Evaluation of Equipment Used for Localized Repair of Pavements

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ABSTRACT

Pothole patching for most highway agencies consumes a considerable portion of available highway maintenance funds. In Pennsylvania, pothole patching expenditures increased from $19 million in 1975-1976 to more than $30 million in 1977-1978. This prompted the Secretary of Transportation to launch an investigative research effort to evaluate the department's pothole repair strategies. As an outgrowth of this evaluation, a research project was awarded to the Pennsylvania State University to review current pothole patching technology of the remainder of the nation with the objective of recommending materials, equipment, and repair techniques that would be compatible with Pennsylvania's program. As a result, approximately $200,000 was expended for some of the more promising patching-related equipment to be field evaluated. This equipment was evaluated in terms of Pennsylvania Department of Transportation's pothole patching policy procedures, standards, and materials only and may not be relevant to other agencies. The equipment that was reviewed and evaluated was related to three equipment-dependent elements of pothole patching: cutting, filling, and compaction. Many of the various pieces available are very specialized and, for various reasons, were not determined to be cost-effective.

A major consumer of maintenance funds in Pennsylvania, as in most other states, is the patching of the ever-present, proliferating pothole. In 1982-1983, the Pennsylvania Department of Transportation expended approximately $37.4 million for the repair of potholes and, of this amount, 26 percent or $9.6 million was expended for equipment rental (outside and departmental). A breakdown for 1982-1983 follows.

	Cost ($000,000s)	Percentage of Total
Contract services	0.8	2
Material	7.2	19
Equipment	9.6	26
Personnel	19.8	53
Total	37.4	100

Because equipment selection has a considerable effect on the efficiency of pothole repair, it must be realized that direct expenditures for equipment are not the total picture and that in the selection of patching equipment life-cycle costs, productivity, crew acceptability, maneuverability, and logistics, among other things, should be considered.

In Pennsylvania, pothole patching expenditures increased from $19 million in FY 1975-1976 to more than $30 million in FY 1977-1978. This prompted the Secretary of Transportation to launch a quasi-investigative research effort to evaluate the department's pothole repair strategies. This research (1), in essence, confirmed the department's repair methods but indicated a need for additional training and possibly for more or different equipment.

As an outgrowth of this evaluation, an additional research project (2) was awarded to the Pennsylvania Transportation Institute, Pennsylvania State University, to review current pothole patching technology in the rest of the nation with the objective of recommending materials, equipment, and repair techniques that would be compatible with Pennsylvania's program.

As a result of this research, approximately $200,000 was expended for some of the more promising patching-related equipment to be field evaluated. The equipment was evaluated in terms of the Pennsylvania Department of Transportation's pothole patching procedures, standards, and materials only, and, because procedures vary considerably among states, the evaluation should be considered appropriate only to Pennsylvania.

PURPOSE

Equipment is an important component of the pothole repair process because it must not only be cost-effective but compatible with manpower availability and the type of material used. A search of the available literature indicates that little published information exists on the performance of various pieces of equipment. The purpose of this paper is to describe some of the equipment and to indicate the limitations and advantages of the equipment. Tables 1 and 2 give a summary of the important characteristics of the equipment considered appropriate for pothole repair.

EVALUATION

The basic equipment-related elements of pothole patching are (a) cutting, (b) filling, and (c) compaction. Equipment needs can be closely identified with these elements. Cutting (pavement breakers) requires

- Air compressors (pneumatic breakers),
- Gasoline-powered breakers,
- Hydraulic compressors and breakers,
- Milling machines, and
- Saws.

Filling requires

- Heated boxes,
- Portable mixers, and
- Recyclers-reheaters.

Compaction requires

- Static rollers,
- Vibratory rollers,
- Vibrating-plate compactors, and
- Tamping-foot compactors.

TABLE 1 Summary of Pothole Repair Equipment

Product Manufacturer, Model	Capacity	Approximate Cost (1983 dollars)	Record of Use	Dwell Time	Method of Feed	Method of Removal	Production Information	Method of Transport
Heated boxes								
Aeroil	2 tons	5,860		Indefinite	Top loaded	Shoveling door at rear		Towed
Aeroil	4 tons	9,993	Ill.	Indefinite	Top loaded	Shoveling door at rear		Towed
Poweray Infrared 2TSU	2 tons	4,809			Top loaded	Rear hopper-20 in. high		Towed
Poweray Infrared 4TSU	4 tons	11,400	Pa.	48 hr	Top loaded	Rear hopper-24 in. high		Towed
Poweray Infrared 4TCM	4 tons	7,618	Pa.	48 hr	Top loaded	Rear hopper		Mounts permanently on chassis behind cab
Poweray Infrared 6TDM	6 tons	7,956	Pa.	48 hr	Top loaded	Dump bed has to be raised	Propane	Mounts on dump truck
PB Loader Asphalt Patcher, B3-SM	4 tons	13,000-18,000	Pa., Wash., Calif., Ariz., Oreg.	Indefinite	Top loaded	Rear dump doors	Propane/butane	Slip in-slip out
Midland Warming Box	8 tons	12,000	N.Y., Wis., Ark., Pa.	8 hr	Top loaded	Rear hopper	Electric heated	Mounts on bed
Recyclers								
Aeroil AR-1000	2 t/hr	8,480	Kans., N.J.		Material thrown in drum	Drum rotates and dumps material in hole	Process ≈ 10-12 min	Towed
Bomag AR-5	5 t/hr	10,975			Shovel loaded	Discharge chute	Process ≈ 6-8 min	Towed
Brown Porta-Patcher	6 t/hr	20,000			Shovel loaded	Rear hopper	300 lb/min recycling, 400 lb/min cold mix	Towed
In-place heaters								
Poweray Heat and Serve	3 tons	24,645	Pa., N.Y.	48 hr	Top loaded	2 doors (on sides)	Propane	Towed
Patchmaster PM 5036	2.5 tons	56,925	Calif., N.Y., Mich.		Top loaded	Auger	Propane	Towed
Mixers								
McConnaughay HTD-F10T	10 ft^3 aggregate	17,000-25,000	Ky.	1 hr	Aggregate shoveled in	Shoveling tray	5 t/hr manual loader, 10 t/hr automated loader	Towed
HTD-10	200 gal asphalt							
McConnaughay HTD-6	6 ft^3 aggregate	13,000	Ky.	1 hr	Aggregate shoveled in	Shoveling tray	Rated 6 t/hr	Towed
McConnaughay HTD-4-T		8,000	Ky.	1 hr	Aggregate shoveled in	Shoveling tray	3 t/hr	Mounted on rear
Barber Greene Asphalt-Mobile		110,295	Pa.		Material self-contained	Discharge chute	12-15 t/hr	Mounted
Multiple purpose								
AMZ		40,000	Tenn.		Screw feeds aggregate into hopper	Compressed air	1-2 t/hr	Towed
RGS Thermo Lay	6.5 tons	18,950	Del. is testing Mo. approved		Top loaded	Hydraulic screw conveyor		Permanently truck mounted
Cutting tools								
Berema Pionjar 120/130	250 rpm	3,190	Pa., Wis.					Carried on truck
Racine Hydraulic MB-600		11,250	Pa.					Mounts on truck
Racine Hydraulic HB-75		2,095	Pa.					Carried on truck
Ingersoll Rand Air Compressor P100 WW	100 cfm/100 psi	10,000	Pa.					Towed
Compactors								
Wacker Vibroplate VPG-160 R		1,385	Pa.					Carried on truck
E-Z Patch Roller			Pa.					Mounts to rear of dump truck
Essick V-30W-R		7,455	Pa.					Carried on tail gate
Gallion 4-6 ton		31,000	Pa.					Towed

