POTHOLE

Guidelines for pothole repairs

(Annex of Final Report of the project "POTHOLE")

Milestone No. 10

Deliverable 5

September 2013

Project Coordinator: Karlsruhe Institute of Technology

Project Partner A: Danish Road Directorate

Project Partner B: Forum of European National Highway Research Laboratories

Project Partner C: Transport Research Laboratory

Project Partner D: University of Žilina

Project Partner E: University of Twente

Project Partner F: Slovenian National Building and Civil Engineering Institute

POTHOLE

This project was initiated by ERA-NET ROAD.

Project No. 832700

Project acronym: POTHOLE

Project title:

Durable Pothole Repairs

Milestone No. 10 – Guidelines for pothole repairs (Annex of final report of the project "POTHOLE")

Deliverable 5

Due date of deliverable: 30.09.2013

Actual submission date: 30.09.2013

Start date of project: 01.10.2011 End date of project: 30.09.2013

Author of this deliverable:

Kathrin Kubanek, Karlsruhe Institute of Technology, Germany

Version: Draft 1.0

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1 Introduction

POTHOLE is a project being undertaken for ERA–NET ROAD by a consortium led by Karlsruhe Institute of Technology (KIT) Institute of Highway and Railroad Engineering, Department Highway Construction Technology from Germany. The other partners are:

- Danish Road Directorate (DRD) from Denmark;
- Forum of European National Highway Research Laboratories (FEHRL) from Belgium;
- Transport Research Laboratory (TRL) from the United Kingdom;
- University of Zilina (UNIZA) from Slovakia;
- University of Twente (UT) from the Netherlands; and
- Slovenian National Building and Civil Engineering Institute (ZAG) from Slovenia.

This document was written as an annex of the final report of the project POTHOLE, but can also be used as a single document when dealing with the repair of potholes. It gives an overview of materials, procedures for the repair of pothole and helps to decide which combination to chose according to the actual need of durability.

The associated final report of the POTHOLE project explains what steps have been taken during the project and how the conclusions in the guidelines have been developed from that.

The final report of the project POTHOLE as well as the more detailed reports of the different Workpackages are available for download on the projects webpage www.fehrl.org/pothole.

2 Basic information for the use of these Guidelines

These guidelines have been developed to offer stakeholders help when dealing with pothole repair and the different possibilities in this context. It gives an overview of materials and procedures for the repair of pothole and helps to decide which combination to choose according to the actual need of durability. Apart from using the appropriate repair materials and procedures, it is also important to choose an appropriate repair strategy for road sections when it comes to cost effectiveness. Therefore different repair strategies are explained as well based upon the conducted Life-Cycle Cost-Benefit Analysis. At the end examples of application of different materials are given.

As this projects aim, which should also be the aim of everyone dealing with the repair of potholes, a durable pothole repair is focused on. Therefore the “worst method” of pothole repairing, “throw and go”, which means putting cold-mix asphalt into the pothole without doing anything else for preparation or compaction is not recommended. Also the other extreme way, the complete renewal of a road construction has not been considered even though normally a renewal has to be done at the end of the service life of each road construction. For a detailed description of different repair techniques also see the report of Workpackage 3.

As a general rule always two main elements of quality pothole repair have to be taken into account otherwise a durable pothole repair cannot be guaranteed. Most of the damages of repaired potholes after a short time period evolve from either bad material or bad repair procedure.
Therefore the two main elements of quality pothole repair are

- material selection and
- repair procedures.

This means that a proper technique has to be used, it doesn’t matter which material is used if the repair is done in a bad way. Even when doing an emergency repair this is important to improve the quality and to ensure that the used material is used in the best way possible. The use of “emergency repair” methods however does not substitute other materials/ procedures which has been shown by the Life Cycle Cost Benefit Analysis during the project (see report of Workpackage 6 of the project).

Experiences showed also that the knowledge and skills of the workers who are performing the pothole repair are of great value. Knowledge on the one hand means that it is important the workers know why special steps are taken within the repair of potholes otherwise sometimes not all steps are done correctly which can’t be always proven afterwards, at least not before new damage occurs. And skills on the other hand means the experience with the work itself which proved to be of great value. Therefore it is essential to have personnel with experience in the field doing the pothole repairs, e.g. by giving them special trainings. Trial sites have showed that the here stated durabilities can be reached. The potholes of trial sites had of course been repaired under best conditions and the repair procedures has been performed seriously. Therefore it is very important to ensure a repair procedure as described in this guidelines if the described durabilities should be reached. And even if done so, no guarantee can be given for the aimed durability as also a lot of other factors e.g. very high traffic or climate factors are involved which are not investigated completely. Therefore this guideline gives recommendations how to use the available materials in the best way possible which represents the state of the art.

