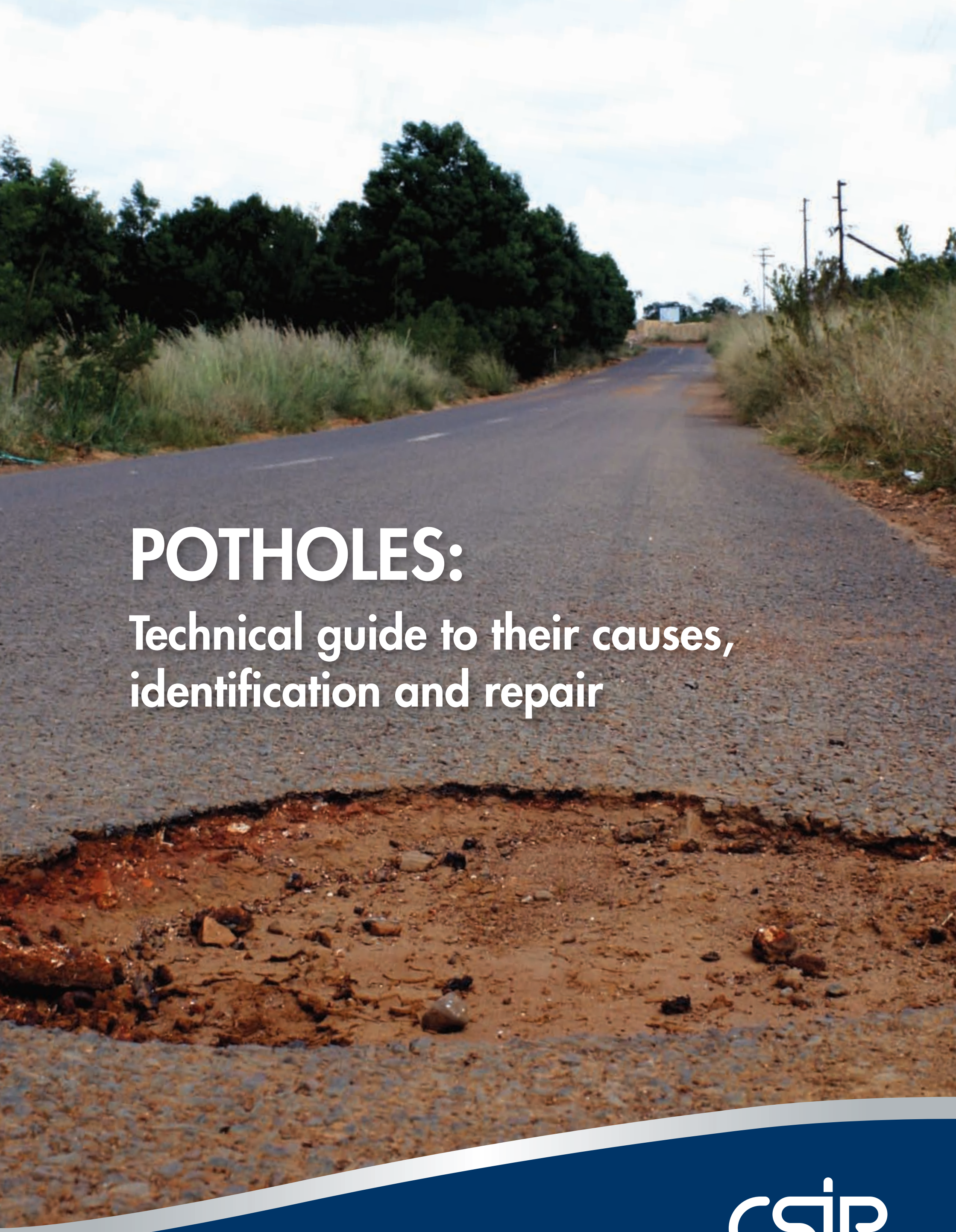

POTHOLES:

Technical guide to their causes, identification and repair

our future through science

POTHOLES: A technical guide to their causes, identification and repair

CSIR Project Team:
Dr Phil Paige-Green (project leader)
Amrita Maharaj
Julius Komba

Note: This comprehensive technical guide on potholes, their causes, identification and repair is accompanied by a short, non-technical guide. The short document summarises the main causes of typical potholes and ways of limiting their formation. The non-technical guide is aimed at people not directly involved in the technical aspects of infrastructure engineering of roads.

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Tel 012 841 2871 • Email lsibanyoni@csir.co.za

FOREWORD

We have great pleasure in presenting this technical guide on potholes, their causes, identification and repair.

Over the past few years, the development of potholes in South African roads has accelerated considerably, leading to serious concern and wide media coverage. The increase in pothole damage can be attributed primarily to reduced preventative maintenance being applied to many roads, combined with particularly wet periods during rainy seasons and rapidly increasing numbers of heavy vehicles.

This guide describes the causes of typical potholes and uses a decision key system to identify the appropriate repair methods. Various methods are described to ensure that repair work is appropriate for the specific type of pothole and that the pothole will thus not form repeatedly due to failure to address the cause. Mechanisms for quality control of pothole repairs are presented. A standard form for use by inspectors during the field rating of potholes and identification of repair methods is included.

A short companion brief on potholes, their causes and prevention has also been produced. This is targeted at administrators and non-technical management officials.

Given the extent of the pothole situation countrywide, we believe the CSIR has an obligation, and is also ideally positioned, to produce such a guideline document. Both documents are available freely for use by the various authorities and interested parties. In this way the CSIR wants to ensure all those responsible for roads have access to the guidelines. We hope that the application of the information presented here will result in the formation of fewer potholes and more effective corrective actions.

Hans W Ittmann
Executive Director: CSIR Built Environment

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LIST OF ABBREVIATIONS

CMA	Cold-mix asphalt
DCP	Dynamic Cone Penetrometer
HMA	Hot-mix asphalt
SAMI	Stress Absorbing Membrane Interlayer
RCCD	Rapid Compaction Control Device

CHAPTER 1

INTRODUCTION

The unprecedented development of potholes during the 2009/2010 summer rainfall season on particularly the South African provincial and metropolitan roads with bituminous surfacings led to widespread concern among road users and significant media reporting.

Numerous claims were laid against road authorities for vehicle damage caused by potholes and even for serious vehicle accidents resulting from excessively large potholes.

Potholes have always been a problem on sealed/paved roads, but never to the extent experienced during the summer of 2009/2010. The causes of the large increase in the degree and extent of potholes during this period were many, but can probably be attributed mainly to the following:

- Insufficient routine, periodic or preventative maintenance leading up to the summer;
- Unusually wet conditions for sustained periods;
- Ineffective or no repair of existing potholes.

The actual costs of potholes in South Africa in terms of damage to vehicles and accidents caused directly by potholes and other road-user effects have not been quantified, but probably run into many millions of rand. It should, however, be noted that this problem is not unique to South Africa. The costs of similar problems over the wet period in the United Kingdom have been estimated as in excess of £10 billion (about R120 billion) (World Highways, June 2010). This is four times more than the entire annual road budget for South Africa. It is anticipated that it might take 15 years to 'fix' the pothole problem in the United Kingdom.

The internet has literally millions of references to potholes, mainly from the United States and generally associated with the spring thaw that occurs in cold regions. In these regions, moisture in the pavement freezes during winter with an increase in volume and a consequent decrease in material density. As the frozen pavement layers thaw out in spring, the moisture content of the material increases (often to saturation), which decreases the pavement support. Under traffic loading, high pore water pressures develop in the wet materials with subsequent failure of the material. The climate in South Africa, however, is such that this problem can be considered minimal and not an important contributor to the overall pothole problem.

