the more popular mixers in use today. An example is shown in Figure 14.



Drum Mixers

Drum mixers are generally the more popular mixers in use today.

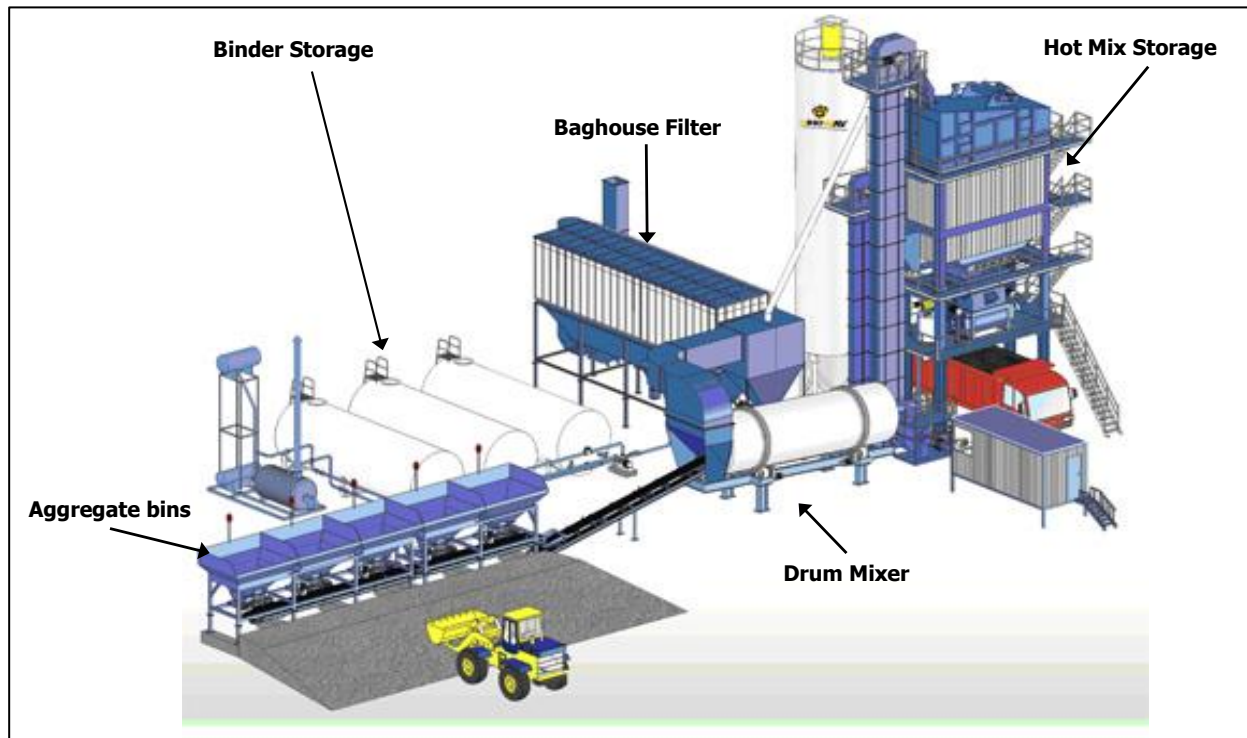


Figure 14. Drum Plant Layout

The continuous flow of a drum mix plant requires the availability of very uniform stockpiled aggregate materials that meet the specifications when proportioned, without rescreening. The individual aggregate materials are proportioned directly from the cold feed bins to the final proportioning of the asphalt mix (job mix formula). The materials are then sent to the drum to be dried and heated. If reclaimed asphalt is introduced into the mix, measures must be taken to ensure that it is not brought into contact with the burner. En route to the drum, the blended aggregate passes over a belt scale, which is a continuous-weighting device. The plant's control system uses the reading from the belt scale to calculate the bitumen and other additives required.

The first drum mixers were parallel-flow dryers, meaning that the aggregate and the process gas flow in the same direction, illustrated in Figure 15. The wet aggregates at ambient temperature are introduced to the entrance and high end of the dryer drum where the burner is located, and the aggregate is dried as it moves away and down from the burner. The binder is introduced near the exit and cooler part of the drum, just prior to discharge of the mix.

Drum mixers have evolved since this early parallel-flow configuration. Recent mixers include several different types of continuous processing, such as counter flow mixers (Figure 16), dryers with a separate continuous mixer, and dryers with continuous mixers fitted together in two concentric barrels (double-barrel mixer). The counter-flow dryer also contains a mixing zone. Aggregate flow is still from high to low or right to left as shown in Figure 16. The burner is inserted further into the drum to provide a mixing area behind the flame. In a flow bath plant drier, shown in Figure 17, aggregate enters the uphill end of the dryer or on the right. Moisture is driven off and the aggregate temperature increases. Note the direction of aggregate versus gas stream.

The driving force behind the latest designs is the desire to create a drum-mix facility that is more environmentally friendly. By introducing the binder outside of the main gas stream used to dry and heat the aggregate, the hydrocarbon particles released are smaller, reducing air pollution and reducing premature ageing of the binder during the batching process.

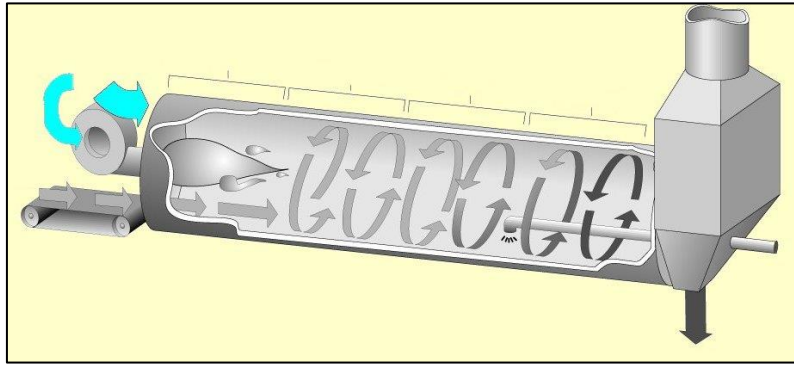


Figure 15. Parallel-flow Drum Mixer

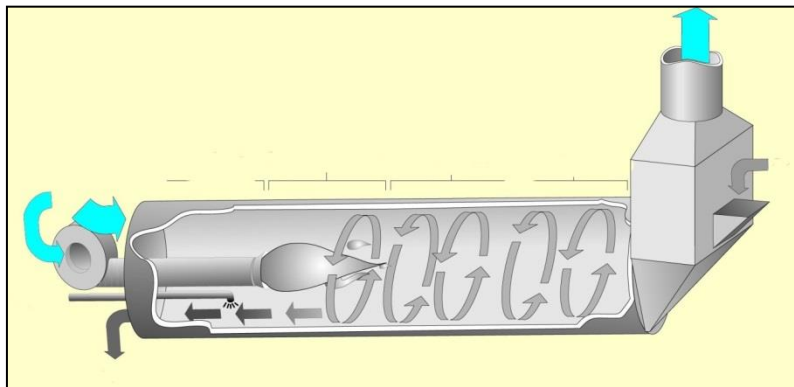


Figure 16. Counter-flow Drum Mixer

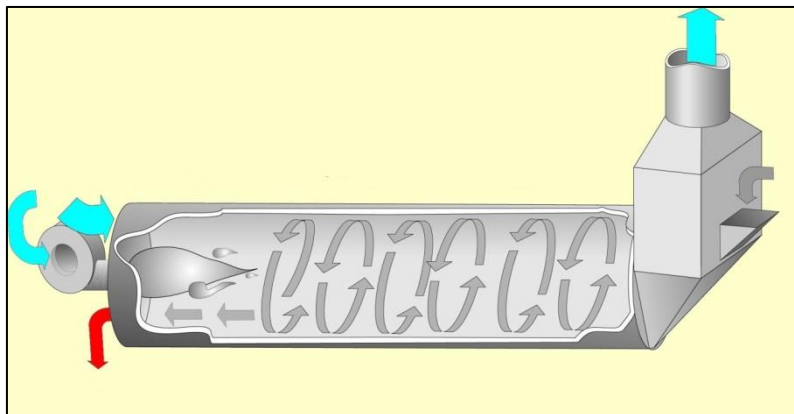


Figure 17. Flow Bath Plant Drier

2.2.2 Processes and Equipment for Batch and Drum Mixers

The main differences between the two types of mixers are their proportioning and mixing styles. Most other processes and equipment are common to both types of plant and are summarised below.

2.2.2.1 Aggregate Stockpiling

Aggregates delivered to plant sites are stockpiled on site and then fed into the cold feed bins with a front end loader, illustrated in Figure 18 and Figure 19. The different aggregate sizes are separated by spacers or dividers, before being loaded into the cold feed bins.

When cold feed bins are changed, care should be taken to prevent contamination of the aggregate with underlying materials, and to prevent segregation or grading changes.

Stockpiles should preferably be located on smooth, well drained concrete surfaces, and be covered with roofs to avoid major changes in moisture content when it rains. Changes in moisture content are catered for by longer heating times, to drive off the moisture.

2.2.2.2 Aggregate Cold Feed Bins

Aggregate cold feed bins, illustrated in Figure 18 and Figure 19, are similar for both batch and drum mix plants. The same style of conveyors is used to transfer the material from the cold feed bins to the drying drum. These conveyors have variable speed motors located below the cold feed bins, to regulate the flow of materials to the drying drum. These variable speed belts are consistent and repeatable, and therefore easy to calibrate. The ton per hour output is determined for different belt speeds, and the required speed setting is calculated for a given mix and production rate. Gate openings should be proportional to the amount of aggregate added, to ensure uniform loading of the belt. This process is usually computerized.

2.2.2.3 Aggregate Drier Unit

The aggregate drier unit ensures the consistent temperature of the produced mix. The drier unit is a long mixing drum, which is inclined and rotates. Driers have a burner and fan fitted at entrance end of the drum to create a hot gas stream through the drum that dries and heats the aggregate. Inside the drum are steel flights or lifters that pick up and drop the aggregate into the hot gas stream as the drum rotates. This is known as parallel-flow type mixing.



Figure 18. Aggregate Bins



Figure 19. Cold Feed Bins with Conveyor

2.2.2.4 Dust Collection Equipment

The gas velocity in an aggregate dryer is quite significant, and removes the fine aggregate fractions from the dried aggregate mixture. Dust collectors are installed on hot mix plants primarily to collect the dust for environmental reasons. Captured dust is often reused, depending on the type of equipment installed at the plant.

There are two stages of dust collection on plant systems:

- **Primary collectors** gather the larger dust particles.
- **Secondary collectors**, such as wet washers or fabric filter collectors (baghouses), gather the smaller particles.

The collected dust can either be returned to the mix-production process or removed from the system. If the dust is returned, it is essential to ensure that it is reintroduced volumetrically through a calibrated feeder valve. Alternatively, it can be weighted back into the production process.

2.2.2.5 Bituminous Binder Storage Tanks

Bituminous binders are generally stored in insulated and heated tanks located next to the other equipment in the facility. The tanks are kept heated to maintain the binder at the proper mixing temperature. An example of binder storage tanks is shown in Figure 20.



Figure 20. Bitumen Binder Storage Tanks

The pipes that transfer the binder to the mixing unit must be insulated, and surrounded with an outer pipe or “jacket”, containing hot oil, to keep the binder at the correct temperature throughout the entire process.

2.2.2.6 Hot Mix Storage Silo

Storage silos for the asphalt mix allow the plant to run continuously, whether or not trucks are available to load the mix. The silos are either surge or storage type:

- **Surge silos** are typically not insulated and are open topped bins.
- **Storage silos** are fully enclosed and are heavily insulated, an example of which is given in Figure 21. They generally have heated cones and some have sidewall heating mechanisms. Storage silos thus allow additional storage times for mixes, without significant heat loss or oxidation of the mix.



Figure 21. Hot Mix Storage Bins

2.2.3 Equipment Control Measures

It is essential that quality control measures are exercised at an asphalt production plant.

2.2.3.1 Aggregate Stockpiles

The following measures for aggregate stockpiles should be followed:

- The **surface under the stockpile area** should be solid, to prevent contamination of the aggregates with underlying materials during the loading operation of the aggregates into the aggregate cold feed bins.
- **Moisture** drastically affects the production of the plant, as the mix temperature fluctuates if the moisture content of the aggregate changes. The **aggregate stockpiles should therefore be kept dry** by covering the stockpiles with roofs or plastic sheets during rainy weather. It is common practice to provide roofing over the stockpiles at many plant facilities overseas. A sloped, smooth, well-drained surface under the stockpile area, also greatly helps to control the moisture content.
- The **different aggregate sizes should be kept separate** by space, or by dividers to prevent mixing of the different sizes.
- **Segregation** is a major concern in stockpile management at a hot mix asphalt plant. Care should be taken when aggregates are dropped from a significant height, such as from a stacked conveyor, or if the aggregates are allowed to flow down the face of a stockpile.
- **Haul trucks or stockpiling equipment** should not be allowed to drive over, or to work on, the stockpile. This could cause breaking down of some aggregates, resulting in a grading change.

2.2.3.2 Aggregate Cold Feed Bins

The following quality control measures should be observed for aggregate cold feed bins:

- The **calibrated output of the conveyor belt feeders** must be checked periodically for maximum mix accuracy. Changes to the speed and output occur because of build-up inside the feed bins or fatigue of the motor/drive unit.
- The **outlet of the cold feed bins** should be checked for blockages, which reduce the quantity of aggregate from the composite blend going into the drier.
- **Dry aggregates** in the bins make the whole operation more predictable, and less energy intensive.

2.2.3.3 Aggregate Drier Unit

The drier drum is responsible for producing a mix with a constant temperature. Retention time of the aggregate in the drier drum is varied by changing the incline of the drum. The steel flights can be configured for different materials, to ensure maximum heat transfer into the aggregate.

The drying effectiveness of the unit should be monitored during production, by recording the surface temperature along the length of the drier shell using an infrared temperature gun. The temperature readings taken at regular intervals along the drier drum should be recorded and plotted. The temperature plot should increase uniformly along the length of the drier shell, to confirm that the drier is working properly. Hot and cold spots along the length of the drier indicate where problems, such as worn flights, are located inside the drier.

If the temperature reduces significantly (more than 25 to 30 °C), between drying the aggregate and loading the mix into the truck, the aggregate is either not completely dry, or not heated all the way through. Mixes with a high percentage of large aggregate, often require elevated drier exit temperatures to compensate for the longer time it takes for the colder centre of the stone to heat stabilize. A temperature drop may also indicate that the stone is not completely dry. When significant temperature drops are encountered, moisture retention tests are needed. If no moisture is present, the uncoated stone can be overheated to compensate for the eventual temperature drop.

2.2.3.4 Dust Collection Equipment

It is essential that if dust is returned to the plant process, the dust return must be constant.

The baghouse cleaning and dust return must stop when the drier stops. This prevents large quantities of dust transferring to the mixing area when the aggregate feed stops.

Large and rapid increases in production rate should be avoided. It takes time for the dust to be collected on the bags, cleaned off the bags and returned to the mixing area. A mix produced during a large and rapid increase in production will be short in fines, and thus have high voids. A mix produced during a large and rapid decrease in production will have the opposite result.

2.2.3.5 Bituminous Binder Storage Silos

The storage temperature should be monitored regularly to ensure that the binder is kept at the proper temperature. Binder temperature affects pumping and metering efficiency, and coating of the aggregate. It is essential that the binder temperature is maintained throughout the production process.

The heating elements on the silo walls should not be hotter than the mix temperature, as this may damage the mix by overheating at the point of contact. Excessively high temperatures cause the asphalt binder to build up and harden around the heating elements. Excessively high temperatures can also prematurely age the binder.

2.2.3.6 Hot Mix Storage Tanks

As with the binder storage tanks, if the sidewalls of the hot mix storage tanks are heated, the heating elements on the silo walls must not be set at higher temperatures than the mix. This damages the mix by overheating it at the point of contact, and may also cause build up on the silo walls. The build-up ultimately acts as an insulator, reducing the long term storage capability of the silo.

2.2.4 Problem Solving

A successful asphalt mix production requires a diligent approach to both the calibration process and the daily operational best practices. A mix



Identifying Problems in the Drier Unit

The drying effectiveness of the unit should be monitored during production, by recording the surface temperature along the length of the drier shell using an infrared temperature gun. The recorded temperature reading should be plotted at regular intervals along the drier drum. The temperature plot should increase uniformly along the length of the drier shell, to confirm that the drier is working properly. Hot and cold spots along the length of the drier indicate where problems, such as worn flights, are located inside the drier.



Binder Temperatures

The binder storage temperature should be monitored regularly and should be maintained throughout the production process.



Asphalt Mix Production

A successful asphalt mix production requires a diligent approach to both the calibration process and the daily operational best practices. A mix must have an accurate and consistent aggregate grading, binder content and temperature. The entire production process should run smoothly and consistently, as starts and stops affect the quality of the mix produced.

must have an accurate and consistent aggregate grading, binder content and temperature. The entire production process should run smoothly and consistently as starts and stops affect the quality of the mix produced. A problem solving guide for drum and batch mix plant production is provided in Table 1.

Table 1. Asphalt Mix Problem Solving

Problem	Possible Cause
Grading Shift: Aggregates	• Cold feed bin flow restriction or change. • Cold feed bin calibration shift. • Grading change in feed aggregates. • Improper loader management on stockpiled material.
Grading Shift: Coarser on 0.075 mm sieves	• Drastic change in production rate (low to high), takes time for baghouse fines to catch up to the cold feed change. Over-drafting the dryer causes less fines in the mix, due to a more open damper, relative to the previous or typical production rate, together with wasting or only partial return of baghouse fines. • Baghouse dust return or mineral filler additive malfunction, causing reduced baghouse dust return or mineral filler additive. • Grading change in feed aggregates (see above).
Grading Shift: Finer on 0.075 mm Sieve	• Drastic change in production rate (high to low) takes time for baghouse fines to catch up to cold feed change. Under-drafting the dryer results in more fines in mix from a less open damper, relative to previous or typical production rate, together with wasted or partially returned baghouse fines. • Baghouse dust return or mineral-filler additive malfunction, causing increased baghouse dust return or excess mineral additive. • Grading change in feed aggregates (see above).
Voids in Mix (VIM): Low	• Dust-return or dust-additive malfunction (see above). • Production-rate change, high to low with immediate sampling. • Lack of draft in dryer, resulting in retained fines in dryer or primary baghouse. • Grading change in feed aggregates (see above). • Binder content high (see below). • Specific gravity change in aggregates.
Voids in Mix: High	• Dust-return or dust-additive malfunction (see above). • Production rate change (low to high with immediate sampling). • Over-drafting dryer, more fines to baghouse versus in dryer, and wasted or partially used baghouse fines. • Grading change feed aggregates (see above). • Binder content low (see below). • Specific gravity change in aggregates.
Binder Content: High	• Calibration of belt scale: reading high. • Binding belt scale: reading high. • Wind effect on belt scale: reading high. • Calibration of binder meter: reading low. • Improper moisture setting: too low. • Incorrect binder weight or litres entry with litres meter: too low. • Inadequate drying of aggregate, drying efficiency low. • Mixing flights inadequate, mix not homogenous.
Binder Content: Low	• Calibration of belt scale: reading low. • Binding belt scale: reading low. • Wind effect on belt scale: reading low. • Calibration of binder meter: reading high. • Improper moisture setting: too high. • Incorrect binder weight or litres entry with litre meter: too high. • Mixing flights inadequate, mix not homogenous.
Binder Content: Varies	• Malfunction in flow-control mechanism: difficulty in regulating, mechanical issue typically. • Improper moisture settings: not changing entry with moisture changes. • Inadequate drying of aggregate: drying efficiency varies and ignition oven binder test method removes water in addition to binder. • Inaccurate binder weight or litre entry with litre meter: not changing entry with binder changes. • Mixing flights inadequate: not tall enough, caked, need different design.
Inadequate Coating	• Asphalt content low: not enough asphalt binder. • Binder injection point too close to discharge: inadequate mixing time. • Mixing flights inadequate: not tall enough, caked, needs different design. • Temperature of liquid-asphalt binder too low. • Insufficient moisture in aggregate.
Temperature Fluctuations	• Worn dryer flights: incapable of drying aggregates sufficiently at all production rates. • Moisture fluctuations in feed aggregates: burner or dryer cannot rapidly adjust to rapidly adjusting moisture variations. • Excessive storage time: mix cooling off from extended storage. • Mix thermocouple malfunctioning or not reading correctly. • Mix thermocouple covered with material and/or not properly positioned in material stream.

2.3 Concrete Mixing Plant

Concrete mixing plants are used to manufacture wet concrete by mixing sand, gravel, cement, water and other materials. The mix is either centrally mixed or truck mixed. There are various types of central mixing plants in use such as pan mixers, split drum mixers and tilting drum mixers, illustrated in Figure 22. The mixing technique is the same for all three mixers, the differences are in the transferal of the mix to the truck. Selecting the one to use is typically based on equipment availability.



Figure 22. Tilting Drum Mixer

One of the key aspects of modern concrete road paving practice is to mix continuously during construction of the layer. It is, therefore, important that the overall concrete operations from batching to final completion of the concrete layer are optimised and balanced.

It is of utmost importance that adequate quality control measures are implemented, to ensure that the end product conforms to the specifications.



Readymix Concrete

Nowadays, most concrete construction is done using readymix concrete, which is brought to site in trucks. Concrete is, therefore, not typically mixed on site.

2.3.1 Equipment Control Measures

The following need to be considered, to achieve continuity of mixing and paving:

- **Masses of aggregates** are within 3% of required amounts, and systems are checked to ensure this.
- **Cement weighing is accurate** to at least 2%, and is checked using a known mass.
- **Water volume measurements** are within 2%. This is checked daily by filling a container of known volume.
- **Admixture delivery systems** are capable of ensuring that the mass is within 2% of the required amount.
- There is **no leakage** of water, mortar, cement or admixtures at the plant.
- The flutes and tines in the mixer meet the **manufacturer's specifications**.
- **Segregation does not occur** at any point in the movement of concrete from the mixer to the transporter.

2.3.2 Problem Solving

The equipment for mixing concrete is robust. The essential part of mixing is using the correct mix proportions.

Stiffening of concrete begins as soon as the cement and water are mixed, and increases with time. Under normal conditions, the degree of stiffening that occurs in the first 30 minutes is not significant. However, high temperatures can accelerate stiffening, and concrete must be kept cool during hot weather.

Concretes with a low water/cement ratio tend to stiffen more quickly than those with higher water/cement ratios. If concrete stiffens to the extent that it cannot be placed or adequately compacted, workability can often be restored by remixing. This should not be done if the concrete is more than two hours old.

Concrete should be designed to have a workability which allows it to be fully compacted by the paving plant. If allowed to dry out during transportation or placing, the concrete loses workability and full compaction may not be possible. Where drying out is a problem, richer, more workable mixes can be used.

Segregation occurs when unsuitable vehicles are used to transport or place the concrete. Jolting and vibration of transport vehicles should be minimized to avoid segregation.

2.4 Bituminous Binder Distributors

Bituminous binder distributors are used to transport the bituminous binder from the refinery or the supplier, to the construction site and to spray the binder at a specified application rate during priming, tack and sealing operations. A typical binder distributor is shown in Figure 23.



Figure 23. Binder Distributor

The binder distributor consists of a number of components that each need to be in a good working order, to ensure the required application rate is consistent and uniform.

2.4.1 Distributor Components

The distributor components for a conventional binder distributor are listed below.

(i) Vehicle

The vehicle should be in a roadworthy condition at all times. It should have sufficient power to accelerate fast enough from a standing start, with the tank filled to capacity, to reach and maintain the speed required to apply the specified application rate.

(ii) Binder Tank

The tank is constructed or mounted on the vehicle in such a way that it can be completely emptied when the distributor is standing on level ground. The tank is normally covered with suitable non-combustible insulation, of adequate thickness to ensure the temperature drop of a full load of binder at a temperature of 150 °C does not exceed 10 °C in any one hour, without circulating and heating the product.

The tank must be fitted with sufficient heating flues, symmetrically arranged to heat the contents of the tank using adjustable burners.

Two suitable thermometers are fitted to the tank, one which can be read from the cab of the vehicle and the other that is read at the back of the vehicle. These thermometers provide an accurate indication of the temperature of the binder as it is circulated prior to, and during, spray operations.

A manhole with a readily removable cover is mounted on top of the tank. The safety aspects related to opening this cover and inspecting the tank contents must be complied with at all times, to avoid fume inhalation and burns.

The tank is fitted with a gimbal and dipstick guide to maintain the dipstick in a vertical position. The dipstick is constructed in the form of a T-piece, which is the fixed reference point for the dipstick readings. Dipstick readings may also be affected by foam in the guide when bitumen emulsions are used. In this case, the foam can be settled by decanting about 100 ml of paraffin down the guide before the dipstick is inserted. The formation of froth on bitumen emulsions can be considerably reduced if the outlet of the pipe discharging into the tank is as near the bottom of the tank as possible.

(iii) Pump and Pipe Work

The pump fitted on the distributor is a positive displacement gear pump, which means that the quantity of bituminous binder delivered is directly proportional to the speed of the pump. The pump is driven by an independent engine, or by power taken from the gearbox of the vehicle. The manufacturer supplies charts to determine the discharge in litres per minute for each nozzle size, as well as the speeds required for various application rates. Corrections for temperature-viscosity variations are also included. Distributors must be equipped with a high pressure pump when non-homogeneous binders, such as bitumen-rubber are used, because of the higher viscosity.

(iv) Spray Bar

The spray bar, illustrated in Figure 24 is one of the most important parts of the distributor. The required quantity of binder must be sprayed through the spray nozzles to ensure that the bituminous binder is spread uniformly on the road surface. The spray bar and related binder delivery pipe work are designed to minimize pressure loss over the length of the spray bar, and to ensure that an equal quantity of binder is delivered through each of the nozzles.



Figure 24. Spray Bar

The prescribed nozzles for a particular job must be used to ensure even transverse and longitudinal spreading of the binder. Typical nozzles range from small nozzles to spray prime coats and diluted emulsions, to medium nozzles for conventional and polymer modified binders, to large nozzles for more viscous modified binders, such as bitumen rubber.

The spray bar has a height adjustment mechanism to set the height to deliver an exact overlap pattern of the nozzle sprays.

2.4.2 Equipment Control Measures

It is essential that the following control measures be implemented on site before the tanker is allowed to commence with the spray operations.

2.4.2.1 Calibration Certificate

Each distributor should have a credible and valid Calibration Certificate, not more than 12 months old. This provides confidence that the binder distributor is operative and capable of delivering the required application rate, within the prescribed tolerances.

The Calibration Certificate, as well as the calibration parameters such as road speed and pump output, must be available for inspection purposes, and to assess the extent to which site tests are carried out.

2.4.2.2 Nozzles

The spray nozzles are shown in Figure 25. All the nozzles must be checked to ensure that they are all the same size and type. The site staff should inspect all nozzles for blockages or wear and tear, and also visually check the angles of the nozzles relative to the spray bar for uniformity.



Figure 25. Spray Nozzles

2.4.2.3 Spray Bar Height

The site staff should carry out a simple test to ensure the proper height setting of the spray bar. This involves closing off the second and third, fifth and sixth, eighth and ninth, etc., nozzles and using the centre section of the bar only, as illustrated in Figure 26. The distributor is then operated at the correct pump speed or pressure with the spray bar height changed not more than 20 mm at a time to produce a single film of binder on the surface with no overlaps and no gaps between the strips. At that point, an exact triple overlap is produced when all nozzles are opened. For best results, the height of the spray bar above the surface to be sprayed should not vary by more than 15 mm. Hence, the site staff must check the measures put in place to limit the height variation as the tank empties. The height of the spray bar should be checked after each run and any necessary adjustment made.

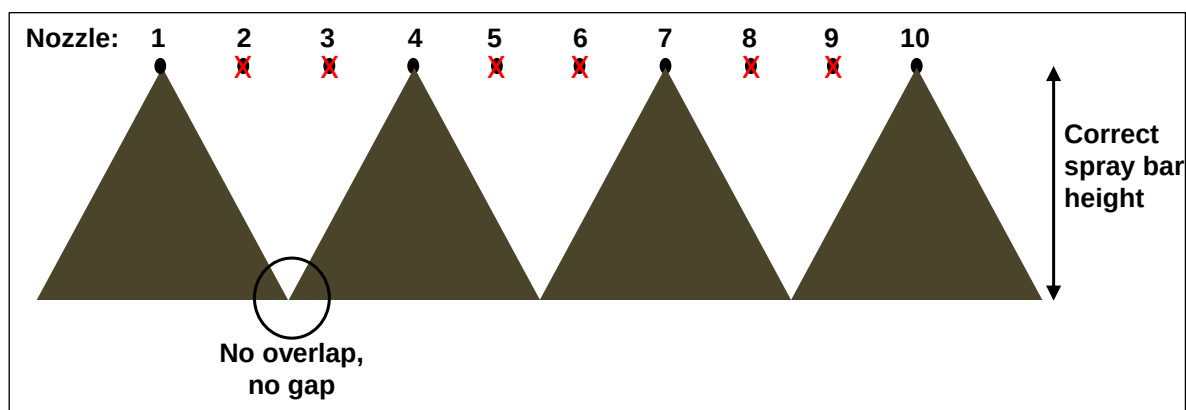


Figure 26. Spray Bar Height Test

2.4.2.4 Transverse Distribution Test (Bucket or "Bakkie" Test)

This standard test determines conformance of the transverse distribution of the spray bar. The test is done by placing buckets below the nozzles, as illustrated in Figure 27. Binder is directly discharged from sets of 3 nozzles into the buckets. The buckets are weighed and should contain the same weight of binder. It is important that the project binder and applicable pump parameters are used. The test is often carried out at the depot, where equipment is readily available to clean and weigh the buckets and site staff can attend the test. It can, however, also be done on site. This test is discussed in more detail in Section 3.10.8.1 with surfacing seals.



Figure 27. Bucket/"Bakkie" Test

2.4.2.5 Road Speed Indicator Test

This test is used to check the distributor speed indicator, to confirm it is within the specified tolerance. The speed indicator may be of any suitable kind, such as a fifth wheel or radar, but should be calibrated as follows:

- **Drive the distributor over a 150 metre test section** of road with a 50 metre acceleration run-up. Drive at a series of uniform speeds from 60 m/min to 300 m/min at increments of 60 m/min.
- **Time each run** using an accurate stopwatch. Calculate the actual speed from the stopwatch readings.
- **Plot a graph** showing indicated road speeds against actual road speeds.
- Any **trends in respect of speed differentials** should be detected and assessed for rectification by the distributor owner. The difference between the actual speed and the speed reading from the speed indicator may not be more than ± 5 percent.

2.4.2.6 Repeat Visits

The next time the equipment and operator arrive on site, the site staff need to assess whether any problems occurred during the previous check assessment, and whether the equipment could have deteriorated or been modified since its last visit to site. Based on this, selected checks should be carried out again to re-assess whether a suitable product can be delivered. Binder distributors are required to keep all records of tests on the vehicle for examination by site staff.

2.4.2.7 Longitudinal Joints

Longitudinal joints between different spray runs always present difficulties. The width of the spray bar should be adjusted so that a minimum number of longitudinal joints are required. The spray pattern leaves a 100 to 150 mm wide edge with less binder, which must be overlapped with the following pass of the distributor, to provide the correct application rate and a neat and tidy joint. Much depends, however, on the skill of the distributor driver in achieving a proper overlap.

2.4.2.8 Trial Section

Before construction of surfacing commences, the distributor owner should demonstrate that the binder distributor has sufficient power to maintain the required constant speed up the steepest incline to be sprayed, and to obtain a uniform distribution of binder. This is done by spraying a trial section of 700 m², or at least 500 litres, of the specified binder, on-site, on the steepest incline.

The optimal spray bar height should be adjusted accordingly before each spray.

2.4.2.9 Spray Rate

It is essential that the spray rate is as accurate as possible. To ensure an accurate spray rate, take note of the following:

- To **obtain the required spray rate**, adjust the pump output to the recommended setting for the appropriate spray bar length, and determine the necessary road speed from the chart supplied. If the required spray rate is obtained, keep to the same settings, road speed and binder temperature for further work with the same binder type.

- The **pump output calibration** is carried out using a special oil with a viscosity that approximates a 150/200 penetration bitumen at spraying temperature. In practice, therefore, the pump output at a certain setting may vary with changes in binder type and temperatures, and even with the same type of binder received from different suppliers.
- If the **required spray rate is not obtained** using the recommended settings, and there is an area that can be used to test the actual spray rate, then the road speed can be adjusted as follows:
 - Note the settings for pump and road speed, as well as the temperature of the binder, for at least two short trial runs. Road speed errors due to operator inefficiency can be checked by stopwatch. Plot the actual spray rate against the road speed on the chart and draw a new line parallel to the calibration line. From this new line, determine the corrected road speed for the particular binder type and temperature.
 - Repeat the above as required, for any change in binder type.
 - Alternatively, use a stopwatch and the “bakkie” test to measure the output rate and adjust the speed accordingly. Note, however, that this only delivers a small quantity of binder and may require refinement using the above trial run procedure.
- For a **consistent spray rate**, the three variables are controlled:
 - Road speed: dependant on operator efficiency
 - Pump output: affected by changes in viscosity
 - Viscosity: affected by changes in temperature
- By keeping the temperature and the setting for pump output constant for any particular binder, only the **road speed should be adjusted**. The operator efficiency can easily be checked by stopwatch.
- The spray rate should be confirmed at the end of each run. This is done by taking a **dipstick reading** from the tanker parked on level ground and calculating the spray rate as a function of the bitumen applied and the surface area sprayed.

2.4.3 Problem Solving

If a distributor functions satisfactorily for a time and then starts giving problems with the spray rate, the cause should be identified immediately. Typical problems experienced with spray rates, and possible causes, are shown in Table 2. Further discussion, with particular application to surfacing seals, is included in Section 3.10.8.1.

Table 2. Spraying Problem Solving

Problem	Possible Cause
High spray rates	• Pump output too high. Check setting of pump output against spray bar length. • Binder temperature may be too high resulting in lower viscosity and thus higher throughput. Check thermometer. • Relief valve pressure may be too high, i.e., too much pressure in the system. • Blocked filter screen on return system. • Road speed may be too slow. Check against stopwatch. • Check all tachometers and pressure gauges for faults (e.g., do they return to the zero setting?)
Low spray rates	• Pump output too low. Check setting of pump output against spray bar length. • Binder temperature may be too low resulting in higher viscosity, and thus lower throughput. Check the thermometer. • Relief valve setting may be too low. Too little pressure in the system, and the binder returns to the tank. • Road speed may be too high. Check against stopwatch. • Pump may be worn out. Check output against stopwatch using a “bakkie” test, or any other method of measuring output rate. • Check all tachometers and pressure gauges for faults (e.g., do they return to the zero setting?).
Streaky sprays (tram lining), illustrated in Figure 28	• Nozzle partially or completely blocked. • Spray bar too high or low above the surface of the road, i.e., not at the correct height for the triple overlap of nozzle sprays. • Nozzles not set at the correct angle to the spray bar. This is normally 32° for slotted nozzles. • Leakage on the suction side of the pump, resulting in air being pumped into the system. • Spray rate too low for adequate transverse distribution. • Temperature of binder too low, i.e., binder viscosity too high.
Erratic spray rates	• Belt drive or clutch between the auxiliary engine and the pump may be slipping. • Faulty dipstick reading. This happens if the guide is a narrow pipe and the dipstick is inserted too rapidly. The binder in the pipe will rise and a number of check dips may give different results. Bring the contents of the tank to rest and insert the dipstick slowly.



Figure 28. Streaky Sprays (Tram Lining)

2.5 Cementitious Agent Tankers

Bulk spreading of cementitious stabilizers is done with tankers fitted with spray bars, as illustrated in Figure 29, although this is seldom used in South Africa. The tanker works on the principle that air is pumped into the tank causing the stabilizer to become like a liquid. The stabilizer is then pumped out under pressure through the spray bar.



Figure 29. Cementitious Agent Tanker



Spreading Cement

Spreading cement through a tanker is seldom done in South Africa. Generally cement is spread by placing bags on the road and spreading by hand. See Section 3.4.2.2.

The spray bar normally distributes the stabilizing agent over a width between 2.1 and 2.8 metres. The amount of stabilizing agent distributed on the road is controlled by adjusting the air pressure in the tank and the speed of the tanker. It is essential that the stabilizer be spread carefully and uniformly over the area to be treated. The uniformity obtained during the spreading operation affects the amount of mixing necessary, and possibly also the standard of mixing finally achieved.

2.5.1 Equipment Control Measures

It is essential that the following control measures be implemented before, and during, bulk spreading of cementitious materials.

2.5.1.1 Stabilizer Quantity

Before bulk spreading takes place, the required mass of stabilizer per square metre and the length of road which can be covered by the particular load are calculated. The minimum quantities of stabilizers that can be efficiently mixed with a grader are:

- **Cement:** 2.0 percent by mass
- **Lime:** 1.0 percent by mass (lower because lime has a lower specific gravity than cement)

2.5.1.2 Marking

The length of the road to be covered by the load of stabilizer must be clearly marked. A true line at the material layer edges should be maintained with a string line.

2.5.1.3 Pipe Spreader Width

The width of the pipe spreader, and/or the number of spray runs, must be determined so the full width of the section can be covered with three or four passes and with minimum overlap or gaps occurring between the strips of stabilizer. The stabilizer is discharged close to the road through several short lengths of pipes. The pressure and truck speed can be adjusted to ensure accurate distribution of the stabilizer.

2.5.1.4 Wind

Bulk spreading of cementitious material agent should not be carried out in strong windy conditions, as this leads to poor distribution and contamination of the environment.

Wind action, created by fast moving vehicles adjacent to the section being treated, should be taken care of by enforcing speed restrictions until the stabilizer is mixed into the material.

2.5.1.5 Stabilizer Density

If a blend of two stabilizers is used, e.g., lime and milled blast furnace slag, the denser of the two should be sprayed first. Mixing should take place only after both stabilizers have been spread.

2.5.1.6 Spread Rate

The spread rate should be checked to confirm the consignment of stabilizer covered the required length of the section, without a shortfall or surplus. The following two methods can be used to check the correctness of the spread rate of the stabilizer:

- **Canvas Mat Test.** This test, illustrated in Figure 30, is carried out by placing a canvas mat of 1 square metre in the spreading path and measuring the mass of stabilizer deposited, as detailed in Equation 1. The spread rates measured is recorded and checked against the allowable deviation from the specified spread rate ($\pm 10\%$). The correct mass of stabilizer should be replaced on the road once the mat has been removed.



Figure 30. Canvas Mat Test

$$M = \frac{L \times W \times T \times D \times P}{100\ 000} \quad (1)$$

where	M	=	Mass on the canvas
	L	=	Length of canvas, in m
	W	=	Width of canvas, in m
	T	=	Thickness of compacted layer, in mm
	D	=	Density of soil, in kg/m ³
	P	=	Percentage stabilizer (e.g., for 3%, P = 3)

- **Ordinary Calculation.** A secondary check on the spread rate is that the consignment of stabilizer should cover the required length of road without a shortfall or surplus. It is most important that this length be calculated correctly, and that this requirement is met.

2.6 Milling Machines

The term “milling machine” is used in the road construction industry to describe a purpose-built machine that removes (“mills off”) asphalt from an existing pavement. These machines can also mill non-asphalt materials, such as thin layers of concrete, or thick layers of crushed stone base material.

The heart of these machines is the “milling drum” that is equipped with many individual cutting tools. The rotating drum is lowered to the required depth in an existing pavement and the machine then advances along the road with the drum rotating (normally) upwards relative to the direction of advance. As the machine moves forward, the material within the milling horizon is broken up and windrowed to the centre. From there it is either lifted onto a conveyor belt that feeds an attendant tipper truck moving at the same speed as the milling machine (see Figure 31), or remains on the milled road surface, usually as a windrow (thereby facilitating pick up).



Figure 31. Example of Milling Machine

Milling machines are used extensively to maintain and rehabilitate existing pavements, where the upper layers consist of asphalt. Milling machines work at ambient temperatures and are used in all climatic conditions, including wet weather. Milling machines should not be confused with hot recyclers, known in the industry as “remixers”, which recover asphalt from an existing pavement after it has been pre-heated.

2.6.1 Types of Milling Machines

A wide range of types and sizes of milling machines are available, each with its own specific capabilities. Different machines are suited to the various types of milling work undertaken. Machine size, width of cut, cut depth and the required production output are the primary considerations. Milling machines are classified into two basic groups:

- **Small machines:** maximum cut width of 1000 mm
- **Large machines:** cut width in excess of 1000 mm



Milling Machine

The term “milling machine” is used in the road construction industry to describe a purpose-built machine that removes (“mills off”) asphalt from an existing pavement.

The appropriate machine for a specific job is dependent on the type of work to be undertaken, and the conditions prevailing on site. This is influenced mainly by the size of the project, i.e., amount of milling undertaken, the time scale, and the number of obstructions that will be encountered. Traffic accommodation and lane closure requirements also influence the decision.

2.6.1.1 Small Machines

These are relatively small, compact machines that are highly manoeuvrable. The majority of these models have the milling drum mounted at the rear of the machine, between the rear wheels, as shown in Figure 32. Larger models in this class are often fitted with tracks for improved stability.

Small machines have numerous application possibilities, including:

- Localised **rut removal**
- **“Dig outs”** for wheel path patching
- Milling around **obstacles**, such as circular manhole covers
- **Cutting transverse joints**
- **Edge tapers**
- **Industrial applications**, where the work is usually both confined and restricted. Most of this type of work involves the repair of concrete floors.



Figure 32. Small Milling Machine

The configuration of the drum and right rear wheel allows these machines to “flush cut” up against kerbs and other obstacles. These machines are often used for production milling on smaller jobs, and as a secondary milling machine on larger sites, thereby allowing the larger milling machines to concentrate on production.

In addition to standard milling drums, several different types of drum can be fitted to these machines for various applications. For example:

- Narrow drums, < 500 mm wide, are fitted to **cut channels in the asphalt** for trench excavations.
- Drums with special tool configurations are used on smaller machines to **remove road markings**.
- Large diameter cutting wheels or saw blades, 20 mm to 80 mm wide, can be fitted for the **installation of loops and cables**.

Small machines, with a cut width more than 500 mm, are capable of cutting to depths of up to 300 mm. Machines with a maximum cut width of less than 500 mm are relatively light, and are limited to a maximum cut depth of 100 mm. Most models are, or can be, fitted with a conveyor at the rear of the machine for loading the milled asphalt onto a truck, as shown in Figure 32. The truck reverses to keep pace with the milling machine. The larger models in this class are equipped with a front-loading conveyor for increased production.

2.6.1.2 Large Milling Machines

Large, heavy milling machines, equipped with milling drums that have a cut width in excess of 1000 mm, ranging up to a 2200 mm on standard machines, and up to 4000 mm for specialised (full lane width) applications. All machines with a cut width in excess of 1300 mm are track mounted and the milling drum is fitted in the centre of the machine, between the front and rear tracks, as shown in Figure 33. This architecture puts the full weight of the machine on the milling drum, allowing deep lifts of asphalt (up to 350 mm) to be removed in a single pass.

These machines are used for production milling, where large areas of existing asphalt are removed, typically on major roads and airport projects. The amount of reclaimed asphalt (RA) removed per working hour is dependent on the size of machine deployed, the quality (hardness) of asphalt, and the efficiency of the site. Larger machines are capable of removing in excess of 250 tons/hour. This makes them ideal tools for runway and highway work when the working window is limited to a few hours, usually at night. See Section 2.6.4 for estimating the production.

2.6.2 Features of Milling Machines

The following sections describe the main features of milling machines. These are not exhaustive and cover only those aspects that are of primary importance when considering the use of these machines on a specific project.

2.6.2.1 Milling Drum

The milling drum is the most important part of a milling machine, since it does the work of breaking down (pulverising) the material encountered in the recycling horizon. Milling drums are manufactured from special steel, in a process that ensures trueness and balance. As shown in Figure 34, cutting tools are attached to the drum in a helical pattern to promote material movement towards the centre where it is lifted onto a discharge conveyor by “lifters” (the plates that can be seen on the middle of the drum).



Figure 33. Large Milling Machine

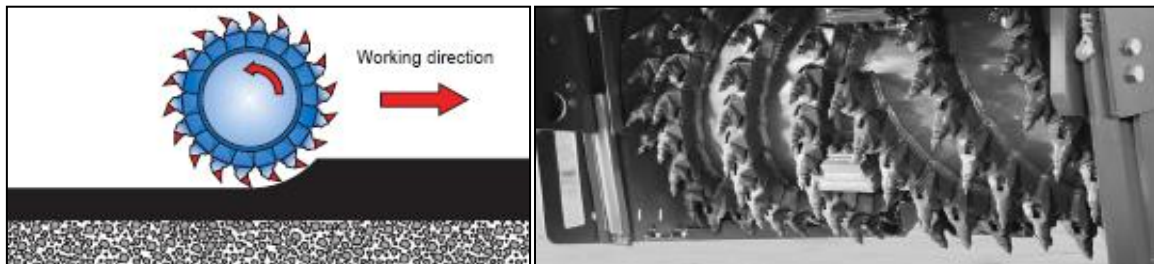


Figure 34. Milling Drum

Milling drums generally rotate upwards relative to the direction of advance, as shown in Figure 34. The speed of rotation varies, normally between 100 and 200 rpm, to suit the hardness of material encountered, the depth of cut and the speed of advance, which are all important features for prolonging the life of the cutting tools.

The milling drum rotates within an enclosed chamber manufactured from abrasion-resistant steel. To cool the cutting tools and reduce dust emission, a fine spray of water is injected into the chamber through a multiple-nozzle spray bar attached to the front face of the chamber. The water is stored in a tank on the machine.

The standard milling drum is equipped with cutting tools attached at regular intervals to achieve a spacing of 15 mm between the cut made by each tool, as shown in Figure 35.

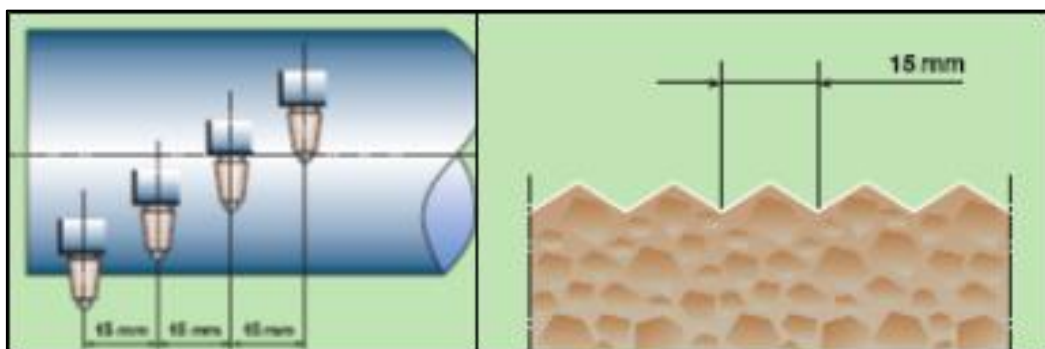


Figure 35. Spacing of Cutting Tools

Different drums, with variations in the number of tools, are used for different milling applications, classified by the different cut spacing achieved:

- **> 15 mm for removing thick lifts** of asphalt in a single pass, known as the **"Eco cutter"**.
- **8 mm for fine milling**, normally followed by the application of a thin surfacing layer, often a slurry.
- **4 mm for micro milling** or texturing, normally followed by the application of a fog spray.

2.6.2.2 Cutting Tools

Cutting tools, also known as point-attack tools or picks, are precision tools manufactured from expensive materials. As shown Figure 36a, the body of the tool is forged steel with a tungsten carbide tip, which does the cutting. Equally important is the base of the tool, which is fitted with a pre-tensioned sleeve that slides into the tool holder mounted on the drum. The sleeve allows the tool to rotate within the holder, thereby allowing the tool to wear symmetrically, as shown in Figure 36c.



References

The following is a valuable reference for milling:
Manual for the Application of Cold Milling Machines. Wirtgen. 2004.

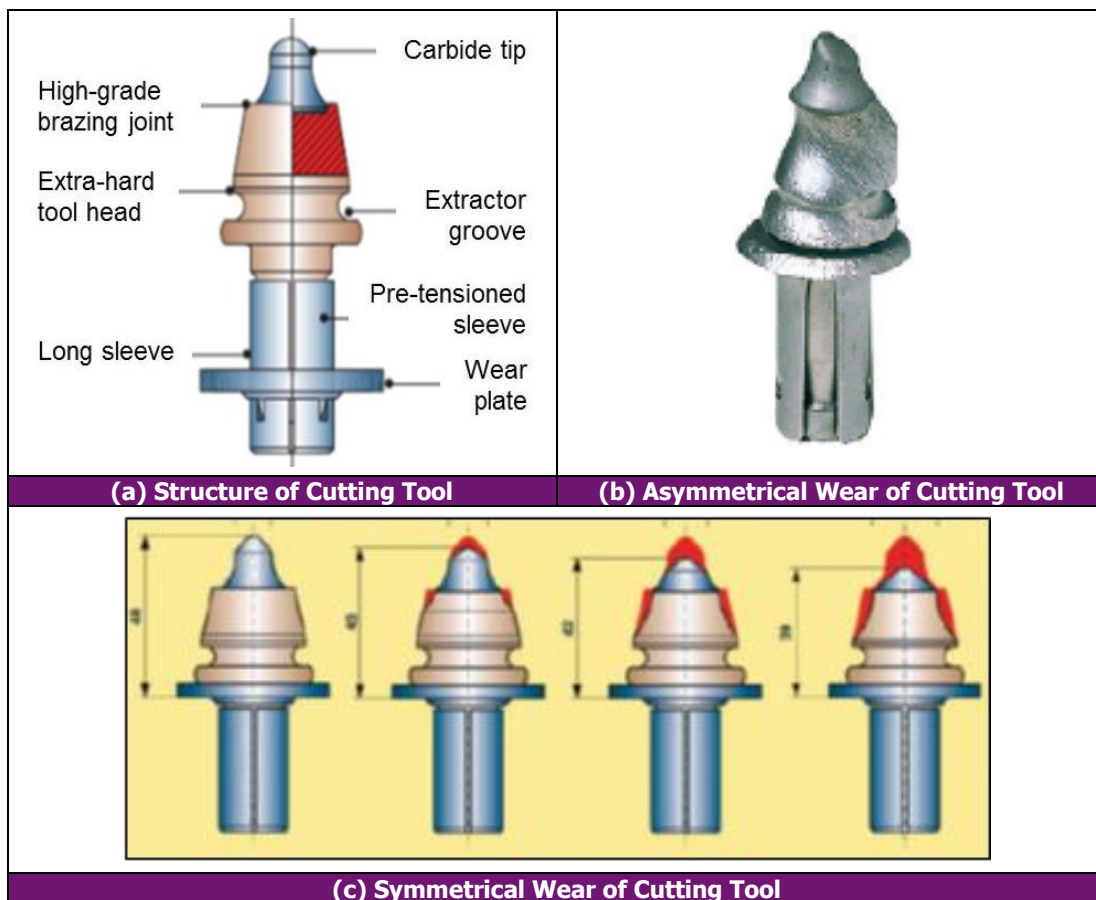


Figure 36. Cutting Tools

If the tool is prevented from rotating, wear concentrates on one side only and the life of the tool is drastically reduced. The wear pattern shown in Figure 36b develops rapidly, within a few revolutions of the drum. If not detected early, the tool will be ground away, exposing the tool holder to rapid deterioration and, eventually, the tool holder mounting and the drum itself are damaged. Regular checks on the condition of the cutting tools are, therefore, one of the most important procedures on a milling job.

