PIARC - Manual: Best Practice Guide

For Maintenance of
Jointed Plain Concrete Pavements (JPCP) and
Continuously Reinforced Concrete Pavements (CRCP)

PIARC-Working Group D2c

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1 Introduction

Concrete pavements reach a high durability and good long-term performance. To ensure this, proper design and construction and the necessary maintenance are needed. The different types of concrete pavements are regionally employed to very different extents. Hence, the experiences concerning the maintenance measures differ greatly. An international exchange of experiences took place only to a very limited extend.

In order to improve the situation, the World Road Association PIARC has taken an interest in this topic. The Subcommittee D2c “Concrete Roads” was, under the title “Issue 2: “Improved Maintenance Methods”, given the task to identify the best maintenance measures for concrete pavements.

Initially, a survey was conducted in which 35 countries, or 56% of the land surface of the earth, participated. The complete network of paved roads contains 26.6 million kilometres, of which 2.1 million, or 8.0%, have concrete pavements. In 20 countries, concrete pavements are used on a large scale, which means more than 200 kilometres. Hence, in the respective countries, the experiences with maintenance and rehabilitation measures of concrete pavements are correspondingly large.

Maintenance measures are being conducted in order to maintain, restore or adapt the road to an increased traffic volume. They start by determining the condition within regular intervals. In doing so, the characteristic features of the pavements are depicted and illustrated. Damages and deficiencies are qualitatively and quantitatively being captured. This can be done either manually or using special recording equipment, and also by means of additional tests, for example tests on cores, bearing capacity measurements or detection of voids. Besides the actual condition or the damage, the intended remaining usage of the road construction has to be considered.
All maintenance measures gathered in the framework of the survey have been analyzed and the best and most tested ones are presented in this document. Some measures are applicable to all concrete pavements. These include the renewal of damaged and/or leaking sealing products at joints, the restoration of the skid resistance by removing concrete or the application of an overlay or a coating, the filling of cracks, lane or slab renewal as well as the improvement of the drainage. Other measures refer specifically to a certain type of pavement. With regard to JPCPs (see Figure 1.1 on the right), these comprise the widening and sealing of cracks, the retrofit installation of tie bars or dowels at cracks and joints, the repair of edge damages and broken-off corners, the lifting of concrete slabs and/or the filling of voids under them and the renewal of individual slabs or groups of slabs. Concerning CRCPs (see Figure 1.1 on the left), the repair of punch-outs is described. This document is intended to make in the future the best maintenance practices accessible to everybody in order to adapt them to regional conditions. When implemented consequently, the working life can be prolonged, the safety and the driving comfort increased and the concrete pavement made economically more efficient. Representatives from Austria, Belgium, Canada, Cuba, Czech Republic, France, Germany, Hungary, India, Iran, Italy, Republic of Korea, Madagascar, Mexico, Morocco, Portugal, Romania, Slovakia, Slovenia, South Africa, Spain, and the United States of America have participated in the preparation process. As illustrative examples, two case-studies from South-Africa and the U.S. are given in the appendix, in which JPCP and CRCP concrete pavements were respectively renewed. Additionally, the results of the survey are included and explained in detail. Nevertheless, the topic of maintenance of concrete pavements is not yet finished. The survey has shown that new materials and repair methods allow for continued development. Reactive resins, as an example, can be employed as a coating to improve or renew the skid resistance of a concrete pavement. This relatively recent procedure is already included in the PIARC-manual. Another procedure is the application of precast elements for the renewal of single slabs. This is made possible by using innovative concretes and lifting gear. However, large-scale application of this procedure is still very recent and almost limited to USA. Therefore, it will be included in the PIARC-manual when more experience will be gained.
2 Condition Assessment

The characteristic condition indicators for the road pavement are described and illustrated below, followed by notes concerning the qualitative and quantitative assessment of faults and damage.

Common causes of damages are listed for some particular examples (see also Table 1: Allocation of condition indicators to possible causes), and may occur individually and in combination. It should be noted that the order of the causes of damage in the list is not intended to provide an indication of their frequency of occurrence.

Possible methods for repairing the damage are mentioned. However, the order they are presented does not provide an indication of their effectiveness.

The condition of the road and, where required, the cause of the damage is determined by visual inspections, measurements and additional tests. Cores are drilled to test the properties of the concrete, and other extracted parts are only used in exceptional cases. However, the performance of the road pavement or of individual layers cannot be determined via these test methods. Therefore, determining the causes of damage may require additional investigations such as determining the load-bearing properties, examination of water drainage or voids under the slabs, measurements of horizontal or vertical movements, and checking the position and condition of the dowels and tie bars.

2.1 Condition Assessment for all types of construction

2.1.1 Damaged joint sealants

A damaged joint sealant (including preformed profiles and hot or cold applied products) is typically detached from the sides of the joint, is pressed upwards or has sagged, is internally cracked or porous, or is no longer present (see Figure 2.1).

![Figure 2.1: Damaged joint sealant](image-url)
Condition indicators
- Percentage of damaged joint sealant
- Appearance
- Missing or removed joint sealant (in the case of preformed profiles, particularly at intersection points)
- Lack of lateral adhesion
- Sagged joint sealant
- Porosity
- Other forms of damage (chemical, thermal, mechanical)

Condition assessment
- Visual (documented using photographic methods)

Causes
- Ageing of the sealant
- Unsuitable sealant or overheated hot-applied product
- Insufficient joint maintenance (tightness)
- Erosion or destruction of the base
- Slab length too large or joints not open (indicated by large cracks between unbroken sections)
- Unsuitable joint formation or arrangement
- Faulty joint creation
- Missing or no longer effective dowels or tie bars (resulting in excessive horizontal or vertical movement of the slabs)
- Edge damage

Measures
Successful repair or maintenance measures require the slabs to be firmly supported and the joint width to be adjusted to the expected range of movement.

Preparatory stabilization or lifting of the slabs by injecting material and possibly, dowel and tie bar retrofit as well as re-cutting the joint can remedy the conditions mentioned.

The following measures can be applied:
- Repair of the joint sealant
- Moving excess sealing compound downwards
- Replacement of the joint sealant
- Widening of the joint
- Placement of additional joints

2.1.2 Surface damage
Typical examples of surface damage are pop-outs (Figure 2.2), repaired pop-outs (see Figure 2.3), wear (see Figure 2.4) or scaling (see Figure 2.5).
Figure 2.2: Pop-out

Figure 2.3: PC mortar repaired pop-out

Figure 2.4: Wear
Figure 2.5: Scaling

Condition indicator
- Percentage of affected slabs
- Percentage of affected area per slab

Condition assessment
- Visual inspection, photographic methods

Causes
- Unsuitable concrete composition (e.g. cement, aggregates, admixtures, additions, air void content)
- Insufficient properties of hardened concrete (e.g. compressive strength, flexural strength, splitting strength, freze-thaw and de-icing-salt resistance)
- Faulty construction (e.g. segregation during concrete placement)
- Unfavourable weather conditions during pavement construction (e.g. heat, rain, frost, wind)
- Insufficient curing time
- Effects of other chemical, thermal or mechanical factors (e.g. de-icing agents, oils, fire, vehicle crashes).

Measures
The adhesion of the coating to the existing concrete pavement must be tested to ensure the effectiveness of the maintenance or repair measure. Adhesive tensile strength must be at least 1.5 N/mm².

- Treatment with reactive resin and coating with reactive resin mortar
- Removal of the concrete
- Localised repair

2.1.3 Reduced skid resistance
Visual evaluation methods are not sufficient to provide an assessment of skid resistance. Skid resistance can only be accurately measured via recognised test methods and equipment.
**Condition indicator**
- Length of track in the lane considered

**Condition assessment**
- By measurements (SCRIM, skid resistance tester (SRT))

**Causes**
A reduction in skid resistance is caused by normal wear as a result of the passage of traffic over time. However, in some cases the following causes may be applicable where abnormally high reductions in skid resistance have occurred:

- Unsuitable concrete composition (unsuitable aggregate, low polishing resistance, e.g.
- Faulty construction (quality and thickness of the surface mortar layer, mortar accumulation in the surface, defective surface texture)
- Insufficient drainage of the surface

**Measures**
The adhesion of the coating to the existing concrete pavement must be tested to ensure the effectiveness of the maintenance or repair measure. Adhesive tensile strength must be at least 1.5 N/mm².

The following measures can be applied:
- Removal of concrete (grinding)
- Treatment with reactive resin
- Coating with reactive resin mortar
- Application of asphalt layers (e.g. stone mastic asphalt (SMA))
2.2 Condition Assessment for the Jointed Plain Concrete Pavements (JPCP)
2.2.1 Vertical slab movement, faulted joints

Slabs or parts of slabs may move under traffic load which may eventually result in faulted joints (see Figure 2.6).

![Figure 2.6: Faulted joints](image)

**Condition indicators**
- Percentage of affected slabs
- Appearance
- Maximum faulting (mm)

**Condition assessment**
- Measurements, visual

**Causes**
- Lack of bearing capacity of the subbase and/or subgrade
- Voids under the joint or crack area as a result of erosion
- Missing or damaged dowels or tie bars

**Measures**
The selection of an appropriate maintenance or repair measure depends on whether the joints are doweled or provided with tie bars, whether the slabs are cracked, and whether they are supported from underneath or lie on a void.

