Cast in place concrete is used in very diverse applications for the construction of road pavement because of numerous advantages i.e.:

- great rigidity and consequently a good distribution of the loads on the foundation and excellent fatigue behaviour,
- great resistance to wear and rutting and edges that do not erode;
- not affected by oil, organic substances, chemicals;
- bright colour, skid resistance and safety in winter;
- environmentally friendly.

Concrete pavements last long too and require little maintenance, at least if they have been designed properly and executed professionally.

If this is not the case, significant premature damage is liable to occur, resulting in high maintenance costs.

Following below, all aspects of the execution of monolithic pavements are discussed. This bulletin is intended to be a reference publication for people who are responsible for the execution of the works and for the supervision of construction.

The evaluation of both older and recent concrete pavements demonstrates time and again how important the quality of the execution is. It requires special attention, both from the contractor executing the works and from the people ensuring that the specifications are complied with.
There are different types of monolithic pavements

I- Plain concrete - short pavement slabs

This type of pavement consists of successive slabs whose length is limited to about 25 times the slab thickness. At present it is recommended that the paving slabs not be made longer than 5 m, even if the joints have dowels to transfer the loads. The movements as a result of fluctuations in temperature and humidity are concentrated in the joints. Normally, these joints are sealed to prevent water from penetrating the road structure. The width of the pavement slabs is limited to a maximum of 4.5 m.

II- Reinforced concrete

II-a Continuously reinforced concrete

Continuously reinforced concrete pavements are characterised by the absence of transverse joints and are equipped with longitudinal steel reinforcement. The diameter of the reinforcing bars is calculated in such a way that cracking can be controlled and that the cracks are uniformly distributed (spacing at 1 to 3 m). The crackwidth has to remain very small, i.e. less than 0.3 mm.

II-b Reinforced pavement slabs

Reinforced concrete pavement slabs are almost never used, except for inside or outside industrial floors that are subjected to large loads or if the number of contraction joints has to be limited.

II-c Steel fibre concrete

The use of steel fibre concrete pavements is mainly limited to industrial floors. However, in that sector they are used intensively. For road pavements steel fibre concrete can be used for thin or very thin paving slabs or for very specific applications.
PREPARATION OF THE SUB-GRADE OR THE BASE

The road subgrade has to be prepared carefully, in order to realize everywhere a pavement structure of an adequate and uniform thickness. This allows to provide a homogeneous bond between the concrete slab and its foundation which is important for the later behaviour of the pavement structure [1].

For roads with a base, drainage of the water must be provided. Mud, leaves, etc. have to be removed [2].

When the base is permeable, it should be sprayed with water in order to prevent the mixing water from being sucked out of the concrete.

However, if the base is impermeable (e.g. if the concrete is placed on a watertight asphalt concrete interlayer) it can be necessary under warm weather conditions to cool down this layer by spraying water on the surface.

The following points are important for roads without a foundation:

- drainage of all surface water;
- good compaction of the subgrade;
- filling and compaction of any ruts caused by construction traffic;
- it is forbidden to level the subgrade by means of a course of sand. If the subgrade has to be levelled, it is advisable to do this by using a granular material: either slag or coarse aggregate e.g. with a grain size 0/20;
- provide an additional width of the subgrade for more lateral support.

It must always be avoided that water is sucked from the cement paste into the substructure or the base. This can be accomplished by either moderately moistening the subgrade, or by applying a plastic sheet on the substructure of the pavement. The latter work must be done with care, to prevent the sheet from tearing or being pulled loose by the wind.

MIXING AND TRANSPORT OF CONCRETE

Note: This bulletin does not deal with the mix composition of the concrete. Yet, this aspect is of utmost importance for a good workability and for the durability of the pavement.

2.1. Concrete mixing plant

The concrete mixing plant [3] must have a sufficient capacity in order to be able to continuously supply concrete to the paving machines. The mix constituents and admixtures have to be dosed very accurately. The number of aggregate feed bins has to equal at least the number of different aggregate fractions. The bins shall have raised edges to prevent contamination of the aggregate fractions. The equipment for loading the materials shall be in good condition and shall have sufficient capacity to be able to continuously feed the bins. The bucket of the loaders shall not be wider than the bins. The content of the cement silos and the water tank are in proportion to the production rates.

For small works, permanent concrete mixing plants are often called on. In that case, mixing plants that are inspected and that can deliver BENOR (Belgian quality certification) concrete should be used.

Furthermore it is useful and even essential to have a communication system between the concrete mixing plant and the construction site in order to coordinate the batching and paving operations.
2.2. Transport of the concrete

Sufficient trucks must be available to continuously supply the paving machines. The number depends on the yield at the construction site, the loading capacity of the trucks and the cycle time (i.e. the transport time plus the time required to load and unload a truck). The loading capacity and the type of truck to be used depend on the nature of the work, the haul roads and the concrete paving machines.

