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Pothole primer

A public administrator's guide to understanding and managing the pothole problem

Robert A. Eaton, Robert H. Joubert and Edmund A. Wright

Approved for public release; distribution is unlimited.

SUGGESTED POTHOLE REPAIR PROGRAM

1. Train a "Pothole Supervisor" to recognize problem areas in your town or city.

2. Conduct an inventory of your pavement system to rate the condition of each street.

3. Develop a maintenance schedule based upon the inventory; establish a regular program of crack sealing and surface treatment.

4. Provide separate budgets for snow removal and road maintenance.

5. Establish a normal program of inspection and removal of debris from drainage ditches and structures.

6. Equip pothole repair crews to blow out, sweep or otherwise remove water and to dry and prepare the hole.

7. Repair potholes successfully by: a) proper hole preparation, b) use of heated asphalt concrete, and c) proper compaction of materials.

8. Repair potholes in the summer based on year-round monitoring and the inventory.

9. Use proper materials and procedures in good weather for permanent "one-shot" repairs.

10. Develop a first-class, strictly enforced system of coordinating the improvements to underground utilities with the street resurfacing program.

11. Establish a system making the utility responsible for the care and maintenance of a patch for at least a year after a pavement cut.

12. Maintain your pavements on a regular and proper basis to protect your investment.

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PREFACE

This report was prepared by R.A. Eaton, Research Civil Engineer, of the Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), R.H. Joubert, District Engineer, The Asphalt Institute (New England States), and E.A. Wright, Technical Writer/Editor, Technical Communication Branch, Information Management Division, CRREL. Funding was provided by DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions*, Technical Area C, *Cold Regions Maintenance and Operations of Facilities*, Work Unit 11, *Repairing Frost-Induced Potholes in Flexible Pavements*.

The authors express their appreciation to the following individuals: William Quinn and Dr. Richard Berg for technical review of the report, Donna Valliere for typesetting and pasteup, Robert Demars for preparing the photographs, Thomas Vaughan for drawing several of the illustrations, and Barbara Jewell for typing the original manuscript.

COORDINATORS' COMMENTS

Robert A. Eaton, Research Civil Engineer, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL)

CRREL is a research laboratory established for the purpose of studying the climate of the cold regions and its effects on military and public facilities, equipment, and operations. CRREL has an obligation to share its findings and expertise in these areas with organizations in the public sector such as highway agencies and municipalities.

Since potholing is generally most prevalent in cold regions, many inquiries have come to CRREL regarding the pothole problem and what can be done about it. The technical aspects are well known to highway people and researchers, yet the problems abound: cars waste gas and suffer damage, and fatalities even occur because of potholing. As a result, the public is asking, "If we can put a man on the moon, why can't the engineers design such a simple thing as a road?"

We at CRREL felt that improved awareness of all the known factors contributing to the problem should be included in any thorough attempt at a response to this question. Additionally, we felt that such a response should be provided in a publication that is readable and useful for the broadest possible audience. We hope that this booklet hits the target.

Robert H. Joubert, District Engineer, The Asphalt Institute (New England States)

Potholes have become a problem of national proportions. We have seen Congress, in 1978, consider a special $250-million "pothole bill," and in 1979 a special Federal-level Task Force was established to study the pothole.

While potholes have offered much in the way of opportunities for humorist Erma Bombeck and opportunists like the students in Pennsylvania who sold potholes for $3.50 apiece, these activities only go to further the myth that potholes occur everywhere and there's simply nothing that can be done about them.

Well, there's a serious side to the pothole problem too. Potholes do not just simply occur everywhere and there's a great deal that can be done about eliminating them if we only focus on where and why they have been increasing in recent years. We hope that through this booklet, a more complete picture of the problems will help a community of any size to work out its own program to eliminate them.

I am most grateful to all those who responded to my inquiries and questions on their experience in handling this problem. I am especially grateful to those who contributed so much at the Pothole Workshop held on September 16 and 17, 1980 at CRREL, without whose help this task would have been impossible.

PURPOSE

This booklet has been prepared for the specific purpose of assisting elected officials and non-engineering administrators of cities, towns, and military facilities in New England in understanding and managing their pothole problems in asphalt pavements. We have attempted to keep this booklet as non-technical as possible so that non-engineers can use it.

This booklet, as the title suggests, is a primer on the subject and only highlights the major causes and general solutions. The serious reader is encouraged to pursue the additional up-to-date detailed references provided at the end of the booklet. These can easily and economically be secured.

This effort was sponsored by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory with assistance from the New England District Office of The Asphalt Institute and the individuals who participated in and contributed to the workshop held on September 16–17, 1980, on this subject. The principal contributors to the workshop were the following:

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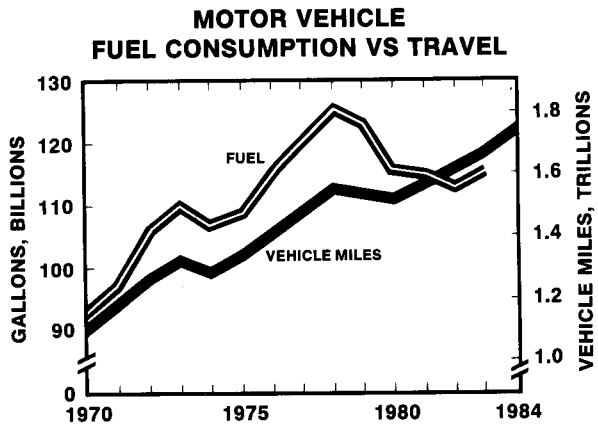
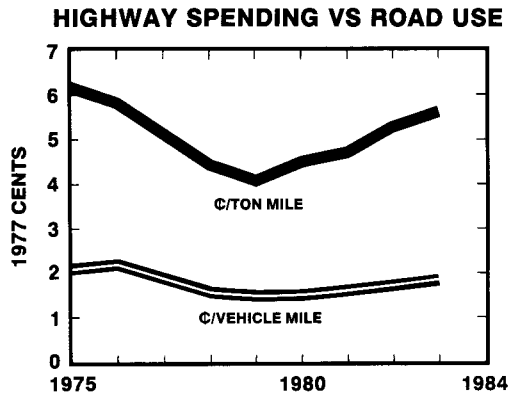
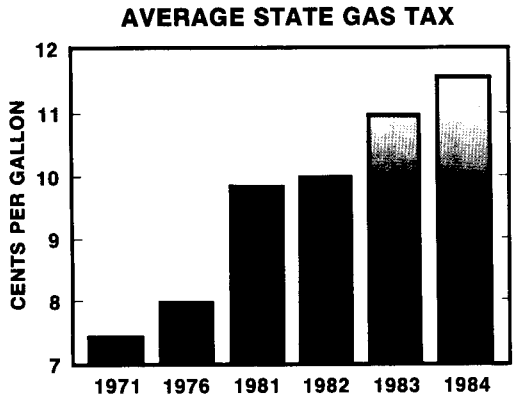


While travel is still increasing, gasoline usage and highway revenues are down due to more fuel-efficient autos



Highway spending, though recently increased, has not reached previous levels



Gas tax increases have steadily risen but have not kept pace with inflation

INTRODUCTION

Many factors contribute to the increase in pothole occurrence, and we have many reasons today for taking a fresh look at them. The project tried to consolidate these factors into 11 manageable categories so that readers could focus on each separately. The categories are:

1. Financing.
2. Traffic growth.
3. Safety, legal and public relations aspects.
4. Weather.
5. Identifying and cataloging causes.
6. Drainage.
7. Preventive maintenance programs and pavement inventories.
8. Utility cut control.
9. Pothole patching procedures.
10. Special focus on intersections and utility castings.
11. Training and education.

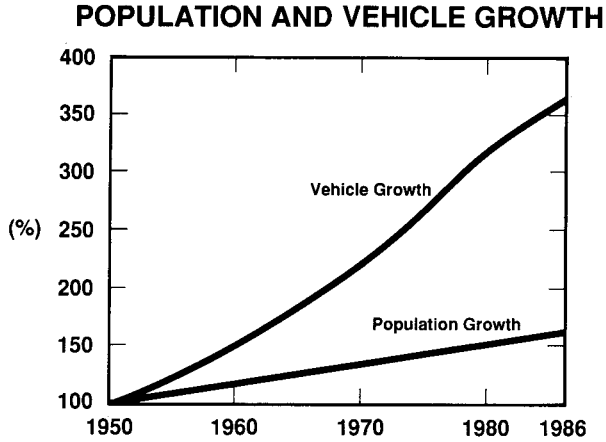
FINANCING

As the charts to the left clearly indicate, several basic financial problems affect the pothole problem and the overall transportation problem.