TABLE 2 Further Summary of Pothole Repair Equipment

Product Manufacturer, Model	Method of Transport	Temperature Information	Emissions	Mix Types	Comments
Heated boxes					
Aeroil	Light		No problem	Hauls hot mix	Includes portable infrared patcher and heated asphalt roller
Aeroil	Light	Maintains hot mix	No problem	Hauls hot mix	25-gal heated tank for tack material
Poweray Infrared 2TSU	Pickup		No problem	Hauls hot mix	Fuel consumption: one 100 lb cyl/8 days
Poweray Infrared 4TSU	Small	Maintains hot mix, heats cold mix to 180°F	No problem	Heats cold mix to 160°F overnight	25-gal heated tank for tack material
Poweray Infrared 4TCM	Dump	Maintains hot mix, heats cold mix to 180°F	No problem	Maintains hot mix, heats cold mix to 180°F overnight	
Poweray Infrared 6TDM	Dump	Maintains hot mix, heats cold mix to 180°F	No problem	Maintains hot mix, heats cold mix to 180°F overnight	Bed of dump truck has to be raised to deliver mix
PB Loader Asphalt Patcher, B3-SM	Truck with: Width: Min 78 in., Length: Min 120 in.	Maintains hot mix, heats cold mix to 120°F in 3 hr	No problem	Maintains hot mix, heats cold mix overnight	Optional 24-gal emulsion tank with heated spray wand and hand torch
Midland Warming Box	Dump	Maintains hot mix, heats cold mix to 225°F in 6-10 hr		Heats cold mix overnight (6-10 hr), maintains hot mix (8 hr)	Material cannot be heated in the field
Recyclers					
Aeroil AR-1000	Light	Heats mix to 325°F	Potential	Old plant or cold mix; reclaims planed asphalt	Auxiliary heating torch; potential asphalt damage
Bomag AR-5	Light	Heats mix to 300°F	Questionable		
Poweray Heat and Serve					Infrared heaters soften pavement before pavement is added; no need for cutting or tacking; no waste materials remain; potential asphalt damage
Brown Porta-Patcher	Dump		Potential	Recycled or cold mix	
Mixers					
McConnaughay HTD-F10T HTD-10	Truck		Potential	Heating and reconditioning, hot or cold mix	Kentucky uses mixers for reclaiming; not recommended by manufacturer
McConnaughay HTD-6	Truck		Potential	Heating and reconditioning, hot or cold mix	Kentucky uses mixers for reclaiming; not recommended by manufacturer
McConnaughay HTD-4-T	Standard dump truck		Potential	Heating and reconditioning, hot or cold mix	Kentucky uses mixers for reclaiming; not recommended by manufacturer
Barber Greene Asphalt-Mobile	Truck		Baghouse collection system		Optional truck-mounted unit
Multiple purpose					
AMZ	Towed behind dump truck that carries the aggregate			Cold mix produced at site	
RGS Thermo Lay	Conventional 84 in. tilt—90 in. cab-to-axle				Uses a hydraulic system; 220-V heater for cold mix (185-200°F in 8-10 hr); installation at site (1 day); can be used in winter as a sander (30-40 min changeover)
Cutting tools					
Berema Pionjar 120/130	Pickup		Potential		Can be used to cut bituminous concrete
Racine Hydraulic MB-600	Truck mounted				Can be used to cut PCC and bituminous concrete
Racine Hydraulic HB-75	Pickup				Can cut bituminous concrete
Ingersoll-Rand air compressor P100 WW	Towed				Can be used to cut both PCC and bituminous concrete pavements
Compactors					
Wacker Vibroplate VPG 160 R	Pickup				Has maintenance problems; takes a long time to provide adequate compaction
E-Z Patch Roller	Mounts to rear of dump truck				Slows patching operation if same dump truck carries patching material
Essick V-30W-R	Mounts on tail of dump truck				Good compaction device
Gallion 4-6 ton	Mounts on tail of dump truck				Inadequate compaction for pothole repair

Cutting Equipment

The selection of equipment for the cutting operation is an important consideration because the cutting tool affects both quality and productivity. Production studies have identified cutting as the most important operation in achieving high production rates. A number of cutting tools are available.