Usually, the specifications prescribe that the concrete has to be transported in dump trucks [4] as paving concrete consists of a relatively dry mix having a consistency that makes transport and unloading in truck mixers difficult. Furthermore, dump trucks can discharge the concrete faster. For small works and in urban areas, the use of truck mixers is increasingly accepted [5]. Under these circumstances an admixture (e.g. a superplastifier) can be mixed in just before discharging the concrete.

The necessary measures have to be taken to prevent changes of the water content and temperature of the concrete during transport. To this end, the specifications prescribe to cover the dump trucks by means of a tarpaulin.

3 | Placing the Concrete

Usually the concrete is placed using slipform paving machines which applies for all categories of roads. This equipment meets both the requirements for quality and for the envisaged rate of production. Conventional concreting trains riding on set up rails, are hardly used any more for roadworks in our country. For this reason this manner of execution will not be dealt with here. However, the technique of manually placing the concrete using forms is still applied in certain cases, such as for the construction of roundabouts with a small diameter, at intersections, for repair work or when the execution conditions are such that slipform pavers cannot be utilized. This occurs increasingly often in urban areas for the construction of pavement surfaces of exposed aggregate and possibly coloured concrete.

3.1. Fixed-form concrete paving

3.1.1. Setting up the side forms

In order to place the side forms [6] properly the alignment of the road has to be staked out carefully. This is usually accomplished by driving iron rods firmly into the subgrade soil or the base at a spacing of maximum 5 m. After the elevations corresponding to the top of the forms have been marked on the rods, they are connected with a stringline that represents the top of the forms. The form sections have to be properly supported on the base at all points. The inner surfaces of the forms shall be installed vertically and on line. In curved areas shorter or bent form sections are used, so as to better match the alignment of the curve.

After the form sections have been properly aligned over a certain distance, they are secured by means of stakes. As the side forms serve as the reference for guiding the vibratory screed, the tolerances for the evenness shall not be exceeded. To accurately place the forms, a rigid template having the same width as the concrete pavement must be available on site, so that it can be checked at any time whether or not the form sections are set up parallel.

The inside surface of the forms should be cleaned and oiled or coated with a form release product, to prevent spalling when the forms are stripped and to facilitate cleaning of the formwork elements before they are used again.

In urban areas, the formwork is often substituted by rows of paving bricks [7]. These are placed on a bed of mortar or concrete with a cement content of at least 350 kg/m³. The rows of paving bricks divide the pavement surface into rectangular sections. They have to be placed a few days before the concrete is cast. If the surface of the stones is uneven, a thin plate is laid on top of them to make the sliding surface for the vibratory screed as smooth as possible.
3.1.2. Equipment

All equipment necessary for executing the paving must be present on site and has to function properly. This concerns primarily: manual needle vibrators and vibrating screed, equipment for floating the concrete surface, for applying the curing compound, for sawing the joints, etc.

The profile of the finishing equipment has to be even, in order to obtain a good final pavement smoothness. To check this, a gauge is placed at each end of the screed to be controlled. Subsequently, a string is tensioned between the two gauges and the distance between the string and the finishing surface of the screed is measured at various points. Another method consists of checking the evenness with a level and levelling rod.

The consolidation equipment has to generate uniform vibrations with the right frequency and amplitude.

3.1.3. Execution

The concrete is supplied by truck mixers or is dumped between the forms and spread with a crane. The drop height of the concrete mix has to be limited and the concrete has to be placed gradually so as to prevent segregation or pre-consolidation. The supply and the placement of the concrete should be synchronized to the same rate, on the one hand to avoid interruptions in the placement of the concrete and on the other hand to avoid that too much time is elapsing between depositing and finishing the concrete. Spraying water on the fresh concrete in order to improve the workability shall be avoided by all means.

The concrete is consolidated with manual needle vibrators and a vibratory screed \([8]\). The consolidation is realized first with the manual vibrators, in particular along the edges and subsequently with the vibratory screed. The freshly placed concrete edges are strutted by the side forms or by adjacent linear elements or existing paving slabs. Especially when the aggregate of the concrete surface is to be exposed later, it is not advisable to carry out manual corrections behind the finishing screed because these can be detrimental for the final homogeneity of the surface. The finishing is completed using a hand float attached to a handle by a double hinge \([9]\).

3.2. Slipform concrete paving

3.2.1. Preparation of the track runway

The quality of the runway for the tracks of the paving equipment \([10]\) is undoubtedly one of the most important factors that contribute to the realization of a smooth pavement surface. In connection therewith, the following criteria have to be met:

- sufficient bearing capacity, so that the slipform paver can proceed without causing deformations;
- good skid resistance to prevent the tracks from slipping, especially when paving on a slope;
- good evenness to avoid that the self-leveling systems have to compensate for excessive differences in height. The track runway is a determining factor for the steering and consequently its surface has to at least as smooth as the concrete paving surface itself. The runway surface has to be permanently cleaned prior to the passage of the tracks.

The track runway has to be wide enough taking into account:

- the greatest width of the paving machine plus an extra width (especially on embankments);
- the necessary space for placing the sensor lines.