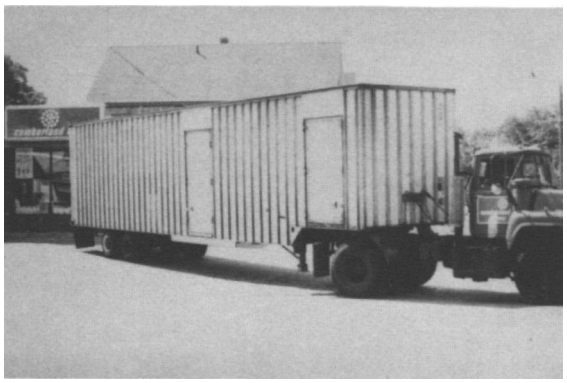
Gas tax revenues are decreasing due to more fuel-efficient cars, and political bodies have been slow to propose increases to adjust to the situation.

Political action demanding decreased local spending has caused financial cuts *first in low profile departments* such as street departments. Maintenance budgets are likely to suffer, even though major deterioration eventually means more expensive reconstruction.

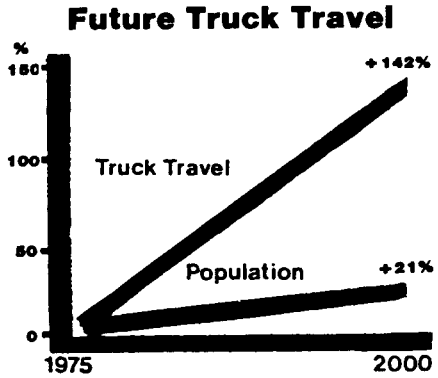
Inflation has increased road maintenance costs 2 to 3 times in the past 10 years, so that fixed maintenance budgets are covering fewer and fewer repairs.



The number of vehicles has increased dramatically.



More big trucks use local roads



Truck travel is still increasing

TRAFFIC GROWTH

Traffic is still growing at very rapid rates and the weight of trucks has changed dramatically in the past 20 years. Many local roads were never designed or built to handle today's traffic. From 1960 to 1980, motor vehicle registrations increased by 75 million while the population grew by only 30 million.

With the decline of the railroads in many areas of the country, our roads and streets have become rubber-tired freightways. The number of trucks more than tripled from 9 million in 1960 to over 30 million in 1980, a trend that is expected to continue to the year 2000.

Compounding this problem even further is the weight of today's trucks. The average fleet truck in 1960 weighed about half of what the average fleet truck weighs today, and depending on the pavement thickness, this increase can have a most significant effect on pavement life. Estimates range from a decrease of 10% in design pavement life on thick pavements to reductions of 90% on thin pavements. Many of our local roads were never designed for the truck traffic they are experiencing today.

We no longer see the small local delivery trucks that used to service the railheads. Now, for economy and efficiency, many stores are serviced by huge trailer trucks. Further, with improved all-season construction techniques, trucks loaded with concrete and building materials roll each year over spring-weakened pavements. So, while finances are decreasing, our traffic needs are still growing.

Many municipalities do not have full-time engineering staffs so that design standards and maintenance practices have not been upgraded for increased traffic.

SAFETY—LEGAL AND PUBLIC RELATIONS ASPECTS

The combined effect of decreasing road maintenance funds and increasing traffic growth will inevitably propel many communities into a severe potholing situation. A community should counteract this trend and start on a program of preventive maintenance.

Small cars of today suffer more damage from potholes

"There's a Gentleman to See You About Potholes..."

(Reprinted courtesy APWA Reporter, American Public Works Association)

Citizens rate roads every single day

The swing to downsizing the U.S. automobile is finally accelerating and the damage from potholes to these small, but very costly, cars has increased substantially. The growing popularity of bicycles, mopeds and motorcycles has increased the danger of potholes and other pavement defects.

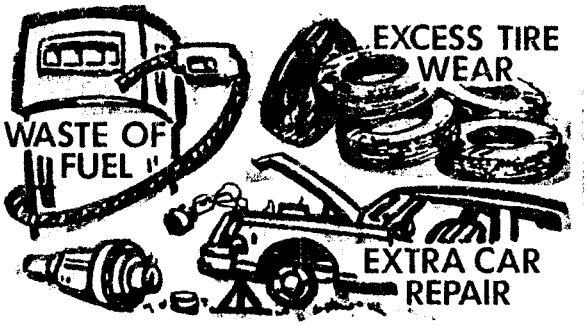
The immunity of the municipalities from legal action arising out of claims from pothole damage has been significantly diminished in recent years and the trend is increasing each year. Television newsmen are even jumping on the bandwagon and leading the lawyers to claims against municipalities.

A UPI article reported that a Brooklyn man, who suffered permanent disabilities when riding in a car that hit a pothole, agreed to accept $365,000 in settlement of a $5 million lawsuit against the city. The claimant lost movement in all four limbs in the accident.

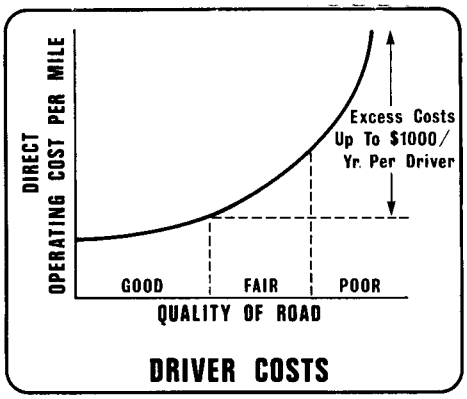
The laws of different states vary widely with respect to the legal vulnerability of a municipality, a municipal employee or elected official. Additionally, the interpretation of these laws is constantly changing as juries have become more lenient toward claimants. If you have a question regarding your status in the community, the advice of your town counsel or the state attorney general's office should be sought.

The cost of automobiles and their repairs has increased citizen reaction to a point where administrative activity can break down during the pothole season to just handling complaints and damage claims. Just two statistics give scale to the size of the problem. After the winter of 1978–79, 650 pothole-related claims were made against the city of Boston. Between March 6th and April 8th 1979, the City of New York filled 211,000 potholes.

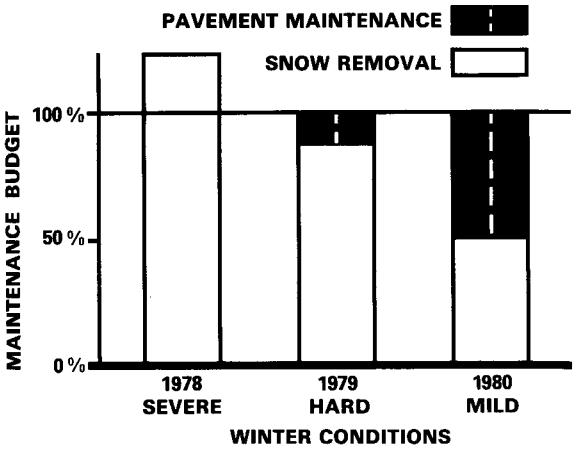
Emergency highway maintenance work, as opposed to planned work, is extremely dangerous. In Massachusetts, at the onset of the February 1978 blizzard, a DPW employee was killed by an automobile while trying to fill a pothole before the storm hit full force and covered this hazard.



Costs of wasted fuel and repairs from potholes are much higher today than ever before



Road conditions vs increased user cost



Weather can eliminate pavement maintenance when budget is combined

Roads and streets are the single public facility which practically every taxpayer uses every day. Unlike other facilities or public buildings he may occasionally visit, roads and streets get a physical and visual rating every day of the year. They are, in brief, the most visible public facility that affects every citizen's safety, comfort and economy each day of the year.

The public relations value of providing timely preventive maintenance and strengthening overlays for increased traffic should be obvious. The efficient, cost-effective use of material for new overlays contrasts sharply with the inefficient and wasteful practice of continually filling potholes. Preventive maintenance is always cheaper, or, as one observer put it, "we never seem to have the money or time to do it right in the first place but we always seem to have the money and time to do it over and over and over."