Several types of tool holders are available, ranging from simple inexpensive weld-on types to complex "quick-change" models that bolt on to mountings positioned on the drum. Since it is the angle-of-attack that is largely



Cutting Tool

Regular checks on the condition of the cutting tools are one of the most important procedures on a milling job.

responsible for rotating the tool within the holder, precise positioning of the tool holder is critical to ensure longevity of the tools.

Cutting tools are expensive items. The cost of one standard all-purpose milling tool is around R30 at 2010 prices. Special-purpose tools, e.g., abrasion-resistant tools, cost more. Cutting tools, therefore, play a major role in the cost of milling, and all facets of the operation influencing tool wear need constant attention. In addition to tool wear, the speed of rotation of the drum, the effectiveness of the water spraying system and advance speed of the machine need monitoring.

2.6.2.3 Scraper Blades

The rear of the milling chamber consists of a thick steel plate that is lifted and lowered by a hydraulic cylinder, thereby allowing the pressure exerted on milled surface to be varied. Wear resistant "scraper blades" are attached to the base of the rear plate, shown in red in Figure 37. These blades pick up and blade forward any milled material that is not lifted on to the discharge conveyor. Both the pressure exerted by the hydraulic cylinder and the condition of the blades, are important determinants of the amount of material, normally fines and dust, that remain on the milled surface after the machine has passed. Such material must be removed before the milled surface can be overlaid with new asphalt.

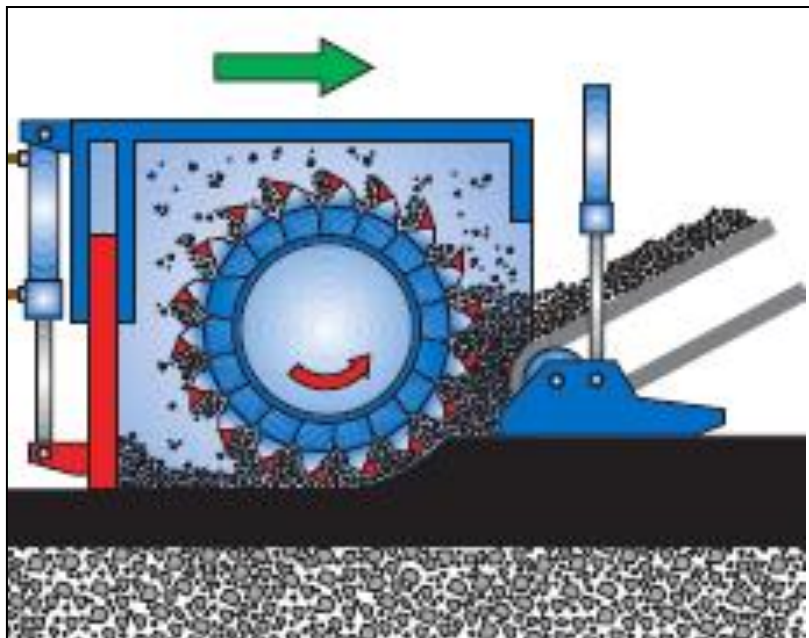


Figure 37. Scraper Blades on Milling Machine (shown in red)

The amount of pressure exerted on the scraper blades also influences the regularity of the milled surface, by removing high ridges caused by irregular wear of individual cutting tools, especially when fine or micro-milling. This practice increases the rate at which the blades wear. Preference should be given to maintaining the condition of the cutting tools, rather than relying on the scraper blades to level off poorly cut surfaces.

Where a conveyor belt is not employed to remove the milled material, the rear plate is lifted to allow the material to exit as a layer of uniform thickness. Some machines, including most of the large models, are equipped with a door in the centre of the rear plate that allows the material to exit as a windrow, thereby making it easier to pick up using a loader.

2.6.2.4 Conveyor Belt

The conveyor belt is a critical determinant of production potential, particularly for the larger machines fitted with a two-belt system. A two-belt system has a short receiving belt directly in front of the milling chamber that receives the milled material and feeds it on to the main delivery belt. The width of the belts and speed of travel are key features. Varying the delivery belt speed facilitates the filling of long trucks, as shown in Figure 38a. A large slewing angle (Figure 38b) allows the feed to be directed from one receiving truck to another, without stopping the operation.

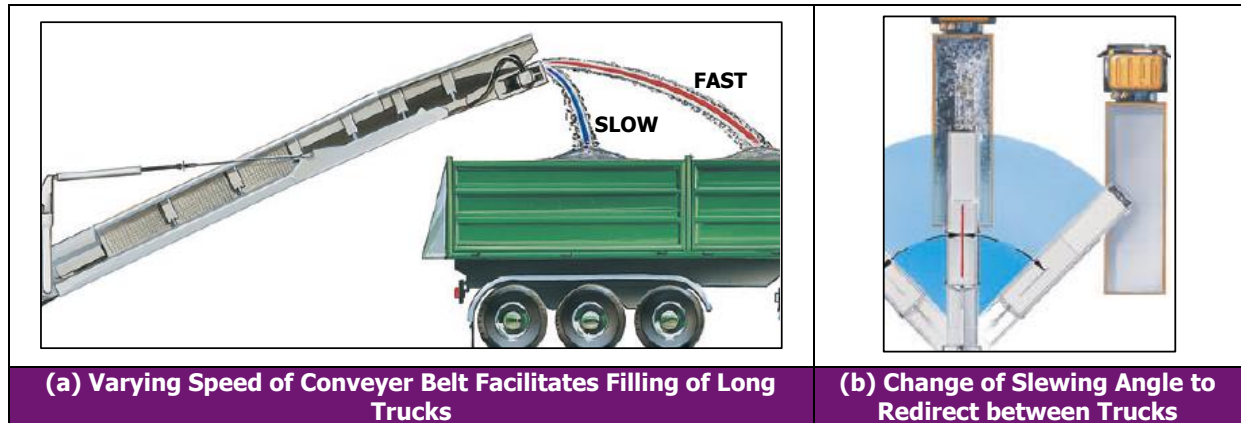


Figure 38. Conveyor Belt for Milling Machine

Some of the more modern large machines are equipped with a dust extractor that operates using the same principal as a vacuum cleaner. The milling chamber is subjected to negative pressure that allows dust particles to be collected, fed forward and deposited on the delivery conveyor. Water sprays directly onto the material as it discharges off the delivery conveyor ensure a dust free operation.

2.6.2.5 Level Control Systems

Unless milling is undertaken solely for the purpose of removing asphalt from an abandoned pavement, milling work is always carried out using a control system that assists in achieving a specific cut profile. This requires the depth of cut to vary continuously, both longitudinally in the direction of travel, and transversely across the cut width. Control systems allow the milling drum to cut to a defined horizon (line, level and cross-slope) by constantly adjusting the height of each leg connecting the machine and the ground, as shown in Figure 39. Whilst the machine follows the existing surface, regardless of the number of dips and bumps it traverses, the cutting drum is locked on to the required horizon.

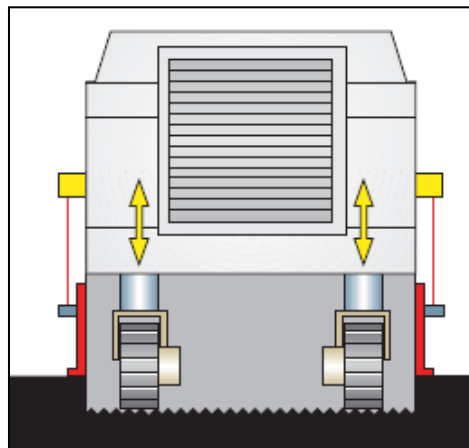


Figure 39. Control Systems on Milling Drum

Several different control systems are available, which all do the same job, but with varying degrees of accuracy:

- The simplest system works on a **wire rope sensor** connected to the side plates of the milling chamber that run on the surface of the existing pavement, sliding up and down relative to the cut depth. The long side plate acts as a skid, levelling out minor local unevenness in the "reference surface" (the existing pavement surface). This system is normally set up with the sensor measuring on one side of the machine only, and the transverse cut slope set to a predetermined value, e.g., 2% on cambered sections.
- **Ultrasonic sensors** use high frequency waves to reflect off a reference surface. Such sensors are contact-free and are, therefore, more reliable. Several different reference surfaces can be employed, ranging from the side plate of the drum housing to pre-surveyed string lines and long skids often used for paving operations. The use of multiple sensors can even out roughness.

- **Rotating lasers** define the reference surface. Sensors on the machine continuously feed data to an on-board computer, which compares the existing and reference surfaces, and adjusts the height of each leg accordingly.
- **3D systems based on an advanced survey system**, for example total station or DGPS, measure the absolute position of the machine in three dimensions and automatically regulate the height and slope to meet the required digital model, which is preloaded in to the on-board computer. These systems achieve the highest degree of milling accuracy and are popular on large projects where multiple cuts are required to cover a wide pavement, such as on multi-lane highways and airport runways.

Regardless of the control system employed, the limitations imposed by wear on the cutting tools must be recognised when searching for accuracy. Specifying tight tolerances for milling, e.g., less than 5 mm, is impractical, since the normal wear over the life of a cutting tool is more than 10 mm (see Section 2.6.2.2). However, where such accuracy is deemed necessary, the milling drum needs to be in excellent condition and all tools changed at regular intervals, not only those showing advanced wear. Such a requirement has a major impact on the cost of the project, especially when using a micro-milling drum fitted with more than 200 tools.

2.6.2.6 Grading Control Beam

Milling operations are generally carried out on old pavements, where the asphalt may be suffering from several different types of distress. Since milling drums normally up-cut, it is not unusual for the layer of asphalt to “slab out” and be pushed along the surface to the front of the milling chamber. This often occurs where relatively thin asphalt layers have delaminated and/or where the asphalt exhibits advanced crocodile cracking. This tendency is significantly reduced with a gradation control beam, which is a standard feature on most large machines.

A gradation control beam is a sturdy steel skid-type of frame, mounted on a swing-arm immediately in front of the milling chamber. The beam is lowered hydraulically and locked in position to run on top of the pavement, thereby preventing slabs of asphalt from lifting in front of the machine. The alternative is to turn the machine around and mill in reverse, thereby achieving a down-cut. This practice, however, is not popular due to increased wear and tool usage.

2.6.3 Milling Operation

Milling machines are primarily used in the following applications to remove asphalt from existing pavements:

- **Bulk asphalt removal.** The most common milling operation is the removal of asphalt wearing courses that have reached the end of their service lives, usually milling a 40 mm thick layer. Deep milling is undertaken to rehabilitate pavements with thick layers of asphalt with full-depth cracking.
- **Address asphalt surfacing deficiencies**, e.g., to improve skid resistance.
- **Special-purpose applications**, e.g., removing the asphalt for trench excavations.

2.6.3.1 Bulk Asphalt Removal

The focus of the type of work is production, achieving maximum output from the resources deployed on the site. As with most production intensive construction operations, the success of a milling operation is a function of experience, coupled with the amount and quality of planning undertaken before the work begins. The following are the most important considerations:

- **Project characteristics** that determine the appropriate milling machine, drum type and the anticipated output in terms of tons of milled material generated per working hour.
- **Number of obstructions and their characteristics** influence the decision to deploy two or more different types of milling machines. For example, small machines for milling around manholes, and cutting tapers at intersections and accesses.
- **Time frame and limitations on working hours.** For example, night work only and the area milled must be repaved prior to opening to traffic.
- Details for **closing off the working area**, dealing with public traffic and access details for the trucks carrying the milled material to the dump site.
- **Logistics** in terms of the location of, distance and routing to, and general arrangements at the site where the milled material is offloaded. This dictates the logistics necessary for achieving production, and is often the limiting factor.
- Compiling a **production plan** including details of how the work will be tackled. Such a plan must include the number and sequence of cuts required to achieve the specified horizon, i.e., depth and width to be milled.

- **Work required before production milling can commence.** In addition to closing off the working area, this includes dealing with obstructions and, where required, establishing the necessary survey controls for accurate milling.
- **Locating and dealing with hidden obstructions.** This usually involves using a metal detector to locate, investigate and, where necessary, remove obstacles such as buried manhole covers.
- **Work required after milling.** In addition to sweeping and removing material remaining on the milled surface, this work often involves the provision of temporary access to properties.
- **Clearing the site at the end of the shift.** This may call for all plant and equipment to be transported to a temporary holding area, that may be distant from the site.
- **Compiling a detailed list of all plant and equipment required** on site, including details of when each item is needed, the duration of deployment and any necessary back-up provision.
- **Deployment of personnel** with suitable expertise, together with a detailed delegation of specific responsibilities.

Logistics always play a leading role in determining the production rate achievable on site. Often a bottleneck is encountered in disposing of the milled material. This may be caused by factors beyond the control of those responsible for the project, e.g., traffic congestion. Material removal then becomes the primary factor to consider when planning the work. It makes little sense to deploy a large milling machine and plan on removing 250 tons of milled material per hour, when it is only possible to transport 50 tons per hour away from the site.

2.6.3.2 Addressing Surface Deficiencies

Milling operations generally focus on achieving quality rather than quantity. Pavements that are structurally sound, but suffer from defects in the asphalt surfacing, can often be treated by milling. Texture problems, i.e., poor skid resistance, and minor deformation, such as shallow ruts, can often be addressed by removing the uppermost portion of the asphalt, normally less than 20 mm, before applying a new surfacing. Depending on the specific pavement, such a new surfacing may call for an asphalt overlay on major roads, or a simple fog spray on low volume roads.

Where an asphalt overlay follows the milling, a standard drum is often used. However, where the milled surface is to be trafficked or where a micro-surfacing or surface treatment is envisaged, a fine milling drum or micro-texturing drum is preferred. Figure 40 shows the difference between a standard milling drum, Figure 40a, with tools positioned to produce cuts at 15 mm spacing, and a fine milling drum, Figure 40b, producing cuts spaced at 8 mm. The texture of the milled surface achieved with a fine milling drum is shown in Figure 40c.

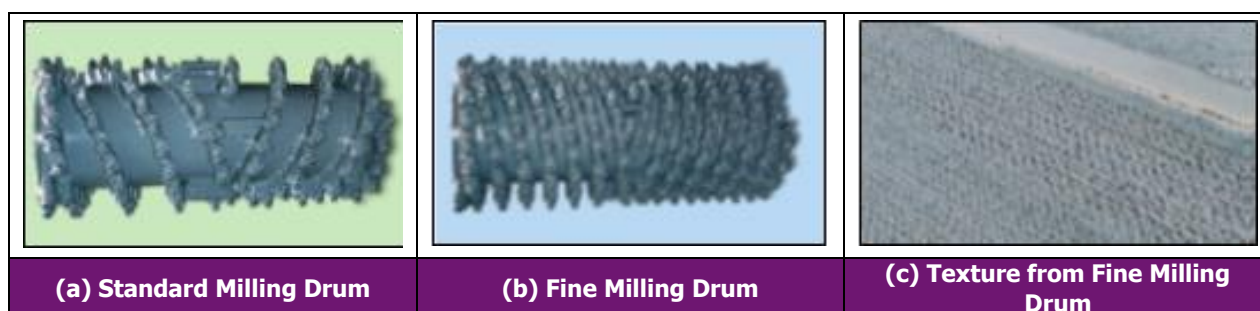


Figure 40. Milling Drums

For special applications, micro texturing drums that cut a 3 mm spacing are also available. The number of tools fitted to a 2000 mm wide drum increases from 146 on a standard drum, to 274 on a fine milling drum, and 672 on a micro milling drum.

2.6.3.3 Special Purpose Applications

Small machines are also used for the following “special application” milling work:

- **Removal of road markings** for less than 500 mm cut widths, using a fine milling or micro texturing drum.
- **Removal of the asphalt portion of the pavement for trenching**, less than 1000 mm cut widths.
- **Removing the asphalt around obstructions**, less than 500 mm cut widths.
- **Creating rumble strips** in the asphalt, using a fine milling drum and less than 200 mm cuts widths. For this application, the rear right wheel of the machine is exchanged for a five-sided wheel, to facilitate a constant cut interval.

- **Cutting slots in the asphalt for cables and loops.** For these applications, special cutting wheels or blades vary in width from 20 mm to 80 mm.

These applications use a standard machine fitted with a special-purpose drum, cutter or wheel. Although they can all be carried out using other tools, for example, a concrete saw and breaker for trench cutting, using a milling machine increases the utilisation of a machine that is often already on site, thereby reducing the overall cost of the project.

2.6.4 Production

The output of a milling machine is influenced by the following primary parameters:

- **Type and condition of the milling machine**, especially the drum
- **Milling requirements**, such as thickness and relative hardness of the asphalt to be removed
- **Site conditions**, i.e., open, obstructions, restricted, or confined
- **Climate**, especially the anticipated temperature range of the asphalt
- **Expected weather conditions**, such as clear, raining, or misty
- **Trucking capacity** for transporting the milled asphalt
- **Site access and traffic accommodation** constraints
- **Competence and experience** of work crew

These factors all need to be considered in estimating the anticipated production on a specific milling project. Production estimates are normally based on performance data obtained from the manufacturer of the milling machine, reduced to realistic expectations by applying a “production adjustment factor” that takes account of the above parameters. The suggested parameters, and effective range of influence that each has on production, are shown in Table 3.

Table 3. Production Adjustment Factor

Parameter	Factor Values
Milling machine condition	Old, poor condition: 0.3. New or reconditioned: 1.0
Site conditions	Urban, obstructions: 0.5. Open (e.g., runways): 1.0
Climate (surface temperature)	1.0 plus/minus the temperature in °C above/below 15 °C
Weather conditions	Dry, sunny: 1.0. Raining, misty: 0.5
Trucking capacity	1.0 minus anticipated time waiting ratio. For example, if trucks have 30% waiting time, then $1 - 0.3 = 0.7$
Site access	1.0 minus time lost due to limited access ratio
Site crew	“Inexperienced”: 0.4 ranging to “Very experienced”: 1.1
Production adjustment factor	Product of all the above factors multiplied together

The procedure used to estimate production is best explained by means of examples in Table 4 and Table 5.

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Table 4. Production Example for Small Milling Machine

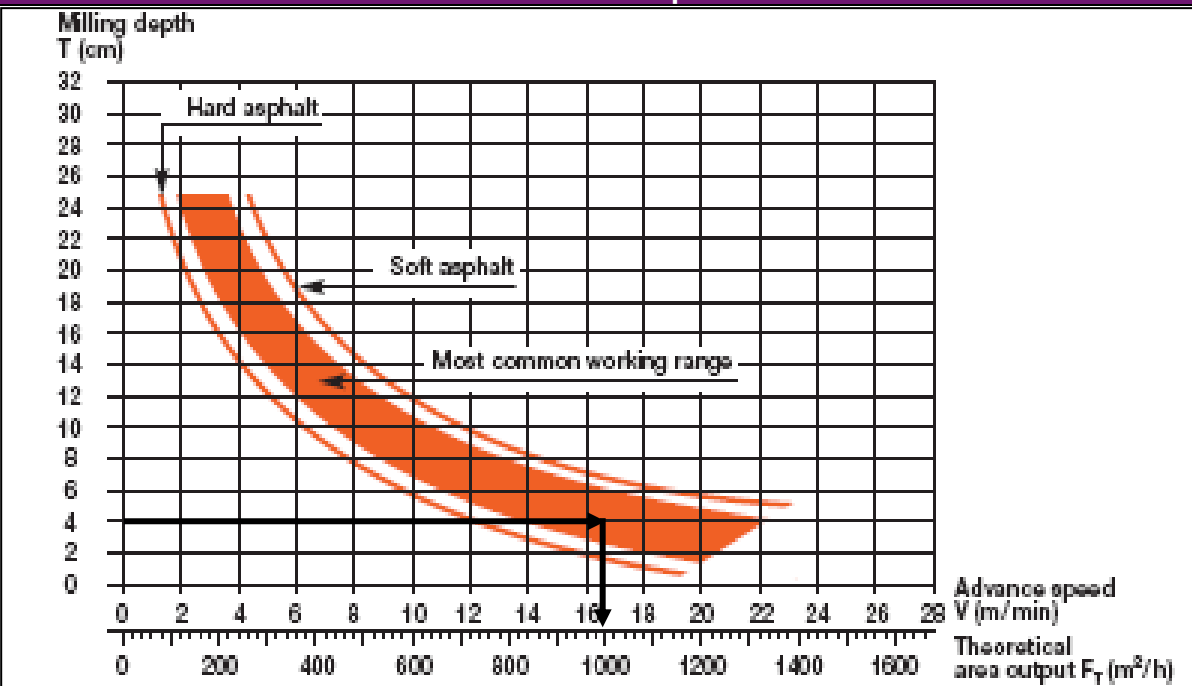
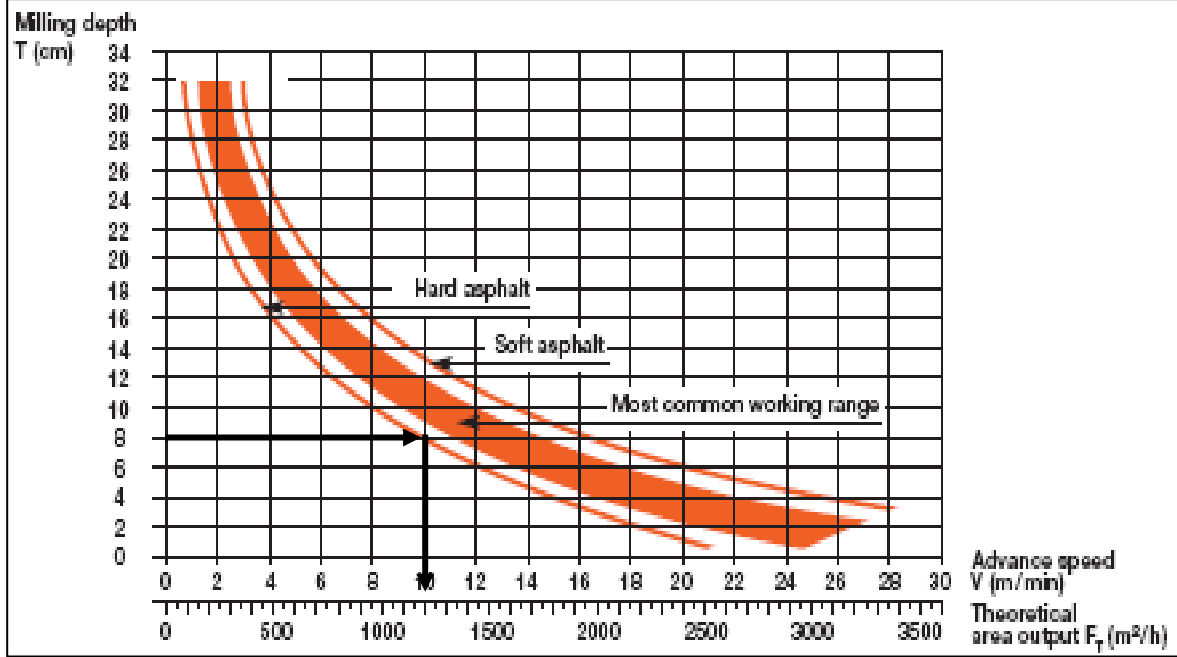
Project		
Description	This example is for a rear loading milling machine with a standard drum (cut width of 1000 mm) operating in an urban environment. Output is based on the performance graph obtained from the manufacturer.	
Details	Mill and remove 0.040 m asphalt (moderate hardness) from 5 000 m ² of urban street.	
Calculate the Production Adjustment Factor		
Parameter	Factor	
Milling machine condition:	Recently reconditioned	1.0
Site conditions:	Urban street with manholes	0.5
Hot climate:	Average daily surface temperature > 45 °C	1.3
Weather conditions:	Clear and dry, no rain forecast	1.0
Trucking capacity:	Sufficient trucks in attendance	1.0
Site access:	Single lane closure, 20% delays	0.8
Site crew:	Experienced team	1.0
Production adjustment factor	0.52	
Total Quantities for Project		
Volume:	5 000 x 0.04 = 200 m ³	
Mass: (assumed density 2400 kg/m ³)	480 000 kg = 480 tons	
Theoretical Output		
		
Theoretical output (from graph)	1000 m ² /hour	
Production Rate		
Volume:	1000 x 0.52 x 0.04 = 20.8 m ³ /hour	
Mass (density 2 400 kg/m ³)	= 49.9 tons/hour	
Time Required		
Working hours:	480 tons / 49.9 tons/hour = 9.6 hours	

Table 5. Production Example for Large Milling Machine

Project	
Description	This example is for a milling machine with a standard drum (cut width of 2000 mm) operating in a rural environment. Output is based on the performance graph obtained from the manufacturer.
Details	Mill and remove an 80 mm thick layer of hard, aged asphalt from 10 km of the slow lane (3.7 m wide) of one carriageway on a heavily-trafficked highway between two towns.
Calculate the Production Adjustment Factor	
Parameter	Factor
Milling machine condition: <i>Reasonable Condition (4 000 hours)</i>	0.8
Site conditions: <i>Rural, no obstructions</i>	1.0
Warm climate: <i>Expected surface temperature > 35 °C</i>	1.2
Weather conditions: <i>30% probability of rain showers</i>	0.9
Trucking capacity: <i>Long haul, expect 20% delays</i>	0.8
Site access: <i>Lane closure: 10% delays</i>	0.9
Site crew: <i>Team well experienced</i>	1.0
Production adjustment factor	0.62
Total Quantities for Project	
Volume:	37 000 x 0.08 = 2 960 m ³
Mass: (assumed density 2350 kg/m ³)	= 6 956 tons
Theoretical Output	
	
Theoretical output (from graph)	1 200 m ² /hour
Production Rate	
Volume:	1 200 x 0.62 x 0.08 = 59.5 m ³ /hour
Mass (density 2350 kg/m ³)	= 139.8 tons/hour
Time Required	
Working hours:	6 956 tons / 139.8 tons/hour = 49.8 hours

2.6.5 Reuse of Asphalt Millings

Asphalt is one of the most recycled materials in the world, primarily as an aggregate substitute in hot mix asphalt, mostly for use in base layers. Recent advances in both cold-mix technology and bitumen stabilization have resulted in an increased demand for reclaimed asphalt (RA), since it provides an ideal parent material, particularly where a superior quality base material is required. However, for all applications, the grading of the RA is of paramount importance, influenced by numerous factors, the primary two are:

- **Machine factors:** The method of reclaiming the asphalt from the existing pavement.
- **Asphalt factors:** The composition, uniformity and condition of the existing asphalt material.

2.6.5.1 Machine Factors

The machine factors influencing the reuse of asphalt millings include:

- Type of milling machine used.** Large milling machines are used on larger projects where high production rates are required and/or thick layers of asphalt are removed with each cut. Smaller machines are normally used on smaller projects and to remove asphalt from confined areas where production output is not of primary importance. As shown in Figure 41, the advance speed of the milling machine, and the depth of cut, have a significant influence on the grading of the milled RA. High production rates demand increased speed. Research undertaken on RA material in Brazil (Bonfim, 2008) showed that advance speed and production rate play an increasingly significant role on the coarseness of the RA as the milling depth is increased. When milling thin lifts, i.e., depth of cut < 50 mm, increasing the speed of advance from "slow" (3 m/min) to "fast" (10 m/min) has little effect on the grading. Newer machines generally produce a more consistent product, thanks to advances in technology incorporated in their design. Such technological advances include engine management systems and gradation control mechanisms.



Recycled Asphalt (RA)

RA is discussed in more detail in:

- Chapter 3: **Materials Testing**, Section 4.2.4
- Chapter 9: **Material Utilisation and Design**, Section 10.1

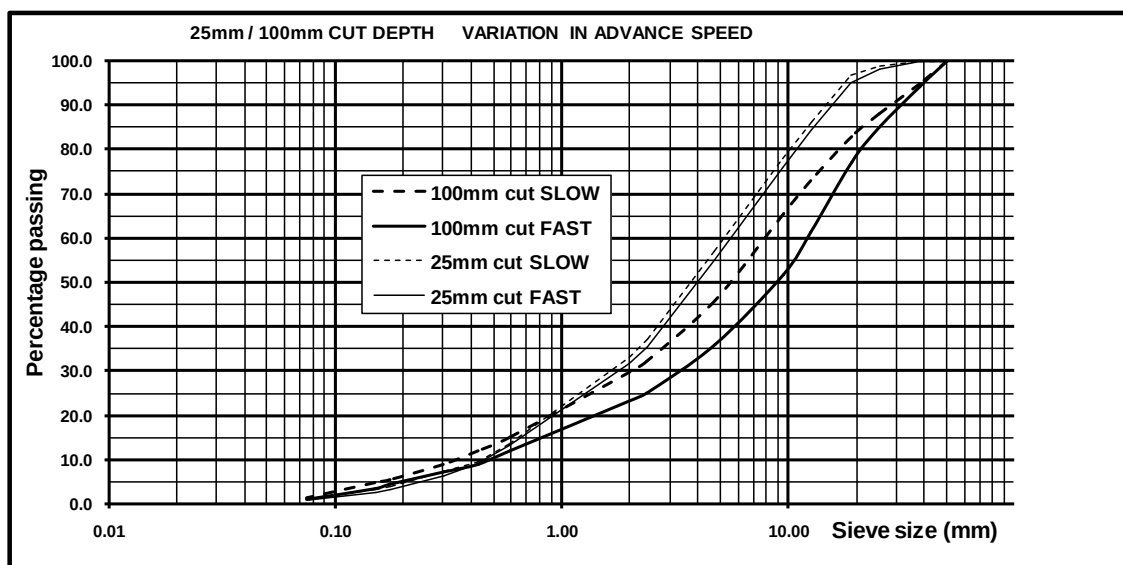


Figure 41. Grading Curves Showing Effects of Increasing Cut Depth and Advance Speed

- Type of milling drum.** The type of milling drum fitted to the machine significantly influences the grading of the RA. Micro-texturing drums with closely spaced cutting tools produce a much finer RA than a standard milling drum.
- Direction of cut.** When the direction of rotation of the milling drum lifts the asphalt (up-cutting), a coarser product results than that obtained when down-cutting, where the cutting tools impact on the pavement from above as the machine advances.
- Condition of the machine, milling drum and cutting tools.** Poorly maintained machines invariably produce a RA material with an inconsistent grading. In particular, the cutting tools play a major role in determining the grading of the milled material; a drum fitted with a new set of tools produces a more uniform product, compared with one where some of the tools are new and some are worn.
- Condition of the scraper blades.** The condition of the scraper blades and, to a lesser extent, the lifting plates on the drum, influence the maximum particle size and amount of material that remains on the milled surface, by escaping under the rear door as the machine advances. This material, later picked up by a sweeping and cleaning team, is usually disposed of separately and not added back to the RA. Since most of this material is composed of fines less than 5 mm, the effect on the grading curve is significant.



Condition of the Milling Machine, Drum and Cutting Tools

Poorly maintained machines invariably produce a RA material with an inconsistent grading. In particular, the cutting tools play a major role in determining the grading of the milled material. A drum fitted with a new set of tools produces a more uniform product, compared to one where some of the tools are new and some are worn.

- **Machine operation.**

- The **machine set up and operation** has a direct influence of the grading of the milled RA. As illustrated by the grading curves in Figure 41, the depth of cut and speed of advance are primary factors. For example, milling a 100 mm thick layer of asphalt in two 50 mm cuts produces a finer RA material than that produced from a single 100 mm thick cut. In addition, drum rotation speed influences the grading; the faster the speed of rotation, the finer the milled product.
- Where the existing asphalt has severe crocodile cracks, **maintaining the depth of cut** within the body of the cracked layer encourages pulverisation, rather than lifting chunks of asphalt from the pavement. When such conditions are encountered, the use and positioning of a gradation control beam has a significant effect on the grading of the product.
- Another important factor is the **consistency of the milling operation**. The RA produced from a steady continuous operation is different from that produced when numerous interruptions are encountered.
- Maintaining a **constant application rate of water sprayed into the milling chamber** also influences the amount of finer material that adheres to the coarser particles, and are thus included with the RA and not left on the milled road surface.

2.6.5.2 Asphalt Factors

The asphalt factors that influence the reuse of asphalt millings include:

- **Composition and nature of the asphalt material in the existing pavement.**

- Where the milling depth encounters **several layers constructed from different asphalt mixes**, e.g., a coarse dense base macadam overlaid with a binder layer and surfacing, the grading of the RA reflects all constituent mixes. Where the existing pavement is relatively consistent, each layer can be milled off separately in an endeavour to obtain a uniformly graded RA material. However, where the pavement includes patches, overlays and other relics of maintenance interventions, the grading and composition of the milled RA will vary.
- The **extent of ageing of the bitumen binder and the binder type** used in the asphalt mix always plays a leading role in determining the grading of milled RA. Asphalt manufactured with polymer modified bitumen and bitumen rubber is tough to mill and produces a relatively coarse RA. Surface treatments applied on top of asphalt also have a significant influence on the grading of the milled RA, often as a consequence of bitumen stripping from the aggregate in the underlying asphalt.
- **Other materials** used to maintain pavements, for example, strips of bitumen rubber from crack sealing, reinforcing layers and stress absorbing membranes that incorporate thick geotextile materials, have a significant effect on the nature of the milled RA, and may even eliminate its potential for reuse in a new pavement layer.

- **Type of distress in the asphalt material.** The grading of milled RA material emanating from severely cracked asphalt differs from that produced when milling an asphalt layer that is badly deformed, but intact, e.g., wheel path ruts. Where cracking is intense, for example, closely spaced crocodile cracks and the thickness of the asphalt is relatively thin, chunks of material (> 50 mm) in the milled RA material are unavoidable.

- **Extent of distress.** The grading of milled RA varies with the type of distress affecting the asphalt. Where cracking is confined to isolated sections in the wheel paths, the grading of the milled RA varies, influenced by the proportion of cracked to uncracked asphalt encountered across the width of cut, at any specific location.

2.6.6 Practicalities

It is important to recognise that the grading of milled RA material is always influenced by the purpose of the milling exercise. Where a contractor is milling for the sole purpose of removing asphalt from the road, the focus is on production at the lowest possible cost, not on the grading of the RA material. However, when the focus changes to milling to recycle the RA, the attention is entirely different, since the grading of the milled product assumes greater importance.

2.7 Recycling Machines

A recycling machine is a large purpose-built machine that recovers and simultaneously re-uses material from the upper portion of an existing pavement for the express purpose of constructing a new layer. These machines are also called “in situ recyclers”. The heart of the machine is the “cutter” that is a large cylindrical drum equipped with a multitude of cutting tools. The rotating cutter is lowered to the required depth in the pavement and the machine then advances along the road with the cutter normally rotating upwards relative to the direction of advance.

As the machine advances, the material encountered within the recycling horizon is pulverised, including previously bound material, such as asphalt. Simultaneously, water and other fluids, for example, bitumen emulsion or foamed bitumen, are accurately metered and injected into the recovered material inside the cutter housing or “mixing

chamber". All materials are mixed together by the rotating action of the cutter to form a homogeneous mix. The mixed material is then placed back on the road at the rear of the machine where it is shaped and compacted to form the new layer. This process is termed the single-pass cold recycling process and is illustrated schematically in Figure 42.

Where the material recycled from an existing pavement is not of sufficient quality for re-use, additional fresh material can be imported, spread and shaped on top of the road surface prior to recycling. In this way, the in situ material is blended together with the new material, to achieve the required quality.

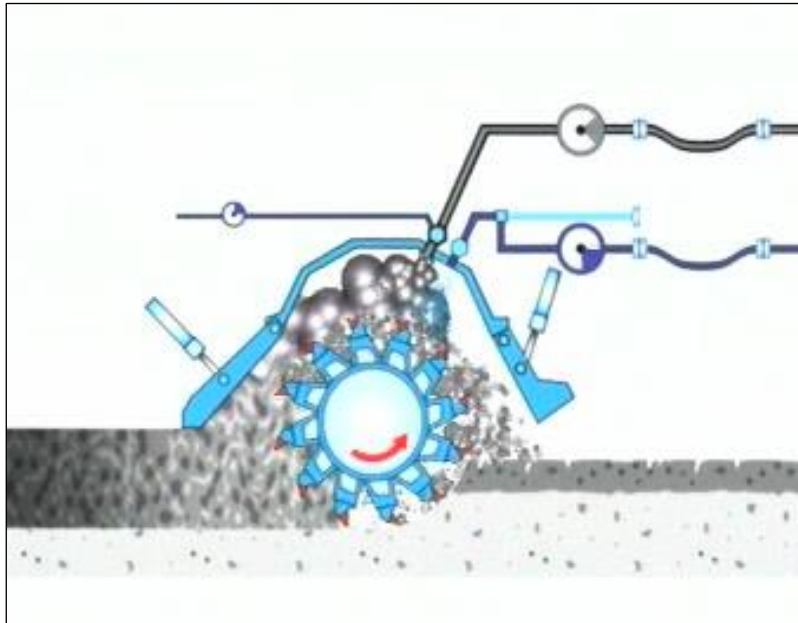


Figure 42. Recycling Machine Pulverising, Mixing and Placing

The depth to which a specific pavement is recycled, and the requirements for stabilizers, are determined in the pavement design process. Although most modern in situ recyclers can operate efficiently at cut depths between 100 mm and 500 mm, the normal depth of cut for most recycling projects is between 150 and 300 mm. This range is used mainly due to difficulties compacting thicker layers.

Recyclers have introduced pavement engineers to a whole new range of possibilities, the most important being the ability to construct thick monolithic layers of a stabilized material. This was not previously possible using conventional road building machines, due to the sheer volume of material that had to be mixed, placed and compacted within a limited period of time. From a structural perspective, a single 300 mm thick layer of stabilized material has a higher load-carrying capability than two separate 150 mm thick layers constructed one on top of the other, due to possible slippage on the interface between the layers.

In situ recyclers are designed to recover and mix the material from all types of flexible pavements whilst pushing (and/or pulling) bulk tankers containing the required additives. They are, therefore, heavy machines equipped with a large engine to deliver sufficient power for this purpose. They also have micro-processor controlled pumping systems and spray bars to regulate the flow rate of stabilizers relative to the volume of material in the mixing chamber. They should not be confused with lighter, less powerful machines that are used to mix relatively soft material, known in the industry as "stabilizers" or "pulvimixers". In situ recyclers can, however, be used as stabilizers but stabilizers are neither capable, nor are they equipped, to recycle pavement layers.

The term "recycler" is sometimes used for off-site mixing plants capable of mixing a variety of materials, including those recovered from pavement layers and placed in temporary stockpile. Where these units are specifically designed to treat materials recovered from existing pavements, usually recovered asphalt millings, with stabilizer (especially foamed bitumen), they are often referred to as "recycling units". This is a misnomer because these machines are actually sophisticated mixing units that treat a range of materials, as well as recycling those recovered from existing pavements.

Two reference documents relevant to recycling machines that can be downloaded at no cost are:

- Wirtgen “Cold Recycling Manual” (2010): www.wirtgen.de
- Asphalt Academy’s TG2 “Technical Guideline: Bituminous Stabilised Materials – A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials”: www.asphaltacademy.co.za

2.7.1 Types of Recycling Machines

There are three types of in situ recycling machines, which are described in the following sections together with their respective capabilities:

- **Tyre mounted** recyclers
- **Track mounted** recyclers
- Machines fitted with an **on-board mixing unit**

2.7.1.1 Tyre Mounted Recyclers

These machines are designed primarily for recycling. All four wheels are fitted with high-flotation tyres, each driven by a hydraulic motor, providing traction and stability. Different sizes of machines are available, ranging from the smallest (± 20 ton/400 HP) models with a cut width of 2.0 m, up to the largest (± 35 ton/800 HP) machines with a cut width option of 2.5 m or 3.0 m. An example of a tyre mounted recycler is shown in Figure 43.



Figure 43. Example Tyre Mounted Recycler Showing Recycling Wheel Paths

The most popular machines have the cutter housing attached to the main frame. The cutter and its motor are mounted on an arm that swings downwards as the drum is lowered into the pavement, thereby increasing the volume of the mixing chamber above the cutter. This feature allows material recovered from varying cut depths, up to a maximum of 500 mm, to be accommodated and effectively mixed in the chamber. Where the cutter and housing are both fixed to the main frame of the machine, the depth of cut is constrained by the fixed volume of the mixing chamber, as is the case with most track mounted machines.

As shown in Figure 44, the point attack tools are positioned in a chevron pattern and mounted on stanchions to promote mixing. This tool configuration promotes mixing in the vertical plane, but not the horizontal. This means that the recovered material is not thrown sideways (laterally) or lengthways (longitudinally) over any appreciable distance from its original location within the pavement. The maximum movement measured from tests is

200 mm. Recycled material can, therefore, not be cross-blended with this type of cutter. Localised areas or strips of different materials in the recycled horizon are returned to the pavement, after recycling, in approximately the same location. The resulting material, therefore, reflects the original differences.



Figure 44. Cutters on a Tyre Mounted Recycler

Layers of dense unbound material are easily broken apart, returning to their original uncompacted state. The degree to which layers of bound material, e.g., asphalt, are pulverised and the resulting grading is influenced mainly by the advance speed of the recycler, but also by the cutter rotation speed. The faster the advance speed, and the slower the speed of rotation, the coarser the product. Large lumps of material that are not pulverised in the process, tend to be thrown to the bottom of the layer and are not easily visible.

Since they are mounted on flexible tyres, these recyclers must attack thick layers of hard or well-bound material from below. The cutter must first penetrate through to the underside of the hard layer before the machine can advance, pulverising the material. Attempting to work with the cutter lowered only partially into such hard material, e.g., aged asphalt, causes the machine to bounce, damaging the tools and tool holders.

The rear wheels of these machines are located inside the extremities of the cut width and, therefore, run on the outer edges of the recycled material. This means that the material in the wheel paths is compacted, whilst the material between the wheel paths remains in a loose ("fluffed") state, as illustrated in Figure 43.

In addition to recycling, the inherent stability and traction capabilities make these machines ideal for soil stabilization. They are also used extensively to pulverise thick layers of bound material in existing pavements, with larger machines used for thicker layers. Increasing use is also being made of these machines to pre-treat thick layers, up to 500 mm thick, in the lower portion of the pavement. Such pre-treatment includes breaking down clods of material or soft rock, with the addition of water to achieve a consistent moisture content that facilitates compaction.

2.7.1.2 Track Mounted Recyclers

These machines, shown in Figure 45, were the first in situ recyclers, preceding the tyre mounted models by several years. They are essentially large milling machines that have been adapted for recycling. The cutting drum, shown in Figure 46, is the same as that used for milling asphalt, with point attack tools mounted in a helical pattern that windrows the material to the centre of the drum.

Instead of being lifted onto a belt and removed, as happens when milling, the recovered material exits through a door in the rear of the milling chamber and passes between the rear tracks to be spread across the width of cut by an auger fitted at the back of the machine. A paving screed is usually incorporated to pre-shape and pre-compact the material spread by the auger. The required surface levels and shape can often be achieved by using such a screed, thereby eliminating the need for a grader to cut final levels.



Figure 45. Example of a Track Mounted Recycler

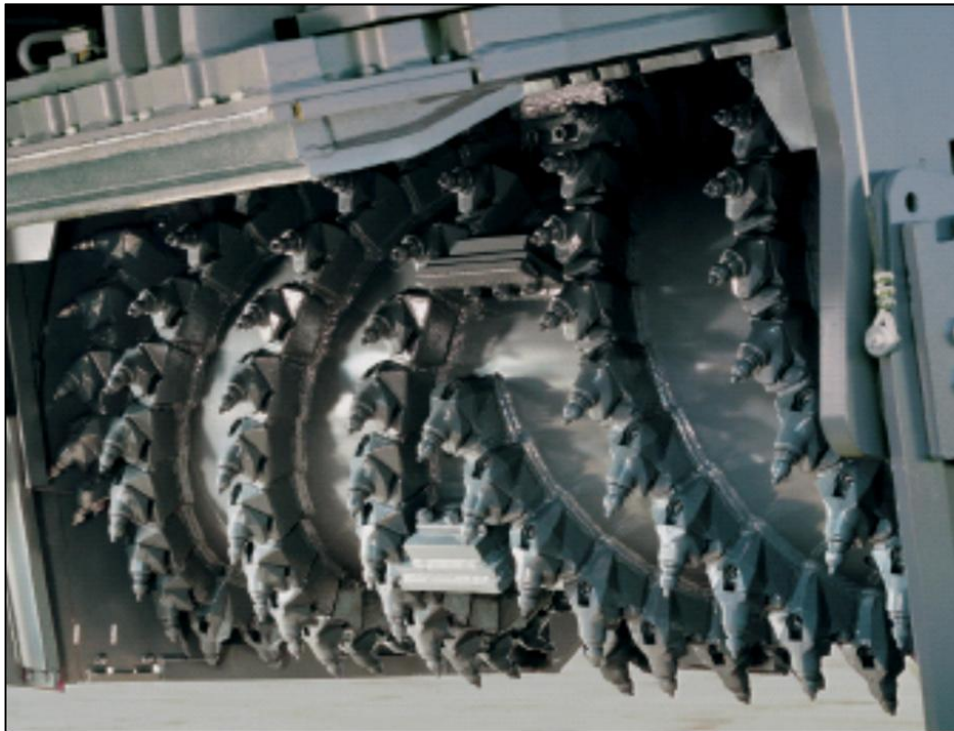


Figure 46. Standard Milling Drum Fitted to a Large Machine

As with the tyre mounted recyclers, micro-processor controlled pumping systems are incorporated. Spray bars attached to the outside of the drum housing inject fluid additives into the material in the milling chamber.

Unlike tyre mounted recyclers, the windrowing action of the tool pattern promotes blending of the material recovered by each half-width of the drum. The material is, however, not fully cross-blended as the material tends to exit through the rear door in the respective halves, and is spread back by the auger over the half where it originated.

Milling machines are designed and built to provide stability when cutting into layers of hard asphalt. Both the drum housing and the milling drum are attached to the frame of the machine, and the depth of cut is varied by lifting or lowering the whole machine. This means that:

- The **drum does not have to penetrate to the underside of thick bound layers** to be able to recycle the material. It is, therefore, possible to recycle only the upper portion of thick bound layers.
- The **volume of the milling chamber is constant, regardless of the depth of cut**. The amount of material that can be mixed is, therefore, limited, and this restricts the depth of cut that can be recycled. A maximum of 250 mm can be cut when treating with a non-cohesive stabilizer, i.e., cement, or less when applying a cohesive stabilizer, i.e., foamed bitumen.

These machines are ideal for recycling 100% asphalt material. As with tyre mounted recyclers, the degree to which the asphalt is pulverised is influenced by the advance speed of the recycler and the rotation speed of the drum. However, unlike tyre mounted recyclers, there are different milling drums that can be used to vary the extent to which the material is broken down. For example, using a fine milling drum with twice the number of point attack tools will produce a significantly finer material. In addition, the direction of rotation of the drum can be changed from up-cutting to down-cutting to promote fragmentation.



Track Mounted Recyclers

These recyclers are ideal for recycling 100% asphalt material.

Furthermore, since milling drums are interchangeable, the width of cut may be selected by fitting a drum with the required width. As an example, a 3.8 m wide drum can be fitted to a large milling machine to allow the full width of a traffic lane to be recycled in a single pass.

2.7.1.3 Machines Fitted with an On-board Mixing Unit

Large track-mounted purpose-built recyclers with a mass in excess of 50 tons are also available in the market, an example of which is shown in Figure 47. These machines are capable of recycling all types of materials normally encountered in the upper portion of flexible pavements. However, being oversized and heavy, they are not as easily transported as the other recyclers. Their application is, therefore, normally confined to projects that include large volumes of recycling and/or where there is a demand for the special features that only this recycler provides. These include:

- **Partial depths of hard material**, e.g., aged asphalt can be recycled in situ up to 200 mm.
- **Adjustable working width**, ranging between 2.8 m and 4.2 m, which allows the entire width of one traffic lane to be recycled in a single pass. It also permits the location of longitudinal joints between adjacent cuts to be selected to fall outside the trafficked wheel paths.
- **Width of recycling can be varied** whilst working, making it easy to recycle tapering sections often associated with highway interchanges and toll plazas.
- **Material in the recycling horizon is milled and lifted into a twin-shaft pugmill mixer** mounted on the machine. Dual pumping systems allow for the accurate addition of stabilizer and water. The mixing quality achieved is similar to that of conventional off-site mixing plants.
- **Lifting the recovered material off the road and mixing on board** the recycler achieves a uniformity of mix across the full cut width. This means that the material recovered from the width of cut is fully cross-blended.

The treated material is discharged from the pugmill mixer onto the road as a windrow and spread by auger, mounted on the machine. A variable width paving screed is attached to the rear of the machine for placing the recycled material true to the required profile. This screed is equipped with both tampers and vibration for pre-compaction. However, since the machine has limited capacity for material retention, existing road surfaces that are badly out of shape need to be pre-milled to the required cross-fall and surface elevations before recycling.

Recycling machines with on-board mixing units are not commonly used in South Africa.

2.7.2 Equipment Control Measures

The following sections describe the main features and control of in situ recyclers. These are not exhaustive, and cover only those aspects that are of primary importance when using these machines on a specific project.



