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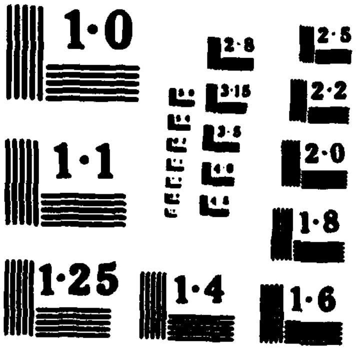
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Suggested Pothole Repair Sequence

1. Identify problem area and make repairs during good weather.
2. Take necessary precautions to protect safety of maintenance personnel.
3. Mark area to be repaired.
4. Cut vertical sides to a depth where sound pavement or base material is found.
6. Tack the hole.
7. Place hot patching material. Use two lifts if patch is thicker than 6 inches. Patching material should either be hot mix, or, if necessary, heated cold mix.
8. Compact each lift sufficiently. Adequate compaction is essential for proper pothole patching.
9. Seal around edges of patch.
10. Perform preventative maintenance to stop pothole problem.

CRREL's *Cold Regions Technical Digests* are aimed at communicating essential technical information in condensed form to researchers, engineers, technicians, public officials and others. They convey up-to-date knowledge concerning technical problems unique to cold regions. Attention is paid to the degree of detail necessary to meet the needs of the intended audience. References to background information are included for the specialist.

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The engineer's pothole repair guide

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Introduction

In 1981, CRREL published the *Pothole Primer: A Public Administrator's Guide to Understanding and Managing the Pothole Problem* (CRREL Special Report 81-21). Its purpose was to provide facts about the causes and costs of potholes in a short and easy-to-understand format. This *Engineer's Pothole Repair Guide* is similar in concept, but is intended for highway engineers, superintendents, and maintenance managers.

As was mentioned in the *Pothole Primer*, many highway engineers agree that expedient techniques for pothole patching are little more than exercises in futility. Nevertheless, proponents of such procedures claim that more permanent repairs are not cost effective, because maintenance personnel must spend too much time preparing the hole, compacting the mix, etc. In terms of dollars spent, this logic simply does not hold up. If a pothole is not permanently patched the first time, subsequent trips must be made to refill the hole. Each time the same pothole is patched, its expense to the agency increases.

A study by the Pennsylvania Department of Transportation in 1976 showed that repeated pothole patching cost five times as much annually as a one-time permanent patch (O'Brien 1976). In addition, a value engineering analysis from the Aberdeen Proving Ground in Maryland showed that

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permanent repair would save an estimated 70% of their current budget for temporary road repair.* Clearly, savings can be realized by correctly repairing potholes the first time, and this effort must be made by highway administrators and engineers.

Potholes

The types of failures in asphalt concrete pavements are many, but the procedures for repairing these failures are the same. Most potholes that form in the winter or spring are temporarily patched, and then left until warmer months for permanent repair. Unfortunately, this system does not work well unless the repair is made correctly. Often these patches last only a few days, or in some areas, only a few hours.

Permanent repairs can be made in any season as long as the proper equipment and correct procedures are used. An initial investment in new equipment may be necessary, but the time and money spent on patching potholes correctly the first time will lead to a break-even point and eventually to substantial savings in maintenance costs. The equipment will literally pay for itself by reducing manpower and material requirements. In addition, liability for the agency is reduced if users have a safe road on which to travel. In short, the procedures and recommendations outlined in this guide will benefit all who are concerned with providing better roads.

Pothole occurrence. Most potholes will result from one or more of the four main causes:

1. Roads that have insufficient thickness to support traffic during winter/spring thaw cycles without localized failures.
2. Poor drainage, which will usually cause failure in combination with thin pavements, but can also affect thick pavements and new overlays.
3. Failures at utility trenches and castings.
4. Miscellaneous paving defects and cracks which are left open and unsealed from water intrusion.

The insufficient thickness of the roadway may be the result of a pavement that is too thin or that has an inadequate base, subbase and subgrade. Nondestructive tests indicating the strength of the materials beneath the pavement can be performed (such as the Benkelman beam test). The thickness of

*Aberdeen Proving Ground, Maryland (1982) Equipment Justification Value Engineering Document (worksheet).

the pavement should be checked according to formulas such as those presented in Asphalt Institute Handbooks.