3 Definition of the term pothole

In this document the repair of potholes according to the following definition is addressed:

> pothole
>
> *a local deterioration of the pavement surface in which the material breaks down in a relatively short time and is lost causing a steep depression*

Notes:

- Generally, potholes require rapid remedial action to maintain the safety of road users.
- Potholes will also need to be reinstated to maintain the functional requirements and comfort, but the time-constraints on rectification for these requirements will not be as immediate.
- Potholes will typically have a depth of at least 30 mm and an area equivalent to a diameter between 100 mm and 1 m with the values for a specific situation depending on several factors including the traffic speed and intensity, the type of vehicle (particularly the presence of bicycles and pedestrians) and the climate.
- Potholes can grow once they have emerged, but generally stop growing after a certain time. However, other potholes can appear close to an existing one.
- Potholes can occur due to several mechanisms (such as fracture, attrition and seasonal).

4 Choice of material and procedure for the repair of potholes

The durability of pothole repair is massively dependent on the combination of material and the chosen procedure. Based upon that an overview of repair materials and their estimated associated durability is given in Table 1 which combines generic types of materials with their estimated durabilities depending on the corresponding repair procedures.

In this table the desired generic type of material can be chosen. For all generic types of materials more than one category of estimated durability is given. This means that the

durability of a material can vary greatly, depending on the procedure, and shows the importance of the used procedure when repairing a pothole.
Therefore, if a certain durability is needed and a type of generic is chosen, chapter 6 explains the according procedure which has to be undertaken to reach the desired durability when using cold- or hot-mix-asphalts.

For further information Chapter 5 gives a complementary catalogue of existing materials and according laboratory tests, whereas Chapter 6 gives a catalogue of pothole repair procedures.

The durability of pothole repair materials is categorised as follows:

Category I: Durability less than 1 year (short-term durability):

intended as emergency repairs of potholes that can last until the weather conditions allows the application of a more durable repair material.

Category II: Durability between 1-3 years (medium-term durability)

intended for repair of potholes where there are plans to replace the surface layer within a few years

Category III: Durability more than 3 years (long-term durability)

intended for repair of potholes in relatively new surfaces with a durability of more than 3 years.

Table 1: An overview of repair materials for potholes classified by generic material types.

	Hot applied asphalt	**Cold applied asphalt**	**Cement-based material**	**Synthetic binder**
Estimated durability (depending on corresponding repair procedure)	Cat. I, Cat. II, Cat. III	Cat. I, Cat. II	Cat. I, Cat. II	Cat. I, Cat. II, Cat. III
Working equipment	Comprehensive	Limited	Limited	Limited
Limitations for application	None	None	Pothole < 0,5 m	Temperature > 10 °C
Ready for traffic	Shortly after application	Shortly after application	< 3 h after application	< 3 h after application
Working environment	Special education	None	None	Special education
Possibility of recycling	Yes	Yes	No	No
Typical type of damage of repaired pothole	Cracks in repair, adhesion failure, immersed chippings	Loss of material, fretting	Cracks in repair, adhesion failure	Cracks in repair, adhesion failure, cracks in the pavement, loss of chippings, loss of material

5 Catalogue of existing materials and according testing methods

5.1 Generic types of materials

5.1.1 Cold-Mix Asphalt (CMA)

Cold-mix asphalt is mostly used for temporary repairs but, with proper installation, it can be more durable. Major limitation for these materials is that they cannot normally be compacted to the same level as hot-mix asphalts. The advantage is short application time and applicability in harsh winter conditions.

The used types of binder and aggregate gradation are very important, even if the information about that are normally not available. It seems useful to determine some requirements for the components of cold asphalts and the parameters of the final mixture (see Table 2). These could include:

- A minimum number of aggregate fractions that should be used in a mixture;
- limitations on the particle size distribution (minimums and maximums passing through defined sieves);
- required air voids content;
- binder properties;
- required values for the results of the selected tests

One of the possible sets of requirements was recommended by the consortium as follows:

- The maximum nominal size of the aggregate used in a mixture should be in the range of 4 mm to 10 mm
- The air voids content of a cold asphalt should be as low as practicable so that it is as similar to the original surrounding material as possible.
- The indirect tensile strength (ITS) of a cold asphalt, as determined according to EN 12697-23, should be at least 20 % of hot asphalts ITS. The ITS requirement should be evaluated for cold-asphalt specimens under the following conditions:
    - temperature of the cold asphalt before compaction of +5 °C;
    - compaction of the specimens by an impact compactor according to EN 129697-30;
    - storage and conditioning of the specimens before testing at +5 °C; and
    - test temperature of +5 °C.