Figure 47. Recycling Machine Fitted with On-Board Mixing Unit

2.7.2.1 Type, Size and Power of the Machine

The machine selected for a specific recycling task must be capable of doing the work, and is the most important consideration of any recycling project. The various aspects described for the different recycling machines, need to be considered in light of the required work. The most important features that influence the suitability of a particular machine are:

- **Operating mass of the machine.** Is the machine big enough for the job?
- **Horsepower rating of the engine.** Is there sufficient power to recycle the material that will be encountered in the pavement?
- **Width of cut.** How many parallel cuts are required to cover the cross-section?
- **Cut depth and mixing capabilities.** In light of the stabilizer to be added.
- **Spray bar configuration.** Are they adequate?
- **Availability.** How many such machines are available in the local industry?



Selecting an In Situ Recycler

Selecting the right machine for the job is the most important consideration on any recycling project. Key considerations are:

- Machine operating mass
- Horsepower rating of the engine
- Width of cut
- Cut depth and mixing capabilities
- Spray bar configuration
- Availability

2.7.2.2 Cutter

The cutter (Figure 44) is the most important part of the recycler. It does the hard work of recovering and breaking down the material encountered in the recycling horizon. It also throws the material around inside the mixing chamber to achieve a homogeneous mix. The cutter fitted to a tyre mounted recycler is different to that of a milling drum on track-mounted machines. The main differences are:

- **Peripheral speed of the point attack tools.** The basic drum diameter on a recycler is larger than that on a milling machine. In addition, the individual tools on a recycler are fixed on stanchions that are attached to the drum, thereby increasing the effective diameter of the cutter to almost twice that of a milling machine, where the tools are fixed directly onto the drum. The peripheral speed of the tools is, therefore, far higher on a recycler than a milling machine, resulting in better pulverisation of the material. This results in a finer grading, especially where layers of bound material are recycled.
- **Elevating the tools on stanchions** provides additional space for mixing the recycled material, especially when the depth of cut increases.
- The **chevron mounting pattern for the tools** on a recycler allows all the energy to concentrate on cutting and mixing the material. The material is not moved sideways (windrowing) as it does with a milling machine where the tools are mounted in a helical pattern.

The cutter must be monitored for wear, and must be capable of rotating consistently at the required speed throughout the layer being processed.

2.7.2.3 Cutting Tools

Different tools are fitted for different cutting conditions:

- Tools with more tungsten carbide are used to recycle **harder materials**.
- Tools with thicker steel collars are used for more **abrasive materials**.

The speed of rotation is changed to influence the grading of the material obtained from previously bound layers, especially asphalt. The faster the rotation speed, the finer the material. However, increasing the speed of rotation increases the rate at which the tools wear down, so there is always a trade-off between achieving an acceptable grading and minimising tool wear.

Tools cost between R30 and R50 each (2010 prices). Therefore, the cost of replacing all ~200 tools on a cutter is a significant component in the total operating cost of recycling. The norm for the average wear rate for recycling an “average” pavement in South Africa is 1 tool per 10 m³ of material recycled, or replace all the tools for every 2000 m³ of material recycled.

All cutting tools must be checked regularly, to ensure that they are replaced before the wear limits specified by the manufacturer are reached.



Cutter and Cutting Tools

The **cutter** must be monitored for wear and must be capable of rotating consistently at the required speed throughout the layer being processed.

All **cutting tools** must be checked regularly, to ensure that they are replaced before the wear limits specified by the manufacturer are reached.

2.7.2.4 Mixing Chamber

The different architecture of the machines means that the volume of the mixing chamber on tyre mounted recyclers increases as the cut depth increases, compared to the fixed volume of the mixing chamber on track mounted machines.

The mixing chamber on tyre mounted recyclers is fitted with front and rear doors that open outwards (hinged at the top) by hydraulic cylinders. The front door is kept closed whilst recycling and a “breaker bar” fitted along the base of the door limits the space between the cutter and the breaker bar. This assists in breaking down oversized lumps of material. A strike-off plate is fitted to the bottom of the rear door and the pressure applied by the hydraulic cylinders dictates how long the material is retained in the mixing chamber. This has a significant effect of the quality of mix, especially where the depth of cut is less than 150 mm. The schematic in Figure 42 illustrates the workings of the mixing chamber.

Track mounted machines usually have a conventional breaker bar, mounted immediately in front of the drum housing. It presses down on the road surface, thereby assisting the chiselling action of the tools and preventing large lumps of material (normally distressed asphalt) from being lifted. However, where fresh material and/or a stabilizer is spread on the road in front of the recycler, care must be exercised to ensure that the breaker bar mechanism does not act as a dozer. The recycled material is windrowed to the centre of the mixing chamber where it exits through a door in the rear of the housing. This windrowing action, coupled with the fixed volume of the mixing chamber, exacerbated by the close mounting of the tools on the drum, places limitations on the depth that can be recycled. The maximum depths are normally 250 mm when mixing with bitumen emulsion or cement, reducing to 175 mm when treating with foamed bitumen, due to the propensity of such material to compact inside the mixing chamber.



Depths of Recycling with Track Mounted Machine

The maximum recycling depths are normally 250 mm when mixing with bitumen emulsion or cement, reducing to 175 mm when treating with foamed bitumen due to the propensity of such material to compact inside the mixing chamber.

2.7.2.5 Pumping Systems and Spray Bars

Recyclers are always equipped with at least one spray bar, attached to the leading face of the drum housing for injecting water into the mixing chamber. The spray bar consists of a feed pipe with a series of injection nozzles spaced equally along the bar at approximately 150 mm intervals. The injection point of the nozzles protrudes into the mixing chamber through holes in the housing. A second separate spray bar, mounted to the drum housing above the first spray bar, is fitted for adding a bituminous stabilizer or other additive.

The width of application for each spray bar must be independently adjustable. The system must allow individual nozzles to be selectively closed off, thereby achieving application of the additive only over the required portion of the cut width. This is important for ensuring that overlaps between adjacent cuts receive the correct treatment. In addition, having the spray bars operating independently of each other allows different treatments to be applied across the cut width, for example, water across the full cut width and bitumen emulsion across only half the width of cut. However, remember that the application rate through a spray bar is constant over the width of treatment, regardless of the selected width, i.e., each nozzle delivers the same flow rate.

The application rate through the spray bars must be micro-processor controlled with each feed line fitted with a flow meter, for the system to be able to accurately regulate pump speed relative to the volume of material in the mixing chamber. A pick-up, normally fitted to the left front tyre or track, constantly feeds the micro-processor with information on the speed that the machine is advancing. The computer then: calculates the flow rate required for each pump, using data that is entered into the computer before starting to recycle; checks the metered flow rate; and, adjusts the pump speed accordingly. The data input includes the average density of the recycled material, application rates for each spray bar, the width of application and the cut depth. On some recyclers, the width of application and cut depth are automatically sensed from the machine settings.

Spray bars are supposed to “spray” into the mixing chamber to assist in the dispersion of the additive. This means that the fluid entering the nozzle must be under sufficient pressure to be able to spray when forced through the nozzle orifice. Low application rates, coupled with slow advance speeds, result in a poor mix, since the lower the flow rate, the lower the pressure in the spray bar. When this situation is encountered, it may be necessary to fit nozzles with smaller openings. To overcome this problem, some manufacturers equip their machines with an electronic function that prevents the pumping system from operating below a minimum advance speed when the machine is set to operate in “automatic” mode. Operators and supervisors need to understand these finer details, since they can affect the uniformity of treatment across lateral joints, particularly at the start and end of cuts where the advance speed of the machine is necessarily slow.

Equipping the individual spray bar nozzles with a “self-cleansing” function is always recommended. Most manufacturers use needle and seat valves to operate the nozzles; the self-cleansing function quickly closes and opens each valve on a regular cycle (usually once a minute), thereby forcibly removing any obstruction lodged on the seat of the valve. This feature is most important for foamed bitumen spray bars, particularly where the bitumen is flue-heated in the supply tanker and where small burnt bitumen particles invariably manage to pass through the openings in the bitumen filter, especially when drawing the last remaining ton from the tanker.

2.7.2.6 Depth of Cut and Inclination Control

Recyclers are set up at the beginning of a cut by lowering the drum into the pavement to the required depth and lifting or lowering the hydraulic legs supporting each tyre or track to achieve the correct inclination or cross slope. Although the machine normally maintains these settings while it advances, it is advisable to check the cut depth, on both sides of the cut, at least once every 100 m and to make any necessary adjustments. However, it must be appreciated that the machine runs on the existing road surface and, therefore, follows the shape and cross-fall of the existing road, including any variation in cross slope, as well as dips and bumps that are longer than the distance between the front and rear tyres or tracks. Such discrepancies in line and level are followed by the bottom horizon of the cutter, resulting in a variable layer thickness when a grader is used to cut final levels in accordance with a smoothed design level.

2.7.3 Problem Solving

Table 6 covers some of the problems, and remedial actions, that are experienced on recycling projects.

Table 6. Recycler Problem Solving

Problem Indicator	Cause and Remedial Action
Poorly pulverised material with variations in the grading across the width of cut	- Recycler is inadequate (too light) for the job. - Cutter is in a poor condition. If replacing tools does not solve the problem, then the cutter needs to be replaced. - Speed of rotation of the cutter is too slow. - Speed advance of the recycler is too fast.
Poor grading with lumps of coarse material (normally asphalt lumps)	- Breaker bar not properly positioned. - Existing pavement includes layer(s) of severely distressed asphalt with closely-spaced crocodile cracks. Pre-mill the top 90% of asphalt thickness with a milling machine operated at slow advance speed and spread and shape the millings over road width. Then recycle. - Cutter is in a poor condition. Replace tools or cutter if necessary.
Colour varies uniformly from darker to lighter across the width of treatment	- Depth of cut on the side with a lighter colour is deeper than the side with a darker colour. Reset the machine to the correct cut depth, measured on both sides of the cut. - Moisture content of the material in the existing pavement varies uniformly across the cut width. Such a pavement is best pre-pulverised, cross blended and pre-shaped/pre-compacted before recycling. The material may need to be dried back before pre-shaping and pre-compacting. - Non-uniform application of liquid through the spray bars.
Wet patches in treated material	- Isolated wet spots are normally caused by tanker or feed pipe leaks. Even a drip will lead to a soft spot if the recycler is stationary for a few minutes, as recyclers do not cross blend material. - Also caused by spillages on pre-pulverised material. - Where patches are randomly spaced, the pumping system feeding the spray bar is probably defective. It can also be caused by air in the feed line causing intermittent flow to the spray bar.
Temperature of the treated material varies across the cut width	Nozzle blockages on the spray bar(s): - If only water is added, a rise in temperature normally indicates a lack of water addition. - If foamed bitumen is added, a rise in temperature indicates that a nozzle is not foaming. A drop in temperature indicates a blocked nozzle. - If bitumen emulsion is added at the normal application temperature of 60 °C, a drop in temperature indicates a blocked nozzle. - Isolate the defective nozzle and either replace or clean out. - In hot climates, a temperature variation can be caused by a varying thickness of asphalt across the cut width. Pre-pulverise and cross-blend to achieve a uniform material before treating.
Poor bitumen dispersion when working with BSM-foam	- Poor foaming characteristics due to either low bitumen temperature (< 160 °C) or insufficient water added to foam the bitumen. - Bitumen pressure too low (< 3 Bar) due to insufficient advance speed, or nozzles jets too large for required application rate. - Contaminated bitumen, including anti-foaming agents. - Insufficient fines (< 0.075 mm fraction) to provide a home for the bitumen stringers. - Moisture content of the material is too low, < 50% of OMC, or the material is saturated, i.e., free water visible. - Temperature of material being treated is below the acceptable limit (15 °C with an absolute minimum of 10 °C). - Mixing chamber of the recycler is choked, i.e., the cut depth exceeds the machine's capacity.
Treated material heaves during compaction	- BSM-foam: Either the moisture content of the in situ material is approaching saturation, or too much water added while recycling. - BSM-emulsion: Added total fluids, i.e., emulsion and water, exceeds the saturation point of the material. - Remedial measures should be to re-recycle 80% of the layer thickness and allow to dry back before re-compacting.
Premature rutting and/or "strip ravelling" after opening to traffic	- Poor overlap control. Longitudinal strips either not treated at all or double treated. - Incorrect nozzle configuration selected on either one or both spray bars, resulting in longitudinal strips not receiving treatment or receiving double dosage. - A grader was used to cut surface levels before the material behind the recycler was compacted to a uniform density, resulting in a transverse density difference across the cut width. Under-compacted material densifies under traffic loading, forming a longitudinal rut. - Remedial measures depend on the type of stabilizer applied and the surfacing to be applied. The entire layer may need to be replaced.

2.8 Hot Mix Asphalt Paving Machines

Hot mix asphalt (HMA) paving machines in use today all have similar operating principles. Examples are shown in Figure 48. Paving machines are made up of three basic units:

- **Tractor:** The tractor portion contains the power unit that provides the power needs of all three units.
- **Material handling system:** The material handling system receives the hot mix asphalt and moves it from the hopper through the paver to the spreading augers in front of the screed.
- **Screed:** The screed levels and profiles the laid material, provides some initial compaction, and smooths the surface ready to be compacted to the final specified density by the compaction equipment.

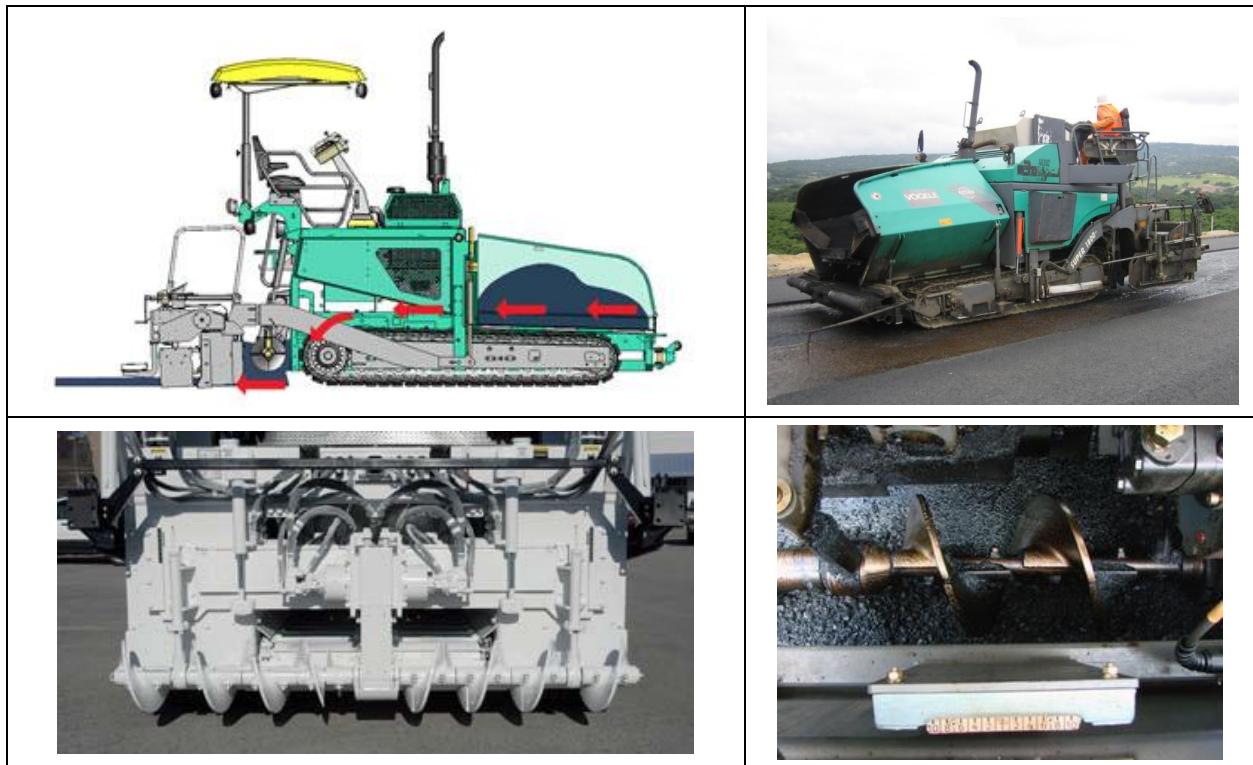


Figure 48. HMA Paver

Most paving machines can place a layer of asphalt less than 25 millimetres to approximately 250 millimetres in thickness over a width between 2 and 7 meters. The wider the paving width, the more difficult it is to have sufficient manufacture, transport and loading equipment to feed the paver with asphalt. Working speeds of paving machines range from 3 to 20 meters per minute.

In some cases, asphalt pavers are also used to lay layers stabilized with cementitious and bituminous binders.

Pavers either have tracks or tyres, each with different advantages and disadvantages.

Pavers are equipped with levelling systems ranging from simple skid systems, which use the longitudinal profile of the existing pavement to maintain line and level, to complex string line, sonic and laser systems.

Newer spray pavers have recently come onto the market which spray a tack coat immediately in front of the placed material. This facilitates laying Ultra-Thin Friction Courses (UTFC).

The main components of an asphalt paving machine are the hopper, augers and screed.

(i) Hopper

The hopper, illustrated in Figure 49, is located in front of the tractor unit and receives the hot asphalt from the hauling trucks. A conveyor system is used to move the material from the hopper through the tractor unit to the augers in front of the screed. The volume of material required to match the width, depth and speed of placement is precisely controlled, either by flow gates mounted at the rear of the hopper, or, by varying the speed of the conveyor

system. The flow gates are adjustable metal plates that change the size of the opening at the hopper discharge, and are used to control the amount of material flowing out of the hopper.



Figure 49. Hopper

When flow gates are not used, the auger and the conveyor are separated and controlled independently, to transfer the correct volume of material. Split systems use an additional material sensor to control the volume of material carried by the conveyor into the auger area.

The hopper is equipped with wings on either side to move material from the side to the centre of the hopper and onto the conveyor.

(ii) Augers

The augers, Figure 48, distribute the material from the conveyers, moving it transversely and uniformly across the full width of the screed. Material sensors, at the outer ends of the screed, control the volume of material in front of the screed by speeding up, slowing down or stopping the rotation of the augers. The augers on the right and on the left are independent of each other and are controlled by separate material-control sensors.

The augers, which are adjusted vertically, should always be 38 to 50 millimetres above the layer thickness being placed. When paving is done with a screed wider than the basic screed, auger extensions and material confining plates known as tunnel extensions should be added, to uniformly carry the material to the full width of the screed. Auger tunnel extensions (slide-out or bolt-on) are located in front of the augers when running at extended widths (4 meters or more). Ideally, the auger tunnel extensions should be 0.3 to 0.5 meters from the edger plate of the screed, to minimize the chances of material segregating.

(iii) Screed

The screed, shown in Figure 50, is located behind the tractor unit and is the most important component of the asphalt paver. It is, essentially, a wide flat piece of heated steel that knocks down and smoothes out the mass of material placed in front of it by the augers. In doing so, it places the material to the proper grade, cross slope and texture, and provides initial compaction of the material.

The screed width can be extended beyond the width of the main screed to facilitate paving widths wider than the basic machine width. The asphalt placed by the extension has the same characteristics in terms of texture, smoothness, and pre-compaction as the material placed by the main screed. The extensions can be angled differently to the main screed, allowing adjacent lanes and shoulders to be paved at a different cross-slope. In some pavers, the screed can be extended hydraulically, providing for paving of variable widths.

Free-floating screeds are a standard feature of asphalt paving machines. The basic principle of a free-floating screed is that, when it is pulled into the material deposited in front of it by the augers, it automatically rides up or down seeking the level where the path of the flat screed plate is parallel to the direction of pull. At this point, the forces which act upon the screed are in balance, and the screed lays a uniform mat thickness until one or more of the forces change.



Figure 50. Screed on Asphalt Paver

Paver screeds have tamper bars at the leading edge of the screed that serve a dual purpose. Firstly, they strike off the material as it passes under the screed, and, secondly, give a greater initial density than a vibratory screed.

Vibrators on the asphalt screed provide some initial density. The compactive force, which is generated by offset weights as they spin at high speeds around a central shaft, is applied to the material as it passes under the screed. The vibrators should not be used when paving a thin lift because the aggregates may be crushed.

At the start of a paving shift, the screed is much colder than the material. To keep the asphalt material from sticking to the colder metal of the screed, it must be preheated. Diesel, gas or electrical heating systems are used to preheat the screed before each day's paving. Diesel burners are simple and easy to use, but they require proper operational procedures so that excess fumes are not produced when air and fuel in the burner chamber are out of balance. Electrical heating systems have heating elements immediately above the screed plate, surrounded by special heat transfer oil, that help heat the screed uniformly without hotspots. This system minimizes fumes and provides an even heat across the entire screed plate. Electrical heating systems operate in a couple of different modes. In one, the screed is heated to operational temperature and the heating system shuts off. Alternatively, the screed is heated to the desired temperature and cycles on and off to maintain this temperature throughout the paving operation.

2.8.2 Equipment Control Measures

It is important to study the paver manuals prior to laying a trial section, and to inspect all items which are identified as potential problem areas, e.g., state of wear and setting of screed plates, tamper bars and augers. Many of the issues and problems related to asphalt paving are contained in the SAT Troubleshooting Guide (SAT, 2005).

Particular equipment adjustments required to obtain satisfactory results are discussed below.

2.8.2.1 Head of Material

The head of material is the depth of material evenly spread in front of the screed by the augers. Controlling the head of material is the most important factor in laying a smooth HMA pavement. The head of material is affected by the volume of the material in the auger chamber. Ideally, the head of material should be maintained at a height that exposes one half of the auger, and not varied by more than ± 25 millimetres. Starving the screed of material results in the screed settling, and causes a dip in the pavement. Excess material in front of the screed guarantees a bump as the screed attempts to crawl over it.



Head of Material in Paver

The head of material is the depth of material evenly spread in front of the screed by the augers. Controlling the head of material is the most important factor in laying a smooth HMA pavement.

2.8.2.2 Paving Speed

Nonstop paving, at a uniform forward speed, results in the highest quality and smoothest pavements, and should be the goal of every paving crew. Changing the paving speed changes the angle of attack on the screed, causing a corresponding change in the mat thickness. Manual adjustments to offset this depth change must be made with the depth screws. When equipped with automatic controls, these devices immediately sense the change in depth caused by speed changes and make the appropriate adjustments to maintain the required depth. Normal operations require that the paver be stopped occasionally. When the paver must be stopped, a rapid stop-start method should be used. This means that the paver should be stopped and started as quickly as possible, without a gradual slowdown or speed-up period, limiting the fall or rise of the screed.



Non-stop Uniform Paving

Nonstop paving, at a uniform forward speed, results in the highest quality and smoothest pavements, and should be the **goal of every paving crew**.

2.8.2.3 Screed Weight

The screed weight is usually translated into kilograms per square meter, or the vertical force applied by the screed onto the asphalt mixture. This unit weight is constant, except when extending or retracting the variable-width screed. Care must be taken to keep the head of material from fluctuating when extending the screed. When the screed is operated manually, a slight change in the angle of attack may need to be made, by using the screed-depth controls, to maintain the desired layer thickness. When extending the screed width, the augers should be controlled manually to supply a constant volume of material in front of the screed extension. When the extension is retracted, the auger should be manually shut off to reduce the amount of material in front of the extension, so that it can be retracted without causing the screed to rise.

2.8.2.4 HMA Stiffness (Loose)

A change in the temperature of the HMA, or the grading of the aggregates, results in a change in the stability or stiffness of the loose material during paving. This change in stiffness causes the screed to either rise or fall as it reacts to a change in vertical force, and seeks to rebalance all of the forces acting upon it.

2.8.2.5 General

The following important points must be kept in mind during paving of an asphalt layer.

To construct a smooth pavement:

- **Never run the hopper empty** between loads. The level of material in the hoppers should never be allowed to fall below the bottom of the flow gates.
- Establish and maintain a **continuous paving speed**. Establish the speed by balancing the delivery of material with the compaction process.
- **Control the head of material** in the auger area to within ± 25 mm.
- Do not allow trucks to **bump the paver**.
- Do not **dump excess material** on the road, such as when dumping directly into the paver hopper or cleaning truck tailgates.
- Do not **fold the hopper wings** into an empty conveyor system.
- Fold hopper wings often enough while moving forward to ensure the first material in is the first material out ("**first in first out**"), and keep material at placement temperature.
- Practice good techniques for **starting and stopping the paver**.
- Watch for **over-correcting the depth screws**.
- Make sure the **edge plate** is adjusted properly.

To construct good longitudinal joints:

- Strive to **minimize segregation** at the outside edges of the new paved layer.
- **Steer a straight line** on the first lane.
- Utilize the **proper overlap**, generally about 50 to 100 mm, of the cold asphalt layer being matched.
- The **depth of the asphalt layer** should be approximately 25 percent greater in depth than the existing compacted asphalt layer being matched, to allow for roll down.



Roll Down

Roll down is a common term used to describe the reduction in thickness of an asphalt layer from compaction.

- Watch that material is not allowed to **flow out or under the edge plates**. This excess material can prevent the making of a good joint, and should be pushed back to the hot side of the joint. Excess material should not be cast across the mat.
- Use **proper rolling procedures** for compaction.

To construct good transverse joints:

- Ensure **proper shutdown** on the original pass. The asphalt layer must be the proper depth and slope, and be checked with a straightedge.
- Construct a **temporary wedge** using some type of bond-breaker material.
- Remove the wedge, and **prepare the area** where the joint is to be made. Clean all dirt, loose material, and tack the area.
- **Align the paver** with the previously laid mat.
- **Heat the screed** properly.
- Use **starting blocks on the surfaces** to be paved, to raise the screed to the correct height and allow for proper compaction of the new asphalt. Normally the screed is 25% higher than the thickness of the mat.
- **Null out the screed** properly on the starting blocks, so it achieves the correct thickness and crossfall when moving off the starting blocks.
- **Fill the augers** properly, by shovelling the material into the corners.
- **Begin paving** and check depth and slope; correct if necessary.
- **Compact the joint**.

2.8.3 Problem Solving

A list of laying problems with possible causes is given in Table 7, as an aid to the correct adjustment of the paver and improved layer control.

Table 7. HMA Paving Problem Solving

Laying Problem	Possible Cause
Dragging of material over whole width of pavement	• Loose tamper frame-retaining bolts • Incorrect protrusion of tamper below screed • Tamper shield clearance too great. Build-up of cold material between tamper shield and tamper bar due to inadequate cleaning • Insufficient paving speed or tamper speed • Material too cold in front of screed. Note viscosity requirements for compaction. • Aggregate of incorrect maximum size in relation to paved thickness
Dragging of material over extensions only	• Loose tamper frame extension bolts • Tamper extension edges not in line with main section • Screed extension plates not true with main section • Bracing turnbuckles loose • Insufficient material feed to the extension. Check auger box setting, gates setting and auger controls. • Too much material being fed and material getting cold at the tamper face
Inability to reduce the material thickness to zero when the screed thickness gauge reads zero, and to obtain maximum depth	• Screed turnbuckles set at incorrect length • Maximum stone size incorrect • Excess material in front of screed
Inconsistency of density and texture of material on the finished pavement	• Screed heat too high or too low • Auger height incorrect • Paving and/or tamper speed incorrect • Material too cold in front of tamper due to low delivery temperature, or it is allowed to get cold. Check plant mixing cycle. • Grading of mix may be too variable and susceptible to segregation • Auger feed inconsistent • Paver hopper wings not actuated regularly, resulting in blemishes due to chunks of cold material
Dragging of material in middle of pavement only	• Incorrect crown set on the screed • Incorrect protrusion of tamper below screed
Scouring in the centre of the mat	• Screed plates broken off from the frame and tearing the asphalt
Screed will not maintain constant level	• Check paver tyre inflation pressures • Check operation and capacity of supply trucks, particularly where steep grades are being paved • Sensor operation defective • Loose tamper frame retaining bolts • On manual machines, bracket holding bevel gears for screed depth control loose • Screed hoist ropes holding screed • Tamper edges worn • Loose anchor bolts on side arm to screed • Material cold or other forms of inconsistency, e.g., temperature variation with resulting viscosity inconsistency. • Auger box overfilled resulting in bulldozing action. Floating screed operates on same principle as skiing in water with forces reaching equilibrium.
Insufficient compaction of material	• Tamper edge and frame bolts loose • Tamper edges worn • Incorrect protrusion of tamper edge below screed • Incorrect auger height for material • Screed lift ropes holding screed • Cold or poorly mixed material • Rollers and/or passes inadequate or poorly controlled
Excessive vibration of screed	• Bolts loose on screed and tamper assemblies • Loose screed sway bar • Incorrect tamper protrusion • Stone size too large for the thickness of the layer

2.9 Concrete Paving Equipment

Concrete paving equipment ranges from relatively basic equipment, that requires a lot of manual work, to very sophisticated mechanised paving trains. There are many different types and makes of machines, each with their own unique advantages and disadvantages. Concrete paving trains and related equipment are discussed in more detail in the Concrete Road Construction Manual (2009) issued by the Cement and Concrete Institute (C&CI).

The equipment is described briefly below.

2.9.1 Placing Equipment

Concrete placing equipment is used to spread the concrete over the width of the paved area. This equipment is normally used with side form construction. The spreader hopper runs on beams supported by the side form, as shown in Figure 51.



Concrete Paving

The following references are valuable for all aspects of concrete paving:

- **Concrete Road Construction Manual**, C&CI (2009)
- CMA. 2009. **Concrete Block Paving. Concrete Manufacturers Association.**
 - Book 1: Introduction
 - Book 2: Design Aspects
 - Book 3: Specification and Installation
 - Book 4: Site Management and LayingAvailable for download from www.cma.org.za



Figure 51. Concrete Placing Equipment

Where concrete paving machines are used, their spreaders are normally integral to the paving machine. They must be capable of spreading the concrete in front of the full face of the paver, so that during paving operations, a small head of material is maintained over the full width. Auger wear must be checked to ensure compliance with the manufacturer's specifications. All moving parts must be checked for wear and alignment.

2.9.2 Pavers

There are two types of concrete pavers: fixed-form and slipform.

2.9.2.1 Fixed Form Paving

In fixed form paving, the spreading, compaction and finishing of the concrete is carried out between fixed side forms. These are normally made of steel or timber temporarily fixed to the subbase. The side form assemblies should incorporate rails to support and guide the paving machine and to support the plastic concrete. A fixed form paver is shown in Figure 52.



Plastic Concrete

Plastic concrete is a standard term used to describe concrete from the time it is mixed until it sets.

Fixed form paving generally involves several individual pieces of equipment. Basic mechanized paving plant normally consists of a spreader, a vibratory compactor and beam finisher, supplemented by poker vibrators. Other equipment is used for wet forming of joints, mechanical placing of tie bars and dowels, and surface texturing and curing.



Figure 52. Fixed Form Paver

2.9.2.2 Slipform Paving

In slipform paving, concrete compaction and finishing is carried out within the length of a single machine frame, between travelling side forms. An example of a slipform paver is shown in Figure 53. Depending on the particular machine, concrete may be supplied directly to the paver, or spread and initially struck off by a separate machine working ahead of the main paver. In slipform construction, the relatively short length of the travelling side forms makes careful control of concrete workability and compaction essential.

The slipform paver compacts concrete over the full paving width by means of internal vibration, or a combination of internal and surface vibration. The forward rate of progress of the paver should not exceed that at which the concrete can be fully compacted. As the travelling side forms provide edge support only during the concreting operation, automated level and steering control is necessary.

Successful and efficient slipform paving depends on continuous and uninterrupted supply of low slump concrete of high mix uniformity. The concrete batching plant and hauling equipment must be capable of consistently providing the required volume of concrete to the paver. Therefore, trial sections are essential.



Successful and Efficient Slipform Paving

Successful and efficient slipform paving depends on continuous and uninterrupted supply of low slump concrete of high mix uniformity. The concrete batching plant and hauling equipment must be capable of consistently providing the required volume of concrete to the paver.



Figure 53. Slipform Paver

2.9.3 Vibrators and Compactors

Compactors are sometimes integral to the paver, as described for slipform pavers. Alternatively, separate vibrating paddles, vibrating beams and poker vibrators are used to compact the concrete. These are illustrated in Figure 54.



(a) Pokers with Vibrating Beam

(b) Vibrating Beam

Figure 54. Vibrators

2.9.4 Dowel Bar Inserters

Dowel bar inserters, shown in Figure 55, are used on some paving trains to insert the bars into the concrete, immediately behind the paver and before the finisher. See Chapter 9: 12.2 for more on dowel installation.

2.9.5 Screeding and Finishing Devices

Various types of finishers are available to screed the final concrete surface to a smooth and level surface. Initial finishing is normally carried out in conjunction with placing and compaction, using screeding devices attached to the paving equipment. The screed is moved forward so that a small surcharge or roll of concrete is always maintained ahead of the paver, as illustrated in Figure 56. In the case of side form paving, a diagonal finisher is normally used for initial finishing. For slipform paving, a number of devices can be used, including tube floats, oscillating longitudinal floats, truss floats and trailing finishing pans, some of which are illustrated in Figure 57.



Figure 55. Dowel Bar Inserters



Figure 56. Surcharge in Front of Beam

2.9.6 Tining and Brushing

Tining and brushing devices are normally moved transversely across the width of the pavement, to obtain grooves or transverse texture for skid resistance, as shown in Figure 58. The spacing of the tines should be random. The tining depth is normally 2 to 4 mm.

Brushes should have stiff bristles, spaced to produce an acceptable texture. Brushes must be replaced when the shortest tufts wear down to 90 mm. Stiff plastic brooms may also be used.

A Burlap drag may also be used to produce a uniform texture with corrugations about 1.5 mm in depth. Photos of automated and manual burlap drag operations are shown in Figure 59. The drag should be such that at least 1 metre of the fabric is in contact with the pavement surface. The drag should consist of sufficient layers to provide the weight required to produce the desired texture depth. Four layers of 340 g/m² burlap have produced satisfactory texture depths. Higher-mass burlaps have closer weaves and produce less texture depth. Texture depth may be increased by removal of the transverse threads from the trailing 150 to 300 mm of the drag. Satisfactory results have also been achieved by threading nails through the trailing edges of the burlaps.

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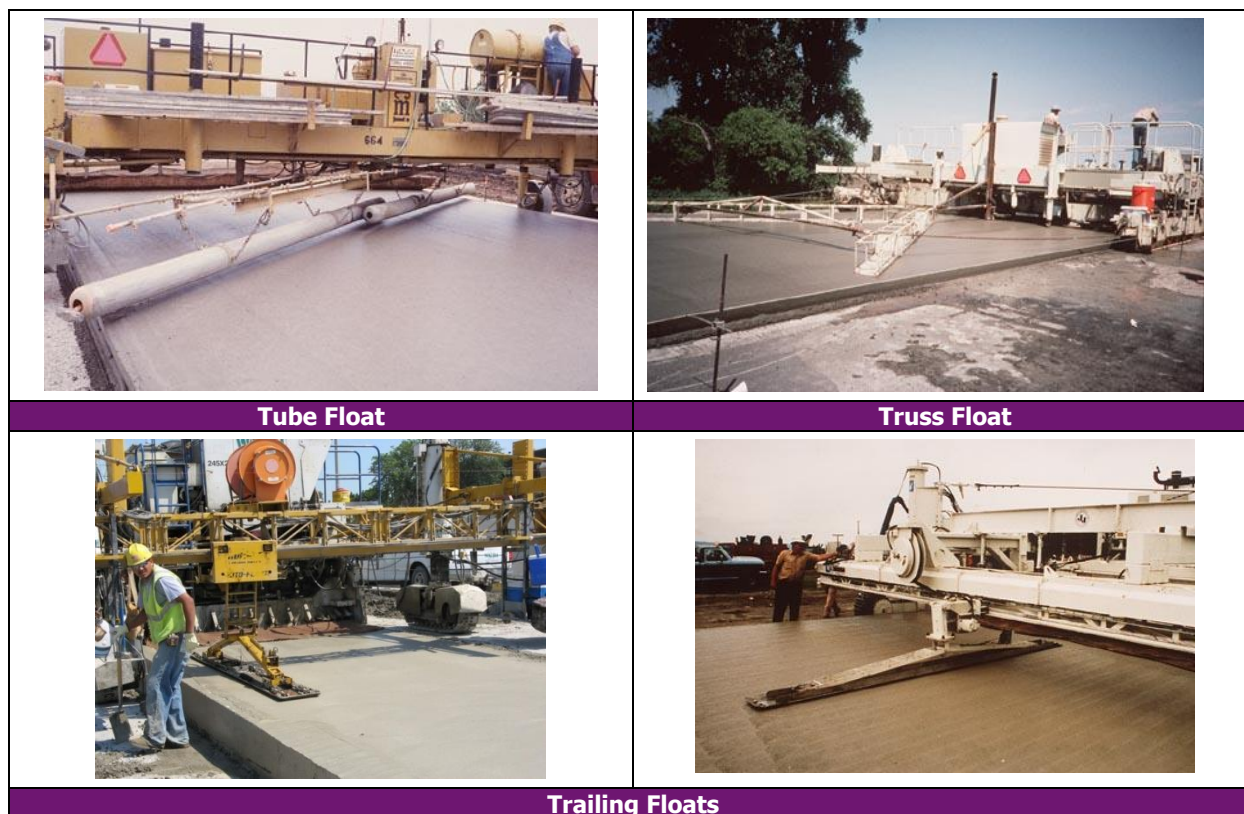


Figure 57. Methods of Initial Finishing



Figure 58. Tining



Figure 59. Burlap Drag

2.9.7 Equipment Control Measures

The following equipment control measures are important to ensure good concrete construction.

2.9.7.1 Placing Equipment

The size of the spreader hopper and transport vehicles must be matched to ensure that a full load is used, to prevent tipping partial loads into the hopper. However, if an agitating mixer is used, partial loads can be accommodated.

The wheels and runners of the spreader must be checked to ensure they are free running. The mechanism for opening the bottom gate of the hopper must be checked to ensure it is in good working order. When concrete is being spread, the machine must be capable of spreading it evenly between the shutters, so that no low spots occur.

Where concrete paving machines are used, auger wear must be checked to ensure compliance with the manufacturer's specification. All moving parts must be checked for wear and alignment.

2.9.7.2 Paving Machines

Equipment control measures for paving devices are complex, and depend on the type and manufacturer of the paver. The primary controls should be directed at ensuring that the paver achieves its purpose, i.e., to spread the concrete uniformly in front to the paver screed, to compact the material thoroughly over its full depth and width, and to obtain a good line and level.

Concrete paving is an unforgiving task. All slight variations occurring during paving manifest as a bumpy ride. It is, therefore, essential that paving crews are properly trained and that daily controls are applied to all plant and equipment.



Concrete Paving is Unforgiving

Concrete paving is an unforgiving task. All slight variations occurring during paving manifest as a bumpy ride. It is, therefore, essential that paving crews are properly trained and that daily controls are applied to all plant and equipment.

2.9.7.3 Vibrators and Compactors

Slipform pavers utilise immersion vibrators and these need to be set to ensure that adequate compaction is achieved, and the concrete is sufficiently liquefied to flow through the paving process. Setting of the vibrators includes the spacing, the vertical alignment and the frequency of the vibrators. The frequency must be set to prevent the occurrence of vibrator trails, illustrated in Figure 60, in the pavement.



Figure 60. Vibrator Trails

2.9.7.4 Dowel Bar Inserters

The inserters (Figure 55) normally induce some vibration, to allow the dowel bar to be easily inserted into the concrete. DBI's are in common usage with slipform pavers, the dowels are mechanically inserted into the fresh concrete. The position of the dowels must be clearly marked to ensure the sawn contraction joint coincides with the dowel position. The orientation of the bar in the inserter must be checked to ensure accurate, consistent and correct alignment with the pavement.

2.9.7.5 Screeding and Finishing Devices

The essential controls on the screeding and finishing devices are aimed at ensuring that the final levels achieved meet the required specification. Therefore, all joints must be firm and the devices must not be lifted by the concrete being finished. The finishing device must keep up with the paver to ensure it only works on wet concrete. It is good practice to have a stand-by device.

The final finish is normally provided by a burlap drag, which must be replaced as soon as any wear becomes apparent.

2.9.7.6 Tining and Brushing

Tining equipment should be set up to ensure a uniform tine depth across the entire pavement width. Tines that are worn by more than 2 mm must be replaced.

To ensure the correct degree of stiffness of individual tufts and bristles, brushes must be replaced when the shortest tufts wear down to 90 mm.

Burlap drags must be replaced when the trailing edges show signs of wear, and inadequate texture depth is achieved.

2.10 Compaction Equipment

There are various types of compaction equipment available which are used to densify pavement layers. The most common are rollers.

2.10.1 Type of Rollers

There are many types of rollers produced by specialised manufacturers. The rollers are divided into the following broad categories:

- **Towed** rollers
- **Single wheel** rollers
- **Tandem** (double drum) rollers
- **Three-wheel** rollers
- **Pneumatic tyred** rollers
- **Specialised** rollers

2.10.1.1 Towed Rollers

Towed rollers normally include grid and odd shaped (Impact) rollers. The advantage of these rollers is that they can be towed behind multi-purpose equipment such as tractors.

(i) Grid Roller

The grid roller is useful for breaking down oversize aggregate particles and is suitable for use on most gravel layers. For a grid roller to be effective, it has to be towed at a relatively high speed, in the order of 30 km/h, and hence requires a long run, about 50 metres, to be effective. At speed, a grid roller has a certain impact effect, and as such, is effective in breaking down large particles to a more acceptable size and shape. The grid roller should, however, not be used on its own to achieve density, but rather in combination with other rollers. The grid roller also has the advantage that it produces less lamination or biscuiting than flat steel wheel rollers.

(ii) Impact Roller

The impact roller is used to achieve compaction at depth on certain materials, such as collapsible sands. There are three and five sided drum impact rollers available. The three side drum rollers provide higher energy displacement than the five sided roller. A 5 sided self-propelled impact roller is shown in Figure 65. These rollers need to be towed at about 10 km/h to be the most effective. Impact rollers are generally not used during the compaction of relatively thin layer works. The disadvantage of these rollers is that they need space to be turned around at the end of a compaction run and to build up speed, and they do not leave a smooth finish on the layer after compaction.

2.10.1.2 Single Wheel Rollers

These rollers normally have a rubber tyred drive wheel and a steel drum that can either be flat or padfoot (Figure 61) and can be vibrated at different frequencies and amplitudes. These rollers are primarily used to compact fine grained materials.



Figure 61. Single Wheel Padfoot Roller

2.10.1.3 Tandem (Double Drum) Rollers

Tandem rollers, shown in Figure 62, are normally specialised rollers used to compact asphalt layers. The rollers consist of two steel drums with equal loading on both drums. The drums are both driven and usually one or both drums can vibrate. Variable vibration amplitude and frequency is normally included for different applications. In addition, specialized controls exist for slowing down and reversing at the end of a roller pass, while at the same time reducing and reversing the vibration. The latest versions are fitted with compaction control devices that measure the response of the pavement to vibration, thereby providing an indication of the level of compaction achieved.



Figure 62. Double Drum Rollers

2.10.1.4 Three-Wheel Rollers

These old flat steel wheel rollers, shown in Figure 63, are used for final rolling on asphalt layers. The roller consists of large and heavy rear drive drums that can be ballasted with water for extra weight and pressure. The smaller light steering drum is not ballasted to prevent it from digging into any loose material, affecting the smoothness of the compacted layer. The weight of this roller is generally between 10 and 14 tons with most of the weight on the large drums. These rollers are also used during the "slushing" process of crushed stone bases (see Section 3.8.1.1(vi)).



Figure 63. Three Wheel Rollers

2.10.1.5 Pneumatic Tyred Rollers

The pneumatic tyred roller, Figure 64, is a good finishing roller and is effective in compacting surface soft spots that steel wheel rollers may override. There are two types of pneumatic tyred rollers available:

- **Single axle (Alboret) rollers**, which are towed by a tractor and are primarily used for proof rolling subgrades.
- **Double axle rollers** with 7 or 9 pneumatic tyred wheels, which are primarily used as finishing rollers on asphalt, to knead and knit the surface.

A pneumatic roller shows up variations and weaknesses in the material layer. The rubber tyred wheel does not form a bridge from one large aggregate particle to another, but rather compacts the weaker materials, which may occur between the larger aggregate particles.



Figure 64. Pneumatic Rollers

2.10.1.6 Specialised Rollers

These include various specialised devices such as Impact rollers (Figure 65) and combinations of steel and pneumatic rollers. For a description of the use of impact rollers see Section 2.10.1.1.

2.10.2 Selection of Compaction Equipment

The best compaction technique and roller combination for a particular material type is fairly easily determined by constructing a test section on which the various rolling techniques and moisture contents can be tried. The material should be moistened to various moisture contents and then compacted using a roller, or combination of rollers, and the density measured with a nuclear density gauge after each pass. A density increase curve should be plotted from the results to determine the required number of roller passes.



Figure 65. Impact Roller

After the best compaction technique and moisture content has been determined, there are two aspects which should be noted during rolling:

- **Rolling must always be carried out systematically** from side to side, or from the sides to the middle where the layer is built with a crown.
- A **complete pass of the surface** is obtained when the entire width of the layer has been covered once by the roller. Half width overlaps are required with each successive roller movement. The number of complete passes must always be recorded.

In practice, it is not cost-effective to apply more than between 2 and 4 roller passes with a vibratory roller and between 8 and 12 passes with other rollers. Further passes normally result in very little increase in density, and if additional density is required, a heavier or alternative type of roller will normally have to be used.

General guidelines for the selection of the most appropriate compaction equipment are provided in Table 8, and are discussed below, as are guidelines for the compaction in different construction processes.

Table 8. Selection of Compaction Equipment

Type of compaction equipment	Rock fill	Sand and gravel		Silt and clayey material		Clay		Surface seals	Asphalt	Stab. layers
		Well graded	Poorly graded	Silty sand silty gravel	Clayey sand clayey gravel	Weak	Strong			
Flat wheel roller		✓	✓					✓	✓	✓
Pneumatic tyred roller ¹		✓	✓	✓✓	✓✓	✓		✓✓	✓	✓
Impact roller	✓	✓✓	✓✓	✓✓	✓✓	✓				
Grid roller	✓	✓	✓	✓	✓	✓	✓			
Vibrating roller	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓		✓✓	✓✓
Padfoot roller				✓✓	✓✓	✓✓	✓✓			

Legend

✓✓
✓

Recommended

Can be used

Notes

1. Pneumatic tyred rollers should not be used on Stone Mastic Asphalt layers. They can damage the surface of the layer.

Guidelines for the compaction in different construction processes are summarized below.

(i) Sand Fills

The best results for sand fills are normally obtained with vibratory rollers with a high frequency and low amplitude, and/or light pneumatic rollers, preferably those on which the tyre pressure can be changed during the compaction process. It is preferable if the compactors do not need to turn around at the end of the construction section.

(ii) Gravel Fills

Vibratory rollers, grid rollers and heavy pneumatic rollers can be used on most materials, and, therefore, are used on gravel fills. Kneading rollers are more effective on clayey materials.

(iii) Rock Fills

Rock fills are not compacted in the same manner as normal gravel fills. A layer of rock is first dumped and flattened with a bulldozer. This is followed by placing a layer of finer material on the flattened surface and vibrated into the interstices between the rocks with vibratory rollers, as illustrated in Figure 66 with a padfoot vibratory roller is being used. There is a high probability that fills will settle with time if the voids between the dump rock are not filled with finer material. Impact rollers can also be used, provided the rock is not so hard that the roller is damaged.



Figure 66. Rock Fill

(iv) Fills in Confined Areas

In confined areas, such as bridge abutments and over pipe culverts, normal compaction equipment cannot be used. Smaller vibratory rollers and plate compactors are used in these areas. In extremely confined areas, tamping equipment has to be used.

(v) Pavement Layers

If coarse material is used to construct the layer, a grid roller may be used to break down the coarse material. When a grid roller is used on a base layer, the roller must be removed before the final grader cut to avoid grid marks on the final surface. A pneumatic and/or flat wheel roller can be used in the final stages of compaction to provide the required finish.

If sandy gravels are used to construct the layer, a combination of rollers can be used for compaction, with the exception of kneading rollers. Vibratory rollers with high frequencies and small amplitudes, grid rollers, pneumatic rollers and flat wheel rollers are all normally used.

If clayey gravel is used to construct the layer, care should be taken not over compact the upper part of the layer, before the bottom has been adequately compacted. This is known as "closing" the layer. The initial use of kneading rollers is preferable, as well as grid rollers if the material is stony. In the final stages of compaction, a pneumatic roller can be used, followed by a flat wheel roller.

(vi) Asphalt

The most commonly used rollers for compaction of asphalt layers are the following:

- **Three-wheel steel drum type.** These compactors are well-known and commonly used. The roller compacts from the top down, based on compression of the particles to squeeze and force them into a tight configuration. Good lubrication is needed for this action, and the rollers are thus most effective when the material to be compacted is hot. These rollers are, therefore, used as breakdown rollers.
- **Vibratory tandem rollers.** This roller can be used on any asphalt layer, provided the appropriate amplitude, frequency and speed are selected. The rollers densify by delivering a rapid succession of impacts on the surface resulting in pressure waves that reduce the internal friction in the material to re-arrange the aggregate into a denser configuration.
- **Pneumatic tyred rollers.** These rollers are usually used in combination with steel drum rollers. They are more capable of increasing density at lower temperatures than steel drum rollers. The wheel loadings are usually the same on all wheels and the back tyres are offset from the front tyres to ensure coverage of the mat in one pass. The roller tyres densify the asphalt layer by kneading. This results in the particles moving around each other to fill up the voids. These rollers also prevent lateral movement during rolling, and provide a more uniform degree of compaction by compacting areas bridged by steel drum rollers. Pneumatic tyred rollers also close and seal the surface of the compacted asphalt layer.

2.10.3 Equipment Control Measures

The control measures differ for each type of roller, with increasing complexity with roller sophistication.

2.10.3.1 Towed Rollers

The control measures of these rollers mainly focus on ensuring the towing unit has adequate speed for grid or impact rolling, and has an area to turn to prevent damage to prepared surfaces.

Grid rollers need to be checked to confirm that the knuckles formed by the grid stand well proud of the rest of the grid, and are not worn and flat.

2.10.3.2 Steel Wheel Rollers

The main control measure of steel wheel rollers is the ballasting weight of the drums. The weight of the drums should be recorded at the start of each compaction operation.