There is no doubt that water is the primary cause of potholes, with the access of water into the road structure to cause the potholes being mostly a function of the surface condition. A lack of periodic and/or preventative maintenance of roads often leads to the development of surface cracks, which allow rapid ingress of water into the structural layers during rainfall.

As road budgets are constrained and preventative maintenance is reduced or prolonged, the potential for the development of potholes during wet weather increases significantly. The main objective in reducing pothole formation is thus to ensure that preventative maintenance is applied timeously and to the appropriate standards. For the foreseeable future, however, this is unlikely to be achieved fully and optimum techniques for repairing potholes should be implemented.

The majority of roads in South Africa are surfaced with bituminous surfacings, which are more prone to potholing than concrete roads, although potholes can and do form in concrete roads.

The information in this document, however, concentrates on the occurrence of potholes on bituminous roads.

This book provides a guide to the primary causes of potholes affecting bituminous roads in South Africa, the means of classifying them for repair purposes and suggested repair methods.

CHAPTER 2
CAUSES OF POTHOLES

Although the presence of water is the primary cause of potholes, their formation differs somewhat depending on the road pavement structure and materials used. Potholes can, of course, also result from diverse, non-structural causes such as diesel (or other chemical) spillages; mechanical damage to surfacings from vehicle rims and/or accidents and fires; damage caused by falling rocks in cuttings; animal hooves on road surfaces in hot weather; and poor road design over certain subgrades, e.g. expansive, collapsible and dispersive soils.

The majority of potholes form in the wet or rainy season, but it is not uncommon for potholes to develop and deteriorate during the dry season due to not only the action of traffic, but also temporary wet conditions resulting from localised irrigation, ponding and/or seepage of water, etc. (Figure 1). The latter can usually be identified by the presence of water-loving (hydrophilic) plants in the area.

Potholes also occur commonly as a result of poor reinstatement of service trenches that are excavated through bituminous-surfaced roads. These are dealt with separately in this document.

Potholes may be accompanied by severe cracking and deformation or distortion of the surfacing around the pothole, indicating a deeper-seated cause for the pothole formation. Where little deformation is observed in the vicinity of the pothole, the cause is more likely to be the entry of water through surficial cracks in the road pavement and deterioration of only the surfacing and upper structural layers of the pavement.

Primary differences in pothole formation arise from whether the bituminous pavement surfacing is asphalt or a thin bituminous-surfacing seal (locally called 'chip and spray', surface dressing, surface treatment or chip seal). These differences are discussed here.

2.1 Asphalt

Where asphalt is used on roads in South Africa, it is typically between 25 and 50 mm thick, unlike the thick asphalt surfacings (and bases) used commonly in many northern hemisphere countries (100 mm plus).

Potholes in asphalt originate in two ways. They are caused either by cracking of the asphalt as a result of fatigue or ageing (binder shrinkage) that allows water into the support, or by the penetration of water to a less permeable interface within the asphalt layer, resulting in stripping of the asphalt.

2.1.1 Cracking of asphalt surfacing

The cracking of asphalt surfacings is typically the result of poor support (unsuitable material types or thicknesses, or excessive water), resulting in fatigue-cracking of the asphalt (Figure 2). In addition, environmental cracking can occur due to ultraviolet light from the sun, heat, oxidation or some other cause that has resulted in shrinkage of the asphalt (Figure 3). Furthermore, reflection cracking due to the shrinkage of underlying

Figure 1: Localised ponding of water from seepage in the adjacent area during the dry season (note the presence of hydrophilic plants near the road)

stabilised materials as the cementitious stabiliser hydrates also leads to cracking (Figure 4).

An underlying weakness in the support layers usually results in high surface-deflections under traffic loading, particularly if the material becomes wet. Moisture may penetrate the pavement layers through incipient cracks from above, or build up beneath the pavement as a result of poor drainage in the area.

Potholes associated with environmental and traffic cracking usually start as spalling of the asphalt adjacent to the crack, which then enlarges with time and traffic to develop a pothole. If the cracks are sealed or the spalling is repaired in time, no

Figure 2: Typical fatigue-cracking of asphalt leading to a pothole

Figure 3: Cracking of asphalt resulting from ageing

Figure 4: Typical reflection-cracking of stabilised material through a G1 base and 30 mm of asphalt (mostly sealed)

significant damage will occur to the pavement, but if left open, the access of water through the cracks results in deeper deterioration of the road.

Irrespective of the cause of the cracking, water entering the road through the surfacing can lead to the rapid development of potholes during wet weather, as seen frequently in recent years.

2.1.2 Water penetration into the asphalt

The separation of asphalt overlays from underlying asphalt (or other bituminous seals) as a result of permeability inversions and/or moisture effects at the interface or possibly the presence of a stress-absorbing membrane interlayer (SAMI), results in the stripping of the asphalt and the development of typically shallow potholes (Figure 5).

It should be noted that the underlying material exposed in the pothole is frequently old and dry asphalt, which is more susceptible to ravelling than the newer asphalt at the surface. If this type of pothole is not sealed or repaired quickly, the surface area enlarges and the underlying asphalt is abraded, leading to the development of deeper potholes that are more difficult to repair.

2.1.3 Traffic loading

Heavy traffic loading (in excess of the pavement design loading) causes excessive road deflections that result in fatigue failures. Repeated high deflections, or even a few passes by overloaded vehicles, cause the road surface to crack, allowing water to flow through these cracks into underplaying layers (base/sub-base), which causes loosening of the material.
This loose material can then be pumped out of the road leaving the upper layers unsupported, which eventually collapse to form a pothole (Figure 6). Overloading control is thus an essential part of preserving road functionality and reducing general pothole formation. This entails the effective control of traffic loading to ensure that it does not exceed the design loading, e.g. by means of signage and enforcement.

Figure 5: Typical shallow failure of asphalt at the interface with older asphalt

Figure 6: Initiation of potholes as a result of overloading of a stabilised base – initial cracking followed by pumping and then potholes

2.2 Thin bituminous-surfacing seals

Thin bituminous-surfacing seals such as single and double seals, Cape seals and slurry seals are the more common types of bituminous surfacing used in South Africa. They are generally durable seals but their performance depends on the underlying material, which is often moisture-sensitive and susceptible to rapid deterioration in the presence of water. Slurry and single (or even double) sand seals on their own are very thin and more prone to irregularities in the top of the base punching through the seal than other seals and forming potholes (Figure 7). These need careful preventative maintenance to retain the integrity of the seal over the design period.

In nearly all cases, the propagation of potholes in thin surfacings progresses from the top, once water is allowed to access the underlying material, whether it is crushed stone, natural gravel or cemented gravel.

Thin bituminous-surfacing seals (possibly apart from slurry seals) are considered to be quite flexible if maintained properly. Such seals can absorb relatively high deflections for some time before cracking, especially when they are constructed using modified binders. However, once cracking starts, the access of water into the pavement structure is rapid and failure (loss of surfacing and upper structural layers) occurs over a much wider extent than when subjected to localised 'breakthrough'. Greater depths of the pavement are affected much quicker. Potholes can also develop in thin bituminous seals as a result of extreme loss of aggregate.

2.2.1 Loss of surfacing ('surface breakthrough')

The localised loss of surfacing, usually leading to relatively small potholes that are not very deep initially, is often caused by mechanical damage to the surfacing. However, surfacings that contain impediments such as stone loss, localised weak

Figure 7: Development of potholes on a low-volume road with thin bituminous surfacing and insufficient preventative maintenance

aggregate, aggregate containing sulphides or large stones may develop small potholes at these sites. Thin bituminous seals such as sand and slurry seals, which are usually less than 5 mm thick – which is similar to the typical irregularity permitted in newly-constructed bases (COLTO, 1998) – can be broken through easily under traffic as they may consist solely of a thin bitumen layer if a 5 mm irregularity (a small protruding stone, for instance) exists in the base. Where this happens, both wear-and-tear under traffic and the entrance of water will result in the formation of potholes, in a similar manner to those developed from mechanical damage to the surfacing (Figure 7).