The following measures can be applied:
- Stabilising or lifting by injection
- Retrofit doweling and/or insertion of tie bars
- Grinding of concrete
- Replacement of slabs or parts of slabs
2.2.2 Edge damage and broken-off corners

Edge damage is characterised by spalling or damage to the concrete at the joint location (see Figure 2.7).

![Figure 2.7: Edge damage](image)

Broken-off corners are another typical form of damage of concrete slabs (see Figure 2.8).

![Figure 2.8: Broken-off corner](image)

**Condition indicators**
- Percentage of slab area damaged
- Number of broken-off corners

**Condition assessment**
- Visual inspection
Causes
- Insufficient concrete strength
- Deformation of the subbase of subgrade
- Faulty joint condition
- Obstructed horizontal or vertical slab movement
- Mechanical stress (e.g. from heavy vehicles such as tracked ones)

Measures
The success of the maintenance or repair measure selected depends on careful removal of the damaged and loose parts of the slab.

The following measures can be applied:
- Repair with reactive resin mortar
- Replacement of slabs or slab sections (with quick-setting concrete, where required)

2.2.3 Lateral displacement of slabs
Slab displacement is apparent where there is a gap of up to several centimetres in width at the location of longitudinal joints between adjacent lanes. (Figure 2.9).

Condition indicator
- Length in metres (m) with gap widths (mm) and the distribution in the road section taken into account.

Condition assessment
- Visual inspection, photographic methods

Causes
- Missing tie bars
- Tie bars no longer effective
Measures
The success of the maintenance and repair measures is dependent upon the early retrofit of tie bars to prevent a further increase in the joint gap width.

The following measures can be applied:
- Tie bar retrofit
- Replacement of joint sealant
- Replacement of slabs or parts of slabs

2.2.4 Longitudinal and transverse cracks

This form of damage is characterised by cracks, either shallow or deep, in a longitudinal and transverse direction, with the exception of ‘hairline’ cracks (see Figure 2.10 and Figure 2.11).

Figure 2.10: Widened and sealed longitudinal crack

Figure 2.11: Transverse crack
Condition indicator
- Percentage of cracked slabs

Condition assessment
- Measurement, visual inspection, photographic methods

Causes
- Damaged base
- Insufficient thickness of the concrete pavement (under-designed)
- Insufficient bearing capacity of the pavement
- Inappropriate slab size or slab shape
- Unbroken dummy joint
- Insufficient concrete strength
- Inappropriate concrete composition
- Defective joint construction (insufficient cutting depth, improper cutting time (too late))
- Faulty pavement construction (e.g. placement, equipment, curing)
- Unusually high stresses (e.g. from heavy traffic)

Measures
The effectiveness of the maintenance or repair measure are improved when further damage (e.g. slab faulting, broken-off corners, etc) is delayed by previous dowel or tie-bar retrofit (e.g. diagonal tie-bar insertion, also called “cross stitching”).

The following measures can be applied:
- Dowel and/or tie bar retrofit
- Widening and sealing of the cracks
- Stabilising the slabs (when distresses are due to erosion damage in the base)
- Replacing slabs and parts of slabs
2.3 Condition Assessment for Continuously Reinforced Concrete Pavements (CRCP)

2.3.1 The punchout phenomenon

In Belgium the "punchout" problem first appeared at the end of the eighties on certain sections of motorway that had been built after 1981. Observations soon showed that the phenomenon was similar to what had already been observed in the United States. Punchouts are pavement failures that usually occur close to the outside edge of the pavement and which lead to the fragmentation of the concrete and the loss of blocks or wedges of paving material as a result of the dynamic impact of the traffic. The occurrence of punchout is the consequence of multiple causes whose simultaneous action causes the problem to lead to a dangerous final stage that makes immediate action necessary, even if this is only provisional. The four essential factors needed for the occurrence of this kind of damage are the presence of water in the interface between the concrete slab and the road base, a base that is prone to erosion, heavy intense traffic at the edge of the slab, and closely spaced transverse cracks. The observed sequence of events is as follows: water that penetrates under the edge of the concrete slab is subjected to pressure when heavy vehicles pass over the pavement. This causes the erosion of the base by repeated pumping at the outer edge of the pavement, giving rise to small voids under the slab. The presence of such voids reduces load transfer at cracks. This in turn leads to a sharp rise in the transverse bending stresses, which after a while results in the development of a longitudinal crack at a distance of 0.5 to 1 m from the edge of the pavement. The concrete block that is isolated in this way rapidly become unstable under the action of the traffic and will disintegrate entirely, and will eventually lead to the loss of the fragments. Figure 2.12 below gives an example of a punch-out. It must nonetheless be pointed out that the existence of successive cracks alone will not lead to a "punchout". The numerous motorways that display this kind of cracking, without any impact on the performance of the pavement, are evidence of this. In addition to the factors mentioned above, all kinds of other causes contribute to a greater or lesser extent to the premature appearance of "punchouts".

![Figure 2.12: Punchout](image_url)
2.3.1.1 The suppression of a bituminous interlayer between the pavement and the road base.

The role of this layer originally was to provide a homogenous and smooth surface underneath the concrete. The structural contribution of the interlayer was not taken into consideration when designing the road. In view of the progress that had been made in the finishing of lean concrete bases and the high price of bitumen in the early 80s, the asphalt interlayer was eliminated. However, the benefits of the interlayer are numerous. It ensures extremely good attachment of the CRC to the underlying surface. Good attachment leads to homogenous cracking of the pavement, which reduces the presence of water under the concrete slab. Resistance to erosion also means that it can withstand the combined impact of water, traffic and road salts. It protects the lean concrete road base and makes it impermeable, even before the concrete pavement is applied. Furthermore its rheological properties means that it can accommodate deformations of the pavement due to the temperature gradient more easily as well as providing a flexible insulating layer between two rigid layers. Finally it also contributes to the overall strength of the structure.

2.3.1.2 The quality of the lean concrete

The risk of erosion is considerably increased if the lean concrete, and its surface in particular, is of poor quality. This also reduces the ability to withstand frost and road salts. The surface of the base must therefore be protected by a compact layer that is insensitive to the effects of road salts. Nonetheless the following defects have been observed on certain sections of affected motorways:
- lean concrete with a very low compressive strength, a heterogeneous nature and mediocre quality;
- little or no protection of the lean concrete against drying out during construction, whereas the emulsion layer provided for in the specifications contributes to making the surface impermeable; construction in the winter months with insufficient protection against frost;
- construction in two layers, one 15 cm thick and the other 5 cm thick, which results in the delamination of the concrete at the interface between the two layers and the erosion of the upper.

2.3.1.3 Weather conditions

The number of "punchouts" rises mainly in the winter months as a result of frost and road salts. Moreover the roads that are most affected usually lie in areas with severe climates and higher frequencies of freeze-thaw cycles.

2.3.1.4 The drainage at the edge of the slab and the degree to which the longitudinal joints are watertight.

Good drainage of the hard shoulder at the junction between the pavement and the base is essential to prevent water, which infiltrates primarily via the longitudinal joint
between the pavement and the hard shoulder, from being trapped under the edge of the slab. For this reason the seal of the longitudinal joints must be as good as possible and be properly maintained. Where applicable a permeable base must be provided under the hard shoulder.

### 2.3.1.5 The thickness of the pavement in CRC

The fatigue strength of a concrete slab increases as a function of slab thickness. In view of the increase in heavy traffic the risk of damage increases because the bituminous layer was suppressed and the thickness of the pavement was not adjusted.

### 2.3.1.6 The importance of edge effects

Stresses in a concrete slab increase progressively as the load moves towards the edge of the slab. The increased aggressiveness of heavy traffic, namely as a result of the use of tridem axles, and any overloading, makes this situation even worse. This problem can be resolved in various ways:
- on existing roads: lane markings should be applied to the concrete pavement and not to the hard shoulder; this approach allows heavy traffic to be shifted 30 cm towards the inner edge of the slab;
- on new roads: the widening of the pavement at least 50 or even 75 cm should be considered. Alternatively the hard shoulder should be laid in concrete at the same time as the pavement, in other words without a longitudinal construction joint.

### 2.3.1.7 The depth of the reinforcing steel and the percentage of longitudinal reinforcement

Increasing the depth of the reinforcing steel, and reducing the percentage of reinforcement, leads to an increase in the width of the cracks on the pavement surface as a result of thermal and hygrometric effects. More open cracks lead to reduced watertightness and poorer load transfer and will therefore be more subject to spalling. It is thus more favourable to place the reinforcement in the upper third of the pavement and to use higher percentage of reinforcement.