WEATHER

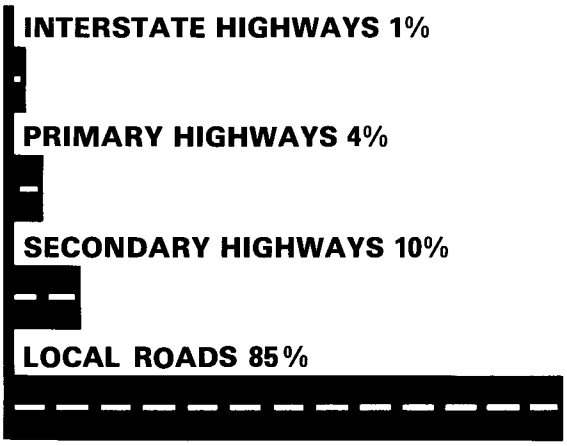
Weather is the most significant contributor to the severity of the pothole problem. Excess water beneath the pavement weakens the soil tremendously, particularly when the ground starts to thaw in the spring and is saturated. The pavement can crack and easily break into pieces if enough heavy loads pass over the pavement in this weakened condition.

The asphalt in the pavement is thermoplastic and becomes very brittle at low temperatures. Therefore, when it is subjected to cold conditions with weak ground support, it will crack at an accelerated rate. Pavements can be built to minimize this effect but many existing pavements were never designed for this condition, particularly on local roads.

If a severe winter uses all of the highway budget in snow removal, no funds are left for road maintenance the following summer. Therefore, separate budget items should be provided for snow removal and pavement maintenance. In most cases, they are not.

What an administrator must remember is not to be lulled into complacency and neglect

One harsh winter can destroy a poorly maintained road (Bangor Daily News)



Estimated % of potholes in New England states (estimated by R.H. Joubert)

Utilities add to municipalities' maintenance problems

annual maintenance when a few mild winters are experienced. It only takes one severe winter to destroy a poorly maintained road and then the investment is lost forever.

In the Netherlands the severe winter of 1978–79 destroyed many of their roads. An investigation determined that it had been the gradual reduction of maintenance over a period of seven mild winter seasons that was the primary cause of the destruction of millions of dollars of pavement.

IDENTIFYING AND CATALOGING CAUSES

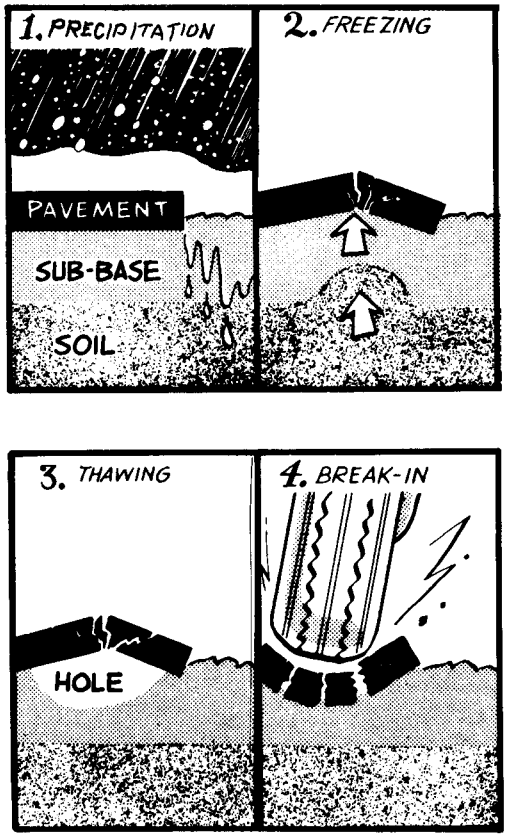
Before examining the cause of potholes, let's first focus on where the largest number of potholes occur. They are found principally on the local road and street system. While highways of the state system also have potholes, they are not nearly as numerous as on the local road system. One reason for this difference is purely logistical: by and large, here in the Northeast, the local system mileage far exceeds the state system mileage.

For example, in New York, Massachusetts, Connecticut and Rhode Island, less than 20% of total mileage is under state control while more than 80% is under local control. In the northern, more rural states, the comparison varies from as low as 20% state control in Vermont to 50% state control in Maine.

Additionally, the local road systems are often occupied by underground utilities where frequent pavement openings and surface access castings for manholes tremendously aggravate the problem of pavement maintenance. While some state system roads also have utilities beneath them, they are present to a much lesser degree.

Another factor that makes the local road situation more vulnerable to pothole conditions than state highways is that development of the state system was planned and financed in an orderly fashion by a steady flow of federal and state gas taxes dedicated for that purpose. Local financing is often barely sufficient, except when things reach a crisis state.

What is a pothole?



Factors leading to pothole failure by fatigue

Pothole occurrence

Potholes, should we try to define them? For openers let's just say that we are talking about any pavement defect involving the surface, or the surface and base, to the extent that it will cause significant noticeable impact on vehicle tires and vehicle handling. Though not a very technical definition, we believe that it is a practical one. We would rather be more specific in classifying the defects that cause the potholes and discuss practical cures.

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

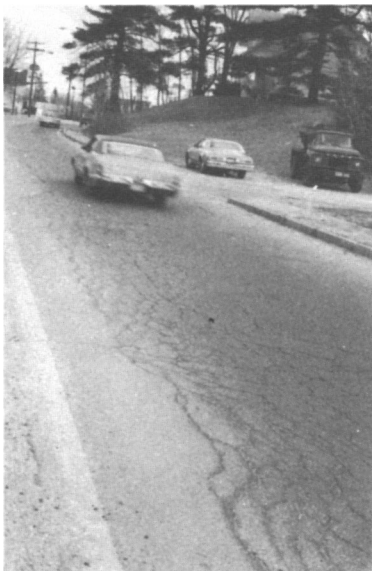
1. Roads that have *insufficient thickness* to support traffic during winter/spring thaw cycles without localized failures.
2. *Poor drainage*, which will usually cause failure in combination with thin pavements, but can also affect thick pavements and new overlays.
3. Failures at *utility trenches and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

How potholes develop

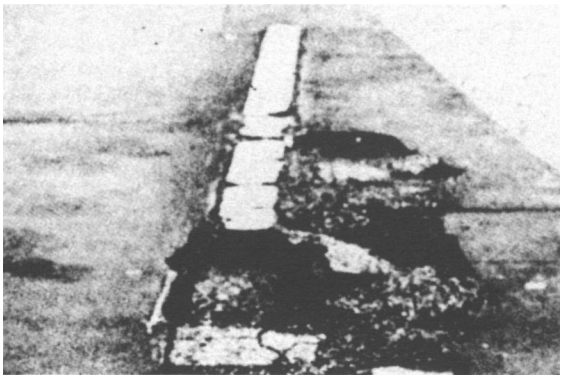
A pothole develops when two factors are present at the same time—water and traffic. This could almost be called the cardinal rule of pothole development, because without water and traffic present at the same time, potholing simply won't develop. *Exceptions to this rule do not exist!*

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 flexing of the pavement which occurs most commonly and sometimes on a grand scale 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 up and down with traffic until it starts to crack and break in several places.



Thick pavements may crack but are difficult to pothole because of their mass



Potholing by raveling

Fatigue failure produces what is considered to be the classic pothole (a bowl-shaped crater) which can occur with very little warning or prediction. If enough traffic passes the pavement 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 period, although it can occur in the summer and fall after heavy rains.

As the pavement approaches a thicker dimension, somewhere between 3 and 4 in., the pavement may also crack by the fatigue mechanism described earlier, but generally the internal forces that cause the slab deformation diminish and prevent breakdown into very small pieces that can easily pop out. Fatigue failure in thick pavements works like a very thick jigsaw puzzle. The pavement may crack substantially and become very rough, yet it will stay safe and serviceable for a long period of time. Rarely will a fatigue failure occur on a 4-in. or thicker pavement and lead to potholing without plenty of notice that maintenance is needed.

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.