Steel wheel rollers are extensively used for compaction of asphalt layers. A thin spray of soapy water is sprayed continuously on the drum to prevent pick-up of the hot asphalt. The spray bar should be checked before the start of the compaction operation, to ensure that excessive spray does not occur, and runoff is avoided.

2.10.3.3 Pneumatic Tyred Rollers

The air pressure in the tyres dictates the area of contact of each wheel. This means that the depth of compaction can be varied by varying the pressure in the tyres. It is generally accepted that relatively low tyre pressures should be used for deeper compaction, while high tyre pressures are effective on surface compaction. It is essential that the tyre pressures are checked, before the compaction operation starts.

The mass of these rollers can be controlled by filling them up with either sand or water. It is essential that the mass of the roller is recorded at the start of the compaction operation.

3. CONSTRUCTION PROCESS GUIDELINES

This section discusses the process control guidelines for construction. The following construction processes are discussed:

- Roadbed preparation
- Fills
- Compaction of soils and gravels
- Cementitious stabilization
- Bitumen stabilization
- Modification of materials
- Cold recycling
- Crushed stone base
- Primes and tack coats
- Surfacing seals
- Hot mix asphalt
- Concrete pavements
- Proprietary products

3.1 Roadbed Preparation

The pavement structure is largely dependent on the roadbed conditions for its long term performance. Hence this part of the construction process is just as important as the pavement construction. The roadbed conditions must be known at the time of construction. Where potential problems arise, the necessary preventative measures must be carried out, or the material must be replaced with more suitable material.

3.1.1 Minimum Preparation

The following minimum preparation should be carried out, before any new construction work is commenced.

- All **organic material**, such as tree stumps and roots, are removed. In most cases, this involves removal to a depth of roughly 200 mm below the natural ground level.
- Where necessary, and possible, **subsurface drainage** is provided to drain the roadbed and ensure that dry conditions prevail.
- The **quality of the in situ soils** are assessed to ensure compliance with the minimum requirements. Any unsuitable material is removed and replaced, or treated to facilitate compaction of the pavement layers over this layer.
- The roadbed must be **effectively compacted** to achieve the required density and in situ shear strength. In all cases, with a reasonable compactive effort, should be targeted. compaction requirements.

3.1.2 Special Preparation

Some roadbed materials require special preparation before a pavement structure can be constructed. Such materials are:

- Active clays
- Collapsing sands
- Dolomite formations
- Dispersive soils



Roadbed Preparation

The following sections in this guideline provide guidance on roadbed preparation:

- Chapter 6: **Road Prism and Pavement Investigations**
 - 5: Road Prism Investigations
- Chapter 7: **Geotechnical Investigations and Design Considerations**
 - 3: Geotechnical Investigations
 - 4: Fills
 - 5: Cuts
- Chapter 9: **Materials Utilisation and Design**
 - 2: Roadbed
 - 3: Earthworks
- Chapter 10: **Pavement Design**
 - 5.1.1: New Design
- Chapter 13: **Quality Management**
 - 2: Road Prism

the highest possible density and strength achievable, This may significantly exceed the typical minimum



Roadbed Density

The roadbed must be effectively compacted to achieve the required density and in situ shear strength. In all cases, the highest possible density and strength achievable, with a reasonable compactive effort, should be aimed for. This may significantly exceed the typical minimum compaction requirements.

3.1.2.1 Active Clays

Active clays occur in many areas of South Africa. They are formed from weathering of basic igneous rocks, such as norite or dolerite, and also from weathering of sedimentary rocks where the original particles were clayey, such as some shales. Most of the darker clays are potentially problematic, while lighter colour clays are normally less active.

Active clays swell and shrink as their moisture content increases or decreases, and this causes deformation of pavements constructed over these clays. The deformation problem is normally more serious in the drier parts of the country, where significant changes in moisture conditions occur between wet and dry seasons. Less deformation occurs in wetter areas, due to a more consistent moisture regime. In these areas, deformation normally occurs due to the withdrawal of moisture by the roots of large trees, particularly blue gum trees. An example of tree damage is shown in Figure 3 of Chapter 13: 2.2.2.4. Active clays are discussed in Chapter 6: 6.3 and 6.4.

The mechanism of pavement distress over active clays normally involves deformation, followed by cracking in the form of widely spaced longitudinal, transverse and crescent shaped cracks. Moisture ingress through the cracks causes shear failures. Deformation is caused by two major factors:

- A **sealed surface** results in an increase in the moisture content of the underlying clay. The lower the initial moisture content of the clay, and the thicker and more active the clay, the more it swells as it absorbs moisture. As it swells it raises the road surface. This seldom occurs uniformly, and is particularly noticeable at culverts where the ingress of moisture into the underlying clay is more prevalent.
- The **moisture content of the clay** under the central portion of the road surface remains fairly constant while that of the material underneath the shoulders varies. This results in the longitudinal edges of the pavement "flapping" up and down, leading to the formation of longitudinal cracks.

Soft clays under embankments also create problems due to settlement over time. The rate of settlement depends on:

- **Mass** of the embankment
- **Stiffness** of the clay
- **Length of the paths** along which moisture has to be expelled during consolidation
- **Permeability** of the clay

In certain cases, if the side slopes are too steep, the in situ soils may be so soft that shear failures may occur underneath high embankments. In these situations, geotechnical investigations and stability calculations are used to determine safer slopes, which are generally in the range of 1:2, or 1:3 in severe cases.

Potential problem areas can normally be identified fairly easily. An initial estimate of the potential swell can be made using the Van der Merwe method (1964). Quantitative predictions of the amount of swell require sophisticated testing, such as consolidation tests.

There are a number of preventative measures applied to reduce or retard the occurrence of deformation and cracking due to active clays, which are described briefly below.

- **Remove active clays and replace with inactive materials.** Such measures are only economical where the thickness of the active clay is limited, or where the replacement material is readily available. The material used to replace the clay should preferably be impermeable so that it does not form a collection point for moisture underneath the road. Clay, which has been removed, can be used to seal the sides of embankments, to prevent moisture ingress.
- **Remove plant growth** within the confines of the roadbed, plus at least 5 metres on either side, at an early stage of construction. The plant growth should preferably be removed using a weed killer. This should be done at least one summer or wet season prior to construction to allow the underlying moisture content to stabilize to a condition likely to prevail once the pavement has been built.
- **Irrigating clay.** In the case of wide roads such as freeways, consideration can be given to irrigating the clay. Clay is relatively impermeable, and irrigation may have to continue over several months. Moisture ingress into



Active Clays

These preventative measures can be applied to reduce or retard deformation and cracking due to active clays:

- Remove and replace with inactive materials
- Remove plant growth
- Irrigate clay
- Retard capillary action and evaporation
- Stabilize with lime
- Grade culverts and surface drains
- Keep shoulder surfaces impermeable
- Use a pioneer layer of dump rock
- Do not plant Blue Gum (*Saligna*) or Karee (*Rhus Lancea*) trees

the clay layer only progresses to a depth of approximately 1 metre, unless sand drains are provided for deeper percolation.

- **Capillary** action and evaporation can be retarded by using a 100 to 300 mm thick layer of sandy material on top of the layer. When construction commences, the sides of the sandy material must also be sealed to stop moisture movements in a horizontal direction.
- **Lime stabilization** reduces the activity of the clay. This can be considered for the upper part of the clay if it is economically justified. The lime should be mixed throughout the clay several times, with intermediate rest periods, so that the calcium ions within the lime can react with the clay. The lime stabilized layer will act as a fairly effective working platform, particularly in wet weather.
- **Grade culverts and surface drains** to avoid water ponding. The culverts must be waterproof and long enough to extend beyond the toe of the embankment. Impermeable material should be used for backfilling.
- **Keep the surface of shoulders impermeable.** Moisture changes in clay and the resulting cracks in the pavement layer are reduced when the shoulders of the riding surface are sealed to be impermeable. Where the shoulders are not sealed, consideration can be given to widening the formation by 3 to 4 metres on either side. High embankments do not need to be widened over their total height and only the lower 1 to 2 metres can be widened to reduce horizontal moisture movements.
- **Dump rock** can also be considered as pioneer layer of roughly 300 to 400 mm thick. Such materials are, however, normally fairly scarce in active clay areas.
- **Blue gum (Saligna) or Karee (Rhus Lancea) trees** should not be planted within 20 metres of the shoulder breakpoint, as these trees have deep roots that aggravate moisture changes.

Rigid cemented (high stabilizer content) pavement layers tend to have wider cracks than unstabilized layers, because the horizontal movements are concentrated at the shrinkage cracks. However, stabilization of the poor materials that normally occurs in these areas is generally required for strength.

3.1.2.2 Collapsing Sands

Collapsing sands consist of sand grains, which are partially cemented with a high void content between the individual particles. These sands consolidate significantly when they are moistened and loaded. Collapsing sands are discussed in Chapter 6: 6.4.

The moisture content of a material normally increases when a road surface is placed over it and this, together with the dead weight of the pavement structure and the vehicle loadings, results in severe deformation.

To avoid this problem, the material should be treated with an impact roller prior to construction of the pavement. However, the strength of the material builds up very rapidly when it is compacted and it often bridges the lower collapsing material to reduce the effect of the impact roller at depth. Hence, impact rolling may require several passes to be effective, and may need to be preceded by irrigation and wetting to weaken the cementitious bonds between the particles. The effective depth of the treatment of the impact roller can be checked fairly easily using a DCP (see Chapter 6: 7.4.5).

3.1.2.3 Dolomite Formations

Dolomite formations can result in sinkholes or compaction subsidence, which have serious economic consequences and can be life threatening. These formations are discussed in Chapter 6: 6.2.

The in situ soils in dolomitic areas may be extremely variable over very short distances. The extent of the variability is normally very difficult to assess. Detailed drilling surveys, coupled with gravity surveys, may be required to identify the dolomite pinnacles and valleys filled with extremely compressible wad. An impact roller, or dynamic compaction in extreme cases, may be used to compact the material to an appropriate depth, before placement of the pavement structure.

In all dolomitic areas, extreme care should be taken to ensure that all run-off water is led away from the roadbed area and that no concentration of runoff, damming or moisture ingress into the subgrade occurs. Any water which ingresses into the subgrade may lead to the occurrence of sink holes and severe deformation.

3.1.2.4 Dispersive Soils

Dispersive soils have a high percentage of exchangeable sodium cations. Dispersion occurs when the molecular electrical charges on the surface of the clay platelets repel, rather than attract, one another. When this material comes into contact with water, the particles go into suspension and are rapidly eroded. This leads to the rapid

formation of erosion gulleys and piping in these soils, particularly at joints, cracks and other areas where water flow is concentrated. An example of an erosion gully is shown in Figure 67. Dispersive soils are discussed in Chapter 6: 6.7.

There are few easy solutions to this problem. Most remedial or preventative measures centre around the construction of drainage berms and channels, or topsoiling and vegetating the material. Treatment with gypsum may be effective.



Figure 67. Erosion of Dispersive Soil Type

3.2 Fills

The construction of high fills or embankments is relatively costly and hence these should be constructed with care, to avoid failures occurring. Such failures are normally of significant extent and can be catastrophic. Therefore, it is essential that high embankments be designed and constructed properly. Embankments/fills are discussed in Chapter 7: 4.

Any fill higher than 10 metres, measured vertically from the toe of the embankment to the edge of the riding surface, is regarded as a high fill. Lower fills also require similar care and preparation, but the scale of this work is less than for high embankments.

The design of high fills is a specialised field. This section only provides broad guidelines regarding the construction of fills of earth and rock.

3.2.1 Earth Fills

No particular material qualities are generally specified for high earth fills. However, the material must be free of vegetation or other deleterious materials, which may affect the performance during the life of the fill. Strict control should be carried out to ensure the best choice of the type of material and placement in the fill. An example of an earth fill is shown in Figure 68.

The following construction control measures should be exercised during the construction of fills.

- All **organic material must be removed**, prior to construction of the embankment.
- **Fill materials should be placed systematically**, in uniform layers with thicknesses not greater than 300 mm, and to the correct width and side slope. The compacted layer thickness is dependent on the maximum particle size of the material, but does not generally exceed 300 mm.
- For **cohesionless sands**, layers of up to 400 mm thick can be compacted, provided the necessary testing is carried out to ensure that the correct densities are achieved.
- Care is required to **avoid loose uncompacted edges** due to either blading off of surplus material or the addition of material, as a result of insufficient width.
- The layers should be placed with a **suitable camber or crossfall** for water to drain freely from the surface, to avoid saturation of the fill material.
- The **quality of the material** should comply with the specifications throughout the fill construction. However, since tests generally only represent a minute portion of the fill, competent judgement must be exercised to

ensure that the areas tested are, as far as possible, representative of the entire fill. This requires continuous visual inspection, to ensure that proper procedures and control requirements are adhered.

- Where **material variations** occur, the correct reference density should be used. In most cases embankments are placed fairly quickly, and attention needs to be paid to density testing.



Figure 68. Earth Fill

3.2.2 Rock Fills

Rock fills are defined as those embankments composed principally of hard, sound, durable rock, an example of which is shown in Figure 69. Rock fills should be constructed with accepted material obtained from approved sources. The rock fill should contain only small amounts of fine particles. When placed and compacted, the stability of the fill comes from the mechanical interlock of the coarser particles, and not from the compaction of the finer material.

Rock fills are normally constructed from rock, with fine materials placed between the rock particles. These are normally constructed by end tipping. Because no density testing can be carried out to determine conformance with a specification, the construction method should be carefully controlled to ensure a stable end-product. All construction efforts should be aimed at ensuring that the voids are filled with finer materials. Individual boulders should not control the layer thickness, as the presence of such boulders prevents the compaction of the rest of the layer.

Rock fills are constructed to ensure rock particle to rock particle contact is maintained, and further movement or consolidation is prevented. Material which breaks down under compaction is, thus, not acceptable as rock fill.

Broken rock should be placed at the bottom of the embankment. Gravel placed on top of this rock material must be forced into the voids as far as possible using vibratory rollers. In this way, further ingress of material into the voids is prevented.

The ultimate performance of rock fill in terms of long-term settlement is an important consideration, particularly where placed as approach embankments to structures, or where an existing roadway is widened.

The requirements for rock fill are an attempt to minimise settlement within the embankment, by providing sufficient fine materials to fill the void space between larger rock particles. To evaluate all aspects influencing the required characteristics of rock fill being placed for large construction projects, large-scale field density tests need to be conducted in trial sections to establish/verify a procedural specification. The trial section offers an opportunity for a compaction study, to assess the effectiveness of different compaction equipment and the break-down/disintegration of the rock fill material.



Figure 69. Rock Embankment

3.2.3 Roadbed Preparation for Fills

All high fills should be regarded as structures. Hence, it is essential that the roadbed conditions are stable. This also applies to high fills against bridge abutments.

All organic material in the natural soil must be removed prior to construction of fill. If this is not done properly, the material can rot, resulting in a weak plane in the embankment. This can lead to severe failure, particularly if the embankment is constructed on a fairly steep side slope.

The roadbed should be assessed for potential instability, such as signs of seepage or springs, hammocking ground or tension cracks, which indicate previous movements and discontinuities in the local geology.

The footprint of the embankment should be proof-rolled to identify any instability.

The in situ soils should all be compacted to at least 90% of maximum dry density (MDD). If this is not achievable, then the in situ material must either be stabilized or removed and replaced with better quality material.

With side embankments, the bottom of the embankment should be constructed in benches, which are cut into the natural side slope, to ensure proper compaction and to avoid sliding of the embankment on the underlying soil. The benches must have a crossfall of 1:50 to ensure surface drainage during construction and sub-surface drainage after construction, if the subgrade is more impermeable than the fill. Blanket filter drains coupled to a series of collector drains must be laid in all areas where water seepage into the fill occurs, or is likely to occur. Cut-off drains can also be installed in certain instances.

3.2.4 Drainage of Fills

Effective drainage of a fill is essential to avoid it to becoming saturated and settling or failing. The drainage of an embankment involves the removal of all storm water as well as subsoil water. In this way, wetting up of the fill is prevented and erosion damage minimised.

Special attention must be paid to all fills which cross valleys, as the transported material on the floor of the valley may provide an easy access point for water penetration. Permeable material should be removed at this point, and a drainage system installed to remove both the normal flood waters and underground seepage water.



Drainage

Different drainage options are discussed in Chapter 7: 6.2.

A good reference for drainage is the **SANRAL Drainage Manual**.

(i) Treatment of Stormwater

Stormwater can be removed by using a large culvert along the natural watercourse, as illustrated in Figure 70. Under no circumstances should such a culvert be shortened to stop above the toe of the embankment. Nor should it deviate from the direction of the original water course.



Figure 70. Removal of Stormwater by a Large Culvert

(ii) Treatment of Subsoil Water

Should the exposed floor of the valley be such that water may enter the fill, a subsoil drainage system must be provided. In the case of benches, a series of blanket filters can be installed and connected to further subsoil drains, to remove water from the embankment. Should the slope on which the embankment is placed be flat enough so that benches are not required, then the blanket filter can be continuous. The lower edge of such a blanket filter must be placed where it will not be blocked over time, and will not trap water within the embankment.

Cut off drains may be required along the upper edge of the embankment. If the entire embankment is placed on a clay layer which can deform, then an additional cut off drain may be required at the toe of the embankment.

3.2.5 Side Slopes

Steps must be taken to ensure that the side slopes are compacted sufficiently, especially in the case of high embankments where the soils are most easily eroded. Loose material on the side slopes absorbs rain water and results in surface failures by material sloughing off the sides of the embankment. An example of a side slope, which has eroded from inadequate compaction, is shown in Figure 71.



Figure 71. Side Slope Erosion due to Inadequate Compaction

3.3 Compaction of Soils, Gravels and Sands

Compaction of material layers is one of the most important determinants of the performance of a constructed fill or pavement structure. The effect of compaction on a material is to improve particle interlock and to reduce the voids between the particles. Poorly compacted gravel materials densify further under traffic, causing rutting and/or shear

failure in the material. In asphalt materials, insufficient density causes rutting and increased permeability of the material, which promotes moisture damage or ageing of bituminous binders. It is, therefore, imperative that compaction is treated as one of the most important aspects of road construction.

To ensure a proper understanding of soil compaction, the factors which affect the compaction achieved in a material must be understood. These factors include:

- **Soil type**
- **Moisture condition** of the material
- **Compactive effort**

3.3.1 Soil Type

Soils are made up of particles of different sizes, shape and hardness, and are classified into gravels, sands, silts and clay. The particle size and shape, and grading and plasticity of these materials vary and have a significant effect on the compaction characteristics. The effects are discussed below.

3.3.1.1 Grading of the Material

The particle sizes in a soil mass are identified through sieve analyses carried out on the material. From the sieve analyses, the material is identified as either:

- Coarse grained material
- Gravelly soil
- Sandy soil
- Fine grained soil
- Silts
- Clays

The result of the sieve analyses is plotted in a graph which represents the grading curve for these materials. Gradings and grading curves are also discussed in Chapter 3: 2.3. The shape of the grading curve indicates the material to be:

- **Continuously or densely graded.** These soils have a reasonably even distribution of particle sizes throughout the soil mass.
- **Uniformly or open graded.** The particle sizes in these soils are mainly single sized.
- **Gap-graded.** These soils lack particles within a certain size range, usually the middle range of sizes.

Each of the above materials has different compaction characteristics. Usually, the more continuously or densely graded a material, the easier it is to compact because the voids between the larger size particles are filled with successively smaller sized particles. In contrast, materials which are very fine, or which consist mainly of single sized particles (uniformly graded), with less than 10% fines (< 0.075 mm), are usually difficult to compact because the layer tends to remain unstable during compaction. Gap-graded soils are also difficult to compact to a very dense matrix with low voids.

3.3.1.2 Particle Shape

The shape of individual particles in a soil mass affects the behaviour of the material. Various shapes such as rounded, cubical, flaky, angular and elongated particles have been identified. Each of these particle shapes has a marked effect on the ability to improve interlock between the particles during densification of the material.



Compaction

It is imperative that compaction is treated as one of the most important aspects of road construction. A lack of compaction has a serious impact of all types of road building materials and the ultimate performance of the road.



Soils and Gravels

Various aspects of soils and gravels are discussed in:

- Chapter 3: **Testing**, Section 2
- Chapter 4: **Standards**, Section 2
- Chapter 6: **Road Prism and Pavement Investigation**, Section 5 and 6
- Chapter 8, **Material Sources**, Section 2 and 3
- Chapter 9: **Materials Utilisation and Design**, Section 4
- Chapter 10: **Pavement Design**, Sections 5 to 9
- Chapter 13: **Quality Management**, Section 3

Flaky, angular or elongated particles are normally more difficult to compact than cubic or round particles. This is because badly shaped particles resist the compactive effort, which results in a higher void content in the compacted material.

3.3.1.3 Particle Hardness

The particle hardness varies in different soil types. Compaction of a soil is affected by the pressure transfer that takes place between particles at their points of contact. When a soil is densified, the applied force must overcome a reactive force caused by the particles resisting movement. If the particles are soft, they break under the compactive effort and form fines, which, if the breakup is excessive, might change the grading of the material.

3.3.2 Moisture Condition

The most important factor affecting the density achieved in a particular soil is the moisture content. For each soil, and each type and compactive effort, there is an "optimum moisture content" of the material at which the highest degree of densification can be achieved. The higher the compactive effort, the lower the optimum moisture content. Just as each compactive effort has an optimum moisture content (OMC), so every type of compaction equipment also has an optimum moisture content for the material, at which compaction should be carried out.

3.3.2.1 Optimum Moisture Content (OMC)

When a granular material is compacted, the finer particles are forced into the voids between the larger particles. When moisture is added, it acts as a lubricant and facilitates compaction. When too much moisture is added, it forms a moisture layer around the various fine particles, preventing intimate contact, thereby reducing the density.

A test to determine the maximum dry density (MDD) and optimum moisture content of soil or gravel was developed by Proctor. This test involves compacting soil in moulds using a standard compactive effort and varying moisture contents, to determine that moisture content (OMC), at which the maximum density is achieved. This is done by plotting the moisture content versus density curve, shown in Figure 72.

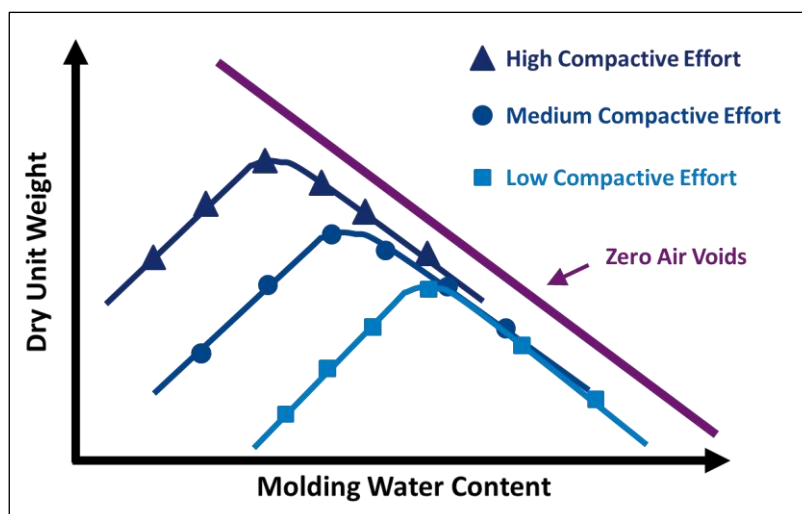


Figure 72. Moisture Content versus Density Curve to Determine OMC

As compaction equipment became more efficient, the Proctor compactive effort was inadequate to simulate the compaction achieved in the field. Therefore, compactive effort used in testing was increased to that required by the newer Modified AASHTO density test. These compaction tests are discussed in Chapter 3: 2.6.

In all testing for road works, the density of natural gravels is expressed as a percentage of the maximum dry density (MDD) achieved with Modified AASHTO compactive effort at the optimum moisture content. In this way, the density actually achieved in the field can be compared to a repeatable and reproducible laboratory value. It should be noted that density is not necessarily an indication of strength, as a high density on a weak material does not necessarily result in a high shear strength or stiffness. In practice, shear strength tests are carried out at more than one density so that the strength-density relationship of the material is determined.

The optimum moisture content and maximum dry density (MDD) values are used as follows:

- To ensure that the material in the field is **compacted at the correct moisture content**.

- The MDD is used as a measure to determine the **relative density of materials** in the field, to be able to judge whether the field density is satisfactory.
- To provide a **reference density** at which to compare the shear strength of various materials and various other material characteristics, such as its resistance to erosion.

The density of the material in the compacted layer is determined using one of two methods, the sand replacement method or with the nuclear density apparatus. The nuclear density gauge is discussed in Chapter 3: 2.7.1. The resulting value is then compared to a reference density and expressed as a percentage, and is known as the relative density. The procedures followed in the field differ depending on the material.

The achievement of the specified density in a cost-effective manner during construction requires careful control of the moisture content, number of roller passes applied and type of roller used. A maximum density is achieved at a particular moisture content when a particular compactive effort is applied. If additional density is required, a higher compactive effort has to be applied, or the moisture content changed.

3.3.2.2 Compaction Moisture

The correct amount and a uniform distribution of moisture are essential for compaction. There are two methods to optimise the compaction moisture of the material. The most common method uses conventional construction equipment such as water tankers, graders and dish ploughs. The other method uses in situ recycling machines.

(i) **Conventional Equipment**

When conventional equipment is utilized, water is applied uniformly over the entire width of the layer with pressure spray tankers, as soon as the material has been spread or broken down with a grid roller. After the water has been added to the layer, it is mixed using disk ploughs and grader tines. All the required water must not be added in a single operation, but that which has been added must be mixed in thoroughly. The moisture content should be checked with a nuclear gauge to assess whether the required moisture content has been reached. The nuclear gauge must be calibrated for each specific material.

When experience with the material has been obtained, it may be possible to assess the OMC by compressing a handful of soil. The OMC is generally near the point where a compressed handful of material just does not fall apart. At this point, the layer normally requires a further single application of water, mixed with a disk plough, to bring it to OMC.

Should the material show wet areas, it should be cut out with the grader and spread uniformly over the rest of the layer, after which the material should again be mixed with the disk plough. Care should be taken to ensure that the moisture is distributed throughout the entire depth of the layer and that a thin dry layer does not occur at the bottom. If necessary, the entire layer may have to be cut to the sides, or the middle of the road, with a grader, to ensure uniform and careful mixing of all of the moisture.

The mixing of water can be facilitated by moistening the layer thoroughly in the afternoon prior to compaction on the following day. Evaporation of water during mixing can be reduced by carrying out this process early in the morning. The length and width of the layer to be processed must not exceed the capacity of the water tanker or mixing or compaction equipment.

When applying water, it is important the tanker does not stand on the layer at the beginning and end of the section. If water drips from the tanker, this results in wet areas in the layer.

(ii) **In Situ Recycling Machines**

When in situ recycling machines are used to optimise the compaction moisture, the water is sprayed into the recycler's mixing chamber. The rate of water delivery is metered accurately through a micro-processor controlled pumping system. The rotating drum mixes the water thoroughly with the recycled material to achieve the moisture content necessary for optimum compaction. See Section 2.7 for more on recycling machines.

The plasticity or clayey nature of a material also influences compaction. Clay is relatively impermeable and the particles are packed into a dense matrix. It is, therefore, difficult to ensure an even distribution of moisture throughout the material.

3.3.3 **Compactive Effort**

There are three different compactive efforts for densifying a mass of material: static, impact or vibration compaction. The manner in which particle interlock is achieved through these compactive efforts differ quite

significantly. The efficiency of static compaction reduces rapidly with depth, whereas impact pressure is very effective for deep densification. Vibration pressure is very effective in overcoming friction between particles as it cause the particles in a soil to move correspondingly in a rotary motion or up and down, and forces the moving particles into a greater degree of interlock. Guidelines on the selection of these rollers are discussed in Section 2.10.2.

3.3.4 Compaction of Cohesionless Sands

Cohesionless sands are generally required to be compacted to 100%. To limit lateral movement during compaction of cohesionless sands, the layer should ideally be covered with a capping layer of granular (more cohesive) material. The AFCAP/ASANRA Guideline: “**Guide for the Use of Sand in Road Construction in the SADC Region**” contains useful information on utilising these types of materials.

3.4 Cementitious Stabilization

Stabilizing road building material with cementitious agents such as cement and lime, or blends of cement with mineral components such as fly ash, ground granulated blast furnace slag and limestone is common practice in South Africa. The first cementitious stabilized pavement layer was constructed during 1941. Most of the major roads in South Africa constructed since then have been constructed with one or more stabilized layers.

The purpose of stabilization is to change the properties of the material, and thereby increase the bearing capacity of the material, or to increase the strength and stiffness of the pavement layer through cementation. The strength of a stabilized material, and the rate of strength development, depends on the following:

- Material **properties**
- **Quantity** of cementitious agent added
- **Characteristics** of the cementitious agent
- **Uniformity** of mixing
- **Moisture** in the material
- **Density** of compacted material
- Method of **curing** and curing period

The main mode of distress in a stabilized layer is through cracking of the layer or carbonation of the material in the layer.

- **Cracking** of a stabilized layer can be either traffic or non-traffic associated. Traffic associated cracking is caused by overstressing the stabilized layer. Non-traffic associated cracking is generally caused by drying shrinkage and thermal movements occurring within the stabilized layer. The degree and extent of this type of cracking can be limited by adding the least amount of stabilizing agent required to achieve the required strength, and by ensuring that the compaction moisture content is limited to the minimum necessary in order to achieve the required level of compaction. Stabilized layers should thus never be “slushed” to achieve a “smooth/uniform” final surface finish.
- **Carbonation** is a process whereby the cementation of the material is adversely affected. It is the reaction whereby carbon dioxide (CO_2) in the air reacts with the calcium hydroxide ($\text{Ca}(\text{OH})_2$) in the stabilized material to form calcium carbonate (CaCO_3), resulting in a volume increase of about 10%. This leads to disintegration of the stabilized layer. The calcium carbonate reduces the pH of the stabilized material to that of calcite (about 8.3), resulting in instability of remaining cementitious products. Various construction control measures can be implemented to limit the carbonation process. Carbonation is described in more detail in Chapter 6: 7.4.1.1 and Chapter 13: 4.2.1.

Quality control during the construction of a stabilized layer is thus of utmost importance to ensure adequate performance.

3.4.1 Types of Cements

Cement specifications in South Africa have to comply with SANS 50197-1, which categorises common cements according to their composition and strength development. This is discussed further in Chapter 4: 5.1.2, and all details of the categories of cement and compressive strength requirements are provided. Cement types used for road stabilization vary, but historically CEM II 32.5N types were mainly used. CEM V type cements have also been used successfully in road stabilization projects. However, the availability of cement types depends heavily on the location of the project and the manufacturing capabilities of cement producers in the vicinity. The desired cement



Cementitious Stabilization

Various aspects of cementitious stabilization are discussed in:

- Chapter 3: **Testing**, Section 5.3
- Chapter 4: **Standards**, Section 5.3
- Chapter 9: **Materials Utilisation and Design**, Section 6
- Chapter 10: **Pavement Design**, Sections 7 and 8
- Chapter 13: **Quality Management**, Section 4

type for road stabilization may, therefore, not be available. It is very important to go through a proper stabilization design process to ensure that the correct cement type, in conjunction with the specific material, is used.

3.4.2 Process Control

The construction of a stabilized layer comprises the following processes, which should be controlled to ensure a high quality stabilized layer:

- Preparation
- Spreading
- Mixing
- Compaction
- Reworking
- Curing
- Limiting carbonation
- Curing techniques
- Safety measures

3.4.2.1 Preparation

The material to be stabilized should be prepared as per the specification, shaped and lightly compacted. It is advisable that the moisture content of the material be corrected to the field compaction moisture content the previous day, so that it can soak overnight to aid mixing of the material and the stabilizer.

3.4.2.2 Spreading

The cementitious agent can either be spread by hand from bags or by bulk using mechanical spreaders. Spreading by hand from bags has increased during recent years, especially due to the enhancement of the labour content on a project, as well as the short length of stabilized sections during rehabilitation contracts. Spreading with mechanical spreaders and tankers is discussed in Section 2.5.



Spreading Cement

Labourers spreading the cementitious agent must wear the necessary **protective clothing**.

If spreading by hand from bags, the following should apply:

- The **bags should be neatly laid out** in 3 or 4 rows, evenly spaced over the width of the road. The number of rows must be chosen that the spacing between rows is approximately the same as the spacing between bags in every row, as shown in Figure 73. The calculation of the bag spacing done using Equation (1).

$$L = \frac{M \times 10^5}{T W P D} \quad (1)$$

where

- L = Length between bags when such bags are placed in a single row, in metres
- M = Mass of the bags, in kg (1 bag cement typically = 50 kg)
- T = Thickness of the compacted layer, in millimetres
- W = Width of the road to be stabilized, in metres
- P = Percentage stabilizing agent required, by mass of stabilizer to mass of raw soil
- D = Density of the soil after compaction, in kg/m³. This is not the modified density of the soil, but the required density that must be obtained after compaction. Supposing the soil's modified density is 2167 kg/m³ and the soil must be compacted to 96%, then
D = 2167 x 96/100 = 2080 kg/m³.



Figure 73. Bag Placement and Spreading

- When the bags are laid out in more than one row, the **distance between the bags** can be obtained by multiplying the distance for a single row (L) by the number of rows.
- After the positions for the bags have been marked on the prepared surface of the layer, the bags can be laid out on these marks. The **bags should be opened** using a spade, and the stabilizer should be spread evenly over the surface. After the stabilizer has been spread with shovels, it is advisable to further spread the material more evenly using hand brooms or squeegees, as illustrated in Figure 73. A grader blade should not be used to spread the stabilizer, unless the surface is very even.
- Where **two stabilizers** are specified, special attention must be given to ensure that each one is spread evenly.
- Labourers spreading the cementitious agent must wear the **necessary protective clothing**.
- An example of **how not to spread cement** prior to stabilization is given in Figure 74. In this situation the cement will be unevenly distributed across the layer.



Figure 74. Example of Incorrect Spreading of Cement Prior to Stabilization

3.4.2.3 Mixing

There are various methods used to mix the cementitious agent and water into the material. The methods most commonly used are with conventional equipment, such as graders and disc-harrows, or in situ recycling equipment. The method followed depends, to a great extent, on the type of material and the availability of plant. The use of in situ recyclers for mixing in the cementitious agent and water has increased significantly over recent years. Guidelines for using in situ recyclers are provided in Section 2.7.

3.4.2.4 Compaction

Stabilized materials should be compacted at a moisture content below 80% of saturation, to reduce cracking in the stabilized layers. Some materials are more difficult to compact after the addition of stabilizer than before, while others become more readily compactable. This behaviour is directly attributed to the change in the grading of the material, caused by the addition of the fine stabilizer. If the material is fine graded, the compaction techniques should be adapted to ensure that laminations (thin layers) are not built into the stabilized layer. For each type of material, the most effective and economical compaction procedure should be established. As the majority of materials tend to become non-plastic with stabilization, they should be compacted with care to prevent the formation of shear planes under the roller. Shear planes are built-in weak spots, which may give problems at a later stage. It is normally preferable to use 10 passes with a light roller, than one pass with a heavy roller, which may overstress the material.

Cementation starts immediately as the soil and cement come into contact with the compaction water. Therefore, the mixing and compaction process should be completed as soon as possible, to maximise the benefits of stabilization. Cognisance should be taken of the fact that the strength gain of the stabilized material is dependent on the type of cement used. A very fine ground cement, such as CEM 1 42.5, has a fast strength gain. This affects the time available to mix, compact and shape the layer. The time generally allowed from the when the stabilizer and water is added to the material to the completion of the layer is 6 hours for cement and 12 hours for lime.

3.4.2.5 Reworking

When a stabilized layer cannot be satisfactorily compacted within the prescribed time, both the dry density and the final strength are reduced, and the layer is not likely to conform to the specification. In this case, the layer must be ripped, re-stabilized and reconstructed. When reworking, not more than half the stabilizer application must be added because, although most of the exchange and flocculation reactions have already taken place, some residual (and still active) stabilizer is left. Reworking should not be permitted more than seven days after the initial construction.

Reworking should not be allowed more than once. When reworking material with additional stabilizer, the maximum dry density (MDD) should be re-determined.

3.4.2.6 Curing

This is the most important aspect of stabilization. The requirements should be strictly adhered to. The most important requirement is that the completed layer should never be allowed to dry out. This is because keeping the layer damp:

- Inhibits **carbonation** of the stabilizer.
- Provides enough moisture at the surface of the layer for **cementation** to take place.
- Prevents the **temperature** of the surface increasing compared to the rest of the layer, which may induce thermal stresses and potentially inducing cracking.

If a course graded material such as a crushed stone is stabilized, slushing of the layer to obtain the required density is not allowed.

The layer should be kept damp for at least 7 days after stabilization and compaction are complete. However, especially for lime stabilization, the curing period should be longer. This could be achieved by, after the 7 day curing period has elapsed and the layer is strong enough for traffic, dumping and spreading the next layer on the lime stabilized layer.

To prevent damage to the layer during the curing period, a very light water cart or a 'side spray bar' should be used to water the layer.

The following curing methods are used:



Curing

Curing is the most important aspect of stabilization. The layer must never be allowed to dry out to:

- Inhibit **carbonation**
- Allow **cementation**
- Prevent **thermal stresses** developing

The layer should be kept damp for at least 7 days after stabilization and compaction have been completed.

(i) Regular Application of Water

The stabilized layer is kept continuously moist by regular spraying with a water bowser. The disadvantage of this technique is that the top few millimetres of the layer tends to dry out rapidly between water applications. This usually results in repetitive cycles of wetting and drying, creating a weak layer in the pavement.

(ii) Covering with Impermeable Sheeting

An impermeable sheet or cover is placed on the finished layer immediately after compaction, and left in place for at least seven days. The cover must be held down with stones, or, preferably a sand-berm to minimise wind ingress. Effective overlap of sheets and close stone placement is essential to ensure a good seal. This method is suitable for all pavement layers, including the base, and ensures a constant, humid environment. It also negates the need for, and prevents, vehicles from travelling on the layer. Unfortunately, the method is expensive and the sheeting is difficult to place and retain in place in strong winds.

(iii) Application of Curing Membrane

The application of a good thick bituminous membrane or tack coat is an effective curing method. A surface treatment grade of bitumen emulsion is probably the most effective, but has practical problems in terms of adhesion to tyres during follow-up sealing operations. Blinding with sand or crusher dust can overcome this problem and provides a temporary riding surface until sealing commences. It is still important that no other traffic is permitted on the surface during the curing period. This is obviously a costly operation for layers other than the base. Also, from a pavement drainage perspective, it is not advisable to have an impermeable layer within the pavement structure.

Curing membranes should be applied as soon as possible after completion of the layer, but not later than 48 hours. The layer being kept continually moist before the membrane is placed.

A disadvantage of this method is that the black mat causes heating of the layer, accelerating the hydration process, and also inducing thermal stresses, which could lead to cracking. The high temperatures in the upper part of the layer also reduce the ultimate strength of the material. In addition, the thick impermeable layer of bituminous membrane on the base layer can create a problem when the final surfacing is applied.

(iv) Covering with Subsequent Layer

The material for the subsequent layer is tipped and spread over the stabilized layer and kept moist. This has been found to be an effective curing technique. Care should, however, be taken to minimise vehicle movements on the stabilized layer, and an end-tipping technique should be used where feasible. Material from the verge can be used on base courses, it is less costly than importing material specifically for curing.

This is the preferred method where appropriate, due to the moisture retention capacity of the material and its cost effectiveness. It is also suitable for the longer curing periods required for lime and, in some cases, lime/slag stabilization.

Over and above curing in order to facilitate the cementation process, protection of the completed layer is also vital when stabilising during expected cold (sub-zero) night temperatures to prevent freeze/thaw damage, particularly on cemented treated bases. Current experience indicates that even by applying a covering layer of only 75 mm of gravel soon after completion of compaction, facilitates the retention of the heat generated during the hydration process. This maintains the cemented layer at a temperature in the order of 5 to 7 °C above the ambient temperature, thus reducing the risk of any potential freeze/thaw damage.

3.4.2.7 Limiting Carbonation

The following construction procedures must be carefully controlled to minimise carbonation of susceptible materials.

- Layers must be compacted to **as high a density as possible**, without excessively disturbing the grading, as soon as possible after mixing with the stabilizer. This expedites cementation, and prevents carbonation reactions. This action helps by sealing the layer and reducing the voids, but is not applicable to lime modification.
- For **stabilized layers thicker than 200 mm**, the bottom half of the layer must, be compacted separately, to ensure that good compaction is obtained throughout the layer. Less than 5 per cent air voids is desirable, which may require additional compaction effort. Layers that are too thin, typically less than 100 mm, may result in "biscuits" layers with consequential problems.
- Where modification is required, and the **material is worked in two stages**, slightly higher stabilizer contents should be applied to compensate for carbonation. Care should be taken to seal the surface after the initial application of stabilizer.

- **Unnecessary delays in the placing of the next layer** on a stabilized layer must be avoided. Stabilized base courses must be sealed as soon as possible after construction.
- The **stabilizer must be as fresh** as possible, and must not be stored for long periods before use.
- Where **difficulties in achieving a well-compacted and cured layer** are envisaged, the thickness of the layer should be increased to allow skimming of the upper layer prior to sealing. Success of this depends, to a large degree, on the grading of the material in the layer.

Emulsion and penetration grade bitumen, when used as a prime coat, are more effective in limiting carbonation than the conventional cut-back bitumen.

3.4.3 Safety Measures

Lime and cement are strongly alkaline and are dangerous, causing serious injuries if not handled carefully. Reference should be made to the Material Safety Data Sheets available from suppliers. The following precautions should be taken when working with stabilization materials:

- Workers should be **trained** in the use of stabilizers and the associated safety precautions and treatments for exposure.
- Wear a **buttoned-up long sleeved shirt** and trousers or overalls.
- Wear **closed shoes** or boots.
- Wear a **hard hat and gloves**.
- Use **goggles and breathing masks**.
- When long periods of possible exposure are expected, **petroleum jelly** (Vaseline) can be rubbed onto the exposed skin.
- Carefully **wash immediately** after the work is completed. A small amount of vinegar in the bath water helps to neutralise the alkali.
- **Clothing exposed** to lime and cement must be washed regularly.
- Whenever hydrated lime or cement comes into **contact with the skin**, it should be washed off as soon as possible.

3.5 Bitumen Stabilization

Bitumen is becoming increasingly popular as a stabilizer, primarily due to technological advances. The bitumen is applied in either an emulsified or a foamed form. Stabilizing with bitumen is a cost-effective way to improve the strength of a material, while reducing the detrimental effects of water. Bitumen stabilization produces a relatively flexible layer, compared to the same material treated with cement.

Material stabilized with bitumen and a low percentage of cement (<1.5%), does not suffer from the shrinkage cracking phenomenon associated with cement treatment. Therefore, they may be trafficked immediately, due to the initial binding and strength of the surface particles that prevent ravelling under the action of traffic.

Bitumen stabilized material (BSM) is characterised by bitumen dispersing mainly amongst the fine particles, typically the fraction less than 0.075 mm for foamed bitumen and coarser for bitumen emulsion. The treated material is, therefore, a granular material with a bituminous mastic.

BSM layers are used instead of crushed stone bases. These materials involve mixtures of emulsion or foamed bitumen and crushed stone or good quality natural gravels, with net bitumen contents ranging from 0.5% to 3%. Approximately 1% cement is also normally added into the material to facilitate complete "breaking" of emulsion and



Bitumen Stabilization

The following are comprehensive guidelines for all aspects of BSMs:

- **TG2** (2009), Second Edition: Technical Guideline: Bituminous Stabilised Materials – A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials.
- **Wirtgen Cold Recycling Manual** (2010), Third edition. Wirtgen GmbH.

Various aspects of bitumen stabilization are discussed in:

- Chapter 3: **Materials Testing**, Section 4.6
- Chapter 4: **Standards**, Section 4.6
- Chapter 9: **Materials Utilisation and Design**, Section 9
- Chapter 10: **Pavement Design**, Section 7
- Chapter 13: **Quality Management**: Section 5

to aid distribution of the bitumen, and for early strength. The cement and bitumen binder together facilitate the construction of a dense, strong, fairly impermeable layer. The additional cost of the bitumen and cement is considerable, and hence BSMs are almost exclusively used when reworking existing base courses, in very wet areas, or where traffic must be accommodated by the layer prior to surfacing. Traffic accommodation on the completed layer is only possible if the surface is enriched with a 50:50 diluted emulsion, and the layer is kept dry. In wet weather, problems can be experienced if traffic is accommodated on this layer without a surfacing. Primes should not be used on BSM layers.



Primes on BSM Layers

Primes should not be used on BSM layers.

3.6 Modification of Materials

In many situations, the available gravels do not meet the necessary requirements for the pavement layer. In these cases, the materials can be modified. Several physical or natural methods of modification are available, which are used depending on the availability of materials. Should the necessary material not be available, then chemical modification may be used.

3.6.1 Natural Modification

There are several forms of natural modification available:

- **Crushing.** Where gravels have a high proportion of oversized material, and where better quality materials are only located at an uneconomical distance, single stage crushing or crushing and sieving of the oversized material should be considered.
- **Material mixtures.** When two materials of very different quality are available, and better quality materials are not available, mixing should be considered to obtain satisfactory performance. The cost of thorough mixing using a disc plough should be compared to the additional cost of hauling the material from a distance.
- **Admixture of clay.** This is normally only used for gravel wearing courses or shoulder materials. The clayey material should not be too active, and a PI of 16 to 24 is preferred. The clay should be stockpiled and dried out, and then crushed with a grid roller, as wet clay cannot be mixed effectively. The fine dry material can then be spread over the gravel, and mixed as if it were a chemical stabilizer. Thereafter the mixture can be moistened and compacted. A maximum of roughly 15% clay should be added. The actual amount used should be confirmed by laboratory PI and CBR tests.

3.6.2 Chemical Modification

Modification of a soil in a pavement layer most commonly involves treatment with lime. The modification is carried out in the following manner:

- Pavement layer **material is shaped**, and the lime is spread and mixed into the material.
- Layer is **lightly compacted to seal the surface** and limit moisture movement, and then left to stand for a minimum of 12 hours. During this period, the majority of the cation exchange reactions occur and particles flocculate.
- After the required **standing time** (typically 24 hours), the layer should be ripped and constructed conventionally.
- The **maximum dry density** (MDD) of the modified material is determined at the time of compaction.

Modification would normally be done on crushed stone or natural base material, to reduce a PI which is slightly outside the standard specification to within the required limits, or on a clayey subgrade to improve workability. There is a strong likelihood that some of this PI could return after some time and it is important that the natural strength of the material meets the required specification.

3.7 Cold Recycling

This section covers the cold recycling process, which has become a very popular construction method since the introduction of in situ recycling machines (Section 2.7). The shortage of construction material, especially in built-up areas, has resulted in the process becoming very popular as a rehabilitation option for strengthening pavement layers.

The cold recycling process is described in detail in the Wirtgen Cold Recycling Technology Manual (2010).

3.7.1 Types of Cold Recycling

Cold recycling can either be “in-plant” where material recovered from an existing road is hauled to a central depot, where it is fed through a processing unit, such as a pugmill-type mixer, or “in-place” using a recycling machine.

3.7.1.1 In-Plant Recycling

In-plant recycling is normally considered where recycled material is used in the construction of a new pavement layer during strengthening of an existing pavement.

In-plant treatment always remains an option that should be considered when recycling is applicable, particularly those that require a blend of recycled and virgin materials to be treated, and when treating with foamed bitumen and stockpiling for later use.

In-plant processing is generally the more expensive option, in terms of cost per cubic metre of material processed, primarily due to haulage and handling costs not applicable to the in-place recycling process.

The main benefits that accrue from in-plant mixing compared to in-place mixing include:

- **Control of input materials.** In-place recycling allows little control on the material recovered from an existing pavement, whereas a required end-product can be obtained by blending different aggregates using in-plant mixing. Input materials can be stockpiled and tested prior to mixing, and input proportions changed as required.
- **Quality of mixing.** Various changes can be made to the mixing operation of the pugmill to vary the time the material is retained within the mixing chamber, thereby changing the quality of the mix.
- **Stockpiling capabilities.** Particularly with foamed bitumen treated materials, the mixed product can be placed in stockpile and used when required, thereby removing the inter-dependency of the mixing and placing processes.
- **Placement.** The materials can be placed using a simple motor grader or asphalt paver.

3.7.1.2 In-place Recycling

In-place recycling is carried out using milling equipment to windrow the milled material in place. Then, remixers can be used to mix in cement or bitumen to strengthen the material, before it is spread and compacted.

However, in-place recycling is becoming very popular due to the advent of large powerful recycling machines (described in Section 2.7), which have the capacity to recycle thick pavement layers up to 500 mm in a single pass. However, the most common recycling depths are 200 to 300 mm.

3.7.2 Process Control

3.7.2.1 In-Plant Recycling

In-plant recycling involves removing material from the road and taking it to the plant where it is processed. It is then brought back to the road to be laid and compacted, as with any other stabilized layer. Therefore, all the process controls and issues that are applicable to cementitious and bituminous layers are applicable. These are discussed in Sections 3.4, Cementitious Materials and Section 3.5, Bituminous Materials.

3.7.2.2 In Situ Recycling

In situ recycling itself is a quick operation, where lack of attention to detail and control very quickly results in major problems. The following sections provide guidelines for controlling the process to ensure a satisfactory result. As with all construction operations, employing well-trained supervisors and operators is a prerequisite for success, not only in terms of quality, but also from a safety perspective.

Construction joints are very important and need attention. There are two types of joints encountered when recycling:



Cold Recycling

The **Wirtgen Cold Recycling Technology Manual** (2010) is a good reference for cold recycling.

Many aspects of cold recycling applied for BSMs are included in TG2: **Technical Guideline: Bituminous Stabilised Materials** – A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials.



Process Control for In Situ Recycling

The construction chapter in the following guideline provides valuable detail on process control for in situ recycling with bitumen stabilized materials.

