NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 63

DESIGN AND USE OF HIGHWAY SHOULDERS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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DESIGN AND USE OF HIGHWAY SHOULDERS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- FACILITIES DESIGN
- PAVEMENT DESIGN AND PERFORMANCE
- OPERATIONS AND TRAFFIC CONTROL
- (HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. AUGUST 1979

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to engineers and others concerned with pavement design or traffic operations and control. Detailed information is presented on highway shoulders including current practice regarding policies and procedures, design, maintenance, and traffic operations.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

The shoulder of a highway might be used as a travel lane for slow-moving vehicles; as a permanent traffic lane; or as a temporary lane during peak traffic periods, maintenance, construction, or emergency operations. It also provides space for emergency stops. These varied uses give rise to questions regarding geometric and structural requirements. This Transportation Research Board report includes a review of shoulder design practices since the mid-1960s. It also analyzes a recent survey of state policies and procedures and design, maintenance, and traffic operation practices concerning shoulders.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

DESIGN AND USE OF HIGHWAY SHOULDERS

SUMMARY

Shoulders are an important element of a highway system. Well-designed and maintained shoulders are essential for safe traffic operations and serve as lateral structural support for the traveled way. Shoulders provide space for emergency stops, recovery space for errant vehicles, clearance to signs and guardrails, space for maintenance operations, and other advantages.

Shoulder design practices have been surveyed and studied at various times in the past 10 years. Those surveys and studies have pointed to similar problems among the states, particularly the joint between a concrete pavement and a bituminous shoulder. Paved shoulders, bituminous and concrete, often have been suggested as a means of reducing or eliminating shoulder problems. Studies on the safety aspects of shoulders have found lower accident rates with wider shoulders and paved shoulders.

As a first step in preparing this synthesis, a questionnaire was sent to the states in 1977. Forty-three states responded. The questionnaire was divided into sections on policy and procedures, design, and operations.

In the area of policy and procedures, the predominant criterion used by the states to select the shoulder type, thickness, width, and slope is the combination of highway classification and traffic volume. Most of the states depend on the cross slope of the shoulders for surface drainage, but a significant number of states use some form of dikes, catch basins, or gutters. For subsurface drainage, the predominant policy is to use underdrains or a free-draining base. Shoulder condition is evaluated in nearly all states through visual inspections, usually by a member of the maintenance team.

In the design area, most states use the same width and slope of shoulders adjacent to both rigid and flexible pavements. On freeways, nearly 80 percent of the states use a 10-ft (3-m) width for the outside shoulder. More than 40 percent of the states use a 4-ft (1.2-m) width for the median shoulder; the other states use a median shoulder of 3 to 10 ft (0.9 to 3.0 m) depending upon traffic volume and number of lanes. The shoulder slope is usually the same for both the outside and median shoulders. The predominant slope is 4 percent or ½ in. per foot.

Most of the states pave the shoulders on the Interstate and major highways, but on local roads the shoulder material is often some form of aggregate, earth, or sod. Forty percent of the states specifically stated that they have no effective method to properly maintain the joint between a bituminous shoulder and a concrete lane, and several of the many that use a joint sealer or filler were not sure that the method was really effective.

In the area of operations, only five states permit regular use of shoulders for slow-moving vehicles, although 10 states permit such use under certain conditions. All states use a 4-in. (100-mm) white reflectorized edge stripe to delineate the out-

side shoulder and a yellow edge stripe to delineate the median shoulder. However, a number of states supplement the edge stripe with contrasting color, texture, or rumble strips on the shoulder. Edge stripes are usually placed on the travel lane at or near the shoulder, although some states place them on the paved shoulder.

Shoulder maintenance is not performed on a regular schedule in most states; even in those states that have a schedule, it frequently applies only to unpaved shoulders. Little data were received on maintenance costs. Only 10 states provided some limited data, and these were quite variable. Estimates of annual shoulder maintenance costs ranged from $38 to $335 per mile ($24 to $208/km) depending on shoulder material and highway classification.

Some of the recommendations of this snythesis include research into the safety effects of shoulders, particularly with respect to the types in use; evaluation of the effects of shoulder types on pavement performance; a study of maintenance costs of various types and designs of shoulders; and more definitive construction costs to enable better selection of shoulder types for given conditions.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

INTRODUCTION

As defined by AASHTO, a highway shoulder is the "portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles for emergency use, and for lateral support of base and surface courses" (*1*). This definition is now almost universally used by all concerned with highway design, construction, maintenance, and operations. AASHTO also defines the characteristics of shoulders as follows:

> The term "shoulder" is variously used with a modifying adjective to describe certain functional or physical characteristics. . . . (1) The "graded" width of shoulder is that measured from the edge of through traffic lane to the intersection of the shoulder slope and the side slope planes. (2) The "surfaced" width of shoulder is that part outside the edge of through traffic lane that is constructed to provide a better all-weather load support than that afforded by the native soils. . . . (3) The "usable" width of shoulder is the actual width that can be used when a driver makes an emergency or parking stop (*2*).

Shoulders are necessary on rural highways with any appreciable volume of traffic (*2*). In urban areas, shoulders are essential freeway elements and are desirable on arterial streets (*3*). Shoulders provide space for emergency stops, recovery space for an errant vehicle or for accident avoidance, lateral clearance to signs and guardrails, improved sight distance in cuts, structural support for the pavement, space for maintenance operations, and other advantages.

Despite shoulders' significance, highway officials realize that the ideal shoulder does not always exist in the real world. Thus the purpose of this synthesis is to determine current practices and evaluate current views with respect to (a) the uses of highway shoulders and the conditions under which they prevail; (b) what their geometric and structural requirements are; (c) what delineation treatment is used for each; and (d) which geometric and structural practices result in the greatest investment efficiency.