This raveling type of potholing can occur on thick or thin pavements with equal severity. While this type of potholing may be more frequent in winter months, a great deal of it is associated with rainfall in milder months. The potential for pothole development by raveling can readily be predicted or monitored as telltale signs are quite obvious and exist for a long period of time (2 to 5 years) prior to disintegration due to potholing. Following a rainstorm,

Moisture lying in pavement leads to raveling type of potholes

Emergency patches frequently fail

Example of the results of poor drainage

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. The reason for this problem is that less durable cold mixes, using liquid asphalt with solvents, must be used in the winter instead of hot mixes with pure asphalt cement. Cold mix does not set up quickly, and when used in wet weather with little or no compaction, the water gets into the mix and traffic rapidly causes the patch to fail.

Some road agencies are now using warm boxes to heat up cold mix to make it more workable, permanent and quicker setting. In Toronto, Canada, a hot mix asphalt plant stays open year round to service 14 warm boxes used by the city. While some special mixes using proprietary additives and anti-strip agents have been reported to work well in cold weather, these generally cost about twice as much as standard mix. This high cost has generally restricted their use to high priority, heavy traffic locations and high-speed arterials.

DRAINAGE

Every engineer is expected to know that drainage is the most important aspect of highway design. Yet, improper attention to poor drainage conditions, frost susceptibility of soils and poor soil support conditions is a major contributing factor to what has been estimated as a $900 billion problem of repairing U.S. roadways between now and the year 2000.

Problems concerning drainage are generally associated with the following:

1. Standing water in ditches.
2. Soils with poor drainage—cracks in the surface of roads.
3. High water tables and seepage.
4. Frost penetration—heaves and cracking of pavement.

5. Subgrades with low permeability.
6. Pumping under traffic.
7. Freeze–thaw deterioration.

These problems may occur together or in various sequences. It is likely that a combination of problems is present in failure areas.

Ditches and storm drainage

Poor shoulder maintenance traps water on road

Standing water in ditches and storm drains is usually a sign of poor design or poor maintenance. There are areas where the surrounding area is flat and where standing water cannot be avoided. In these areas, the cross section of the road must be built with enough height of the correct materials above the water to provide strength and to prevent frost damage.

Too often, standing water occurs because of poor maintenance. Ditches become filled with growth and debris above the maximum grade and slope permitted. A normal program of inspection and removal of debris is mandatory for the maintenance of any road.

Cracks let water in and weaken the base, subbase and subgrade

Partially or completely blocked storm drains and culverts are a major culprit contributing to the problem of filled ditches. With flat grades the velocity through storm drains and culverts is often not fast enough to clean the piping. When a culvert silts, the upstream ditch will also become filled. A regularly scheduled program to clean storm drains is a must in the maintenance program for cities, towns and rural areas.

Vegetative growth in a flat ditch slows the flow of water and can in time contribute to the problem. Paved and lined ditches are sometimes needed as a permanent solution when the grades on the ditch line are nearly flat.

Curbs, paved shoulders, and sealed shoulders

Curbs and shoulders have a primary function of carrying away the surface water rapidly to the ditches and storm drainage. Edge joints and cracks between the shoulder or curb and normal pavement section must be maintained and sealed.

Clearing drainage to prevent edge failures

Maintenance of drainage features offers the greatest return for most rural counties, towns, and townships in the spending of annual funds

Good ditch and shoulder maintenance

TRANSVERSE SLOPES OF PAVEMENTS, SHOULDERS, AND DITCHES

Feature	Slope	
	Inches per foot	Percent
Pavement (Crown)	3/16–3/8	1.5– 3.0
Shoulder	1/2 –3/4	4.0– 6.0
Ditch	3–6	25.0–50.0

Recommended minimum slopes for positive drainage

Curbs provide good drainage where adjacent grade is higher

for maintenance of roads. It does not require highly skilled or highly paid staff, the results are easy to inspect and the net effect is easy to demonstrate. Unfortunately, drainage maintenance is a low-profile task that is often not immediately visible and is often the first to be cut from local budgets.

Poorly maintained shoulders also allow water to penetrate the pavement section. Raveling and potholing of the shoulders is a frequent problem.

Crown and cross section

The crown and cross section of roadways usually get the greatest attention from designers and engineers. Frequently, problems occur with all roads and highways at areas where low spots occur. Potholes frequently appear in low spots: a) at curb lines, b) in the transitional areas between curves, and c) at intersections where roads with slightly different cross-slopes intersect. Recommended minimum slopes are provided to the left.

Cracks in the pavement surface must be sealed. A regular program of surface treatment and sealing cracks offers long-term benefits for many urban and rural roads. In areas where surface treatments are undesirable, a $\frac{1}{2}$- to $\frac{3}{4}$-in.-thick asphalt concrete overlay offers long-term benefits, particularly where the additional strength is not required.

Installing underdrains

Underdrains can be installed along the shoulders of roads with poor drainage and where experience and inspection show that the subgrade remains saturated. This can be scheduled between overlay periods or just before resurfacing.

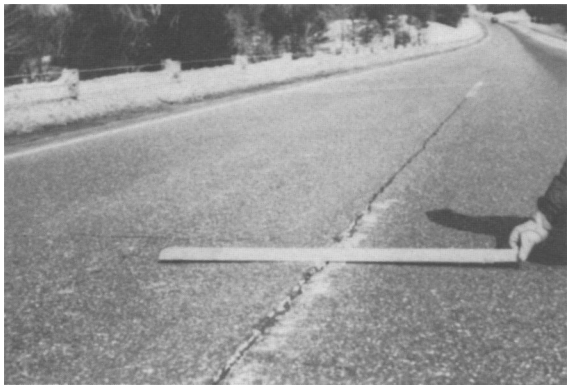
Other maintenance options

Other maintenance options for drainage problems include:

- Limitation of truck traffic during periods of poor subgrade support
- Limitation of truck traffic on certain roads
- Thickened patches (see also *Utility Cut Control*)

Periodic surface treatments seal out water

Surface water flows into cracks



Water entering cracks leads to heaving and progressive weakening

PREVENTIVE MAINTENANCE PROGRAMS AND PAVEMENT INVENTORIES

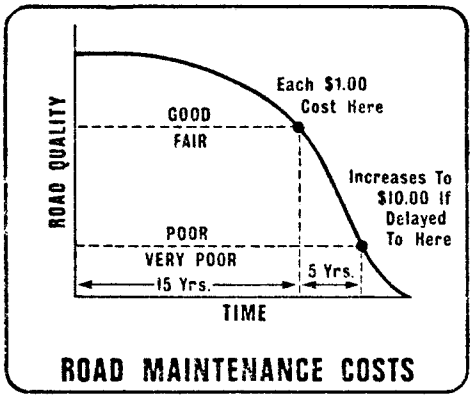
Preventive maintenance

Preventive road maintenance must be an annually planned program to preserve, repair and restore a system of roadways and its elements. Roadway elements include travelway surfaces, shoulders, roadside growth, and drainage facilities (including gutters, ditches, and pipes). A policy of only repairing potholes and blocked drains is not a maintenance program. Unfortunately, due to slashed budgets or a lack of foresight, many departments can do little more today.

Timing is vitally important. The trained personnel of any highway organization must closely watch for early signs of pavement defects and then follow through with prompt action before loss of pavement or other detrimental events occur. The best strategy is that of preventing potholes before they can develop. Preservation of highway pavement integrity can be greatly enhanced by performing numerous pavement maintenance activities exclusive of full width resurfacing. Knowledge of each technique is essential in the selection of repair operations for a given situation.

When potholes develop, prompt action is required to correct the defect before wheels and water combine to increase the size and severity of the defect. Most potholing develops in the spring breakup period before frost has completely disappeared or during brief winter thaws. Hot mix should be used whenever possible for best results. The success of pothole repairs can be directly related to good preparation of the hole and the amount of compaction attained.

Selection of the proper resurfacing method for a given section of highway is dependent on several factors including traffic, roadside congestion, design speed, alignment, physical characteristics and standards of original construction and subsequent improvements. Ideally, resurfacing should be accomplished before major defects or deterioration develop that will



Economics of timely maintenance

Patch potholes promptly

A good inspector can spot areas that need repair before a pothole develops

substantially reduce the structural integrity of the pavement and thereby avert the need for expensive reconstruction.

