



HIGHWAYS DEPARTMENT

GUIDANCE NOTES ON PRESERVATION OF CONCRETE CARRIAGEWAY

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1.0 INTRODUCTION

These Guidance Notes provide advices on the preservation techniques for concrete carriageway. Whilst guidance has also been provided on the selection of appropriate repair materials, it is not possible – due to the wide range of products that are available – to provide detailed advice for every product that might be used.

These Guidance Notes are the extension of the Guidance Note on the Repair of Spalled Concrete Road Joints (RD/GN/028) which is hereby superseded.

2.0 PRESERVATION STRATEGY

With the high strength and durable characteristic of concrete, concrete carriageways have particular advantages over road sections subjecting to heavy and frequent braking and steering force. In a technical report titled “Long-life Concrete Pavements in Europe and Canada” published by the United States Department of Transportation in 2007, “concrete pavements” are considered synonymous with “long-life” by Canada and other 5 European countries. Their concrete pavements have design lives of 30 or more years before rehabilitation or replacement is required. Little if any maintenance intervention is expected over the service life. Instead of large-scale reconstruction works, their maintenance and rehabilitation practices on concrete pavements mainly include inlays, overlays, slab replacements, diamond grinding and joint resealing, with due consideration of the life cycle costing.

According to our Guidance Notes on Pavement Design (RD/GN/017), the design life for most of our rigid pavements is 40 years. This is comparable to the current design philosophy for long-life flexible pavement. Our concrete carriageways are constructed of either jointed plain concrete or jointed reinforced concrete, over which discontinuities in form of different joint types are present by nature. With proper quality control, localized repair or bay replacement would not affect the overall integrity of the pavement structure.

From past maintenance practice over the years, such localized treatment approach, instead of full reconstruction, can satisfactorily maintain the pavement within the “long-life” domain. It has also been evident as an effective and practical means in up-keeping the performance of our rigid pavement assets. Such practice avoids highly socially disruptive and costly full-scale reconstruction works. The above maintenance experience obtained from the past is summarized in Figure 1 as a general guideline for preservation of concrete carriageways.

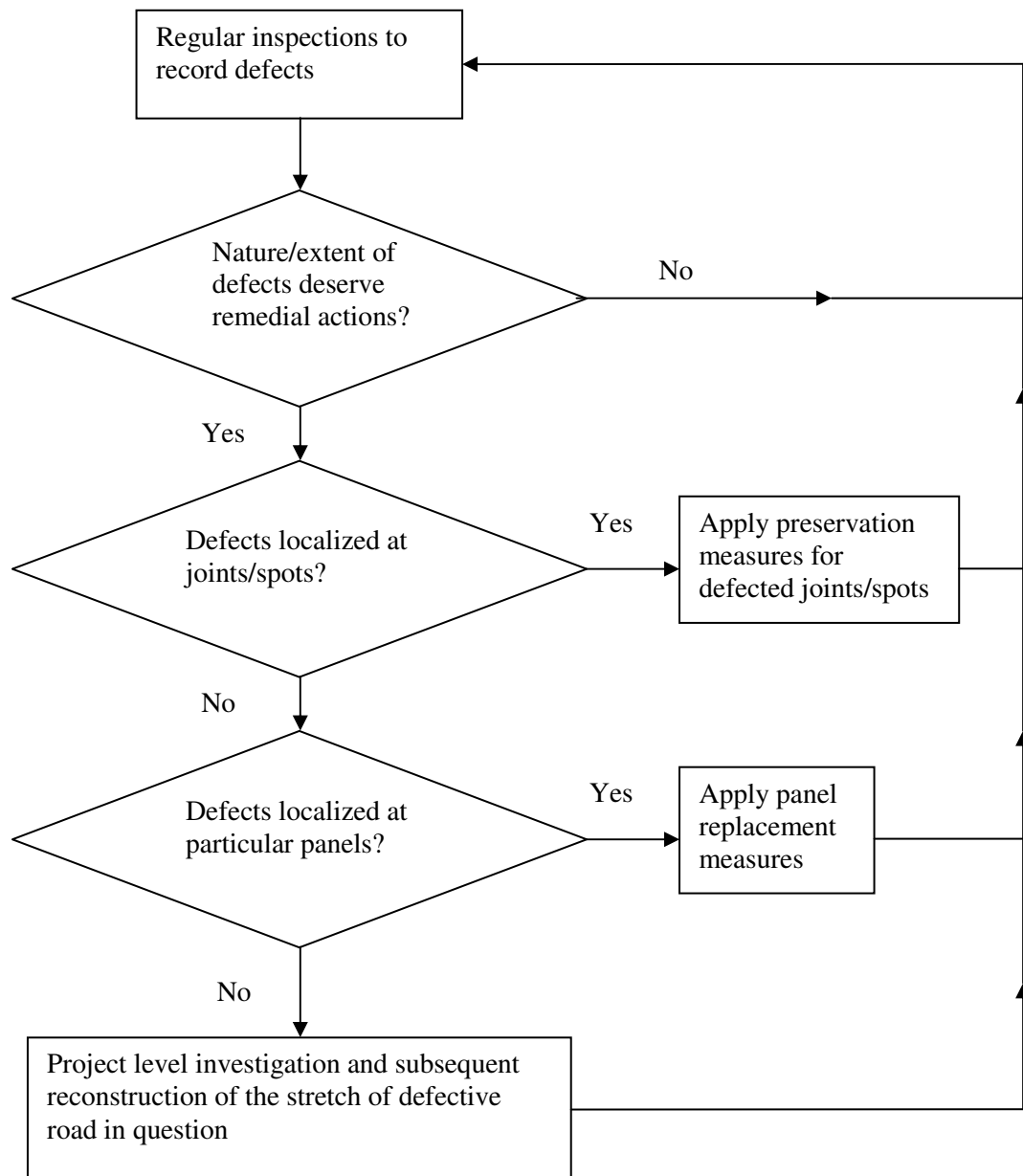


Figure 1 Preservation Strategy

3.0 ROAD INSPECTIONS

In order to maintain the carriageway in a serviceable condition, regular inspection is of utmost importance. The aim of any inspection is to obtain data that will allow the engineer to plan the appropriate maintenance treatments and restoration programme. A logical, systematic and standardised system of recording defects should be adopted so that a history of fault development and repair can be established.

Detailed procedures for and frequencies of inspections should be referred to Road Inspection Manual (RIM).

4.0 CATEGORY OF ROAD DEFECTS

There are five predominant modes of distress in concrete carriageway namely:-

- Cracking;
- Deformation;
- Joint sealant defects;
- Spalling; and
- Surface texture defects.

Detailed description of the defects should be referred to the Guidance Notes on Catalogue of Road Defects (CORD).

5.0 MATERIALS FOR REPAIRS

5.1 General

In general, the ‘concrete’ group would be more cost-effective for repairs of normal to large sizes, whereas the ‘mortar’ group might be more appropriate for thin or small repair sizes. Due to numerous products currently available in the market, it is not possible to provide detailed guidelines for every product that might be used. The engineer responsible for the works should use the guidelines provided in these Guidance Notes to determine which materials are most suitable for producing a satisfactory repair under his particular circumstances.

Some materials have tight working tolerances, such as air temperatures and surface wetting conditions during placement, mixing quantities and time and maximum depths of placement. Additionally, material cost, shelf life, physical properties, workability and performance vary greatly among the different material types and from brand to brand within each type. It is important, therefore, that manufacturer’s literature is carefully studied to ensure that the correct material is selected.