Other potholes in thin surfacings can result from localised weaknesses in the base material or construction (Figure 8), large stones beneath the seal (Figure 9), underlying weak layers (Figure 10) or surface laminations in stabilised bases (Figure 11).

Figure 8: A typical pothole formed under a thin surfacing with a granular base

Figure 9: A pothole resulting from large stones in the base beneath the seal

Figure 10: A typical pothole resulting from a weak upper-layer of stabilised material

Figure 11: A pothole resulting from lamination, carbonation and weak layers in the top of a stabilised base material

Figure 12: Fatigue cracking of a thin bituminous seal with pothole formation

2.2.2 Cracking

With time, bituminous surfacings will crack without ongoing preventative maintenance, primarily as a result of oxidation and drying of the bitumen binder, but also through fatigue as the pavement deflects under traffic (Figure 12). Routine preventative maintenance such as the periodic application of fog sprays, timeous resealing and the sealing of cracks will avoid this. At present this is generally not practiced in South Africa.

2.2.3 Poor repairs

Although highly undesirable, it is not uncommon for potholes to be repaired with material obtained from the roadside (Figure 13). This should **never** be done, as subsequent sealing of the pothole often involves removal of some of the upper (poor) material and replacement with asphalt. This new asphalt is directly underlain by a weak, water-sensitive material which will fail rapidly when wet. Only appropriate materials should be used for pothole filling, even when done as a temporary measure.

2.2.4 Poor adhesion between base and seal

The development of potholes commonly results from a lack of adhesion between thin surfacings and the base course, particularly stabilised ones. This is demonstrated clearly in Figure 14, where carbonation of the upper portion of the base resulted in a thin layer of loose material between the base and the seal. The passage of heavy traffic caused lateral movement of the seal, extension cracking and the development of potholes.

Sometimes the poor adhesion between the base and seal can be the result of a localised loss of prime prior to sealing. This too leads to stripping of the surfacing in these areas and the development of potholes (Figure 15).

Figure 13: A pothole (filled with roadside material) resulting from unsealed cracks in a thin bituminous surfacing

Figure 14: A typical pothole formed as a result of carbonation of a stabilised base

Figure 15: The initiation of potholes due to a lack of prime

Figure 16: A pothole developing as a result of excessive soluble salts in the pavement base layer

Figure 17: Repaired potholes caused by mole-rats

Figure 18: A typical pothole formed adjacent to a service trench

Figure 19: Failure of a patch within one year of repair – note standing water adjacent to the road in this area

Figure 20: Strongly-cemented gravel patches

Figure 21: A patch using strongly-cemented gravel (almost concrete). Note cracking in the road due to differential stiffness between the patch and the road

2.3 Unusual forms of pothole development

Potholes can be formed by a number of other causes. An unusual cause of loss of bond between the base and a bituminous surfacing is the presence of excessive soluble salts in the pavement. If water evaporates through the surfacing (either as a result of high permeability or the presence of any defects – cracks, excessive voids, etc.), soluble salts can be deposited between the seal and the base at these points. This will cause a loss of bond (Netterberg, 1979) and lead to potholes. These potholes are not considered part of routine maintenance and cannot be repaired following the methods described in section 4. Special treatments are usually required – these are not described in this document.

In certain areas of South Africa, potholes have also been caused widely by mole-rats. These animals tunnel under roads (particularly in sandy areas), causing the collapse of the road surface above the tunnels and particularly where cavities are excavated and where the excavated material is ejected at the surface (molehills) (Figure 17). These potholes can be quite deep and often need specialised attention, which is also not covered in this document.

2.4 Reinstated service trenches

Trenches are regularly excavated across many urban and occasionally some rural roads to install or repair various underground services such as electric cables, water reticulation systems, sewage pipes, etc. These works are normally carried out by the relevant municipal authority or contractors appointed specifically for this. In either case, the quality of repair of these trenches is often not done by road repair 'specialists' and thus seldom meets the required standards. This results in settlement of the surfacing (leading to ponding of water, cracking and potholes), cracking or opening of the joins between the new trench and the adjacent existing seal and the development of potholes (Figure 18).

Repair of these problems should follow the same process as for any other similar potholes described later in this document.

2.5 Failure of existing patches

Many instances are observed where pothole patches have failed. This is normally the result of either the original cause of the problem not being addressed, or the effect of poor patching workmanship.

Where patches fail (as illustrated in Figure 19), the full classification and repair process described later should be followed. In most cases, the size of the new patch is likely to exceed the size of the original patch in order to eliminate the primary cause of the problem.

The repair of patches using strongly-cemented materials is not recommended (Figure 20). The patch is usually significantly stiffer than the surrounding material, starts to 'rock' under traffic and results in failure of the surrounding contact areas (Figure 21).

2.6 Mechanisms of pothole development

A well-constructed and maintained, intact, flexible bituminous seal should not develop potholes. It may deform as the underlying layer fails, but without the development of cracks in the seal or actual loss of the seal, potholes will not develop. Preservation of the seal in a good condition (with regular application of fog sprays and reseals) will thus avoid the formation of potholes.

The majority of potholes in roads are associated with wet conditions, while water in the pavement structure will seldom cause distress or potholes without the application of loads from vehicles. Once the pavement is loaded, shear failure of the material in contact or close to the loaded tyre will occur. This is caused by the applied stresses exceeding the shear strength of the material, which at this stage is usually saturated and subjected to effective stresses with high pore-water pressures (a phenomenon exacerbated by rapid loading).

If the material is only moist and not saturated, but the total stress exerted by the wheel load exceeds the strength of the material, shear failure may also occur – the depression formed in this way usually leads to a pothole over time (Figure 22). It is sometimes seen that the exposed material in potholes starts to ravel (especially when the plasticity is low) and de-densify as the pothole enlarges. This material, apart from having a low shear-strength, is also subject to whip-off and loss of material from the pothole under rapidly moving traffic (Figure 23).

In addition to the direct stress/loading effects, it is also possible that the seal/base interface becomes weakened and more prone to abrasion under wheel movement, resulting in enlargement and deepening of the pothole. As the pothole becomes deeper, the impact of vehicle tyres on the weakly-supported edge of the pothole results in collapse or disintegration of the seal and accelerated enlargement of the pothole to potentially dangerous conditions.

2.7 Location of potholes

The actual location of potholes within the road carriageway can be a useful indication of the origin or cause of the pothole. The majority of potholes seem to occur in the outer wheel paths of single carriageway roads leading to extensive patching (Figure 24). These can usually be attributed to the effects of increased moisture in the subgrade and pavement layers during the wet season. This results from seasonal moisture fluctuations within the outer 600 to 1 200 mm of the carriageway, as described by Emery (1992). This effect is probably exacerbated by the extra load on the outer wheels of heavy vehicles as a result of the road camber.

Figure 22: Shear failure in the base (note heaving of the asphalt adjacent to the yellow line) and a patched pothole that formed

Figure 23: Enlargement of an unrepaired pothole through ravelling and whip-off

Figure 24: Moisture/traffic-associated cracking in the outer wheel track leading to potholing and extensive patching

Figure 25: Potholes resulting from construction deficiencies

Potholes that develop along the centre-line of the road are frequently the result of poor sealing/bonding of joins between successive runs during the sealing process. Water can enter the pavement along these joins, weakening the material and forming potholes. Other construction deficiencies (e.g. localised areas of poor compaction because they are too wet during construction, material segregation, lack of bond between base and seal, etc.) can also lead to potholes not directly relating to the seasonal moisture movements (Figure 25). The width of the road and whether the shoulders are sealed can also affect the location of potholes. On narrower roads, the inner wheel paths in the two directions may overlap, resulting in an effective doubling of the load in this area and possible development of potholes.