Drainage problems can result from inadequate slopes due to poor design or to low spots from settlement of base, subbase and subgrade materials. Potholes frequently occur at curb lines, and at intersections where roads with different cross-slopes intersect. Often, drainage problems can be caused by inadequate maintenance of drains and ditches at the shoulders of the roadways. A periodic program of clearing ditches of vegetation and debris from storm drains and culverts can greatly increase the longevity of the roadway surface.

Well-drained base and subbase materials will, of course, reduce the incidence of frost heave—a major cause of potholes. In well-drained soils, water will not be drawn upward from the water table to cause ice formation at the freezing front and subsequent frost heave.

Failures at utility trenches and castings are often the result of improper installation. (See the *Pothole Primer* for a discussion of this problem).

Paving defects and cracks can be caused by such things as plastic deformation, subgrade or base consolidation, entrapped water or just normal wear. An important maintenance operation is the sealing of surface cracks to prevent water intrusion.

How potholes develop. A pothole develops when two factors are present at the same time: water and traffic. Since water and traffic must be present together, it can easily be seen that the most common location for pothole development is in the wheel paths of traffic. There are two major methods by which these factors (water and traffic) lead to pothole development.

1. *Fatigue failure* is caused by excessive repeated flexing of the pavement, which occurs most commonly on thin pavements when excess water is in the base. Meltwater formed during the spring thaw or water from poor drainage weakens the soil under the pavement. Then the pavement excessively flexes under traffic until it starts to crack and break in several places.

Fatigue failure produces what is considered to be the classic pothole (a bowl-shaped crater) (Fig. 1) which can occur with very little warning. If enough traffic passes the pavement

1. Pothole caused by fatigue failure.

while excess water is present, it will eventually pothole. Thinner pavements (under 3 in.) are more prone to this type of potholing because the pavement disintegrates into very small, 1- to 2-in. pieces that traffic can easily dislodge. This type of failure is most common in the spring traffic although it can occur in the summer and fall after heavy rains.

2. *Raveling failure* is significantly different but, again, occurs only when traffic is present and water actually washes away the adhesive asphalt films that hold the stone aggregate together. This leads to a gradual raveling away of the stone particles. This condition occurs when the water has a chance to permeate a pavement that lacks sufficient density to prevent water penetration. Raveling may also occur at edges or openings in pavements such as at cracks and joints or other defects that have not been maintained by timely sealing (Fig. 2). The potential for pothole development by raveling can

2. Potholing by raveling.

readily be predicted as the deterioration is quite obvious and can exist for a long period of time (2 to 5 years) prior to disintegration due to potholing. Following a rainstorm, potential raveling locations always stay damp or wet-looking for long periods of time after the rest of the pavement has dried out.

Potholing patch failures are classic examples of raveling, and these will occur on very short notice. It has been reported that some street departments have filled the same hole 10 times in one day under adverse weather conditions when enough water and traffic were available to simply strip the aggregate away.

Materials for patching

Hot mix. The best material for patching potholes is hot mix from an asphalt plant. The drawbacks to using hot mix for pothole patching are:

1. Availability—Most asphalt plants close during winter months or periods of no construction.

2. Quantity—When hot mix is available, the typical truck load obtained (1-8 tons) necessitates patching many potholes to use up the mix. By the end of the day the hot mix has cooled before it is used, and proper compaction is impossible to obtain. Nonetheless hot mix is appropriate at any time and is possible to use year-round with currently available hot boxes or small portable recycling equipment.

Cold mix. Cold mix is usually made with a cutback (asphalt cement that has been liquefied with solvents that evaporate on exposure to air) or with emulsified asphalt. More often than not, a cold mix stockpile is maintained at local garages and maintenance yards.

Mix design is critical for a cold mix to perform properly. The Indiana and Pennsylvania Departments of Transportation, for example, have developed cold mixes that perform very well and are currently in use for small patching jobs. Most local highway departments do not, however, have the staff or facilities to develop these mixes, and therefore must rely on local batch plants that often sell poor quality cold mix. The key to using cold mix is to obtain proper curing by evaporation of the diluents.