It is suggested that any proposal relating to the use of a new repair material be referred to R & D Division for preliminary review.

5.2 Concrete

□ *Portland Cement Concrete (PCC)*

Where sufficient time is available to accommodate the long curing time before opening to traffic, PCC represents the most cost effective repair material. Additionally, provided the repair is executed correctly, no problems should arise due to differential shrinkage, differences in elastic modulus or bonding. In view of its good performance and cost-effectiveness, it is suggested to use PCC for full depth repairs when the situation allows.

□ *Rapid Hardening Cementitious Concrete*

Rapid hardening cementitious concrete is a concrete that generally sets and develops early strength within a short time. While it can be suitable for situations where repair works must be completed quickly, it should be noted that

the early strength development of this type of concrete is ambient temperature dependant and the development rate decreases significantly as ambient temperature falls. This dependency also varies amongst products of different brands and an example is illustrated in Figure 2 below. It is therefore necessary to carefully determine the dependency of the early strength development and ambient temperature of the proposed fast hardening concrete before its use so that the curing time requirement of the pavement at different time in a year can be accurately taken into account in formulating the repair works.

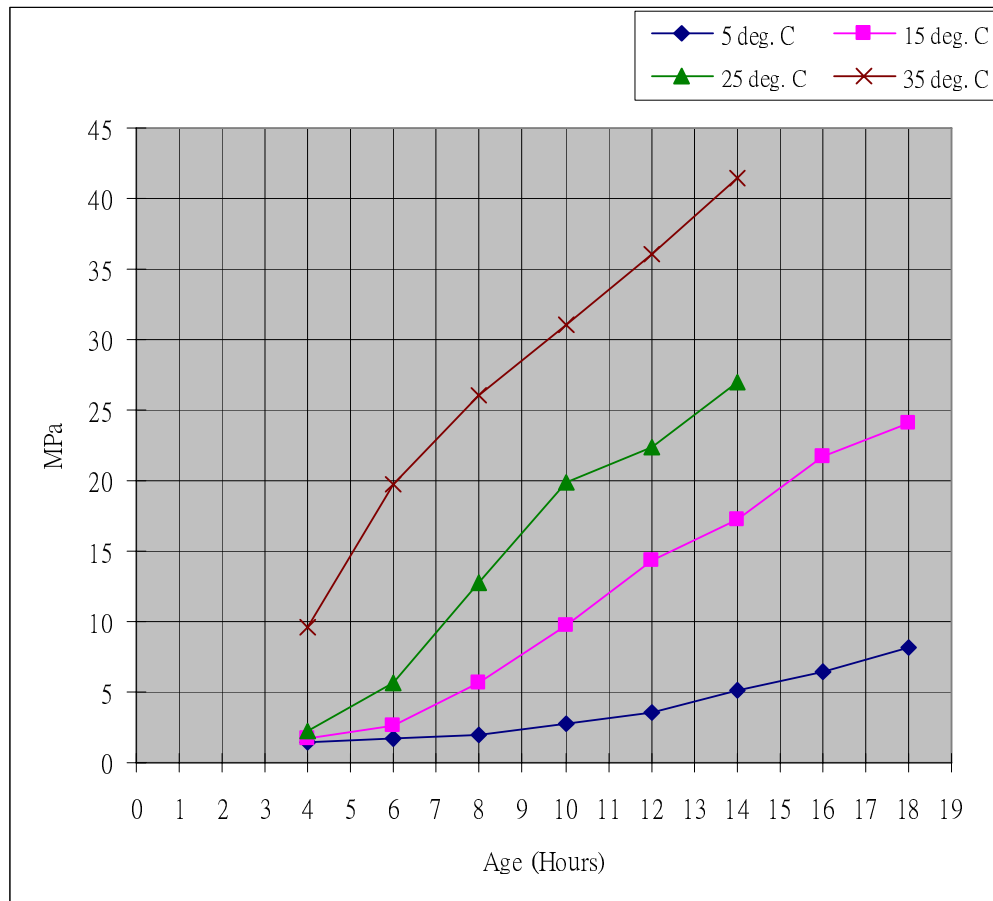


Figure 2: An Example of Compressive Strength Development of Rapid Hardening Concrete Under Different Curing Temperatures

Rapid hardening cementitious concrete is placed, compacted and textured in a similar manner of PCC. Due to the short setting time of the concrete, skilful labours are required to place, compact and texture the concrete before it is set. There are two kinds of technological approaches commonly used in Hong Kong to achieve the rapid hardening property. They respectively employ the use of superplasticizer with set accelerator, and the use of calcium sulfoaluminate cement (CSA).

Rapid hardening cementitious concrete using the superplasticizer with set accelerator is produced as ready mixed concrete. At ambient temperature of 25°C, it can typically achieve adequate strength for live traffic around 12 hours. It is mixed in batching plant and delivered to site by concrete truck. Set accelerator is then added to the mix on site prior to the placing of the concrete by the concrete supplier. In Hong Kong, there are at present more than six concrete

suppliers producing this kind of concrete. Each concrete truck can only carry about 2.5m³ of concrete to reduce the risk of concrete hardened inside the truck mixer. Taking into account the part-loaded effect of the concrete truck and the site supervision charge for adding set accelerator on site, the cost of this rapid hardening cementitious concrete is typically about 4 to 5 times of PCC at the time of writing this report.

Rapid hardening cementitious concrete using CSA is produced as site mixed concrete. The CSA, fine and coarse aggregates are pre-packed and are suitably mixed with water on site when it is used. It can achieve adequate strength for live traffic within 2 hours and has a short setting time. It has a low shrinkage value and good sulfate resistance. In Hong Kong, there are more than three suppliers providing this kind of concrete at present. The cost of this kind of concrete is about 6 to 12 times of PCC at the time of writing this report. However, in view of the difficulty in controlling the quality of site mixed concrete, the relatively high cost and limited experience in its application to road pavements under local conditions, it is not recommended to use this kind of concrete.

❑ *Polymer Concrete*

Polymer concrete is the composite material made by fully replacing the cement hydrate binders of conventional concrete with polymeric binders or liquid resins such as thermosetting resins, vinyl monomers, and tar modified resins. They do not contain a cement hydrate phase. Most of the thermosetting resin and monomer systems for the polymer concrete are polymerized at ambient or room temperature. Fresh polymer concrete are placed and finished in a manner similar to conventional cement concrete. However, due to the short setting time, skilful labours are required to place, compact and texture the concrete.

In comparison with ordinary cement concrete, the properties such as strength, adhesion, watertightness, chemical resistance, freeze thaw durability, and abrasion resistance of the polymer concrete are generally improved to a great extent by polymer replacement. On the other hand, poor thermal and fire resistance and large temperature dependence of mechanical properties are disadvantages of the polymer concrete. In addition, the cost of various polymers for the polymeric binders is quite high compared to that of Portland cement and other cements.

In view of the above disadvantages and high cost, it is not recommended to use the polymer concrete except where there is insufficient time for adequate curing of cementitious concrete and the scale of repair is not excessive.