Furthermore, if the longitudinal slope is 4 % or more, the track runway has to be stabilised to prevent slipping. In addition to this the tracks can be equipped with plates or hooks or the paving can preferably progress downhill.
3.2.2. Placing the sensor lines

Together with the preparation of the track runways, properly placing the sensor stringlines [11] is one of the most important prerequisites for constructing a smooth pavement surface.

The following recommendations apply:

- if the roadstructure is located on an embankment, install the line support stakes far enough away from the top of the embankment slope in order to achieve sufficient lateral stability;
- only use stakes with adjustable rods and clamps;
- drive the stakes deep enough into the subgrade or the base in order to firmly fasten them;
- respect the proper spacing between the line support stakes:
  - on straight sections of the road a maximum spacing of 7 m;
  - on horizontal curves this distance shall be adjusted according to the rate of curvature in order to match the alignment of the curve as well as possible and to avoid that the sensor is jumping off the wire. Furthermore, the smallest radius of the curve that the machine can realize has to be taken into account;
- avoid deformations in the profile of the pavement surface by adjusting the tension in the stringline in such a way that the line is sagging as little as possible upon its placement and upon sliding of the sensor along the line (lifting or pushing down the line by the sensor). The sag under a mass of 50 g, applied two successive clamps shall not exceed 3 mm. Fluctuations in temperature will make the line expand or contract so that the tension in the line changes. Therefore in hot weather, the line has to be tightened whereas in cold weather it has to be loosened;
- firmly anchor the ends of the stringlines into the subgrade or the base;
- permanently check the setting of the stringlines in order to immediately detect any errors or shifts. Never adjust with a mason’s spirit level or at sight. Any corrections needed must be made utilizing topographic instruments.

3.2.3. Equipment

The principle of a slipform paving machine [12] is the following:

- The machine consists of a frame that is hydraulically supported on two or four tracks.
- The height and direction is regulated by means of sensors and a sensor reference line. The latter consists of:
  - either two sensor lines, one tensioned on either side of the machine,
  - or one sensor line and the adjacent hardened concrete slab,
  - or one sensor line and a cross slope regulator,
  - or the base itself (in this case the hydraulic self-leveling system is blocked);
- Depending on the type, the machine can carry out one or more of the following tasks:
  - spreading of the concrete over the entire working width,
  - vibrating and profiling the concrete,
  - finishing the surface.

In addition to the slipform paver it is useful or even essential to have the following equipment available on the construction site:
• one or more manual needle vibrators to compact the concrete along the transverse or longitudinal construction joints;
• light form sections and attachment stakes to support or to form the concrete if necessary;
• a gangboard just behind the profile pan from which, if necessary, finishing corrections can be made (13).

3.2.4. Execution

The supply of the concrete has to be arranged in such a way that a continuous placement can be guaranteed without detrimental interruptions as each standstill can cause unevennesses. This implies a sufficient capacity of the concrete mixing plant and of the means of transportation of the concrete.

The concrete is discharged:

• either directly in front of the machine, using dump trucks. The concrete must be discharged gradually, in order to limit the drop height. A crane is often necessary, especially for larger working widths, in order to adequately spread the concrete mix, (14);
• or in the bin of a side feeder, for example if transport by dump trucks on the foundation is impossible because of the presence of dowel chairs or reinforcement steel;
• or in a supply container, from which the concrete is scooped with a crane.

It cannot be overemphasised that properly spreading the concrete in front of the slipform paving machine is very important for the final quality of the work, especially with regard to the smoothness. It is of great importance that in front of the slipform paver, a constant and sufficient amount of concrete is available at all times so that a continuous paving process can be guaranteed. The paver should never be used to push the concrete forward.

For large casting widths the concrete is preferably spread either by means of a placer/spreader machine (15) that operates in front of the paver or, by the slipform paver itself (side feeder (16), spreading augers, wagon,…). The use of a placer/spreader, allows the slipform paver to proceed more steadily. The distance between the placer/spreader and the slipform machine has to be kept small enough to limit changes in the water content of the concrete mix.

The paving rate has to match the concrete delivery rate, but the consistency of the concrete and the evenness of the track runways must also be taken into consideration. In practice, the optimum speed of the paving machine lies between 0.75 and 1 m/min. A steady progress of the paving operations without detrimental interruptions guarantees quality, whatever type of machine is used.

All regulating devices of the paving machine have to be tuned before any paving is started. However, this regulation should also be monitored during the entire course of the paving process and adjusted if necessary, so that the concrete pavement is executed correctly: thickness, flawless edges, surface smoothness.

Some machines are equipped with a dowel bar inserter or an anchor bar (also called tie-bar) inserter. Dowel bars are inserted in the fresh concrete down to the correct elevation after the vibrator but before the tamper bar (17). The dowel bar inserter preferably operates in a continuous operation. Every precaution must be taken to place the dowels correctly and not to disrupt the evenness of the concrete surface (composition of the concrete, paving speed, etc.).