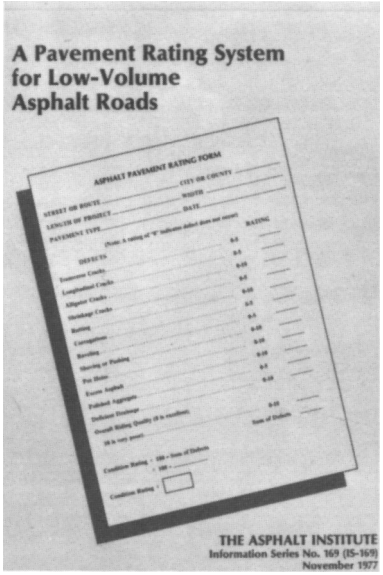
One chart (shown on the left) from a paper by M.J.E. Sheflin, Transportation Commissioner of Ottawa–Carleton, Canada, succinctly tells the story of the economic value of timely maintenance. This dramatically shows that maintenance must be a continuous process treating a certain percentage of the system each year.

In trying to zero in on maintenance activity, the most effective method appears to be the assignment of special crews that are well-trained and skilled in the detail required for the hand work, the crack sealing, ditch cleaning and patching required to repair localized defects. Key to the efficient deployment of these crews is a foreman inspector or engineering aide who is a local expert in surveying the streets and selecting the areas that are to be given priority for repairs. In short, it takes a person who can see the importance of his task in the overall perspective, and can exercise good judgment and make value decisions—his job is going to be more demanding than simply selecting streets that need overlays. Given time on the job, the individual will become an expert in selecting those defects that truly need immediate attention and those that can be let go for a year or two. As time goes on, he will develop a sense of how the road system is responding to the stresses of winter, and he will be able to predict the best overlay candidates and will more than earn his salary by stopping needless overlays where only selective repair and strengthening is required.

Pavement inventories

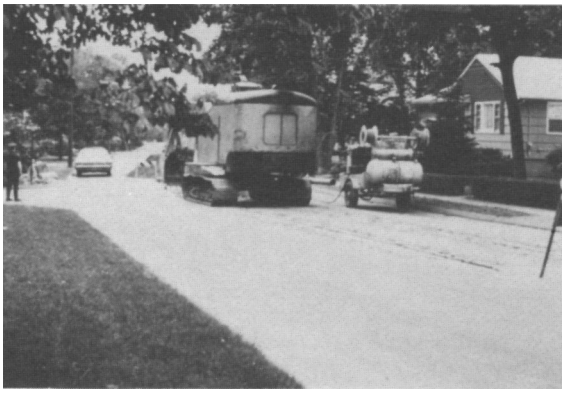
The best way to coordinate an annual maintenance program and a plan for strengthening overlays is to have some sort of comprehensive inventory of all the roads in the system. It can be a simple system for small towns, and must be more complex for large cities and towns where traffic and utilities complicate matters.

The pavement inventory should be a complete survey of all sections of roadway to determine pavement type, thickness and condition of roadway. Several rating methods are avail-



A suggested method of rating low-volume roads for inventories

Failing utility trench patch



Utility cut operations should be coordinated with resurfacing

able for an engineer or highway superintendent to pursue (see Reference 7).

Once the inventory and rating are completed a statement of needs can be accurately projected and programmed. The best maintenance approach appears to be one that tries to accomplish 10% of the repairs and replacements per year over a 10-year period in order to bring pavement up to an acceptable level. For those pavements in need of major strengthening, the program may have to be spread over 15 or 20 years.

In any event, the community will generally find that as the major strengthening (higher cost) work is completed and the roads become more permanent, the annual maintenance costs will continually decrease to some minimum level, which will be far lower than for communities without such a program.

UTILITY CUT CONTROL

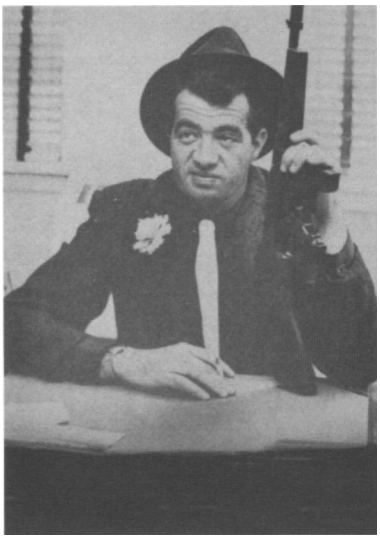
In any city or town with underground utilities, there also exists a tremendous potential for pothole development related to cuts in the pavement. In New York City, a recent study showed that more than 85% of the pavement defects were related to utilities. Whether or not a community has a pothole problem related to these cuts simply depends on the degree of quality control it demands from utilities and contractors. The key elements for effective management of this problem appear to be coordination control and a strictly enforced utility pavement cut permit system. Let's look at the essential features of these two control mechanisms.

Coordination control

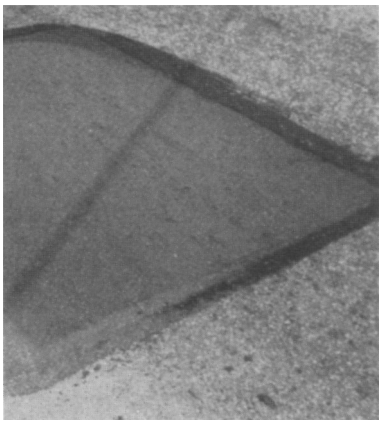
The primary objective of this administrative activity is, simply put, to let the right hand know what the left hand is doing. A tremendous side benefit can be the cost savings in sharing of expenses to install utilities. Coordination control will avoid the ridiculous situation of seeing a street paved in June only to see it ripped up again in August for a utility improvement. Here is a recommended approach and some of the side benefits of a good system.

Develop a first-class, strictly enforced system of coordinating the improvements to un-

It may look bad, but the patches are good



A good permit system will not require this type of enforcement



Edge sealing of patch (above) is an important detail that prevents early edge failure by intrusion of water

derground utilities with the street resurfacing program. It is essential that maps and overlays be constantly updated and consulted before any permits or projects are initiated. An engineer cannot remember all the activities going on in a large town or city.

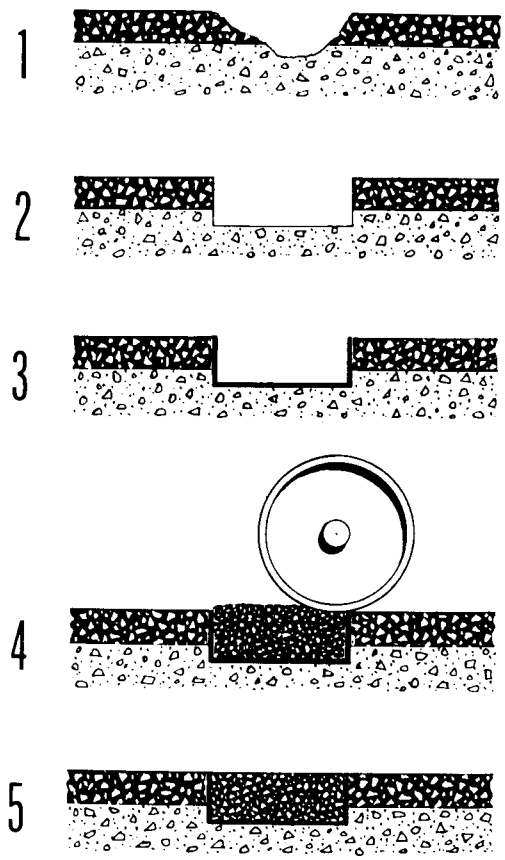
The cities of Fort Wayne, Indiana, and Phoenix, Arizona, have both reported very successful experiences with "Utility Coordinating Committees." They found that the use of Committees, representing all utilities and street maintenance operations, eliminates the conflict and chaos that occur without them. Highlights of the improvements experienced are:

- Better plans with more detail
- Cooperation in advance exploration of site conditions
- Better scheduling
- One-call central information centers
- Uniform location standards

Both cities adopted the standard color code created by the American Public Works Association's Utility Location and Coordination Council to mark the location of their underground utilities. This substantially helps prevent digging into other utilities. This system can also be used to identify defective utility patches so that they can be promptly reported to the right utility without a delay associated with a records search.

Utility pavement cut permit system

Permit system management is probably the single most troublesome item for the administrator. The policy of enforcement must be explicit and uniformly applied (against municipal agencies as well as contractors). Firm and fair inspectors should be permanently assigned to this activity, as spot checks and continuous changes of personnel break the back of this system. A system that makes the utility responsible for the care and maintenance of a patch, for at least a year or two after opening, reduces significantly the amount of personal inspection and enforcement by the town. Utilities will, under this system, do even better work than they would by personal enforcement by the town. The utilities are also finding it cheaper to do a thorough job the first time.



