State-of-the-Art Review of Paved Shoulders

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Paving shoulders of highways was begun by state highway agencies to eliminate maintenance and safety problems brought about by increasing traffic densities and axle loads. Not all states have established policies concerning the paving of shoulders. In many, the decision to pave the shoulder is still made on an individual project basis and depends on engineering judgment, past experience, and availability of funds. Because paving highway shoulders is a relatively new practice, state agencies have not had sufficient time to accumulate data for cost-benefit analyses on which to base the justification for paving shoulders. The paved shoulder has not solved all maintenance and safety problems and has even generated several. In addition, it requires a higher initial investment than that required for an unpaved shoulder and is therefore not economically feasible for low-volume highways. Nevertheless, it has gained the general acceptance of both highway engineers and motorists. This report discusses all aspects of shoulder paving and presents methods used by state highway agencies to cope with all types of problems that they encounter in paving shoulders in their highway systems.

The term "paved shoulder" applies to any one of a wide range of all-weather highway shoulders including bituminous surface-treated shoulders, bituminous mats on stabilized gravel base, full-depth asphalt shoulders, and portland cement concrete (PCC) shoulders. They are constructed adjacent to main-line pavements of equal or better type. Unless specified otherwise, the term "shoulder," in this paper refers to the shoulder to the right of the traffic lane.

Except on Interstate and federal-aid routes where shoulder requirements are specified, the decision on whether a shoulder should be paved and what type of pavement to be used is, in most cases, the result of balancing engineering judgment and maintenance and accident experience on existing shoulders against economic considerations. Engineering judgment includes considerations of wheel load estimates for shoulder design, effect of types of shoulders on plans for future widening or upgrading and on traffic and maintenance operations, and intangible benefits derived from paving the shoulder.

This report summarizes available information on paved shoulders is based on a review of existing literature. It does not in any way attempt to offer solutions to the problems associated with paved shoulders. It does present different ways in which state highway agencies and other concerned groups have tried to cope with these problems. It is hoped that a knowledge of what has been done and what is being done can serve as a guide to future studies and investigations needed to better understand paved shoulders and to improve their performance.

DEFINITION, FUNCTIONS, AND REQUIREMENTS OF PAVED SHOULDERS

Definition

The American Association of State Highway Officials (AASHO) (1), which is now the American Association of State Highway and Transportation Officials (AASHTO), defines the shoulder as

> the portion of the roadway contiguous with the traveled way for the accommodation of stopped vehicles, for emergency use, and for lateral support of base and surface courses. It varies in width from only about 2 ft or so on minor rural roads, where there is no surfacing or the surfacing is applied over the entire roadbed, to about 12 ft on major roads, where the entire shoulder may be stabilized or have an all-weather surface treatment.

The all-weather surface treatment may consist of a bituminous surface treatment with a minimum thickness of about 2.54 cm (1 in) or a bituminous mat over a stabilized gravel base. The entire shoulder structure may be either an extension or a variant of the main-line paving as are full-depth asphalt shoulders, PCC shoulders, and shoulder areas in full-width paving.

Publication of this paper sponsored by Committee on Shoulder Design.

Functions

The conventional functions of the paved shoulder embodied in the AASHO definition of shoulders are as follows:

1. Accommodation of vehicles for emergency or other use and
2. Lateral support of base and surface courses.

A vehicle stopped on a travel lane for any reason forces moving vehicles to merge into fewer lanes at lower speeds. By providing refuge for stopped vehicles, a paved shoulder helps to maintain the capacity of a highway (2). Studies conducted by Billion (3), Bellis (4), and Bergsman and Shufflebarger (5) identified the reasons for, and frequency of, shoulder occupancy by motorists on urban and rural freeways. Reasons for emergency stops, occurring once per approximately 1900 vehicle-km (1200 vehicle-miles), included tire changing, vehicle checking, running out of gas, and overheating. Leisure or convenience stops, making up three-fourths of the total stops, were made for resting and eating, caring for children and pets, and obtaining bearings. Moskowitz and Schaefer (6) observed that a vehicle leaving the roadway has a good chance of avoiding an accident if sufficient maneuvering room is available. A paved shoulder also serves as a detour for traffic during maintenance or construction operations or after an accident while main lanes are being cleared. Bergsman and Shufflebarger (5) ascribe 6 to 8 percent of the total use of shoulders to accidents.