The use of a ‘supersmoother’ (longitudinal floating tool) is highly recommended and in some specifications it is even made compulsory whenever a slipform paver is used and especially for pavements for high speed roads. The supersmoother is a beam float suspended from the backside of the slipform machine and that moves back and forth in the longitudinal direction while simultaneously traversing the freshly
finished concrete surface [18]. It allows to eliminate small finishing errors or any remaining high and low spots behind the slipform paver. This improves the driving comfort and limits the nuisance caused by unevennesses with a short wave length (noise, vibrations). Small traces of cement slurry produced after the passage of the supersmoother, are subsequently removed by dragging a section of burlap or a dragplate. The supersmoother can also be used for other road categories, including bicycle paths.

3.2.5. Measures to obtain a good evenness

A good evenness depends primarily on the following factors:

- a concrete mix with an uniform consistency, adapted to the paving machines and the working circumstances,
- a regular supply of concrete and a uniform spreading in front of the paver,
- correct operation of the paving machines, which in turn depends on the setting of the forms or the sensor lines, the quality of the track runways, the regulation of the sensors, etc.,
- steady progress of the paver, without interruptions and with a speed compatible with the consistency of the concrete and the working circumstances,

use of specific tools or equipment to eliminate small bumps after the paving machines: correction beam, supersmoother, etc.

4. EXECUTION OF JOINTS

All the equipment that is necessary to make joints in the fresh or hardened concrete must be present at the construction site.

The saw blades [19] have to be suitable to the quality of the concrete, i.e. to the hardness and the abrasion resistance of the aggregates. It is useful to have spare equipment available in case of a defect.

The beam for making a construction joint shall be rigid and shall allow the realization of a straight joint perpendicular to the axis of the road. This beam has to be adapted to the type of pavement (jointed pavement, continuously reinforced concrete pavement).

4.1. Transverse joints

4.1.1. Contraction joints

Crack onsets are executed to avoid uncontrolled (“wild”) cracking of the concrete by shrinkage [20]. Contraction joints have a crack onset which extends to a depth of one third of the slab thickness and can be equipped with dowels.

On main roads, the contraction joints are usually made by sawing. The saw cutting should occur as soon as possible, usually between 5 and 24 hours after placement of the concrete. It is obvious that the concrete should have hardened sufficiently in order to prevent the edges of the joint from being damaged. In case of high temperatures, special equipment is available to execute saw cutting within 3 hours subsequent to the placement of the concrete. In that case, light equipment is used to make saw cuts of about 2.5 cm deep. Every sawcut that has not instigated a crack within 24 hours is deepened up to 1/3 of the slab thickness.

Making crack onsets for contraction joints in the fresh concrete is a technique that is practically no longer applied except for country roads or municipal roads whenever the traffic intensity and evenness requirements permit so.

To make such a joint, a thin steel blade (no more than 6 mm thick) is vibrated into the fresh concrete to a depth of 1/3 of the slab thickness.

The joint can be made both with flexible and with rigid joint strips. In the first method, a thin plastic strip twice as wide as the depth of the crack point plus 2 cm is laid on the fresh concrete. The steel blade is
1. PREPARATION OF THE SUBGRADE OR THE BASE

1- evenness (*)
2- cleanliness

2. MIXING AND TRANSPORT OF THE CONCRETE

3- concrete mixing plant
4- dump truck
5- truck mixer

3. PLACING THE CONCRETE

(3.2. Slipform)
10- track runway
11- stringlines
12- slipform paver
13- gangboard
14- crane
15- placer/spreader machine
16- side feeder
17- insertion of the dowels
18- super smoother

(4.3. Dowels / tie bars)
25- cracking at the end of the dowels
26- anchoring of the dowel chairs
27- covering of the dowel chairs with concrete
28- marking of the joint

(3.1. Fixed forms)
6- fixed formwork
7- paving blocks
8- poker vibrator
9- floating the concrete surface

30- reinforcement steel
31- reinforcement of a roundabout
32- end-of-day joint

5. PARTICULAR CASE: CONTINUOUSLY REINFORCED CONCRETE

(*) The numbers refer to the pictures

6. SURFACE TREATMENT

33- texture

(6.1. Brooming)
34- manually brooming
35- mechanically brooming

(6.2. Exposed aggregate finish)
36- setting retarding agent
37- manually spraying
38- protection with a plastic sheet
39- brushing
40- high-pressure water jet

(6.3. Pattern imprinted concrete)
41- imprinting pattern
42- view of the finished surface

Execution of concrete pavements
7. PROTECTION OF THE CONCRETE

(7.1. Against drying out)
43- curing compound

(7.2. Against rain)
44- plastic sheet

(7.3. Against frost)
45- insulating plates

(7.4. Against mechanical influences)
46- damaging
47- fencing

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8. SPECIAL MEASURES

48- slope (uphill)
49- slope (downhill)

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9. OPENING TO TRAFFIC

50- rapid repairs

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4. EXECUTION OF JOINTS

19- saw cutting machine

(4.1. Transverse joints)
20- contraction/bending joint (a)
21- expansion joint (b)
22- construction joint (c)

(4.2. Longitudinal joints)
23- contraction/bending joint (d)
24- construction joint (e)

29- sealing of the joint

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positioned in the middle of the strip and is subsequently vibrated into the fresh concrete. In the second method the rigid joint strip is inserted into a groove priorly made by vibrating the steel blade in the concrete. The top of the strip must be flush with the pavement surface.