### 2.3.1.8 Distance between the reinforcement and the edge of the pavement

If the distance between the first longitudinal reinforcing bar and the edge of the slab is too great, load transfer at that location will be reduced and transverse bending stresses will increase. The first reinforcing bar should be located at less than 13 cm from the edge, whereas a distance of more than 25 cm was observed in some motorway sections. The blow-up phenomenon in a CRCP is confined to those locations where the concrete has a certain fragility, often as a result of a poor compaction. Blow-ups usually occur at the location of end-of-day joints as a result of poor compaction or a lack of care during construction. Concrete expands in very hot weather, and the horizontal forces are transferred in their entirety to the upper layer of the better compacted concrete (eccentric force), leading to its fracture and
fragmentation and finally to an uplifting of the pavement. Moreover the very porous or high-void concrete below the reinforcing steel is often saturated with brine originating from de-icing salts. Over time this causes accelerated deterioration of the concrete as a result of freeze-thaw cycles and ultimately the corrosion and even the breakage of the reinforcement. In general blow-ups occur at the end of spring, towards the end of May or in early June. This is when the concrete is still full of moisture and is still "swollen up". Any expansion that occurs during the first warm weather is thus much more severe. Moreover, in June the hours of sunshine are approaching the maximum and the difference between night and day temperatures can still be very large.
3 Maintenance Measures

3.1 Maintenance Measures for all Types of Concrete Pavements

3.1.1 Repair and renewal of joint seals

Repairs of joint seals are small scale repair measures that can be performed with little effort, usually by hand, and should be conducted immediately after localised damage has occurred, in order to restore the sealing effect of the system.

Repairs of joint seals should be performed with the same materials that were initially used. They may be hot or cold-applied joint sealants or preformed joint profiles.

The sealant in either contraction, expansion or construction joints should be replaced when it is no longer effective (e.g. due to ageing of the joint sealant and/or joint profiles). It is desirable to treat all joints in consecutive sections across the entire width of the carriageway when the concrete pavement is fairly evenly used.

Economic considerations indicate that joint sealants should be replaced with joint sealants and joint profiles should be replaced with joint profiles. Cost-effective repair of minor edge damage in the joint area can be achieved by filling the damaged areas with a hot- or cold-applied joint sealant. The traffic area must be kept free of traffic during joint-filling work.

Remains of the old joint sealant that may still adhere to the sides of the sealing groove must be considered when the new joint sealant is to be applied. It must be checked before the installation of the new joint sealant whether the edges have to be re-cut in order to provide clean joint edges as a new adhesion surface. Re-cutting the joint gap provides the best possible conditions for good adhesion of the new material. Reshaping the joint edges may also be necessary when the joint sealant to be replaced was not able to accommodate the experienced variation in joint width without damage because the joint sealing groove was initially under-dimensioned.

When hot-or cold-applied sealants are replaced by preformed profiles, the joint edges must always be re-cut so that the joint profiles can be installed in an appropriate manner.

When old joint profiles are replaced by new ones, it must be checked whether the joint sealing grooves have the correct width to ensure the required parallel alignment of the joint edges. They have to be re-cut when this is not the case to fulfil this requirement. Re-cutting and additional chamfering can be used to remove minor edge spalls. Major edge spalls must be repaired with concrete partial-depth patches before the installation of the joint profiles. The existing joint sealant must be removed down to the new installation depth while simultaneously protecting the joint edges.

When replacing a sealant with a new one, residues of firmly adhering joint sealant and usable backing materials may remain in the joint groove. The edge adhesion of the residue as well as its compatibility with the new joint sealant must be ensured and is required to be tested in an appropriate manner. The joints must be re-cut if these requirements are not fulfilled.
Re-cutting can be omitted when joint profiles are replaced by hot- or cold-applied joint sealants. The joints are in this case cleaned, provided with a backing material (heat-resistant, closed-cell foamed plastic or sponge rubber) to prevent sagging of the joint sealant and then their sides coated with a primer and sealed.

The brushing machine must be cleaned after removing the old joint sealant. Dirt at the joint edges must be removed.

A primer is recommended to improve the adhesion of the sealant to the joint edges.

Joint sealing must only be performed when the weather is dry and the surface temperature of the joint edges is at least 0°C. The joint edges must be dry and dust-free.

Hot-applied joint sealants materials must be installed in a way that ensures that a tray-shaped recess of at least 1 mm and at most 6 mm is formed below the road surface. This is necessary to prevent the joint seal from protruding at higher temperatures. Overfilling must be avoided.

Transverse joints that are not chamfered must be chamfered before they are filled. Chamfering can be omitted when the joint sealant is installed in joints with widths > 15 mm or when joint profiles are installed in joints with widths > 20 mm. Joint profiles (see Figure 3.1) have an advantage over hot- or cold-applied sealants as far as installation is concerned, because they can also be installed in wet weather. However, the joint groove must be free of ice at the time of installation.

![Figure 3.1: Installed joint profile](image)

Care must be taken that all joints have an even cross-section when joint profiles are used. The joints must be re-cut, where required.

The current joint depths must be inspected. Existing profiles that are more than 15 mm deep cannot be used as backing material for the sealant, as this would cause detachment of the latter.
3.1.2 Removal of concrete

Concrete is removed in the event of:
- Unevenness
- Surface damage of individual areas
- Drainage obstructions to surface water
- Formation of steps at joints and cracks
- Lack of skid resistance

Suitable methods are:
- Milling
- High-pressure water blasting
- Water blasting with or without water additive, steel blasting
- Chiselling
- Machine chiselling
- Grinding
- Grooving

The measures listed in Table 3.1 are used to prepare the concrete for the application of coatings, surface area protection layers, road markings or as a final measure to provide better surface properties:

Table 3.1: Removal of concrete

<table>
<thead>
<tr>
<th>Method</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of concrete</td>
<td>As preliminary treatment</td>
</tr>
<tr>
<td>Milling for removal</td>
<td>x</td>
</tr>
<tr>
<td>Milling for roughening</td>
<td></td>
</tr>
<tr>
<td>High-pressure water blasting</td>
<td>x</td>
</tr>
<tr>
<td>High-pressure water blasting for cleaning</td>
<td></td>
</tr>
<tr>
<td>Blasting with water additive, steel ball blasting</td>
<td>x</td>
</tr>
<tr>
<td>Chiselling*</td>
<td>x</td>
</tr>
<tr>
<td>Machine chiselling</td>
<td>x</td>
</tr>
<tr>
<td>Grinding</td>
<td></td>
</tr>
<tr>
<td>Grooving</td>
<td>x</td>
</tr>
</tbody>
</table>

*Only for small areas
3.1.2.1 Milling

In the past, machine milling of concrete surfaces was used to improve skid resistance. However, the rough surface texture created by milling leads to increased tire-road noise and milling is therefore now uncommon, except for the removal of bumps and steps (danger points) that occur unexpectedly.

3.1.2.2 High-pressure water-blasting method

High-pressure water-blasting methods are suitable for surface cleaning and removal of layers with low strength, e.g. paint, coatings and worn-off tyre rubber).

High-pressure water blasting is commonly used on newly constructed concrete pavements as a preparatory measure before the application of the first road markings.

The waste water produced may not be drained over surfaces that are used by traffic.

3.1.2.3 Blasting with or without water additive, steel blasting

Blasting methods are gentle methods for removing surface pollution and thin layers and to roughen a surface (improve the micro-roughness). Also whole, uneven areas can be treated without affecting the surface strength.

Steel blasting (steel ball blasting) is a high-performance method (daily output approx. 5,000 m²), which is used instead of sand blasting when the surface has to be prepared without formation of dust and residues, in particular for improving skid resistance.

3.1.2.4 Chiselling

Chiselling is suitable for removing thick concrete layers in small areas, e.g. broken-off edges and corners. The concrete structure in the broken-off area is loosened and weakened by chiselling. Additional treatment of the broken-off areas might be required to repair the pavement, depending on the thickness and size of the layers. It is recommended to surround the damaged area to be chiselled off with a vertical separating cut (down to 5 cm depth) to prevent damage to the concrete structure.

3.1.2.5 Machine chiselling

Machine chiselling makes use of chiselling machines with vertically acting chisels. Machine chiselling is particularly useful for removing concrete layers with low strength and for improving the evenness of small areas. The concrete structure in the broken-off area is loosened and weakened. Subsequent resurfacing requires additional treatment (e.g. by steel blasting).
3.1.2.6 Grinding

Devices with diamond cutting discs on horizontal shafts are used for grinding. Grinding facilitates very accurate removal of concrete and can be used to create different groove patterns (see Figure 3.2) without altering the strength of the surface. Grinding is suitable for improving the evenness and skid resistance of the surface and for reducing noise emission. The processing depth is usually up to 10 mm. The removal of a 2-3 mm thick layer is usually sufficient to improve skid resistance. Hardened, repaired areas as well as joint edges are not damaged by grinding. The grinding sludge must be vacuum cleared.

3.1.2.7 Grooving

Grooving is used for surfaces with inadequate surface drainage, where there is a risk of aquaplaning, or to improve skid resistance. Transverse grooving may result in increased tire-road noise.

The reference values for execution are as follows:
- for transverse grooves:
  Width and depth 6 mm each.
  The distance between the transverse grooves should be between 100 and 150 mm.
- for longitudinal grooves:
  Width 4 mm, depth 6 mm, centre-to-centre distance 25 mm

The grooves must have sharp edges and no spalls. Once a grooving distance has been selected, it must be retained.