Hand Tools

The advantage of hand tools is the low capital investment. There are no other advantages to their use. Hand tools are detrimental to the quality of the repair because it is difficult to remove all of the loose material from the edge or bottom of the distressed area. Also the hole cannot be cut with

vertical edges, so the patch may fail by rutting or shoving.

Cutting a pothole with hand tools is very fatiguing and time consuming. It takes 30 min or longer to cut an average-size pothole. At this rate, it is impossible to achieve even minimal levels of production, hence the use of hand tools in Pennsylvania has been largely abandoned.

Air Compressor

Undoubtedly the most efficient pavement breaker in terms of productivity is one powered by compressed air. Air compressors have the advantage of operating multiple breakers in high-density pothole areas; compressed air is available for cleaning debris from the hole and can power a variety of tools. The compressor can also be used for other activities such as painting and sandblasting. It is the only unit recommended for use on concrete pavements.

An average-size pothole can be cut in less than 5 min. Flexible 50-ft hoses enable several holes to be prepared before the compressor must be moved to a new location. The only disadvantages that were noted are (a) high capital investment of $14,500 or more, (b) high energy consumption, and (c) towing vehicle is required.

Hydraulic Pavement Breakers

The hydraulic-powered tools provide many of the advantages of the air-operated tools for less cost. The models tested in Pennsylvania are skid mounted, can be carried in the bed of a pickup truck, and cost approximately $4,500. The hydraulic pump can also power a variety of tools including forestry tools (chain saws, pruners, and chippers) that are used by roadside crews. The quality of the pothole repair is equal to that of the air compressor provided the bit is sharp. However, no compressed air is available for cleaning.

Hydraulic-powered tools are not as efficient as air-powered tools, requiring approximately 10 percent longer to prepare an average-size hole. Nevertheless, a pothole can be completely cut in less than 6 min. Flexible hoses should be 50 ft long to provide maximum coverage at each location before moving to a new location.

Gasoline-Operated Pavement Breakers

The only gasoline-operated pavement breaker evaluated in Pennsylvania was the Pionjar model 120. It is a versatile tool that comes with a variety of attachments. The primary advantage of the Pionjar over air or hydraulic tools is superior maneuverability characteristics; it is not attached to a power source and requires no special transport equipment. The Pionjar costs approximately $3,000 and must be properly maintained for maximum efficiency.

The advantages of cost and maneuverability are offset by reductions in production. For example, when compared to an air compressor, the Pionjar will take approximately 50 percent longer to cut an average-size hole (about 7 1/4 min). The Pionjar cannot be used on concrete pavements. Nevertheless, the Pionjar is capable of achieving daily production rates in excess of 6 tons of asphaltic concrete or composite pavements. The department of transportation owns approximately 270 Pionjar pavement breakers that are used primarily as supplemental cutting tools.

Milling Machines

Milling machines, although not evaluated and not widely used for pothole repair per se, have seen limited use in one of the commonwealth's engineering districts. The Barco-Mill 100 has been used on some contracted pothole repairs with apparently encouraging results. It has also been used to cut extensive areas of deteriorated pavement at reflective and widening cracks in preparation for overlaying. On this type of operation, productivity far exceeds that of all other cutting devices. Although the use of milling is discouraged for small pothole repair, it will be further evaluated in preparing pavements for overlay.

Saws

The department of transportation owns or rents a few gasoline-operated saws for concrete pavement patching and, occasionally, for pothole repair; however, these were not specifically addressed in the Pennsylvania State University study (2). Despite the attractive feature of low cost, there are numerous disadvantages to saws. First, they leave a smooth vertical edge that is semipolished. This surface makes it difficult for the new patch material to adhere and may cause early patch failures. Where water is used to cool the saw blade, it will partly fill the hole causing additional cleaning problems. The depth of cut cannot be readily adjusted, and the production rate is slow compared to that of the other tools that are available. Furthermore, a pavement breaker will still be needed to loosen the material inside the perimeter of the cut. Also, saws lack versatility because they cannot be used in other applications. Considering the overwhelming disadvantages, the use of saws is not recommended.

Cleaning Equipment

Cleaning must be accomplished by hand, although it may be augmented with compressed air. The first step in cleaning is to remove the chunks of asphalt from within the perimeter of the cut. This is done with a conventional shovel. One with a long handle will minimize worker fatigue. Most of the small loose debris and stones can also be removed with the shovel.

It the hole is wet, most of the water can be removed with a broom. In some states a butane torch is used to further dry the hole; however, the practice is not followed in Pennsylvania. Studies by Pennsylvania State University indicate that the hole need not be totally dry to provide a permanent repair.

Loose debris that builds up in the corners must be removed. This can be done either with a stiff long-handled broom or with compressed air. Cleaning with compressed air is the easiest and most effective method. A blow tube should be used and the pressure should not exceed 30 psi. Compressors should be equipped with two lines the second of which is used for cleaning purposes only. To achieve high production rates, the cutting operation should not be stopped to allow cleaning to be done.

Tack Equipment

The most common tack materials used are emulsions and synthetic resins; each is used only with hot mix patching materials and requires different application equipment. To be successful, the tack must be applied in a thin coating, which can only be accom-

plished by brushing or spraying. Pouring from a pot or kettle is not acceptable. The resins are sufficiently fluid to be pumped through garden-type sprayers, but the resins are very volatile and safety concerns about using this material in an unapproved pressure vessel eliminated this method from consideration. Synthetic resins are normally brushed onto the surfaces.

To date, suitable equipment to apply tack material, other than the integral systems contained on the sophisticated patching equipment, has not been found. Experimentation on pressurized spraying containers is continuing with a few promising products.

Mixing and Filling Equipment

There are many devices manufactured for the heating and mixing of bituminous patching material. These vary from sophisticated mobile plants to simple reheaters. For the purpose of this paper, they are classified as (a) portable mixers, (b) reheaters-recyclers, and (c) reconditioners. Portable mixers vary widely in size and capacity and are generally used to combine virgin components (some in a more controlled manner than others) to produce a patching material. Reheaters-recyclers are generally used to reheat cold patch material or, in some cases, to reheat and recycle reclaimed asphalt pavement. Reclaimers are capable of heating distressed pavement areas with either radiant or infrared heat and adding material from self-contained heated storage units.