Potholes between the centre-line and the outer wheel track, in the zone of moisture equilibrium, are generally the result of unsealed cracks, poor bonding between the base and seal, or localised areas of poor construction or material quality.

2.8 Non-labour-based repair

The majority of pothole repairs will normally be undertaken using teams of road workers, usually with a mechanical compactor. However, when potholing becomes extensive or affects long, linear sections of road (Figure 26), it may be more effective to use a small recycler or milling machine to remove the affected area and replace the material with an appropriate repair material. This process is not discussed in this document and should follow conventional recycling or large repair procedures.

Figure 26: Long, linear development of potholes, resulting from inappropriate layer materials

CHAPTER 3

CLASSIFICATION AND MANAGEMENT

3.1 Classification

Prior to any successful pothole repair, it is essential to have identified and classified the cause of the problem. The surficial repair of potholes, without attending to the fundamental causes, is normally a complete waste of time and resources – incorrectly repaired potholes are likely to fail again soon after repair (Figure 19).

To assist with the identification of the causes of potholes, the decision key process shown in Table 1 can be used. Table 1 shows that the classification process is purely visual, except for Key point 10, where it is necessary to determine whether the top of a cementitiously-stabilised base has carbonated. This requires the application of a small quantity of dilute (5N) hydrochloric acid. If the acid effervesces (or fizzes) vigorously, this is a strong indication of excessive carbonation. The use of phenolphthalein to confirm the absence of severe carbonation may also be necessary.

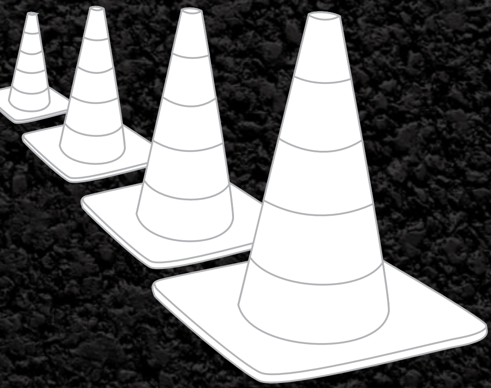
Similarly, the determination of whether the subgrade is excessively wet requires some judgement, which is gained with experience. An assessment of whether water-loving vegetation or evidence of ponding is present in the area (see Figure 1) will usually be an initial guide to whether excessive moisture (not necessarily seasonal moisture fluctuations) is the cause of problems. Seasonal moisture fluctuations in the outer zone of the road adjacent to unsealed shoulders are a necessary and expected part of road performance. Failure in this zone is usually attributed to marginal or poor material quality, resulting in excessive moisture sensitivity of the material strength. This key is followed numerically with reference to various correction or repair techniques described in Section 4.

It is important to classify asphalt pavements with care. If the asphalt has been resealed with a thin bituminous surfacing (slurry and chip seals are common applications over asphalt), the pothole should be classified as an asphalt pothole for repair-identification purposes. The application of asphalt overlays on top of old surfacing seals is rare, but could occur. In these cases, the surfacing would be classified as asphalt for pothole cause-identification purposes. It is also commonly seen on older roads that numerous chip seals have been applied over the years, resulting in an effective seal of 25 mm thickness or greater. These seals should still be classified as thin bituminous seals and not as asphalt for repair purposes described in Section 4.

Potholes are seldom deeper than 150 or 200 mm, as they then become serious safety hazards and are generally repaired or filled with local materials at that stage. The failure of layers beneath (or even within) the sub-base is thus very seldom visible from the surface. Potholes associated with failures of deeper materials tend to be manifested by visible surface deformation (rutting, shearing, mounding, depressions, etc.). Evidence of this indicates the need for deep repairs, as discussed in the following sections.

Table 1: Key to the decision process for the repair of potholes

KEY	DEFECT	REPAIR ACTION	GO TO
1	Surfacing is asphalt		2
	Surfacing is thin bituminous seal		4
2	Pothole is deeper than asphalt wearing course		3
	Bottom of pothole is within asphalt wearing course	Shallow asphalt (HMA or cold mix)	
3	Pothole caused by cracking due to fatigue of asphalt	Deep repair after sub-soil drainage installation	
	Pothole caused by localised surface water ingress with no associated crocodile cracking	Medium-depth asphalt repair	
4	Pothole has exposed an unstabilised base		5
	Pothole has exposed a stabilised base		10
5	Pothole is not associated with cracks		6
	Pothole is associated with cracks		8
6	Pothole affects seal and top of base only (< 50 mm)	Shallow surface repair	
	Pothole extends > 50 mm into base		7
7	Pothole affects only the base	Medium-depth repair	
	Pothole extends below the base		8
8	Pothole does not affect entire pavement structure (only base and sub-base)	Medium-depth or deep repair	
	Pothole affects entire pavement structure		9
9	Pothole is the result of saturated subgrade or support	Deep repair after sub-soil drainage installation	
	Pothole is the result of poor material – no evidence of excessive subsoil water	Deep repair	
10	Top of base has carbonated and is weak		11
	Top of base has not carbonated excessively and is still strong	Shallow surface repair	
11	Pothole is associated with crocodile cracking	Deep repair	
	Pothole is not associated with crocodile cracking	Medium-depth repair	



3.2 Management

For effective management and control of potholes, particularly during the wet, rainy season when large potholes can form literally overnight and a rapid response is necessary, it is essential that a coordinated reporting system be implemented.

Probably the most effective system is the one currently in use by the South African National Roads Agency Ltd (SANRAL), making use of appropriate notice or sign boards with a telephone number that is operational 24/7. This does, however, require that the public is made aware of the system and has confidence that reports will be responded to timeously. It also requires trained stand-by maintenance crews to repair potholes immediately after information has reached the specific road authority.

A more arduous and costly system would normally involve regular inspections by suitably-trained staff of the road authority, particularly during and after periods of heavy or prolonged rainfall. The assessor should be able to classify the nature and cause of the pothole on site and make a recommendation (using Table 1) as to how it should be repaired.

For effective repairs of potholes, it is essential that the correct resources are readily available. Equipment such as picks and shovels, compactors, a diamond-saw for cutting of surfacing, drums of bitumen emulsion and pockets of approved cold-mix asphalt (as discussed in section 4.4.1) must be readily available to the repair teams. A range of appropriate compaction equipment (hand rammers, small plate compactors and/or pedestrian rollers, as necessary) should also be available.

Appendix A provides a standard form for the field assessment of pothole types and recommendations of the repair actions. This can be used by field evaluators to assess each of the parameters necessary for the decision process for pothole repair required in Table 1.

CHAPTER 4
REPAIR/CORRECTION

Prior to any pothole repair, it is essential to have identified the cause of the problem as described in the previous section.

4.1 Background

Other than for shallow potholes affecting the surfacing only, without repairing or attending to the fundamental problem, pothole repairs will rarely be successful and will require repeated repair (Figure 27). During this time the degree and extent of the potholes will increase significantly. The overall riding-quality of the road generally decreases simultaneously. Aspects relating to attending to the fundamental problems are included in this section of the document under the different repair techniques.

The fundamental principle relating to pothole repair is to produce a patch with a deflection under traffic similar to the adjacent road. Significant differences in deflection will lead to cracking at the interface of the patch, as frequently seen at the junctions between manholes in the road (essentially deep and stiff enough to avoid any deflection under traffic) and the adjacent road. Any cracking that develops between patches and the road under traffic loading will lead to ingress of water and additional potholing.