To drain the surface of sections with a change in the transverse slope, one diagonal cut with a width of 10 mm must be made in each slab. The cutting debris must be vacuum cleared.

Figure 3.2: Grooving

3.1.3 Lane replacement

An unforeseen increase in the amount of commercial vehicles, and especially an increase in axle loads, can result in concrete layers being under-dimensioned. Damage is mainly found in the heavy traffic lane. Replacing only this lane constitutes
an economical alternative to a full-width replacement. Under-dimensioned shoulders are to be replaced with a view to future shoulder use.

Single-lane replacement is to be used as an alternative when the replacement of individual slabs or slab components does not result in any improvement in driving quality or in any long-term improvement of the layer substance, and where future damage to the concrete layer can be expected.

The use of machines to build the new pavement will usually result in better quality and a more even finish. Single-lane replacement must take the form of an inlay, retaining the original height and transverse slope (see Figure 3.3 and Figure 3.4).

![Figure 3.3: Single-lane replacement: preparation and concreting](image)

![Figure 3.4: Single-lane replacement: smoothening the concrete and cutting joints](image)

When replacing concrete lanes and increasing the existing layer depth (e.g. a 30 cm concrete layer on a gravel base course), the edges of the unbound layers under the remaining concrete layer of the adjoining lane or shoulder must be protected to avoid material detachment as a result of vibrations or wash-outs.
Where there is a cement-bound base underneath the remaining concrete layer, care must be taken that any surface water that has penetrated can be drained along the construction joint.

A suitable way to achieve this is to install a draining concrete strip and non-woven geotextile according to Figure 3.6 or a longitudinal drain.

Where a concrete lane is to be replaced, the new pavement must be connected to the existing one using dowels at transverse joints and tie bars at longitudinal joints between the repaired area and the adjacent overtaking lane or shoulder. This is a necessary condition for a proper performance of the new pavement.
To insert the dowels, holes must be drilled sideways into the existing concrete slabs; care must be taken that guides or templates are used to ensure that the hole pattern is even in the direction of the gradient or parallel to the surface.

Where the depth of the existing concrete layer and the lane to be renewed differ, the tie bars, (see Figure 3.7) and dowels must be fixed half-way down the existing concrete slab to prevent any spalling. The risk of damage to the dowels and tie bars caused by sawing is avoided, as the sealing grooves will not require deep notching, but only a shallow cut.

The hole diameter for dowels is 27 mm, with a hole depth of 25 cm. It is important to keep the hole diameter within a tolerance range of +/- 1 mm. An under-dimensional hole diameter may result in damage to the plastic sheath of the dowels during installation. An over-dimensional hole diameter will prevent both the horizontal positioning and parallelism of the dowels, resulting in a misalignment of the dowels inside the holes.

The dowels are inserted into the holes and are used for load transfer. This should make it possible for the slabs to move horizontally and the dowels are therefore not glued. In the case of expansion joints, the free ends of the dowels must be covered with caps.

Deformed tie bars must be horizontally fitted into the longitudinal contraction or construction joints to prevent any joint movements or lateral displacement of the concrete slabs. Deformed tie bars usually have a diameter of 20 mm and a length of 650 mm. In the vicinity of the corresponding joint, they must be coated in plastic to a minimum length of 200 mm and symmetrically sharpened at one end.

When using two-component adhesives, the tie bar must be twisted in to ensure mixing of the two components. The hole diameter depends on the adhesive used and the existing material volume of the cartridge. Execution shall be in line with the certification of the accredited systems. The hole depth in the case of injected two-component adhesive systems shall be 25 cm, while the diameter of the hole should be at least 27 mm. A larger hole diameter will not cause a problem, but will result in higher material costs. For both systems, the part of the steel tie bar inserted into the hole must be fully sheathed. Adhesive tie bars must withstand pull-out forces of at
least 80 kN.

Where the existing cement-bound base is not removed and the existing (possibly under-dimensioned) layer depth is to be retained, with only a single lane being replaced, the distances between the transverse and longitudinal joints may be halved to extend the service life of the slabs.

The use of concrete with a high flexural strength of up to 8 N/mm² should be considered if the existing (possibly under-dimensioned) pavement thickness is to be retained. The lane to be replaced must be removed in such a way that neither the adjoining lane nor the base is damaged. The concrete layer must be cut to its full depth. Any tie bars and dowels must be cut.

Additional longitudinal and transverse cuts can be made into the slabs to ensure that they can be carefully removed.

Where the base is damaged (cracks, spalls), reflection cracks in the new concrete layer can be avoided by repairing the base and covering it with non-woven fabric.

Any loose pieces on the base course must be removed before laying the concrete.

The joint pattern of the existing slabs must be taken into account when determining the location of transverse joints in the new pavement.

Slab lengths shall be in accordance with those of the adjoining lane. Dowels must be installed at transverse joints at a uniform dowel distance of 25 cm.

### 3.1.4 Surface treatment with reactive resin

During surface treatment using reactive resin, the reactive resin/hardener mixture is automatically proportioned, mixed and applied to the prepared concrete layer, which is hereafter referred to as the bedding layer. Depending on the surface texture (depth) of the bedding layer and the desired texture of the surface treatment, the binder volume will range from 700 to 1600 g/m². Depending on the amount of binder used, a crushed aggregate mixture with a grain size of 1/2, 2/3 or 3/4 is to be used for chipping (see Table 3.2).
Table 3.2: Binder volume, chip size and chip volume for surface treatment, depending on the average texture depth of the bedding layer.

<table>
<thead>
<tr>
<th>No.</th>
<th>Average texture depth [mm]</th>
<th>Binder volume [g/m²]</th>
<th>Chip size [mm]</th>
<th>Chip volume [kg/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤ 0.5</td>
<td>700 to 1 000</td>
<td>1 / 2</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>&gt; 0.5 to 1.0</td>
<td>&gt; 1 000 to 1 300</td>
<td>2 / 3</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>&gt; 1.0 to 1.5</td>
<td>&gt; 1 300 to 1 600</td>
<td>3 / 4</td>
<td>14</td>
</tr>
</tbody>
</table>

In addition to using suitable resin components and chips, this type of repair will only be durable in the long term if the concrete base is of a high quality, to ensure good adhesion between the reactive resin and the concrete. The durability will be increased by working carefully and choosing favorable weather conditions to favour setting.

Joints in the concrete bedding layer to be treated should normally not be masked, as the function of the joint will not be adversely affected due to the small amount of material applied.

A particularly careful examination and possible pre-treatment of the surface is required before applying the surface treatment.

Smoothness cannot be improved by means of a surface treatment. The reactive resins and aggregates used for chipping must be dry and dust-free. The most important precondition for long-term adhesion (adhesion and durability) of surface treatments with reactive resins is to provide a dry and carefully prepared concrete surface.

The tensile strength of the coating on the concrete base must be at least 1.5 N/mm², otherwise long-term performance cannot be guaranteed. Tensile strength may be improved by means of shot-blasting.

The surfaces must be free from substances such as oils, greases, rubber debris, curing compounds and marking materials.

Any unstable fine mortar layers must be removed from the concrete surface. The type of preparatory work (cleaning and/or milling) depends on the condition of the concrete surface. As well as a visual inspection, the strength of the concrete near the surface is to be determined.
The reactive resin applied must have hardened to such an extent that vehicles and pedestrians will not cause any damage by the time the road is opened to traffic - at the latest after 24 hours, depending on the prevailing temperature. Reactive resins may only be applied at concrete surface temperatures of at least + 8°C to a maximum of + 40°C, while the temperature of the concrete base and the materials used must be at least 3 K higher than thaw point temperature.

Where the surface temperature is rising rapidly, the application of reactive resins must be discontinued, as air escaping from the concrete layer will cause bubbles to form at the surface of the coat. Application shall take place while the component temperatures are dropping. No surfacing may take place in humid weather (e.g. rain, fog, dew).

The reactive resin is usually applied by machine (see Figure 3.8). The crushed, dust-free aggregate is to be evenly applied immediately after the reactive resin and either pressed down or rolled on (see Figure 3.9).

The aggregate must be applied in such a way that the required adhesive tensile
strength and long-lasting embedding can be ensured; the largest aggregate particles should be embedded in the reactive resin to a depth of approximately half its diameter.

![Figure 3.10: Sweeping away the excess aggregate](image)

After setting, the excess aggregate must be swept away. It can be reused. To check the adhesive tensile strength, three adhesive tensile tests must be carried out before opening the coated concrete surface to traffic.

### 3.1.5 Surfacing with reactive resin mortar

During application, the composition of the reactive resin/hardener mixture with added sand is automatically proportioned, mixed, applied to the prepared and pretreated concrete layer - hereafter referred to as the bedding layer -, and then chips are spread. The reactive resin mortar volume and chip size used for surface coating depends on the surface texture (depth) of the bedding layer and the average layer thickness. For average texture depths of 0.5 to 1.5 mm and for average layer thicknesses ranging from 2 to 5 mm, the information in
Table 3.3 must be taken into account.