In case a polyester concrete is used for repair, it is recommended to add fabric reinforcement into the concrete. In particular, chicken mesh is recommended for use as fabric reinforcement in view of its low material cost and ease in handling and fixing. According to the Technical Report RD/TR/056, the use of polyester concrete with chicken mesh shows an improvement of about 60% of fatigue resistance under wheel tracker tests when compared with the use of polyester concrete without reinforcement.

5.3 Mortar

□ *Cement Mortar*

Cement mortar shall consist of ordinary Portland cement, sand and water. It requires less skilled workers when compared with other resin mortars, and is the cheapest repair material if sufficient time is available to accommodate the long curing time before opening to traffic. Due to vulnerability of the thin cement mortar to damage under heavy wheel load, bonding between the cement mortar and the parent concrete will determine the durability of the repaired pavement.

□ *Polymer Mortar*

Polymer mortar is the composite material made from polymeric binders or liquid resins with sand. They do not contain a cement hydrate phase and most of them are polymerized at ambient or room temperature. They are placed and finished in a manner similar to conventional cement mortar. However, due to the short setting time, skilful labours are required to place, compact and texture the concrete.

Similar to polymer concrete, the properties such as strength, adhesion, watertightness, chemical resistance, freeze thaw durability, and abrasion resistance of the polymer mortar are generally improved to a great extent in comparison with cement mortar. However, poor thermal and fire resistance and large temperature dependence of mechanical properties are disadvantages of the polymer mortar. In addition, the cost of various polymers is quite high compared to that of Portland cement and other cements.

- *Resin Mortar*

Resin mortars are based on reactive resins filled with carefully graded aggregates. They are generally supplied as two or three component systems: resin and hardener (either or both may contain fillers) or resin, hardener and fillers.

Resin mortars provide rapid strength development, high bond strength and a wide chemical resistance. However, the coefficient of thermal expansion of most resin materials is several times greater than that of concrete and, consequently, can lead to failure of large, thin-bonded repairs. In order to minimize the difference in thermal properties, its sand content shall be in accordance with the manufacturer's requirements in the range between 7 and 11 to 1 of resin.

Additionally, as the cooling and hardening of most resin materials involves an exothermic reaction, contraction of the material as it cools may contribute to eventual failure. Therefore, the volume, thickness and temperature of the resin materials and the cure temperature should be carefully considered and in accordance with the manufacturer's requirements.

Of the resin systems, epoxy resin mortars are the most widely used in concrete repairs. Polyester and acrylic resin-based mortars are used, generally for small-area repairs where their very rapid development of strength is required. High-modulus, rigid polyester and acrylic mortars are not suitable for larger area repairs because of its short workable period.

(i) Epoxy Resin Mortar

Epoxy resins consist of a reactive resin and a hardener. To achieve the full properties of the cured resin system, correct proportioning and thorough mixing are imperative. Fine aggregate shall be mixed with the epoxy resin and appropriate hardener in the recommended proportions to form the epoxy resin mortar in strict accordance with the instructions of the manufacturer.

Some epoxy resin mortars have added styrene butadiene rubber (SBR). From experience, the rubber improves their flexibility and their bonding with the substrate and enhances the durability of the mortars. However, due to the very high cost of such kind of products, they should only be used when exceptionally high durability is an absolute necessity.

(ii) Polyester Resin Mortar

Polyester resin mortar shall normally compose of two part components of liquid resin and hardener. Mixing, compaction and curing of polyester resin mortar shall be in accordance with the manufacturer's recommendations. Aggregates if required for mixing shall be in accordance with the manufacturer's recommendations on type, gradation, and quantities.

5.4 Typical Characteristics of Common Repair Materials

The typical characteristics of some commonly used materials in permanent repairs are listed in Table 1 for reference.

Table 1
Typical Characteristics of Common Repair Materials

Material				Typical Material Properties						
	Thickness Limitations	Installation Temperature	Curing	Drying Shrinkage	Coefficient of Thermal Expansion	Compressive Strength (MPa)				Elastic Modulus (GPa)
						2 Hrs	24 Hr	3 Days	28 days	
Portland Cement Concrete	> 40mm	5 – 32°C	Wet 7 days	Moderate	$7-12 \times 10^{-6}$	0	5	20	40	23
Rapid Hardening Cementitious Concrete	> 50mm	5 – 30°C	Wet 2-12hrs	Moderate	$8-20 \times 10^{-6}$	0-20	20-40	-	55-85	1-30
Polymer Concrete	>30mm	7 – 35°C	Wet 2-3hrs	Low	$7-12 \times 10^{-6}$	20	30	40	50	22
Epoxy Resin Mortar	>5mm	10 – 32°C	Air	Low	$25-30 \times 10^{-6}$	0	70	80	85	0.5-20
Polyester Resin Mortar	>5mm	0 - 60°C	Air	Low-Moderate	$25-35 \times 10^{-6}$	60	80	-	100	2-10

Note: Drying Shrinkage:

Very Low	=	<0.025%
Low	=	0.025% - 0.05%
Moderate	=	0.05% - 0.1%
High	=	>0.1%

5.5 Temporary Repair Materials

On some occasions it may be necessary to undertake temporary or emergency repairs quickly, using materials which can be trafficked in a short time. However it is advisable to carry out permanent repairs as soon as practicable, otherwise further deterioration of the slab may occur. Temporary repairs may be required to perform satisfactorily for a period of time and therefore adequate preparation, such as removal of all loose and damaged concrete and making the pavement surface clean and free from debris, should be carried out.

For full depth temporary repairs, either dense bituminous macadam or hot rolled asphalt may be used. Partial depth repairs using either normal bituminous or instant filling material may be undertaken as a temporary remedy to shallow or deep spalling at joints or to surface scaling. If compacted by hand it may be necessary to lay the repair material slightly higher than the surface of the surrounding slab to allow for further compaction under traffic. It is recommended that the minimum thickness of this type of repair should be 20mm and if the repair is a deep one, it is advisable to apply the repair material in layers approximately 50-100 mm thick.

Materials that are applied across a joint should have elastic properties that will enable them to accommodate movement at the joint. If necessary, the surface of temporary repairs may be 'dusted' with cement or sand to prevent the repair materials being picked up by the tyres of vehicles which traffic it soon after the repair.

❑ *Bituminous Materials*

Bituminous materials are used almost universally as temporary repair materials for concrete carriageway. Under circumstances where permanent repairs cannot be carried out in a timely manner due to traffic and/or environmental constraints, temporary repairs of bituminous materials may be left in place for a considerable period of time without jeopardizing road users. They are relatively inexpensive, easy to place and can prolong the life of the pavement by preventing rapid deterioration.

❑ *Instant Filling Material*

Instant filling material consists of a controlled blend of fine aggregates and a special bituminous liquid. It can be applied cold with no tack coat, no mixing, no special skills and no special tools required. It cures partly by exposure to air and partly by manual compaction. It is fast setting when exposed in air and capable of sustaining road traffic immediately after applying. However, instant filling material only has an application period of several months and hence permanent repair should be carried out within the application period.

5.6 Principle on Specifying the Use of Proprietary Products

If there is a need to specify the use of a proprietary product, such as there is no proper means of providing a functional specification that can completely prescribe the meritorious performance of a proprietary product which has proven record to substantiate its conduciveness to the works, the engineer should seek approval in accordance with established procurement procedures and guidance for the

procurement with reasons. The justification and approval should be properly documented.