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

To patch potholes properly reasonably humane conditions must exist to execute the work. When such conditions prevail all of the steps illustrated above should be followed. Greatest emphasis should be placed on shaping the hole *and* compacting the mix!

The Public Works Departments of Worcester, Massachusetts, and Manchester, Connecticut, have offered their permit manuals as examples for other communities to use in setting up a permit system. These communities have offered to mail the booklet free-of-charge to any requestors if they enclose a stamped self-addressed 9- × 12-inch envelope with $1.00 for postage. The addresses are as follows:

Mr. F. Worth Landers, Commissioner of Public Works
City of Worcester Department of Public Works
20 E. Worcester St.
Worcester, MA 01600

Mr. Ronald Charter, Engineering Department
Town of Manchester Department of Public Works
41 Center St.
Manchester, CT 06040

POTHOLE PATCHING PROCEDURES

Is the humor and criticism directed at highway crews that patch the same hole over and over justifiable? On rare occasions it may be, but for the most part, it should more correctly be directed at the administrators who let the road system get into such an unmanageable condition in the first place.

Patching of normal potholes

A comparison of effectiveness for different techniques of pothole repair is shown in a value engineering study reported in 1976 by Louis O'Brien, Director, Bureau of Highway Maintenance, of the Pennsylvania Department of Transportation. Let's look at the costs. This study, which is summarized in more complete detail in the following table, shows that patching potholes the wrong or expedient way costs $300.00/ton, while doing it the right way costs $60.00/ton or one-fifth the cost. Clearly method 1, which does not include any effort to prepare the hole and compact the mix, does not last long (only 1 month) and is therefore the most expen-

Comparison of costs for different methods of pothole repair (from Ref. 12)

No.	Description	Equipment	Tons in place per shift (7.5 hr)	Cost per ton of material in place ($)	Life of patch (months)	Annual cost per ton ($)
1.	Fill hole in one lift with mixture, and compact by hitting the patch with the back of a shovel twice. No effort made to clean or shape the hole, and no tacking of the exposed surfaces of the hole.	Dump truck Shovels	18.0	25.64	1	307.68
2.	Same as no. 1, except compaction is performed with the tire of the dump truck.	Dump truck Shovels	12.0	31.80	2	190.80
3.	Shape the area to be patched with an axe and sledge, remove loose asphalt with mattock, sweep area clean, tack the exposed surfaces of patch area, shovel in material and level with lute. Compact with wacker (vibratory compactor) and seal edges with tack oil and #IB stone.	Dump truck, Pickup Heating kettle, Wacker Axe, Sledge, Brooms, Mattocks	6.0	63.29	7*	63.29
4.	Same as no. 3, except a pup roller is used for compaction .	Dump truck, Pickup Heating kettle, Pup roller, Axe, Sledge, Brooms, Mattocks	7.0	61.41	7*	51.41
5.	Same as method no. 4, except the area to be patched is shaped with a pavement breaker.	2 Pickups, Dump truck, Heating kettle, Air compressor and Pavement breaker, Pup roller, Brooms	7.0	65.22	7*	65.22

* For methods 3, 4 and 5 it will be assumed that failure will occur after 12 months, though in all probability patch life will extend beyond one year.

sive, as the hole must be refilled time and time again in one winter. Even compaction by the truck tire in method 2 does not offer much improvement. Neither of the expedient methods is nearly as effective as methods 3, 4 and 5, all of which include *preparation of the hole and some significant compaction effort* with small rollers or vibrating plate compactors.

One can easily see that the annual cost to make pothole repairs correctly is in the range of one-fifth the cost to do it poorly or expediently. Why then don't the crews do it right the first time? The basic problem, restated for emphasis (as it is also the key to the solution), is that they simply don't have the time or decent conditions.

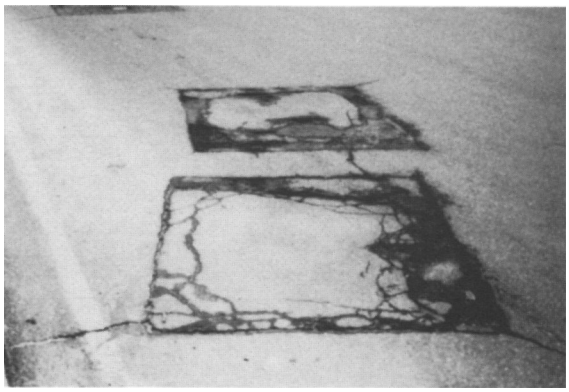
Potholes occur and multiply rapidly, particularly after a period of wet weather. Potholes are usually caused by weaknesses in the pavement system. Once the surface is broken, deterioration continues at an accelerated rate.

Pothole maintenance is a continuing problem and usually appears at a time when it is difficult to make permanent repairs. Too often the solution consists of a few shovelfuls of premixed asphalt patch material deposited in the hole with the hope that traffic will provide compaction. To achieve proper pothole maintenance it is necessary to take into consideration the following important items:

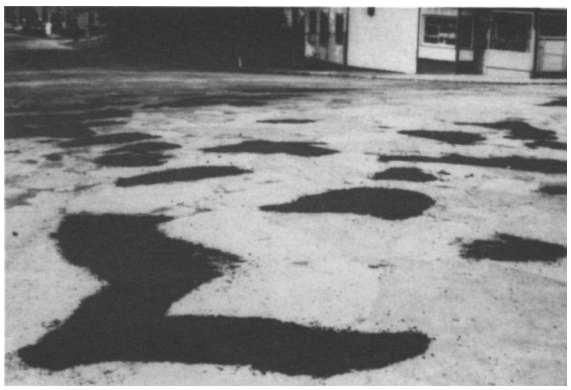
1. Weather
2. Trained personnel
3. Identification of the problem
4. Use of suitable materials
5. Safety

1. Weather

Best results will be achieved by scheduling repair work during dry, warm weather. However, the problem is usually most urgent during wet weather. This requires greater care and proper equipment to ensure success. Personnel assigned to pothole repairs should be aware of material limitations during cold and wet weather.



Failure by water intrusion



"When potholes occur on a poorly maintained system they come in such numbers in a short period of time that the crews simply don't have the time to patch properly."

2. Training of personnel

It is easy to blame material for failure, but even the best available materials will fail when improperly used. Therefore, the most important item for successful pothole maintenance is providing sufficiently trained personnel to identify the problem and to apply an appropriate technique to make the repair.

3. Problem identification

A properly trained operator will recognize the cause and plan the repair to eliminate recurrence. Failure to provide proper drainage is one of the most common causes of failure. In emergency situations, temporary measures may be necessary, but even then a little extra attention will increase the level of success. All pothole crews should be equipped to blow out, sweep, or otherwise remove water and should have the equipment to dry and prepare the hole.

4. Materials selection

Patching may be done with cold mix asphalt materials, hot mix asphalt materials, concrete, or other suitable patching material (see Appendix).

5. Safety

Pothole patching is usually done under traffic conditions. The safety of working personnel and the traveling public is of utmost importance. Maintenance personnel should work from the center of the road to the shoulder to avoid stepping into the opposite traffic lane and should be equipped with reflective clothing. Personnel should be trained in traffic safety as well as safe use of all equipment.

Patching procedures for other types of potholes

So much for the repair of the classic bowl-shaped pothole that is most often caused by fatigue failure. Let's now take a look at causes and repair of the many other forms of potholing that occur primarily as a result of a lack of density and manifest themselves by the raveling mechanism discussed earlier.

Severe case of poor density that led to raveling failure

1. Pavement that lacks density

When an entire layer of paving material lacks density it will show up early in the pavement's life by staying damp for a long period of time after the rest of the pavement dries following wet weather. The next stage will be gradual raveling of the aggregate in the mix.

If the area is small and not allowed to get too deteriorated, it can be spotted by maintenance crews and sealedwith a slurry of liquid asphalt and fine aggregate. Severe cases should be removed and replaced with new material.

2. Joints

Longitudinal joints between paver passes may open up if not compacted to the correct density. A poorly densified joint will also appear damp for a long period after the rest of the pavement dries.