Apart from using suitable resin components and chips, this type of repair will only be durable in the long term if the concrete base is of a good quality, to ensure good adhesion between the reactive resin and the concrete. The durability will be increased by working carefully and choosing favorable weather conditions to favour setting.

A particularly careful examination and possible pre-treatment of the surface is required before applying the surface treatment.
Table 3.3: Reactive resin mortar volume and chip size used for surface coating, depending on the average texture depth of the bedding layer and the average layer thickness

<table>
<thead>
<tr>
<th>No.</th>
<th>Average texture depth [mm]</th>
<th>Average layer thickness [mm]</th>
<th>Reactive resin mortar volume*) [kg/m²]</th>
<th>Chip size (quartz sand) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤ 0.5</td>
<td>2 to 3</td>
<td>4 to 6</td>
<td>0.3 to 0.8 or 0.7 to 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 3 to 4</td>
<td>&gt; 6 to 8</td>
<td>0.7 to 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 4 to 5</td>
<td>&gt; 8 to 10</td>
<td>0.7 to 1.2</td>
</tr>
<tr>
<td>2</td>
<td>&gt; 0.5 to 1.0</td>
<td>2 to 3</td>
<td>5 to 7</td>
<td>0.7 to 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 3 to 4</td>
<td>&gt; 7 to 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 4 to 5</td>
<td>&gt; 9 to 11</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&gt; 1.0 to 1.5</td>
<td>2 to 3</td>
<td>6 to 8</td>
<td>0.7 to 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 3 to 4</td>
<td>&gt; 8 to 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 4 to 5</td>
<td>&gt; 10 to 12</td>
<td></td>
</tr>
</tbody>
</table>

*The listed volume includes the embedded chippings

The surface coat consists of a primer course using reactive resin and chips, as well as a surface course using reactive resin mortar and chips. Aggregates must be dry and free of foreign particles.

The most important precondition for the long-term adhesion and durability of a surface coat using reactive resin mortar is to have a dry, carefully prepared and pretreated concrete surface. The adhesive tensile strength on the concrete base must be at least 1.5 N/mm². The surfaces must be free from substances such as oils, greases, rubber debris, curing compounds and marking materials.

Any unstable fine mortar layers must be removed from the concrete surface. The prepared surface is usually pretreated (primed).

Concrete surfaces generally have to be prepared. The preparatory process is determined by the results of the concrete surface evaluation. After preparation, the surface tensile strength should be at least 1.5 N/mm².

Depending on the prevailing conditions, several methods according to Section 3.5 may be used to prepare the concrete surfaces. After preparation, the surfaces to be coated must be swept and cleaned with oil-free, dry compressed air (wind direction must be taken into account).

While the concrete surface is being cleaned, heat damage or contamination, for example by condensation or particles suspended in the hot air, should be avoided.

The joint seals must be removed from the joints and any remaining sealing product
removed from the edges. Damaged joint edges must be cut back down to stable concrete. The joint edges must be repaired according to Section 3.4. Before coating, the prepared joints must be provided with a provisional insert that can be easily removed after coating.

Deep cracks in the pavement slabs must be cleaned to remove dirt or any sealing compound and provided with a provisional insert, so that they can be filled with sealant after coating. Where required, these cracks must be widened before coating.

Roadway markings must be removed before spreading the coat.

The layer of mortar applied must have set to such an extent that vehicles and pedestrians cannot result in any damage, before the road is opened to traffic. The setting time should not be longer than 24 hours. The surface of the mortar after installation must be even and provide adequate skid resistance in the long term. The choice of aggregate should be in accordance with the concrete surface and its color should contrast sufficiently with the road markings.

3.1.5.1 Composition and production of reactive resin mortar

The reactive resin components and the aggregate must be subjected to forced mixing, for example via the use of a mechanical mixer.

Where reactive resin components already containing aggregate and/or pigments are delivered to the construction site, the content of these containers must be thoroughly stirred before application.

The thickness of the reactive resin mortar layer depends on the requirements. Reactive resins may only be applied at concrete surface temperatures of at least +8°C to a maximum of 40°C, while the temperature of the concrete base and the materials used must be at least 3 K higher than thaw point temperature.

Where the surface temperature is rising steeply, the application of reactive resins must be discontinued, as air escaping from the concrete layer will cause bubbles to form at the surface of the reactive resin layer. Application shall take place while the component temperatures are dropping. No surfacing may take place in humid weather (e.g. rain, fog, dew).

The concrete surfaces must be primed. The primer must be thin and free of solvents and must be applied in such a way that the concrete surface is evenly wet and covered. Where bubbles form, they must be opened up immediately and evened out. The primer is usually applied to the prepared surface by machine, directly followed by the application of an aggregate with a grain size of 0.3 to 0.9 mm to ensure good adhesion of the mortar. Any non-adhering chips must be thoroughly swept off the surface, and may be reused.
3.1.5.2 Coating

Before coating, the prepared joints and deep cracks must be provided with a provisional insert that can be easily removed once the coating has set. Coatings must be separate for the entire joint or crack width in places where there are joints or cracks.

The reactive resin mortar is usually applied to the prepared and primed surface by means of a machine.

Immediately after application, sharp-edged, dust-free aggregate must be liberally and evenly applied to the mortar and pressed down or rolled on to improve skid resistance.

The aggregate must be applied in such a way that the required skid resistance and long-lasting adhesion to the surface can be ensured; the largest aggregate should be embedded in the reactive resin to a depth of approximately half its diameter.

After setting, the excess aggregate must be swept away, and can be reused.

3.1.6 Resurfacing

Resurfacing is the restoration of the service life of a pavement by applying a new layer of concrete to the existing pavement or by replacing one or several layers of the latter. It is important to differentiate between:

Resurfacing by means of an overlay
Resurfacing combining an overlay with the removal of some layers of the existing pavement

Resurfacing is necessary when the factors causing the identified condition cannot be properly addressed with maintenance or repair measures. Renewals particularly become necessary when distresses have been caused by an inadequate bearing capacity (e.g. under-dimensioning).

Before carrying out the resurfacing, it should be checked whether it is necessary to improve the subgrade, base or pavement and to what extent the functionality of the drainage system can be guaranteed. Changes required to the gradient and transverse slope may be implemented during renewal.

During resurfacing, the thickness of the new concrete layer must be adjusted. In each case the condition of the remaining pavement layers, the available vertical clearances, the condition of the existing shoulders and the changes in traffic volumes are to be taken into account.

3.1.6.1 Overlays

When an overlay is built, the existing pavement can remain in place. The overlay may also consist of a new asphalt surface.
Where the existing concrete pavement is to be overlaid with concrete, it must be broken up into pieces measuring no more than 0.5 x 0.5, while overlaying with asphalt requires a maximum piece size not exceeding 1.0 x 1.5 m. The stress-relieved pavement should then be re-compacted, using a suitable compacting device (static, vibration) and used as a base for the new pavement.

The stress-relieved concrete pavement can then either be covered with a concrete levelling layer with a minimum compressive strength of 25 N/mm² (see Figure 3.11) or with an asphalt layer.

![Concrete levelling layer](image.png)

**Figure 3.11: Concrete levelling layer**

The concrete levelling layer must be notched according to the joint pattern of the future concrete layer, and taking into account the joint pattern of the old concrete pavement. Notching will not be required where non-woven fabric has been used.

Improvements in the transverse slope and the gradient can be accommodated by correctly dimensioning the concrete levelling layer.

In the vicinity of overhead structures, a minimum clearance height of 4.50 m must be maintained. Where this cannot be guaranteed, the overhead structure must either be raised or, where this is not possible (e.g. framework construction), the road surface must be lowered in the area by lowering the gradient for a corresponding distance in front of and behind the construction.

The design for a possible overlay must be checked in the vicinity of underpasses. Where such an overlay is not possible for structural reasons, a reduction in the gradient to the correct length must be planned and the corresponding section in front of and behind the structure must take the form of an inlay.

### 3.1.6.2 Resurfacing combining an overlay and the removal of some layers

When a resurfacing takes place as a combination of an overlay and an inlay, only the upper layer of the existing pavement is removed and replaced with a newly dimensioned pavement (possibly on top of a concrete levelling layer), retaining the existing lower layer.
Where the existing base layer consists of a notched cement-treated base course with hydraulic binder, the overlay can be built on it, provided that the existing concrete pavement is divided into small panels, using saw cuts or other techniques, to ensure that they can be removed without damaging the base course.

By installing a non-woven fabric across the entire width of the roadway, any cracks in the hydraulically bound base can be prevented from reflecting in the new concrete surface.

Mechanically compacted non-woven fabric made of polypropylene fiber, with a mass per unit area of 500 g/m², is to be used.

Gradient and transverse slope changes can be achieved by laying a concrete levelling base with a compressive strength of at least 25 N/mm².

3.1.7 Surface crack filling

Concrete pavements may have surface cracks through which water or de-icing salt solutions can penetrate into the concrete and cause structural damage. It is difficult to fill these fine cracks with a joint sealant but damaged areas can be effectively treated by means of gravity filling with an adequate material. During filling, the cracks are filled up without pressure from above. Low-viscosity resins are used with this aim.