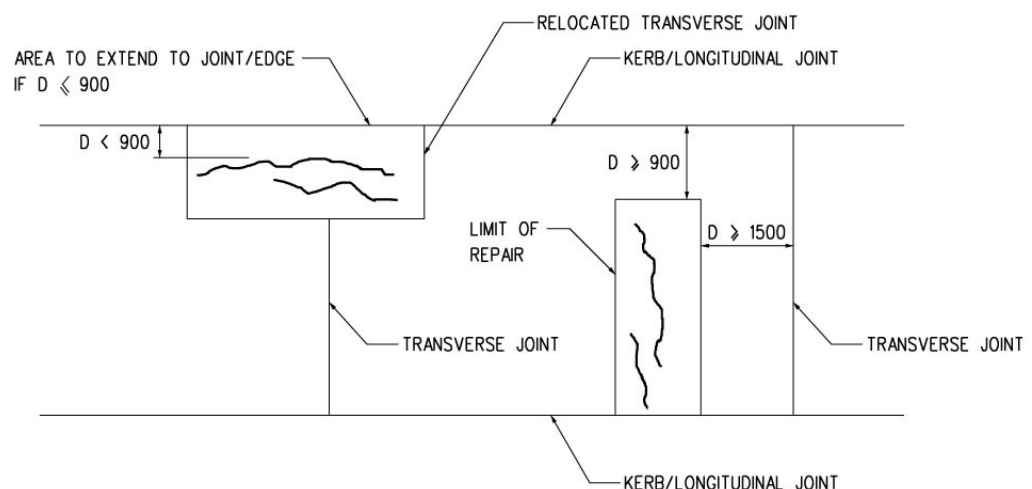
6.0 COMMON METHODS OF REPAIRS

6.1 Repair Size Consideration

The size and geometry of a repair can affect the speed of completion. Accurately defining the repair boundaries is essential to completing any repair quickly.

To simplify concrete removal, as well as to maintain proper visual patterns, repair areas should be rectangular in section. Additionally, in order to reduce the number of joints required, it is cheaper and easier to combine adjacent repair areas into one single rectangular area. Where the distance between repair areas is 300mm or less, they should always be combined to form a single rectangular repair.

Full depth repairs should have a minimum width of 900mm to enable dowel holes to be drilled. The repair area shall either abut or straddle a joint/an edge of the concrete slab or be at a minimum distance of 900mm from longitudinal joints and 1500mm from transverse joints (Figure 3). If a repair passes a transverse joint, the portion of the transverse joint in the repaired area should be relocated to its end nearest to the original transverse joint. The longitudinal joint between this new transverse joint and the remaining portion of the original transverse joint should be constructed without tie bars.



Note: D denotes distance measured in millimetre.

Figure 3 *Plan View of Full Depth Repair*

Thin bonded repairs should be limited in depth to the top one-third of the slab and should never come into contact with dowel bars. If dowel bars are reached, a full-depth spall repair must be carried out. The practical minimum depth of thin bonded repair is 10mm and the minimum width of the repair should be 150mm or 100mm if resin mortar is used.

6.2 Thin Bonded Repairs

Resin mortars are in effect the only practical materials applicable for thin bonded repairs in many circumstances. Particular care is needed when selecting an appropriate repair material for thin bonded surface repairs, which involves bonding the new repair material to existing concrete. Since resin mortars' coefficient of thermal expansion and elastic modulus are considerably different from those of PCC, the durability of the repaired pavement largely depends on whether the bond strength between the repair material and the parent concrete can overcome any shear induced due to the difference of material properties. Proper site control to ensure good bonding is therefore critical, else debonding of the repair or further cracking of the existing concrete will ensue.

The procedures of thin bonded repairs to surfaces of slabs are described in Appendix A.

The success of thin bonded repairs depends largely upon developing good bond at the interface between the repair material and the existing concrete. This is best achieved by compacting the repair material against a freshly scabbled, clean surface. The finished repair must be flush with the existing slab surface and must not bridge the joint.

The procedure described in Appendix A requires the delineating groove to be chased out rather than sawn in order to provide a roughened surface against which the repair material can be properly bonded (Figure 4). Sawing produces a polished surface which inhibits good bond and which is difficult to roughen sufficiently without the risk of further spalling. There is also an undesirable tendency for the sawn grooves to extend beyond the corners of the repair. If required, however, a shallow delineating groove may be sawn to start with and subsequently chased out to the full depth.

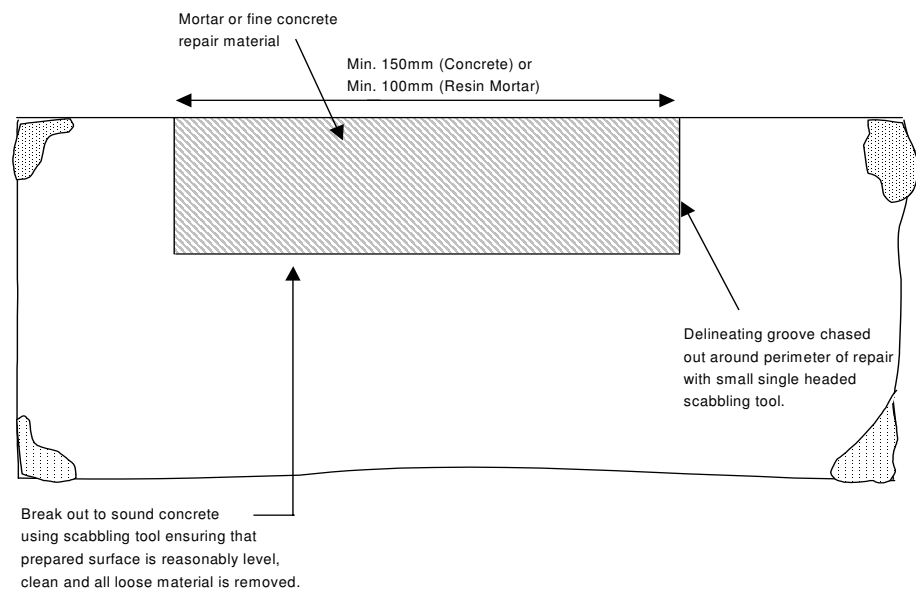


Figure 4 Sectional View of Thin Bonded Repair

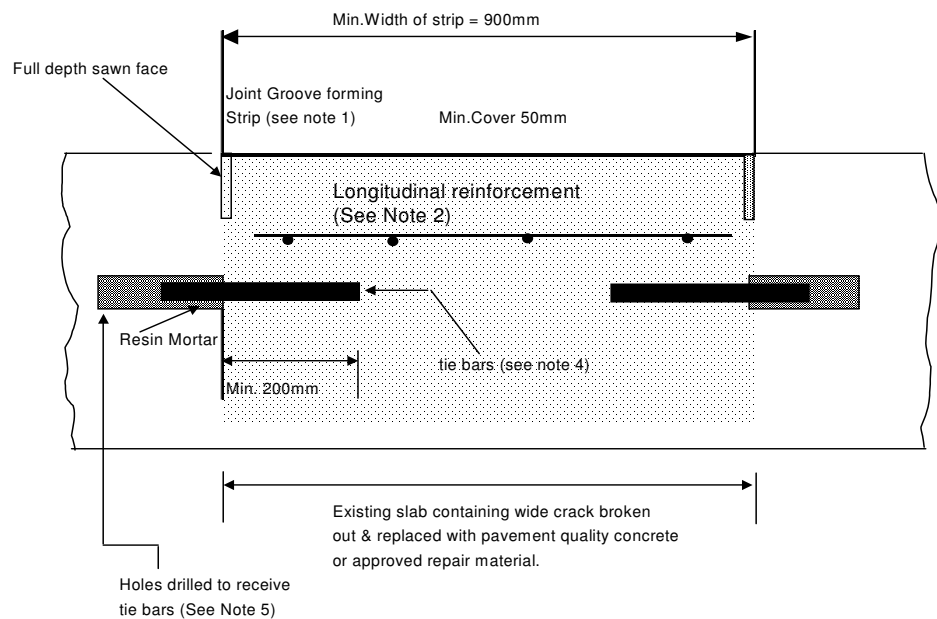


Figure 6 Longitudinal Full Depth Repair

Notes:

1. Polyethylene foam joint groove forming strip 3mm wide x 40mm deep stuck along top edges of remaining slab.
2. Appropriate longitudinal mesh reinforcement, main bars parallel to longitudinal direction.
3. Dowel bar of 25mm diameter and 650mm long with 75mm tight fitting PVC anti-corrosive sleeve should be fixed into holes using resin mortar at mid-depth and at 300mm c/c except where it abuts a transverse joint.
4. Tie bars to be 20mm diameter for slabs up to 225mm thick and 25mm diameter for slabs thicker than 225mm.
5. Holes drilled 150-200 deep to receive tie bars at 600mm c/c.

6.3.3 Using Precast Concrete Approach

The use of precast concrete panels for maintenance works is an efficient, less disruptive, cost effective and environmentally friendly method in rectifying defects that require full depth repairs where the time for the maintenance works is limited.

A precast concrete panel is fabricated off site using PCC based on the area to be repaired. The existing concrete pavement is removed, free-flowing fast hardening mortar is used as bedding, and the precast concrete panel is then lifted to the required position. This repair method can shorten the site construction time to as short as one night (about 5 hours) for small panels repairs and two nights for larger scale repairs. The detailed method of using precast concrete panel for full depth repair of concrete carriageway is described in Appendix B.

Lifting arrangement is one of the most important aspects to be considered in designing the precast concrete panel. Adequate reinforcement must be provided in the panel so that it is structurally stable during lifting. The bending stress, shear stress and punching shear stress during lifting have to be checked to ensure its structural stability.

The precast concrete panel shall be flushed with the adjacent panels to ensure the road safety. To achieve this, steel sections are fixed near each corner of the panel and a free-flowing fast hardening mortar is used as the bedding. Typical arrangement is shown in Appendix B.

The use of cement/sand bedding is not recommended because it is difficult to adjust the bedding level if the precast concrete panel is found to be not flush with the adjacent panels. In addition, the curing time required by cement/sand bedding will largely sterilize the benefit of using precast concrete for repairs.

Since the concrete panel is precast with adequate curing time, the quality of the pavement is good. In addition, the PCC used in the precast concrete panel is compatible with the existing concrete carriageway and hence differential thermal expansion would not be a problem. However, no dowel bar can be inserted in repairs with precast concrete panels. Stepping with adjacent carriageway may be encountered in the long term if differential settlement occurs.

7.0 REPAIRS ON CRACKS

7.1 General

Narrow transverse cracks are a normal feature of all reinforced slabs and roadbases. They are considered to be structurally insignificant, not expected to deteriorate any further, and consequently unlikely to require any remedial treatment. However, longitudinal cracks are not expected and may well deteriorate and develop further unless remedial measure is taken.

Where longitudinal and transverse cracks cross there is a risk of spalling occurring, particularly if they cross obliquely. Reinforcement at medium transverse cracks may not have yielded completely and action should be taken to prevent the ingress of water, brine etc which could lead to corrosion and spalling. The reinforcement at wide cracks is almost certainly yielded. In effect the cracks are likely to be acting as either undowelled or untied joints and consequently require at least a full depth and perhaps a bay replacement repair.

No crack of any type is expected to occur between the joints in unreinforced slabs. In case narrow transverse cracks occur, it is quite likely that they will become wider in a fairly short time in this type of slab. Hence, although narrow transverse cracks may not require any immediate treatment, they need to be regularly inspected. Medium and wide cracks should be treated in the same way as similar cracks in reinforced slabs.

The most likely cause and appropriate remedies for structurally significant cracks are given in the Table 2.

Table 2 Causes of Cracks and Remedies

Type of defect	Cause	Remedies
Transverse cracks	Excessive bay length	Medium width cracks - form a groove and seal
	Dowel bar restraint at joints	Wide cracks - transverse full depth repair (refer to section 6.3)
	Late sawing of joint grooves	
	Inadequate reinforcement lap	
	Sub-base restraint (lack of separation layer or excessive irregularity of sub-base)	
Longitudinal cracks	Excessively wide bays	Narrow cracks in reinforced slabs require no immediate action
	Omission of bottom crack inducer at longitudinal joint	Narrow cracks in unreinforced slabs and medium cracks in slabs of all types should be remedied by means of a stitched crack repair
	Compression failure	
	Settlement	Wide cracks in all slabs should be remedied by a longitudinal full depth repair (refer to section 6.3)

7.2 Sealing

The procedures of crack sealing are similar to joint sealing. A groove is first sawn along the crack. It is then cleaned and dried and a proper size, closed cell backer rod is then placed into the groove. Either silicone or hot pour sealant is then applied to seal up the groove.

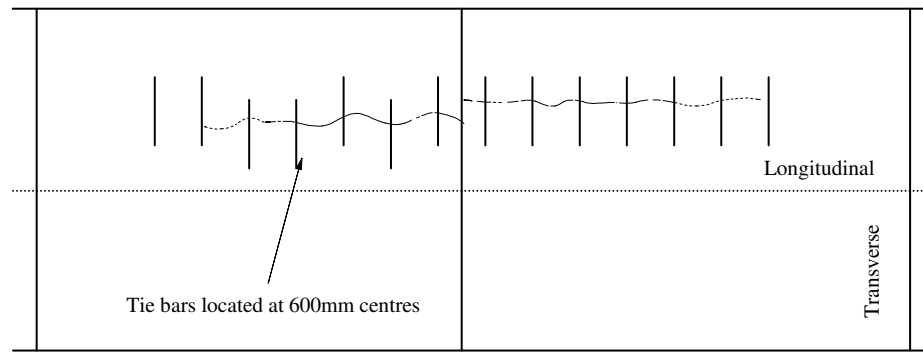
A sawn groove is preferred to one that is chased out by a router or single headed scabbling tool, because it is much more regular and can be made narrower. A clean and dry crack face is necessary for good adhesion. This is imperative for a successful sealing project. In addition, a proper groove shape in accordance with manufacturer's recommendation is necessary for the seal to work properly.