Portable Mixers

Four types of portable mixers were evaluated:

Asphalt-Mobile Mixing Plant

The Asphalt-Mobile mixing plant is a completely self-contained asphalt plant mounted on a truck chassis or semitrailer. The plant is capable of producing high-quality hot mixes of any design. It combines all drying, heating, and mixing operations and operates on volumetric control; it has a two-bin aggregate system (one fine, one coarse) each bin of which holds approximately 100 ft^3 and a 320-gal insulated, heated tank for asphalt supply capable of maintaining temperatures of 350°F. The unit is equipped with a baghouse-type dust control system that meets Environmental Protection Agency emissions standards. Each aggregate bin, complete with scalper screen, has an apron feeder underneath that moves the material through calibrated gates to a bucket elevator (38 tons per hour capacity) to the dryer. A counter-flow rotary dryer-heater system dries the material at a rate of up to 25 tons per hour depending on moisture removal requirements. Heated liquid asphalt is metered into the mixer in the desired proportion. Manufacturer's literature claims production capacities of up to 25 tons per hour; however, the department is generally finding an average of approximately 10 tons per hour to be more practical.

Because this unit is very expensive and produces at least 11 times the amount of material expected to be used by a patching crew in a day's production, it would be grossly inefficient to assign to an individual crew. Its use as a stationary plant to supply heated storage units at a central location was also considered and tried, but because of logistic problems of supplying and storing raw material and the traveling distances of crews, this idea was not thought to be cost-effective.

The unit produced material of very high quality, was well received by crews, and is well engineered. Nevertheless, it is very expensive, approximately $170,000 (1979 dollars) for the trailer model and approximately $230,000 (1979 dollars) for the truck-mounted model. With the emphasis in the department on treating the present high-quality cold mix (485) as a permanent repair material, there appears to be little justification for purchasing any additional Asphalt-Mobiles.

McConnaughay Mixer Model HTD-10T

The McConnaughay mixer is a towable mixer used to produce hot mix patching material. It operates on a drum-dry principle and combines, mixes, and heats components to approximately 300°F in 2-3 min. The mixer is equipped with a 10 ft^3 aggregate bin and an optional 200-gal heated asphalt supply tank. The manufacturer claims production capacities of up to 10 tons per hour, which, on the basis of field observations, seem to be optimistic.

It is not a self-contained unit because blended aggregate must be charged into the hopper. There are no quality control features associated with the HTD-10T. Aggregate blending is external to the operation and the proportioning of aggregate and asphalt is done manually. Although there is a timer, the mixing time is controlled exclusively by the operator and, in part, is determined by the moisture content of the aggregate. There are no controls or meters and there are no emission controls. Because of the volatile nature of cut-back asphalts, the unit can only be operated as a mixer if asphalt cements or emulsions are used. Both must be stored in insulated, heated tanks in order to maintain the proper viscosity. This aspect greatly limits the use of the HTD-10T in the winter. Experience in Cambria and Westmoreland counties indicates that a satisfactory temperature for asphalt cements cannot be maintained. Also, the asphalt supply lines are not insulated, hence extreme care must be exercised in cold weather to prevent material from solidifying in the lines.

There is no automatic ignition system; the unit must be ignited with a match and a rag on a stick. Control valves for the asphalt are surrounded by heated pipes and are not easily reached. There are two control valves for the heated asphalt located on opposite sides of the unit; because they are manually controlled, they cannot be operated concurrently.

A.M.Z. System

The A.M.Z. system is a pneumatically operated pothole repair system that can be operated with a two-man crew (not including traffic control). The equipment is basically self-contained; it needs only a truck to tow the equipment and to haul the aggregate. It is equipped with a high-volume lobe blower, a 120-gal asphalt storage tank, an aggregate hopper and supply system, and an applicator hose system including a lightweight nozzle equipped with controls. The operator controls the total operation at the nozzle and is capable of blowing the hole clean, tacking, and filling by a simple maneuver of the control valves. The A.M.Z. system is capable of providing a skin patch (a thin application of asphalt followed by a one-layer depth of aggregate) or a deep patch where the aggregate is coated (mixed) with asphalt within the nozzle and directed into the hole at a velocity of 60 mph (97 km/hr). According to the manufacturer, this adequately compacts the material.

Although the claims of the manufacturer must yet be evaluated in a field test, this equipment does show considerable potential especially for lighttype flexible pavements on which skin patching is most prevalent. Contrary to the manufacturer's claims, cutting to sound material, as with all other repairs, should be done ahead of this operation. One obvious drawback to this system is lack of quality control of the mixed material. The operator controls the ratio of asphalt to aggregate by manipulation of the controls. An attempt to evaluate this system will be made by the department during the spring of 1984.

Reheaters-Recyclers and Reconditioners

Reheaters-recyclers and reconditioners for the purpose of this paper are separated into two groups. The reheaters-recyclers are those that operate on a drum-dryer mixer principle. Included in this group are the Brown Porta-Patcher, the Bomag AR-5, and the Aeroil reclaimer AR-100. The Poweray Infrared Heat and Serve and the Patchmaster are representative of the reconditioners that rely on infrared or radiant heat to recondition pavement surfaces in place.

Brown Porta-Patcher

The Brown Porta-Patcher is one of several drum-type reheaters designed to recycle asphaltic material and to heat cold mix. The manufacturers claim that the heating process drives off the volatiles, leaving a quality hot mix. Laboratory tests of material samples run through the Porta-Patcher indicate that some of the volatiles are removed and that the material quality may be somewhat enhanced. The heat source for the Porta-Patcher is liquid propane. There is an electric spark ignition system and adjustable temperature control. Cold mix is manually fed into a hopper at one end of a revolving drum. The material is gravity fed through the drum while it is simultaneously exposed to the heat from the burners. It takes approximately 2-3 min for the material to be processed.