- **TG2: Technical Guideline: Bituminous Stabilised Materials** – A Guideline for the Design and Construction of Bitumen Emulsion and Foamed Bitumen Stabilised Materials.

longitudinal joints running parallel to the centre line of the road, and lateral joints that run at right-angles to the centre line. All joints are essentially discontinuities in the pavement and, unless they are properly treated, have the potential to negatively affect the structural integrity of the recycled layer. Longitudinal and lateral joints are very different. Longitudinal joints are "designed" to fit the road geometrics, while lateral joints are produced every time the recycling operation stops.

The recycling process is relatively simple, as most of the process is taken care of by the recycler and its related control equipment. However, the equipment and related checks must be carefully controlled to provide a satisfactory result. The various operational control measures are summarised as follows:

(i) Planning

The day's activities must be planned to conceptualise the cut plan, detailing overlaps between the various cuts and the consequential requirements for configuring nozzle closures on each spray bar.

(ii) Preparatory Work

This must be completed before recycling commences, including any pre-milling or pre-pulverising requirements.

(iii) Start Up

This includes pre-start checks on all plant and equipment, especially the pumping systems and spray bars on the recycler. Also included in these checks are the critical temperatures, e.g., in the material to be recycled and the bitumen products in supply tankers. Thereafter, the start-up procedures must be strictly followed.

(iv) Recycler Set Up

The recycler must be correctly set up with the spray bar correctly configured in terms of nozzle closure, the tankers properly connected and the correct information input into the computer. The operator must have an unambiguous understanding of the procedures to be followed, and be provided with a clear steering guideline.

(v) Stabilizer

Any stabilizer or active filler requirement is accurately spread on the layer surface ahead of the recycler (see Section 3.4.2.2).

(vi) Routine Checks during Recycling

Routine checks during recycling include:

- Accurately follow the **correct line of cut**
- Maintain the **speed of advance** within specified limits
- Physically measure the **depth of cut** on a regular basis
- Check the **moisture content and consistency** of treated material
- **Visual appearance** of the treated material, e.g., grading, mix quality and colour variations
- **Temperature** measurements across the cut width
- Read the **pressure gauges and flow meter displays** fitted to the spray bar feed lines

These checks are on-going. It is imperative that they are carried out on a regular basis to ensure that the recycled product consistently meets the quality requirements. This demands diligence on the part of the supervising team. Recycling is monotonous and, when everything is working properly, carrying out regular checks appears to be unnecessary. However, thanks to the high output achieved by recycling, if something does go wrong and the problem is not immediately detected, remedial measures can be onerous.

(vii) Compaction

Compaction is carried out immediately behind the recycler using the correct roller combination and rolling technique. See Section 2.10 on rollers.

(viii) Final Levels

Final levels must be accurately cut and the layer correctly finished off.

(ix) Longitudinal Joints



Cut Plans for Longitudinal Joints

Achieving properly overlapped joints is important for the ultimate performance of the recycled layer. The cut plan detailing each overlap is one of the first requirements when planning a project. Clear guidelines must be established for each cut, not only the first cut.

The width of the recycled cut is invariably less than the road or carriageway width. Several passes (or cuts) are, therefore, required to completely recycle the full width, resulting in a series of longitudinal joints between adjacent cuts. Overlaps are required along the full length of each joint to achieve continuity between the two cuts. Therefore, only the first cut recycles virgin material over the full drum width. Thereafter, the effective width of all subsequent cuts is reduced by the width of overlap. Careful consideration must be given to ensure that the application rate of stabilizer and water is both uniform and continuous across all overlaps.

The number of cuts necessary to recycle the full road width, and the location of each longitudinal joint is influenced by:

- **Width of road to be recycled and cross-section details.** Cambered roads should preferably be treated in half-widths to achieve a uniform depth of recycling across the crown. The first cut on the first half-width to be recycled is normally extended across the centre line by the width of the overlap. The first cut on the second half-width is then positioned to follow the centre line, thereby re-establishing the crown.
- **Type of recycling machine being used on the project.** In particular, the width of the milling drum.
- **Width of overlap.** Recyclers are large machines and require a tolerance for adhering to a steered line. The recommended minimum overlap width is 150 mm. This may be generous when working with an experienced team, when it may be relaxed to 100 mm, the absolute minimum. To take cognisance of the propensity of coarse materials to segregate, the width of overlap should increase with layer thickness and coarseness.
- **Longitudinal joints.** These should always be located away from the outer wheel path.

The cut plan detailing each overlap is one of the first requirements when planning a project. The overlap must be subtracted from the drum width to determine the effective stabilizing width for each cut that, in turn, governs the quantity of water and stabilizer to be added. Where there is any doubt about the uniformity of application for water and stabilizers across the width of an overlap, an enlarged cut plan should be compiled, showing the overlap relative to the position of the relevant spray bars.

The achievement of properly overlapped joints is important for the ultimate performance of the recycled layer, and must receive due attention. Where problems arise, they are generally caused by the improper operation of the recycler, resulting in unrecycled strips between adjacent cuts or double-dosing due to accidentally increasing the width of overlap. To assist the operator in steering the recycler correctly, a clear guideline must be established for each cut, not only the first cut. Before starting a fresh cut, the guideline must be checked to ensure that it is clearly visible over the full length of cut. In addition, the nozzle configuration should be checked before starting to ensure that the correct nozzles are closed, in accordance with the planned overlap. Examples of cut plans and nozzle configurations are given in TG2 (2009).

(x) Lateral Joints

Lateral joints are discontinuities across the width of cut that are formed each time the recycling operation starts or stops. Every stoppage, even those that take only a few minutes to change tankers, creates a lateral joint. Such a joint is a change in the uniformity of the recycled material. Care should, therefore, be exercised to minimise stoppages and, where they are unavoidable, to ensure continuity across the resulting joint.

The key to treating these joints properly is to have a clear understanding of what is happening inside the recycler's mixing chamber, particularly the process of adding stabilizer. Most problems encountered are the result of under or over-application of stabilizers and/or water at the joint.

Two of the most important features concerning lateral joints are:

- **Start-up procedures.** When starting to recycle, all start-up procedures must be carefully followed. Especially procedures to bleed air from each spray bar supply line, i.e., any air trapped in these lines first has to be displaced before the fluid reaches the spray bar. Unless properly bled, it is possible to recycle several metres without additive, resulting in an unstabilized (or dry) section of pavement.
- **Slow advance speeds when stopping and starting.** Although automatically controlled by the micro-processor, a very slow advance speed (< 2 m/min) results in such a low application demand that operating pressures in the spray bars reduce to a point where fluid injection is ineffective, and the fluid dribbles rather than sprays. The best way to overcome this problem is to "enrich" the joint area by pre-treating. This is



Lateral Joints

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achieved by reversing the train at least the diameter of the milling drum (approximately 1.5 m) back into the previously recycled material, thereby ensuring that all material receives treatment across the effective width of joint. When starting, the operator should apply full power and accelerate immediately to the usual operating speed.

Similar to paving asphalt, lateral joint problems only arise when the operation stops. The recycler should, therefore, only be stopped when really necessary, for example, when a supply tanker is empty, or at the end of the day's production.

3.8 Crushed Stone Base

This section covers the construction of crushed stone and crushed slag layers, as the techniques for both aggregates types are essentially similar. A crushed stone base is the most popular base in pavements constructed in South Africa. The performance of this layer is very dependent on the method in which it is constructed. For this reason, the method of construction is dealt with in detail in this chapter. A crushed stone layer consists of crushed stone or blast furnace slag uniformly graded from a minus 37.5 mm or minus 28.0 mm maximum size to dust, and which is compacted to form a tight, dense integral mass. The strength of the layer is primarily obtained by the mechanical interlock of the various size aggregate particles.

A distinction must be made between "crusher run" and "crushed stone".

- **Crusher run** includes the material obtained by crushing rock in a crusher, and uses the total crushed product without applying strict grading or other specifications.
- **Crushed stone** involves crushed rock, which conforms to strict specifications.

Crushed stone is often used in high quality bases, such as G1 or G2 bases. One of the primary requirements for the successful performance of a crushed stone base layer is adequate support in the form of a well cemented subbase layer. The cemented subbase layer is less moisture susceptible, and this facilitates slushing of the crushed stone layer with water to achieve the required high density. The strong support provided by the cemented layer allows a high density to be achieved, and has a confining effect on the base layer, which increases the stiffness and reduces the probability of shear failure occurring within the crushed stone layer.

3.8.1 Process Control

The process control for crushed stone and crushed slag differ, as described in the following sections.

3.8.1.1 Crushed Stone

The construction of the crushed stone layer comprises the following processes, which should be controlled to ensure a high quality crushed stone base layer is constructed.

(i) Construction of Gravel Shoulders

Where gravel shoulders are being used, the shoulder material must be dumped on the road in a predetermined pattern, so that the layer has the specified thickness after shaping and compaction.

The heaps of shoulder material must be flattened and watered to optimum moisture content. Thereafter, it should be compacted and cut to the required level. After final compaction, the inside of the shoulder must be cut at right angles to the surface of the subbase. All excess material must be removed from the subbase surface, to prevent contamination of the crushed stone layer.

Provision must be made for draining the crushed stone layer at low points, particularly if the shoulder material is fairly impermeable.

If the shoulder is too narrow for normal construction equipment, then it is normally constructed wider and cut back to the required width.



Crushed Stone Bases

Crushed stone bases are discussed in:

- Chapter 3: **Testing**, Section 3
- Chapter 4: **Standards**, Section 3
- Chapter 8: **Material Sources**, Section 2 and 3
- Chapter 9: **Materials Utilisation and Design**, Section 5
- Chapter 10: **Pavement Design**, Sections 7, 8 and 9
- Chapter 13: **Quality Management**, Section 3

(ii) Dumping Crushed Stone on the Road

The crushed stone must be dumped on the road so that it has the required thickness after shaping and compaction. In most crushed stone material, a thickness reduction factor of between 1.4 and 1.5 is allowed for compaction.

The crushed stone must be dumped between the built up shoulders and, preferably, along the centre line of the road. It is essential that material be dumped as evenly as possible to ensure that it can spread uniformly. Where cross overs are required for traffic, it is preferable for the traffic to drive over the spread crushed stone. Photos of dumping and spreading crushed stone are given in Figure 75.



Figure 75. Dumping and Spreading of Crushed Stone

(iii) Spreading of Crushed Stone

To ensure that the layer is constructed successfully, it is essential to avoid segregation within the layer and to ensure that moisture is mixed uniformly throughout the crushed stone layer. These two factors ensure that the material is compacted in the most cost-effective manner, and that the highest possible density is achieved.

Segregation generally originates during the building phase of the crushed stone stockpiles. The stockpiles should be built in layers and care should be taken not to end tip the material near the perimeter of the stockpile which results in the courser material running down the sides of the stockpile, causing segregation. Loading material from the stockpile should also be controlled. A front end loader should be used and loading should be done from the bottom upwards, to ensure that the different layers of material in the stockpile are mixed before it is dumped in the trucks. It is thus essential that segregation be controlled at the stockpile site before the material is dumped on the road. Figure 76 shows a typical segregated stockpile showing the extent of single size coarse aggregate. Figure 77 shows a typical non segregated stockpile.

On the day prior to the compaction of a particular section, the material which has been dumped along the centre of the road should be spread in such a manner that a water bowser can drive on it. An example is given in Figure 75. In view of the fact that the material is dry, segregation easily occurs, and, therefore, the material must be moved as little as possible. The material can normally be effectively spread with a grader.

Uniform mixing of the moisture throughout the crushed stone layer requires the water to be added at least 12 hours prior to the actual mixing. The moisture spreads throughout the crushed stone layer on its own accord, which facilitates mixing of the material and inhibits segregation, as many of the finer particles adhere to the coarser particles.

After the material has been spread out, it must be watered. The water bowser drives over the spread material and waters the full width of the material. The quantity of water required varies, and care should be taken to ensure that the optimum moisture content for this specific material is not exceeded.



Figure 76. Segregated Material in Stockpile



Figure 77. Suitable Stockpile with No Sign of Segregation

(iv) Mixing

After the layer has been watered, the material is spread and mixed over the full width of the layer to be constructed. The material is cut from one side of the road to the other, using a grader blade. The amount of material handled within each pass should be such that the power of the grader is adequate to maintain a reasonable speed. It is highly undesirable for the machine to move at a variable speed, and skidding and sliding must be avoided.

During the final stage of mixing, the blade of the grader must be in contact with the subbase to avoid leaving a layer of fine material on the surface.

Should the material be too dry, it should be watered and remixed. The exposed surface of the subbase can also be watered at this stage if it is too dry. The mixing process must continue until all the material is mixed uniformly over the entire width of the road. Material which has already been mixed, must be placed in its final position to avoid unnecessary cutting and segregation.



Watering Crushed Stone Layers

The optimum moisture content for the particular material and compaction method should not be exceeded, as it will be difficult to dry out the material.

When the layer is too wet, compaction should be postponed until the layer has dried out sufficiently.

It must be emphasized again that the optimum moisture content for the particular material and compaction method should not be exceeded, as it will be difficult to dry out the material.



Figure 78. Mixing Crushed Stone

(v) Compaction

The layer is compacted starting with the rollers at the outside edges of the layer, and working towards the centre line, to maintain its shape. Where vibratory rollers are used, initial rolling may have to be carried out without vibration. The recommended number of coverages, prior to re-shaping the layer, is typically between 2 and 4 complete coverages with a vibratory roller and/or a pneumatic roller. Results from the test section aid in determining the number of coverages. Should problems be experienced with the density or grading of the material, then it may be necessary to construct the layer in 50 mm thick increments, using pneumatic and/or grid rollers.

The layer must be cut and shaped during the early stage of compaction. The first cut should start at the windrow and the cut should be such that the blade is full of mixed material. After the layer has been cut back into shape, compaction continues until the layer achieves stability and the required density.

As soon as the layer has reached a stable condition, a further cut of the windrow is made to spread finer material from the windrow over the entire width and length of the layer. At this stage, no attempt should be made to cut the layer to the correct shape or height, as it should already have been compacted to that position and shape.

After the final cut, the layer is finished with a vibratory roller, 10 to 12 tonne combination roller, or a flat roller, provided that the moisture content of the layer does not exceed the optimum for this particular roller. The optimum moisture content for a crushed stone is normally in the range of 2% to 4%. Where it is found that the layer is too

wet, the rolling process should be postponed until the layer has dried out sufficiently. Thereafter, the rolling is continued.

The rolling is carried out systematically from the sides towards the middle of the road with half-wheel overlaps, until the entire surface is covered, and the layer is not rolled out of shape. It is also important to carry out the first pass with the driving wheels of the roller in front, otherwise some material could be pushed in a wave in front of the roller, which could result in corrugations. The rolling continues until the material shows minimum movement underneath the roller. It is essential that no movement occurs towards the end of this process, as stability at this stage aids the slushing process significantly.

Dry crushed stone fines can be rolled into any loose or segregated areas at this stage to further aid the slushing process.



Figure 79. Compacting Crushed Stone

(vi) Slushing

The process of slushing is a critical operation. The purpose is to ensure that all aggregate particles interlock with one another to form a dense integrated mass of particles. Proper slushing results in closure of all the openings in the upper surface of the layer, and a smooth mosaic of stones. The purpose of slushing is not to simply slush fines to the surface of the road. The slushing process also provides a good test for the stability of the layer under saturated conditions.

Slushing is carried out by watering the layer thoroughly, and then rolling with vibratory rollers without vibration, pneumatic rollers or static rollers, and squeezing fines to the surface. The fines are subsequently broomed towards the coarser areas and finally broomed off the road surface. Because the volume of air between the aggregate particles decreases as the particles interlock, fine material in the form of a slush migrates to the surface. The fines that are almost totally saturated with water act as a lubricant.

The layer can be slushed immediately on completion of compaction, provided that the layer is stable. Alternatively, the process can be postponed for a day or two so that the surface of the layer dries out and achieves stability. The process should however, not be delayed for too long, otherwise the layer will dry out too much for slushing to be effective.

In general, 5 to 7% fines are required to fill all the voids between the coarser aggregate particles. Therefore, if



Slushing

Slushing is carried out by watering the layer thoroughly and then rolling the layer with vibratory rollers without vibration, pneumatic rollers or static rollers, and squeezing fines to the surface. The fines are subsequently broomed towards the coarser areas and are finally broomed off the road surface.

The purpose of slushing is to ensure that all aggregate particles interlock with one another, to form a dense integrated mass of particles. Proper slushing results in closure of all the openings in the upper surface of the layer, and a smooth mosaic of stones.

the crushed stone initially contains less than this amount of fines, then all the voids will not be filled and no fines will be slushed to the surface. In this case, the required density will also probably not be obtained.

The water application rate should be kept as low as possible. It is more effective to apply small quantities of water more regularly than large quantities at longer intervals. With large quantities, a lot of water runs off the road without performing any useful task, and is just wasted. The water should primarily be applied to the higher parts of the road profile, such as the centre of a crown or the high edge, in the case of a super-elevated section.

The crushed stone is normally slushed in short sections of between 30 and 50 metres depending on the number of rollers and brooms available. Normally, at least two rollers should be used for slushing. In general, the rollers should gradually be moved from the edges towards the middle of the road, with regular overlaps.

In the early stages, the fines can be broomed down the length of the road or across the road to obtain a uniform texture. Stiff hand brooms or a light mechanical broom are used for this purpose. When a uniform texture is achieved, the road must be rolled systematically from the sides to the middle, and all excessive fines must be removed from the road with brooms. The fine material must be removed before it dries out and hardens. At all times, care should be taken not to roll a layer out of shape.

Should segregation occur, it may be necessary to concentrate rolling in the areas where more fines occur, and these can then be broomed over to the coarser areas.

The slushing process must continue until the slushing water is clear. The fines which slush out of the layer are normally silty, and care must be taken not to over slush the layer. If the slush becomes coarser and sandy, slushing must be stopped, otherwise the layer may loosen and become unstable. Slushing should not be used to provide significant additional density. Excessive densification during slushing causes deformation of the surface profile.

In certain situations, the outer 500 to 800 millimetres of the crushed stone tends to become over-saturated when a shortage of fines is present in these areas. It is desirable to construct small furrows through the shoulder to the full depth of the crushed stone layer, to drain excessive water from the layer. In extreme cases, these furrows could be placed at 2 metre intervals.

The most important practical requirement when slushing, is that no movement should be present under the roller at the end of the slushing process. Should the layer continue to move under the roller, even after slushing for a considerable period, then the layer should be broken up, remixed and re-compacted. In isolated cases, small movements occur under the roller after slushing. In these cases, it may be possible to stop the slushing process temporarily to let the layer dry out for a few days. If the layer is then slushed again, movement should cease. Should movement, however, still occur, then the layer must be ripped up, remixed and re-compacted.

After the excess fines are squeezed out of the layer and a close-knit, stable surface has formed, the layer should be watered again and all the free water broomed off the layer without further rolling. A photo of a segregated material is shown in Figure 81, where a lack of large aggregates is visible. A well knitted surface is shown in Figure 81.



Layer Movement after Slushing

The most important practical requirement when slushing, is that no movement should be present under the roller at the end of the slushing process. Should the layer continue to move under the roller even after slushing for a considerable period, then the layer should be **broken up, remixed and re-compacted**.



Figure 80. Segregated Material



Figure 81. Well-knitted Crushed Stone Surface

(vii) General

During the slushing process, care should be taken not to pick up any shoulder material with the roller, to avoid rolling this into the crushed stone. The surface of the crushed stone layer should be broomed with a mechanical broom not more than 24 hours prior to the application of prime.

The prime should be applied as soon as the moisture content at any point in the layer is less than 50% of OMC. Should the weather be inclement and the layer does not dry out, the prime can be applied even if the layer is wet, but the application rate should be reduced slightly as less prime will be absorbed by the layer. In any event, the layer should be moistened immediately prior to the application of a prime. No unnecessary traffic may be allowed on

the layer until a surfacing layer has been placed. The layer should not be surfaced until it has dried out to well below saturation.

The purpose of the prime on the crushed stone layer is not to penetrate the upper surface of the base, but rather to protect the surface of the base from construction traffic and to allow better bonding between the surfacing and the base.

(viii) Testing

Cohesionless materials, such as crushed stone, do not have a clearly defined moisture density curve and hence it is difficult to determine the maximum density and optimum moisture content in a similar manner to that of natural gravels. Therefore, instead of using the maximum dry density, crushed stone is controlled using another reference density, called the apparent density. The apparent density is that density which would theoretically be achieved if the material were compacted to such an extent that no air or moisture remains between the aggregate particles. This is similar, although not exactly the same, as the specific gravity of the material, as some small voids are present within the aggregate particles themselves, which cannot be eliminated in the test procedure.

The apparent density depends on the type of material and its specific gravity, as well as the degree to which moisture is absorbed by the aggregate particles. It is determined using SANS 3001-AG22. The test is discussed in Chapter 3: 3.2.9.



Apparent Density

Crushed stone is controlled using a reference density called the apparent density (AD-CS). This is the density which would theoretically be achieved if the material were compacted to such an extent that no air or moisture remain between the aggregate particles. See Chapter 3: 3.2.9.

The apparent density of materials with the same aggregates but different gradings varies and, hence, this value should be determined at every position at which an in situ density is determined. The nuclear apparatus provides a fairly reliable indication of density on this material. However, when the surface is rough it must be smoothed out as specified in the test method. The sand replacement method also provides reasonable results if carried out properly, but can often lead to higher values than are actually present, due to disturbing the sides of the density hole and the volume reducing.

3.8.1.2 Crushed Slag

Construction of a crushed slag layer is basically similar to crushed stone, with a few minor differences, which are highlighted in the following paragraphs:

(i) Grading

The grading of the crushed slag must be within the specifications for crushed stone. Should the material be too coarse, particularly the percentage retained on the 5 and 2.0 mm sieves, then it will be more difficult to compact. It is also important to ensure that the percentage fines (passing the 0.075 mm sieve) should not be less than 5%.

(ii) Handling

Segregation is a serious problem when handling crushed slag. The coarse and fine particles separate easily and handling must be minimized. If possible, material should be loaded directly from the crusher's conveyor belt into waiting trucks and then dumped on the road.

(iii) Compaction

Vibratory rollers are preferred for compaction of slag. Should these not be available, grid rollers can be used for initial rolling, because they will assist in breaking down the coarser aggregate particles and producing more fines. Wet slag can be rolled out of shape fairly easily with a heavy pneumatic roller. Therefore, it is preferable to carry out all initial rolling with a vibratory or grid roller, until the material is stable.

(iv) Addition of Fines

Should it be impossible to achieve the specified grading with the slag, and if stability is not achieved during the compaction process, fines may be added to the slag. Only approved fines should be used that are either applied after initial compaction by spreading over the surface of the layer, or prior to the mixing process by spreading the correct amount over the surface of the dumped and spread slag. When applying fines after compaction, care should be taken to spread the material in a uniformly thick layer. Areas with excessive fines create several problems and tend to pick up under the roller. After spreading the fines, it is rolled into the material with a vibratory or flat roller. Simultaneously, water is applied to wash the binder into the interstices within the crushed slag. Should the surface

be very coarse and loose, a grid roller can also be used to roll the fines into the slag. As soon as the slag is filled with fines, the slushing process can commence.

(v) Slushing

Slushing should proceed in a similar manner to that on normal crushed stone.

(vi) General

Segregation of slag is a significant problem and should be continually guarded against. In addition, the slag can become unstable, in which event it easily deforms under the roller, particularly in the early stages of compaction. Therefore, rollers and graders should be used very carefully during this stage of compaction. Due to the porosity of the material it is, in most cases, difficult to achieve the specified density, and modifications to the test methods and density requirements are necessary.

3.8.2 Waterbound Macadam Base

Waterbound macadam is a special form of a crushed stone layer. Chapter 9: 5.2 discusses the various forms of macadam layer available, but the discussion in this chapter focusses on waterbound macadam as it is the most commonly used form.

The construction of waterbound macadam may be divided into two components: firstly, the placement of the large aggregate, and secondly, the filling of the voids in the large aggregate skeleton with a fine filler. Manual labour may be used to varying extents in each of these components, but the principles of construction should remain the same for labour-intensive or plant-intensive construction. The following steps in the construction process are discussed:

- Subbase and **edge restraint** preparation
- Placement of the **large aggregate**
- **Filling of the voids** in the coarse aggregate skeleton with a fine filler

3.8.2.1 Subbase and Edge Restraint Preparation

The use of lightly cemented subbase layers is strongly recommended if the wet method of construction is used, and should be considered if the slushing process is used. Normal construction procedures should be used to construct the stabilized layer (see Section 3.4).

Edge restraint preparation is essential when a waterbound macadam layer is constructed. Permanent and temporary edge restraints serve a dual purpose during the construction. Firstly, they act as an edge restraint to box-in the large aggregate during construction, and secondly, they are used without exception to provide a reference for the control of levels on the waterbound macadam base layer. The construction of a permanent concrete edge restraint incorporating a side drain is preferred in the wetter regions of South Africa, such as the coastal areas. These edge restraints provide confinement of the waterbound macadam layer and the side drains drain away excess water during construction and the service life of the pavement. In the dryer regions of the country, the use of temporary steel shutters in combination with gravel shoulders is the preferred method of edge restraint.



Edge Restraints for Waterbound Macadam

Edge restraints, either permanent or temporary, are the first step in the process of level control of the waterbound macadam base layer and should receive the necessary attention.

If concrete edge restraints are used, the line and level of the shutters on the front face of the edge restraint are surveyed at 20 metre intervals on straights and 10 metres on curves. String lines and dipsticks are then used from the top of the completed concrete edge restraints for level control on the waterbound macadam base. The problem with string lines is that they sag towards the centre line if the span across the road is too wide. Modern laser instruments used to control the levels are, therefore, preferable if the span across the road is wide.

If temporary steel shutters are used on the centre line and at the edges of a carriageway, the coarse aggregate for the waterbound macadam may be levelled against a screed rail placed on spacers on top of the steel shutters. The problem with this method is that, because of the fixed height of the shutters, any undulation at the top of the subbase is reflected to the top of the base layer. It is, therefore, recommended that the steel shutters should only be used as an initial thickness guide and should be removed before any compaction is applied to the coarse aggregate layer. Final level control should then be done by string line and dipstick from levelled survey pegs.

3.8.2.2 Placement of the Coarse Aggregate

The placement of the coarse aggregate may be done in three ways:

- From **stockpiles by hand** labour using coal forks.
- With a **grader** if the coarse graded aggregate is dumped on the subbase.
- With a **mechanical paver**. The use of a mechanical paver generally results in slightly better riding qualities on the surfaced road than the labour-intensive and plant-intensive methods.

About 33 per cent reduction in the thickness of the loose, coarse aggregate should be allowed for during compaction. Spacers of the required height are therefore placed on the edge restraints and the coarse aggregate is spread to the top of the spacers using the preferred method. Before any compaction is done on the coarse aggregate layer, a level surface finish should be obtained. This is done by filling in lean spots on the surface of the layer by hand, and by removing excess material from high spots. An uneven surface of the loose coarse aggregate layer before compaction results in an uneven surface after compaction.

The maximum layer thickness constructed in one lift should not exceed twice the size of the coarse aggregate, to ensure the proper penetration of the layer with the fine aggregate. Once a level surface is achieved on the loose, coarse aggregate layer, the spacers are removed from the concrete edge restraints or the temporary shutters are removed. The furrows left by the temporary shutters are then filled with loose aggregate. The coarse aggregate layer is now ready for compaction. A 12 ton, 3 wheel roller; an 8 ton tandem roller, or, a vibratory roller is used for the compaction of the coarse aggregate layer. Breaking or crushing of the coarse aggregate under the roller should be monitored. Ideally, a trial section should be constructed to determine the degradation of the coarse aggregate under 12 ton or vibratory compaction. If degradation of the coarse aggregate proves to be a problem, 8 ton tandem rollers should be used.

The coarse aggregate layer is first rolled on the lower outside edge and then on the higher outside edge, after which compaction is continued to the centre of the layer. If gravel shoulders are used, the drum of the roller is allowed to overlap onto the shoulder. After the initial compaction passes, the surface of the layer is again rectified by hand. Rolling should continue until no movement of the coarse aggregate is visible under the rollers and the coarse aggregate is keyed-in.

3.8.2.3 Filling of the Voids in the Coarse Aggregate with Fine Aggregate

The fine aggregate is spread on the keyed-in coarse aggregate layer by hand using shovels or by mechanical chip-spreader. The thickness of the loose filler placed in one application should not exceed 25 mm and should be evenly distributed over the surface of the coarse aggregate layer. If the material is slightly moist, it should be left to dry before vibratory compaction is applied, to enable the fine aggregate to filter down into the voids in the coarse aggregate layer. The process of successive applications of fine aggregate and vibratory compaction is continued until the layer is choked with fine aggregate. If the dry process is selected, the construction process stops at this point. The dry method is appropriate for arid areas where very little water is available for construction. In this case, waterbound macadam construction compares favourably with the construction of a continuously graded material, which requires compaction water.

If slushing is selected, the choked layer is watered and compaction should resume, working from the highest to the lowest point. Drainage outlets should be inspected to ensure that the construction water drains freely from the layer. The excess fine aggregate should be slushed from the layer and broomed to the side of the layer. After completion of the slushing process, the layer should be left to dry and then broomed again. The layer is then ready to be primed. A blanket of loose fine aggregate may be left on top of the layer to prevent kick-out of the coarse aggregate under construction traffic, but all loose material must be broomed off before the prime is applied. If the layer needs to be trafficked, a slurry penetration layer can be used in the top portion of a waterbound macadam base layer to prevent damage to the base layer.

A completely wet process can be used in areas where the fine aggregate will not dry sufficiently to flow freely into the coarse aggregate layer. A water cart with a modified spray bar can be used to blast the fine aggregate into the voids with water jets. If this technique is used, the drainage outlets should be inspected to ensure that the construction water drains from the base layer.

3.9 Primes and Tack Coats

The question whether to “prime and tack or mat” is a long standing debate in the South African road industry. In many instances, primes and/or tack coats are not applied due to time constraints or other reasons, rather than from a technical perspective.

A very comprehensive and useful document titled "Guidelines for using Prime and Tack Coats" was prepared in 2005 by the Federal Highway Administration under the sponsorship of the US Department of Transportation. The Southern African Bitumen Association (SABITA) published Manual 26 titled "Interim Guideline for Primes and Stone Precoating Fluids". These two publications were used to prepare the following guidelines for the appropriate usage of primes and tack coats.

3.9.1 Prime Coats

A prime is a coat of suitable bituminous binder applied to a non-bituminous granular pavement layer as a preliminary treatment, prior to the application of a bituminous base or surfacing. The main function of a prime is to penetrate the layer to which it is applied, while leaving a small residual amount of binder on the surface to:

- Assist in **promoting adhesion** between the base and newly applied bituminous surfacing or layer.
- **Inhibit the ingress of water** from rain into the base, while not hampering the migration of water in the vapour phase out of the base.
- **Limit the absorption of binder** from the next spray application into the base.
- **Bind the finer particles** in the upper zone of the base to accommodate light construction traffic for a short period, until the new surfacing is placed.

Inspection notes for the application of prime coats:

- Assure that the aggregate base course is constructed in accordance with the **plans and specification**, prior to the application of the prime.
- The base should be broomed to **remove any loose material**, with the sweeping being carried out carefully so as not to damage the surface of the layer.
- Before priming, the **moisture content** of the material at any point in the base layer should not be more than 50% of its optimum moisture content.
- Construct a **trial section** to determine the application rate. Proper binder distributor construction procedures should be followed to prevent streaking, and allow a proper application rate and uniform coverage.
- **Application rates** are a function of the openness of the aggregate base, and vary slightly with the absorption of the aggregate. An appropriate initial application rate should be selected for the aggregate base course type. Open graded bases require more prime than dense graded bases.
- No more prime should be applied than the **aggregate base can absorb** in 24 hours.
 - Prime oils that ball up may indicate too little prime.
 - Fat spots or puddling indicates too much prime.
- The prime must **adequately penetrate** the aggregate base layer for 5 to 10 mm. This is to protect the layer from wet weather by providing a temporary waterproofing layer, and stabilizes and binds the surface fines, which promotes bonding with the asphalt surfacing layer.
- The surface of the aggregate base course should be **slightly damp** prior to application of the prime. Water may be added to the surface of the aggregate base to achieve the slightly damp condition. The damp surface:
 - Lowers the application rates by preventing excess absorption of the prime by the aggregates.
 - Prevents bulking of the prime with dust particles on the surface.
 - Aids penetration.
- The **viscosity of the prime coat binder** must be maintained to ensure uniform application of the prime. This is achieved by heating MC cutbacks and emulsions, or diluting emulsions with water.
- **Excess prime** that is not absorbed into the aggregate base course after 24 hours should be removed with blotter sand, to prevent wash off into waterways and tracking and pick up of the material by traffic. The excess blotter sand should be broomed from the surface before the surfacing layer is placed, to ensure a proper bond.
- Prime coats must **cure completely** to function properly, especially to be able to accommodate construction traffic. The prime generally takes several days to cure properly.
 - Curing of prime coat depends upon the weather. If the weather is hot, the prime coat cures quickly, but if the weather is cool and damp, the prime coat cures slowly.



References for Primes and Tack Coats

The following references are recommended:

- FHWA, 2005, "**Guidelines for Using Prime and Tack Coats**"
- SABITA Manual 26, "**Interim Guideline for Primes and Stone Precoating Fluids**"



Moisture in Base before Priming

Before priming, the moisture content of the material in the base should not be more than 50% of its optimum moisture content.

- Emulsified products generally cure faster than cutback bitumens. Bitumen emulsions require a minimum of 24 hours to fully cure, while cutbacks require a minimum of 72 hours to fully cure.
- It is riskier to place an asphalt layer over an uncured prime coat than an unprimed base, because the uncured prime can cause more base movement than construction on an unprimed base. Excessive prime remaining on the surface can also be absorbed into overlying asphalt layers. The solvents in the prime used to liquefy the bitumen, typically kerosene or diesel fuel, can damage the asphalt layer quickly, contributing to pavement slippage or rutting and lateral movement of the asphalt during rolling operations. At a minimum, construction traffic should be kept off a fresh prime coat until cured sufficiently, to prevent tracking of the prime.
- Primes should not be applied unless the **air temperature in the shade and pavement temperature** are 10 °C, and rising, and when the weather is foggy or rainy.

A checklist for construction with primes is given in Table 9. A printer ready version of this checklist is included in Appendix A.



Weather Conditions for Prime Application

Primes should not be applied unless the air temperature in the shade and pavement temperature are 10 °C, and rising, and when the weather is not foggy or rainy.

Emulsified products generally cure faster than cutback bitumens. Bitumen emulsions require a minimum of 24 hours to fully cure, while cutbacks require a minimum of 72 hours to fully cure.

3.9.2 Tack Coats

A tack coat is applied to a primed surface or bituminous surface to promote adhesion between the existing and new asphalt layer. The function of a tack coat is to ensure bonding between the new asphalt layer and the primed surface or old asphalt layer. The tack coat is applied in a thin coat and uniformly covers the entire surface, including all vertical joint surfaces. Too little tack coat causes debonding, and too much tack coat can cause slippage between the layers.

Inspection notes for the application of tack coats:

- Assure that the layer to be tacked is constructed in accordance with the **plans and specifications** prior to the application of the tack coat.
- **Construct a trial section** to determine the application rate. Proper binder distributor construction procedures should be followed to prevent streaking and allow a proper application rate and uniform coverage. To achieve a uniform coverage, the viscosity of the tack material must be maintained.
- The **timing of the tack coating operation** is important. It is good practice to spray the tack coat well in advance of paving, but not more than about 18 hours. The Standard Specifications specify a maximum delay of 24 hours. This enables the diluted bitumen emulsion tack coat to break and “set up”, which reduces pick-up of the tack coat on the tyres of supply trucks and the wheels of the paver.
- **Traffic**, both construction and local, should be kept off a fresh tack coat. A freshly applied tack coat surface is too slick for safe driving, particularly before the emulsion has broken.
- The **curing rate** of tack coats depends upon the weather. The tack coat should thus be applied on a dry surface when the air temperature in the shade is above 2 °C and rising.
- **Vertical surfaces** of transverse joints, longitudinal joints, curbs, gutters, manhole inlets, etc., should receive a tack coat. However, tacking of the joints is not necessary when the asphalt layer butting the joint is paved on the same day and the mix has not yet cooled to a temperature below 50 °C.
- A tacked joint is not required with **open-graded surfacing mixes**. This is because the tacked joint tends to prevent water drainage across the pavement.
- Tack coats should be applied **uniformly and completely** by fogging with a hand spray attachment or by another approved method.
- If **excess binder** is applied, squeegee the excess from the surface.



Application of Tack Coats

Tack coats should be applied in a thin coat and uniformly cover the entire surface, including all vertical surfaces of joints.

- **Too little tack coat** can cause debonding
- **Too much tack coat** can cause slippage between the layers

Table 9. Prime Checklist

Aspect		Yes/No
Base preparation	Completed	
	According to specification	
	Cured	
	Within time limit for stabilized base	
	Granular base < 50% of OMC	
Spray preparation	Cleaned	
	Dampened	
	String lines	
	Joint paper	
	No wet prime	
Materials: Sampling, testing and specifications	Binder	
	• Correct type	
	• Stored temperature	
	• Spray temperature	
	• Properties	
	Aggregate	
	• Blinding for excess removal	
	• Blinding for traffic accommodation	
	• Treatment of wet areas before seal	
	• Aggregate properties	
"No go" environmental conditions	Misty or wet conditions	
	Rain threatening	
	Strong wind blowing that would cause an uneven application	
	Temperature of the road surface dropped below 20 °C before priming (10 °C in case of MC-10 or emulsion)	
	After sunset	
Equipment condition checks	Binder distributor	
	Water sprinkler	
	Rotary broom	
	Other equipment	
Application rate	Trial confirmation	
	Effective width	
After care	Traffic off	
	Dry before sealing	
	Blinded for traffic accommodation	

3.9.3 Environmental Issues

The primary pollutants of concern from asphalt paving operations are volatile organic compounds (VOC). Cutback bitumens are the major source of VOCs, only minor amounts of VOCs are emitted from bitumen emulsions. Therefore, to eliminate VOC emissions, bitumen emulsions are preferred to cutback bitumens.

Binder products, including prime and tack coats, must be kept out of waterways. Prime and tack coats enter waterways through a direct spill, or through a spill entering storm water, waste water sewers, drainage ditches, etc.

Rainwater can also wash a freshly applied uncured prime coat into a waterway. Primes should thus not be placed if there is a high probability of rain within 24 hours of application, or before the prime can be fully absorbed into the base and the excess removed with blotter sand.

3.10 Surfacing Seals

Surfacing seals are a relatively simple and inexpensive road treatment, which are highly effective as a final surfacing. Seal design details, including an extensive explanation of various seals and their application, is contained in TRH3: Design and Construction of Surfacing Seals. Seals are also discussed in several chapters of this manual (see sidebar). This section primarily focuses on construction issues.

3.10.1 Seal Types

There are a number of different types of surfacing seals used on newly constructed bases, or as reseals on existing surfaced roads. The seals most commonly used are

- Single stone seals
- Double seals
- Cape seals
- Slurry seals
- Sand seals
- Inverted double seals
- Split seals
- Choked seals
- Geotextile seals
- Otta seals



Surfacing Seals

The following is a comprehensive guideline for all aspects of surfacing seals:

- **TRH3:** Design and Construction of Surfacing Seals.

Various aspects of seals are discussed in:

- Chapter 2: **Pavement Composition and Behaviour**, Section 2.3.1.2
- Chapter 3: **Materials Testing**, Section 4.4
- Chapter 4: **Standards**, Section 4.4
- Chapter 9: **Materials Utilisation and Design**, Section 11
- Chapter 13: **Quality Management**, Section 7

Illustrations of these seal types are included in Chapter 2: 2.3.1.2, Chapter 9: 11 and TRH3. Stone seals are constructed by evenly spraying a thin layer of bitumen on the surface and thereafter distributing aggregate evenly over the sprayed area, and finally rolling the aggregate to embed in the layer of bitumen to create a smooth riding surface. The success of stone seals depends on the adhesion of the stone to the binder and road surface. Hence, both the stones and the road surface must be clean and free from dust during the seal process, so that the binder is able to adhere properly to both.

The performance of stone seals is influenced by various factors such as:

- **Condition** of pavement structure
- Road **geometry**
- **Design** of the seal
- **Quality** of binder and stone
- Preparation, repair and pre-treatment of the **surfacing** on which the seal is to be constructed
- **Construction** of the seal
- Road, and ambient **temperatures**, during or soon after sealing operations
- **Maintenance strategy**



Length of Seal Construction

Typically, approximately 1.5 lane kilometres of seal can be constructed in one day.

A fine slurry seal provides an economic treatment to improve the surface texture of a road that needs resealing. A coarser slurry seal provides an effective reseal for roads to improve the riding quality.

3.10.2 Safety

Safety audits are required at regular intervals to ensure adherence to the Occupational Health and Safety Act (OHS, 1993).

Seal construction most often occurs under traffic, requiring extreme care to avoid accidents, injuries and loss of life. Specific attention to road signs and traffic accommodation is required. Typical problems on seal construction are:

- Non-conformance to **road sign layout**
- Barricades and delineators not adequate to prevent **traffic entering the construction zone**
- Not adjusting road sign layout for **adequate sight distance**, specifically in mountain passes
- **Loose aggregate**
- **No flagmen** at farm entrances and between stop-go positions
- **Pedestrians** running across the hot bitumen layer
- **Vehicles driving on bitumen** before aggregate application



Process Control of Seals

Inappropriate specifications, poor materials and bad workmanship can drastically reduce the service life of a seal. Process control is therefore, critically important.

Hot bituminous binders are applied up to 210 °C, requiring the use of protective clothing. Specific attention should be given to training and dealing with bitumen burns. It should be noted that immediate evacuation to an appropriate medical care facility is required. **DO NOT EVEN TOUCH.** Refer to SABITA Manual 8.



Hot binders

Hot bituminous binders are applied up to 210 °C, requiring the use of protective clothing. Specific attention should be given to training and dealing with bitumen burns. Immediate evacuation to an appropriate medical care facility is required. **DO NOT EVEN TOUCH.**

3.10.3 Environment

Typical problems to avoid during seal construction are:

- **Spillage** of bitumen at batch plants, precoating areas and where testing the distributor nozzles.
- **Draining** of precoating materials from stockpiles.

3.10.4 Traffic Accommodation

Apart from safety issues, proper traffic management is essential for the good performance of newly constructed seals. Typical problems to avoid, where possible, are:

- **Dust** from deviations and haul roads.
- **Stop-go positions at steep grades and tight curves** forcing heavy trucks to stop and accelerate on a sensitive new seal.
- Allowing dual directional traffic on a sensitive new seal by **sealing the adjacent lane the following day.**
- **Not treating or blinding intersections** to accommodate traffic turning actions.

Traffic volumes and the heavy vehicle components and actions could change during the course of a project due to construction traffic movements, road conditions and closures elsewhere, as well as traffic accommodation arrangements. These changes might require protection of the new seal, redesign or changing the surfacing or seal type.

3.10.5 Design Alterations and Application

Although it is the responsibility of the design engineer to ensure that the design is accurate and appropriate for the conditions, several factors can lead to the need to adjust application rates, binder type or even selection of a more appropriate seal type. These are:

- **Climatic conditions** must be monitored on a daily basis, recorded and compared with historical data obtained during the design phase. Sudden changes in temperatures can occur, specifically during the months of March, April, September and October, requiring an evaluation of the appropriateness of binder type, application rates, seal composition and construction method.

Risks of premature aggregate loss could be minimized during colder periods by:

- Addition of **additional binder**, e.g., 0.2 l/m²
 - Application of **fog sprays**
 - **Blinding** specific areas with coarse, precoated sand
 - Converting to a **double seal** or Cape seal
 - Keeping **traffic off during night times**, or when the road surface temperature < 25 °C
 - **Attention** to construction process and additional rolling
- Changing traffic situations and impact of **traffic accommodation**
 - Availability of **suitable equipment**
 - Availability of **specified binder and aggregate** at time of construction
 - **Variation of aggregate** properties, even though within specification

3.10.6 Surface Preparation Checks

The behaviour and performance of a seal is directly dependent on the condition of the surface to which it is applied. Preparation of the base coarse, in the case of new construction seals, and the existing road surface, in the case of a reseal, must be undertaken timeously. Preparation before seal work is described in detail in Chapter 13: 7.2.

3.10.7 Weather Conditions

The supervisor should be satisfied that the weather conditions at the time of spraying and the expected weather conditions for the following 24 hours, are in accordance with the grade of binder.

If wet stone is used for sealing, or if rain is expected within the first 24 hours after the construction of the seal, a wetting agent may be used. The wetting agent is added to the binder shortly before spraying and circulated in the tank to mix through. Or, the aggregate can be covered directly with the wetting agent. These agents are not stable at high temperatures, and should, therefore, not be kept at spraying temperature for long periods.

3.10.8 Process Control

Poor materials and bad workmanship drastically reduce the service life of the seal. Process control is, therefore, critically important. Process control for stone seals and slurry seals are discussed in this section.

3.10.8.1 Stone Seals

Process control during the construction of stone seals is of utmost importance to ensure that the seal performs satisfactorily. The control of aggregate and binder related factors are especially important. Once the quality of the component materials are verified and approved, and the recommended application rates are determined, it is necessary to consider the following aspects.

(i) Road Surface Conditions

When newly constructed layers are to be surfaced, the following aspects are required:

- **Visual observation** of the exposed mosaic of the base.
- **Moisture content** of the base before priming, and after priming if the road surface has been exposed to intermittent rain, must be checked and be within acceptable limits (less than 50% of optimum at all points in the layer).

When an existing surfaced road is to be resealed, the following are important:

- **Pavement defects**, such as potholes, ruts and edge breaks, must be repaired.
- The **essence and texture of the existing surface** should be assessed, and pre-treatment such as a thin slurry for texture correction applied, if required.
- **Surface must be cleaned** with either rotary or hand brooms, air or water under pressure.
- **Moisture condition of the base layer** must be checked after rain spells, since moisture ingress is possible due to fine cracks in the surface, which cannot be practically or economically treated, or lean, dry, or open seals that can be porous. Depending on the moisture content, a delay in the operation may be necessary. Apart from the standard laboratory tests to determine the in situ moisture content of the layer, a field test known as the "Glass plate test" can be used, as illustrated in Figure 82. A glass plate approximately 300 mm x 200 mm in dimension is placed on the road surface and checked for moisture vapour after approximately 15 minutes. If no sign of moisture vapour is noticed on the underside of the plate, the layer is ready for the application of the seal.



Figure 82. Glass Plate Test

- If the **existing surface is porous or very dry**, it can be pre-treated with a surface enrichment. This ensures that the binder needed for the seal is not absorbed by the dry surface, which causes stone loss on the new seal due to insufficient binder left for retention of the aggregate in the new seal.

(ii) Aggregate

- Aggregate **stockpiles** should be spaced at economic intervals along the road, for easy accessibility when loading trucks, and to minimize loading and travel time between stockpiles and the seal site.
- **Stockpile sites** must be properly cleared to minimize contamination and pollution.
- Each stockpile must be properly **sampled** to ensure the required field samples are obtained, and all relevant tests are carried out to determine the quality of the aggregate and to establish application rates for the different aggregate sizes.
- **Uncoated, single-sized, coarse aggregates** in a stockpile may, in certain cases, be dampened with water to eliminate the negative effect of excessive dust adhering to the aggregates. When using certain types and grades of binders, excessive free water on the aggregate is detrimental to the breaking, curing and adhesion of the binder to the aggregate.
- The type of **precoating fluid** used to precoat the aggregate, and the application rate required to ensure a uniform coating and prevent ageing, depends on the time interval between the coating and the seal operation. Fresh, dry precoated aggregates are required to ensure the effectiveness of the seal.
- **Temperature of the aggregate** in the stockpile, especially when damp and after unexpected cold nights, also has an influence on the adhesion of the binder to the aggregate.

(iii) Binder

- **Site location** for stationary bulk tankers should be such as to enable easy accessibility for filling the bitumen distributor, and to minimize the refilling and travelling time between the bulk tanker and the site.
- A **site should be levelled** to enable correct volume measurements of binder in the distributor obtained by dipstick readings.
- An **appropriate, specified binder**, must be ordered, delivered and correctly transferred to a stationary bulk tanker reserved for that specific binder. Different types and grades of bitumen binders must not be mixed.
- **Particulars of the binder supplied**, such as batch number, viscosity and recommended spray temperature, must be provided by the supplier.
- For **modified binders**, the blending process on site must be according to the prescribed procedure or method.
- Only **water which is compatible** with the appropriate type of emulsion should be used for diluting the emulsion or with slurry seals.
- **Recommended application rates** for each type and size of aggregate, as well as binder type and grade, need to be obtained.
- **Temperature of the binder** in the distributor must be according to the required spray specification.

(iv) Binder Distributor

The supervisor should ensure that:

- Distributor has a **valid certificate** for spraying bituminous binders, issued by an acknowledged fixed test pit facility. The certificate must be valid for 12 months.
- **Identification and/or serial numbers** of the bitumen pump, spray bar and dipstick are clearly marked on the sprayer. These numbers must also appear on the calibration certificate.
- Distributor is equipped with at least two **fire-extinguishers** in a working condition.
- Distributor is not **leaking oil, diesel fuel or bitumen**.
- The **master screen** of the distributor is clean, especially when bitumen rubber is used, or after conventional bitumen is sprayed.
- The distributor does not start from a **stationery position** at the beginning of sections to be sprayed, but starts 4 to 5 meters back from the start to build up speed.
- Distributors must be capable of making a **standing start**, fully laden, on ascending grades of up to 10%, and be able to maintain a uniform rate of binder application.
- The distributor is equipped with proper "**fish plates**", when needed, fitted at each end of the spray bar. The correct position of the fish plate is 50 mm from the last nozzle, as shown in Figure 83. Fishplates are normally used on the outer edges of the road.



Dipsticks

A dipstick is only calibrated for one distributor.

(v) Distributor Spray bar

The spray bar on the distributor is an essential component of seal work.

The transverse distribution test, or “bucket/bakkie” test (SANS BT24), shown in Figure 84 and described in Section 2.4.2.4, must be done to check the distributor complies with the requirements. The maximum permissible tolerance permitted between the troughs, excluding the outer 300 mm of the spray bar, is dependent on the viscosity of the binder type, and should be as follows:

- **Emulsions**, cut back bitumen and penetration grade bitumen: 5%
- **Homogeneous** polymer modified binders: 7%
- **Non homogeneous binders** (bitumen rubber): 10%

For more information see TRH3.