5.1.2 Hot-Mix Asphalt (HMA)

It presents a more durable solution, it is easy to install and to compact, it enables more effective bonding with existing asphalt pavement. Attention must be paid to appropriate mixture temperature for compaction (hot-box equipment is used to maintain material above appropriate viscosity temperature which ensures that material remain suitable for compaction).

5.1.3 Cement based materials

These fast-setting or rapid-hardening cement-based materials are intended for rapid pavement repair.

As repaired patch deflection under the traffic should be similar to the surrounding pavement, the repair using strongly cement-based materials is not recommended.Significant differences in the deflection could lead to cracking at the joints between patches and the road under traffic loading. This would make the ingress of water possible which may result in additional potholes. When the repaired patch is significantly stiffer than the surrounding (more flexible) asphalt material, it could start to ‘rock’ under the wheels of the vehicles which leads to failure of the adjacent contact areas. Another disadvantaged of this material is the difficulties with recycling when the construction is completely renewed.

5.1.4 Synthetic-binder-based materials

Synthetic-binder-based materials are multi-component systems, most with two or three components. So far only a few have been used in situ for pothole repairs. When using synthetic binders it is necessary to use the prepared mix very quickly as it hardens after a short period of time. Despite the difficulties with handling first tests have shown that very high strength values in comparison with cold- and also hot-mix asphalt can be reached. But also with synthetic based binders the difficulties with recycling appears when renewing the construction.

5.2 Associated test procedures for pothole repair materials

For the investigation and comparison of the properties of asphalt-based materials for pothole repairs a list of recommended laboratory tests is given in table 2.

These requirements are divided into two categories (basic and supplementary), and the relevant test method is identified for each of them.

It is recommended to perform the basic tests if properties of pothole repair materials have to be determined. Supplementary tests should be chosen and performed individually based upon special requests of the current situation which could be e.g. huge potholes or expected very heavy traffic loads.
In regions with harsh winters/ with high number of freeze-thaw-changes the focus of material testing should be on that property.

Table 2: Recommended laboratory tests

Basic tests	**Test method**
Aggregate gradation and maximum size of aggregate	EN 12697-2, EN 933-1
Binder content	EN 12697-1
Air voids content	EN 12697-5, 6, 8
Compactibility (workability)	EN 12697-10
Indirect tensile test (stiffness - strength)	EN 12697-23
Water sensitivity	EN 12697-12
Sensitivity to conditions (freeze/thaw cycles)	EN 12697-12 (modified, see report of Work-package 5 for details)
Supplementary tests	
Deformation resistance	EN 12697-22
Macrotexture depth	EN 13036-1
Skid resistance (pendulum test)	EN 13036-4

6 Catalogue of pothole repair procedures

The following repair procedures only refer to asphalt-mixes as so far asphalt products are the mainly used products for pothole repairs and for that reasons the procedures are described in the following.

6.1 Category I: Temporary repairs/ short-term durability

For temporary repairs mostly cold-mix asphalt is used.

The different methods are:

- Throw-and-roll:

  no preparation and cleaning of the pothole, compaction by tyres of maintenance crew truck, usable in harsh winter conditions, high rate of performing, normally with cold-mix asphalt.

- Edge seal method (for improving patch performance):

  similar to throw-and-roll method (compaction by truck tyres) but then improved by placing a ribbon of bituminous tack material on top of the patch edge (tack material should be placed on both patch and adjacent pavement surfaces). At the end, a layer of sand is placed on the tack material to prevent tracking by vehicle tyres.

- Spray-injection patching:

  placing heated bitumen emulsion (as binder) and virgin aggregate simultaneously into a pothole, no compaction, higher equipment costs, lower material costs, high rate of productivity

- Throw-and-go:

  no preparation and cleaning of the pothole, compaction by traffic only, usable in harsh winter conditions, high rate of performing, but the worst durability, normally with cold-mix asphalt.

  Note: The Throw-and-go method is not recommended!

6.2 Category II: Semi-permanent repairs/ medium-term durability

For temporary repairs cold-mix asphalt or hot-mix asphalt is used.

The procedure is

- removing water and debris from the pothole
- forming the vertical edges (up to sound surrounding pavement) - edges straightening is done by using hand-held saw, jackhammer or cold-milling machine)
- placing the mixture (CMA or HMA) in the hole
- compaction using vibratory plate compactors, drum vibratory rollers or tamper
- An option for smaller potholes is leave out edges straightening, but this omission could have an effect of shorter durability.