After having made the crack onset, the concrete surface along the joint should be smoothened again. However, manual corrections should be kept to a minimum as much as possible, since they can cause spalling of the joint edges later.

4.1.2. Expansion joints

Expansion joints [21] are only used exceptionally. In these rare cases, they have to meet the necessary requirements so as not to cause difficulties later.

The execution of expansion joints requires special attention when using slipform paving machines.

Special attention shall be paid to the following:

- the wooden joint filler board shall be firmly attached to the base by means of metal stakes, so that it cannot move while the concrete is being placed;
- the height of the joint filler board shall be slightly (2 to 3 cm) shallower than the thickness of the concrete slab, in order not to hinder the placement of the concrete. As soon as the slipform paving machine has passed, the concrete above the joint filler board shall be removed over a width at least equal to the thickness of the board, so that no “concrete arch” is made at the top of the joint;
- expansion joints shall always be provided with dowels, even for roads with less intense traffic. At one end of each dowel a cap filled with a compressible material accommodates the movements of the concrete.

4.1.3. Construction joints

Construction joints [22] - also called end-of-day or working joints - are made at the end of the daily production or when the paving process is interrupted for at least 2 hours. The face of these joints is plane, vertical and perpendicular to the axis of the pavement. They are always doweled.

Upon resuming the paving the fresh concrete is placed against the concrete that has already hardened. The concrete is consolidated on both sides of the joint with a separate manual needle vibrator.

4.2. Longitudinal joints

Longitudinal joints run parallel to the axis of the road and are only necessary if the pavement is wider than 4.5m. They can be provided with tie bars.

4.2.1. Longitudinal contraction / bending joints

These joints are realised between adjacent concrete lanes that are executed simultaneously [23]. They are sawcut in the hardened concrete, no later than 24 hours after the concrete has been placed. The depth is at least 1/3 of the thickness of the slab.

4.2.2. Longitudinal construction joints

These are joints between two adjacent concrete lanes that are executed successively [24].
4.3. Placement of dowels or tie bars

4.3.1. Placement of dowels

4.3.1.1. Placement of dowels on dowel chairs

It has to be checked whether or not the dowels and dowel chairs meet the requirements specified. Deformable dowel chairs are rejected. The same applies to the dowels. They must be perfectly straight, cut off straight and shall not have any burrs. Dowels that are not maintained perfectly parallel to the surface of the concrete pavement slabs can block the opening up of the joint and subsequently induce cracking at the end of the dowel [25].

Following below are some requirements for storing and installing dowels and dowel chairs:

- The dowel chairs have to be distributed along the road under construction on a flat and clean surface (i.e. not on the side slopes) to prevent deformation or contamination. If the chairs have welded connection bars, they have to be cut before the concrete is placed so as not to jeopardize the proper functioning of the joint.

- If the pavement is laid on a bound foundation (lean concrete or bituminous interlayer), the dowel chairs can be anchored in the base with clamps [26]. When looking in the direction of the concrete placement, the clamps should be installed beyond the transverse bars of the chairs. It must be ensured at all times that the chairs and dowels remain in place while the concrete is cast. This is necessary to counteract the forward pressure that the concrete exerts at the front of the paving machine. At the start of the concrete placement, the anchoring strength of the clamps must be checked as the paving machine is passing over the first dowel chairs.

For pavements without a base or with a granular base it is very difficult or even impossible to fasten the chairs. If, in such cases, the contractor does not have the equipment to vibrate the dowels in the concrete, it is possible to use the following method:

- After positioning, the dowel chairs are covered with concrete by means of a crane or bucket [27], whereby the concrete is placed gently so as not to move the dowel chairs. This covering of the chairs should precede the paving operation over a sufficient distance so that the chairs are already covered by concrete when the paving machine is arriving. No more than two to three chairs should be prepared in this way in advance while the paver has to follow within 30 minutes.

- When using a slipform paver, special care shall be taken that the dowels remain in place when the machine is passing.

4.3.1.2. Automatic insertion of dowels

The specifications can stipulate that the dowels have to be inserted automatically into the fresh concrete (see §3.2.4). In that case, the longitudinal location at which the dowels are to be placed must be indicated very carefully along both sides of the road so that later, the joints are sawed precisely above the middle of the dowels [28].

4.3.2. Placement of tie bars

Tie bars can be installed in the longitudinal joints as follows:

- either by inserting them into the fresh concrete by means of a tie bar inserter attached to the slipform paver;

- or by placing them on metal supporting chairs; in that case the same precautions have to be be taken as described for placing dowels;or by chemically anchoring them in holes drilled in the hardened concrete.

In no case tie bars can be inserted into the fresh concrete once the slipform paver has passed.
4.4. Sealing the joints

Transverse and longitudinal joints are usually sealed with a joint sealant [29] to prevent water infiltration under the paving slabs in the future. To this end, hot or cold joint sealants or prefabricated joint strips are used. To achieve a durable seal, this work must be done with the utmost care.