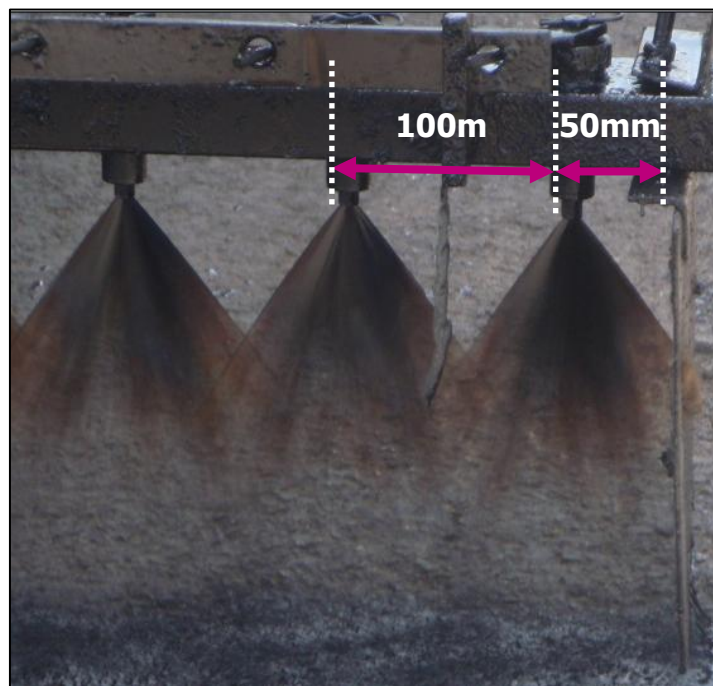


Figure 83. Fish Plate Position

(vi) Nozzles

The nozzles must be uniform in size, and aligned correctly at 30 degrees. Incorrect alignment and angle settings lead to flair interference and a poor spray, as illustrated in Figure 85 and Figure 86. All the nozzles must be clean, open and function properly. This is tested by spraying a trial on reinforced paper, well away from the road prism.

(vii) Spray Bar Height

The distributor spray bar must be adjusted to the correct height. This is to obtain a proper cross-distribution though a selected overlap configuration, e.g., double or triple overlap. Incorrect bar heights result in uneven distribution of the binder on the surface, as shown in Figure 87. Although the height can be calculated taking into account the nozzle spacing, nozzle angle and the flair angle, the pressure at which the product is sprayed, viscosity and nozzle design also influence the flair angle and, therefore, the calculated “correct” bar height. The best way to ensure an accurate overlap is to close two nozzles, or one in case of a double overlap, and adjust the bar height to ensure that the two adjacent flairs just meet, as illustrated in Figure 88.

Note the following:

- The **Standard Specifications** only refer to a double overlap. For this reason, the overlap is specified as 100 mm.
- **Hot modified binders** are normally sprayed with a uniform triple, or even a quadruple, overlap.
- **Lower viscosity binders** can be applied with only a double overlap.



Figure 84. Transverse Distribution Bakkie/Bucket Test



Figure 85. Flair Interference Due to Wrong Angle Settings

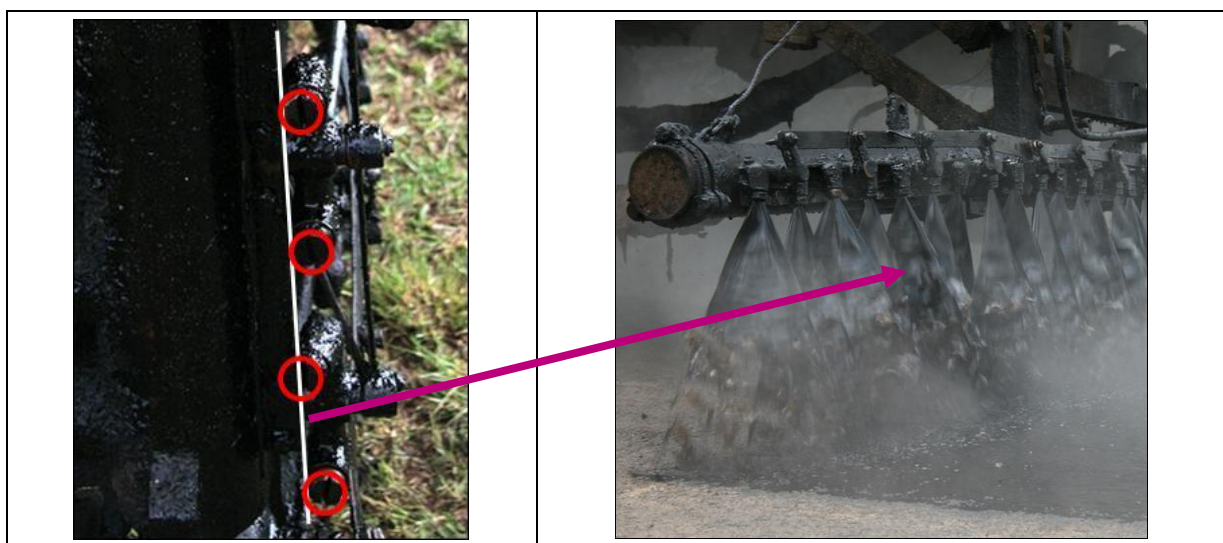


Figure 86. Effect of Poor Nozzle Alignment

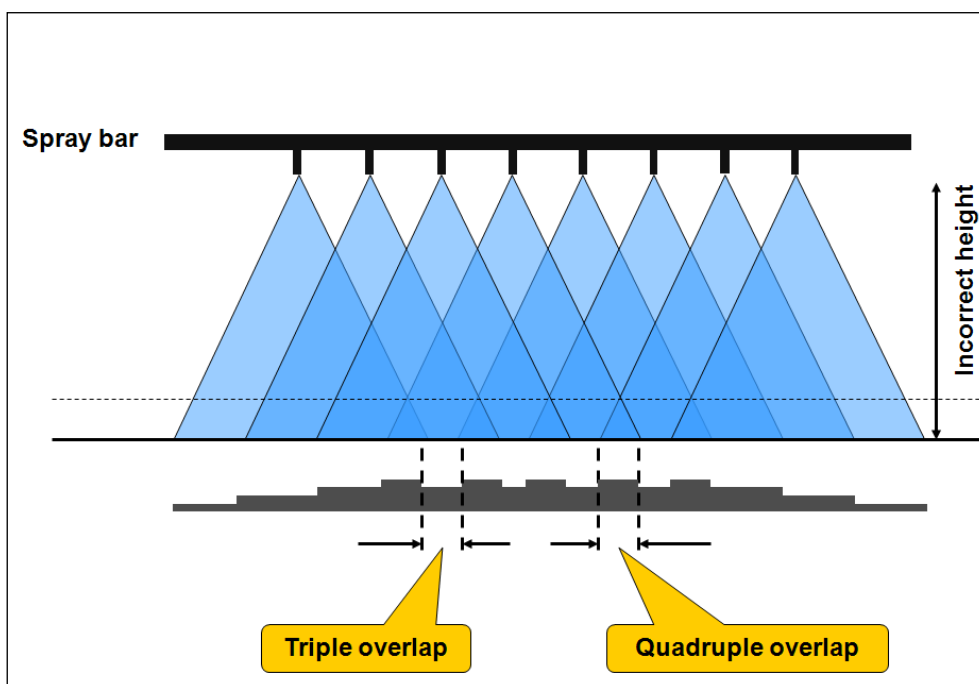


Figure 87. Poor Transverse Distribution due to Incorrect Bar Height

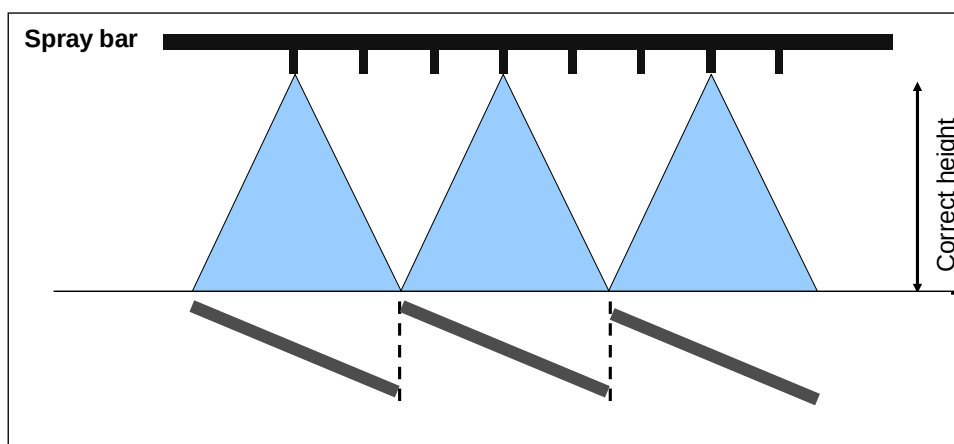


Figure 88. Adjusting Spray Bar to Correct Height

(viii) Uniformity of Spray

After the first test section is sprayed, the transverse and longitudinal spray distribution across the surface must be uniform, and comply with the specified rates of application for any width of spray, up to the maximum effective width for which the distributor has been certified.

(ix) Spray Bar Pressure

The spray bar pressure is important, as even though "Bakkie Test" results are acceptable and the height of the bar correctly adjusted, poor transverse distribution can still occur as a result of too high viscosity or too low pressure in the spray bar. Figure 89 demonstrates the resulting problem.



Viscosity and Spray Bar Pressure

Even though "bakkie Test" results are acceptable and the height of the bar is correctly adjusted, poor transverse distribution can still occur as a result of too high viscosity or too low pressure in the spray bar.

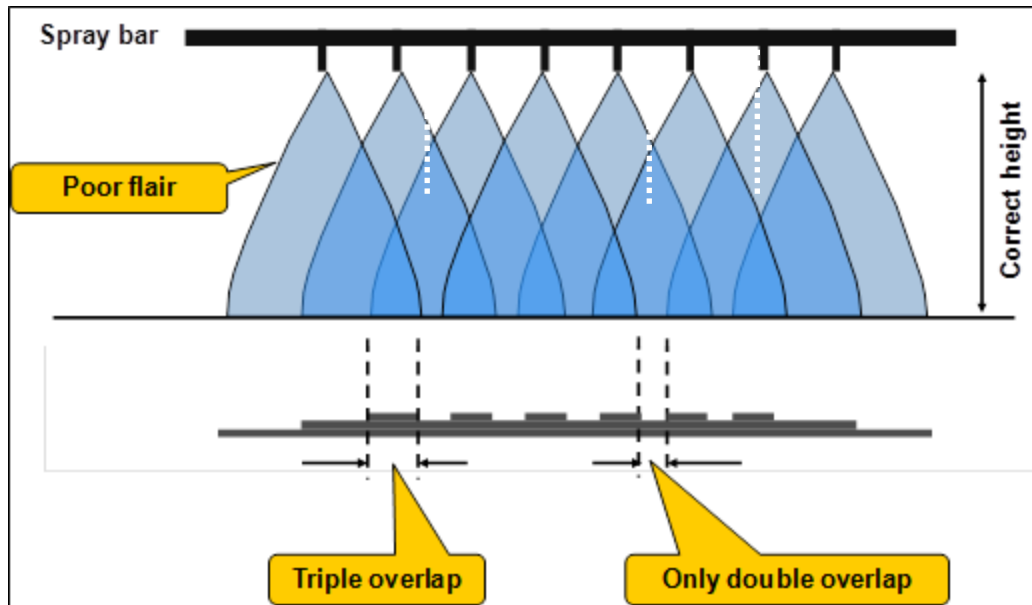


Figure 89. Poor Distribution Due to Low Bar Pressure

(x) Self-Propelled Chip Spreaders

The supervisor should check the following:

- The **rollers on the distribution bin** are not worn or bent. The roller drum support bearings must be in a good condition.
- The **conveyor belts** of the chip spreader are in a good condition and not cut or worn, to ensure continuous application of aggregate.
- The **bin gates** are uniformly and correctly adjusted, to give a uniform application of aggregate on the road.
- The **chip gates** are open to the correct width, to ensure that the tyres do not come into contact with the sprayed binder.
- The **sieve in front of the roller** of the distribution box is in place and adjusted to ensure that clean aggregate initially falls on the binder and, if any dust is present, this falls on top of the aggregate.
- The **chip spreader is wider than the planned binder spray width**. The effects of a wider binder spray than the chip spreader are illustrated in Figure 90.



Figure 90. Binder Not Fully Covered by Aggregate

Control and verification of the spread rate is a critical component of seal work. The following guidelines should be followed:

- As part of the trial section, the **target spread rate** (final matrix) should be determined by hand packing, e.g., on 1 m². Figure 91 shows a hand packed 1 m² mat.
- A **dry trial run** could be done away from the road, to ensure that the aggregate is uniformly applied at the target spread rate.
- The aggregate distribution should be tested by means of **canvas patches**, each 1.0 metre by 1.0 metre and placed side by side. The mass of chips spread onto each individual canvas patch should not deviate by more than 10% from the calculated average spread per canvas patch.
- The design engineer, supervisor and operator should **agree on the acceptability of the spread rate** and the final matrix, in comparison with the target set.



Figure 91. Target Matrix by Hand Packing

After the trial run with the chip spreader, the full scale seal construction trial can commence. Control of the aggregate spread is exercised by measuring the aggregate weight per m², as shown in Figure 92.



Figure 92. Measurement of Aggregate Spread Rate

(xi) Trucks and Loader

There should be sufficient trucks in good working condition, free of oil and fuel leaks, to enable each spray to be covered within 3 to 5 minutes after application of the binder. The loader should also have sufficient capacity to not delay the seal process. In the case of hot modified binder application, the time lag before aggregate application and rolling should be minimized. In such cases, the chip spreader must follow immediately after the distributor, and rolling should commence immediately thereafter.

The truck should have the following features:

- The **correct couplings** to couple to the chip spreader.
- The **lids of the trucks** should seal properly, without any leakage or spoiling of aggregate.



Spreading Aggregate on Hot Modified Binders

With hot modified binder application, the time lag before aggregate application and rolling should be minimized. In such cases, the chip spreader must follow immediately after the distributor, and rolling should commence immediately thereafter.

(xii) Rollers

The supervisor should ensure that the contractor has at least two self-propelled pneumatic tyred rollers, fully ballasted on site in good working condition (20 tons unballasted), and depending on the daily output planned by the contractor. An additional pneumatic roller is recommended if more than 7500 m² per day is planned.

Heavy pneumatic rollers are specified for single seal reseal work and new construction seals. Light steel wheel rollers (6 to 8 ton) are specified, in addition to heavy pneumatic rollers, for double seals and could be used on single seals where the existing surface is smooth, to iron it out before the application of a fog spray.

The following are required of the rollers:

- **No leaks or spillage** of any kind from the equipment, e.g., oil and fuel, on the surface of the road, either before or after the seal is applied.
- The **mass per wheel** of the pneumatic roller should be more than 2 tons.
- The tyres should be in a **good condition**.
- The **tyre pressure** of pneumatic tyred rollers should be checked for correctness and uniformity, generally 6 to 8 bar for seal work.
- **Tyre sizes and shapes** should be uniform. Only tyres manufactured for the purpose should be allowed.

(xiii) Rotary and Drag Brooms

Rotary and drag brooms remove excess stones from the seal. The following are required:

- **At least two rotary brooms** in good working condition, with uniform broom segments.
- **Sufficient hand brooms and shovels** to remove any excess aggregate, which may have been applied at joints or truck changes, and for any other emergencies resulting from equipment breakdown.
- When **heavily trafficked roads** are being sealed and the width of the carriageway exceeds two lanes, it is advisable to use a **vacuum broom** with at least two self-propelled brooms to leave the surface free of loose stone when the road is opened to traffic at rush hour.
- For new construction of double seals, it is desirable to have a **T or a Z-type drag broom** (Figure 93) on site. This is to achieve a uniform shoulder to shoulder mosaic effect on the aggregate.

(xiv) Water Bowsers

Sufficient water trucks should be available to lay the dust on deviations adjacent to the surfacing project.

When an emulsion binder is used and only dusty aggregate is available, a light spray of water on the aggregate improves the adhesion of the binder, and the quality of work.



Roller Selection

Heavy pneumatic rollers are specified for single seal reseal work as well as on new construction seals. **Light steel wheel rollers** (6 to 8 ton) are specified, in addition to heavy pneumatic rollers, for double seals and can be used on single seals where the existing surface is smooth, to iron it out before the application of a fog spray.



Figure 93. Z-Type Drag Broom

3.10.8.2 Slurry Seals

A slurry manufacturing system involves a continuous mixing process in which a bitumen emulsion is combined with high quality aggregates, to produce cold mixed "slurry". A small amount of cement or lime is normally added to the slurry to facilitate "breaking" of the binder.

Finer slurry is generally placed by hand squeegees. Coarser slurry is placed using a spreader box, which is normally part of a purpose built slurry mixing and placing machine.

(i) Placement of Slurry Seal

Process control for slurries placed by hand squeegees as texture correction involve the following aspects:

- Prior to placing the slurry, the road surface should be **cleaned and pre-wetted** by water fogging, but no free water should be present. The slurry should be placed and spread only by competent operators with good quality rubber-bladed squeegees, as illustrated in Figure 94.
- Not moving the slurry with squeegees **more than 5 metres**.
- Monitoring the **road surface temperature** to ensure it is less than 55 °C.
- Checking the **consistency** of each mix.
- Slurry mix should be homogenous with **no instances of premature breaking** of emulsion during the mixing process. The consistency of the slurry mix, immediately before pouring in small manageable increments on to the road surface, should have a flow measurement (using the slump test) of between 30 and 40 mm for slow setting fine slurry.
- **Embedment of the slurry layer** and the filling of voids between the coarse aggregate of the existing surfacing layer should be such that, after completion of the process, the aggregate should still be proud of the slurry and achieve a mosaic appearance on the final surface.
- The **spread application**, expressed in kg/m², is calculated using only the total mass of fine aggregate, excluding the cement or lime active filler, divided by the area.

Process control for slurries for surfacing layers placed by spreader box includes:

- Prior to placing the slurry, the road surface should be **cleaned and pre-wetted** by water fogging, but no free water should be present.
- Slurry mix should be **placed by a spreader box** and by competent operators with additional rubber-blade squeegees available for rounding off, where necessary. A spreader box is shown in Figure 95.
- The **spreader box should be of a proven and approved type**. The box should be constructed to distribute the weight onto metal skids in such a way that no damage is be done to the surface when the box is in operation.

- **Soft rubber belting** should be attached to the frame in such a manner as to prevent the slurry from spilling past the sides of the spreader box, when in operation.
- The spreader box should be capable of **spreading a uniform application of slurry** in adjustable widths of 1.5 m up to 3.7 m for general purposes, at specified spread rates.
- The slurry mix should be **homogenous, with no segregation or premature breaking of emulsion** during the continuous flow mixing process. The consistency of the slurry mix, should be such that no flowing of the fresh slurry occurs due to high flow characteristics or a steep gradient. For a coarse slurry, the flow measurement should not exceed 10 to 20 mm.
- With **volume batching**, in determining the spread rate, expressed in kg/m^2 , the theoretical mass of only the fine aggregate is obtained by compensating for unit mass and moisture corrections.
- **Rapid setting coarse slurries** should be sufficiently stable to be rolled after 45 minutes, before opening to traffic.
- When coarse slurries are used to **improve the rideability** of roads, it should be placed as follows:
 - **Step 1:** Place the corrective layer, or layers, by setting the sliding rails as low as possible, preferably on the existing surfacing. After the emulsion in the slurry mix has broken and the layer is dry enough, roll it thoroughly with heavy pneumatic tyred rollers before the second layer is applied.
 - **Step 2:** Place the wearing course layer with a uniform minimum thickness of approximately 10 mm. Compact it properly with pneumatic tyred rollers before opening to traffic.



Figure 94. Slurry Placed By Hand



Figure 95. Slurry Spreader Box

(ii) Mixing of Slurry

- Mixing of the slurry system should be carried out in a **mixing machine** designed to provide a rapid mixing time, and be capable of continuous mixing.
- The purpose designed mixing machine should be equipped with **precise metering systems** to enable the various constituents to be combined continuously to the desired formulation. No central mixing plant should be allowed.
- **Stationary or mobile batch mixers** must be in a good operational condition, while weigh bridges and volume indicators must be calibrated.
- **Mobile continuous flow mixing machines** must be roadworthy. The volume or mass of the hopper capacity must be recorded. Operational functions of the mixer and spreader box must be in good condition, and adjustable for various widths.

(iii) Construction of Slurry Seal

- Coarse slurry is normally placed in **8 to 10 mm layers (wet thickness)**.
- After placement, slurries are **left to set**. The setting process is illustrated in Figure 96. The slurry is brown when the bitumen is in an emulsified state. As the emulsion breaks, and the slurry sets, the colour changes to black. It generally takes about 3 hours for the slurry to set.
- As soon as the coarse slurry has **set sufficiently**, and can be compacted without undue displacement, rolling should commence using only proven and approved pneumatic tyred rollers. Rolling should proceed from the haunch, kerb or channel, working towards the crown or upper end of crossfall/superelevation of the road. Rolling can commence as soon as clear water can be pressed out of the slurry mixture with a piece of paper, without discolouring the paper. Rollers should not be permitted to stand on newly laid coarse slurry until it is fully compacted and has set completely. Care should be exercised against premature rolling of shaded areas and areas with thicker slurry.
- Slurries should not be applied when **air temperatures are less than 7 °C** when temperatures are rising, or less than 13 °C when temperatures are dropping. Special measures, such as spraying the surface with water to lower the road surface temperature, are required during hot weather to prevent quick setting of the slurry.
- Slurry **operations should be suspended when rain is imminent**, or strong winds are blowing.



Figure 96. Slurry Setting as Emulsion Breaks

(iv) Rolling of Slurry Seals

For thin fine slurry seals, e.g., texture slurries, it is not necessary to use pneumatic tyred rollers to do the compaction, normal traffic action should suffice. However, coarse slurries and layers thicker than 4.0 mm should be rolled with heavy pneumatic tyred rollers, approximately 22 ton, prior to opening the road to traffic. As with all compaction, the rollers must be checked to ensure there are no leaks and the tyre pressures are correct. If rolling is deemed necessary, the following aspects should be noted:

- Rolling only takes place once it has been ascertained that the **emulsion has broken**.
- Rolling is **systematic**, done from side to side, ensuring sufficient cover is provided.
- Emulsions in conventional slurry seals with stable grade emulsions are dependent on **air and road temperatures** to break. High air and road temperatures enhance the breaking process of the emulsion. The rolling of layers at such high temperatures can be done sooner, normally within 2 to 3 hours.

- Due to the additive in the emulsion of **quick set slurries**, the breaking process of the emulsion is not dependent on air and road temperatures, but it is chemically controlled by the amount of additive added. Quick set slurries can be rolled 20 to 30 minutes after placement.

(v) Colour Variations

Colour variations in slurry seals occur as a result of any of the following reasons:

- Variation in **bitumen content**
- Variation in the **grading** of the sand
- **Direction of movement** of the slurry machine
- Variation in the **quality of the emulsion**
- **Rain** during, or shortly after, placement of the slurry

When a colour variation is noticed on a completed slurry seal, it should be determined whether it has a damaging effect or not, to be able to take remedial and or preventative steps.

3.10.8.3 Cape Seals

Cape Seals consist of a single seal of 14 mm or 20 mm aggregate, penetrated with a binder (fog spray) and covered with a slurry seal. A 14 mm aggregate is covered with one layer of slurry. On 20 mm aggregate, two layers of slurry are applied.

Depending on the volumes of slurry mix required, it can be mixed with a concrete mixer. When large volumes need to be placed, it is normally mixed in a batching plant.

The single seal is constructed as described in Section 3.10.8.1. However, the aggregate spread rate is normally much lower to accommodate the layer(s) of fine slurry.

3.10.8.4 Slurry Application

The following details on the application of the first layer of slurry must be noted:

- The slurry should be applied **not less than four days**, and not more than four weeks, after the penetration layer and/or fog spray.
- When the **penetration or fog spray is dry** (cured), the surface is given one complete roll with a 6 to 8 ton steel wheel roller. Rolling should preferably be done as early as possible in the morning to prevent pick-up.
- Before the slurry is applied, the road surface should be **lightly sprinkled with water**.
- Under no circumstances must **free water** be present on the surface when the slurry is applied. No additional water should be added to the slurry on the road to improve the workability.
- The **consistency of the slurry mix** should be controlled using the ASTM method D3910 with a slump of 30 to 40 mm at the time of placing. It is desirable that the slurry has a wet consistency.
- The **first slurry layer** should be spread to the full width of the chip application.
- The slurry must be applied by means of **hard rubber squeegees** in a layer of sufficient thickness to fill the voids between the chips, while leaving just the top of the chips exposed.
- It is essential that the slurry is applied with **to-and-fro and sideways movements** of the rubber squeegees to ensure that the slurry enters all the interstices.
- **Spreading of each batch** must be completed before the next batch is discharged.
- After the **emulsion has cured** sufficiently, the layer should be rolled properly with heavy pneumatic tyred rollers.
- **Rolling** must not be done later than the first working day after the slurry was placed.
- After the rolling is finished, the layer can be **opened to traffic**.

When a second layer of slurry is required, it should preferably be placed within four weeks of the first slurry opening to traffic. The layer is placed as described above for the first slurry, with the following additional points:

- The second slurry is spread to the **full width of the sealed surface**.
- The **edges are finished off** in a straight line and the final surface is dense with a uniform appearance, with just the tops of the aggregate exposed after rolling is finished.

3.10.8.5 Graded Seals

Graded seals consist of crushed coarse to fine single sized aggregates. A good bond between the seal and the base coarse is very important. Otta seals are one type of graded seal.

Binders used for Otta seals are normally relatively soft binders with low viscosities, i.e., penetration grade bitumens not harder than 150/200 or cut-back bitumens.

The following are indicators of good practice:

- At least two 22 ton pneumatic tyred rollers are essential for **proper rolling on the day of construction**. This is to knead the binder upwards into the aggregate particles, and to apply pressure over the entire area.
- A **minimum of 15 passes with pneumatic tyred rollers** over the entire surface area, including the shoulders is required on the day of construction.
- **Early trafficking** is advantageous to the seal, but it must be done in such a manner that the entire surface area is uniformly exposed. This can be done by directing traffic into designated "lanes" marked by traffic cones or delineators.
- **Heavy traffic** should be allowed on the seal immediately after the initial rolling with heavy pneumatic tyred rollers is complete, to assist with kneading of the binder and aggregate mixture.
- The **speed of the traffic** should, however, be limited to 40 to 50 km/hour.
- It is advantageous if **one pass of a 6 to 8 ton steel wheel roller** is applied over the surfaced area, after the initial rolling with the pneumatic tyred rollers is completed. This improves the density of the layer by breaking down weaker aggregate. This roll can be repeated two days after sealing.
- For **two to three weeks after completion**, excess material dislodged by traffic should be swept back into the wheelpaths to achieve maximum aggregate embedment. After this period, excess material can be swept away.



Graded Seals

Graded seals consist of crushed coarse to fine single sized aggregates. A good bond between the seal and the base coarse is very important. Otta seals are one type of graded seal.

3.10.8.6 Double Otta Seal and Combination Seals

When a double Otta seal or a combination seal is used, the following should be noted:

- The first Otta seal should be allowed to **cure for at least 8 to 12 weeks**, depending on curing conditions and binder type, before the second seal is applied. This is to minimize fatting up due to evaporation of the cutting oils.
- It is essential that when applying **sand cover seals**, enough sand is applied, and that dislodged aggregate is swept back onto the surface.
- A **minimum longitudinal joint overlap of 150 mm** must be attained, and additional heavy rolling must be applied to even out the joints.
- It is desirable to **spray the full width of the road in one pass**. If longitudinal joints cannot be avoided, they should be positioned outside the wheel paths.
- **Transverse joints should be offset**, and not placed one above the other.

3.11 Hot Mix Asphalt

The term "hot mix asphalt" (HMA) is generically used to include many different types of mixes of aggregate and bitumen that are produced at an elevated temperature in an asphalt plant. HMA is divided into three main mix types, depending on the grading of the aggregate in the mix, e.g., dense-graded, open-graded and gap-graded. There are also other mix sub-types, which are generally used in asphalt pavement layers. HMA is discussed in various chapters of this manual, see the sidebox for specific cross-references. Information with respect to the standard types of asphalt mixes normally available and selected is contained in the Standard Specifications and the relative SABITA Manuals.



Hot Mix Asphalt (HMA)

Various aspects of hot mix asphalt are discussed in:

- Chapter 3: **Materials Testing**, Section 4.2
- Chapter 4: **Standards**, Section 4.2
- Chapter 9: **Materials Utilisation and Design**, Section 10
- Chapter 10: **Pavement Design**, Section 7
- Chapter 13: **Quality Management**, Section 6

3.11.1 Process Control

The control of the quality of the asphalt layer starts at the production plant. From the production plant the hot mix asphalt is transported to the paving site by trucks where it is paved using an asphalt paving machine. The paved layer is compacted using compaction equipment.

The quality control measures at the production plant are dealt with in Section 2.2. The control measures applied during hauling, paving and compaction operations are discussed below.

3.11.1.1 Hauling

Hauling of HMA from the production plant must consider the following:

- Trucks should be fitted with **elongated tailpieces** to prevent spillage around the paving unit.
- An acceptable **release agent**, such as water containing a small proportion of detergent, is used to prevent asphalt adhering to the body of the truck. Oil-based materials such as engine oil, paraffin or diesel fuel must not be used.
- Trucks should be in a **roadworthy** condition and, especially, be free of oil leaks.
- To minimise heat loss and hardening of the binder films because of exposure to air flow, the asphalt in the trucks is covered with a **tarpaulin or a suitable thermal blanket**.
- Trucks are of **sufficient capacity** to ensure a continuous supply of asphalt to the paver.
- Risk of “**drain-down**” of the binder in open-graded type of mixes, such as SMA or porous asphalt, when transported over long distances or very rough delivery routes.

3.11.1.2 Paving

The paver unit and operation is described in detail in Section 2.8, and includes construction control measures to ensure a smooth pavement and good joints. The following control measures should be given additional attention during the paving operation.

(i) Level Control

- **Level control equipment** depends on the required smoothness of the finished paving, and the smoothness of the surface on which the layer is laid.
- To **average out the level** of the base or existing surfacing, and thus achieve a desired average mat thickness, a levelling beam (Figure 97) is used for level control.
- To **pave to a design level**, a line on pedestal is used.
- To **tie in to an existing level**, a joint matcher is used.
- To **achieve a constant crossfall**, a beam, joint matcher or line on pedestal on one side with the constant cross sensor on the other side, are used.

(ii) Loose versus Compacted Mat Thickness

The uncompacted mat behind the screed must be paved thicker than the final required thickness, as compaction reduces the loose thickness. Different asphalt mixes have different compaction factors and the final paved thickness thus depends on the type of asphalt mix. Typical compaction factors are given in Table 10.

Table 10. Compaction Factors

Type of Mix	Compaction Factor
BTB ¹ , LAMBs ²	0.7 to 0.75
Continuously graded	0.7 to 0.83
Open graded, UTFC ³	0.9 to 0.92

Notes

1. BTB = bitumen treated base
2. LAMB = large aggregate mixes for bases
3. UTFC = ultra-thin friction courses



Hot Mix Asphalt (HMA)

The **Hot Mix Asphalt Trouble-shooting Guide**, published by the Society for Asphalt Technology (2005) is a very useful reference for the construction of asphalt.



Figure 97. Levelling Beam for Level Control

3.11.1.3 Good Paving Practices

The following are good paving practices, which should always be followed:

- Pave at a **constant speed**, selected to suit the compaction effort.
- Feed the paver with a **constant supply of material**, to reduce start/stop activities to an absolute minimum.
- Before paving, **clean the screed**, check for wear and then heat to suit the mix type.
- **Tow points**, which control how the paver moves up and down, are correctly set for the required mat thickness.
- Paving **always starts on starter blocks** under the screed.
- **Paving lines are marked out** each side of the paver for guidance.
- **Extension augers** are attached to suit the paving width.
- **Forward movement only commences** once auger boxes are filled over their full width.
- A **constant head of asphalt** across the entire width of the screed is maintained.
- The **hopper is not emptied between loads**. The new load is added to the hopper so as to heat up the remaining asphalt from the previous load.
- **Tipping of trucks is well controlled** to avoid spillage in front of the paver.
- **Paving thickness** is checked regularly by calculations and with a dip rod. Adjustments are made gradually and evenly.
- **Excessive manual adjustment** of the tow points is not allowed.
- Frequently check the **mat finish between the paver and the rollers** with a straight-edge and visually, to identify any problems.
- **Avoid walking on the unrolled mat**.
- **Handwork is limited** to areas inaccessible to the paver, or for correcting deficiencies.

3.11.1.4 Compaction

The compaction operation is the most important aspect of the paving process. Compaction develops the strength and stability of the mix, and closes the interconnected voids through which water and air could penetrate the mix in the layer. Compaction equipment, i.e., rollers are discussed in Section 2.10.

(i) **Compaction Stages**

Compaction is carried out in three stages:

- **Breakdown rolling** (150 °C – 120 °C range)



Compaction

The compaction operation is the most important aspect of the paving process. Compaction develops the strength and stability of the mix.

- 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% of Maximum Voidless Density (MVD) behind the screed, to about 91% of MVD.
- 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 static steel wheel rollers, especially three-wheel rollers.
- Vibratory rollers have a wider compaction temperature range than static rollers, and achieve density in fewer passes.
- Pneumatic tyred rollers can achieve the required density, but on a very hot mat may give rise to rideability problems.
- **Intermediate rolling** (120 °C – 90 °C range)
 - This stage follows directly after breakdown rolling while the mat is still plastic and at a temperature that permits further compaction. This stage of compaction continues until the required compaction is achieved, and the density is increased to the specified requirement, e.g., 93% to 95% MVD and the surface is well knit.
 - This stage is best accomplished by rollers effective at lower temperatures, i.e., generally in the range of 95 to 135 °C. Vibratory and pneumatic tyred rollers are suitable for this stage, with pneumatic tyred rollers effective at temperatures as low as 70 °C, and where knitting of the surface is required.
 - 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 90 °C, although evening out of the surface may be achieved at temperatures as low as 70 °C, depending on the viscosity of the binder.
 - Modified binders may have a marked influence on the compaction temperatures. Workability of these mixes should be carefully investigated during trial sections, and when any changes of binder and additive sources occur, to set appropriate construction controls.
- **Finishing rolling** (90 °C – 70 °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.

(ii) Good Rolling Practices

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 does not apply to all rollers. For this reason, the best rolling pattern for each roller used must be established and followed to obtain the most uniform compaction of the paved width.

The following control measures should be checked:

- 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.
- All **sprinkler systems, mats and scrapers** are in good operating condition.
- **Rollers should not turn**, change direction or be stationery 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.

3.11.1.5 Asphalt Placement during Night Work

With traffic volumes steadily increasing, it is becoming more common to carry out asphalt construction during the night, especially in metropolitan areas where traffic accommodation is a major issue. Whilst mix selection and manufacture is essentially similar irrespective of when placed, particular construction issues may arise when working at night, such as:

- The normal tack coat of stable grade **emulsion will not break speedily**, due to a lack of evaporation. Thus, an alternative product may be necessary to ensure an adequate bond with the substrate.
- If even only a light rain has occurred, **drying out of the surface** can be a lengthy process at night, resulting in possible delays in commencement of work.

- Due to the inherently **colder ambient temperatures**, commencement of the compaction process has to be more timeous and efficient to achieve the required level of compaction, especially for relatively thin surfacing mixes.
- Even with **adequate lighting**, aspects such as segregation and unevenness are more difficult at night, and, as such, more vigilance/supervision is invariably necessary.

3.12 Concrete Pavements

Concrete pavements are rigid pavement structures that are generally constructed using slipform or side form pavers. Concrete pavements are discussed in various chapters of this manual, see the sidebox for specific cross-references.

A number of concrete pavement types have been constructed in South Africa, and are mainly differentiated by their crack control features. These are:

- **Plain jointed unreinforced** concrete
- **Jointed reinforced** concrete
- **Continuously reinforced** concrete (CRC)
- **Ultra-thin continuously reinforced** concrete (UTCRC)
- **Ultra-thin reinforced** concrete (UTRC)

Illustrations and descriptions of these types of concrete pavements are included in Chapter 2: 2.4 and Chapter 9: 12.2.2.

Research has shown that areas of premature failures on concrete pavements are mainly attributed to poor workmanship or construction problems. It is, therefore, essential that control measures are implemented during construction, the various construction processes are continuously monitored for conformance to the techniques, and plant selections agreed upon at the relevant trials. The processes associated with concrete paving are discussed in this section.



Concrete Pavements

The following is a comprehensive guideline for all aspects of concrete pavements:

- **Concrete Road Construction**, Cement and Concrete Institute (C&CI, Perrie and Rossmann, 2009)

Various aspects of concrete pavements are discussed in:

- Chapter 2: **Pavement Composition and Behaviour**, Section 2.4
- Chapter 3: **Materials Testing**, Section 5.1
- Chapter 4: **Standards**, Section 5.1
- Chapter 9: **Materials Utilisation and Design**, Section 12.2.2
- Chapter 10: **Pavement Design**, Section 8
- Chapter 13: **Quality Management**, Section 8
- Chapter 14: **Post Construction**, Section 4.2

3.12.1 Subbase Construction

The subbase in a concrete pavement has considerable influence on the long-term performance of the completed pavement, both in terms of uniform support and to provide an erosion-resistant layer beneath the concrete. The subbase is often constructed much earlier than the main pavement and is used as a haul road for site traffic, especially for vehicles delivering concrete. It must, therefore, be sound enough to support construction traffic. The requirement for a subbase, the choice of material and thickness, and whether it is to be bound or unbound is based on traffic volumes, subgrade conditions, type of concrete pavement and the economics of a particular situation. In most cases, subbases under concrete pavements are of a high quality, well stabilized cementitious or bituminous layers. The selection of the subbase is an important part of the design process.

At the time of placing the concrete, primer coats must be properly dried. The surface of the subbase must be kept cool and damp, to reduce the risk of heating the new concrete, which can lead to premature cracking, particularly in hot weather.

Immediately before placing the concrete, any excess water should be broomed off the subbase to ensure that the subbase is still damp, but free of puddles of water.

3.12.2 Formwork

3.12.2.1 Side Forms

Side forms consist of steel units that are capable of carrying the paving equipment. Steel form units usually consist of straight steel sections 3 metres long, while shorter lengths may be required in undulating terrain or for curves with tight radii. A side form is illustrated in Figure 98.

Wood forms should only be used where the project is small and relatively unimportant, or steel forms are unsuitable, such as for short-radius curves. Forms should be provided with adequate devices for secure setting so that they can also withstand, without visible spring or settlement, the impact and vibration of the compacting and finishing equipment. When checked for straightness, forms should not vary by more than:

- 3 mm in 3 m from the **true plane surface** on the top
- 6 mm in 3 m along the **face of the form**



Figure 98. Side Forms

Forms should contain provisions for locking the ends of abutting form sections together tightly. Flexible or curved forms are recommended when the curve has a radius of 30 m or less.

Keyway strips, shown in Figure 99, must be soundly attached to the faces of the forms to ensure that keyways between form sections form a smooth horizontal plane. All forms must be cleaned and oiled before use.

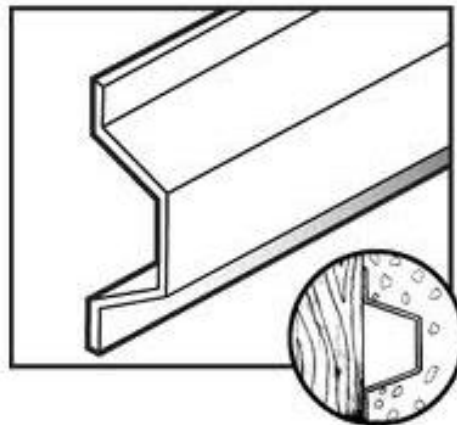


Figure 99. Keyway Strip

3.12.2.2 Setting of Forms

Forms should be pinned or staked into place with not less than three pins for each 3 metre section, with a pin placed at each side of every joint. The pins should be of sufficient length to hold the forms securely in position during construction. When the forms have been set accurately to line and grade, form wedges and locks for steel form units are driven tight. Forms may be adjusted to the correct level by the use of steel shims or wedges. The space between the supporting layer and the forms can be filled with a semi-dry 1:3 cement/sand mortar. The setting of forms is illustrated in Figure 100.

3.12.2.3 Removal of Forms

Forms should remain in place for at least eight hours from the time of concreting, or until the concrete is ready for saw cutting of joints. If the air temperature drops below 10 °C during this time, the removal of forms may need to

be delayed to ensure that pavement edges are not damaged. Forms should be carefully removed to avoid damage to the pavement, and especially the top edge of the pavement, and any projecting tie bars at longitudinal joints. The specified curing procedure should be initiated on the exposed vertical edge of the slab immediately following removal of the form.

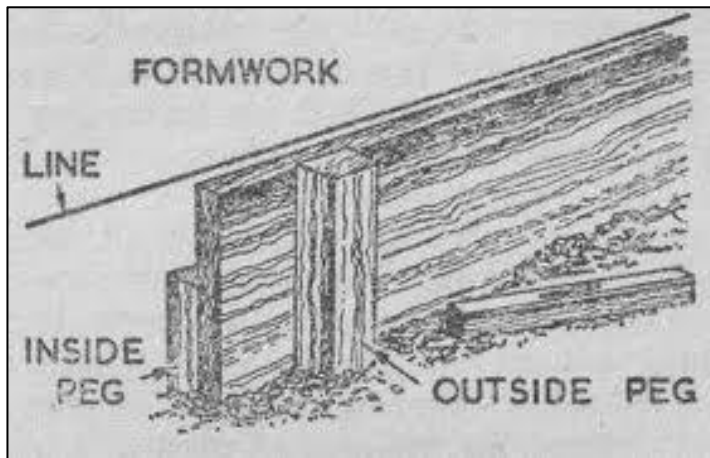


Figure 100. Setting of Forms



Removal of Forms

Forms should remain in place for at least eight hours from the time of concreting, or until the concrete is ready for saw cutting of joints. If the air temperature drops below 10 °C during this time, the removal of forms may need to be delayed to ensure that pavement edges are not damaged.

3.12.3 Guide Wires or Stringlines

Where a slipform paver is used, two guide wires called stringlines are usually provided, one on each side of the concrete slab being laid, at a constant height above, and at a constant horizontal distance from the edge of the proposed pavement. Typical stringlines are illustrated in Figure 101.



Figure 101. Stringlines

The stringline should be supported by finely adjustable connectors attached to steel stakes. The connectors should be free of play. The stakes are typically spaced 8 metres apart, and closer on vertical and horizontal curves. The staking system normally includes hand winches at appropriate intervals to tighten the line, and prevent sagging and deflection.

The stakes should be positioned, the connectors set, and wires securely fixed and tensioned on the connectors sufficiently in advance of the paver to permit checking and inspection. The stringline should be checked periodically during the day to ensure that the tension is appropriate and has not changed with temperature.

3.12.4 Working with Concrete

3.12.4.1 Manufacturing and Hauling Concrete

Materials for concrete pavements are normally specified in great detail. It is essential that the construction control ensures that all the specified requirements are met.

The consistence of the concrete mix has a major impact on the final surface finish and riding quality of the pavement. Consistence is measured using a slump test, or Vebe test when the slump of the concrete is less than 35 mm. With hand paving, concrete consistence is usually measured by means of a slump test. These tests are discussed in Chapter 3: Section 5.1.8.

A concrete road pavement has a very large surface area in relation to its volume. The surface is subject to temperature and wind effects immediately after placing. To limit these effects, and to permit the early finishing and curing of the concrete, the mix proportions should be such that the stiffest possible consistency is produced, providing it is compatible with the paving plant.

Continuous pouring is essential for a consistent finish. Therefore, it is important that the concreting operations can achieve constant production.

The following aspects need to be considered to achieve continuity of mixing and paving:

- The batch plant capacity is capable of **supplying the paver continuously**, and receiving the required materials to ensure this is achieved.
- The **hourly concrete demand** is based on rate of progress and related volume calculations.
- **Aggregate heaps are** contained to avoid segregation and mixing of different aggregate sizes and types.
- **Aggregate moisture content** is consistent, and wet delivered aggregate allowed to dry out for at least 12 hours before use.
- **Mass batching** is preferred. If **volume batching** is used, container masses and related volumes should be checked daily.
- The **moisture content of the fine aggregate**, is to be checked daily.
- Cement to be used in a **first in first out basis**.
- **Concrete batch sizes** do not exceed manufacturer specifications. Mixing times should be at least 1 minute, or greater depending on tests for uniformity of mix.
- The **size and number of haulage vehicles** is sufficient to suit the batch plant capacity, haul distances and site issues such as tie bars, shutters, reinforcing and dowel bars. Side tipping is often required to avoid driving over reinforcing steel and dowel bar cages.
- If trucks are not typical **agitator trucks**, **tipping trucks** should have watertight bodies, high tipping angles and large fillets in internal corners. Provision should be made for covering the concrete to prevent drying out of the concrete in transit.
- With **truck mixers or truck agitators**, the **time between mixing and discharge** does not exceed 60 minutes, or less depending on temperature.
- Where concrete is **transported in non-agitating equipment**, discharge is completed within 45 minutes after mixing, which can reduce to 30 minutes with high environmental and mixing temperatures.
- **No water may be added** to the mix during transport.

3.12.4.2 Placing and Spreading Concrete

To avoid depressions or cavities in the surface of the pavement, the concrete is placed directly in front of the paver, or distributed by auger or shuttle feeders incorporated in the paver so that a small roll of excess concrete is continuously carried forward by the paver. It should be placed to a sufficient loose thickness to provide a proper surcharge for subsequent finishing operations. Finding the suitable amount of surcharge for the spread concrete, that results in the correct level after compaction, is a matter of trial and error, but is typically around 15%. To achieve an even surcharge with manual laying, a strike-off beam is used. This consists of a beam 300 mm longer than the width of the lane, with battens as thick as the surcharge, nailed to the underside near the ends, as illustrated in Figure 102.

Concrete should not be placed haphazardly, and shoved or vibrated into its final position. Where necessary, hand spreading is done with shovels and not rakes. Workers are not allowed to walk in the freshly placed concrete with boots coated with earth or other foreign substances.

Placing is continuous between planned construction joints, without the use of intermediate header boards. An interval of more than thirty minutes between placing of any two consecutive loads of concrete may require stopping paving operations, and making a construction joint in the concrete already placed.

Precautions are taken when placing concrete, to ensure that the fixed side forms and preset reinforcement and dowels are not damaged or disturbed, and that the concrete does not segregate.



Figure 102. Strike-off Beam

In fixed form construction, placing starts from the corners and the lowest level of the area being paved. Each load of concrete is placed into the face of previously placed concrete.

On steep grades, the direction of paving is always up the slope and slots of keyed joints on the downhill side, so that the concrete flows into the cavity. The water content of the concrete mix is reduced to make the concrete stiffer, to prevent it from flowing downhill during compaction. This may require greater compactive effort and finishing to prevent bulging on the downhill side. Steep grades also impose a greater requirement for good skid resistance, especially when the surface is wet. Deep tining or an alternative texture may be appropriate.

Concrete should not be placed during rainy weather and waterproof covers for the protection of the surface of the plastic concrete should be available at all times. In addition, with slipform paving, acceptable emergency protection for the slab edges should be provided. When rain appears imminent, paving operations should cease and the necessary steps for complete protection of the plastic concrete commenced.

All reasonable precautions should be taken to ensure that the temperature of the pavement concrete does not fall below 5 °C during the first 48 hours after placing. When prevailing temperatures are low, or when cold weather is forecast, concreting operations should cease. Alternatively, the pavement should be protected with covers that ensure a minimum pavement temperature above 5 °C for the 48 hours.

Hot, dry, windy weather causes cracking in the pavement and/or impairs the quality of fresh or hardened concrete, and requires precautions. Such precautions include placing concrete during the coolest part of the day and keeping mixing water and aggregates cool. Paving operations should cease when the concrete temperature, as discharged at the paving site, exceeds 32 °C, as finishing will become difficult.

When concrete is placed adjacent to an existing pavement, the equipment supported on the existing pavement should be equipped with protective pads and offset not less than 300 mm from the edge of the pavement, to avoid breaking or cracking the pavement edge.



Temperatures for Concrete Pavement Construction

All reasonable precautions should be taken to ensure that the temperature of the pavement concrete does not fall below 5 °C during the first 48 hours after placing. When prevailing temperatures are low, or when cold weather is forecast, concreting operations should cease.

Paving operations should cease when the concrete temperature, as discharged at the paving site, exceeds 32 °C, as finishing will become difficult.

3.12.5 Compaction

The purpose of compacting concrete is to ensure the maximum density is obtained, and that complete contact between the concrete and reinforcing steel, dowels, tie bars, and side forms is achieved. The entire volume of the pavement should be compacted in as effective a manner as possible. Particular attention should be given to edges and joints. The rate of forward progress of the plant should not exceed that at which full compaction of the concrete can be achieved. All vibration should be stopped when the paver is stopped. Over-vibration, resulting in segregation, surface laitance, or leakage, should not be allowed. However, with a well-designed mix, segregation due to over vibration is unlikely.



Laitance

Laitance is a milky deposit on the surface of new cement or concrete, usually caused by too much water.

A vibrating beam or truss strikes off the concrete in addition to compacting it, as illustrated in Figure 54 in Section 2.9.3. The vibrating beam is lifted onto the spread concrete and, as the concrete is vibrated, the underside of the beam or truss comes to rest on the side forms. With a double-beam unit or truss, a small roll of concrete should be maintained in front of both beams as the vibrator is pulled along. Usually, at least two passes are required. These concepts are illustrated in Figure 54 and Figure 56 in Section 2.9.

A poker vibrator is used in areas adjacent to edges and corners, to supplement compacting by hand tamper or vibrating beam. However, where the thickness of concrete exceeds 150 mm, a poker vibrator should be applied over the whole area and depth of the concrete, including along the faces of all forms. See Figure 54 for an example of a poker vibrator.

Compacting and striking off should be completed before any excess water bleeds to the surface.