At the Western Association of State Highway Officials road test conducted in Malad, Idaho, from 1952 to 1954, it was found that, without a paved shoulder, the outer wheel paths of a pavement structure were inferior to the inner wheel paths in their ability to support test loads (7, pp. 203-204). With paved shoulders providing support to the pavement structure, the conditions of interior loading always apply. Treybig, Hudson, and Abou-Ayyash (8) showed in their study with concrete shoulders constructed integrally with the pavement that the maximum deflection caused by an 80.1-kN (18-kip) load about 0.3 m (1 ft) from the edge of an 18 or 20-cm (7 or 8-in) continuously reinforced concrete pavement slab without concrete shoulders was about twice that in the same slab with concrete shoulders.

Other conventional functions of paved shoulders not explicitly embodied in the AASHO definition given at the beginning of this section are

1. Facilitation of water removal from the main-line pavement,
2. Aesthetic value as an aid to driver comfort and freedom from fatigue,
3. Provision of bicycle routes (Hawaii and Michigan are paving some of the shoulders on their primary and secondary systems to accommodate bicycle traffic), and
4. Provision of space for routing traffic during construction and operating space for maintenance equipment.

Innovative uses of paved shoulders, devised in recent years and aimed primarily at increasing travel lane capacity, are as follows (9):

1. Provision of room for slower vehicles to permit passing maneuvers,
2. Extra lane for added capacity during peak periods, and
3. Widening of existing two-lane highways by overlaying travel lanes and both shoulders and remarking with solid double centerline to provide an undivided four-lane highway ("poor-boy design" now in use in Texas).

Requirements

For a paved shoulder to perform its functions as defined, it must meet certain requirements.

1. It must be stable in all kinds of weather to withstand (a) the standing load of a disabled or otherwise stopped vehicle or of maintenance equipment, (b) occasional traffic when the shoulder is used for detours or during maintenance operations, (c) through traffic when the shoulder is used as an extra lane for peak periods in states where this is not prohibited, and (d) the tearing effect caused by a vehicle that leaves the highway at high speed, when a motorist suddenly applies the brakes or attempts to change the direction of the vehicle (10).
2. It must be wide enough to accommodate parked vehicles. Objects on the shoulder that leave a clearance of 0.9 m (3 ft) or less from the pavement edge have been established to constitute a hazard.
3. It must be in such condition that a motorist can safely leave the travel lane at high speed when necessary to avoid or lessen the severity of an accident. This condition further requires the paved shoulder to be (a) continuous (intermittent turnouts at some facilities do not provide the distance needed for decelerating or reentering the traffic stream quickly and safely), (b) flush with the pavement edge [Brittenham, Glancy, and Karrer (11) found shoulder heights uneven with the edge of pavement because of settlement or heave of the shoulder structure at nearly three-fourths of all the accident locations they studied], (c) sloped sufficiently to drain surface water across but not sloped too steeply to constitute a hazard or create driver fear of rolling off, (d) free of ruts and potholes, and (e) skidproof.
4. The paved shoulder must be easy to maintain. Shoulder maintenance requires workers and machines to be working close to traffic, and, in spite of all precautions taken, this is a constant source of danger to the workers as well as to the traveling public passing them.

TYPES OF PAVED SHOULDERS

There are five general types of paved shoulders.

1. The bituminous surface-treated shoulder consists of a gravel shoulder on which coats of liquid bituminous material have been applied; surface mat thickness is at least 2.54 cm (1 in). Regional terminology such as armor coat, inverted penetration, multiple (double or triple) surface treatments, and seal coats all apply to bituminous surface treatments (12).
2. The bituminous aggregate shoulder is usually constructed adjacent to a flexible or a rigid main-line pavement. This shoulder consists of a bituminous mat on top of a gravel base course of variable depth that may or may not be stabilized with a bituminous mixture.
3. For the full-depth asphalt shoulder, asphalt mixtures are employed for all courses and are laid directly above the prepared subgrade (13). It is intended for construction adjacent to better quality roadways that are either flexible or rigid.
4. Shoulder areas of asphalt highways paved full width are built integrally with the pavement; subbase, base, and surface layers are placed across the entire section ditch to ditch. They are not to be confused with conventional shoulders of highways in which an overlay from shoulder edge to shoulder edge gives the surface

the appearance of full-width paving.