The cold mix designs for patching used by the Pennsylvania and Indiana Departments of Transportation are shown in Table 1.

Heated cold mix. An alternative to cold patch is a method

Table 1. Cold mix designs used by Pennsylvania and Indiana Departments of Transportation.

Sieve no.	*Gradation of aggregate (% passing)* *Pa.*	*Ind.*
½ in.	100	85-95
4	85-100	38-55
8	10-40	16-35
16	0-40	12-25
200	Maximum 2	Maximum 6

Asphalt content average 4.9% (by weight) if absorption of aggregate is less than 1%. For absorption of:

1.1% to 1.5% binder residue = 5.0%.*

1.6% to 2.0% binder residue = 5.5%

2.1% to 2.5% binder residue = 6.0%

Binder: MC-250 with an anti-strip agent which is compatible with the aggregate.

*The more absorptive the stone is, the more binder (asphalt) must be added to the mix to bind it together. If the stone absorbs 1.2%, add 5% asphalt; if the stone absorbs 2.3%, add 6% asphalt.

where the cold mix is stockpiled until ready for use, then heated in portable patching machines. The diluents in the mix are driven off quickly by the high temperatures produced in the machines, leaving what is essentially hot mix for the patching procedure. The efficiency of the available machines varies—but the fact remains that *heated* cold mix, however supplied, is superior to *unheated* cold mix. Another advantage of these machines is that an amount of mix required for the specific job or pothole can be prepared in a relatively short amount of time.

In the case of both hot mix and cold mix, an aggregate that provides for good workability as well as stability should be used. Aggregate with an angular, rather than rounded, shape is recommended. Crushed stone works well for this purpose. The size of the aggregate should be limited to material passing the No. 4 sieve.

In order to test for the proper mix design, one can mix trichloroethylene with the mix to strip the asphalt from the stone and run the stones through sieves to be certain that the gradation is met. Also, distillation tests can be run to recover the asphalt and test its properties (see *The Asphalt Handbook* by the Asphalt Institute).

Recycled mix. Recycled mix has gained in popularity recently, due mainly to the increasing cost of virgin asphalt material. Material that has been removed from a paved surface can be reused in a portable recycling/patching machine or at a batch plant because heat is needed to soften the old asphalt and make the mix workable. It should also be noted that aged asphalt concrete (as in a recycled pavement) tends to be brittle because of oxidation over time. To be effective the mix should be blended with new material. Recycled pavement might be blended with cold mix in a patching machine or perhaps a rejuvenator to produce a better or more effective patching material. A rejuvenator is a light oil, containing some of the ingredients found in asphalt that oxidize or age with time. By adding this oil to the old pavement, it can extend or increase its durability.

Tacking materials

Cutbacks. Generally speaking, RC (rapid curing) cutbacks (RC-70, 250) are used for tacking purposes. They should be applied at about 0.10 gal./yd^2. If too much is applied it will lead to shoving, or bleeding, and premature failure of the patch.

Emulsions. Asphalt emulsions consist of three basic ingredients: asphalt, water, and an emulsifying agent.

RS (rapid setting) emulsions set too quickly to be used for tacking, but MS (medium setting) and SS (slow setting) emulsions (MS-1, SS-1, 1h, and CSS-1, 1h) are acceptable for use.

Sealing materials

Emulsions—RS emulsions (RS-1, 2 and CRS-1, 2) are particularly good for sealing the edges of pothole patches. Although less desirable, MS emulsions (MS-1, CMS-1) can also be used. SS emulsions set too slowly to be used for sealing.

Cutbacks—RC cutbacks (RC-250, 800) can be used for sealing as well as MC's (MC-250, 800). Each RC cutback grade has a different use, depending on weather, traffic, and materials.