With a paver, the concrete is extruded between the bottom of the profile pan or conforming plate and the side forms and subbase. The mass of the paver provides pressure on the conforming plate, while immersion vibrators ensure adequate compaction is achieved, and the concrete is liquefied enough to flow through the paving process. Setting of the vibrators includes the spacing of the vibrators, the vertical alignment of the vibrators and their frequency. The frequency needs to be set to prevent the occurrence of vibrator trails in the pavement. See Figure 60 for a picture of vibrator trails, and Section 2.9.7.3 for a discussion on vibrators.

3.12.6 Steel

Concrete pavements use steel for dowel bars, tie bars and reinforcing. The process control for these components is discussed below.

(i) Dowel Bars

Dowel bars are used in transverse joints to transfer load across a contraction or expansion joint. At least one end must be lubricated and free to move, to permit opening and closing of the joint. To allow this movement, dowels must be made of smooth steel, and sawn and not cropped. All burrs on the ends must be removed. Dowels must be straight and free from dirt or excessive rust. To permit joint movement, the free end of the dowel must be smooth and greased, to ensure sliding can occur freely. Excessive grease, that can create a void, should not be allowed.

Dowels can be placed in assemblies at joint locations in advance of paving operations, or can be installed mechanically with both fixed form and slipform pavers.

Dowel alignment in both planes must be maintained by a suitable supporting frame left permanently in place, as illustrated in Figure 103. Failure to meet this requirement may result in joints locking up, thus inducing cracking within the slab at or near the ends of the dowels. Misalignment should not exceed 1 mm, measured from the one end of the dowel bar to the other.

Dowel assemblies should be simple and offer no restraint to longitudinal movement at the joint. The locations of dowel assemblies should be suitably marked prior to concreting, to ensure accurate cutting of the contraction joint over the dowel. Where doweled contraction joints are skewed, the assemblies require careful preparation to ensure that the dowels remain parallel to the pavement centre line, to ensure freedom of the longitudinal movement at the joint.

Where dowels are inserted mechanically, the set-up of the paver should be checked to ensure that the dowels can be placed by the machine to the required level of accuracy. Covermeters can be used to check the alignment of mechanically inserted dowels. See Section 2.9.4 and Figure 55 for dowel bar inserters.



Figure 103. Installation of Dowel Bars

(ii) Tiebars

Tiebars are used in longitudinal joints. They are designed to hold a joint tightly closed, whilst permitting a small amount of warping or hinging at the joint. They must, therefore, be firmly anchored in the concrete. For this reason, tie bars are relatively thin and deformed to provide the necessary anchorage.

In the case of multiple lane paving, tiebars are either placed on cages, or stabbed into the fresh concrete with an automatic inserter. In longitudinal joints between paved lanes, the tiebars are inserted into the edge of the pavement. These are either bent tiebars or one half of a two-piece tiebar.

(iii) Reinforcement

If the slab is reinforced, the steel may be supported on stools at the proper location (see Figure 104), and the concrete compacted from the surface. Alternatively, the concrete layer below the mesh should be struck off, the reinforcement placed and tied, and the top course spread.

Steel reinforcement should be pre-positioned on the prepared subbase on chairs/stools, or other suitable supports, sufficiently in advance of paving, to permit inspection and checking of the reinforcement. The minimum cover of 50 mm should be applied, and steel should be placed one-third of the slab thickness from the surface. As with any concrete, all steel reinforcement used in concrete paving must be free of rust, oil and grease, to ensure a good bond with the concrete.

Light reinforcement in the form of sheets should be handled with care, so that they remain reasonably flat and free from distortions. Bars should be free from kinks or bends that may prevent them from being properly assembled or installed.

3.12.7 Joints

Transverse expansion joints are constructed perpendicular to the centre line of the pavement and extend the full width of the pavement.

Sawing of joints is tricky as concrete has to achieve a certain strength to enable sawing of the joints. At the same time, the longer the period between casting and saw cutting, the greater the possible moisture loss from the concrete, and the higher the risk of shrinkage cracks occurring before the joints are cut. A trial section greatly assists in deciding on the cutting time. The trial must use the same materials and conditions similar to those anticipated for the actual construction. Two-stage saw cutting can also be used. An initial narrow cut induces a crack at the planned joint location, which later widens when the concrete hardens. Joints must be correctly positioned above dowels and tie bars.

Longitudinal joints are provided either in the form of construction joints or weakened plane joints in multiple lane paving. All longitudinal joints are tied together using



Joints

Joints must be correctly positioned above dowels and tie bars.

deformed tie bars, either set on the subbase in assemblies for multiple-lane paving, or mechanically inserted into the plastic concrete. Tie-bars are located at mid slab depth in construction joints, or at mid-depth of the reduced section in contraction joints. Where placed in assemblies, or at construction joints, tie-bars should be secured to the extent that they do not deflect during paving operations.

Longitudinal joints and transverse joints must be sealed. See Section 3.12.11 for details.



Figure 104. Reinforcement

3.12.7.1 Joints Between Asphalt and Concrete Pavements

Concrete inlays are sometimes used on the slow lane of major highways, with the shoulders and fast lane(s) constructed with asphalt. In these situations, the vertical joint between the asphalt and concrete should be specially constructed to ensure that the asphalt bonds to the concrete. Figure 105 illustrates how the joint should be constructed. When constructing the concrete layer, a chamfered edge form is used, to create the 45° angle. Normally, the concrete is constructed slightly higher than the original surface. The asphalt is paved at a later stage, and paved into the angled edge of the concrete.

These types of joints are only necessary for the longitudinal joint, i.e., for shoulders next to slow lanes, or slow lanes next to fast lanes. Transverse joints between asphalt and concrete pavements only require a straight vertical joint, as these joints can be sealed.

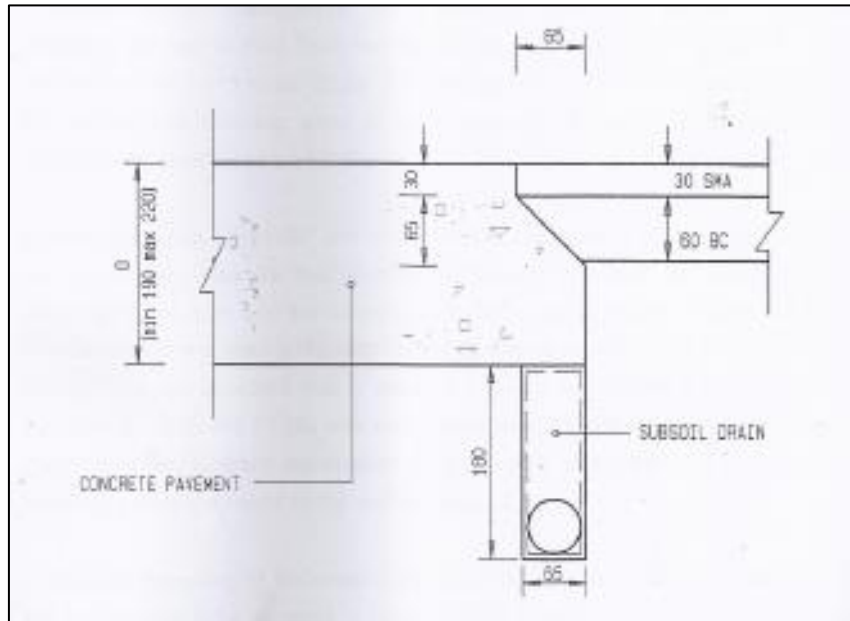


Figure 105. Vertical Interface between Asphalt and Concrete Pavements

3.12.8 Finishing

Finishing includes both initial finishing, involving screeding the concrete to the required cross section profile, as well as final finishing, involving floating the pavement.

Achieving a satisfactory surface on the concrete pavement, requires controlled finishing techniques. To assist in the proper application of these techniques, the concrete mix should be such that there are just sufficient fines (cement and sand) to allow a mortar to be worked to the surface with vibration. Too much fine material makes finishing easier, but probably leads to surface bleeding, as well as being more expensive than a well-proportioned mix. Too much water in the mix creates delays in finishing, as well as producing a weak surface layer that exhibits poor resistance to wear and abrasion.

Screeding ensures that the concrete achieves its final surface tolerances, while final finishing begins when the sheen has left the surface. In the case of air-entrained concrete, there may be little bleed water and no visible sheen, and it may be possible to finish this type of concrete after a short delay. Finishing should not be attempted in any area where there is free surface water. Working the surface too soon creates a weak surface and produces laitance. Working the surface too late, however, requires considerably more finishing effort and may cause crumbling of the concrete surface.

Neither cement nor water should be used to influence surface conditions and the ease of finishing, as this produces surfaces with reduced abrasion and wear resistance.

Floating involves smoothing any irregularities in the surface following screeding, and preparing the surface for texturing. It can also assist in closing minor surface cracks, which may occur as the surface dries. Floating is not a substitute for proper compaction after placement of the concrete, and should be kept to the absolute minimum necessary to achieve the required results.

Edge tooling by hand at transverse or longitudinal joints should not be permitted. All edges on pavements should be left square. Any spalling resulting from the failure of the edge is only minor, and will not cause a maintenance problem.

Any depressions should immediately be filled with freshly mixed concrete and not mortar or slush, struck off, compacted, screeded and refinished. High areas should be cut down and



Finishing Concrete Pavements

The importance of checking the pavement surface and correcting any irregularities when the concrete is still in a plastic state, cannot be over-emphasized. The relative difficulty and cost of surface correction in hardened concrete is much higher.

Any depressions should immediately be filled with freshly mixed concrete and not mortar or slush. The concrete is then struck off, compacted, screeded and refinished. High areas should be cut down and refinished.

refinished. Monitoring of the pavement surface is carried out simply using suitable lengths of light extruded metal sections or timber, placed carefully on the pavement surface both longitudinally and transversely. They must not disturb the concrete surface. These checks are carried out at the same time as a regular visual inspection by supervisors. Special attention should be given to ensure that the refinished surface across joints formed in the plastic concrete meet the requirements for smoothness. Surface corrections should continue until the entire surface is found to be free from observable departures, and the slab conforms to the required grade and cross section.

The importance of checking the pavement surface and correcting any irregularities at this stage of the paving operations cannot be over-emphasized. The relative difficulty and cost of surface correction in the hardened concrete is much higher.

3.12.9 Texturing

After placing, compaction, finishing and the completion of any wet-formed joints, and before the commencement of curing, the surface of the concrete should be provided with a surface texture. This operation should commence before the concrete is in a condition that the surface could be torn and coarse aggregate particles unduly loosened.

With mechanized paving, texturing may be carried out by means of a machine spanning the concrete slab and guided in both level and direction by side forms, by the paver guide wires in the case of slipform construction, or by suitable manually operated equipment.

For manual paving operations, or where lane-at-a-time paving is employed, hand drawn brooms provide a suitable means of surface texturing. For municipal type works, hand drawn brooms are usually preferred.

When a burlap drag is used (see Section 2.9.6 and Figure 59), the first pass should commence as soon as construction operations permit and before the water sheen has disappeared from the surface. This should be followed by as many passes as required to produce the desired texture depth. There should be no delays between passes. The drag should be damp during use and should be maintained clean and free from encrusted mortar. Additional burlap drags should be kept on site for ready use to eliminate delays due to dirty and worn drags. The burlap should be wetted each morning, and maintained in a moist condition throughout the day. At the end of the day's pour, the burlap drag should be cleaned, or discarded and replaced if cleaning is unfeasible.

Directly after completing the burlap finish, the surface of the pavement is grooved with a metal tining device (see Section 2.9.6 and Figure 58). The depth of the grooves produced should be monitored to ensure a depth of 2 to 4 mm. Where tining is done manually, the tining device is operated against a straightedge to ensure straight grooves.

Where noise is of concern, an exposed aggregate concrete surface has been shown to produce a quieter surface than those described above. The texture is achieved using a smaller than normal coarse aggregate, i.e., 7 mm rather than 14 mm, and applying a set-retarding agent to the surface. Following the prescribed period, the surface is brushed with a mechanical rotary broom to remove the thin layer of mortar and expose the aggregate. The coarse aggregate should have a polished stone value of at least 50 (see Chapter 3: 4.2.2.)

3.12.10 Curing

From the time concrete has been placed and compacted, and until it is a few days old, it must be protected against damage from environmental factors. Such damage is primarily cracking caused by drying shrinkage, that is in turn influenced by relative humidity, concrete and air temperatures, and wind velocity. There are a number of procedures for minimizing plastic-shrinkage cracking that all involve reducing temperature and evaporation.

In addition, the concrete must be allowed to cure through proper hydration in the presence of moisture and a curing compound or wet or impermeable covering. Curing compounds should be applied in accordance with the manufacturers' specifications. During spraying operations, the curing compound is agitated or stirred to keep pigments in suspension. To avoid loss of spray, and a reduced application rate, the spray distributor must, at all times, be protected by a suitable hood or screen and should be operated as close as practical to the pavement surface. The curing membrane should remain intact for seven days after placing the concrete. Any damage to the curing membrane should be made good by hand spraying of the affected areas.

3.12.11 Joint Sealing

Joints should be sealed as soon as practical, after completion of the pavement curing period and before the pavement is opened to traffic. The sealing material should be applied to joints to conform to the details shown on the plans. Any discrepancies between specifications and manufacturer's recommendations should be analysed before work commences.

Preformed sealants require strict control of saw width; worn blades or variations in blade thickness between different blades can result in sealant failure.

As a general rule, joint faces must also be dry since the sealant has to bond with the concrete. Inspection of each joint is essential prior to placing backup materials, priming or sealant installation. It is also wise to check the joint width and temperature of the concrete against the assumptions made in the joint design.

Application of the sealant to fill the joint reservoir is a skilled operation and must be carried out by skilled and trained operators.

Compression seals require a uniform joint width, with straight, smooth, spall-free joint faces, to permit proper installation and provide uniform contact. The joint need not, however, be cleaned to the same extent as is required with field-moulded sealants. It is important to install the seal at the specified depth, usually 3 to 6 mm below the surface, to keep it out of contact with the tyres. The seal should be installed in as long a continuous piece as possible.

Curing compounds and other materials should not contaminate joint faces. Where the original curing is broken by construction operations before the joint edges and faces have fully cured, supplementary curing must be applied.

3.13 Block Paving

Concrete block paving, also known as segmented concrete paving, comprises of small individual shaped blocks laid shoulder to shoulder on a sand bedding layer. Sand is placed in the network of closely spaced joints between the blocks to fill the gaps and to enhance interlock between the blocks. This system of blocks, jointing sand and bedding layer provides a durable wearing course. The design of block pavements is discussed in Chapter 9: 13 and Chapter 10: 9.

The paving blocks act as a structural layer, rather than merely providing a wearing course, if the block paving is properly constructed, ensuring interlock or lock-up between individual blocks. There are several aspects of the block paving wearing course layer that have a significant effect on the performance of the layer. It is thus essential that all these aspects receive the necessary attention and control during both manufacturing of the blocks and construction of the layer, to obtain the maximum structural strength.

There are various specifications and guideline documents published to assist in the successful construction of block paving. The following publications are most widely used in South Africa:

- **The current specification** in South Africa for the requirements for concrete paving blocks is SANS 1058 – Concrete Paving Blocks.
- **The current specification** in South Africa for the construction of concrete block paving is SANS 1200 MJ – Standard Specification for Civil Engineering Construction: Segmented Paving.
- **The Standard Specifications** also have specifications for block paving, which need to be complied with on COLTO based projects. These specifications may be different to those of SANS and CMA.
- Cement & Concrete Institute (C & CI) issued a technical note “**The Manufacture of Concrete Paving Blocks**” that covers the basic principles of block paving and aims to assist manufacturers to produce a durable and consistent product. This note can be downloaded from www.theconcreteinstitute.org.za.
- CSIR published the **Urban Transport Guideline (UTG2)**: Structural Design of Segmental Block Pavements for Southern Africa.
- The **Concrete Manufacturers Association** (CMA) has four books on **Concrete Block Paving**. These books can be downloaded from www.cma.org.za. The books are titled:
 - Book 1: Introduction
 - Book 2: Design Aspects
 - Book 3: Specification and Installation
 - Book 4: Site Management and Laying
- The **CMA** also has guideline brochures on several aspects of **concrete block paving**, which can be downloaded from www.cma.org.za.
 - A Step-by-Step Guide to Perfect Paving



Block Paving in High Speed Traffic Areas

In areas where relatively high traffic speeds are expected, block paving should be used with caution unless proper construction practice and maintenance of the joints in the early stages of its life can be guaranteed.



Design of Block Pavements

The design of the components of block pavements is included in Chapter 9: 13.

The pavement design for block pavements is included in Chapter 10: 9.

- Good Earthworks Practice
- Drainage of Concrete Block Paving
- Technical Note for Steep Slopes
- Efflorescence is only a Temporary Problem
- An Introduction to Permeable Concrete Block Paving
- Other very useful guides on various aspects of concrete block paving are publications by the **Concrete Masonry Association of Australia** (CMAA), which can be downloaded from www.cmaa.com.au.

3.13.1 Paving Blocks

Paving blocks are the main element of the system. It is thus essential that the block strengths, shape and dimensions are tightly controlled, to ensure a constructed layer of adequate strength.

3.13.1.1 Block Strength

The required strength of concrete block pavers is significantly higher than the strength of concrete bricks, which have compressive strengths in the order of 7 MPa. The strength of the blocks should be sufficient to ensure that the blocks have adequate resistance to withstand the wedging effect between adjacent blocks during traffic loading, and the abrasion effect of the tyres during traffic movements. It is thus essential that the strength of the individual blocks is controlled to ensure proper performance.

The specification currently used is SANS 1058, referred to in the Standard Specifications, which requires the following for the blocks:

- Minimum wet **compressive strengths** of:
 - 25 MPa for paving blocks for light traffic conditions
 - 35 MPa for heavy traffic conditions, with wheel loads higher than 30 kN
- Minimum **tensile splitting strength** of:
 - 2.2 MPa for light traffic conditions
 - 2.8 MPa for heavy traffic conditions
- The average and individual **mass loss of blocks** shall not exceed 12 g and 15 g respectively during the abrasion resistance tests. This test is discussed in Chapter 3: 5.2.
- The average and individual **water absorption** measured in the blocks shall not exceed 6.5% and 8.0% respectively. This test is discussed in Chapter 3: 5.2.

Although the specifications require a minimum strength for the blocks, research has shown that compressive and tensile strengths significantly higher than the minimum specified have little structural advantage to the block paving layer.

3.13.1.2 Block Shape

There are three different types of shapes of concrete paving blocks manufactured in South Africa. The difference between the types is the effective interlock achieved between adjacent blocks in a laying pattern. The different shape types are: Type S-A, Type S-B and Type S-C. These are discussed and illustrated in Chapter 9: 13.1.2. Clay bricks are not used as paving blocks anymore, as they are generally only rectangular in shape.

3.13.1.3 Thickness

Block pavers of variable thickness are available, but the most common thickness used in heavily trafficked areas is 80 mm.

3.13.1.4 Dimensional Tolerance

It is very important for block pavers to be of similar dimensions to ensure good interlock between the pavers and to provide a smooth surface on the constructed layer. The required tolerances on individual blocks as specified in SANS 1058 are ± 2 mm on plan dimensions and ± 3 mm on thickness.

The specification also requires that the thickness of the block, as measured at any point along the perimeter, not vary by more than 2%. This specification is necessary to ensure an acceptable riding quality of the paved layer.

3.13.2 Laying Patterns

The laying pattern is an important contributor to the performance of the block paved layer. The efficiency of a block layer is the degree to which blocks must rotate to achieve interlock. There are numerous patterns for the laying of paving blocks. The following patterns are the most common, and are illustrated in Figure 106:

- **Stretcher** pattern
- **Herringbone** pattern
- **Basket weave** pattern

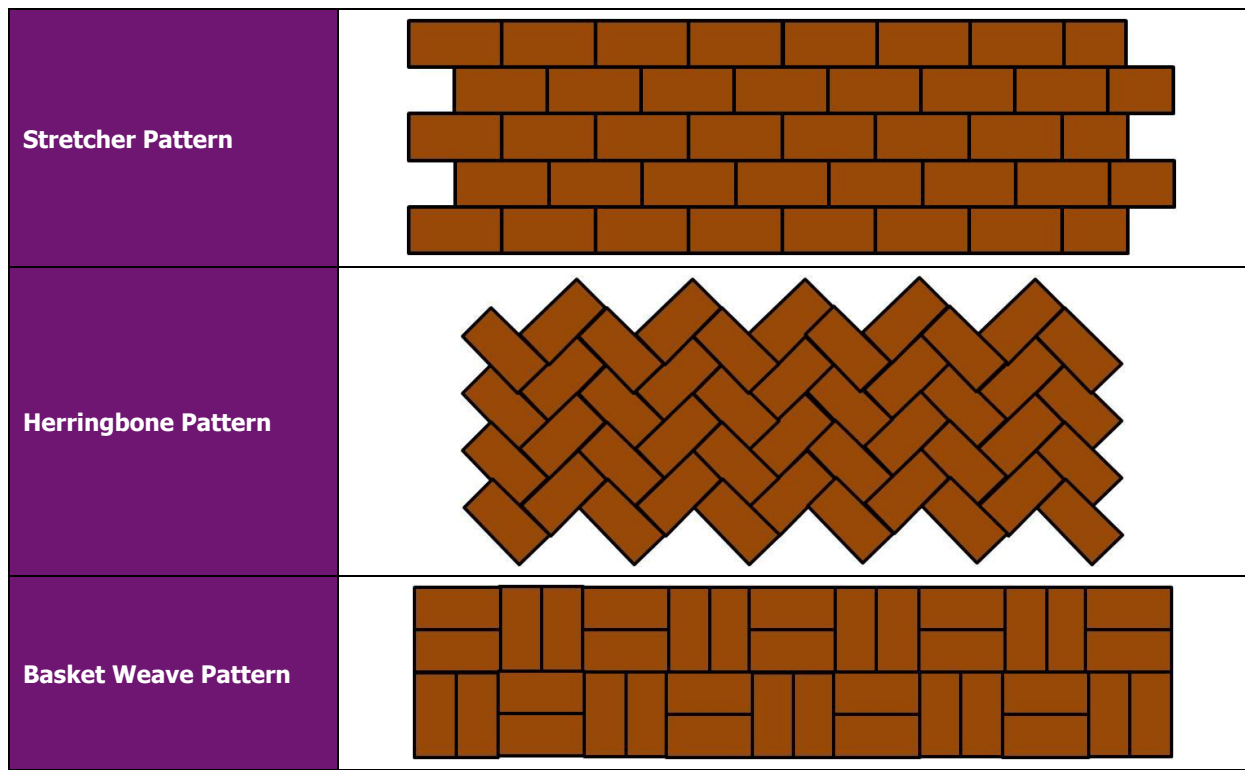


Figure 106. Common Laying Patterns of Paving Blocks

Paved areas with laying patterns other than the herringbone pattern are generally disturbed by traffic loading and movement during the early stage of trafficking. This disturbance leads to irregular gaps between rows of pavers, which in turn leads to a loss of jointing sand, resulting in excessive movements between blocks. An example is shown in Figure 107. The excessive movements between individual blocks results in spalling of the contact points between blocks. Another benefit of the herringbone laying pattern is that it can be laid around bends and corners without interrupting the laying pattern.



Figure 107. Excessive Openings in an Area Paved with Type S-C Blocks

3.13.3 Edge Restraint

Edge restraint is required along the edges of a block paved area. It is very important to retain the bedding sand, and to ensure that the paving blocks at the edge of the paved area do not creep outwards or rotate under load, causing opening of the joints and loss of the interlock between the paving blocks. The integrity of the paved layer is lost if the joints open.

Various types of edge restraint are used, including concrete drains, concrete kerbs and edge beams. The edge restraints should have sufficient stability to withstand occasional vehicle impacts. They can also be used to separate areas of different laying patterns, or as kicker blocks where steep grades are encountered.

3.13.4 Joint Filling Material

Filling the joint or gap between individual pavers is crucial to the performance of a concrete block paving layer as block pavers develop very little, or no, strength with open joints. A block paving layer develops its structural capacity by the wedging action between individual pavers during construction and under traffic.

The small gaps or joints, nominally 2 to 5 mm wide, between the block pavers are filled with a fine continuously graded dry sand. The use of cement in the joint filling material is not recommended. Maintaining the jointing sand protects the structural integrity of the paving layer. If sand is lost, it is essential to refill the joints, especially when windy conditions and/or fast moving traffic are experienced.

The cumulative compactive effect of traffic causes the blocks to bed further into the bedding sand layer, and displaces some of the jointing sand upwards. Vehicle movements remove some of the joint filling sand, which becomes part of the detritus on the surface of the paved layer. This detritus eventually forms an upper plug over the jointing sand and assists in sealing the block paving layer.

3.13.5 Bedding Sand Layer

The bedding sand has a crucial influence on the performance of a block paving layer. The following three factors are the main contributors to the uniformity of the layer and should be controlled during construction:

- **Thickness** of the sand layer
- **Grading** and **angularity** of the sand
- **Moisture content** of the sand during construction and in service

The thickness of the bedding sand layer is between 25 to 30 mm in a loose condition. Most failures in block paving occur because the bedding sand layer exceeds the recommended limits. Bedding sand thicker than 30 mm can result in differential compaction under the blocks, leading to loss of interlock between the blocks.

In addition, the following material requirements should be noted:

- Materials, such as clean graded **crushed quarry fines** and good quality **concrete sands** perform well, provided the paving blocks are constructed correctly.
- Bedding sand shall be free from **deleterious substances**, be **non-plastic** and **permeable**. The silt and clay contents should be less than 20%.
- **Single-sized, gap-graded** or material containing an excessive amount of fines, reduces performance. The proportion of silt and clay material smaller than 0.075 mm should be less than 15%.
- **River sand** should be used with caution as the angle of shearing resistance is generally low due to the rounded shape of the particles.
- Use of **cement-bound material** is not recommended.

The material should have a uniform moisture content of 4 to 8% when placed. Saturated material should not be used.



Thickness of Bedding Sand Layer

The thickness of the bedding sand layer is between 25 to 30 mm in a loose condition. Most failures in block paving occur because the bedding sand layer exceeds the recommended limits. Bedding sand thicker than 30 mm can result in differential compaction under the blocks, leading to loss of interlock between the blocks.

3.14 Proprietary Products

The construction of layers using proprietary products is essentially the same as the construction of granular layers (Sections 3.3 and 3.8). The products are typically used as a compaction aid for granular materials. The manufacturer may, however, have special requirements that should be followed.

Proprietary products are discussed in:

- Chapter 3, **Materials Testing**, Section 6
- Chapter 4, **Standards**, Section 6
- Chapter 9, **Materials Utilisation and Design**, Section 14

4. TRIAL SECTIONS

A trial section is usually constructed to enable the assessment and verification of the proposed construction procedures for the particular construction process. A trial section is recommended for all pavement layers constructed with problem or sensitive materials. Trial sections should be constructed using the same materials, plant, equipment and procedures as will be used in the permanent works.

Trial sections form a very important part of a proactive approach to quality control. Any problems with mix sensitivity, constructability, uniformity of product properties as well as surface and smoothness can be identified timeously, and corrected prior to commencement of the permanent works. The successful trial is the reference against which the permanent works are compared, and ultimately accepted. It is, therefore, important that a high level of monitoring, including careful visual assessment, data recording and testing, is carried out. It is vitally important that the design engineer is present at the trial section.

Each specific product type and/or layer has its own unique requirements for trial section procedures and information. It is important to ensure that the condition and settings of equipment, as well as construction procedure and techniques utilised for the construction of the approved trial section, remain constant throughout construction of the permanent works.

The purpose of a trial section is to evaluate:

- The **contractor's** ability to build the product according to the approved design and required properties.
- Suitability of the **contractors' plant** to place and process the product.
- Suitability of the contractor's **construction techniques**.
- **Behaviour and relevant properties** of the product constructed at the limits of the allowable tolerances.

Checklists for the more commonly constructed layers, which should be used as a basis for commencing and evaluating trial sections are included in the relevant sections, and in printable format in the Appendix.

4.1 Asphalt Pavement Layers

Trial sections of asphalt pavement layers are essential to ensure that results obtained from laboratory testing can, in fact, be achieved in practice. Most laboratory testing is carried out on laboratory compacted specimens of laboratory or plant mixes. Trial sections involve laying a section of the asphalt mix to assess whether the batching plant and laying systems are all working satisfactorily. Therefore, it is essential that everything is checked to ensure that the trial section has a high probability of meeting requirements, and will not need to be milled and replaced.

For this reason, it is also essential that a trial section involves a reasonable amount of material, and not just one or two loads. Therefore, a typical trial section involves around 100 tons or 200 lane metres of a single asphalt mix, to facilitate a thorough test of all equipment.

The site selected for the trial section depends on the purpose of the mix, and the related functional and structural requirements.

If the requirements are not severe, consideration can be given to laying the trial mix on the road to be constructed. However, in most cases, the trial mix is laid on an adjacent lower class road with a similar surface, strength and gradient to that on which the design mix will be laid.

The trial section should only be started if there is confidence that the trial mix will be supplied and placed as specified. Aborted trial mixes lead to a waste of time and money, especially when waiting for plant and equipment repairs or replacement.



Trial Sections

The construction of trial sections is very valuable, and allows any problems to be sorted out in advance of the permanent construction.

The trial section is generally part of the main construction, done at the beginning of the section.

A trial section is recommended for all pavement layers constructed with problem or sensitive materials.

A successful trial is the reference against which the permanent works are compared, and ultimately accepted.

It is vitally important that the materials engineer is present at the trial section.



Volume of Asphalt for Trial Section

A typical trial section should utilise around 100 tons, or construct about 200 lane metres of a single asphalt mix. This is to facilitate a thorough test of all equipment.

Important aspects to note during asphalt trial sections are:

- **Temperatures** of the material:
 - As placed in the truck at the batching plant
 - As truck arrives on site
 - When placed in the paver
- **Uniformity of the temperature** of the mix placed in the paver, and when extruded out of the paver, should also be assessed using infra-red thermometers and/or video cameras.
- **Condition of road surface**, which should be clean and the tack coat should be dry with no puddles.
- **Temperature of the road surface** on which the material is laid.
- **Rolling pattern** to ensure complete coverages and proximity to the paver, as well as any problems related to tender materials or roller pick-up.
- **Straightness of the edge** of the paved layer.
- **Smoothness of the surface** of the layer, and any stop starts that influence the smoothness.
- **Uniformity of the surface** of the layer.
- **Neatness of handwork** and removal of any edge spillage and loose materials.
- **Number of roller passes** to achieve required density.

A checklist for asphalt paving trial sections is given in Table 11.

Table 11. Asphalt Paving Trial Section Checklist

Check	Confirm/Reject (Y/N)
1. Paver	
a. <i>Truck pushing rollers</i>	
i. Clean	
ii. Free Running	
b. <i>Hopper</i>	
i. Are sides reasonably smooth	
ii. Does side tilt mechanism work properly	
iii. Are rubber skirts in good condition	
iv. Do feed control gates work smoothly	
v. Are feed conveyors in good condition	
– Flights	
– Bed (no holes)	
– Chains, conditions and tension	
c. <i>Screed Unit</i>	
i. Are pivots free running	
ii. Are screed plates smooth and flat	
iii. Is bevel on tamper bars to specification	
iv. Are tamper bars straight	
v. Is clearance between tamper bars and screed correct	
Note: Clearance mm, Specified Clearance 0.05..... mm	
vi. Is protrusion of tamper bar below screed correct	
Note: protrusion mm, specified protrusion 0.05 mm	
vii. Is gap between tamper bars and screed clean	
viii. Are crown controls for screed working smoothly	
ix. Is locking system for crown control adequate	
x. Is screed inclination set correctly	
Note: Turnbuckle gauge reading: Actual:..... Specified:.....	
xi. Are augers in good condition and tight on shaft	
xii. Are the centre auger flights reversed	
xiii. Are augers set at correct height: Actual:..... Specified	
xiv. If telescope screed is fitted:	
– Do parts move smoothly	
– Do wings form a smooth continuation of main screed without steps	
– Are spreader screws extensions in good condition	
– Are tamper bar extensions to specification and is clearance between tamper and screed correct	
– Do tamper bar extensions protrude the correct distance below the screed	
xv. If screed is not telescopic:	
– Are there sufficient extension boxes	
– Are screed, tamper bars, spreader screws in good condition	
– Does extension form a continuation of main screed unit without steps	
– Are tamper bars and screed correctly set relative to each other	
– Do extensions to spreader screws attach tightly to main section	
xvi. Are screed heater burners working properly	
xvii. Does screed control at working platform work correctly	
xviii. Attachments	
– Are side cut off plates free to move	
– Is joint matcher securely attached to chassis	
– Is joint matcher in good condition	
– Is mounting for travelling straight edge securely attached to chassis	
– Is travelling straight edge free to slide on its mounting	
– Is travelling straight edge correct length	
– Are shoes on straight edge free to move	
– Is tensioning winch in good condition	
– Is sensor unit working	
– Are tyre pressure and ballast correct	
Note pressure kPa and ballast Specified	
– Are solid tyres on small wheels clean and intact	
– Check for fuel, oil hydraulic leaks	
– Is paver free of leaks	
– Is guide chain arm free to move in chassis	

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Check				Confirm/Reject (Y/N)
2.	Aggregates			
a.	Is there sufficient stockpile area			
b.	Is the material recovered from each stockpile pile uniform			
	Stockpile (Size of aggregate)	Uniform Yes/No	Conformance to design grading	
3.	Hot Storage for Binder			
a.	Is capacity sufficient for the programmed rate of production Capacity t Estimated daily demand t /day			
b.	Are tanks fitted with automatic temperature recording systems			
c.	If a modified binder is to be used, are the blending facilities and methods appropriate to ensure a uniform product with the required properties			
d.	Is heating thermostatically controlled			
e.	Is there a warning system for variation in temperatures			
f.	Is binder circulated in tank and between tank and mixer			
g.	Are supply pipes lagged			
h.	Is there a level indicator			
i.	Are sampling points to specification			
4.	Cold feed bins			
a.	Are methods of controlling rate of feed operating smoothly			
b.	Are these controls accurate			
c.	Are precautions available to prevent spill over			
d.	Is there an adequate warning system if rate of feed alters			
e.	Is there an efficient interlock between cold feed and binder feed			
f.	Are fine aggregate feeds susceptible to arching			
g.	Is there a method of detecting and compensating for variations of moisture in the aggregates			
h.	Has contractor calibrated rates against RPM of belt pulley			
5.	Mixing Plant			
a.	Is rated capacity sufficient for the programmed rate of laying Rate Capacity.....t/h Required Capacity.....t/h			
b.	Are the proposed heating fuel and burners compatible			
c.	Is the method of control of the fuel/air mixture adequate			
d.	Are burners clean and nozzles to specification			
e.	Are drum rollers correctly set and in good conditions			
f.	Are drum flights in good conditions			
g.	Are binder spray bar and nozzles clean and in accordance with specification			
h.	Can position of spray bar be altered so as to control filler in mix and can adjustments be easily made			
i.	Method of determining temperatures of binder at plant: Is this adequate and are the results visible to the operator			
j.	Temperature controls of aggregate and final mix: Are these adequate and are the results available to the operator			
k.	Is the plant fitted with suitable filler feed to allow accurate control of the filler content			
6.	Emission Control			
a.	Type:			
				
b.	Is dust collector matched to capacity of mixer			
c.	What method is used to return a portion of the recovered fines to the mix			
d.	What method is used for the disposal of unwanted fines			
e.	Do emissions from the stack comply with Act 45 of 1965 (as amended)			
7.	Buffer Storage			
a.	Is this of adequate capacity			
b.	Is this properly lagged			
c.	Do discharge gates operate smoothly			
8.	Elevator between Mixer and Buffer Store			
a.	Are buckets in good condition			
b.	Are chains and cables in good conditions			

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Check		Confirm/Reject (Y/N)
9.	Steel Wheel Rollers	
	a. Are edges of rollers in good condition	
	b. Is change of direction smooth (no backlash)	
	c. Is roller properly ballasted (Record mass and position)	
	Mass..... t Position.....	
	d. Do wheel spray bars give a uniform cover on wheels	
	e. Are wheel-cleaning mats in good condition	
	f. Are scrapers in good condition and set	
	g. Check for oil, fuel and hydraulic leaks	
	h. Is roller free of leaks	
	i. Do brakes work	
	j. Is reversing smooth	
10.	Pneumatic Rollers	
	a. Are tyres in good condition	
	i. Is there a variable pressure system for tyre pressure. If so, is it working and is pressure gauge working and visible to driver	
	ii. Are all tyre pressures uniform. Note tyre pressures kPa	
	b. Are rollers properly ballasted (Record mass and position)	
	Roller 1: Mass t Position	
	Roller 2: Mass t Position	
	e. Are spray bars working uniformly	
	f. Are cleaning pads in good condition	
	g. Check for fuel, oil and hydraulic leaks	
	h. Is roller free of leaks	
11.	Hand Tools, etc.	
	a. Straight edge: Is it clean and straight	
	b. Rakes and shovels: Are they clean and in good condition	
	c. Are thermometers available: No. Size	
12.	Haulage Vehicles	
	a. Are the basins clean	
	b. Do tailgates open and close properly	
	c. Are load covers fitted	
	d. Are vehicles free from fuel, oil and hydraulic leaks	
	e. Does tipping gear work	
	f. Registration numbers of vehicles	

4.2 Stone Seals

At the commencement of seal operations, a trial section is required. The minimum road surface, air and aggregate temperature at sunrise, as well as just before the first trial section, and the temperature of the binder in the distributor must be measured and recorded. All requirements should meet the specifications.

For an efficient first trial section, a reasonable length of road section should be sprayed, which should be determined according to the volume of the aggregate in the chip spreader and/or trucks available awaiting discharge into the spreader. The length sprayed must be such that it does not exceed the length that can immediately be covered with the aggregate, to prevent the binder cooling, or starting to break before the application of the aggregate, or acquiring a coating of dust that retards adhesion. This length is approximately 200 to 300 metres.

4.2.1 Binder Application Rate

The following problems with the binder application rate for surfacing seals occur, and can be remedied as suggested:

- **Erroneous binder spray application.** Reject for acceptance, and remedy with remedial action.
- **Single application, under-spray.** Adjust to obtain the correct total volume of binder by applying a second spray, either diluted or undiluted.
- **Minor single spray over-application.** As an interim remedy, blind with fine aggregate. With severe bleeding, the seal must be removed.
- **Double binder spray application.** Under-spraying or over-spraying of the first spray (tack coat) can be corrected with the necessary adjustment in the second spray to obtain the required total volume of binder.

4.2.2 Aggregate Spread Rate

The following corrections to problems in the aggregate spread rates are recommended:

- **Under chipping, i.e., spreading too thin.** Immediately correct by back chipping by hand, followed by rolling.
- **Uneven and/or overspreading.** Brooming is required after the layer of aggregate has been rolled.
- **Under or overspreading of the first trial run.** This normally requires a second trial run, making necessary adjustments to the spreader box opening and/or travelling speed. The total volume (m^3) of aggregate spread divided by the area (m^2) covered by binder sprayed, gives the spread rate in m^3/m^2 . When acceptable, it should be used for the full-scale seal operation.

A checklist for trial sections of stone seals is given in Table 12.



Following Construction Processes

The construction process, as determined and fixed during the trial section, must be regularly checked during construction.

Table 12. Stone Seals Trial Section Checklist

Check	Confirm/Reject (Y/N)
1. Pre-treatment done, waiting periods and QA complete	
a. Crack sealing	
b. Edge break repair	
c. Surfacing patching	
d. Base patching	
e. Functional patching	
f. Rut filling	
g. Texture treatment	
h. Fog spray	
2. Road Surface	
a. Road surface	
b. Is surface to be sealed clean	
c. Is edge line of spray properly demarcated	
d. Vegetation at edges, fine cracks cleared	
e. Surface clean: no dust, mud, droppings, oil, etc.	
3. Spray lanes demarcated with fibre rope	
a. Straight 15 m pinned	
b. Curves 2-3 m pinned	
c. Measured from centre line	
d. Joint positions not under wheel tracks or yellow line (offset 200 mm)	
e. Reinforced paper at transverse joints	
4. Traffic accommodation and safety	
a. Road signs in place	
b. Cones, delineators, barricades positions and spacing	
c. Flagmen	
i.	
ii.	
iii.	
d. Stop-go setup and communications/standby	
e. Safety & protective clothing	
f. Dust control (deviations)	
g. Standby traffic light system	
h. Double traffic on new seal (due to half-width construction)	
5. Weather limitations applicable to binder and seal to be applied	
a. Past 24 hours minimum temperature check	
b. Weather forecast: temperature, rain and wind	
c. Look up	
d. Air temperature	
e. Surface temperature (at different positions)	
f. Aggregate temperature	
g. Wind	
h. Base moisture/existing surface wet?	
6. Aggregate	
a. Clean and uncontaminated	
b. Precoating uniform	
c. Precoating dry	
7. Binder	
a. Has correct binder type been delivered	
b. Is there a manufacturers' certificate	
c. Are there any test results supplied	
d. Date of dispatch of load _____?	
e. Storage period complies with specification	
f. Binder temperature _____ °C complies?	
8. Distributor	
a. Valid certificate Expiry Date _____ < 12 months old	
b. Pump Serial No. _____ : Matches certificate	
c. Spray Bar No. _____ : Matches certificate	
d. Dipstick No. _____ : Matches certificate	
e. Are their oil leaks	
f. Are there binder leaks	

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Check	Confirm/Reject (Y/N)
g. Is spray bar height uniform and correct h. Are nozzles of uniform type i. Are nozzles correctly aligned j. Are fishplates in place at ends k. Is reinforced paper available l. Has tray test been carried out m. Is variation within 5%	
9. Chip Spreader a. Spreader width _____ m Correct? b. Do gates move freely when hopper is loaded c. Does charging hopper move easily across spreader when loaded and on an adverse camber d. Are agitator prongs in good condition e. Are planks available to allow wheels to travel on hot mix f. Are 1 m² canvas sheets available g. Is 15 or 20 kg spring balance available h. Check for fuel and oil leaks. Is spreader free of leaks i. Are rollers of distribution bins worn j. Are conveyor belts in good condition k. Are gates of the bins uniform and adjusted correctly l. During "dry" run is chip application uniform m. During "dry" run is chip application accurate n. Is there a chip spreader on stand by	
10. Steel Wheel Roller a. Are edges of roller in good condition b. Is change of direction smooth (no backlash) c. Is roller properly ballasted (Record mass and position) Roller 1: Mass..... t Position..... Roller 2: Mass..... t Position..... d. Do wheel spray bars give a uniform cover on wheels e. Are wheel cleaning mats in good condition f. Are scrapers in good condition and set g. Check for oil, fuel and hydraulic leaks. Is roller free of leaks h. Do brakes work i. Is reversing smooth	
11. Pneumatic Rollers a. Are tyres in good condition b. Is there a variable pressure system for tyre pressure c. If so, is it working and is pressure gauge working and visible to driver d. Are all tyre pressures uniform Note tyre pressures kPa OK? e. Is roller properly ballasted (record mass and position) Roller 1: Mass..... t Position..... Roller 2: Mass..... t Position.....	
8. Trucks and Loader a. Are there sufficient trucks for production rate b. Are they in good condition; no oil leaks, etc.	
9. Brooms a. Are the rotary brooms in good condition b. If required, is the "Z" broom in good condition c. Is there sufficient labour with hand brooms	

4.3 Crushed Stone Layers

The crushed stone trial section involves assessing the following construction processes, and related material characteristics:

- **Dumping.** The material is brought to the road and dumped at pre-determine intervals. The trial section must assess whether the selected intervals of the dumped material result in the correct layer thickness. Normally, the material dumped allows for 5% excess material, to avoid having a too thin layer and to allow for some spillage along the sides of the layer.
- **Spreading.** The trial section is used to assess the spreading operation and how uniformly the material is spread with the equipment and operators available, and to avoid having irregular spillage along the edge of the road.
- **Watering.** Once the material is spread it is thoroughly wetted while in its loose state. The optimum moisture content for a crushed stone layer is near saturation and it is difficult to retain this moisture content throughout the spreading and compaction processes.
- **Compacting.** When the layer has been thoroughly wetted and spread, compaction procedures are assessed to develop rolling patterns that result in a well compacted layer. The density after such compaction before slushing should be uniformly approximately 94% to 96% of apparent density.
- **Slushing.** When the layer has been compacted, watering is continued and slushing commences. The trial section is used to assess what it takes to wet the material thoroughly, and how easily it compacts to the specified density without over-slushing the layer and it starting to loosen up again. The visual appearance of the typical stone-on-stone mosaic pattern achieved must be carefully assessed, and agreed upon for the remainder of the project.
- **Drying.** The moisture content of layer must be assessed throughout its depth to determine how quickly it dries out, and when it can be primed. Obviously this depends on the weather, but it is useful to know the minimum number of days it takes before the material has dried sufficiently to be primed.
- **Testing.** Various tests are carried out on the final layer to assess how well it complies with the specified requirements. These include:
 - **Density.** The trial section provides an opportunity to assess the consistency of the Apparent Density (AD), and how consistently the compaction requirements are met. Any density outliers must be carefully assessed to determine the causes.
 - **Grading.** The grading of the material in its compacted state must be compared with the specified requirements and with the grading of the material as delivered. In this way, how many fines are typically washed out in the slushing process as well as any material breakdown during compaction is assessed.
 - **Plasticity Index (PI).** The plasticity of the compacted material is also measured and compared to the specification and the PI of the material as delivered. If any high PI's, or major changes in PI occur, these should be investigated further.
- **Review of the Results.** The trial layer and test results are reviewed in a technical meeting to assess whether the constructed section conforms to the specifications. If not, another trial section must be constructed with new procedures, to assess whether any changes can produce the required result.

A checklist for trial sections of crushed stone layers is given in Table 13.

Table 13. Crushed Stone Base: Checklist for Site Operations

Check	Confirm/Reject (Y/N)
1. Before Start of Activities	
a. Confirm material quality and properties with laboratory before placing on site	
b. Confirm water quality to be used during mixing	
c. Confirm correct grading as per specification	
d. Inspect underlying surface to be in good condition and not damaged either mechanically or by rain	
e. Inspect dumped material on preparatory section for any deleterious material	
f. Inspect layer and evaluate effectiveness of pre shaping, i.e., quantities vs layer thickness required (Refer to COLTO Section 3200 for preparation of material)	
g. Check temperature and wind speed for current and forecast conditions	
h. PPE equipment (masks, gloves, shoes, protection wear) available?	
2. Processing	
a. Ensure and evaluate moisture content of mixed material (preferably 1 or 2% over OMC)	
b. Confirm correct compaction equipment on site (grid, smooth and 3-point roller/oscillating roller)	
3. Compaction	
a. Check density as compaction increases	
b. Monitor compaction process to avoid under or over compaction	
c. Monitor compaction process to avoid under or over vibrating material	
4. Slushing	
a. Check slushing equipment for condition and effectiveness	
– Rotary Broom	
– Smooth drum roller	
– Water cart (spreading ability)	
b. Monitor slushing sequence and process as described in COLTO Section 3604(c)	
c. Inspect finished surface for tight fit closely knit mosaic pattern, free from excess fines	
d. Inspect surface to check rolled smoothly and not rolled out of shape	
e. Sample final surface after slushing for Indicator tests (grading and PI) and ARD (Apparent Relative Density)	
f. Carry out density testing at 50 mm intervals and record	
5. Curing and Finishing	
a. Take levels on completed surface and evaluate against specification	
b. Check density obtained against specification	
c. Check grading against specified target grading and grading envelope, refer to COLTO Table 3602/4	
d. Approve or reject layer accordingly, as per statistical judgement plan	
e. Monitor layer drying process (should be 50% below OMC at 100 mm depth)	
f. Record moisture contents before applying prime	
6. Trial Sections	
a. The above steps should be followed prior to production processing as part of a trial section	
b. During production mixing, the same checking procedures as above should be applied	

4.4 Cementitious Stabilized Layers

During laying of a trial section of a stabilized layer, the following aspects must be assessed.

- **Gravel Material.** Materials used in stabilized layers are often not very uniform and not well graded. The finer and more variable the material, the more problematic it is to construct a uniform strong layer. Therefore, the trial section should involve some of the more difficult materials to assess how well the equipment and procedures work with the materials. There should be sufficient fines in the material to facilitate the growth of the cementitious bonds throughout the stabilized material.
- **Stabilizer.** The stabilizer needs to be uniformly spread over the surface of the layer to be stabilized, to ensure a uniform transverse and longitudinal distribution of stabilizer. After spreading, various measurements of the thickness of the stabilizer should be made to assess uniformity and to ensure a good result is achieved.
- **Mixing.** The stabilizer should be mixed uniformly through the length, breadth and depth of the layer without any unstabilized loose layers at the bottom. Various test holes must be dug through the loose mixed material and visually assessed for uniformity. Any visual non-uniformities are an indication of more severe uniformities that cannot be detected visually, and mixing must continue until a uniform result is achieved, or alternatively, different equipment and techniques used to produce the required result. The procedures required to achieve the required result must be monitored and noted for future reference.
- **Watering.** Cementitious stabilized layers must be compacted within only a few hours of adding the stabilizer and water. Therefore, all mixing, watering and compaction equipment must be of good quality and capable of producing the result in the required time.
- **Compacting.** When the stabilizer and water is uniformly mixed with the material, and the layer has been trimmed to the required level, compaction commences. The rolling procedures and number of coverages are monitored to assess when to stop compacting, and how uniformly the layer is compacted.
- **Testing.** Finally, the completed layer is tested for:
 - **Density.** The density of the layer is measured and compared to the reference density. This should preferably be done as soon as possible after construction. Measurements taken after 48 hours typically cannot be referenced to the original maximum dry density (MDD), and a new reference density must be determined. This is undesirable because the cementitious bonds are broken.
 - **Uniformity of stabilizer and moisture.** The amount and uniformity of stabilizer and moisture in the top, middle and bottom of the layer, and over the length and width of the layer, must be assessed through testing.
- **Review of the Results.** The observations, tests and results from the trial section must be discussed in a technical meeting, to assess any issues and decide on the procedures to be followed in future. Criteria for constructing another trial section also need to be decided.

A checklist for trial sections of cementitious stabilized layers is given in Table 14.