5. The PCC shoulder consists of a variable-depth PCC slab placed on a stabilized base or a prepared subgrade. A PCC shoulder can be constructed integrally with the main-line pavement or can be placed after the main-line pavement has hardened. It may be conventionally reinforced, continuously reinforced, or nonreinforced and be with or without tie bars. The PCC shoulder is no longer considered experimental by the Federal Highway Administration (FHWA) as of June 1974.

POLICIES CONCERNING PAVED SHOULDERS

An examination of the responses of state highway agencies to queries sent them concerning their current shoulder policies indicates that

1. Fifteen states have documented policies,
2. Twenty-eight states have no separate policies but have shoulder paving standards (six of these states prefer to make judgment decisions on paving after evaluation of the individual project), and
3. Five states pave shoulders integrally with the main-line pavement.

Whether there is a written policy or not, decisions concerning paved shoulders for new construction are shown, in the responses, to be based on one or on a combination of the following: (a) type of main-line pavement, which is often a function of classification; (b) traffic volumes [average daily traffic (ADT)], vehicles per day, daily hourly volume (DHV), or percentage of commercial vehicles; (c) engineering judgment and overall experience gained from previous construction of a similar type of facility; and (d) availability of funds.

Upgrading existing shoulders by paving involves maintenance and safety experiences, engineering judgment, and availability of funds.

Shoulder paving practices, based on 47 of the responses received for this report, are as follows: 23 states pave all shoulders; 5 states pave according to classification (for example, class 3 and higher freeways and class 1 freeway and expressway facilities); 8 states pave according to traffic volume (2 states use percentage of commercial vehicles as a basis); 6 states pave primary and major highways; and 5 states pave major highways and selected locations. This distribution agrees with that of Heimbach and Vick (14).

The Missouri State Highway Department has developed a set of criteria for paved shoulder types from implementation of a shoulder study by using relative cost and performance of a variety of shoulder designs to determine optimum shoulder designs for a given traffic intensity at particular locations in Missouri (15). The North Carolina Department of Transportation and Highway Safety has completed a study of cost effectiveness of paved shoulders for establishing priority warrants (16). This study concludes that a range of paved shoulder construction costs can be economically justified on the basis of accident cost reductions for two-lane, two-way rural primary highways with ADT volumes of 2000 to 15 000.

SHOULDER DESIGN

Like its main-line counterpart, a shoulder pavement needs to satisfy certain geometric, drainage, and structural requirements. AASHTO policy publications present a comprehensive treatment of design standards for highway shoulders; therefore, only a brief review will be presented here.

Geometric Design Elements

The widths of usable shoulders given here are prescribed by AASHO (1, 48).

For two-lane rural highways with ADT less than 250, desirable width of usable shoulder is 1.8 m (6 ft) [minimum 1.2 m (4 ft)]. For DHV over 400, desirable width is 3.6 m (12 ft) [minimum 3 m (10 ft)]. A reduction of 0.3 or 0.6 m (1 or 2 ft) in difficult terrain is allowed if the normal shoulder width is 1.8 m (6 ft) or more so that the minimum, regardless of terrain, is 1.2 m (4 ft).

For divided highways, the width of usable outside shoulder is 3 m (10 ft) [minimum 2.4 m (8 ft)]. Where truck combinations are high and grading costs are low, 3.4 to 3.6 m (11 to 12 ft) may be considered. On divided highways with three or more lanes in each direction, a full-width median shoulder of 2.4 to 3 m (8 to 10 ft) is desirable to give the driver in distress in the lane nearest the median a place of refuge.

Shoulders must be continuous not only on pavement sections but also across structures.