6.3 Category III: Permanent or more durable repair/ long-term durability

The procedure is

- preparation including edge formation (by saw cutting)
- cleaning excavation with removing all debris, loose material and water (drying)
- application of bond coat to base (bottom) and sides
- infilling with asphalt material (mostly hot-mix, also cold-mix asphalt or cement-based material is used)
- compaction with vibrating plates, drum vibratory rollers or tamper

The proper preparation of potholes is essential for a good repair. No matter how good quality and durable the material that is used for pothole infilling is, it will not perform well and not last long enough if it is applied in inappropriate circumstances. The prepared patch area (normally rectangular shape) must include the whole area affected by the pothole and any associated distress in surroundings. The cut edges should be clean and neat. All unsound and debonded material should be removed.

Cationic emulsion is normally used for bond coating (it must be evenly applied).

Every type of infill material should be fully compacted. Attention must be paid to the proper mixture temperature when HMA is used. Special care should be devoted to the pothole edges and corners of rectangular patches. Because the joints between the patch and the adjacent pavement are the areas that fail most frequently (open cracks), sealing the joints is advisable for better durability (geosynthetic crack-sealing strip over the joints, using a layer of bitumen emulsion to stick the strip and a second layer on top of the strip to 'waterproof' the geosynthetic). Finally, blinding with some coarse sand over the second layer of emulsion ensures that the bitumen does not stick to vehicle tyres.

For deeper potholes (more than 40 mm), the asphalt should be installed in more layers (each compacted separately). Also, coarse crushed stone material or cementitious material could be used in the bottom layer.

This method using hot-mix asphalt represents the most durable solution for pothole repair and it should ensure the service life as of surrounding pavement.

7 Life-Cycle Cost-Benefit Analysis based upon repair strategies

A repair strategy describes what type of repair is done and at which time during the service life of a road section. Generally two situations can distinguished here:

- The potholes are always repaired immediately after their occurrence, the period between pothole occurrence and repair is very small and can be neglected.
- The pothole repair is deferred, the period between the pothole occurrence and repair is long enough to be not neglected.

Whether potholes should be repaired immediately or the pothole repair can be deferred depends on the number of potholes that have to be patched in one year. If there is only one pothole to be repaired in one year, it does not make sense to wait, because the agency costs remain the same, but the user costs will increase. If there is more than one pothole to be repaired, it can be beneficial to wait with the patching. Because there is some uncertainty attached to number of potholes and the time when they occur within a year, the length of the period between pothole occurrence and repair is uncertain as well.

Because of these uncertainties a Life-Cycle Cost-Benefit Analysis (LCCBA) has been developed (for details see the report of Workpackage 6) during the project based upon special assumptions. This can be used as guidance for an adjusted LCCBA for a certain road section as well as for a basis for further comprehensive Pavement Management Systems (PMS). Nonetheless road agencies have to consider the peculiarities of their road networks in the LCCBA, in order to obtain managerial relevant results.

Based on the conclusions from the conducted LCCBA the following recommendations can be formulated:

- If road agencies consider user costs in LCCBA, potholes should be repaired immediately after occurrence. The longer a pothole exists, the higher the user costs will be.
- If road agencies can chose between different repair alternatives for the immediate repair, they should always prevent an unprepared patching with cold-mix asphalt.
- In situations with a high number of expected potholes for a road section, road agencies should choose a repair strategy with an approximate patching survival of at least two-thirds of the remaining service life.
- In situations with a low number of expected potholes for a road section, road agencies should choose a repair strategy with an approximate patching survival of the remaining service life.
- In situations with a high traffic intensity, and if road agencies cannot do an immediate patching repair, a deferred resurfacing of the road section should be done.
- In situations with a low traffic intensity, and if road agencies cannot do an immediate patching repair, a deferred patching of the potholes should be applied.

8 Examples of Application

This chapter gives examples of application of different materials.

8.1 Application of hot applied bituminous materials

8.1.1 Application of Mastic Asphalt

Area: 1 x 1 m, depth 25 mm

Heating Equipment for Mastic Asphalt

The area is heated with a jet blaster

Mastic Asphalt is tapped from the kettle at 224 °C

Mastic Asphalt is transferred to the area

Mastic Asphalt is distributed in the area with a grater

The surface is dusted with Quarts 1/2 mm

The completed repair

8.1.2 Application of Flexible Plug Expansion Joints

Area: 700 x 600 mm, depth 60 mm

The area is heated with jet blaster

The sealer is tapped from the kettle at 140 °C

The sealer is poured into the area so only the bottom is covered

The area is filled with steel slag 11/16 mm

The area is compacted while the surface is heated with a jet blaster

A new layer of sealant is poured over the steel slag

A second layer of steel slag 11/16 mm is added

The area is compacted while the surface is heated with a jet blaster

A third layer of sealant is distributed

The surface is dusted with Quarts 2/3 mm

The completed repair

8.1.3 Application of Crack sealing material

Area: 1 x 1 m, depth 25 mm

Area: 700 x 700 mm, depth 45 mm

Equipment for heating device

Special container for paving

The sealer is tapped from the kettle at 220 °C

The area is filled with sealant.