Table 14. Chemical Stabilization: Checklist for Site Operations

Check	Confirm/Reject (Y/N)
1. Before start of activities	
a. <i>Inspect layer and evaluate effectiveness of pre shaping, i.e., quantities vs layer thickness required. (Refer to COLTO Section 3200 for preparation of material)</i>	
b. <i>Material is damp</i>	
c. <i>All oversize material is removed or crushed to maximum size required</i>	
d. <i>Pre shaped material in a fairly smooth ride able condition</i>	
e. <i>Check temperature and wind speed for current and forecast conditions</i>	
f. <i>PPE equipment (masks, gloves, shoes, protection wear) available</i>	
2. Before spreading of stabilizer (pockets)	
a. <i>Confirm cement quality and type of cement specified</i>	
b. <i>Count pockets against square meter vs percentage stabilizer required i.e., $L \times W \times D \times MDD \times \% \text{stabilizer} \times \text{compaction required} = \text{kg/m}^3$ (divide by 50 = pockets required)</i>	
c. <i>Count pockets per m^2 after spacing at correct intervals</i>	
3. Before spreading of stabilizer (mechanical spreader)	
a. <i>Collect and inspect weighbridge ticket from spreader supplier</i>	
b. <i>Check pressure gauges on spreader tanks at required setting</i>	
c. <i>Place square metre mats at pre-determined intervals to weigh the cement after spreading</i>	
d. <i>Check hand scale for correctness and calibration before use</i>	
4. During stabilization	
a. <i>Check speed of spreader during application by mechanical spreader by weighing each mat against calculated weight cement content</i>	
b. <i>Check type of compaction equipment and mixing equipment for suitability and effectiveness</i>	
c. <i>Ensure laboratory is notified for taking UCS, MDD and Indicator samples</i>	
d. <i>Monitor specified mixing time against type of stabilizer (see COLTO Table 3503/1)</i>	
e. <i>No traffic allowed on freshly compacted surface</i>	
5. Compaction	
a. <i>Do nuclear tests to determine density (including calibration of testing equipment)</i>	
b. <i>Sample material for laboratory testing before final compaction</i>	
6. Finishing and curing	
a. <i>Take levels on completed surface and evaluate against specification</i>	
b. <i>Check curing method applied and ensure constant moist surface to avoid carbonation</i>	
c. <i>Check density obtained from nuclear gauge against specification and specified statistical judgement plan</i>	
d. <i>Check laboratory obtained strengths for UCS and ITS</i>	
e. <i>Check Indicator test results obtained from laboratory against specification and specified statistical judgement plan</i>	
f. <i>Approve or reject layer accordingly</i>	

4.5 Bitumen Stabilized Materials

Trial sections for Bitumen Stabilized Materials are discussed in great detail in TG2. The following checklists for BSMs are provided:

- In situ recycling with BSM: typical checklist (Table 15)
- In situ recycling
 - Foamed bitumen (Table 16)
 - Bitumen emulsion (Table 17)
- In plant treatment: foamed bitumen (Table 18)

Table 15. In Situ Recycling with BSM: Checklist

Check		Confirm/ Reject (Y/N)
1.	Recycler <i>a. Is recycler model appropriate for depth to be worked (Manufacturers limits)</i> <i>b. Is recycler in good condition</i> <i>c. Is the drum fitted appropriate for recycling</i> <i>d. Are all picks in good condition and present</i>	
2.	Tankers <i>a. Does tanker have the correct stabilizer</i> <i>b. Are there sufficient water tankers for production rate</i> <i>c. Do bitumen tankers contain the correct grade of bitumen/emulsion</i> <i>d. Are they fitted with dipsticks</i> <i>e. Is binder at correct temperature (Temperature.....°C)</i> <i>f. Are supply pipes properly lagged</i> <i>g. Are all pipes fully "bled"</i>	
3.	Steel Wheel Rollers <i>a. Are edges of rollers in good condition</i> <i>b. Is change of direction smooth (no backlash)</i> <i>c. Are rollers properly ballasted</i> (Record mass and position) <i>d. Do rollers have variable amplitude/frequency settings</i> <i>e. Settings used for trial:</i> Passes No. () Amplitude () Passes No. () Frequency () <i>f. Are wheel cleaning mats in good condition</i> <i>g. Are scrapers in good condition and set</i> <i>h. Check for oil, fuel and hydraulic leaks</i> <i>i. Do brakes work</i> <i>j. Is reversing smooth</i>	
4.	Pneumatic Rollers <i>a. Are tyres in good condition</i> <i>b. Is there a variable pressure system for tyre pressure</i> <i>c. If so, is it working, and is pressure gauge working and visible to driver</i> <i>d. Are all tyre pressures uniform</i> Note tyre pressures kPa <i>e. Is roller properly ballasted (record mass and position)</i> Mass.....t Position.....	
5.	Process <i>a. Are the number of cuts for the total width defined</i> <i>b. Is the width of overlap for each longitudinal joint defined</i> <i>c. Is the length of cut (i.e., when train should return for adjacent cut) defined</i> <i>d. Is there sufficient volume of imported material for planned production</i> <i>e. Is there sufficient bitumen/emulsion for planned production</i> <i>f. Is there sufficient water for planned production</i> <i>g. Is outer edge of 1st cut clearly demarcated</i> <i>h. To ensure correct grading has rotation speed of drum been defined</i> RPM _____ <i>i. To ensure correct grading has forward speed of recycler been defined</i> m per minute _____ <i>j. Is moisture content of recycled material as per spec</i> mc _____ % <i>k. Is application of cement in front of train as per spec</i> kg/m ² _____ <i>l. Is grading of milled material similar to "design material"</i> <i>m. Is depth of cut on both sides of drum uniform as per spec</i> <i>n. Is final product completed within the allowable time period</i> _____ hours	

Table 16. In Situ Recycling: Foamed Bitumen Checklist

Pre-Start Checklist		Confirm/ Reject (Y/N)
1.	Recycler (Start of shift) <i>a. Check the bitumen system heaters are operational</i> <i>b. Check the temperature of the road surface (digital thermometer)</i> <i>c. Check that the foam-water tank is full</i> <i>d. Remove and clean the foam-water filter</i> <i>e. Remove and clean the bitumen filter</i> <i>f. Lift machine / lower drum / open chamber doors for visual inspection</i> <i>Check: all foamed bitumen nozzles clear</i> <i>all water injection nozzles clear</i> <i>g. Check each expansion chamber for blockages using "pre-water" function</i> <i>Switch #</i> 1 2 3 4 5 6 7 <i>Nozzle #</i> 1 & 3 2 & 4 5 & 7 6 & 8 9 & 11 10 & 12 13 & 15 <i>Note any blockages:</i> <i>h. Obtain loading / weighbridge certificate for bitumen tanker</i> <i>i. Calculate cut lengths / finalise cut plan (with the operator)</i> <i>j. Reset the on-board computer, enter data and check</i> <i>Density</i> <i>Cut depth</i> <i>Application width</i> <i>Bitumen application rate</i> <i>Foam water</i>	
2.	Setting up the Recycling Train (Each new cut / tanker load) <i>a. Check cut guideline and position recycler on first cut</i> <i>b. Check bitumen temperature in tanker (loading hatch)</i> <i>c. Check bitumen tanker for leaks. Crack valve, check for cold plug</i> <i>d. Check water tanker is full and free of leaks</i> <i>e. Couple up bitumen tanker and bleed air from system</i> <i>f. Check that the bitumen foams using test nozzle</i> <i>g. Couple up water tanker and bleed air from system</i> <i>h. Check all supply lines and feed pipes for leaks</i> <i>i. Confirm cut plan / check computer settings & nozzle closure</i> <i>j. Check solenoid lights controlling spray bars / nozzle closure</i> <i>k. Close front & rear doors. Lower recycling drum to cut depth</i> <i>l. Lift drum and measure temperature of material on cut face</i> <i>m. Roller in place, drivers ready. Level control team standing by</i>	

Table 17. In Situ Recycling: Bitumen Emulsion Checklist

Pre-Start Checklist		Confirm/ Reject (Y/N)
1.	Recycler (Start of shift) <i>a. Check the bitumen emulsion system has been flushed.</i> <i>b. Check the temperature of the road surface (digital thermometer)</i> <i>c. Lift machine / lower drum / open chamber doors for visual inspection</i> <i>Check: all bitumen emulsion nozzles clear</i> <i>all water injection nozzles clear</i> <i>d. Obtain loading / weighbridge certificate for bitumen tanker</i> <i>e. Calculate cut lengths / finalise cut plan (with the operator)</i> <i>f. Reset the on-board computer, enter data and check</i> <i>Density</i> <i>Cut depth</i> <i>Application width</i> <i>Emulsion application rate</i> <i>(percentage emulsion)</i>	
2.	Setting up the Recycling Train (Each new cut / tanker load) <i>a. Check cut guideline and position recycler on first cut</i> <i>b. Check emulsion temperature in tanker (loading hatch)</i> <i>c. Check emulsion tanker for leaks. Crack valve, check flow</i> <i>d. Check water tanker is full and free of leaks</i> <i>e. Couple up emulsion tanker and bleed air from system</i> <i>f. Couple up water tanker and bleed air from system</i> <i>g. Check all supply lines and feed pipes for leaks</i> <i>h. Confirm cut plan / check computer settings & nozzle closure</i> <i>i. Check solenoid lights controlling spray bars / nozzle closure</i> <i>j. Close front & rear doors. Lower recycling drum to cut depth</i> <i>k. Lift drum and measure temperature of material on cut face</i> <i>l. Roller in place, drivers ready. Level control team standing by</i>	

Table 18. In Plant Treatment: Foamed Bitumen Checklist

Pre-Start Checklist		Confirm/ Reject (Y/N)												
1.	Mixing Plant (Start of shift) a. Check the bitumen system heaters are operational b. Check the temperature of the material stockpiles c. Check that the water tank is full d. Remove and clean the foam-water filter e. Remove and clean the bitumen filter f. Aggregate feed bins. Check for material packing / blockages Bin # 1. Material: _____ Setting _____ Bin # 2. Material: _____ Setting _____ g. Check the active filler bin and auger feed system h. Open pugmill hatch and visually inspect for blockages Check: all foamed bitumen nozzles clear all water injection nozzles clear i. Check each expansion chamber for blockages using "pre-water" function Nozzle # <table border="1" style="display: inline-table; vertical-align: middle;"><tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr></table> Note any blockages: j. Obtain loading / weighbridge certificate for bitumen tanker k. Check delivery conveyor is clean and running free l. Reset the computer, enter data and check Material density <table border="1" style="display: inline-table; vertical-align: middle;"><tr><td> </td></tr></table> Active filler <table border="1" style="display: inline-table; vertical-align: middle;"><tr><td> </td></tr></table> Application rate <table border="1" style="display: inline-table; vertical-align: middle;"><tr><td> </td></tr></table> Bitumen application rate <table border="1" style="display: inline-table; vertical-align: middle;"><tr><td> </td></tr></table> Foam water <table border="1" style="display: inline-table; vertical-align: middle;"><tr><td> </td></tr></table>	1	2	3	4	5	6	7						
1	2	3	4	5	6	7								
2.	Setting up the Plant for Mixing (Each new batch / tanker load) a. Check bitumen temperature in tanker (loading hatch) b. Couple up bitumen tanker and bleed air from system c. Check that the bitumen foams using test nozzle d. Water supply. Open valves and bleed air from system e. Check all supply lines and feed pipes for leaks f. Check ancillary plant and equipment is ready for mixing													

4.6 Concrete Pavements

Research has shown that in the majority of cases, areas of premature failures on concrete pavements can be attributed to poor workmanship or construction related problems. A very high and continuous level of supervision and quality of batching, as well as placing operations, is, therefore, necessary to eliminate the risk of premature failures.

Trial sections on concrete pavements, therefore, form a very important part of the proactive approach to quality control. Any problems with mix sensitivity, constructability, uniformity of product properties and surface finish and smoothness can be identified timeously and, thus, corrected prior to commencement of the permanent works. It is, therefore, important that a high level of monitoring, including data recording and testing, is carried out by the supervisory staff, especially during the trial. A successful trial is the reference against which the permanent work should be compared and ultimately accepted.

There are various types of concrete pavements of which jointed unreinforced, jointed reinforced and continuously reinforced pavements are the most commonly constructed in South Africa. See Chapter 2: 2.4 or Chapter 9: 12.2.2 for illustrations of the different pavement types.

Each specific pavement and product type has its own unique requirements for trial section procedures. It is very important to ensure that the condition and settings of equipment, as well as construction procedures and techniques utilised for the construction of the approved trial section, remain constant throughout construction of the permanent works.

The following typical tests are required to monitor properties of the concrete materials, to ensure the concrete in the pavement complies with the quality standards.

- **Aggregate grading:** A grading analysis of the sand should be made on at least each 100 m³ of sand used. An additional analysis should be carried out at any time that a change in the sand, or, in the workability of the mix is apparent.
- **Moisture content of fine aggregate:** The moisture content of fine aggregate should be determined at the beginning, and halfway through each concreting shift, after showers or rain, or at other intervals as required.
- **Slump of concrete:** Slump testing should be carried out on the same sample of concrete from which 7 and 28 day compressive strength specimens are manufactured, and at such times or intervals as required.
- **Air content:** Air content testing should be performed on the same sample of concrete from which the compressive strength specimens are manufactured, and at such times and intervals required.
- **Compressive strength of concrete:** Two samples for compressive strength tests should be taken from at least every 100 m³ of concrete placed. From each sample of concrete, a group of not less than six test cubes is made for testing. Three of these cubes are to be tested at seven days and three at 28 days.
- **Flexural strength of concrete:** The flexural strength of the concrete should be monitored regularly. Three flexural strength specimens are to be made from each sample taken for testing, and tested at 28 days.

The selection of the contractor with the most appropriate construction plant and paving techniques, together with the consistent application thereof, plays as important a role in the ultimate performance of the pavement as the selection and utilisation of appropriate materials of uniform quality.

A checklist for trial sections of concrete pavements is given in Table 19.

Table 19. Concrete Paving Trial Checklist

Check	Confirm/Reject (Y/N)
1. Aggregates	
a. Do aggregate sizes conform to that approved in the design	
b. Have stockpiles been constructed correctly	
c. Are materials in stockpiles of uniform grading and quality	
d. Is moisture content of fine aggregate stockpile consistent	
2. Cement	
a. Is the correct cement stored in silo	
b. Are test certificates available	
c. If cement extenders are used, is the method of blending approved	
3. Admixtures	
a. Does the admixture conform to the specifications	
b. Is the admixture being stored correctly	
c. If required, is the admixture agitated prior to use	
4. Batch Plant	
a. Is the batch plant clean and in good working order	
b. Are bins for storing aggregate separated adequately to avoid contamination	
c. Have concrete slabs at base of bins been constructed according to the requirements to avoid contamination	
d. Have the batch plant scales been checked and calibrated	
Certificate of Calibration	
e. Has the accuracy of the scales been checked under dynamic conditions	
Weigh full batches on weigh bridge and compare to batch plant print out	
f. Do dials or digital read out return to zero after discharge of each batch	
g. Do mixing blades have less than 10% wear	
h. Is water-metering system accurate	
i. Is admixture dispenser operating correctly and accurately	
j. Does size of batch and speed of rotation comply with manufacturers specifications	
k. Is mixing time adequate to ensure a homogenous mix	
m. Are bins of trucks clean and are correct protection measures in place during transport	
5. Supporting Substrate Layer	
a. Has the layer been wetted for a minimum of 1 hour before paving	
b. Is the substrate surface clean of all debris and free water	
c. Is there evidence of heaving in the layer	
d. Has the layer been fully accepted according to specified criteria	
6. Slipform Paving	
a. Is paver in good condition with no oil leaks	
b. Are power tracks clean	
c. Are guide wires staked firmly in ground	
d. Has position and level of guide wires been checked	
e. Is track path clean, firm and level	
i. Are sufficient canopies available for protection of paved concrete	
7. Side Form Paving	
a. Are paving machines in good condition with no oil leaks	
b. Are side forms clean and in good repair	
c. Are form faces perpendicular to the base	
d. Are forms true to line and level	
e. Are forms true in all directions (< 3 mm in 3 m)	
f. Are locks securely fastened	
g. Are forms fixed securely to substrate	
h. Is packing placed under forms adequate, and is mortar (1:3 cement/sand) packing flush with inside face	
i. Have forms been oiled immediately prior to concrete placement	
j. Are sufficient canopies available for protection of placed concrete	
8. Tie Bar Inserters	
a. Are bars of correct diameter and length	
b. Are inserters set at the correct distances from edge of pavement	
c. Are the inserters set to the correct depth	
d. Are there sufficient stocks available	
9. Dowel Bar Inserters	
a. Are the dowels of correct diameter and length	
b. Are the dowels clean with sleeves properly fitted	
c. Are the inserters set for the correct position and depth	
d. Is there any excessive movement or lifting off the rails by the inserter during placement	

Check	Confirm/Reject (Y/N)
<i>e. Are the inserted dowels, after compaction, within the allowable tolerances with regards to alignment</i> <i>– parallel to the finished surface</i> <i>– to the centre line of the carriageway</i> <i>– to each other</i>	
10. Finishing, Texturing and Curing	
<i>a. Does the burlap drag conform to specification</i>	
<i>b. Do the metal grooving tines conform to specifications</i>	
<i>c. Are random spacings of tines set correctly</i>	
<i>d. Is depth of texturing within specified tolerances</i>	
<i>e. Are spray nozzles for curing compound clean</i>	
<i>f. Are adequate protection measures available for spraying during windy conditions</i>	
<i>g. Has the correct curing compound been supplied</i>	
<i>h. Can the curing compound be continuously agitated during spraying</i>	

4.7 Block Pavements

A checklist for the construction of block paving trial sections is given in Table 20.

Table 20. Block Paving Trial Checklist

Check	Confirm/Reject (Y/N)
1. Formation to receive paving	
<i>a. Levels</i>	
<i>b. Area (particularly width)</i>	
<i>c. Soft spots</i>	
<i>d. Root growth requiring removal</i>	
<i>e. Smoothness</i>	
<i>f. Compaction</i>	
<i>g. Services needing protection</i>	
2. Kerbing	
<i>a. Excavation</i>	
<i>b. Levels</i>	
<i>c. Alignment</i>	
3. Bedding sand	
<i>a. Right type</i>	
<i>b. Grading</i>	
<i>c. Pre-compaction prevented</i>	
<i>d. Protection: Rain</i>	
<i>Strong winds</i>	
<i>e. Thickness before compaction</i>	
4. Laying	
<i>a. Main axis of laying</i>	
<i>b. Laying pattern</i>	
<i>c. Infill blocks</i>	
<i>d. Primary compaction</i>	
<i>e. Joint sand: Right type</i>	
<i>Grading</i>	
<i>f. Pre-compaction levels and smoothness</i>	
<i>g. Secondary compaction</i>	
<i>h. Damaged blocks</i>	
<i>i. Finished levels</i>	
<i>j. Joint widths</i>	
<i>l. Tidy up site</i>	

5. PRODUCTION RATES

To facilitate scheduling and an understanding of the rate at which construction can occur, Table 21 contains a list of typical production rates. These rates are given purely for illustrative and estimated programming purposes. The actual rates of production are obviously very dependent on numerous factors, such as:

- Capacity of the relevant batching plants
- Distance from source
- Traffic accommodation constraints
- Restricted access

Table 21. Typical Production Rates

Construction Process	Typical Production Unit (per day)
Single seal	10 000 – 20 000 m ² (full width)
Double seal	10 000 – 12 000 m ² (½ width)
Asphalt surfacing	350 – 400 tons
Asphalt Base	400 – 600 ton
G1 base	2 500 – 3 000 m ²
BSM base	3 000 – 4 000 m ²
Cemented subbase	3 000 – 4 500 m ²
Natural gravel layers	4 000 – 5 000 m ²
Waterbound macadam (hand placed)	400 m ²
Prime/tack	15 000 – 50 000 m ²
Concrete	
– JRCP (220 mm hand placed)	420 m ²
– CRCP (180 mm hand placed)	480 m ²
UTFC	6000 - 8000 m ² (400 tons)

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TRH Revisions

Many of the TRH guideline documents are in the process of being updated. See the SANRAL website, www.nra.co.za for the latest versions.

- WIRTGEN. 2004. **Manual for the Application of Cold Milling Machines.** Wirtgen GmbH. Windhagen, Germany. (Available for download at www.wirtgen.de)
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- WIRTGEN. 2010. **Wirtgen Cold Recycling Technology.** 3rd Edition. Wirtgen GmbH. Windhagen, Germany. ISBN 3-936215-05-7. (Available for download at www.wirtgen.de)

CHAPTER 12: CONSTRUCTION EQUIPMENT AND METHOD GUIDELINES

APPENDIX

Nuclear Density Meter Checklist
Asphalt Paving Trial Section Checklist
Stone Seals Trial Section Checklist
Prime Checklist
Crushed Stone Base Checklist for Site Operations
Chemical Stabilisation Checklist for Site Operations
In Situ Recycling with BSM Checklist
In Situ Recycling with Foamed Bitumen Checklist
In Situ Recycling with Bitumen Emulsion Checklist
In Plant Treatment with Foamed Bitumen Checklist
Concrete Paving Trial Checklist
Backfill to Structures Checklist
Gabions Checklist
Earthworks Cut Checklist
Drainage Pipes Checklist
Concrete Side Drains Checklist

NUCLEAR DENSITY METER CHECKLIST		Doc No:	
		Rev No:	
		Date:	
Project: _____		Contract No: _____	
Check		Confirm/ Reject (Y/N)	
1.	Has the operator proved capable of operating the instrument and is acquainted with all the safety precautions?		
2.	Confirm the log-book has been completed every time the gauge has been, and is, removed from its storing facility.		
3.	All transport radiation labels are placed on the transport vehicle when transporting the gauge.		
4.	The gauge source is locked in the shielded or off position.		
5.	The emergency procedures in case of an accident and the relevant emergency telephone numbers are available.		
6.	The shutter mechanism is thoroughly cleaned.		
7.	The battery is fully charged.		
8.	The gauge is locked in its shipment box when not in use.		
9.	The following documents are with the gauge: <i>a. Monthly standard counts log-book</i> <i>b. Operational manual</i> <i>c. Compliance certificate (12 months)</i> <i>d. Leak test results (certified)</i> <i>e. Authorisation to operate the nuclear gauge</i> <i>f. Authority to possess a nuclear gauge issued by the Department of Health</i>		
10.	The following must be carried out before the operation of any count: <i>a. Gauge is in the correct test mode.</i> <i>b. All offsets have been disabled.</i> <i>c. Correct depth measurement has been selected.</i> <i>d. Correct time duration of the count has been selected (4 min. for standard count and 1 min. for field count).</i> <i>e. Material's MDD and OMC are entered into the gauge's memory.</i> <i>f. Area is cordoned off with appropriate signage.</i> <i>g. Gauge is warmed-up for 20 minutes, or according to the manufactures instructions, before operation to allow the regulators and detectors to stabilise. Source rod should be in the "safe" position at all times during the warm-up period.</i>		
11.	Gauge should be at least 10 m away from any other nuclear device, and at least 3 m away from other objects, to prevent external factors influencing the density measurements.		
12.	The following is ensured during pre-drilling of the hole to accommodate the source probe and during insertion of the source probe into the hole: <i>a. Hole is vertical, or the gauge will not seat properly causing inaccurate test results.</i> <i>b. The pre-drilled hole is 50 mm deeper than the desired depth to be tested.</i> <i>c. The drill rod does not vibrate when it is hammered into the test material.</i> <i>d. The guide plate is seated level on the surface of the test material.</i> <i>e. The source probe or rod rests snugly in the hole before a count is taken.</i>		
13.	The following checks are carried out before commencing with the count: <i>a. All offsets are disabled.</i> <i>b. Correct standard density for the material has been entered.</i> <i>c. Gauge is in the correct mode.</i> <i>d. Correct depth of measurement has been selected.</i> <i>e. Correct time for the duration of the count has been selected.</i> <i>f. Testing is done as soon as possible after final compaction (± 24 hours)</i> <i>g. No testing in rainy or wet conditions, or directly onto water-laden material.</i> <i>h. Surface of the test material is level, smooth and free from voids.</i> <i>i. Shutter mechanism is thoroughly cleaned.</i> <i>j. Handle of the source rod engages properly into the catch position for the different positions of measurements.</i> <i>k. Bottom of the gauge does not stand proud of the level surface of the test area due to excessive wear of the base of the gauge (rocking).</i> <i>l. Only half the counts are received due faulty detector tube, or only one is functioning.</i> <i>m. Detector tubes out of alignment due to excessive bumping of the gauge.</i> <i>n. Voltage low, or voltage module is broken, leading to the incorrect quantity of counts detected by the detector tubes being recorded.</i> <i>o. Incorrect count ratio due to excessive source decay, or standard count determined in a cold state, i.e., gauge not sufficiently warmed-up.</i> <i>p. Source probe or rod depth divisions out of alignment.</i>		
Acceptance/Approval		NAME	SIGNATURE
Client's Rep _____		_____	_____
Contractor's Rep _____		_____	_____

ASPHALT PAVING TRIAL SECTION CHECKLIST		Doc No:	
		Rev No:	
		Date:	
Project: _____		Contract No: _____	
Check		Confirm/Reject (Y/N)	
1. Paver			
a. <i>Truck Pushing Rollers</i>			
i. Clean			
ii. Free Running			
b. <i>Hopper</i>			
i. Are sides reasonably smooth			
ii. Does side tilt mechanism work properly			
iii. Are rubber skirts in good condition			
iv. Do feed control gates work smoothly			
v. Are feed conveyors in good condition			
– Flights			
– Bed (no holes)			
– Chains, conditions and tension			
c. <i>Screed Unit</i>			
i. Are pivots free running			
ii. Are screed plates smooth and flat			
iii. Is bevel on tamper bars to specification			
iv. Are tamper bars straight			
v. Is clearance between tamper bars and screed correct			
Note: Clearance mm, Specified Clearance 0.05..... mm			
vi. Is protrusion of tamper bar below screed correct			
Note: protrusion mm, specified protrusion 0.05 mm			
vii. Is gap between tamper bars and screed clean			
viii. Are crown controls for screed working smoothly			
ix. Is locking system for crown control adequate			
x. Is screed inclination set correctly			
Note: Turnbuckle gauge reading: Actual:..... Specified:.....			
xi. Are augers in good condition and tight on shaft			
xii. Are the centre auger flights reversed			
xiii. Are augers set at correct height: Actual:..... Specified			
xiv. If telescope screed is fitted:			
– Do parts move smoothly			
– Do wings form a smooth continuation of main screed without steps			
– Are spreader screws extensions in good condition			
– Are tamper bar extensions to specification and is clearance between tamper and screed correct			
– Do tamper bar extensions protrude the correct distance below the screed			
xv. If screed is not telescopic:			
– Are there sufficient extension boxes			
– Are screed, tamper bars, spreader screws in good condition			
– Does extension form a continuation of main screed unit without steps			
– Are tamper bars and screed correctly set relative to each other			
– Do extensions to spreader screws attach tightly to main section			
xvi. Are screed heater burners working properly			
xvii. Does screed control at working platform work correctly			
xviii. Attachments			
– Are side cut-off plates free to move			
– Is joint matcher securely attached to chassis			
– Is joint matcher in good condition			
– Is mounting for travelling straight edge securely attached to chassis			
– Is travelling straight edge free to slide on its mounting			
– Is travelling straight edge correct length			
– Are shoes on straight edge free to move			
– Is tensioning winch in good condition			
– Is sensor unit working			
– Are tyre pressure and ballast correct			
Note pressure kPa and ballast Specified			
– Are solid tyres on small wheels clean and intact			
– Check for fuel, oil hydraulic leaks			
– Is paver free of leaks			
– Is guide chain arm free to move in chassis			

ASPHALT PAVING TRIAL SECTION CHECKLIST (2 of 3)			
Check			Confirm/Reject (Y/N)
2. Aggregates			
a. <i>Is there sufficient stockpile area</i>			
b. <i>Is the material recovered from each stockpile pile uniform</i>			
	Stockpile (Size of aggregate)	Uniform Yes/No	Conformance to design grading
3. Hot Storage for Binder			
a. <i>Is capacity sufficient for the programmed rate of production</i>			
Capacity t Estimated daily demand t /day			
b. <i>Are tanks fitted with automatic temperature recording systems</i>			
c. <i>If a modified binder is used, are the blending facilities and methods appropriate to ensure a uniform product with the required properties</i>			
d. <i>Is heating thermostatically controlled</i>			
e. <i>Is there a warning system for variation in temperatures</i>			
f. <i>Is binder circulated in tank and between tank and mixer</i>			
g. <i>Are supply pipes lagged</i>			
h. <i>Is there a level indicator</i>			
i. <i>Are sampling points to specification</i>			
4. Cold feed bins			
a. <i>Are methods of controlling rate of feed operating smoothly</i>			
b. <i>Are these controls accurate</i>			
c. <i>Are precautions available to prevent spill over</i>			
d. <i>Is there an adequate warning system if rate of feed alters</i>			
e. <i>Is there an efficient interlock between cold feed and binder feed</i>			
f. <i>Are fine aggregate feeds susceptible to arching</i>			
g. <i>Is there a method of detecting and compensating for variations of moisture in the aggregates</i>			
h. <i>Has contractor calibrated rates against RPM of belt pulley</i>			
5. Mixing Plant			
a. <i>Is rated capacity sufficient for the programmed rate of laying</i>			
Rate Capacity.....t/h Required Capacity.....t/h			
b. <i>Are the proposed heating fuel and burners compatible</i>			
c. <i>Is the method of control of the fuel/air mixture adequate</i>			
d. <i>Are burners clean and nozzles to specification</i>			
e. <i>Are drum rollers correctly set and in good conditions</i>			
f. <i>Are drum flights in good conditions</i>			
g. <i>Are binder spray bar and nozzles clean and in accordance with specification</i>			
h. <i>Can position of spray bar be altered so as to control filler in mix and can adjustments be easily made</i>			
i. <i>Method of determining temperatures of binder at plant: Is this adequate and are the results visible to the operator</i>			
j. <i>Temperature controls of aggregate and final mix: Are these adequate and are the results available to the operator</i>			
k. <i>Is the plant fitted with suitable filler feed to allow accurate control of the filler content</i>			
6. Emission Control			
a. <i>Type:</i>			
.....			
b. <i>Is dust collector matched to capacity of mixer</i>			
c. <i>What method is used to return a portion of the recovered fines to the mix</i>			
.....			
d. <i>What method is used for the disposal of unwanted fines</i>			
.....			
e. <i>Do emissions from the stack comply with Act 45 of 1965 (as amended)</i>			
7. Buffer Storage			
a. <i>Is this of adequate capacity</i>			
b. <i>Is this properly lagged</i>			
c. <i>Do discharge gates operate smoothly</i>			
8. Elevator between Mixer and Buffer Store			
a. <i>Are buckets in good condition</i>			
b. <i>Are chains and cables in good conditions</i>			

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STONE SEALS TRIAL SECTION CHECKLIST		Doc No:	
		Rev No:	
		Date:	
Project: _____		Contract No: _____	
Check		Confirm/Reject (Y/N)	
1. Pre-treatment done, waiting periods and QA complete			
a. Crack sealing			
b. Edge break repair			
c. Surfacing patching			
d. Base patching			
e. Functional patching			
f. Rut filling			
g. Texture treatment			
h. Fog spray			
2. Road Surface			
a. Road surface			
b. Is surface to be sealed clean			
c. Is edge line of spray properly demarcated			
d. Vegetation at edges, fine cracks cleared			
e. Surface clean: no dust, mud, droppings, oil, etc.			
3. Spray lanes demarcated with fibre rope			
a. Straight 15 m pinned			
b. Curves 2-3 m pinned			
c. Measured from centre line			
d. Joint positions not under wheel tracks or yellow line (offset 200 mm)			
e. Reinforced paper at transverse joints			
4. Traffic accommodation and safety			
a. Road signs in place			
b. Cones, delineators, barricades positions and spacing			
c. Flagmen			
i.			
ii.			
iii.			
d. Stop-go setup and communications/standby			
e. Safety & protective clothing			
f. Dust control (deviations)			
g. Standby traffic light system			
h. Double traffic on new seal (due to half-width construction)			
5. Weather limitations applicable to binder and seal to be applied			
a. Past 24 hours minimum temperature check			
b. Weather forecast: temperature, rain and wind			
c. Look up			
d. Air temperature			
e. Surface temperature (at different positions)			
f. Aggregate temperature			
g. Wind			
h. Base moisture/existing surface wet?			
6. Aggregate			
a. Clean and uncontaminated			
b. Pre-coating uniform			
c. Pre-coating dry			
7. Binder			
a. Has correct binder type been delivered			
b. Is there a manufacturers' certificate			
c. Are there any test results supplied			
d. Date of dispatch of load _____?			
e. Storage period complies with specification			
f. Binder temperature _____ °C complies?			
8. Distributor			
a. Valid certificate Expiry Date _____ < 12 months old			
b. Pump Serial No. _____ : Matches certificate			
c. Spray Bar No. _____ : Matches certificate			
d. Dipstick No. _____ : Matches certificate			
e. Are their oil leaks			
f. Are there binder leaks			
g. Is spray bar height uniform and correct			
h. Are nozzles of uniform type			

STONE SEALS TRIAL SECTION CHECKLIST (2 of 2)

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IN SITU RECYCLING WITH BSM CHECKLIST		Doc No:	
		Rev No:	
		Date:	
Project: _____		Contract No: _____	
Check		Confirm/ Reject (Y/N)	
1. Recycler <i>a. Is recycler model appropriate for depth to be worked (Manufacturers limits)</i> <i>b. Is recycler in good condition</i> <i>c. Is the drum fitted appropriate for recycling</i> <i>d. Are all picks in good condition and present</i>			
2. Tankers <i>a. Does tanker have the correct stabilising agent</i> <i>b. Are there sufficient water tankers for production rate</i> <i>c. Do bitumen tankers contain the correct grade of bitumen/emulsion</i> <i>d. Are they fitted with dipsticks</i> <i>e. Is binder at correct temperature (Temperature.....°C)</i> <i>f. Are supply pipes properly lagged</i> <i>g. Are all pipes fully "bled"</i>			
3. Steel Wheel Rollers <i>a. Are edges of rollers in good condition</i> <i>b. Is change of direction smooth (no backlash)</i> <i>c. Are rollers properly ballasted</i> (Record mass and position) <i>d. Do rollers have variable amplitude/frequency settings</i> <i>e. Settings used for trial:</i> Passes No. () Amplitude () Passes No. () Frequency () <i>f. Are wheel cleaning mats in good condition</i> <i>g. Are scrapers in good condition and set</i> <i>h. Check for oil, fuel and hydraulic leaks</i> <i>i. Do brakes work</i> <i>j. Is reversing smooth</i>			
4. Pneumatic Rollers <i>a. Are tyres in good condition</i> <i>b. Is there a variable pressure system for tyre pressure</i> <i>c. If so, is it working and is pressure gauge working and visible to driver</i> <i>d. Are all tyre pressures uniform</i> Note tyre pressures kPa <i>e. Is roller properly ballasted (record mass and position)</i> Mass.....t Position.....			
5. Process <i>a. Is the number of cuts for the total width defined</i> <i>b. Is the width of overlap for each longitudinal joint defined</i> <i>c. Is the length of cut (i.e., when train should return for adjacent cut) defined</i> <i>d. Is there sufficient volume of imported material for planned production</i> <i>e. Is there sufficient bitumen/emulsion for planned production</i> <i>f. Is there sufficient water for planned production</i> <i>g. Is outer edge of 1st cut clearly demarcated</i> <i>h. To ensure correct grading, is rotation speed of drum defined</i> RPM _____ <i>i. To ensure correct grading, is forward speed of recycler defined</i> m per minute _____ <i>j. Is moisture content of recycled material as per spec</i> mc _____ % <i>k. Is application of cement in front of train as per spec</i> kg/m ² _____ <i>l. Is grading of milled material similar to "design material"</i> <i>m. Is depth of cut on both sides of drum uniform as per spec</i> <i>n. Is final product completed within the allowable time period</i> _____ hours			
Acceptance/Approval		NAME	SIGNATURE
Client's Rep _____		_____	_____
Contractor's Rep _____		_____	_____
Comments:			

IN SITU RECYCLING WITH FOAMED BITUMEN CHECKLIST

Pre-Start Checklist		Supervisor:	
		Date:	
		Machine ID:	
Project:		Contract No:	
Check			Confirm/ Reject (Y/N)
1. Recycler (Start of shift) <i>a. Check the bitumen system heaters are operational</i> <i>b. Check the temperature of the road surface (digital thermometer)</i> <i>c. Check that the foam-water tank is full</i> <i>d. Remove and clean the foam-water filter</i> <i>e. Remove and clean the bitumen filter</i> <i>f. Lift machine / lower drum / open chamber doors for visual inspection</i> <i>Check: all foamed bitumen nozzles clear</i> <i>all water injection nozzles clear</i> <i>g. Check each expansion chamber for blockages using "pre-water" function</i> Switch # 1 2 3 4 5 6 7 Nozzle # 1 & 3 2 & 4 5 & 7 6 & 8 9 & 11 10 & 12 13 & 15 <i>Note any blockages:</i> <i>h. Obtain loading / weighbridge certificate for bitumen tanker</i> <i>i. Calculate cut lengths / finalise cut plan (with the operator)</i> <i>j. Reset the on-board computer, enter data and check</i> Density Cut depth Application width Bitumen application rate Foam water			
2. Setting up the Recycling Train (Each new cut / tanker load) <i>a. Check cut guideline and position recycler on first cut</i> <i>b. Check bitumen temperature in tanker (loading hatch)</i> <i>c. Check bitumen tanker for leaks. Crack valve, check for cold plug</i> <i>d. Check water tanker is full and free of leaks</i> <i>e. Couple up bitumen tanker and bleed air from system</i> <i>f. Check that the bitumen foams using test nozzle</i> <i>g. Couple up water tanker and bleed air from system</i> <i>h. Check all supply lines and feed pipes for leaks</i> <i>i. Confirm cut plan / check computer settings & nozzle closure</i> <i>j. Check solenoid lights controlling spraybars / nozzle closure</i> <i>k. Close front & rear doors. Lower recycling drum to cut depth</i> <i>l. Lift drum and measure temperature of material on cut face</i> <i>m. Roller in place, Drivers ready. Level control team standing by</i>			

IN SITU RECYCLING WITH BITUMEN EMULSION CHECKLIST

Pre-Start Checklist		Supervisor:	
		Date:	
		Machine ID:	
Project:		Contract No:	
Check			Confirm/ Reject (Y/N)
1. Recycler (Start of shift) <i>a. Check the bitumen emulsion system has been flushed.</i> <i>b. Check the temperature of the road surface (digital thermometer)</i> <i>c. Lift machine / lower drum / open chamber doors for visual inspection</i> <i>Check: all bitumen emulsion nozzles clear</i> <i>all water injection nozzles clear</i> <i>d. Obtain loading / weighbridge certificate for bitumen tanker</i> <i>e. Calculate cut lengths / finalise cut plan (with the operator)</i> <i>f. Reset the on-board computer, enter data and check</i> Density Cut depth Application width Emulsion application rate (percentage emulsion)			
2. Setting up the Recycling Train (Each new cut / tanker load) <i>a. Check cut guideline and position recycler on first cut</i> <i>b. Check emulsion temperature in tanker (loading hatch)</i> <i>c. Check emulsion tanker for leaks. Crack valve, check flow</i> <i>d. Check water tanker is full and free of leaks</i> <i>e. Couple up emulsion tanker and bleed air from system</i> <i>f. Couple up water tanker and bleed air from system</i> <i>g. Check all supply lines and feed pipes for leaks</i> <i>h. Confirm cut plan / check computer settings & nozzle closure</i> <i>i. Check solenoid lights controlling spraybars / nozzle closure</i> <i>j. Close front & rear doors. Lower recycling drum to cut depth</i> <i>k. Lift drum and measure temperature of material on cut face</i> <i>l. Roller in place, drivers ready. Level control team standing by</i>			

IN PLANT TREATMENT WITH FOAMED BITUMEN CHECKLIST

Pre-Start Checklist		Supervisor:								
		Date:								
		Machine ID:								
Project:		Contract No:								
Check			Confirm/ Reject (Y/N)							
1. Mixing Plant (Start of shift) <i>a. Check the bitumen system heaters are operational</i> <i>b. Check the temperature of the material stockpiles</i> <i>c. Check that the water tank is full</i> <i>d. Remove and clean the foam-water filter</i> <i>e. Remove and clean the bitumen filter</i> <i>f. Aggregate feed bins. Check for material packing / blockages</i> <i>Bin # 1. Material: _____ Setting</i> <i>Bin # 2. Material: _____ Setting</i> <i>g. Check the active filler bin and auger feed system</i> <i>h. Open pugmill hatch and visually inspect for blockages</i> <i>Check: all foamed bitumen nozzles clear</i> <i>all water injection nozzles clear</i> <i>i. Check each expansion chamber for blockages using "pre-water" function</i> Nozzle # <table border="1" style="border-collapse: collapse; text-align: center;"> <tr> <td style="width: 20px;">1</td> <td style="width: 20px;">2</td> <td style="width: 20px;">3</td> <td style="width: 20px;">4</td> <td style="width: 20px;">5</td> <td style="width: 20px;">6</td> <td style="width: 20px;">7</td> </tr> </table> <i>Note any blockages:</i> <i>j. Obtain loading / weighbridge certificate for bitumen tanker</i> <i>k. Check delivery conveyor is clean and running free</i> <i>l. Reset the computer, enter data and check</i> Material density Active filler Application rate Bitumen application rate Foam water			1	2	3	4	5	6	7	
1	2	3	4	5	6	7				
2. Setting up the Plant for Mixing (Each new batch / tanker load) <i>a. Check bitumen temperature in tanker (loading hatch)</i> <i>b. Couple up bitumen tanker and bleed air from system</i> <i>c. Check that the bitumen foams using test nozzle</i> <i>d. Water supply. Open valves and bleed air from system</i> <i>e. Check all supply lines and feed pipes for leaks</i> <i>f. Check ancillary plant and equipment is ready for mixing</i>										
<u>NOTES:</u> 										

CONCRETE PAVING TRIAL CHECKLIST		Doc No:	
		Rev No:	
		Date:	
Project: _____		Contract No: _____	
Check		Confirm/Reject (Y/N)	
1. Aggregates			
a. Do aggregate sizes conform to that approved in the design			
b. Have stockpiles been constructed correctly			
c. Are materials in stockpiles of uniform grading and quality			
d. Is moisture content of fine aggregate stockpile consistent			
2. Cement			
a. Is the correct cement stored in silo			
b. Are test certificates available			
c. If cement extenders are used, is the method of blending approved			
3. Admixtures			
a. Does the admixture conform to the specifications			
b. Is the admixture being stored correctly			
c. If required, is the admixture being agitated prior to use			
4. Batch Plant			
a. Is the batch plant clean and in good working order			
b. Are bins for storing aggregate separated adequately to avoid contamination			
c. Have concrete slabs at base of bins been constructed according to the requirements, to avoid contamination			
d. Have the batch plant scales been checked and calibrated			
Certificate of Calibration			
e. Has the accuracy of the scales been checked under dynamic conditions			
Weigh full batches on weigh bridge and compare to batch plant print out			
f. Do dials or digital read out return to zero after discharge of each batch			
g. Do mixing blades have less than 10% wear			
h. Is water-metering system accurate			
i. Is add mixture dispenser operating correctly and accurately			
j. Does size of batch and speed of rotation comply with manufacturers specifications			
k. Is mixing time adequate to ensure a homogenous mix			
m. Are bins of trucks clean and are correct protection measures in place during transport			
5. Supporting Substrate Layer			
a. Has the layer been wetted for a minimum of 1 hour before paving			
b. Is the substrate surface clean of all debris and free water			
c. Is there evidence of heaving in the layer			
d. Has the layer been fully accepted according to specified criteria			
6. Slipform Paving			
a. Is paver in good condition with no oil leaks			
b. Are power tracks clean			
c. Are guide wires staked firmly in ground			
d. Has position and level of guide wires been checked			
e. Is track path clean, firm and level			
i. Are sufficient canopies available for protection of paved concrete			
7. Side Form Paving			
a. Are paving machines in good condition with no oil leaks			
b. Are side forms clean and in good repair			
c. Are form faces perpendicular to the base			
d. Are forms true to line and level			
e. Are forms true in all directions (< 3 mm in 3 m)			
f. Are locks securely fastened			
g. Are forms fixed securely to substrate			
h. Is packing placed under forms adequate, and is mortar (1:3 cement/sand) packing flush with inside face			
i. Have forms been oiled immediately prior to concrete placement			
j. Are sufficient canopies available for protection of placed concrete			
8. Tie Bar Inserters			
a. Are bars of correct diameter and length			
b. Are inserters set at the correct distances from edge of pavement			
c. Are the inserters set to the correct depth			
d. Are there sufficient stocks available			

CONCRETE PAVING TRIAL CHECKLIST (2 of 2)

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[illegible]

BACKFILL TO STRUCTURES CHECKLIST	DOC No:	
	REV No:	
	DATE:	

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Project: _____

Contract No: _____

Structure: _____

Date: _____

Element: _____

Inspection No: _____

Drawing No: _____

Quantity (m³): _____

Rev No: _____

Location: _____

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Acceptance/Approval	NAME	SIGNATURE	DATE
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	NAME
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SIGNATURE

	DATE
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Client's Rep: _____

Contractor's Rep: _____

Comments:

GABIONS CHECKLIST

DATE:

Contract No: _____

Date: _____

CH Finish: _____

Inspection Request No.:_____

Revision: _____

ITEMS TO BE CHECKED	CHECKED BY (Initial & Date)			REMARKS
	Contractor	Foreman/ Contractor	Client's Rep	
Correct Drawing Revision or as per RE's instruction				
Gabions: Material and Size-Specification				
Setting out – Alignment/Position				
Setting out – Level				
Excavations				
Gabions Bedding				
Mesh size: 80 mm x 100 mm				
Min wire diameter: 2.7 mm				
Mattresses, Standard size : L=6 m; W=2 m; Depth=0.2 m; 0.3 m or 0.5 m				
Boxes, Standard size: L=1 m, 2 m, 3 m or 4 m; W=1 m; Depth=0.3 m, 0.5 m or 1 m				
Filter Fabric type. Filter fabric to have min 300 mm overlap and to be fastened at joints				
Stone/Rock size: ALD= 125 mm Maximum stone size: 150 x 200 x 250 mm				
Internal horizontal bracing wires at 330 mm vertical centers wrapped around 2 mesh wires at the front and back (4 to every 1 cube of fill)				
Securely wire/lace along all the edges (top, bottom, sides and at diaphragm points) and to all adjacent boxes/mattresses before filling with rocks				
Internal vertical bracing wire @ 330 mm where water falls onto boxes and at mattresses (high water velocity)				
End of lacing wire turned to the inside of the box/mattress				
Vertical facing plumb and straight				
Top level checked				
Backfill/Soilcrete				
Suitable for the next level basket				

DATE _____

[illegible]

EARTHWORKS CUT CHECKLIST

DOC No: _____

REV No : _____

DATE _____

Project: _____

Contract No: _____

Section: _____

Inspection Request No: _____

Chainage: _____

Drawing No: _____

Slopes: _____

Date: _____

ITEMS TO BE CHECKED	CHECKED BY (initial & date)		REMARKS
	Foreman/Site Engineer:	Client's Rep:	
Latest Drawing revision used			
Received approval of disposing materials			
Equipment inspection and approval			
Is protection of services in place			
Survey-natural ground level recorded			
Clear & grub approved			
Stripping of topsoil approved			
Survey: setting out of profiles			
Earthwork cut: Constantly checking cut slopes			
Are undercuts identified			
Temporary drainage: maintenance satisfactory			
Survey payment line measured and recorded			
Formation level			

Acceptance/Approval

NAME

SIGNATURE

DATE

Client's Rep:

Contractor's Rep:

Comments:

DRAINAGE PIPES CHECKLIST

DOC No: _____

REV No: _____

DATE: _____

Project: _____

Contract No: _____

Section: _____

Diameter: _____

Chainage: _____

Orientation: _____

Drawing: _____

Revision: _____

Inspection Request No: _____

Date: _____

ITEMS TO BE CHECKED	CHECKED BY (Initial and Date)			REMARKS
	Sub-contractor	Foreman/ Site Engineer	Client's Rep.	
Latest drawing revision used				
Piping material: Size and state				
Setting out work: Alignment and level				
Permission to excavate received				
Excavate: Correct depth and width				
Compaction of excavation floors				
Density test done on excavation floors (attach lab result)				
Bedding material and thickness				
Check that pipes are free from damage				
Check seating of joints				
Check joint seal; bidum and wrapping				
Check wrapping overlaps				
Check orientation and line				
Check invert levels				
Check connection into inlet and outlet structures				
Repair to lifting holes and release to backfill				
Acceptance/Approval	NAME	SIGNATURE	DATE	
Sub-Contractor's Rep:	_____	_____	_____	
Contractor's Rep:	_____	_____	_____	
Client's Rep:	_____	_____	_____	

CONCRETE SIDE DRAINS CHECKLIST

DOC No:	
REV No:	
DATE:	

Project: _____	Contract No: _____
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Section: _____ Chainage: _____ Drawing: _____ Inspection Request No: _____	Date: _____
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ITEMS TO BE CHECKED	CHECKED BY (Initial and date)			REMARKS
	Sub-contractor	Contractor	Client's Rep.	
Position as per drawing				
Levels checked				
Contraction joints @ 2.5m c/c				
Contact area @ joints painted with bitumen				
Expansion joints @ 30 m c/c				
Excavation compacted to 93% Mod. AASHTO Density				
Reinforcing: Welded steel fabric Ref 311				
Saw cutting of road: Cut to full depth of concrete: _____ mm				
Saw cutting of road: In straight line				
End shutters (traverse shutters) flush with surfacing and back shutter				
Back shutter in straight line				
0.15mm Polyethylene sheeting or invert bitumen emulsion to trimmed excavation surfaces				
Approval obtained from Engineer to cast concrete				
Concrete: Class 30/19				
Concrete: Surface finish U2				
Expansion joints sealed with flexi cell				
Acceptance/Approval	NAME	SIGNATURE	DATE	
Sub-Contractor's Rep:	_____	_____	_____	
Contractor's Rep:	_____	_____	_____	
Client's Rep:	_____	_____	_____	