A cross slope of 4.2 cm/m ($\frac{1}{2}$ in/ft) is used by most states; 3.1 or 6.2 cm/m ($\frac{3}{8}$ or $\frac{3}{4}$ in/ft) is not uncommon; and occasionally a slope of 8.3 cm/m (1 in/ft) is used. The lower the shoulder type is, the greater the slope will be.

The desirability of providing contrast between the pavement and the shoulder and the methods and problems of achieving the contrast are discussed in the section on field performance.

Design of Drainage

Drainage of surface water from the main-line pavement to the ditch is generally accomplished by providing the shoulder with an impermeable surface combined with the right amount of cross slope. However, excess water may accumulate beneath the surface of the main-line pavement not only by infiltration from the top but also from other conditions such as capillary moisture, trenched pavement design, and hydrogenesis (water formation mechanism). Reducing the accumulation of excess moisture under the surface of the shoulder by design takes three forms. The first is using a granular subbase or equivalent plane layer of sufficient thickness across the full shoulder width to the in slope to interrupt capillary action. The thickness of the interrupting layer varies from 8 to 63 cm (3 to 25 in).

The second method is improving shoulder foundation design to eliminate conditions conducive to swelling, heave, volume change, and settlement. Brakey (17), in reporting on bumps and swells on roads built over shales in dry, rainless regions, believes that conditions of hydrogenesis are present in road subbases in those areas. Colorado's answer to hydrogenesis is the use of full-depth asphalt that is impermeable to air or the use of an impervious asphalt membrane directly on top of the subgrade and underneath a 5-cm (2-in) sand layer. Wyoming uses a 5-cm (2-in) sand blanket on top of an asphalt membrane.

The third method is providing supplementary subsurface drainage. Virginia designs pavement edge drains under the shoulders at low points of vertical curves. Arkansas provides aggregate outlet trenches from outside the shoulder edge at 61-m (200-ft) minimum intervals. Many states used underdrains for both edges of the pavement but provided no details on their use.

Structural Requirements

Two primary considerations used to determine structural requirements are the expected loading and the supporting ability of the subgrade. An additional consideration for the paved shoulder is the percentage of travel lane loading estimated to use the shoulder. As of 1973, only California and Iowa had a design load criterion for paved shoulders. The California Department of Transportation bases its shoulder design on 1 percent of the wheel loads in the adjacent lane with no traffic index less than 5.0. Iowa designs its shoulders on the assumption that the paved strip must carry the heaviest wheel load (18). States that pave full width have their road shoulders built to 100 percent the structural strength of their main-line pavements. In most other states, the general idea is to build higher type of shoulders for higher type of cross sections or systems or higher ADT roads; the shoulders are designed for lighter or fewer wheel loads than those anticipated on the corresponding main-line pavement.

Current structural designs of paved shoulders consist mainly of type and thickness of surface and base. Bituminous mats vary from 4.4 cm (1¾ in) thick to more than 13 cm (5 in) thick in some states and up to 23 cm (9 in) thick in others. Base courses, 15 cm (6 in) or more in thickness, are plant-mixed bituminous base, calcium chloride stabilized based, or dense-graded aggregate base. If a subbase is provided, the purpose is invariably to improve subsurface drainage. Availability of aggregates and climatic conditions have been suggested as factors influencing variations in relative thickness of surfacing and base course of bituminous shoulders (19, p. 100).

The thickness of PCC shoulders found in current designs varies from 20 or 23 cm (8 or 9 in) uniform or tapering from pavement thickness at the inside edge to 15 cm (6 in) at the outer edge. The need for reinforcement in PCC slabs for shoulders has not been established. The Illinois study showed that a 15-cm (6-in) thickness of plain concrete is adequate with 0.8-m (30-in) tiebars spaced 0.8 m (30 in) on centers. The need for tie bars between the shoulder and main-line pavement slabs has not been established. It has also been shown that joint keys can be omitted. The Illinois concrete shoulder study also indicated that fairly close spacing [6 m (20 ft)] of transverse joints is desirable (20).