Figure 27: Repeated repair of potholes due to the fundamental problem (subsurface drainage) not being addressed

Figure 28: The effective use of a geosynthetic crack-sealing strip to seal the edges of a patch

When the extent of the potholes is large or the degree of failure is severe, a decision needs to be made whether the repair of the potholes is justifiable economically and what the options are. Typically these would be to either implement a holding action (e.g. patch and place a bitumen rubber seal) or whether to rehabilitate the road or parts of the road (e.g. in situ recycling). This decision is best made by a specialist pavement engineer, who should be consulted.

4.2 Safety and traffic control

Potholes can occur in all areas of all types of road. Their repair thus poses significant safety issues. The normal safety precautions relating to the provision and visibility of safety apparel, appropriate safety vests, safety training of patch-repair teams and the use of appropriate traffic-control measures are absolutely essential. Details in this regard are not dealt with in this document and should follow conventional safety requirements.

4.3 Preliminary treatment

The area to be patched must be marked using chalk, spray paint or crayons ensuring that the entire 'failed' area together with some sound area is included. It is essential that the marked area includes the whole area affected by the pothole and any associated distress. This is often the primary distress (cracking, spalling, etc.) that led to the formation of the pothole in the first instance.

The patch should be marked using straight lines as these can be cut more neatly than round or oval patches. A diamond saw should be used to cut through the surfacing and to give a neat and clean, well-shaped patch. Once the surfacing has been cut, the material to be replaced can be excavated using a pick and spade or jackhammer, if necessary.

The majority of patches will normally be rectangular with sides parallel to the edge of the road. This is certainly recommended for large patches of more than 1 m in dimension. Experience has shown that for smaller areas, a diamond-shaped patch with the upper and lower apices in the direction of traffic movement tends to be more effective and durable. The impact of tyres on the edge of such patches is not uniform and the stresses appear to be absorbed differentially, reducing the tendency of the patch to crack at the edge or deform longitudinally. Round patches would probably have similar benefits, but are more difficult to construct with a reasonable aesthetic quality.

The join between the patch and the existing road is the area that fails most frequently, with an open crack developing that allows the access of water and premature failure of an otherwise satisfactory patch. The application of a geosynthetic crack-sealing strip over these

joins, using a layer of bitumen emulsion to stick the strip and a second layer on top of the strip to 'waterproof' the geosynthetic, has been shown to be a good means of minimising damage at this interface (Figure 28). Blinding with some coarse sand ensures that the bitumen does not stick to vehicle tyres.

The excavated hole will need to be well-cleaned prior to any repair. The depth of the material that needs to be removed depends on the cause of the pothole (see section 4.5) and the material in which it occurs. It is necessary to remove all loose and unbonded material as well as material that has been affected by the pothole, whether it is de-densified, sheared or excessively moist. Once this is complete, the hole should be cleaned of all loose material by sweeping it. Without ensuring that all unsound material is removed, even the best repair of the pothole will soon be affected by continued failure of material outside the pothole patch.

4.4 Materials for filling potholes

Small potholes are usually repaired by filling them with cold-mix asphalt material (CMA). Large ones can be repaired more effectively using hot-mix asphalt (HMA), but the location of the potholes needs to be within a suitable haul distance from an HMA source. The material ordered needs to be of significantly large quantity to make the delivery cost-effective and within a suitable proximity so that the material can be delivered at a temperature that allows successful placement and compaction without excessive cooling.

Asphalt can, however, be rather costly. It is best to replace the bulk of the material removed from deep potholes with natural, cemented or bitumen-treated materials and restricting the use of asphalt to the upper portion of the repair.

4.4.1 Cold-mix asphalt (CMA)

This is the material mostly used for small to medium potholes. The material is usually available in bags (25 to 40 kg) from commercial suppliers. Most cold-mix materials cannot be supplied in bulk, as the majority make use of bitumen emulsion or cut-back bitumen as the binder. The binder needs to be sealed from drying out (loss of cut-back) or the 'breaking' of the emulsion. Even bags that are torn or broken may result in unsuitable materials for patching potholes after a relatively limited time. Most products have a specified shelf life and care should be taken to ensure that the material is still in a workable condition.

There are numerous commercial suppliers of CMA in South Africa. The products have a wide variety of mixes, components and properties and thus potential uses. No general recommendations regarding their use can therefore be made.

No standard specification for the requirements or properties of CMA is available, but Agrément South Africa compiled a document recently for the certification of cold-mix materials (Agrément South Africa, 2010). This outlines certain performance levels for a range of tests (aggregate polishing value, resistance against moisture-induced stripping and permanent deformation, aggregate strength, voids content, permeability, etc.). Materials complying with these requirements and which are Agrément certificated are expected to perform satisfactorily for pothole patching.

The permeability (or voids content) of the asphalt is one of the major factors affecting its suitability. All asphalt for patching should be as impermeable as possible, this being a function of the grading of the aggregate used for manufacture of the mix (as well as the degree of compaction after placement). To ensure a low permeability, a grading that is continuous and balanced (Fuller type) should be used.

As commercial suppliers may change the composition and formulation of their products periodically, it is recommended that specific products are tested and identified for use. Close contact should be maintained with suppliers so that any changes will be noted and additional testing and proving done. The ad hoc procurement of cold mix should be avoided and any tender processes should ensure that a suitable product, and not necessarily the lowest-priced one, is purchased. Large stocks should not be kept to avoid deterioration of the material over time.

CMAs that make use of cut-back bitumen can be difficult to work with when cold and often require 'warming up' in the sun before use. Emulsion-based products do not usually present this problem.

With CMA, it is necessary to ensure that the entire patched area that will be in contact with the CMA is covered with a tack coat, usually bitumen emulsion, to ensure good bonding with the excavated hole.

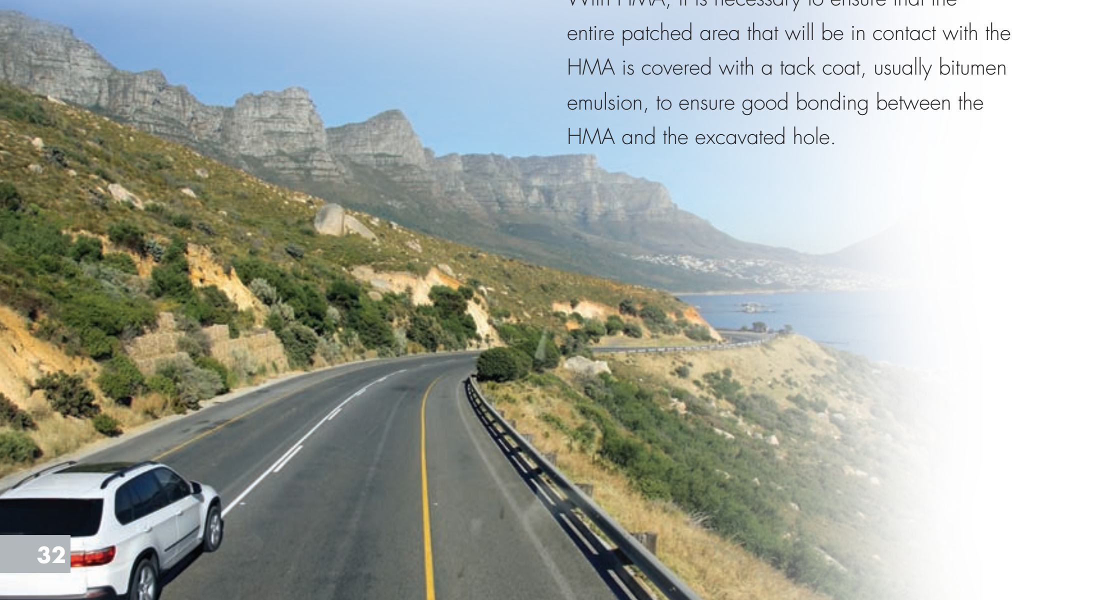
4.4.2 Hot-mix asphalt (HMA)

Where potholes occur within a reasonable haul distance of an HMA plant and the quantity of asphalt required to patch the potholes warrants an adequate supply (usually in urban areas), HMA is probably the best material for patching potholes.