Production capability seems to be adequate, but productivity would be reduced because of the need to have an additional crew member feed the material into the hopper. There might be times when the crew would have to wait for more material to be processed, but, with proper instructions from the foreman, such delays could be minimized.

The Porta-Patcher is trailer mounted and can be towed by a dump truck. It weighs 3,900 lb with a tongue weight of 320 lb. There are no unusual maneuverability or logistic characteristics.

There are no special training requirements for operating the Porta-Patcher. However, it takes a while to learn how to tilt the drum properly. If the drum tilts too low, it is possible to burn the asphalt. No safety hazards were noted except that the workers were often irritated by the fumes coming from the rear of the drum.

The 485 cold mix used in Pennsylvania does not seem compatible with the Porta-Patcher. During the studies conducted in Allegheny County, air pollution problems resulted because of the high asphalt content of the 485 mix. A special mix would probably need to be designed for the Porta-Patcher and similar types of reheaters.

Bomag AR-5

The Bomag AR-5 is a portable drum-type reheater similar to the Porta-Patcher but smaller. The rated production capacity is 5 tons per hour, about half of the Porta-Patcher's capacity. Nevertheless, production appears quite adequate. The Bomag AR-5 weighs 1,350 lb with a tongue weight of 120 lb and can be towed by a crew cab. Problems with pollutants and fumes were not documented.

Aeroil Reclaimer AR 1000

The third type of reheater is similar to a small concrete mixer and if necessary can be used as such. Material is manually charged into the drum, is heated with propane burners directed into the opening of the drum, and is then discharged by tipping the drum.

Manufacturers of all of the equipment discussed normally promote their equipment to reheat milled, cold planed, or cold patch material. The equipment requires an additional crew member to operate and also requires double handling of material, both of which seriously decrease productivity.

In view of these comments and the concentrated effort Pennsylvania has made to develop a high-quality cold patch material to perform as a permanent patch and when one considers that material cost only accounts for approximately 20 percent of the patching cost, these units are not considered compatible with the department's philosophy. These units appear to be more compatible in the municipal area.

Poweray Infrared Heat and Serve

The Poweray Infrared Heat and Serve unit incorporates an infrared heater to heat a 6 ft x 8 ft area of existing pavement. New hot material stored in an integral heated box is added to and blended with the reheated pavement. There is no need to cut vertical edges with a pavement breaker or to apply a tack coat. Material can be blended at the edges, and there is no need to dispose of waste materials. The infrared radiation is created by premixed propane gas and air delivered under pressure to energy converters. No flame is produced that may alter the binding characteristics of the asphalt. The unit has two energy converters rated at 15 000 Btu each.

The quality of the repair produced by the Heat and Serve unit is limited in certain respects. Where several layers of overlays exist, the softening only penetrates the first layer; thus the effective depth may only be an inch or two. Heating is not effective where pavement markings exist or on heavily oxidized pavements, and moisture and dirt slow heat penetration. In a department evaluation, the Heat and Serve unit heated asphaltic pavement to 300°F at a depth of 1 1/2 in. in approximately 4 min. It seems unlikely that depths much greater than this can be softened as rapidly as needed. Table 3 gives the results of five holes repaired during 1979-1980. As

TABLE 3 Temperature Characteristics of Heat and Serve (1979-1980)

Hole Number	Heating Time (min)	Pavement	Temperature (°F)	
			Mix (surface)	At 1 in. Penetration
139	4	90	245	
140	4	93	223	150
141	7	98	300	156
142	7	102	300	200
143	7.5	104	280	

can be seen, the heated temperature diminished rapidly as a function of depth.

The Heat and Serve unit does not seem applicable to pothole patching except on a very limited scale. It is perhaps better suited to the repair of alligator cracks, bridge approaches, and the like; like the reheaters-recyclers, this unit may have considerable potential in the municipal area primarily for repairing utility cuts that have settled.

Patchmaster

The Patchmaster operates on the same principle as the Heat and Serve except that it uses radiant heat instead of infrared. It is a well-engineered device but expensive ($42,000 in 1981). The heating limitations of the Patchmaster are similar to those of the Heat and Serve.

The radiant heaters have approximately 50 000-Btu capacity, and in a field demonstration the asphalt was burned and a rejuvenator was necessary. Because of the potential harm to the pavement and the very high cost, this unit is not recommended for pothole repair work.

Heated Boxes

Heated boxes consist of insulated metal containers mounted on trucks or trailers. The boxes are heated in various ways and are used as storage vessels to transport and make possible the use of hot patching material by patching crews during the entire workday. The boxes are generally used to retain the heat of hot plant mix or to elevate the temperature of stockpile patching material to improve handling characteristics.

Thermo-Lay Pothole Patcher

This patcher is manufactured in three models: The Thermo-Lay model TM375-200 is a heated box mounted on a truck chassis. The model TRL 375-200 is a comparable trailer model and a slip in-slip out unit; model DM 375-200 is also available. This must be mounted on a truck bed or chassis, and for all practical purposes it is a permanent installation. Each comes with a variety of optional accessories. Model TM375-200 was evaluated.

The primary feature of model TM 375-200 is the insulated storage box. It is a combined heater and dispenser system. The insulated box has 3 3/4 yd^3 capacity. A 350 000-Btu propane burner is designed to heat cold mix overnight or to maintain hot mix temperatures. The burner system seems to be adequate. The material is dispensed via a 10-ft screw auger powered by a reversible 11-gal/min, 2,000-psi hydaulic motor. Early experience with the Thermo-Lay suggested that in traveling to the work site some compaction takes place around the auger. A larger hydraulic pump (18 gal/min, 2,000 psi) was installed that eliminated the problem. The material is discharged into a chute that can rotate 180 degrees. The chute eases the difficulties of shoveling the material, but positioning the truck so the material can be discharged directly into the hole is a problem. Typically, the material is discharged onto the pavement before it is shoveled into the hole. Other standard features of the Thermo-Lay include

- Heated asphalt system: 235-gal capacity, 20 gal/min, 1,200 psi reversible pump;
- Electrical heating system for overnight heating: 230 volt, 6 kw with thermostat control unit;
- Propane hand torch: 200 000 Btu with 10-ft hose;
- Diesel fuel storage for flushing asphalt pump: 18-gal capacity; and
- Hydraulic pavement breaker: 37 lb (67 and 85 lb sizes are optional).