7.3 Stitched Crack Repair

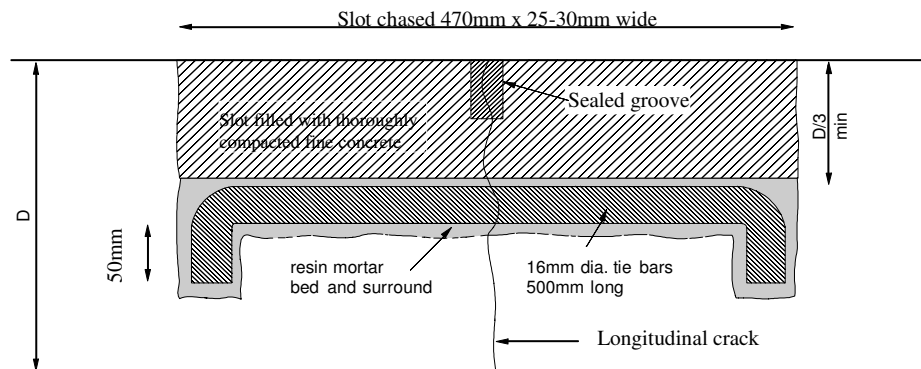
As shown in Figure 6, there are two types of stitched crack repair. Their procedures are described in Appendix C.

The reason for carrying out a stitched crack repair is to convert the crack into a tied warping joint which will allow the slab to "hinge" at that point whilst preventing the crack from becoming wider. The use of resin mortar to bond-in the tie bars is recommended. The aim is to ensure that the repair material can be hardened before movement at the crack disrupts the repair. It may be necessary to use a purpose made crack saw to cut the sealing groove along the line of a meandering crack.

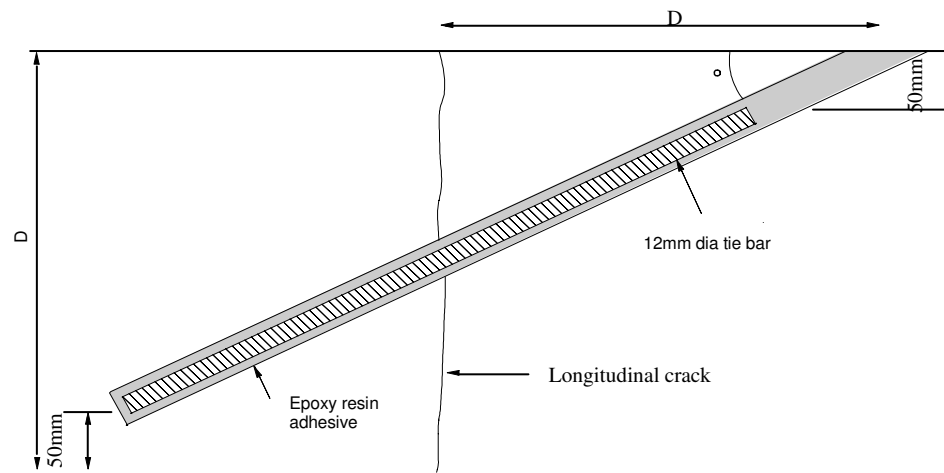
If the crack occurs within the middle third of the length of the tie bars at a longitudinal joint, it will not normally be necessary to install new 'staple' tie bars and only the sawing and sealing of a groove along the crack will usually be required.



Plan



Type 1 Repair



Type 2 Repair

Figure 7 Stitched Crack Repairs

8.0 REPAIRS ON ROCKING AND STEPPING

8.1 General

Vertical movement of the slab may develop either in the form of dynamic movement called rocking which occurs under passing traffic or permanent movement in the form of settlement of the slab or stepping at joints or cracks.

Rocking may be associated with pumping, the usual signs of which are muddy stains on the surface of the slab which, unless remedied, is likely to eventually result in multiple cracking of the slab. Pumping is probably also indicative of poor pavement or sub-soil drainage which should be corrected before any remedial work to the slab is undertaken. Seepage of water up through joints or along the edges of the slab may also indicate poor drainage.

Settlement is most likely to occur as a result of consolidation or compaction of the fill material in embankments, particularly in the back-fill behind structures or when the pavement is constructed on ground which has a low bearing capacity. It may also occur where there are shallow mine workings etc.

Stepping in the form of permanent relative vertical movement at joints and wide cracks is a phenomenon which can occur in slabs where there is no effective load transfer in the dowel or tie bars at joints, and in which the reinforcement, if any, has yielded to the cracks.

Rocking and stepping can be remedied by full depth repair or pressure grouting. Details of full depth repair and pressure grouting are described in section 6.3 and section 8.2 below.

8.2 Pressure Grouting

Pressure grouting is used either to fill small voids and stabilise dynamic movement of the slab or to fill the voids that are created when slabs are raised to correct settlement or stepping at joints and cracks (Procedure given in Appendix D). As well as cementitious or resin grouts, a dry mix mortar may also be used to fill voids, but it may be necessary to raise the slab initially to a slightly higher level than is actually required to allow for future compaction once trafficked. Fluid grout is more suitable for the filling of smaller voids under the slab.

9.0 REPAIRS OF JOINT SEALS

9.1 Defective Joint Seals

It is essential that joint seals are maintained in an effective condition if their function of preventing silt, grit, stones and water from entering the joint is to be preserved. If detritus is allowed to enter the joint, free movement of the slab may be impaired and spalling or “blow-up” expansion type compression failures may occur. For joints with mechanical load transfer devices (dowels), water infiltration can lead to corrosion of the steel dowel, which may impair the function of the joint and result in cracks and spalling.

Effective resealing of joints in concrete carriageway can prevent infiltration into the joints so that the pavement life can be extended until other major rehabilitation work is necessary.

9.2 Concurrent Work

There are a number of other types of repair that should be considered at the same time when necessity of joint resealing is observed. These repair works are summarised below:

1. Full-depth repair and spall repair of joints exhibiting deterioration.
2. The resealing of other joints (e.g. longitudinal) and cracks.
3. Sub-drainage improvement.
4. Restoration of load transfer where poor load transfer exists.
5. Sub-sealing of voids beneath joints.

9.3 Joint Seal Type

Joint seals must have the capability to withstand:

- horizontal movement and vertical shear if poor load transfer is encountered.
- effects of the environment, such as ultraviolet light, extreme temperatures, moisture etc.

Three main types of seals are commonly used. They are hot-applied sealants, cold-applied sealants and compression seals. Table 3 provides details of these joint seal types.

Table 3
Joint Seal Types and Properties

Classification	Chemical	Physical Type	Life	Type of Joint
Hot Applied	PVC/pitch polymer Polymer/Bitumen	Elastomeric Elastomeric	Medium Medium	All All
Cold Applied	Polysulphide Polyurethane Silicone	Elastomeric Elastomeric Elastomeric	Medium Medium Medium	All All Warping
Compression	Polychloropene	Elastomeric	Longest	All

Whilst all of the materials shown in Table 3 can be used, gun-grade cold applied materials are probably the most appropriate where only small quantities are required. In case there is limited time for repairing joint seals, fast curing joint sealants should be considered.

The performance of liquid sealants is heavily dependent on the shape and dimensions of the joint reservoir. The ratio of depth D , to width W , is known as the sealant shape factor. Research studies have shown that, for elastomeric sealants the

closer D/W is to 1 the lower the stresses and strains and the better the subsequent performance of the sealant. For hot poured elastomeric sealants, a depth of 15mm to 25mm is normally recommended to provide adequate adhesion with the joint sidewalls. For elastomeric silicone sealants, a minimum depth of 6mm to a maximum depth of 13mm is recommended.