Filling may not be carried out in wet weather. The cracks to be treated are to be dried and cleaned before filling, using an appropriate method (e.g. industrial vacuum cleaner). To achieve the required filling depth, an adequate flow of material into the crack must be ensured within the processing period for the filling material and is dependent on the construction temperature. The possibility of aerating the crack must be considered.

Wider cracks may necessitate preparatory work, e.g. routing.

The cracks must be filled up to a minimum depth of 5 mm or up to 15 times the width of the crack (whichever is smaller).

The lowest application temperature for filling with epoxy resin is 8°C.

The treated surface is to be protected with quartz sand before the working life of the treatment has expired. Additional subsequent filling is not permitted.

3.1.8 Injection

Cracks and small voids may form in pavements above the dowels and tie bars that have been embedded into the fresh concrete by vibration. Resulting long-term damage may occur (microstructural damage to the concrete as a result of the effects of frost / de-icing salt, tie bar corrosion).

This type of damage may be prevented by filling up such cracks or voids by injecting them with low-viscosity resin, using a low-pressure process (e.g. a pressure of 1.5
bar). Before injection, the concrete surface around the cracks must be cleaned, using an appropriate procedure (e.g. industrial vacuum cleaner). Cement sludge must be removed using suitable equipment. The concrete surface must be dry and clean.

The cracks and voids must be continuously filled with a self-injecting piston injection device at low pressure. Cracks and voids up to a depth of 25 cm can be filled up in this way.

When injecting the cracks and voids with epoxy resin, the temperature of the concrete surface may not fall below 8°C, while the component temperature must be 3 K above thaw point.

The treated surface is to be protected with quartz sand before the working life of the treatment has expired.

3.1.9 Drainage improvement

When planning and carrying out maintenance measures, it should be checked whether any measures to improve drainage are required.

It is essential to keep water out of pavement in order to maintain the road. Constant drainage is required to maintain the bearing capacity of the road. Water which has permeated must therefore be drained, using an effective drainage system, to avoid saturating the base or the subgrade.

Some examples of retrofit drainage systems are described below. In each case, a decision must be taken about the measures that can be taken to drain the water under the given circumstances.

Where drainage pipes are to be provided, these should have adequate cross-sections.

3.1.9.1 Additional seepage pipes along the edge of the roadway

A seepage pipe must be installed along the edge of the roadway. To ensure that the seepage pipe cannot freeze, it must be installed at a depth and a lateral distance from the surface of the embankment that is greater than the frost-proof thickness of the pavement. Connection to a drain pipe is essential.

3.1.9.2 Drainage when replacing lanes or slabs

Where concrete pavements and bases thicker than the existing ones are required for lane or slab replacement, the local conditions must be taken into account when taking the necessary steps to drain the underlying subgrade (also see Section 3.1.3 and Figure 3.5 and Figure 3.6.)
3.1.9.3 Drainage retrofit of the bedding layer

Where water has penetrated underneath the concrete layer because of a lack of lateral drainage, e.g. in older pavements with thick road markings or when the base layers are of different thicknesses, drainage can be ensured by incorporating a seepage line into the base course. The seepage line (drain pipe, drainage channel, etc.) must be drained by a transverse collector pipe.

3.1.9.4 Improvement of the surface water drainage

Where water remains on the pavement, e.g. due to a lack of transverse or longitudinal slope or a drainage obstacle, water drainage can be ensured by transverse or longitudinal grooving, by grinding or by using box channels, see Figure 3.12, and slot channels, see Figure 3.13, positioned transversally to the direction of travel.

Figure 3.12: Retrofit installation of a box channel

Figure 3.13: Retrofit installation of a slot channel
3.2 Maintenance Measures for Jointed Plain Concrete Pavements (JPCP)

3.2.1 Widening and filling cracks

It is necessary to differentiate between surface cracks and deep cracks. Deep cracks often lead to a faulting of the crack edges. Drilled cores from the crack area provide more detailed information. Surface cracks may remain untreated under continued observation. Deep cracks must generally be widened and filled.

The treatment of the cracks depends on their width and the variation in the crack width.

The crack must be treated in a manner that allows expansion when the crack edges move. In such cases, permanent renewal requires the installation of dowels.

Deep cracks that penetrate through the entire depth of the slab must be widened with suitable devices, so that a joint sealant can be applied. They must be filled with hot-or cold applied joint sealants. Spalls at the crack edges must be repaired with reactive resin mortar or cement mortar with a plasticizer.

Sufficient material must be applied to the crack during the processing time. The amount required to ensure complete filling of the crack depends on the temperature of the pavement. Care must be taken to ensure that air can escape from the crack.

The cracks must at least be filled to a depth of 5 mm or 15 times the crack width (the smaller of these values applies). The cracks must be treated in the same way as joints before they are filled.

Surface cracks (hairline cracks, shrinkage cracks and cracks with a width of up to 1 mm) must first be examined to determine whether any treatment is required or useful (e.g. for expansion reaction damage caused by an alkali-silica reaction) or whether observation of the damage should be continued.

Cracks of up to approximately 1 mm width can be filled with low-viscosity reactive resins.

During the filling procedure, the cracks are filled from the top without pressure. Filling with appropriate sealant material (low-viscosity resins) can be used to fill cracks close to the surface.

The cracks must be cleaned using appropriate methods before filling and must be dry during the filling procedure.

3.2.2 Dowel and tie bar installation at cracks

The following measures are to be considered for tie bar or dowel installation at longitudinal and transverse cracks in jointed concrete pavements, depending on the crack width, the location of the crack and the crack pattern:

The interlocking effect, which is present even with small crack widths, e.g. \( \leq 2 \) mm, contributes to the transfer of loads. No measures are required as long as no faulting
is found. However, the crack development should be monitored. It should be decided in each individual case whether maintenance measures are required, e.g. widening the crack and filling it with a sealing material. Maintenance or repair measures become necessary when the crack width exceeds 2 mm. It might be necessary to remove faulting of neighbouring slabs as a preliminary step.

Longitudinal or transverse cracks at a distance of more than 75 cm from a longitudinal or transverse joint must be widened and sealed with a sealing material. The crack should be widened to a width of 8 mm and a depth of 25 mm.

Larger crack widths require dowel or tie bar installation to connect the slab parts as shown in Figure 3.14 to Figure 3.19. Two methods are of particular interest for tie bar retrofit; tie bars with bent ends ("staples" or "U-bars") and stitching with diagonal tie-bars ("cross-stitching").

Tie bar retrofit using U-bars provides additional restraint to crack movement due to the angled ends of the bars, which are to be inserted into two holes that are required to be drilled for this specific purpose.

Diagonal tie bar stitching uses diagonal tie-bar pairs as follows:

- Transverse cracks: 5 diagonal tie-bar pairs per slab
- Longitudinal cracks: 5 diagonal tie-bar pairs per slab within the wheel track
  3 diagonal tie-bar pairs per slab outside the wheel track

The appropriate measure for longitudinal or transverse cracks at a distance of less than 75 cm distance from a longitudinal or transverse joint is cutting out and replacing a part of the slab (full-depth patch). The patches should have a minimum width of 1.50 m. Damage to the base (if evident) is to be repaired during this step. The connections of the patches to the remainder of the slab are to be implemented as construction joints and, for example, provided with four deformed tie bars with $\varnothing$ 20 mm per metre.

Dowels according to Figure 3.14 are to be provided for transverse joints.

Figure 3.14: 1 Retrofit Doweling

In the event of ramified cracks, cracks affecting several lanes or several parallel cracks in a slab, it has to be decided in each case whether dowel or tie bar retrofit
with diagonal tie-bar pairs is a suitable maintenance measure, whether a slab portion should be replaced, or whether it would be more appropriate to replace the entire slab.

Dowels are bars made of coated, smooth, round steel, e.g. $d = 25$ mm and $l = 500$ mm, that are inserted into transverse joints. They are used for transfer load and to ensure that the neighbouring slabs remain the same level. They allow free movement of the slabs and should be installed according to Figure 3.15.

Deep transverse cracks that are required to perform the function of transverse contraction joints must be dowelled in the longitudinal direction.

Tie bars are deformed steel bars, e.g. $d = 20$ mm and $l = 800$ mm, that are inserted into longitudinal joints. They are intended to prevent adjoining slabs from moving apart.

Deep longitudinal cracks as well as other cracks that do not have to perform the function of transverse contraction joints must be retrofitted with tie bars.

Three installation methods can be used for tie bar retrofit, and are described in the following series of figures.

- Tie bar retrofit as shown in Figure 3.16, with deformed steel bars, $d = 20$ mm and $l = 800$ mm.
- Tie bar retrofit as shown in Figure 3.17 with deformed round steel bars with angled ends, $d = 20$ mm and $l = 650$ mm,

- Tie bar retrofit as shown in Figure 3.18 with diagonal tie-bar-pairs with deformed, round steel bars, $d = 20$ mm and $l = 450$ mm at a pavement 26 cm thick.
Diagonal tie bar retrofit as shown in Figure 3.19 is performed as follows: two diagonal holes \(d = 32\, \text{mm}\) are practiced at a distance of 50 cm and filled with liquid reactive mortar, and the tie bar pair is inserted.