The HMA should comply with the necessary specification for continuously-graded asphalt as specified for a project, or in COLTO Section 4203 (COLTO, 1998). The minimum working temperature is a function of the viscosity of the material (which depends on the binder grade) determined in the laboratory and will be identified for each mix. In most cases this should not be less than about 135 °C. It is, however, essential that the material is not too cold as compaction will then not be effective.

Most continuously-graded HMAs will have a low permeability, an essential requirement for successful pothole patching. Despite certain current practices, it is not recommended that HMA be used to patch potholes with a thickness of more than 75 mm, as it is difficult to ensure adequate compaction of thicker layers.

With HMA, it is necessary to ensure that the entire patched area that will be in contact with the HMA is covered with a tack coat, usually bitumen emulsion, to ensure good bonding between the HMA and the excavated hole.



4.4.3 Natural gravel

If the material originally used for the specific layer is still available or a nearby borrow-pit with essentially the same material exists, this would probably be the best material to use for the repair of deep potholes. Use of a similar material compacted to the same density will ensure that the material strength is similar, that there are no significant permeability differences, and settlement or further compaction of the patch under traffic will be minimised.

Where the same materials are not available, similar materials complying with the TRH 4 (1996) and TRH 14 (1985) requirements for the specific layer should be used.

4.4.4 Cemented material

Natural gravel treated with a small percentage of cement is commonly used to fill the bulk of the pothole. This can be very effective if proportioned correctly, but too frequently, the percentage of cement is excessive. The material placed in the pothole then acts as a single mass of lean concrete in the road structure, rather than a continuous material with approximately uniform properties. This results in the material deflecting under traffic in a more rigid manner than the flexible pavement surrounding it. The effect of this is cracking at the interface between the cemented material and the surrounding material, possible rocking of the stiffer 'block' and ultimately access of water into the pavement as the cracks widen.

Where stabilised materials are to be used to repair potholes which contain a stabilised layer, a stabiliser type and content similar to that of the original structure should be used as far as possible. The material should be compacted to 96 or 97% Mod AASHTO density, as this would probably have been the typical target density for the stabilised layer during the original construction.

4.4.5 Bitumen-stabilised material

Natural or processed gravel treated with a small quantity of bitumen emulsion can also be used to replace material removed from a pothole. Bitumen-treated materials are usually more water resistant than natural materials and the addition of bitumen emulsion usually improves the properties, particularly the strength of the materials significantly.

Recommendations on the type of material and possible application rates and properties of bitumen-stabilised materials are provided in Manual TG2 (Asphalt Academy, 2009). Note that foamed bitumen, unless produced at a local batch plant, is seldom used for pothole patching.

4.4.6 Material from the roadside

The repair of potholes with material extracted from the road shoulders or road reserve is very seldom successful (Figure 13). This material should **never** be used to repair potholes, even temporarily, as it is not adequately durable and results in rapid deterioration of the entire potholed area. Drivers are also given a false sense of security when they see that the potholes have been repaired, although significant depressions may still be present, often caused by compaction and/or whip-off by traffic.

4.5 Pothole repair methods

4.5.1 Shallow asphalt

This type of repair is generally restricted to potholes that occur entirely in an asphalt layer and will seldom require more than a 75 or 100 mm-thick asphalt layer.

Method

Once the area to be patched has been identified, marked, cut, excavated and cleaned (section 4.3), the entire exposed area (vertical and horizontal exposure) of the patch must be covered (painted) with an appropriate bitumen emulsion tack coat[1]. The asphalt (HMA or CMA) should then be placed into the hole and raked level, normally in a single layer. If the hole is more than about 75 mm deep, it should be filled in layers not exceeding 75 mm, each one compacted separately. The asphalt should then be compacted using hand tampers or plate compactors, although small pedestrian rollers can be used for larger patches.

All loose material should be swept from the patch area. It is useful to blind the patch with some fine sand or gravel to avoid adhesion to tyres in the period immediately following compaction. The patch can then be opened to traffic.

The surface finish of the final patch should be checked for level, using a straight edge (section 5). No depressions or unevenness should be allowed. In fact, it is recommended that the final surface should be between 5 and 10 mm above the surrounding road, depending on the thickness of the fill, to allow for a nominal amount of traffic compaction with time.

4.5.2 Medium-depth asphalt repair

If the pothole is deeper than the asphalt thickness and passes into the base course, but is no deeper than the bottom of the base or the upper part of the sub-base, the pothole should be patched as described for shallow asphalt in section 4.5.1. If the pothole is, however, larger than 0.5 m^2 in area, it may be more economical to fill the pothole partially to within 75 mm of the surface with crushed stone, natural gravel or treated gravel (cement or bitumen emulsion). This needs to be as similar to the surrounding material as possible and compacted to the same density as the surrounding material.

Method

Once the area to be patched has been identified, marked, cut, excavated and cleaned (section 4.3), the entire exposed area (vertical and horizontal exposure) of the patch must be covered (painted) with an appropriate bitumen emulsion, if a full-depth asphalt patch is to be used. The asphalt (HMA or CMA) should then be placed into the hole and raked level, normally in a single layer. If the hole is more than about 75 mm deep, it should be filled in layers not exceeding 75 mm, each one compacted separately. The asphalt should then be compacted using hand tampers or plate compactors, although small pedestrian rollers can be used for larger patches.

All loose material should be swept from the patch area. It is useful to blind the patch with some fine sand or gravel to avoid adhesion to tyres. The patch can then be opened to traffic.

The surface finish of the final patch should be checked for level, using a straight edge (section 5). No depressions or unevenness should be allowed. In fact, it is recommended that the final surface should be between 5 and 10 mm above the surrounding road to allow for a nominal amount of traffic compaction with time.

If crushed stone, gravel or cemented gravel is to be used as partial filler, this must be placed in the prepared hole to the required depth (taking into account the bulking factor, typically of about 30%) at optimum moisture content for the material. The edges of the cleaned

[1] The suppliers of certain cold-mix asphalts indicate that tack coats are not necessary – this may possibly apply to those that are emulsion based, but it is recommended that a tack coat be used where cold mix and asphalt are in contact and on the top of the base layer.

hole should be moistened – not soaked – to improve adhesion of the material to the edge of the hole. The optimum compaction moisture content can be estimated by moulding the material into a 'sausage', which should just fracture when squeezed between the thumb and forefinger – if the material compresses, it is too wet and if it crumbles, it is too dry.

This material must then be compacted using hand tamping (or a plate compactor if the hole is large enough), preferably in layers not exceeding 100 mm. It is important that the edges of the material in contact with the in situ material are compacted to the same degree as the rest of the material to eliminate any permeability differences.

The upper surface of the compacted material and the edges of the hole above this level must then be 'painted' with bitumen emulsion before the asphalt is placed and compacted as described above.

4.5.3 Deep repair (asphalt surfacings)

Deep patches in asphalt-surfaced roads are necessary when the pothole is the result of structural failure at depth. This is usually indicated by localised crocodile cracking and is primarily the result of excessive water in the lower portion of the pavement, or poor quality materials. In theory, the source of the water should be eliminated prior to patching, otherwise there is a strong probability that the patched and/or adjacent area will fail again.

Elimination of the water will often require the use of sub-soil drains adjacent to the road (see TRH 15, 1984) and will usually require significant investigation and drainage design. If the water is permeating into the pavement from beneath the surface, failure to take care of this will certainly lead to recurring problems.

Method

Patching in such areas will require marking and cutting of the surfacing and the removal of all failed material as well as any material that contains excessive moisture. If the drainage has not been attended to, this must be replaced with material that has preferably been stabilised with cement or bitumen emulsion to improve its moisture resistance and structural capacity. It is, however, probable that the surrounding material will fail before the replaced material.