In an FHWA Notice of June 5, 1974, in which state highway agencies were notified that construction of PCC shoulders adjacent to PCC main-line pavements is no longer experimental, the FHWA laid out design criteria for PCC shoulders concerning slab thickness, base course, joint requirements, reinforcement, and corrugations.

SHOULDER CONSTRUCTION

Standard procedures for the construction of paved shoulders are essentially similar to those for their main-line pavement counterparts; therefore, no more than an occasional reference to either will be made here. The construction of paved shoulders has, in fact, brought out the ingenuity and creativity of engineers and contractors faced with a task for which their standard equipment was suddenly not suitable. The contractor who built the first PCC shoulders in Illinois (the first in the country) in 1965 used an extruder or slip-form paver made in his shop. He also had to devise a float from a 9-m (3-ft) strip of corrugated metal to form the shoulder corrugations and a rig to drill the tie bars into the old concrete (21, 22).

Currently available slip-form paving equipment can be used with either transit-mixed or central-mixed concrete. These pavers can control line and grade electronically, place tie bars to the edge of existing slabs with self-drilling or nondrilling expansion anchors, and lay 12.5 m (41 ft) of paving [(1.5 m (5 ft) for left shoulder, 7.6 m (25 ft) for main line, and 3.3 m (11 ft) for right shoulder] in a single pass. Corrugations are formed by a separate power-driven corrugated roller (23). Asphalt paving contractors have recently devised procedures for grooving 7.6-cm-thick (3-in-thick) asphalt shoulders to create a rumble effect (24).

Most of the states queried expressed no serious problems encountered in the construction of paved shoulders. Those that did have problems indicated the following: (a) difficulty in attaining proper compaction in the shoulder area closest to the main-line pavement; (b) softening of the shoulder subgrade because of exposure to rain and to joint-cutting water; (c) possible relationship between sequencing of shoulder paving and shoulder settlement; and (d) separation at longitudinal joint between PCC pavement and bituminous shoulder.

Inadequate compaction in the area adjacent to the main-line pavement has been identified as a prime cause for the settling of shoulders and of pavement edge failures. Part of the problem is believed to be the inability of equipment to get close enough to the pavement edge to properly compact that area of the shoulder.

Michigan, experimenting with the use of sawed-sealed longitudinal joints between PCC pavements and bituminous shoulders as a means of reducing shoulder surface cracking, found that seal-treated interface joints did not completely prevent longitudinal shoulder cracking although they at least temporarily reduced the total cracking in that project (25). Michigan no longer seals joints of this type. The Pennsylvania Department of Transportation has also eliminated mechanical grooving and sealing between its roadway pavement and shoulder (26). Problems of longitudinal joints are treated in detail elsewhere (49).

FIELD PERFORMANCE

The decision to pave a shoulder, or the choice of shoulder paving, is justifiable on the basis of field performance as evidenced by smoother traffic operations, greater safety, and lower maintenance.

Traffic Operations

Paved shoulders have been demonstrated to affect traffic operations in certain ways.

1. They improve lateral placement of vehicles on the main-line pavement by increasing the "effective width" of the pavement. In a speed-placement study, Taragin found in 1945 (27) that bituminous shoulders at least 1.2 m (4 ft) wide adjacent to 5.5 to 6.1-m (18 to 20-ft) surfaces improved the lateral placement of free-moving vehicles to a greater extent than was obtainable by increasing the surface width to 6.1 to 6.7 m (20 to 22 ft) respectively.
2. They ease driver tension by giving the driver a sense of openness and an ensurance of space for emergency maneuvers. (This is closely connected to item 1 although it is not so easily quantifiable.)
3. They maintain highway capacity by providing an area for stopped vehicles.
4. They increase highway capacity in those parts of the country where the paved shoulder serves as a courtesy lane for slower moving traffic to allow faster moving vehicles to pass or as an auxiliary lane during peak periods.
5. They obtain more uniform traffic speed by allow-

ing motorists to leave the traffic lane at higher rates of speed so that following vehicles do not have to slow down considerably.