The holes are drilled at an angle of 27° to 30°. The tie bar length and hole depth depends on the thickness of the pavement.

### 3.2.3 Repair of edge spalls and broken-off corners

Edge spalls and broken-off corners that may lead to water penetration in the joint area and/or affect traffic safety are required to be repaired. Repair of edge spalls and broken-off corners should be combined with other maintenance measures, e.g. repair of the joint sealant, where possible.
Such repair measures may only be performed on slabs that are firmly supported. The joints must remain functional under all circumstances.

Repairs of this kind can only be effective when the mortar composition is optimised and the surface of the remaining concrete is properly prepared to ensure good bonding between the reactive resin mortar and the concrete base (bottom layer).

Edge spalls concerns distresses that do not penetrate through the entire concrete pavement. They may be the result of mechanical damage, or may have already existed as a result of cutting the slab too early during construction. However, timely cutting is necessary to prevent uncontrolled crack formation. The risk of cracking is particularly high when the pavement is exposed to rapid temperature fluctuations, e.g. cooling down due to a heavy rain. In such cases it may be sensible to risk small edge spalls due to cutting too early in order to prevent uncontrolled cracks, as spalls up to 5 mm are removed during the creation of the joint notch and the chamfering of the joint edges.

PC mortar is to be used for the repair of spalls (earliest possible use is 7 days after the concrete was laid). Appropriate tested mortars with graded aggregates are to be used for different layer thicknesses.

The service life of the concrete pavement is not affected by appropriate repairs.

Chipped corners (see Figure 3.20) are edge distresses in the corner area of a concrete slab and have to be treated in the same manner.

![Figure 3.20: Chipped corner](image)

Broken-off corners (see Figure 3.21) are a form of damage to the corners of concrete slabs. Usually, a crack with some minor additional spalling is visible on the surface. Broken-off corners show cracks that are either straight or diagonal and penetrate through the entire concrete slab. The area between the crack and the existing joints has often sunken.
Small, broken-off corners can be repaired with a concrete replacement system. Early high-strength concrete and quick-setting concrete can be used to repair broken-off corners larger than 50 mm. The material used depends on the period for which the road can be closed. However, replacement of the affected part of the slab, which is also required when larger parts of the corners are broken off, is the preferred method, because experience has shown that repair with concrete replacement materials is not a successful long term solution. Care should be taken to ensure that the minimum dimensions for the replacement of slab portions, (specified in Section 3.7) are respected.

3.2.4 Slab lifting and stabilization

Slab lifting and stabilization can prevent the premature destruction of roadway pavements. As the various lanes are subject to different loads, it is rare to have slabs lifted up over the entire width of a roadway; however, when the commercial traffic lane is subject to high loads, the overtaking lane may also be affected, with under-filling possibly being required in such cases as well.

Injection mortar with hydraulic binder is used to lift and stabilize slabs. This mortar must be free-flowing and quick-setting. Where necessary, an accelerating admixture may be used. The consistency must be constantly checked during installation. Care must be taken that the water/solid ratio according to the test certificates is accurately adhered to, as changes to these values are used to adjust the compressive strength. The uncontrolled addition of water is not permitted.

The mortar is to be injected into the boreholes under controlled pressure conditions. When stabilizing slabs, the injection pressure must be selected in such a way that unintentional lifting of the slabs is avoided. The injection pressure must be automatically controlled. Work may only be carried out at air and mortar temperatures between 5°C and 30°C. If the temperatures are exceptionally low during injection, the setting time of the injection mortar will be too long. Where the temperatures are too high, the compressive stress as a result of the longitudinal expansion of the slabs is so high that it becomes very difficult to lift the slabs. During the months with high day-time temperatures, injection work should take place during the night (night-time construction).

There is as yet no adequate experience with lifting and stabilization when unbound
bases are present. As unbound bases will rarely be subject to "pumping" in the vicinity of the transverse joints, it is rare to find settlements in the joint area, which means that stabilizing and lifting the slabs will only become necessary in exceptional cases.

When lifting and stabilizing slabs on cement-bound bases and an intermediate layer of non-woven geotextile, individual measurements have shown that this process may be used without problems. As the non-woven geotextile prevents any "pumping", with material being pumped through the transverse joints, it is rarely necessary to stabilize newly laid slabs. Only when settlements occur on a significant scale, usually caused by factors related to the base, can the evenness of the concrete layer be restored by lifting the sunken slabs.

Before under-filling, the slabs must first be separated from the base in a separate work step, using compressed air. Only then can the slabs be fully under-filled.

Improper execution of the slab lifting process may accelerate the destruction of the slabs. This would, for example, be the case when an attempt is made to lift the slabs using only the material injection pressure. This may result in incomplete under-filling of the slab. Cones of material will form underneath the drill-holes. Voids between these cones will result in cracks forming between the holes and ultimately in the destruction of the slabs.

To check the quality of execution, it should be ensured that the material injected is squeezed out through the adjoining drill-holes.

To ensure that the injection mortar is evenly distributed and that the lifted slab is supported over its entire area, a vibratory roller with a service weight of 3 to 4 t is to be used directly after under-filling the slabs. For lifting purposes, the slabs must be loosened from their base before under-filling (e.g. using compressed air).

Where lifting is prevented by dowels and tie bars, these must be cut and subsequently replaced.

The slab movement must be constantly checked during the lifting process. When mortar is being pumped of adjoining drill-holes before the lifting process has been completed, these holes must be plugged with pegs.

Once the mortar has set, the drill-holes previously filled with injection mortar must be filled with cement or resin-based mortar up to a depth of at least 3 cm. Any injection mortar that may be present in the drill-holes must be first removed to an appropriate depth.

Once the slabs have been lifted, the joint seals around the under-filled slabs must be replaced.

Stabilization of slabs is carried out at a maximum pressure of 0.5 MPa (5 bar).

To achieve the desired long-term results with slab lifting, the correct time to open the road to traffic must be observed. This is determined by the setting process of the
mortar, as specified by the manufacturer and as proven by the results of initial tests. The road may be opened to traffic no less than one hour after the process of setting the injection mortar with hydraulic binders has begun, with the minimum compressive strength of the injection mortar being 2.0 N/mm². Tests, e.g. indentation tests, must be carried out at regular intervals to check whether setting has begun. To determine the degree of setting of the injection mortar, a rod with a diameter of about 3 mm at its tip (e.g. a pencil cap) is to be pressed into an injection mortar cake (with a diameter of 100 mm and a thickness of 10 mm) placed onto a glass plate. The start of setting is characterized by the fact that a crack forms during the indentation test, running in a radial direction from the edge to the point of indentation.

When using expansion resins or compact silicate resins, the time for opening the road to traffic is determined by the manufacturer's specifications. This can be easily referenced via the product data sheet. Compact silicate resins are normally formulated in such a way that the roads can be opened to traffic immediately after execution of the work.

In addition to the commonly used injection mortars (such as hydraulic binders), silicate resins and expansion resins (foams) may also be used.

Silicate resin has easily controllable flow properties. It does not foam, thus the slabs will not lift up at a later stage. The silicate resin hardens to become solid matter and has good elastic properties. It hardens immediately after injection, which means that the pavement can be loaded shortly after injection. Work may be carried out even if the ground is saturated, as the resin will adhere to both humid slabs and slabs contaminated with dirt on the surface. Any stagnant water will be pressed out. The material has good long-term stability, is water-resistant and will not become saturated.

For economic reasons, this material has only previously been used on a small scale.

After injection, expansion resins will form an open-cell foam, usually with plastic qualities. Controlled foaming when combined with water should be tested before use. Use of such resins is more economical than the use of compact silicate resins, but not as economical as the use of hydraulic injection mortars. The long-term characteristics under traffic load and in combination with saturation have not yet been proven. Application should therefore currently only take place as part of projects with a limited service life.

3.2.5 Replacement of slabs and slab portions

Slabs that have been damaged by cracking, have broken corners or large vertical slab movements that have resulted in step formation must be partially or completely replaced to their full depth. The long-term replacement of individual slabs and slab portions (minimum dimensions length- and cross-wise 1.50 m) must be done with concrete of the same thickness as the existing concrete slabs (see Figure 3.22).
The replacement of entire slabs must be considered in the event of crack patterns 1 and 2 (see Figure 3.23) and when there are multiple cracks, large stepping or settlements of slabs or slab portions. However, where crack patterns 3 to 6 are observed, only portions of the slabs are required to be replaced. These slabs or slab portions must be connected to the adjoining slabs using dowels and/or tie bars (see Figure 3.22). In the case of crack patterns 7 to 10, it will not be necessary to replace slabs or slab portions, unless stepping or settlement are evident. Dowel/tie bar retrofit of the cracks according to Section 3.2.2 should be undertaken.

The slabs and slab portions to be replaced must have the same thickness as the adjoining concrete slabs. The edges of the slab portions to be replaced should run parallel to the longitudinal or transverse grooves along the entire length or width of a slab. The patch width should be at least 1.50 m (see Figure 3.24). The transverse contraction joints of the replaced slabs must form part of the joint grid of the adjoining slabs.
By reducing or halving the distances between joints, the traffic volume can be increased without increasing the slab depth.