In the figures (see previous pages) the dimensions of the joint sealant reservoir are given for contraction joints or construction joints. For expansion joints the width of the sealant reservoir must be at least as wide as the width of the compressible joint filler board. The edges of the joint are chamfered in order to prevent spalling and to provide space for expansion of the joint sealant.

5.1. Placing the reinforcement

Reinforcing bars for continuously reinforced concrete pavements are usually delivered to the construction site in packs and subsequently hand-placed [30]:

- transverse bars welded to supports,
- longitudinal reinforcing bars.

However, as is the case for the execution of reinforced concrete pavement slabs, the reinforcement can also be delivered and placed on site as factory-made steel fabric.

5.1.1. Manual placement of reinforcement

The longitudinal and transverse reinforcement must be transported, unloaded and stored at the construction site in compliance with specific rules:

- delivery in packs that contain exactly the number of bars that are required to make the reinforcement mesh for the entire pavement width;
- unloading these packs with a crane equipped with a loading beam to uniformly suspend the steel pack so as to avoid permanent deformation;
- storage of the packs in areas free of mud.

If the transverse reinforcement supports have been welded to the transverse bars at the factory, it must be ensured that the bars and the supports do not become tangled.

The transverse reinforcement is placed on the base, at intervals that are checked with templates. Subsequently the longitudinal bars are laid on the transverse reinforcement bars, in such a way that bar splices are skewed at an angle that depends on the width of the pavement. At each splice the two bars are tied together with two iron wires.

The longitudinal bars are either tied or clipped to the transverse bars at every other bar intersection. For small curvatures (curves with small radius, roundabout [31]), the longitudinal bars have to be bent in such a way that the curvature is matched as closely as possible.
5.1.2. Welded reinforcement mats

If prefabricated welded mats are used the following measures have to be taken into consideration:

- The reinforcement mats are delivered to the site in packs whose size is adapted to the distance between the consecutive unloading locations.
- If the mats are delivered with welded-on supports, the supports must be protected, (e.g. with wooden beams that are attached under the panels).
- In order to properly unload the packs of mats, lifting equipment with sufficient capacity and having a loading beam with lifting loops should be used. The packs are lifted and stored by the side of the road in the direction in which they will be placed, at intervals equal to the length that can be laid with one pack of reinforcement mats.
- The binding wires of the packs are cut. Each mat is lifted separately by the crane - again using a loading beam - and laid in its final position on the foundation.
- For continuous reinforcement the mats are positioned in such a way that both the longitudinal bars and the transverse bars are well aligned and that the specified splicing length is obtained.

5.2. Execution of an end-of-day joint (construction joint)

This joint has to be executed with the utmost care. If not, significant damage is liable to occur. In the worst case the concrete can buckle at the joint under very hot weather conditions. In particular, the concrete must be carefully consolidated with a manual needle vibrator, both at the end of the day and when the concreting work resumes. When making the joint, the use of a steel headerboard that is attached to the reinforcement, is recommended [32]. This headerboard is slotted to allow the reinforcing bars to pass through the joint. Vertical steel form plates are inserted at the slots to contain the concrete at the bottom of the headerboard.

SURFACE TREATMENT

The surface treatment that is applied after the placement and finishing of the concrete is intended to give the pavement surface optimal properties with regard to skid resistance and rolling noise without detrimental effects on the smoothness of the pavement surface. The aim is to give the concrete surface such a texture that even at high speeds on wet road surfaces a great skid resistance and a limited tire/pavement noise is achieved. This applies especially for roads with intense and high speed traffic [33].

Contrary to what is sometimes believed, the surface treatment can never camouflage certain defects of the surface that are due to incorrect concrete paving operations. To the contrary, it will often reveal such defects. The homogeneity of the concrete surface is determined by the care that is given to the placement of the concrete mix.

Special attention has to be paid to the following items:

- the surface has to be very smooth before the treatment;
- the surface treatment shall not disrupt the smoothness and may not obstruct surface drainage;
- the composition of the concrete mix at the surface shall be homogeneous, especially if the technique of exposed aggregate is applied.

In the past, various surface treatment techniques have been applied: brooming or tining, gravelling and exposed aggregate. Hereinafter, only the following surface treatment techniques are described:
• brooming in the transverse direction (or in the longitudinal direction);
• exposed aggregate;
• pattern imprinting

The technique of exposed aggregate is primarily used for motorways and roads with intense and high speed traffic. It is also used for pavements in public spaces in order to emphasize the aesthetic characteristics of specific aggregates. In the other cases (e.g. for lowly trafficked roads, industrial roads, car parks, cycle paths, etc.) the surface treatment usually consists of brooming in the transverse direction.

6.1. Brooming

When treating the surface by brooming, the brooms shall be suitable to apply the desired texture over the entire width of the pavement. Immediately after the final finishing, hard brooms with closely spaced hairs are dragged across the surface of the fresh concrete. This treatment can be done manually [34] or mechanically [35]. In both cases, the surface shall not be treated too rough, otherwise imprints may be made in the fresh concrete or the edges may be damaged. Sometimes the broom is dragged in the longitudinal direction e.g. for rural roads or cycle paths.