Several optional features are also available. These include

- Hydraulic tamper, Stanley TA55112;
- 24-in spoils bin;
- Sanding attachment;
- Side board brackets to increase material capacity to 5 yd^3; and
- Vibratory plate compactor, model AP 2000, 4 hp.

The Thermo-Lay appears to be well engineered. Satisfactory temperatures were maintained. The hydraulic conveyor system was adequate when the larger pump was installed. The heated tack oil system used for tacking purposes was probably the best system observed. The tack material was discharged in a fine mist. Unlike nozzles of other heated systems, the nozzle did not become clogged after intermittent use. This is because the asphalt pump is reversible and the lines can be cleaned with the diesel fuel flushing system. The electrical heating system was not used during the study.

Several comments about the tack oil system are worthwhile. The need for such a system cannot be entirely justified at this point. A previous study has shown that there is little evidence to suggest that the tacking operation increases patch longevity. Further, departmental policy is not to tack cold mix. Thus, a pressurized tacking system may be considered an unnecessary expense. If tacking proves to be beneficial, an effective tacking program requires the use of different tacking materials, depending on moisture and weather conditions, time of year, and material availability. It is not known if the tack oil system on the Thermo-Lay will function properly with emulsions, synthetic resin, and cutbacks. A final drawback of the tack oil system is its effect on productivity. Certain tack materials, such as synthetic resin, may require a curing period of 10-20 min. An unattached tacking system is desirable to permit tack coating the holes well in advance of the filling operation; otherwise the filling operation will be delayed or curing requirements will be ignored.

Vibratory plate compactors and hydraulic tampers and pavement breakers will be discussed later. The 67-lb hydraulic pavement breaker is recommended in lieu of the 37-lb one. Also, a 50-ft hose should be specified instead of the standard 25-ft one.

High production levels will not be attainable with the Thermo-Lay for several reasons. First, production is limited by the 3 3/4 yd^3 hopper. If the truck returns for more material, it takes away the cutting capabilities. Returning for more material seems impractical. Even the increased 5 yd^3 capacity is below the departmental production goal.

The crew cannot be dispatched in an assembly-line fashion ("productionized") because the cutting, filling, and compaction operations are tied to a single unit. Productionizing the crew is a prerequisite to high daily production. A 50-ft hose on the hydraulic pavement breaker and a detached compaction device would help, but the improvements seem superficial.

P.B. Patcher Model B-3

The P.B. Patcher is a heated storage unit similar to the Thermo-Lay. The unit is manufactured as a unit-

ized model (B-4) mounted on a truck chassis and a slip in-slip out model (B-3) to be used in conjunction with a dump truck. The model B-3 has a 3-yd³ (4-ton) capacity and the B-4 has a 4-yd³ (5-6-ton) capacity. The heat is provided by a thermostatically controlled propane or butane heater. The B-3 slip in-slip out model was evaluated.

Loading of hot mix at the asphalt plant is facilitated by hydraulically operated doors on the top of the box. The self-contained hydraulic system also controls individual dump doors. During the study, considerable difficulties were encountered with this system. Discharge of material is accomplished by raising the bed of the dump truck. The asphalt is discharged onto an optional shoveling apron that has a 1/4 yd³ capacity. The P.B. Patcher is equipped with an emulsion tank and hand spray wand attached to a 25-ft hose. A diesel flushing system is included. An optional hand torch is also available. The heating, hydraulic, and emulsion spray systems are activated by an electronic ignition system. The starter switch caused considerable problems during the evaluation.

The overall performance of the P.B. Patcher was not good. The problems with the hydraulic system and ignition switch were not resolved during the evaluation.

The model B-3 has a 4-ton capacity, which is considerably short of the daily target value of 6 tons. There is no way of achieving this 6-ton goal unless the truck leaves the work area for more material or a second dump truck loaded with cold mix is used. Either approach is costly in terms of delay time and equipment costs. Thus, the P.B. Patcher does not appear adaptable to high production needs.

At first, the logistic features of the P.B. Patcher appear good, because it is easily hauled to the work area. However, the shoveling apron prevents the towing capabilities of the dump truck from being used. If an Essick roller is being used, it must be attached to the snow plow attachment or to the tailgate of another truck. Furthermore, there is no place to put the old pavement that has been cut out unless a second dump truck is used.

The cost of the P.B. Patcher is $8,000-$10,000. This is quite expensive in light of the fact that similar systems are available without the unnecessary accessories or required features such as hydraulic doors.

For productivity reasons, the only time when these units seem to be acceptable is when holes are widely distributed. Perhaps the best use for them is, again, in the municipal sector. Acceptable production levels cannot be achieved with the Thermo-Lay, the P.B. Patcher, and most other self-contained repair systems.

Poweray Model 4TSU

The Poweray model 4TSU is a low-cost, towed, heated box. It is the same type of insulated storage unit as the Thermo-Lay and the P.B. Patcher but without the added accessories and systems. The loading doors and shoveling doors are manually operated. There is no hydraulic system and the liquid asphalt system is optional. The heat source is propane gas, and the temperature control is manual. The material capacity is 4 tons. A 24-in. shoveling apron reduces spillage. The quality of the 4TSU is quite good, largely because there are few systems (only the burner system) that can malfunction. These units have been used by the department for a number of years and seem to be durable.