The surface texture of the slabs and slab sections to be replaced should be similar to adjoining slabs. Excessive roughening, for example to increase skid resistance, will result in changes in the noise level and thus have an adverse effect on driving comfort. Texturing is usually completed with the aid of a brush designed specifically for that purpose. The choice of an appropriate texturing brush and the technique to be used are to be carefully coordinated.

Differences in the surface texture between existing and new slabs shall not be regarded as constituting a fault.

It is recommended to repair the slabs at a time at which the minimum joint gap is to be expected.

Quick-setting concrete can be used for rapid repairs of slab portions; and can be opened to traffic after only a few hours. The slabs to be replaced must be removed in such a way that adjoining slabs are not damaged. The slabs or slab portions must be cut to their full depth along the edges and then lifted out. Dowels and tie bars must be cut. The slab panels can be lifted more easily by making additional separation cuts at a slight incline to the initial cuts.

Repairs to the base which may be required should be carried out using the same construction method as for the existing one.

When the cement-bound base course is cracked, a non-woven geotextile or membrane should be placed between it and the concrete pavement.

When used as a base, unbound layers must be compacted.

Before laying the concrete, dowels and tie bars should be inserted into the existing concrete slabs and slab sections.

Appropriate measures are to be taken to ensure that no fresh concrete can penetrate the transverse grooves and cracks of the adjacent concrete pavement.
Where the aim is to ensure stable bonding with the existing layer, the surface of the cross-cut is to be roughened to a depth of up to 75 percent of the layer depth.

Where preformed profiles are used at joints, they may be installed immediately after the cut of the sealing groove. To avoid damage to the edges, the compressive strength of the concrete when inserting the profiles should amount to at least 70% of the values required for the pavement to be opened to traffic. In this way, the road can be opened to traffic at an early stage.
3.3 Maintenance Measures for Continuously Reinforced Concrete Pavements (CRCP)

3.3.1 Replacement of areas with punchout

Damage to pavements in continuously reinforced concrete is manifested by the failure of the concrete above the reinforcing steel (punchout) or pavement blow-up. The causes are in construction errors (poorly constructed end-of-day joints, defective operation of the concrete paver) with the result that the lowest layer of concrete - in the main - is insufficiently compacted, or in design errors (erodible base not protected by a bituminous interlayer or a geotextile, inadequate drainage, etc.) The area requiring repair is usually limited to a few metres, although in certain cases it may be tens of meters long. In such cases it is a matter of a succession of local defects.

In technical terms repair comprises the following phases:

First there has to be a determination and marking of the areas that have to be repaired. Visual inspection makes it possible to pinpoint zones suffering scaling, spalling and high concentrations of irregular cracks. In some cases more intensive sounding of the bordering areas may be required. Such examination may possibly be supplemented by taking cores. The length of the area to be repaired, measured parallel to the axis of the road, is never less than 1.50 m, whereas its minimum width is 1.50 m. Should more than one lane show defects, the work must be carried out in successive phases. The repairs are carried out on one lane at a time, so that a gradual transfer of the internal stresses in the reinforced concrete structure is assured. It is for example advisable to repair the fast lane first and then to repair the slow lane. Where the road has three traffic lanes, it may sometimes be possible to deal with the two faster lanes at once.

3.3.1.1 Making the sawcuts

Once the area to be repaired has been marked out (always as a rectangle), the concrete is cut through its entire thickness (including the reinforcement). The sawcuts are made perpendicularly to the pavement surface. Two additional sawcuts with a depth of between 4 and 7 cm, depending on the position of the reinforcement, are made at least 1 m beyond the first 2 sawcuts. These latter sawcuts may in no case cause damage to the longitudinal reinforcement. This procedure makes it possible to expose the existing reinforcement during demolition and the new reinforcement may be attached to the existing reinforcement using steel wire. However, this method cannot be applied if the bituminous interlayer or the road base must be repaired. In such cases the reinforcement must be replaced by drilling holes with a diamond drill and using chemical anchoring.

3.3.1.2 Demolition

The marked zone is demolished using a suitable method. The adjoining areas of the pavement may not be harmed. In those places where the existing longitudinal reinforcement is recovered the concrete is removed using pneumatic hammers taking care not to damage the reinforcement (the reinforcement may not be bent, etc.). The concrete around the edges of the area to be repaired is cut away vertically beneath the sawcut. Should it appear during the removal of the concrete that the damaged
area is more extensive than anticipated, a new sawcut will be made and the concrete removed as far as the new sawcut. Damage caused to the bituminous interlayer or the base during the removal of the concrete must of course be repaired. Repairs to the base are made with roller compacted concrete with a depth of at least 15 cm. Minor damage to the base (e.g. mildly eroded lean concrete) may after cleaning be repaired by treating with a poured bituminous mortar.

3.3.1.3 Repairing the reinforcement

The original reinforcement is repaired with reinforcing steel with a diameter at least the same as that of the existing reinforcement. If the existing reinforcement has been cut off so that a length of at least one metre is exposed, the new reinforcement is attached to it with steel wire in at least 2 places over the distance of one metre. If the existing reinforcement has been cut off (as in the case where the interlayer and/or the road base has to be repaired), the new reinforcement must be anchored chemically in holes drilled with a diamond drill. The holes, which shall have a diameter at least 6 mm greater than the reinforcing steel, are drilled so that they lie parallel to the surface and the axis of the pavement with a depth of 40 cm, close to the existing longitudinal reinforcement. Any overlapping of new reinforcing bars should be at least 75 cm. These must be secured with steel wire in at least 2 places. To strengthen the attachment of the new concrete to the old concrete, it is advisable to double up the longitudinal reinforcement by placing new reinforcement in the lower third of the pavement. The depth of the reinforcement is maintained by one or more supports made by a transverse bar with a diameter of 12 mm placed at right angles to the axis of the road on chairs with suitable dimensions. The maximum distance between the transverse steel bars or between a transverse steel bar and the sawcut side of the concrete is 75 cm. The tie bars in the longitudinal joint have a diameter of 16 mm and a length of 800 mm. They are provided every 80 cm in such a way that the existing transverse and longitudinal reinforcement is not touched during drilling. The tie bars are installed so that they lie parallel to the surface of the concrete pavement. After drilling they are fixed over half their length in the concrete by casting. Small repairs (with a length of less than 2 m), however, may be completed without installing tie bars.

3.3.1.4 Composition of the concrete

A quick setting concrete (fast-track or even ultra fast-track) is used. Where long repairs must be made (>6 m) the repair will be made in two separate phases using 2 different concrete compositions, as shown schematically in Figure 3.25. Only the end parts with a length of ± 2.0 m are made from quick setting concrete. First of all concrete is laid in the central part. This part is built in the same way as a newly built CRCP. The longitudinal reinforcement is replaced over the entire length of the repair in advance. The concrete of the end parts is laid at least 3 days after the placement of the concrete of the central part.
3.3.1.5 Placement of the repair concrete

The base is moistened prior to laying the concrete. If the area of the repair is only a few sq m, the concrete may be compacted using a poker vibrator or a vibrating beam screed. A double beam screed is, however, essential if the area is larger. Nonetheless the concrete at the edges must be carefully compacted using a poker vibrator. A slip form paver will be used when repairing long sections. The profile of the repaired area must be carefully integrated into the existing lane. The quick setting concrete must of necessity be laid in the morning (the ideal time is usually between 10 and 11 am). The tensile strength of the concrete must be high enough to absorb the tensile stresses by the time of the first contraction of the CRC after the completion of the repair (i.e. when the ambient temperature starts to fall). If the concrete is laid in the morning, the quick setting concrete will have several hours during which it can build up tensile strength. It has been estimated that the compressive strength of concrete that is 10 hours old should approach at least 20 N/mm².

3.3.1.6 Finishing the concrete

The repaired area should have a surface texture similar to that of the surrounding pavement. The concrete is immediately protected from drying out by application of a curing compound and by covering with a protective layer with a view to improving the development of mechanical strength by retaining the released hydration heat in the concrete.
3.3.1.7 Weather conditions at the time of the repair

If the repair has to be carried out in extremely warm weather, it is advisable to cool the adjoining concrete for 50 m on both sides by spraying water onto it in order to reduce longitudinal pressures. Other possibilities include spreading a layer of wet sand over the same 50 m or covering it with a reflecting foil (polyethylene with a silvered layer).

3.3.1.8 Opening to traffic

The repaired pavement is opened for use after it has been restored to its original condition (sealing of longitudinal joints, cleaning, etc.) and as soon as the concrete has reached a minimum strength of 40 N/mm$^2$ as measured on 100 cm$^2$ cores, or of 35 N/mm$^2$ on test cubes with a side of 15 cm cast on expanded polystyrene moulds.
4 Appendix 1: Results of the survey on maintenance of concrete roads
Appendix 2: Case Study “Full Depth Replacement of Concrete Panels with Rapid Strength Concrete in California”
6 Appendix 3: Case Study “REHABILITATION OF CRCP WITH HIGH EARLY STRENGTH CONCRETE ON THE SCHOEMANN FREEWAY IN SOUTH AFRICA”