6.2. Exposed aggregate finish

This technique consists of chemical stripping by spraying a setting retarding agent on the surface of the fresh concrete immediately after the concrete has been finished [36]. Later on, the non-hydrated skin of concrete mortar is removed so that the stone skeleton of the concrete is exposed.

The setting retarder has to prevent the concrete mortar skin from hydrating during a period that, amongst other things, depends on the quality of the concrete and on the weather conditions. The amount of agent to be applied is determined in accordance with the supplier’s instructions and in function of the intended result. For this treatment the concrete surface must be tight, so that the retarding product cannot penetrate into the concrete.

The setting retarder has a bright colour because a pigment is usually added to it. On the one hand it shall be sufficiently viscous, regardless of the slope, in order not to run off after being sprayed, on the other hand it must also remain possible to spray it with a suitable apparatus (pump, spraying nozzle). When the paving train has stopped it shall be avoided that too much retarding agent is sprayed at the same location. To achieve this, a gutter can be placed under the sprayer whenever the paving equipment stands still. Small surfaces can be sprayed by hand [37]. Immediately after spraying, the surface is protected either by means of a watertight plastic sheet [38], which is kept in place until the skin of concrete mortar is removed or by applying a special curing compound (see § 7.1).

About 20 hours after the concrete has been finished the non-hydrated layer of concrete mortar is washed out by means of a steel broom. This minimum waiting time is extended if it becomes apparent that on the inside the concrete has not hardened enough to start brooming without the risk to damage the concrete.

The brooming is done intensively by means of a rotary broom of steel wires that is mounted on a self-propelled vehicle [39]. Hydraulically operated brooms with 0.8 to 1 mm thick wires of woven steel are preferable. The height and angle of the rotary broom shall be adjustable. On each side the broom shall be 30 cm wider than the outside of the wheelbase in order to avoid that the wheels are nearing the edges too closely.
The number of passes of the broom depends on the desired texture depth.

On small surfaces, the skin of concrete mortar can also be removed with a high-pressure water jet [40]. This is usually done between 6 and 24 hours after the concrete is finished.

The watertight plastic sheet is removed progressively as the brooming continues to avoid that the retarder is drying up. In hot weather it can even be useful to moisten again beforehand the surface to be treated.

The necessary measures have to be taken to prevent cement slurry from running in the storm drainage system (gutters, inlets, subsurface drains, culverts) or on the adjacent strip of concrete pavement. If this has happened anyway, the cement slurry must be removed immediately. It is important that the concrete be protected against drying out for at least 72 hours after completion. Therefore, after chemical stripping of the concrete surface and before it is dried out, a new protection has to be applied to the surface e.g. by spraying a curing compound or by placing a watertight sheet.

### 6.3. Pattern imprinted concrete

Pattern imprinted concrete is a method of stamping a pavement pattern in the surface of the freshly poured concrete [41]. This surface treatment is intended for special applications, especially in urban areas. The surface is given a relief structure to resemble real paving elements, e.g. paving bricks etc. [42].

A colour hardener (mixture of colouring and hardening powder) is dry-shaken onto the fresh concrete surface at a rate of at least 3 kg/m². The concrete is then floated with a float attached to a handle by means of a double hinge. Subsequently a form release powder is dry-shaken on to the concrete (at least 150 g/m²) to ensure that the concrete does not stick to the tools. The desired pattern is then immediately stamped into the concrete using special imprinting tools. The concrete is protected during 72 hours against drying out with a plastic sheet. A few days after the concrete has hardened, the surface is cleaned with water. As soon as the surface is thoroughly dry, an acrylic resin is applied.

### 7.1. Protection against drying out

The quality of hardened concrete, and in particular, the durability of the surface, depends directly on the protection of the fresh concrete against drying out. It is detrimental both to the strength and to the shrinkage (risk of cracks forming) and also to the durability when the fresh concrete loses water. As a result of their large exposed areas, pavements are greatly subjected to drying out. E.g. at an ambient temperature of 20°C, a relative humidity of 60 %, a temperature of the concrete of 25°C and a wind speed of 25 km/h, 1 litre of water will evaporate every hour from every m² of pavement surface. Note that the upper surface layer (a few cm thick) of the concrete only contains about 4 litres of water per m².

A curing compound is usually used to protect road concrete against drying out [43]. This coating is sprayed on the concrete top surface and on the vertical surfaces immediately after the paving train has passed and, if applicable, after the concrete surface has been broomed.

In case of an exposed aggregate finish, the setting retarder must also have the property that it protects the concrete against drying out. If not, the concrete must be covered with a plastic sheet as soon as the setting retarder is applied. As stated above, subsequent to the removal of the skin of concrete mortar, the concrete is protected against drying out a second time by spraying a curing compound or by covering the surface with a plastic sheet. The latter method is particularly used in urban areas on coloured exposed aggregate concrete.
The curing compound has to be applied at a rate of at least 200 g/m² and its effectiveness coefficient shall be greater than 80%. Curing compounds are pigmented white or have a metallic gloss so as to better reflect sunlight which limits the warming up of the concrete.