Longitudinal joint needs routing and filling

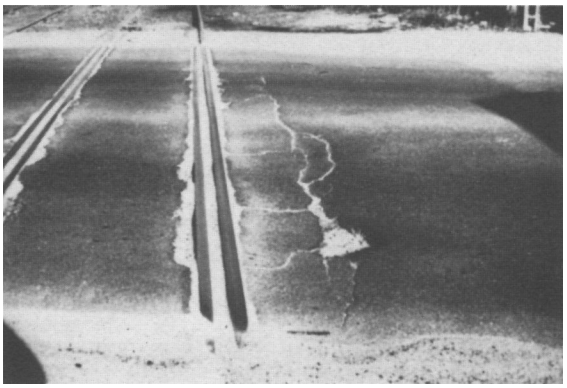
As soon as the joint is $\frac{1}{2}$ in. or larger in size, it should be thoroughly routed, widened and filled with a pourable sealant. If already wider than $1\frac{1}{2}$ in., the joint should be routed to sound material and a fine, dense-graded, high-asphalt-content hot mix used and compacted while the mix and joint are hot. Joints should be crowded, not just matched, and a good tack on the joint with emulsified asphalt will also help.

Some highway departments promptly paint these damp joints with a thin coat of liquid asphalt covered with sand. This rapidly reduces the number of times the joint opens up and seals water out of the pavement layer.

Bridge deck failure

3. Bridge decks

The action of deicing salt on decks without membranes or with ineffective membranes causes the portland cement concrete underneath to disintegrate. As this type of failure requires substantial technical detail to properly correct, permanent repair is best referred to a specialist. Repair methods are restricted to the best emergency procedures available—removing all loose material and using good hot mix or special quick set concrete patch materials.



If ties are moving potholes occur at end of ties

Overlay too thin to cover trolley tracks adequately.

Delamination of thin overlay

4. Railroad crossings

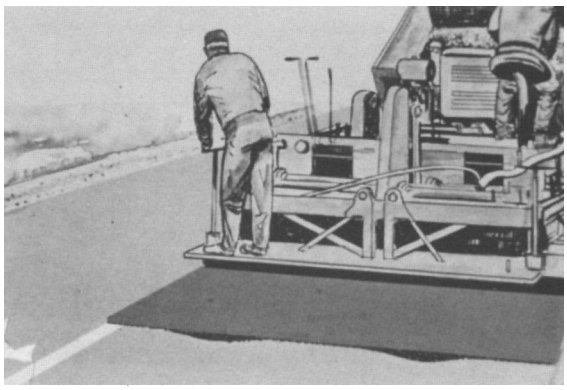
While many grade crossings have been paved successfully to the guide rails, movement of insecured rails or ties can cause significant flexing of the rail and the tie line. Eventually this flexing will let water in, leading to breakouts ranging from difficult to impossible to repair.

Rail and tie movement must be eliminated entirely by the ties being reballasted and the rails respiked before any permanent repair is used. Hot mix asphalt, placed full depth from the tops of the ties to the top of the rail, works well for most conditions. The asphalt must be compacted well, and a good joint must be made against the rail by coating it well with liquid asphalt. A narrow 2-in. coating of liquid asphalt on the pavement surface along the rail line will also enhance the sealing of this junction. If the problem persists, prefabricated crossings designed to keep the tie, rail and pavement surface acting as a unit may be the only answer.

Old trolley tracks can be paved over successfully, provided that enough depth is used. The guide rails should first be filled and thoroughly compacted by using a very fine hot mixture so that it can be worked into the narrow trough. Then the tracks should be thoroughly tack-coated or painted with liquid asphalt. Finally, a minimum layer of 4 in. of asphalt mixture should cover the rails—this may be made thinner at the curb, but should be at least 4 in. thick over the rails.

5. Delamination

Delamination occurs when a large section of pavement surface literally peels off the pavement below. While more common on portland cement concrete overlays where a tack coat was not used or the thickness was not sufficient, it can also occur on an asphalt overlay where the lack of tack coat is compounded by wheel ruts not being leveled before overlaying. Poor density results, water gets in between the overlay, and traffic works at it until stripping and raveling lead to eventual delamination. Delamination is usually identifiable by spots of damp pavement in wheel paths that take significantly longer periods of time to dry out. The



Rutted roadways should be leveled and compacted before overlaying to prevent delamination

extent of the weakness sometimes can be isolated by a hollow ringing sound when a solid aluminum rod is tapped on the pavement.

Repair is difficult with cold mixtures in these thin areas, and sometimes it is better to enlarge the section, bevel the edges and leave it alone until hot mix with good tack coat and sufficient compaction equipment can be used under dry conditions.

Most delamination involves thin layers, and the procedure above is generally safe. If the delaminated area is greater than 2 in. thick, place hot mix with good tack and the best compaction effort possible.

6. Macadam pavements

One final case of severe potholing that's caused, or started at least, by raveling can be found on old macadam pavements with very thin asphalt concrete overlays on top of them. Most of them were built about 5 to 7 in. thick and are strong enough not to fail by fatigue. However, they were generally only surface treated or had very thin hot mix asphalt overlays, and once water starts to get into them and causes a popout, they unravel like a woolen sweater. Prevention is possible by prompt seal coating and overlaying at early signs of water intrusion.

Macadam pavement unravels dramatically when water enters

INTERSECTIONS, UTILITY CASTINGS, AND OTHER COMMON PROBLEM AREAS

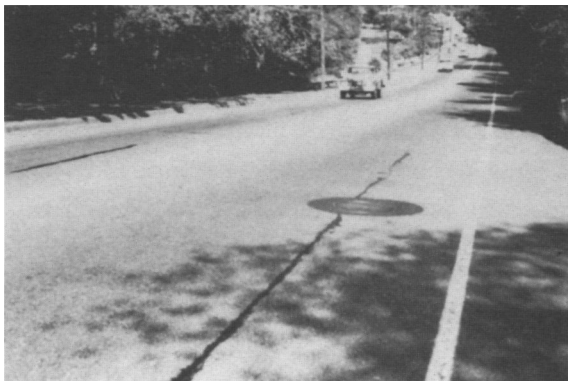
Intersections

Many street intersections are major pothole generators, even though the streets leading to them are in excellent condition. They are, quite often, severely weakened by having numerous manhole castings, water main shutoff valves and other utility structures cutting up the overall continuity and strength of the pavement. If we were able to look at intersections in elevation view, many would look like a piece of Swiss cheese. This weakness shows up in overall performance.

Pothole problem at intersections

Intersections also take a great deal of abuse in terms of the stopping, starting and turning

Repair should extend for about 5 feet in a square or circular area around manhole (a large enough area to remove stressed asphalt pavement)



Sealing cracks and repairing pavement at manholes prevents potholes

manhole structure be used to thicken the pavement to at least 4 in. Preferably it should be thickened to the full depth of the manhole casting or 8 in. This area should be compacted with extra care to be sure that good densification occurs around the manhole. If a relatively thick pavement is put in and not properly densified, post-construction compaction may leave an undesirable lip at the casting.

Another manhole casting detail used by many agencies is a portland cement concrete collar around the casting. This is generally placed from the base of the casting to within 1 or 2 in. of the top of the casting. The top 1 or 2 in. is then filled with hot asphalt mix as part of the finished pavement surface. The concrete collar arrangement has, in some cases, worked well and, in other cases, it too has performed poorly. The problem is that densifying 1 to 2 in. of hot mix on top of the concrete is most critical to the performance, as water can easily get into or through the thin 1- or 2-in. layer. As deicing chemicals permeate this layer and get to the concrete, portland cement concrete deterioration continually takes place. This condition leads to continuous raveling, which is very difficult to patch permanently.

TRAINING AND EDUCATION

Unfortunately, today few formalized courses are taught in vocational or other schools that help prepare someone for maintaining pavements. While more common in other sections of the country and in some state and federal agencies, these courses are not readily available in the Northeast for practitioners on the local level. Many college graduates of civil engineering programs do not receive training in this area, as most colleges have reduced or limited exposure to this subject in order to cover newer technologies.