The production capacity of the 4TSU is less than the daily 6-ton goal. However, this apparent deficiency is not as acute as it is with the Thermo-Lay and P.B. Patcher. Because the 4TSU is towed, the bed of the dump truck can be used to carry additional unheated cold mix. When empty, the 4TSU can be parked at a convenient location while the unheated cold mix is being used. Also, there should be room in the dump bed for the old pavement material, thus eliminating the need for another truck. Another advantage of the 4TSU is the relatively low initial cost. Operating and maintenance costs are also favorable.

Poweray also manufactures a truck-mounted slip in-slip out unit (model 6 TDM) that has basically the same features as the 4TSU except a slightly larger capacity (6 tons). This unit, because it is truck mounted, has several drawbacks:

- Loading height is approximately 12 ft, which practically limits loading to a plant;
- Shoveling aprons are too high;
- The unit is secured to the truck by bolting, which, for all practical purposes, makes the 6 TDM a permanent unit; the unit is not easily installed or removed; and
- The changing of propane tanks was very difficult and required a loader to lift them from the truck.

Midland Warming Box

This unit is similar to the Poweray 6 TDM and has the same general disadvantages but one significant disadvantage, namely the unit is heated electrically, requiring 240-volt alternating current, which prevents the application of heat when on project and requires the unit to be parked at a location with an adequate power source.

Wylie TMH 250

This unit is a towed unit similar to the Poweray 4TSU; it has the same general advantages but it also has a few significant disadvantages. The propane system has no automatic tank-switching capabilities. The tongue seemed to be too short, which made maneuvering more difficult, and the thermostat is electrically operated requiring a battery to be connected to keep material at a workable temperature and prevent overheating. The thermostat and lights are on the same circuit with no switching capability. This makes it necessary to leave the lights on or remove the bulbs when heating overnight.

Compaction Equipment

The compaction of patch material is perhaps the most critical step in the repair process. Four basic types of compaction equipment were considered: vibratory plate, steel-wheeled vibratory rollers, two-wheeled static rollers, gasoline-powered breakers and hammers, and tamping-foot compactors.

The Pennsylvania State University recently undertook a comprehensive study of the department's pothole repair policy and procedures (2). Four types of compaction equipment were studied:

1. The vibrating plate (Wacker VPG-160R) is a small hand-operated device consisting of a gasoline engine that vibrates a flat plate. The device is often used for patching operations but its principal use is as a soil compactor.
2. The vibrating roller (Essick V30W-R) is a small roller of the walk-behind type. It has a vi-

bration capability that is combined with the weight of the machine to create the compactive effort. This roller is very maneuverable and can be towed on a flatbed trailer behind a small truck, or it can be carried on the tailgate of a dump truck.

3. The 4-6-ton roller is a static steel-wheel roller that can be towed behind a small maintenance dump truck. The roller has rubber tires that can be raised or lowered. The roller is usually operated at 5 tons. It does not have vibration capability.

4. The gasoline jackhammer (Pionjar model 120) is a hand-held, gasoline-operated cutting tool. The cutting tool can be removed and replaced with a small tamping foot. Compaction is achieved by the up and down action of the device.

Hot mix and cold patch were compacted with this equipment into holes of varying sizes and depths, and nuclear density and core density measurements were taken (Kilarski and Anderson, unpublished results).

Hydraulic tampers, truck-mounted rollers, and tamping-foot compactors were not considered satisfactory for various reasons and were not studied.

Study variables included hole size, hole depth, number of lifts, and number of passes. Densities were measured after each set of passes with the equipment. After the hot mix patch material was compacted, cores were taken at the center and corner of each hole. It was not possible to core the holes filled with cold patch.

Discussion of Results--Cold Patch Material

Some of the results of the evaluation of the cold mix material are shown in Figures 1 and 2. These figures show the compaction growth curves for the material with respect to hole size and the type of compaction equipment used.

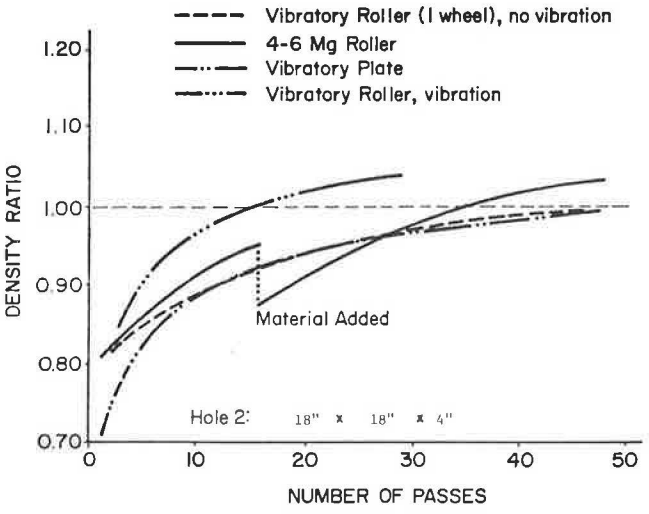

FIGURE 1 Cold mix growth curve—hole 2, 4 in. deep.

It can be seen that, for the majority of the holes, 95 percent Marshall density was achieved with the vibratory roller (with vibration) after approximately 10 passes of the device, whereas the small vibratory plate must make about 20 coverages for 95 percent density. A coverage is defined for the vibrating-plate compactor as the movement of the plate across the entire surface of the patch. This may take several back-and-forth or side-to-side passes

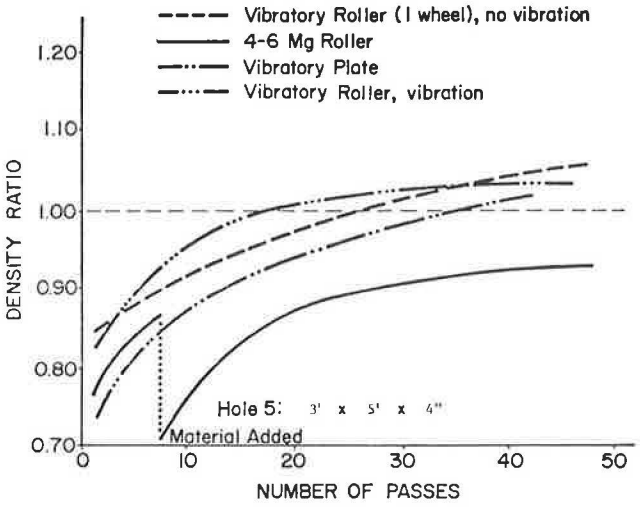

FIGURE 2 Cold mix growth curve—hole 5, 4 in. deep.

with the device. Approximately 25 min were required to obtain 20 coverages on 3 x 5 ft holes. The 4-6-ton roller also needs about 20 passes to obtain 95 percent density, but it should be noted that for two of the larger holes, density was not achieved even after 25 passes. These results indicate that the small vibrating roller achieves the best compaction of the cold mix. The vibrating plate does an adequate job, but it takes longer to achieve compaction, and, in some cases, the 4-6-ton roller does not perform adequately.