Despite the operational advantages gained by paving the shoulders, two kinds of problems have been identified. The first is the tendency of vehicles to encroach on a paved shoulder or to use the paved shoulder as a travel or turning lane. Clearly, this is a problem only on facilities or in states where the use of the shoulder for travel is prohibited or discouraged. This prohibition exists because the shoulder has not been designed to support the same intensity of load as has the main-line pavement. It has, furthermore, been argued that, if the shoulder is intended to serve as a refuge for stopped vehicles, then allowing travel on the shoulder creates a hazard for both traveling and stopped vehicles. The second problem is differentiating the shoulder from the travel lanes. Both problems take on significant dimensions only where paved shoulders are reserved for conventional uses. District engineers admit that much shoulder encroachment is random, is not done on purpose, and is attributed to an increased sense of security afforded by a paved shoulder to a motorist who feels secure enough to drive close to the edge of the travel lane and to occasionally ride on the shoulder area. Except for the Williston study of edge striping in Connecticut (28), most of the shoulder delineation studies have been conducted in the western portion of the country (29, 30, 31, 32, 33). Findings have indicated that less shoulder encroachment was observed when the shoulder was differentiated from the travel lane by contrast in surface appearance, texture, or slope.

Shoulder delineation has been accomplished in many different ways for various shoulder materials and lane materials. (A few of the methods covered in this section were used in connection with delineation studies, but whether they were implemented in later projects is not known.)

Methods When Travel Lane and Shoulder Are of PCC

1. Provide a color difference between travel lane and shoulder (23, 34). A bituminous overlay for the shoulder area also provides effective visual delineation.
2. Paint a 10 to 15-cm (4 to 6-in) continuous stripe on the edge of the pavement either alone or in combination with corrugations, or paint stripes on the corrugated area (35).
3. Use raised markers (a problem in snow-removal areas).
4. Use corrugations.
5. Use burlap drags, shallow corrugations, metal lath impressions, raised ceramic squares, red precast concrete, or ceramic tile jiggle bars, all of which have been tried or used in Texas (36, 37).

Methods When Travel Lane and Shoulder Are of Bituminous Surface

1. Use pavement edge stripes as required for Interstate projects.
2. Use different-colored cover aggregates (usually lighter colored) on the shoulder area. Experiences with this method have not been encouraging; contrast fades with time when cover aggregates are sloughed off or compacted into the bituminous layer.

Methods When Travel Lane and Shoulder are of Different Surfaces

1. Take advantage of built-in delineation when a bituminous shoulder adjoins a PCC pavement. Iowa deepens the contrast by spraying liquid asphalt on the aggregate cover. Chip seals are sometimes used to further increase demarcation.
2. Use pavement edge lines.

Other Methods

1. Render shoulder slope uncomfortable for use in traveling but safe for emergency use (38).
2. Paint diagonal stripes on the shoulder area.
3. Use signs that convey the message not to travel on shoulder. There is no general agreement on the usefulness of these signs by themselves, although they may be used to reinforce other methods.
4. Pave only a 0.6 to 1.2-m-wide (2 to 4-ft-wide) strip adjacent to the pavement and leave the rest of the shoulder as 1.8 to 3 m (6 to 10 ft) of stabilized gravel of adequate strength. The strip will take care of the lateral support function and occasional encroachment, and the gravel area will discourage travel. A main objection to this method is the expense of maintaining both a paved and a gravel surface.

Safety

Safety studies found in the literature relating to shoulders are mainly concerned with the effect, if any, of the width of the shoulder, paved or unpaved, on accident frequency. These studies, conducted by Raff (39), Belmont (40, 41), Head and Kaestner (42), Stohner (43), Billion and Stohner (44), Blensly and Head (45), and Brittenham, Glancy, and Karrer (11), covered a variety of possible accident factors such as design features, traffic volumes, types of shoulders, widths, cross sections, alignment, and bridge approach widths. The findings obtained to determine the relationship between accident experience and shoulder characteristics have not been consistent. One of the conclusions brought out by Heimbach and Vick (14) is that the effect of paved shoulders on accident experience and traffic operations can only be correctly determined when all other roadway and traffic characteristics are examined at the same time.