:nt are needed for effective pothole

and sealing equipment.
:quipment.
ment.

d sealing equipment. Cleaning, tack-
ient should include brooms, brushes,
l seal), rags, and torches (for drying).
ssor with a sprayer will be used for
: hole and also for drying. Then spray
essure application of the tack and seal
om and/or brush can be used to re-
debris from the hole before squaring
gs will be needed for clean up and, if
e used to dry the hole. A torch is also
eaning rakes, shovels and other equip-
ing operation.

uipment. The best tool for squaring a
al sides is a pavement breaker (jack-
rs are hydraulically driven by a gaso-
es them self-contained, an obvious ad-
intenance crew), and some require a
r. A chisel point with one flat side is
the sides of the hole will be vertical.
not be used because it leaves smooth
de good bonding for the tack coats or
ld only be used if pavement breakers
re is no other way to make the vertical

ent. The most important step prior to
compaction. The repair crew must try
nsity in order to make the patch last
ater out. (It is unlikely that a pothole
-compacted, given the conditions that
: patching operation.)
orating roller compactors are the most
work" the mix while it's hot and help

ive compactors are the heavy "static"
wheel rollers for larger potholes.

If other types of compactors are used (s
pers), place the hot material 1- to 2-in. lif
care to properly compact the patch. As sta
the most critical part in the patching pro
mines the life of the patch.

If desired, one can determine density by t
asphalt concrete and testing in the laborato
clear density gauges to measure density in
partments of Transportation usually have

The hole should be overfilled by ¼ to ¾
the depth of the hole (¼ in. for holes up to
for holes 2-4 in. deep, and ¾ in. for holes
deep). This is for guidance only and will var
the mix you use. This overfilling is required
paction. When compaction is complete,
should be just slightly higher than the surrc
so that a "birdbath" or low spot does not
will collect and cause future problems.

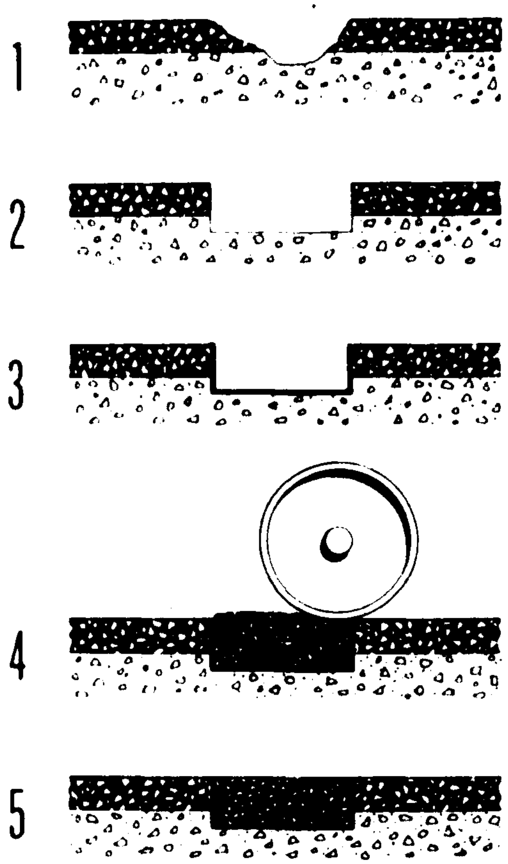
Mix equipment. There are many types c
can be used to mix, heat, or recycle patchi
include recyclers, stockpile heaters, and hc

Recyclers. Most portable recycling mach
to be towed behind a pickup or dump tr
brought near the holes being patched. Som
for throwing broken pavement pieces fro
rectly into the machine and recycling at th

Recycling machines (mix equipment) usu
crew of at least 4 or 5 to ensure good prod
machine and procedure will dictate how ma
needed for the job.

Stockpile heaters. Some of these portabl
set up at a central maintenance yard and us
asphalt plant. Stockpiled cold mix, chunk
phalt pavement, or virgin aggregate to wh
cement is added can be used. These "po
chines prepare mix from these materials w
into trucks with hot boxes and then deliver

Hot boxes. The hot boxes can be little m
boxes, or they may have their own heat sou
available trailer-type hot boxes, 2- or 4-t
on wheels, are heated underneath and alo
gas. They can also be mounted on trucks.



3. Pothole permanent repair. 1) Untreated pothole, 2) Surface and base removed to firm support, 3) Tack coat applied, 4) Full-depth asphalt mixture placed and being compacted, 5) Finished patch compacted to level of surrounding pavement.