Preformed compression seals rely heavily on compressive forces from the joint to keep them in position, there being little or no bond between the seal and joint face. If the joint opens wider than the seal, the seal will either fall into the joint or be pulled out by traffic. The uncompressed width of compression seals and the initial width of the sealing groove should be related to the distance between joints and in accordance with the manufacturer's recommendations, so that when inserted into the sealing groove they remain in compression at all times. The initial width of grooves sealed with compression seals should not be more than 30mm and when open at its maximum anticipated width, the width of the groove should not be more than 70% of the uncompressed width of the seal.

9.4 Joint Resealing

Joint resealing procedure is described in Appendix E.

When hot poured sealant is used, temperature indicators should be checked regularly to ensure that the heating system is maintaining the temperature required by the sealant manufacturer.

For silicone sealant, it may be pumped directly from the storage containers through pumping equipment designed for use with moisture cured silicone sealants. Sealant application nozzles should be designed so that the sealant is applied within the joint slot and should be applied such that it is held below the surface of the slab, but completely fills the joint. Immediately following application, the sealant must be tooled to provide firm contact with the joint edges and to form the 6mm recess below the slab surface. The depth of sealant over the crown of the backer rod should be 6mm – 13mm.

Silicone skins over quickly and is generally fully cured within 7 days. If the sealant is applied in joints where no rocking or slab deflection is expected, traffic may be allowed over the slab within 1 hour of application. If, however, large vertical movements are expected, it should be allowed to cure for a longer period to prevent displacement of the sealant due to backer rod movement and to obtain adhesion to the primed joint surfaces. Overnight curing is recommended.

Preformed sealants are designed with the intent that they will always be in compression. A minimum compression of 20% from the normal uncompressed state is required, the maximum allowable compression being 50%. It should be noted that a preformed seal's performance relies heavily on its ability to maintain sufficient contact with the joint walls. The preformed seals must be free from twisting and stretching; a maximum of 5% stretch is permissible. The joint surfaces must be dry.

10.0 REPAIRS ON RAVELLING AND SPALLING

Ravelling is the progressive breakdown (roughening) of the slab to depths commonly of 6mm to 12mm. Mortar and aggregates are lost independently of each other.

Spalling is a condition where distinct, usually angular pieces of concrete have flaked (cracked), or are showing a tendency to flake from the concrete surfaces. This occurs usually at joints, edges, corners or forms directly over reinforcing steel particularly when the steel has inadequate cover.

Ravelling and shallow spalling can be remedied by thin bonded repair, which is described in section 6.2. Deep spalling should be remedied by full depth repair which is described in section 6.3.

11.0 REPAIRS ON SURFACE TEXTURE DEFICIENCY

11.1 General

There are several different methods of restoring skid resistance to concrete roads, but the most suitable depends on the type of road, speed of traffic, the risk factor and the aggregate used in the concrete. Some methods will restore macrotexture while others only improve microtexture, and some do both.

11.2 Grinding

Improved skidding resistance can be achieved by roughening the worn surface by the use of abrasive blasting, scabbling, grinding or milling equipment. Abrasive blasting is effective in restoring slow speed skid resistance and equipment is available which is suitable for treating both large and small areas.

The effectiveness of the surface texture produced by scabbling and milling will be influenced by the properties and characteristics of the coarse aggregate in the concrete that is exposed.

Any retexturing treatment gives an increase in high speed skid resistance resulting from a greater depth of texture. Treatments are likely to be accompanied by some increase in the amount of tyre noise, the nature of which will depend on the type of treatment that is adopted.

11.3 Grooving

Worn, rain damaged or inadequately textured surface slabs can be macrotextured by sawing grooves in the hardened concrete surface at right angles to the longitudinal axis of the pavement with machines using diamond or other abrasive cutting discs.

Grooves shall be 2-5mm wide and 3-7mm deep. To reduce the tire/pavement noise nuisance, grooves shall be irregularly spaced with spacing between 30mm and 55mm. For better result, it is recommended to follow this sequence of distances between groove centres in mm: 40, 45, 35, 45, 35, 50, 30, 55, 35, 30, 50, 30, 45, 50, 30, 55, 50, 40, 35, 45, 50, 40, 55, 30, 40, 55, 35, 55. A tolerance of ± 3 mm shall be allowed on each of the spacings.

Slurry from the sawing process shall be prevented from flowing into joints, drains or into lanes being used by traffic, and all resultant debris from the grooving shall be removed.

11.4 Anti-skid dressing

A very high level of low speed skid resistance can be achieved by the application of a surface dressing consisting of an epoxy resin based binder and highly abrasion resistant calcined bauxite chippings. Surface dressings may not have a very long life where turning heavy commercial traffic is likely to scour the surface.

The procedure of applying the anti-skid dressing is described in Appendix F. The method of application shall be in accordance with the manufacturer's instructions.

Appendix A – Repair Techniques

Thin Bonded Repair Procedure

1. Determine the area of unsound concrete by tapping with a steel rod.
2. Mark out a square or rectangular area around the defect at least 150mm x 150mm and extending a minimum of 50mm beyond all unsound concrete.
3. Chase out a delineating groove around the perimeter of the repair and to the required depth, which shall be at least 10mm, using either a router or single-headed scabbling tool and template to form a vertical edge to the repair.
4. Using either a single or multi-head scabbling tool, remove all the concrete from within the repair area to a reasonably even surface at a depth that ensures all unsound concrete is eliminated.
5. Clean out the repair area using oil-free compressed air to remove all dust and loosened concrete. Any partially loosened concrete that remains should be removed by wire brushing after which the area should be cleaned out again using compressed air.
6. If the repair extends to the edge of a bay, provide and firmly fix shuttering or a groove former, as appropriate, in position along the edge.
7. Apply sufficient water to ensure that the repair area is kept damp until the repair material is placed. (Note: When proprietary materials are used the manufacturer's recommendations should be followed).
8. Remove any excess water from the repair by brushing or blowing with oil-free compressed air to ensure that there is no free water remaining on the prepared surface.
9. Brush in an approved bonding agent to prime the prepared surfaces if required.
10. Place the repair material immediately, spread loosely to a 20% surcharge and compact thoroughly (by vibration or as per manufacturer's instruction) to work the repair material into the prepared surface paying particular attention at corners and around the edges of the repair to ensure a good bond with the old concrete.
11. Finish flush with the surrounding slab. Lightly brush the repair material against the hardened edges around the perimeter with a soft brush and apply a surface texture after initial set to match the existing.
12. Cementitious materials should be cured immediately after texturing by the use of either an approved resin based, aluminised curing compound or, wet hessian covered by a polythene sheet. For other materials the manufacturer's recommendations should be followed.

Full Depth Repair Procedure Using Cast Insitu Approach

1. Mark out a square or rectangular area encompassing the crack or deep spall.
2. Make a vertical saw cut through the full depth of the slab around the perimeter of the repair, taking care to ensure that the saw cuts do not extend into adjacent bays. Further saw cuts may be made to enable the slab to be removed in convenient pieces.