Responses by state highway agencies to queries concerning the safety of paved shoulders showed general agreement where paved shoulders are compared with gravel, turf, earth, or surface-treated shoulders. No numerical data were received except from the Louisiana Department of Highways, which had conducted an informal accident survey and came out with the following accident figures: 0.22, 0.77, and 1.47 accidents/million vehicle-km (0.36, 1.24, and 2.37 accidents/million vehicle-miles) for asphalt, gravel and shell, and grass shoulders respectively. The following general comments were offered by state highway agencies: Vehicles are reluctant to leave the paved surface and park on a grass shoulder; some head-on collisions have been avoided; additional room is available for overly wide loads to maneuver without cutting ruts along the slab edge; drainage carried completely across the top of the roadway to the in slope has lengthened pavement life and has done away with accidents caused by vehicles dropping off onto a soft shoulder; flow of travel is now smoother; traffic does not seem to follow as close to the painted centerline stripe; accident rates have been lowered; vehicular control is superior to that on a stone surface; driver fatigue and necessity for maintenance forces in the roadway area have been reduced; driver fear of steering near the travel lane edge has been eliminated; greater separation of opposing traffic flow is now possible; accident potential of exposed shoulder edges has been reduced.

Maintenance

Paved shoulders are the latest in a series of attempts to build an improved shoulder that would eliminate the maintenance problems existing for previous types of shoulders and provide for future increases in traffic volume and axle load. Thus technology has progressed from earth shoulders, to turf or sod shoulders, to gravel or stone shoulders, to surface-treated or bituminous sealed shoulders, and finally to bituminous or PCC paved shoulders. With the high degree of maintenance required for unpaved shoulders, it is not surprising that highway engineers would look to shoulder paving for relief. The fact is, however, that, although paved shoulders have eliminated soft shoulders, blading, reshaping, and replacement of shoulder materials, a new set of operational problems and maintenance problems have moved in, namely, settlement, heaving, cracking, and separation at the longitudinal joint.

From the maintenance point of view, two types of paved shoulders are performing well enough to justify their construction. These are the PCC shoulder adjacent to PCC pavement and the bituminous paved shoulder adjoining flexible pavement or built integrally with it. Included in the second are the "beefed-up" and full-depth asphalt shoulders.

Maintenance requirements on the bituminous shoulders previously mentioned are usually the same as those required for the main-line pavement so that both get the same amount of maintenance, which in some states is scheduled every 5 years.

PCC shoulders are practically maintenance-free. Full-width paving, characterized by the absence of longitudinal joints between the main-line pavement and the shoulder area, reduces the type of maintenance equipment needed and lessens the number of operations required (46). Full-width and full-depth construction is strongly recommended where future shifts of centerline may occur or additional lanes may be constructed. The need for shoulder removal and construction is eliminated at a critical time adjacent to intense traffic.

Problems Generated by Shoulder Paving

Longitudinal joint problems are encountered in bituminous shoulder adjoining PCC pavements. Separation of the shoulder from the pavement at the joint seems typical and is accompanied by vertical displacement, longitudinal cracks about 0.6 m (2 ft) from the pavement edge, and random cracks in the 0.6-m-wide (2-ft-wide) area. Michigan and Minnesota are experiencing these problems. The separation at the joint is followed by entry of water into the base and subgrade, loss of supporting power, deterioration of shoulder surfacing, settlement of the shoulder structure, and development of ridges and bumps. When these problems exist, shoulder paving can hardly be viewed as a maintenance advantage. New York and Minnesota have been investigating the causes of shoulder settlement and cracking (47), and an intensive study of pavement-shoulder joint design under the National Cooperative Highway Research Program is being conducted (49).

Slope erosion is a minor problem occurring on the area where the shoulder meets the in slope. It is due to the increased runoff from both pavement and paved shoulder. If the sod is not maintained in that area, that portion is eroded away after a few heavy downpours. To minimize this problem, Iowa includes a rock fillet at the shoulder edge. Virginia solves this problem by placing a bituminous curb in a protected position under the guardrail to carry the surface water to a paved down drain. Illinois employs a drain of coarse aggregate similar to Iowa's rock fillet.