Although there is a scarcity of formal courses in pavement maintenance, meetings of state associations of highway officials provide excellent opportunities for sharing information. Town administrators should encourage and

support the participation of their road maintenance superintendents in them. A national organization covering all aspects of public works is the American Public Works Association, which is most active in conducting schools, seminars, and conferences on specific subjects as the need arises. APWA's address is 1313 E. 60th St., Chicago, Illinois 60636.

Trade magazines and journals, such as *Better Roads* and *Rural and Urban Roads*, carry many articles specifically on road maintenance authored by highway superintendents to help others through sharing their experience. *American City & County* and *Public Works Journal* cover the entire range of public works activities, including roads.

The Asphalt Institute is continuously disseminating information and advice on maintaining asphalt pavements at the state and local level. From their field offices, District Engineers conduct special schools, conferences and seminars on asphalt pavement at the invitation of state, local or private consulting engineers. While some programs are on formalized annual schedules, others are designed to suit a specific need.

The Asphalt Institute has a comprehensive manual on Asphalt in Pavement Maintenance (MS-16) and a 64-minute slide tape show that guides one through the manual. The slide tape show (VA-13, "Pavement Maintenance with Asphalt") is available and has been used by the city of Edmonton, Alberta, Canada, as a model to produce its own slide show. The slide program is available for purchase from the Asphalt Institute, Lexington, Kentucky 40512-4052.

REFERENCES

Over 60 references were provided by the coordinators and the participants at the pothole workshop. The complete list may be secured by writing to Robert A. Eaton at CRREL. For the purpose of recommending those that are most useful and practical to secure, the following list is provided.

1. *AASHTO Guide for the Design of Pavement Structures*, 1986. $35.00 + $4.50 shipping. American Association of State Highway and Transportation Officials, 444 N. Capital St. NW, Suite 225, Washington, D.C. 20001. (202) 624-5800.

2. *AASHTO Maintenance Manual*, 1987. Covers all aspects of highway maintenance. $18.00 + $3.00 shipping (AASHTO).

3. Asphalt Institute, *List of Publications and Visual Aids* (Lists all manuals mentioned in booklet plus others). Asphalt Institute, Research Park Drive, P.O. Box 14052, Lexington, Kentucky 40512-4052.

4. *Bituminous Paving for Townships and Boroughs*. Correspondence course from Pennsylvania State University, College of Agriculture, University Park, Pennsylvania 16802.

5. *Bituminous Patching Mixtures*, NCHRP Report 64, September 1979. $4.80. Transportation Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20036.

6. *Maintenance and Repair of Surface Areas*, U.S. Army Technical Manual TM 5-624. Available from U.S. Army AG Publications Center, 1655 Woodson Rd., St. Louis, Missouri 63114.

7. *Pavement Maintenance Management for Roads and Parking Lots*, 1981. By M.Y. Shahin and S.D. Kohn, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, Illinois, Technical Report M-295.

8. *Potholes—A Simple Problem with a Few Simple Solutions*. Maintenance Aid Digest no. 17, July 1978. AASHTO Committee on Maintenance. Free-of-charge (AASHTO).

9. *The Nation's Highway Transportation System: Its Background, Current Status and the Future*. Highway Users Federation, 1776 Massachusetts Avenue NW, Washington, D.C. 20036.

10. Optimizing Maintenance Activities. Fifth Report, *Bituminous Patching*. Report No. FHWA-TS-78-220. Combined State Studies of Selected Maintenance Activities. Limited number of complimentary copies. Federal Highway Administration, 400 Seventh St. SW, Washington, D.C. 20590.

11. *Roadway Design in Seasonal Frost Areas*. NCHRP Highway Practice Manual 12, 1974 edition. $6.00. Transportation Research Board.

12. *Value Engineering as Applied to Pothole Patching*, Nov 1976. By L. O'Brien, Paper presented at AASHTO meeting, Birmingham, Alabama.

TRB and AASHTO periodically issue lists of their publications. An up-to-date list and order form will be provided free if requested.

APPENDIX: MATERIALS AND EQUIPMENT FOR PATCHING

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 may not sell optimum 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.

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

Sieve no.	*Gradation of aggregate (% passing)*	
	Pa.	*Ind.*
3/8 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 averages 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.

Heated cold mix. An alternative to cold patch is a method 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 *Asphalt in Pavement Maintenance* 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. Adding this oil to the old pavement 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-l, SS-l, lh, and CSS-l, lh) are acceptable for use.

Sealing materials

Emulsions—RS emulsions (RS-l, 2 and CRS-l, 2) are particularly good for sealing the edges of pothole patches. Although less desirable, MS emulsions (MS-l, CMS-l) 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.

Patching equipment

Four types of equipment are needed for effective pothole patching:

1. Cleaning, tacking and sealing equipment.
2. Hole preparation equipment.
3. Compaction equipment.
4. Mix equipment.

Cleaning, tacking and sealing equipment. Cleaning, tacking, and sealing equipment should include brooms, brushes, spray cans (for tack and seal), rags, and torches (for drying). Ideally, an air compressor with a sprayer will be used for blowing debris from the hole and also for drying. Then spray cans will provide low pressure application of the tack and seal coats. Any type of

broom and/or brush can be used to remove water and loose debris from the hole before squaring and undercutting it. Rags will be needed for cleanup and, if required, a torch can be used to dry the hole. A torch is also useful in heating and cleaning rakes, shovels and other equipment used in the patching operation.

Hole preparation equipment. The best tool for squaring a hole and making vertical sides is a pavement breaker (jackhammer). Some breakers are hydraulically driven by a gasoline engine (which makes them self-contained, an obvious advantage for a small maintenance crew), and some require a portable air compressor. A chisel point with one flat side is recommended, so that the sides of the hole will be vertical.

A power saw may leave smooth sides that do not provide good bonding for the tack coats or patch. Care should be taken, particularly with sealing the joints, when power saws are used.

Compaction equipment. The most important step prior to and during patching is compaction. The repair crew must try to obtain optimum density in order to make the patch last longer and keep the water out. (It is unlikely that a pothole patch will ever be overcompacted, given the conditions that usually exist during the patching operation.)

Vibrating plate or vibrating roller compactors are the most suitable because they "work" the mix while it's hot and help densify it by vibration (see CRREL Special Report 84-1).

The next most effective compactors are the heavy "static" or non-vibrating steel wheel rollers for larger potholes.

If other types of compactors are used (such as hand tampers), place the hot material in 1- to 2-in. lifts and take extra care to properly compact the patch. As stated before, this is the most critical part in the patching procedure and determines the life of the patch.

If desired, one can determine density by taking cores of the asphalt concrete and testing in the laboratory, or by using nuclear density gauges to measure density in-place. State Departments of Transportation usually have this equipment.

The hole should be overfilled by $\frac{1}{4}$ to $\frac{3}{4}$ in. depending on the depth of the hole ($\frac{1}{4}$ in. for holes up to 2 in. deep, $\frac{1}{3}$ in. for holes 2–4 in. deep, and $\frac{3}{4}$ in. for holes greater than 4 in. deep). This is for guidance only and will vary depending upon the mix you use. This overfilling is required to allow for compaction. When compaction is complete, the patch surface should be just slightly higher than the surrounding pavement so that a "birdbath" or low spot does not exist where water will collect and cause future problems.

Mix equipment. There are many types of equipment that can be used to mix, heat, or recycle patching material. These include recyclers, stockpile heaters, and hot boxes.

Recyclers. Most portable recycling machines are designed to be towed behind a pickup or dump truck which can be brought near the holes being patched. Some have provisions for throwing broken pavement pieces from the pothole directly into the machine and recycling at the repair site.

Recycling machines (mix equipment) usually will require a crew of at least 4 or 5 to ensure good production. The actual machine and procedure will dictate how many workers will be needed for the job.

Stockpile heaters. Some of these portable machines can be set up at a central maintenance yard and used like a miniature asphalt plant. Stockpiled cold mix, chunks of broken up asphalt pavement, or virgin aggregate to which liquid asphalt cement is added can be used. These "portable plant" machines prepare mix from these materials which is then loaded into trucks with hot boxes and then delivered to the work site.

Hot boxes. The hot boxes can be little more than insulated boxes, or they may have their own heat source. Commercially available trailer-type hot boxes, 2- or 4-ton insulated boxes on wheels, are heated underneath and along the sides by LP gas. They can also be mounted on trucks.

Pavement management

Ideally, pavements should be maintained so they will not deteriorate to the point where pot-

holing 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 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.