7.2. Protection against rain

Concreting is stopped if it rains. Furthermore, the necessary measures have to be taken to prevent that the concrete surface is washed out by rain. This applies both to freshly spread concrete that has not been compacted yet and to smoothed concrete. Plastic sheets [44] or mobile shelters are suitable means of protection.

7.3. Protection against frost

When concrete is placed in cold weather (see also § 8.4.1) the pavement surface has to be effectively protected against frost in such a way that the temperature at the surface of the concrete does not drop below +1 °C for 72 hours after placement. This protection can consist of, for example, non-woven geotextile or polystyrene foam plates with ballast [45].

7.4. Protection against mechanical influences (traffic signposting)

Every necessary measure shall be taken to protect the fresh concrete from damage due to all kinds of mechanical influences (cars, bicycles, pedestrians, animals, etc.) [46].

In urban areas these measures are even more necessary [47].

8 | SPECIAL MEASURES

8.1 Workability period

It must always be ensured that the concrete is processed as quickly as possible, certainly within 2 hours after batching including the surface treatment and the protection measures. In hot, dry weather an even shorter workability time has to be observed (maximum 90 minutes). Unless special precautions are taken that have been approved by the manager of the works, concrete can only be laid if the air temperature at 1.5 m above ground under thermometer shelter does not exceed 25°C (see also § 8.4.2).

Furthermore, all necessary measures shall be taken to keep the water content of the concrete as constant as possible from the time of batching until completion of the placement.

8.2. Paving interruptions

Whenever the supply of concrete is interrupted, the driver of the paving machine shall immediately take the necessary measures to lower the speed of the paving train and to ensure that the machine stops as little as possible.

For a short interruption, the machine should be stopped before the deposited concrete in the vibrating chamber has dropped to such a level that the vibrators become visible. If the supply is interrupted for more than 60 minutes (45 min. in hot weather), a construction joint has to be made.

Upon a long-lasting defect of the paving equipment, the supply of fresh concrete has to be stopped immediately and an attempt must be made to complete the current paving phase. If the circumstances and the elapsed workability time no longer make a proper completion possible, the concrete, that has been deposited but not yet finished, has to be removed.

To achieve a continuous profile, particular care is taken of the execution of the construction joints, both at the end of the day and every time work is resumed. The concrete is compacted preferably with a separate vibrating needle before the paving machine is passing in order to obtain properly compacted concrete on both sides of the joint.
8.3. Placement of concrete on a slope

When placing concrete on a slope of less than 4 % it is recommended to work uphill, in order to prevent tension cracks at the surface [48]. Furthermore, the consistency of the concrete and the working speed of the paver have to be adapted to the working conditions.

However, if the longitudinal slope is more than 4 %, unevenness can occur as concrete falls back when the machines have passed. In that case, a suitable composition of the concrete mix has to be realized and it is recommended to work downhill [49]. It must be ensured that enough concrete is deposited in front of the paving machine to prevent the concrete from sliding down. Concrete pavements have been successfully executed on slopes of 10 to 12 %. At one time the slope was even 18 %.

8.4. Special weather conditions

8.4.1. Concrete paving in cold weather

When placing concrete in cold weather the setting and hardening time of the concrete increases due to the slower hydration of the cement.

Concrete pavement can only be laid if the air temperature measured at 8 o’clock in the morning at 1.5 m above ground under thermometer shelter, has reached at least +1°C and if, during the night, the temperature has not dropped below -3°C.

If circumstances so justify or require, the concrete placement can be continued at low temperatures provided additional precautions are taken to prevent frost damage, e.g.:

- addition to the concrete mix of a setting accelerator such as dissolved calcium chloride (except for reinforced concrete), at a rate of no more than 2 mass-% of the cement;
- improved protection of the pavement during the first days, by placing an insulating material on the surface.

8.4.2. Concrete paving in hot and/or dry weather

Hot and/or dry weather can have two adverse effects:

- faster drying out of the concrete, which is accompanied by shrinkage deformation (cracks forming due to plastic shrinkage);
- thermal deformations as a result of the concrete mass heating up.

At air temperatures above 25°C, or at a relative humidity below 50 %, special measures have to be taken to protect the fresh concrete against drying out and being warmed up by the sun:

- apply additional curing compound to the fresh concrete;
- moisten the concrete as soon as it has hardened sufficiently.

Other measures, having the same purpose, can also be considered, e.g.:

- sprinkling the foundation just before the concrete is deposited;
- adding a setting retarder to the concrete mix;
- shifting the working hours.
It is pointless to talk about quality if not all employees, each at his own level, make a special effort to understand the rules of good practice, upgrade their know-how and act accordingly.

The success of a project requires:

- a thorough study of the project and very good specifications;
- a quotation that takes into account all the difficulties that will occur during the work;
- a careful execution by skilled personnel that respect the code of good practice;
- a correct and accurate control, before, during and after the execution of the work.
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"Originally published in 2001 as technical sheet n° 26 of the FEBELCEM "DOSSIER CEMENT". 