Repair procedures

There are seven basic steps to pothole patching. Some steps can be adjusted to the conditions that exist, but for the most part, all steps must be closely followed to ensure a long-lasting patch (see Fig. 3).

Of course, before the patching is begun, one should have determined that this is the correct procedure. For example, in badly deteriorated sections, a complete overlay may be required. Of utmost concern should be the safety of the repair crew.

1. *Marking*—The area around the pothole must be marked with chalk or paint in order that the workman doing the cutting can easily and quickly remove the failed material. Marking is done to include only portions of the pavement that will provide a good surface against which the patch is to bond; that is, these portions should have no cracks and appear solid compared to the area immediately adjacent to the pothole.

2. *Cutting*—The workman doing the cutting should avoid cutting more than is marked (excess cutting reduces cost effectiveness due to increased material use). The walls of the

hole should be made vertical to provide a good surface for adhesion and "locking" the patch in during compaction. Cutting should continue to a depth where good pavement or base material exists.

If the pavement that is cut away is to be recycled, care should be taken to avoid including base and subbase material to prevent contamination of the mix. When the cutting is complete the large chunks of pavement should be removed and stockpiled, if not used immediately, for future recycling.

3. *Cleaning*—This step includes removing any remaining debris from the hole. (Compressed air works well for this). If the hole has been made to the base or subbase, these materials, if disturbed, must be compacted so that compaction by traffic will not occur after the patch is in place.

If the hole has water in it, the bonding of the patch will be poor. The hole must be dried as much as possible by using compressed air, a torch, rags, broom, etc.

It should be stressed that all debris must be removed from the sides of the hole. Loose material will cause a poor bond, and lead to early failure of the patch.

4. *Tacking*—A tack coat should be used to provide a bond between old and new surfaces. Too much tack coat will result in an excess amount of asphalt, which will lead to rutting, and eventual failure of the patch.

Hot mix, as well as recycled mix or cold mix should always be tacked. The best method for tacking is to spray the tack in a thin coat. Brooming and pouring are generally not effective because excess tack material usually accumulates at the bottom of the hole around the edges.

Either cutbacks or emulsions are used for tacking and they are described in the "Materials" section of this guide.

5. *Placing*—Holes deeper than 6 inches should be filled (and compacted) in more than one lift. Placing should be done with a shovel in one lift working from one side of the patch to the other. To prevent segregation, the material should be laid, rather than thrown or raked, into the hole. The patch should be made so that after final compaction, it is slightly (about ¼ inch) above the surrounding pavement to allow possible future compaction by traffic and eliminate "birdbaths." No patching material should be left on the surrounding surface.

6. *Compaction*—It is crucial that the patch be compacted properly. Poor compaction will cause shrinkage of the patch,

allowing intrusion of water around the edges and ultimate failure.

The compaction method should match the size of repair. A one-square-foot patch does not require compaction with a 10-ton tandem steel-wheeled roller. Most road repairs can be made with small- to medium-sized vibrating plate or roller compactors. Care should be taken by the operator to ensure that the compaction force is directed on the patch and not the surrounding pavement.

7. *Edge sealing*—Edge sealing is done to keep water out of the joint between the pavement and patch. Any material can be used, so long as it does not cause excess asphalt to bleed around the patch. A layer of fine sand can be used to blot the seal.

Pavement management

Ideally, pavements should be maintained so they will not deteriorate to the point where potholing occurs. Pavement management systems provide detailed information about the road network to the manager so that decisions about maintenance can be made. Highway administrators and engineers should take the initiative and explore this new technology.

Particularly recommended is the PAVER pavement management system developed by the Construction Engineering Research Laboratory of the U.S. Army Corps of Engineers and which is being promoted by the American Public Works Association (APWA). PAVER (Shahin and Kohn 1981) is a manual or computer-based decision-making procedure for identifying cost-effective repairs for roads, streets and airports that has been developed and tested over the past 10 years at a number of military installations and cities. Cities currently using the PAVER system include Tampa, Florida; Tacoma, Washington; and Ann Arbor, Michigan. The University of Illinois at Urbana-Champaign and the APWA offer courses on the use of the PAVER system.

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