3. Carefully break out and remove the concrete from within the repair area without damaging the remaining slab and with the minimum of damage to the base.
4. Clean out and tape over any joints, cracks and grooves in the sides of the repair.
5. Drill holes in the vertical exposed faces of the slab, parallel to the surface and sides of the slab.
6. Reinststate the base/sub-base and separation layers if necessary.
7. Clean out the drilled holes, using oil-free compressed air if necessary.
8. When dry, prime and plug the drilled holes with resin mortar and insert new dowel bars and tie bars, accurately aligned parallel to the surface and sides of the slab.
9. Stick groove-forming strips along the top edges of the surrounding slab.
10. Position mesh reinforcement when required.
11. Place and evenly spread pavement quality concrete or approved repair material to the appropriate surcharge. Thoroughly compact using both internal and surface vibration and finish flush with the surface of the surrounding slab to a tolerance of $\pm 3\text{mm}$ and with a difference of not more than 4mm between the surface and the underside of a 3 m straightedge. Particular care is needed to ensure full compaction around the edges of the repair.
12. Apply a wire brush or similar surface texture and cure immediately using an appropriate curing agent.
13. Remove the groove formers.
14. The repair should not be trafficked until the minimum required curing period has elapsed.

GENERAL NOTES

When removing slabs or parts of slabs, during periods of high temperature, additional cracking can occur due to the compressive stresses being concentrated on less than half the width of the slab once the saw cuts are made. This may cause longitudinal cracking or localised compression failures at joints. To reduce this risk:

- (a) Saw full depth cuts at cooler periods of the day.
- (b) Saw along the joint before making cuts each side to eliminate a badly spalled joint.
- (c) Cool the concrete with water.
- (d) If a series of repairs is required make intermediate cuts to relieve stress at intervals rather than cutting sequentially along the road.

Appendix B –Full Depth Repair Using Precast Concrete Approach

1. Preparation stage:

- (a) Carry out detailed on-site measurement of the road defects and check as-built records of the concrete carriageway and its underground utilities.
- (b) Fabricate a precast concrete panel using grade 40/20 concrete according to the site measurements and cure the panel in accordance with the General Specification for Civil Engineering Works.
- (c) Install anchor bolts onto the precast concrete panel for lifting.
- (d) Install four u-channels near each corner of the panel for levelling.

2. Implementation stage:

- (a) Before the removal of the existing defective carriageway, utilities detection has to be carried out to ascertain the locations of underground utilities.
- (b) Set out the repair area.
- (c) Saw cut around the perimeter of the repair.
- (d) Carefully break out and remove the concrete from within the repair area without damaging the remaining slab and with the minimum of damage to the base.
- (e) Reinststate the sub-base.
- (f) Apply a layer of fast hardening mortar over sub-base as bedding.
- (g) Lift the precast concrete slab into position with the four u-channels rested on adjacent carriageway surface.
- (h) Remove anchor bolts and seal the holes.
- (i) Remove the four u-channels after the bedding is hardened and gained sufficient strength to support the precast concrete panel and seal the holes.
- (j) Seal joints with joint filler/expanding foam and joint sealant.



Two anchor bolts are used for lifting small panel



Four anchor bolts are used for lifting large panel

Appendix C – Stitched Crack Repair Procedure

Stitched Crack Repair - Type 1

1. Chase out slots 25-30mm wide by 470mm long at 600mm centres and at right angles to the line of the crack. The depth of the slots shall be such as to ensure that, when bedded, the tie bars lie between 1/3 and 1/2 the depth of the slab below the surface.
2. Drill holes 25-30mm in diameter by 50mm deep at each end of the slots.
3. Clean out the slots using oil-free compressed air.
4. When in a dry state, prime the slots, place the staple tie bars into beds of epoxy resin mortar and cover to a minimum depth of 30mm with the same material.
5. Prepare the sides and complete the filling of the slots with thoroughly compacted resin or cementitious mortar.
6. Cure and open to traffic.
7. Saw a groove along the line of the crack and seal.

Stitched Crack Repair - Type 2

1. Ascertain the depth of the slab.
2. Mark out drilling points at a distance from the crack equivalent to the depth of the slab, at 600mm intervals along the crack with alternate points on opposite sides of the crack.
3. Drill holes (min. 16mm diameter) at approximately 26° to the surface of the slab to a depth which allows 50mm cover at the bottom of the slab.
4. Place in cartridges of epoxy resin type adhesive.
5. Insert 12mm diameter deformed tie bars through the cartridges.
6. Rotate the bars for about 1 minute to ensure adhesive is well mixed.
7. Cut the bars so that the end is approximately 50mm below the surface.
8. Alternatively, the length of the tie bars may be pre-determined by measuring down the hole and notching the bars at a point 50mm below the surface. After the bars have been driven in, rotated and the mortar set, the surplus can be broken off by twisting. Any bars which continue to twist after the mortar should have set shall be deemed to be unbonded. They shall be withdrawn and the hole redrilled.
9. Plug the remainder of the hole with an epoxy resin mortar.
10. The road may be opened to traffic as soon as the mortar in the holes has set.

Appendix D – Pressure Grouting Procedure

1. Avoiding services, drill 32mm to 36mm diameter grout injection holes through the slab and any bound sub-base on a 1m x 1m grid extending over the whole area of the void under the slab.
2. Remove any water from the void by blowing with compressed air at each end of the grout holes in sequence, working progressively across and along the bay, down crossfalls and longitudinal gradients.
3. Inject fluid grout or dry mix mortar under pressure at each of the grout holes in sequence, working progressively across and along each bay. Grouting shall continue at each hole until refusal. Temporarily plug adjacent holes when excess grout or plumes of dry mortar emanate from them.
4. Upon completion of the pressure grouting process any surplus grout shall be removed from the surface of the slab and the holes cleaned out and made good with resin or cementitious mortar. Any resin grout which cannot be removed from the surface of the slab may be blinded with calcined bauxite if this can be done before the grout has gelled.
5. Open to traffic after the appropriate minimum curing period has elapsed.

Appendix E – Joint Resealing Procedure

1. Remove all existing sealant and incompressible material from the joint by raking the joint with a rectangular shaped tool. V-shaped tools should not be used as these will spall the concrete and not completely remove all the sealant that remains.
2. Reconstruct defective joints where spalling is serious.
3. Reface the joint or crack sides using a diamond saw, this provides a clean surface for the sealant to bond to and can be used to improve the shape factor by increasing the joint width.
4. Clean the newly sawn faces, with a high-pressure air jet if necessary.
5. If liquid seals are used, install a backer rod to fill the joint so that the correct sealant reservoir depth is achieved in accordance with manufacturer's recommendation.
6. Apply the sealant under pressure from the bottom up to prevent air entrapment. The joint must not be overfilled.

Appendix F – Anti-skid Dressing Procedure

1. Prior to the application of the anti-skid surface dressing, all surfaces to be treated shall be cleaned, dried and freed from any contaminants or foreign matter.
2. Concrete surfaces shall be prepared by grinding using grinding machine or other method in accordance with manufacturer's recommendation.
3. Road studs, thermoplastic markings, manhole covers, valves and other ironwork and the like shall be masked before work commences. Expansion and contraction joints in concrete slabs must not be bridged by the dressing.
4. After preparation, concrete surfaces shall be treated with a low viscosity, solvent free epoxy resin primer.
5. The binder shall be thoroughly mixed and evenly applied to the road surface at a minimum rate of 1.5 kg/m² excluding filler or otherwise in accordance with the manufacturer's recommendations.
6. The calcined bauxite dressing shall be sprinkled evenly over the surface at a minimum rate of 10 kg/m². The excess material has been removed by vacuum sweeping.
7. Before curing, the material used for masking shall be removed. The curing time shall be in accordance with the manufacturer's instructions, with due allowance being made for the ambient temperature. Traffic must not be allowed onto the finished surface until curing is complete.