The stabilised material needs to be compacted as densely as possible in layers not exceeding 100 mm-thick up to between 75 and 100 mm from the existing pavement surface. Placement of asphalt in this upper area will follow the procedure described earlier.

4.5.4 Shallow-surface repair (thin bituminous seals)

These failures are usually the result of a loss of bonding between the seal and the underlying layer and are common particularly with thin bituminous seals on stabilised bases. These are seldom more than 50 mm deep.

Method

In these cases the pothole should be marked, cut and excavated to at least 75 mm deep. The hole must be cleaned carefully, painted with bitumen emulsion and the pothole repaired as described in section 4.5.1. It is recommended that the join between the bituminous seal and the newly-placed asphalt is sealed with a geosynthetic crack-sealing strip and well-covered with bitumen emulsion. The total patched area should then be blinded with a graded, coarse sand (maximum size 4.75 mm).

4.5.5 Medium-depth repair (thin bituminous seals)

Where potholes have formed in thin bituminous-sealed pavements as a result of seal damage, loss of bonding with the base or some other surficial defect, failure to patch the pothole quickly results in a rapid deterioration of the surface. Enlargement and deepening of the pothole will follow, usually into the base or even sub-base. In these cases the underlying support layers are normally still adequate, unless the pothole is not patched for an extended period, and do not need deep repair. This type of failure is usually indicated by a lack of severe crocodile cracking of the seal in the failed area and affects the full base-depth and possibly the sub-base.

Method

In these cases, the damaged volume (and a little beyond) must be marked, cut and removed totally and the edges and bottom cleaned to leave a hard, compacted surface. Layers of crushed stone, natural gravel or cement-treated material (75 to 100 mm thick) to match the existing base (and sub-base, when necessary) should be constructed in the moistened hole to provide continuity of the layers as far as possible. The top of each layer must be roughened lightly before placement of the following layer.

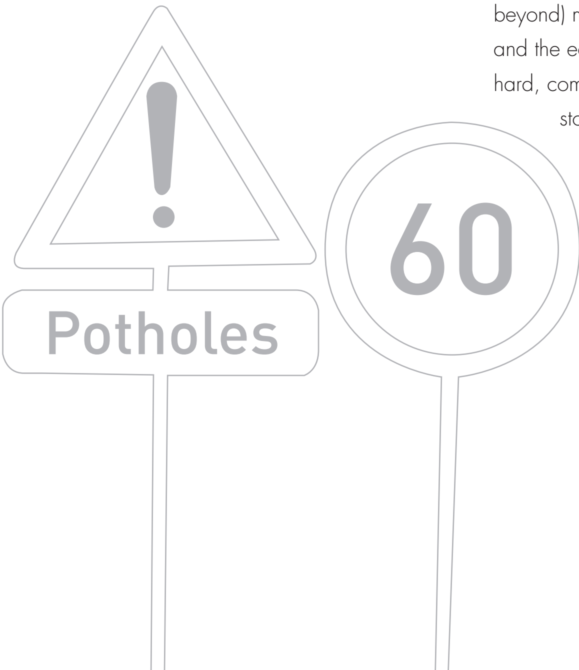
The asphalt patch at the top of the reconstructed pothole area should not be less than 50 mm thick and should be constructed as described previously with the joins sealed using a well-bonded geosynthetic strip.

4.5.6 Deep repair (thin bituminous seals)

When the pavement is structurally unsound or water has entered the pavement structure at depth, the road surface will usually form a depression, crocodile cracks will appear in the surfacing and this will start to ravel and spall, forming large potholes. Although these usually affect the base and sub-base, failure to repair the underlying support material will result in an inadequate repair.

Method

In these cases, the damaged volume (and a little beyond) must be marked, cut and removed totally and the edges and base cleaned to leave a hard, compacted surface. Layers of crushed stone, natural gravel or cement-treated material should be constructed in the same locations (and to the same densities) as the existing pavement layer materials to provide continuity of the layers as far as possible. The top of each layer must be roughened lightly before placement of the following layer.



The asphalt patch at the top of the reconstructed pothole area should not be less than 50 mm thick and should be constructed as described previously.

4.5.7 General

Stabilised layers in the road structure will carbonate over time. This often makes it difficult to use a comparable stabilised material for that layer in deep patches. In these cases, it is probably best to try to use a material that is similar to the stabilised material, once it reaches the equivalent granular state (TRH 13, 1986) or to use a bitumen emulsion-stabilised material.

To achieve similar densities as the original construction, it is unfeasible to determine actual densities in the field. The following densities should thus be assumed:

Base	98% Mod AASHTO
Sub-base	95% mod AASHTO
Cemented materials	97% Mod AASHTO
Upper selected subgrade	93% Mod AASHTO
Other layers	93% Mod AASHTO

Pothole patching is essentially a labour-intensive operation (Figure 29). A full method-statement for pothole patching has been produced by Sabita (2010) which can be used to supplement this document. It is, however, essential that the pothole patching teams are properly trained to ensure effective and durable repairs.

Figure 29: A typical pothole-patching operation on a rural road


Potholes

CHAPTER 5
QUALITY CONTROL

5.1 General

For the repair of potholes to be effective, a controlled quality-assurance programme must be followed. Each stage of the process should be checked to ensure that it conforms to the requirements for that stage.

For pothole repairs, the primary requirements are that:

- The fill materials are suitable for the specific layers
- Each layer is properly and adequately compacted to meet density requirements
- If HMA is used, the compaction temperatures should not be too low
- The final riding quality is acceptable
- The pothole surface does not form a depression after traffic compaction but rather be slightly raised compared with the rest of the road
- All joins are properly sealed
- The patch must be aesthetically pleasing.

5.2 Control

5.2.1 Materials must be suitable for the specific layers

The crushed stone, natural gravel or stabilised gravel materials used for filling the potholes should be tested to ensure that they are suitable. It is unlikely that materials from the same source as those originally used in the construction will be available. The materials should then comply with typical requirements for the appropriate material for that layer, as identified in TRH 4 (1996), e.g. a G1 to G4 for base course, a G5 or C4 for sub-base, etc.

Locally-available materials to be used should be tested and their properties checked to conform to the necessary requirements. Stockpiles should be kept expressly for pothole patching.

5.2.2 The layers should be compacted properly

To minimise the potential for the materials used to repair potholes to further compact under traffic, it is essential that they are compacted properly during patching and the density is controlled. This is usually done using nuclear-density methods (with gravimetric moisture correction), but this is not effective within smaller holes or for very thin, localised surface layers. It is often better to use portable in situ test equipment such as a Rapid Compaction Control Device (RCCD) or Dynamic Cone Penetrometer (DCP) calibrated on the material used for the patch under controlled laboratory conditions. Any holes left in the patched material by the in situ testing should be filled as well as possible.

The actual control of compaction of material added to a small patch can be approximated by measuring the quantity (mass) of material and the change in volume in the hole during compaction. The density (and relative compaction) can then be determined. Correlation with laboratory testing using properties such as the bulking factor and refusal density can assist in making the necessary estimates.

Figure 30: A poorly-finished and untidy patch

Figure 31: A well-executed and aesthetically-pleasing rectangular patch next to a less effective 'circular' patch

5.2.3 HMA compaction temperatures must not be too low

A remote digital thermometer should be used to ensure that the application and compaction temperatures of any HMA are above the lower limit recommended for that particular mix.

5.2.4 Final riding quality should be acceptable

A straight edge should be used to ensure that the final patch is not too high (> 5-10 mm) above the surrounding pavement. A 5 to 10 mm 'hump' will allow for some traffic compaction without causing a significant effect on riding quality in the longer term.