The sealant is laid out side the edge of the area

The surface is dusted with aggregate 2/5 mm

The sealant is applied in a thin layer over the aggregate

Each paving lane is dusted with aggregate 2/5 mm

The completed repair

The completed repair

8.2 Application of cold applied bituminous materials

8.2.1 Application of a polymer modified bitumen based emulsion

Area: 1 x 1 m, depth 25 mm

The emulsion is applied with a brush as a primer

The primed area

Aggregate 0/5 mm is transferred to a mixing container

The emulsion is poured over the aggregate in the mixing container

The mixture is stirred mechanically

The mixture is poured into the primed area

The mixture is distributed with a trowel

The material quantity is adjusted with a straightedge

The surface is leveled

The surface is dusted with sand

The completed repair

8.2.2 Application of a bitumen based hardening asphalt

Area: 1 x 1 m, depth 25 mm

A primer is sprayed on the bottom and up along the edges

Asphalt mixture is poured into a wheelbarrow

Water is applied to the mixture

Asphalt and water are mixed with a shovel

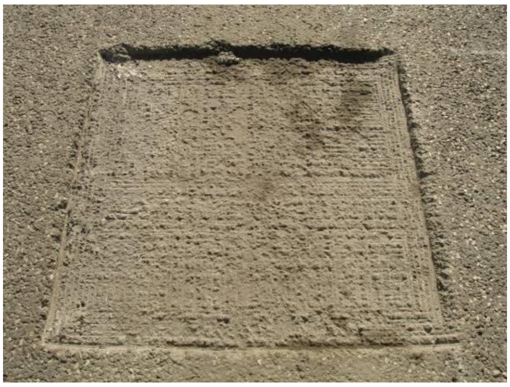
The asphalt/water mix is poured in to the area.

The mix is distributed in the area with a grater

The area is compacted

The completed repair

8.3 Application of cement based materials



Area: 1 x 1 m, depth 25 mm

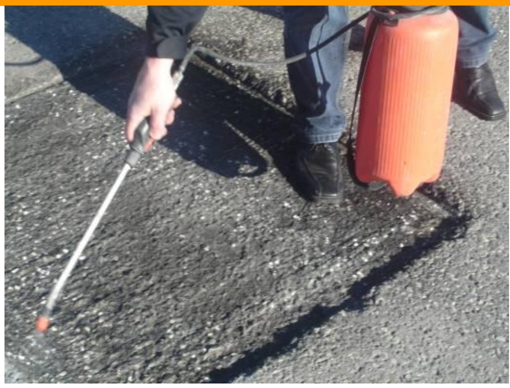
The area is cleaned by vacuuming

The dry parts are poured into a paddle mixer

Water is added

A part of the mix is tapped form the forced action mixer

A stapling improver is added until a slurry consistency is achieved



The area is sprayed with tap water

The slurry is distributed with a broom

The cement mortar is poured in to the area

The cement mortar is distributed with a trowel

The surface is trimmed

The completed repair

8.4 Application of materials based on synthetic binder

Area: 1 x 1 m, depth 25 mm

Area: 550 x 550 mm, depth 50 mm

The area is cleaned with compressed air

The two components of the synthetic binder are mixed

An accelerator is added

The mixture is stirred mechanically

The mixture is distributed as a primer

The mixture is poured over the aggregate

The mortar mixture is stirred mechanically

The mortar mixture is poured into the primed area

The mortar is distributed with a trowel

The surface is brushed with a binder mixture

The surface is dusted with aggregate 0,5-1,0 mm

The completed repair

The completed repair

8.4.1Application of epoxyasphalt

Area: 1 x 1 m, depth 25 mm

Area: 500 x 400 mm, depth 60 mm

The two components of the synthetic binder are mixed

The mixture is stirred mechanically

Aggregates are added the binder mixture

The mortar mixture is stirred mechanically

The mortar mixture is poured in to the area

The mortar is distributed with a trowel

The surface is dusted with aggregate 1-3 mm

The completed repair

The completed repair