Discussion of Results--Hot Patch Material

The results of the evaluation of the hot mix material are shown in Figures 3 and 4, which show the number of passes needed to achieve 95 percent density. For the small holes, about 20 passes of the vibrating roller were required, whereas only 10 passes were needed for the large holes. The small vibrating plate did as well as or better than the vibrating roller in most cases. For two of the small holes and two of the large holes it took only about

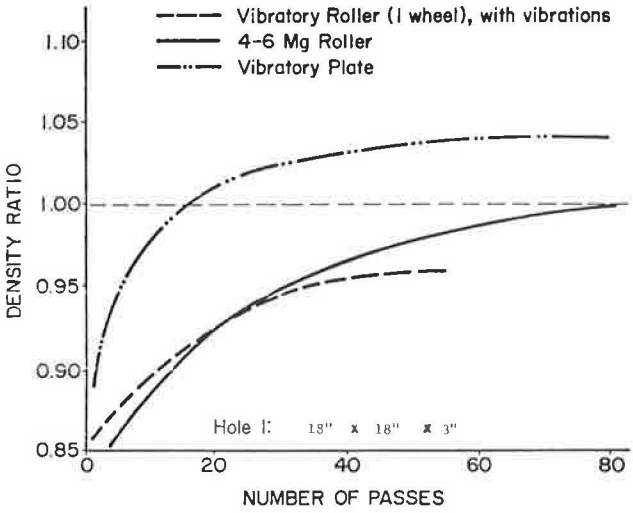

FIGURE 3 Hot mix growth curve—hole 1, 3 in. deep.

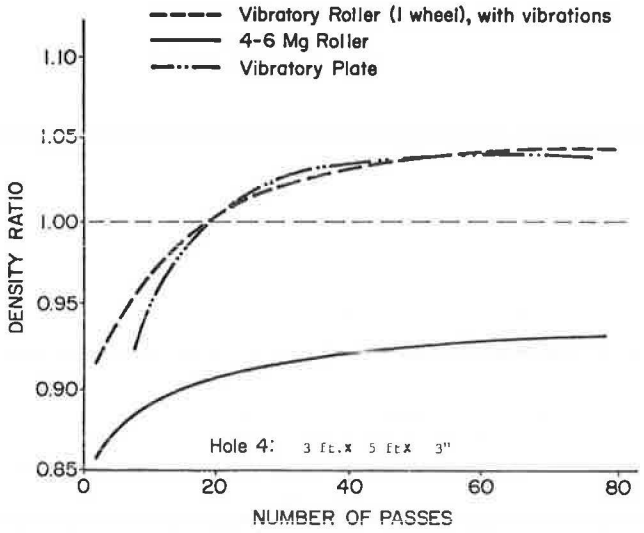

FIGURE 4 Hot mix growth curve—hole 4, 3 in. deep.

5 passes of the vibrating plate to achieve 95 percent density. The 4-6-ton roller took 40 or more passes to achieve 95 percent density on the large holes. This makes the 4-6-ton roller an ineffective compaction device for pothole repairs with both cold and hot material.

As with the cold mix, the vibrating device will overcompact the material in both the small and large holes. In particular, the vibrating plate shows a very steep growth curve on the small shallow hole, which indicates that overcompaction can occur quickly.

Comparison of Compaction Devices

Surprisingly high levels of compaction were obtained with the vibrating-plate compactor when it was used to compact hot patch material. However, the department has had problems maintaining this equipment and the crews do not like to use it. The device is heavy; it cannot be easily moved along the pavement; and it requires long periods of time to obtain proper compaction. In practice, the compaction obtained by crews using the vibrating-plate compactor may be much lower than indicated by the growth curves reported in this paper, especially for larger holes, because the time required to obtain proper compaction is considerably longer than that currently used by the crews.

The single-wheel vibrating roller is by far the most satisfactory of the compaction devices. It is mobile, can be mounted on the tailgate of a truck, and provides excellent levels of compaction. However, for the equipment to be effective it must be used in the vibratory mode. One or two passes must be made initially without vibration. Additional passes without vibration should be avoided because this inhibits further compaction when the vibration is applied.

Finally, regardless of the demonstrated effectiveness of the compaction device, its effectiveness is lost if the hole is underfilled. In the past department policy was to fill the hole so that after compaction it was flush with the pavement. This practice is not acceptable for holes that the compactor can bridge. Slight overfilling is needed to ensure that the compactor is bearing on the patch material and not on the surrounding pavement.

SUMMARY

Of the varied pieces of equipment available for pothole repairs, many are specialized and were not determined to be cost-effective for organizations that have large-scale pothole problems and that are production oriented. Some of this equipment may, however, have an application in the municipal sector.

This evaluation has generally served to confirm, and in a few areas enhance, the department's philosophies about patching equipment.

The typical patching crew equipment recommendation is

- One air compressor or Pionjar breaker,
- One Essick vibratory roller,
- One Poweray 4TSU heated transport (hot box),
- One small dump truck (approximately 33,000 lb GVW), and
- One crew cab pickup truck (Foreman).

This complement does not include any specialized equipment and is considered cost-effective for the majority of the department's organizations.

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