5.2.5 The pothole surface must not form a depression

No patch should exhibit any depression under the straight edge before traffic compaction occurs, as any additional compaction will have a detrimental effect on the riding quality of the road.

5.2.6 Joins should be sealed properly

All patches should be inspected to ensure that there are no open joins between the patch and the surrounding material. It is strongly recommended that a geosynthetic strip be 'glued' with bitumen emulsion over the joins and then 'painted' with bitumen emulsion and blinded with coarse sand.

5.2.7 The patch must be aesthetically pleasing

The final patch should blend into the road as far as possible and should have the appearance of a well-engineered product, e.g. straight edges and smooth finish.

5.3 Field test equipment

To carry out appropriate quality control, various simple pieces of equipment can be used. These include:

- A straight edge and wedge
- A digital thermometer for measuring asphalt temperature
- A simple device for assessing the compaction of gravels and stabilised materials (RCCD or DCP)
- A method for checking the adhesion of crack-sealing material and geosynthetic strips
- A camber board to ensure that pothole patches near the edge of the road are constructed to the correct camber and do not interfere with road surface drainage.

These controls are mostly visual although a number of the properties can be tested. The CSIR has developed a field kit for quality assurance of general sealed-road maintenance, which includes all the apparatus necessary to monitor and quantify the measurable properties identified above. Full instructions are provided with the kit.

Figure 30 shows a recent patch that, although effective, is untidy and poorly finished. It is also clear that the problems leading to the original pothole have not been attended to (e.g. open cracks and deeper fatigue) and the area is likely to require repeated patching. The height of the patch is also such that the riding quality of the road would be affected. A well-constructed and more pleasing rectangular patch is shown in Figure 31, together with a less-pleasing, smaller 'circular' patch that required additional work. The rectangular patch has performed well thus far, even without the geosynthetic sealing strip, although the join was well sealed with bitumen emulsion.

CHAPTER 6
CONCLUSIONS

Budget constraints reduce preventative road maintenance, with the prevalence of potholes likely to increase significantly. Potholes are typically 'repaired' by mostly unskilled or badly-trained teams on an ad hoc basis, quite some time after formation, thus leading to additional deterioration. The patches are seldom sufficient to address the basic cause of the problem and this usually results in the need to return to the site repeatedly for ongoing repairs.

This document provides a procedure to identify the causes of the problems and summarises repair techniques relevant to the specific type and cause of each problem. The aim is to minimise the need to return continually for additional repairs. A standard field rating form is provided to assist in the classification of the type of pothole and associated repair requirements.

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APPENDIX A – STANDARD FORM FOR THE FIELD ASSESSMENT

Inspector ____

Weather ____________________________________ Date ______________

ROAD NO.	LOCATION	SURFACING TYPE	LAYERS AFFECTED	CROCODILE CRACKING	SURFACE DEFORMATION	SUBGRADE SATURATED

CODES:

Surfacing type: **A** – Asphalt **TS** – Thin seal

Layers affected: **S** – Surfacing only **B** – Surfacing and base **SB** – Surfacing, base and sub-base

Crocodile cracking, surface deformation (mounding, rutting, shearing, etc.), subgrade saturated, stabilised base, carbonation of base: **Yes/No**

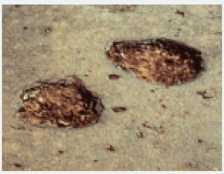
STABILISED BASE	CARBONATION OF BASE	ACTION	COMMENTS

APPENDIX B

KEY TO THE IDENTIFICATION OF POTHOLE REPAIR MEASURES

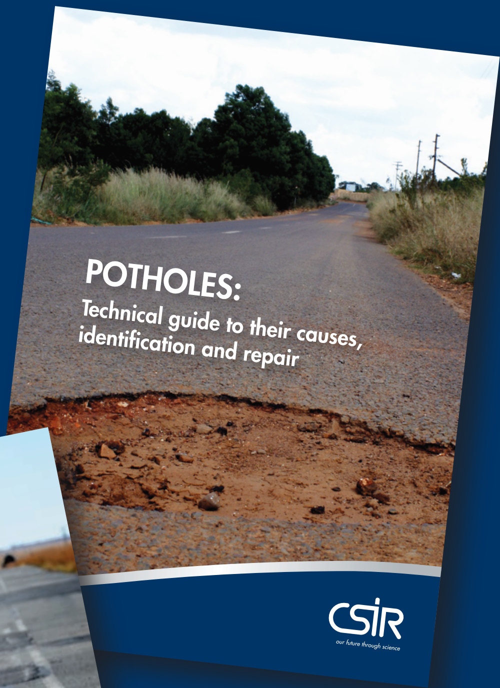
The following key to the identification of pothole repair measures is provided to illustrate the pothole types. It will require enlargement of some of the photographs to identify finer details.

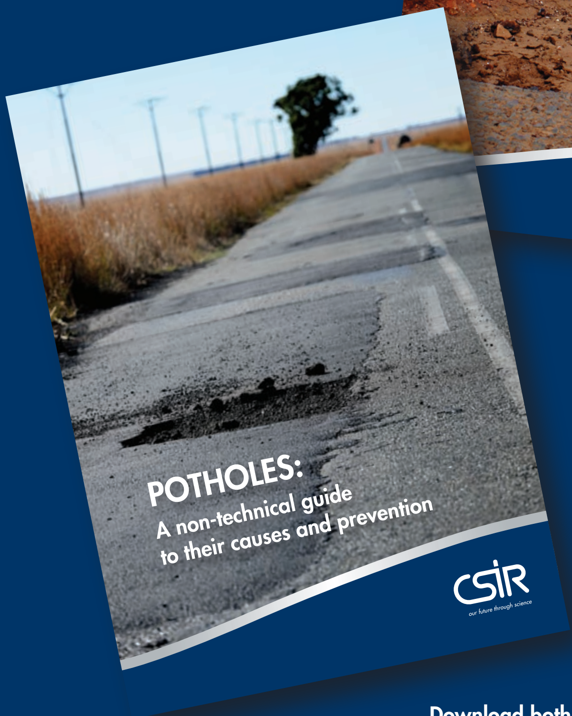
To use the key, one must start at the top left-hand box and sequentially follow the vertical numbering and horizontal boxes until a repair technique is identified. These then refer to the process described in the main text (Section 4.5).

1	Surfacing is asphalt .... > 2		Surfacing is thin bituminous seal .... > 4	
2	Pothole is deeper than asphalt wearing-course ....> 3		Bottom of pothole is within asphalt wearing-course **Shallow asphalt (HMA or CMA)**	
3	Pothole caused by cracking due to fatigue of asphalt **Deep repair after sub-soil drainage installation**		Pothole caused by localised surface water ingress with no associated crocodile cracking **Medium-depth asphalt repair**	
4	Pothole has exposed an unstabilised base ....> 5		Pothole has exposed a stabilised base .... > 10	
5	Pothole is not associated with cracks .... > 6		Pothole is associated with cracks .... > 8	

6	Pothole affects seal and top of base only (< 50 mm) **Shallow-surface repair**		Pothole extends > 50 mm into base .... > 7	
7	Pothole affects only the base **Medium-depth repair**		Pothole extends below the base .... > 8	
8	Pothole does not affect entire pavement structure (only base and sub-base) **Medium-depth or deep repair**		Pothole affects entire pavement structure .... > 9	
9	Pothole is the result of saturated subgrade or support **Deep repair after sub-soil drainage installation**		Pothole is the result of poor material – no evidence of excessive sub-soil water **Deep repair**	
10	Top of base has carbonated and is weak .... > 11		Top of base has not carbonated excessively and is still strong **Shallow-surface repair**	
11	Pothole is associated with crocodile cracking **Deep repair**		Pothole is not associated with crocodile cracking **Medium-depth repair**	

Notes





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