Vegetation growth is not a serious problem, although it is a chronic nuisance. It is more of a problem in the southern states where longer growing seasons prevail. Some states in the north and south have more problems than others because of the persistence of tougher types of weeds indigenous to their areas. Salt grass is a problem in the more arid parts of Nebraska. Success with this problem has been reported for many combinations of herbicides and modes of application.

Shoulder Upgrading

Because of the increased acceptance of paved shoulders, attention is being directed to the remaining thousands of kilometers of substandard shoulders, gravel, and seeded earth adjoining bituminous and PCC pavements. In the interest of safety, some states, such as New Hampshire, New York, and Michigan, have been upgrading shoulders on a statewide scale. Michigan has just started a program that will stabilize 686 km (426 miles) of substandard shoulders in the primary and secondary systems by using 77 to 136-kg (170 to 300-lb) bituminous mat. Most of the shoulders will be 0.9 m (3 ft) wide. About 97 km (60 miles) will be 2.4 m (8 ft) wide to accommodate bicycle traffic.

SUMMARY

Most states have well-defined policies concerning shoulder paving or have their policies embodied in their design standards and criteria. In general, paved shoulders are justified by

1. Smoother traffic operations. Effective width of the traveled pavement is increased. Uniform traffic speed is obtained. Highway capacity is maintained or increased.
2. Safer traffic operations. Space is provided for emergency maneuvers, vehicle check or repairs, and rest and breaks in long-distance driving. Driver tension is eased by a sense of openness, and driver fear of rolling off the pavement edge is eliminated, thus providing greater separation of opposing traffic flow. Because space is available for routing traffic during maintenance operations, safer working conditions for maintenance forces are possible.
3. Reduced maintenance requirement on shoulder and main-line pavement. Lateral support provided by the shoulder improves the condition and longevity of the main-line pavement. Surface runoff is drained across the shoulder. Continual regrading, reshaping, and replacement of shoulder material are eliminated.

Shoulder design of both bituminous and PCC shoulders is generally an extension or variation of the corresponding bituminous and PCC main-line pavement design, as practiced in the different states with reduced thicknesses for the component courses in the shoulder pavement. Only California and Iowa have criteria for shoulder structural strength. Judgment and past experience with similar types of shoulders enter heavily into shoulder design practices. Geometrics are all guided by AASHTO policy.

Field performance of well-designed paved shoulders has been demonstrated to be generally better than that of unpaved shoulders. Although there have not been enough recorded data to substantiate claims that a highway with paved shoulders is safer than one with unpaved shoulders, the elements that differentiate the paved from the unpaved can be identified as contributing to greater highway safety. Separation of the bituminous shoulder from the PCC main-line pavement at the longitudinal joint and the attendant shoulder cracking and distress still represent the most troublesome aspect of shoulder paving at the present time.

RECOMMENDED RESEARCH

Both the literature and current practices on paved shoulders have shown the need for study and investigation to arrive at

1. A more or less uniform set of loading criteria for different types of paved shoulders.
2. Comprehensive methods of maintenance accounting that will yield data for a complete maintenance history for a given section with a given type of shoulder.
3. A method of evaluating paved shoulder performance to include in either a pavement feedback system or a shoulder feedback system.
4. An evaluation of effects of various types of paved shoulders on the performance of main-line pavement types.
5. Determining the cause of the separation of bituminous shoulders from PCC main-line pavements.
6. Establishing the relation of paved shoulder to accidents.

CONCLUSION

Highway engineers have recognized the advantages of the paved shoulder, and motorists have responded favorably to it. Some states have already embarked on statewide programs of rehabilitating the shoulders that were built before the benefits of paved shoulders were recognized and accepted. A few states would recommend the paving of shoulders of high-traffic routes and selected locations but doubt that paving is economically feasible for the rest of their state highway networks. Shoulder paving has grown from an art to a technology, but it is still a young technology. There is much to learn and much to do in the years ahead.

ACKNOWLEDGMENT

The information in this paper was compiled by the Michigan Department of State Highways and Transportation in cooperation with the Federal Highway Administration, U.S. Department of Transportation, under contract DOT-FH-11-8194. The work described reflects the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration.

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