As a first step, in early 1977 a questionnaire was sent to all the states. The questionnaire (Appendix A) consisted of a series of items divided into three main areas of concern: policy and procedures, design (geometric and structural), and operations (traffic and maintenance). Replies were received from 43 states.

A review of the literature, both published and unpublished, revealed that shoulders have been of concern to highway officials from the very beginning of highway design, construction, and particularly maintenance. During the late thirties and early forties, such organizations as the American Association of State Highway Officials (AASHO) [now the American Association of State Highway and Transportation Officials (AASHTO)], the Bureau of Public Roads [now the Federal Highway Administration (FHWA)], and the Highway Research Board (HRB) [now the Transportation Research Board (TRB)] organized committees to study and evaluate the various problems associated with highway shoulders.

Problems with shoulders on two-lane rural highways have occurred because over the years travel lanes have increased in width from 9 to 12 ft (2.7 to 3.7 m) on a fixed roadbed width. Although originally an 8-ft (2.4-m) shoulder was provided, the shoulder width was sacrificed to provide improved travel lanes within the existing right of way. Many miles of these two-lane roads had unstabilized shoulders, and operational problems occurred because of the frequent drop-off at the pavement edge. Maintenance of the shoulders, even though desired by the states, suffered considerably because of the ever-present lack of funds.

With the advent of the Interstate highway system, much more attention has been given to the geometric and structural design of freeway facilities. Shoulder standards for new construction of such facilities were upgraded. However, where older roadways were incorporated as part of the Interstate, the shoulders remained much as they were originally built, and problems developed because of their inadequate width, structural strength, drainage, and pavement support.

What then are the desirable criteria for the geometric design and operation of highway shoulders? In 1972, Loutzenheiser (*4*) answered that question with four categories (which basically are those given in the AASHTO Policy on Geometric Design): (a) features, (b) functions, (c) geometric details, and (d) delineation and contrast.

The desirable *features* of a shoulder along a high-type facility, as described by Loutzenheiser, included clear delineation between travel lanes and the shoulder; adequate cross-slope for good drainage; enough width for emergency use, to control drainage, and for guardrail installation; flush and level at the through lane edge; inherent structural stability; a pavement-shoulder interface (joint) design that remains sealed; efficient and economical maintenance requirements; and low total construction and maintenance cost.

The *functions* of shoulders are largely evident in the preceding list. The main ones are: delineation, drainage, structural support, and emergency and safety uses.

The *geometric details* consist of three main elements: width, cross-slope, and continuity. Shoulder width is a very important element. For safety, a shoulder should be of sufficient width so that a stopped vehicle clears the traffic lane by 1 or 2 ft (0.3 or 0.6 m). Hence, a desirable shoulder is 10 ft (3 m) for passenger cars and 12 ft (3.7 m) for commercial vehicles. Shoulder cross-slope should be steeper than that of the traffic lane to drain the surface water rapidly but not so steep that it may be hazardous in use. Highway shoulders should be continuous to promote safety.

For proper *delineation*, the shoulder should contrast with the traffic lane day and night, and in good weather or bad, yet still have reasonable construction and maintenance costs.

These, then, are the desirable criteria for highway shoulders. But do the existing shoulders on the various highway systems meet these criteria? This synthesis is an attempt to answer that question.

1967 HRB SURVEY

A comprehensive survey of shoulder design, construction, and maintenance was conducted during 1967 by HRB Committee D-A6, Shoulder Design, in cooperation with the Bureau of Public Roads. Responses from the states were tabulated but were not published. Some states gave more than one response to each question, so totals are not possible. Much of the information obtained then is still applicable. A brief summary of the results follows.

In the 1967 survey, replies to the question of what criteria are applied in selecting a standard shoulder design for a given highway classification indicated that 20 states used traffic, 18 used standard drawings and designs, 14 used the type of facility, 8 used AASHO policy, 6 used construction and maintenance costs, and 20 listed a total of 10 other criteria.

Responses to the question of what criteria are used for determining when and how wide to pave shoulders indicated that 9 states used AASHO policy, 10 used standard drawings and designs, 9 used traffic, 20 paved all shoulders, 5 used type of facility, and 8 listed 4 other criteria.

The surface, base, subbase, and drainage data were not easily obtained from the replies, and no summary totals were attempted. The reported construction and maintenance costs varied widely and reflected a range of data from quite detailed to a quick guess.

One question related to the development of a system for rating the relative performance of alternate shoulder designs. Only one state, Florida, had such a rating system in 1967.

The states were asked if they had any special safety features in connection with the design and construction of shoulders. Twelve states considered delineation by contrasting surface texture, color, or edge stripe a safety feature, 9 states reported 6 other features, and 31 states replied they had no special safety features.

As for the problems encountered in shoulder serviceability and maintenance, 23 states listed joint failure at pavement edge, 12 listed a problem in adequately maintaining unpaved shoulders, 28 listed 13 other problems, and 11 stated they had no problems.

Research activity prior to 1967 was very limited and fragmentary. Twenty-eight states indicated no research activity, and of the 20 states listing some activity, 13 were informal studies with no reports or publications.

1972 CONFERENCE SESSION ON SHOULDER PRACTICES

During the 1972 Annual Meeting of the Highway Research Board, a conference session was held on "Current Practices in Shoulder Design, Construction, Maintenance, and Operations" (*5*). Rowan, reporting on a survey of shoulder design and operations practices, stated that "results indicated general agreement on the basic need for good shoulders. In addition, a majority of respondents expressed agreement regarding shoulder criteria for the Interstate Highway System" (*6*). However, in other areas of design criteria, dissenting opinions appeared. Although all respondents endorsed the use of edgelines, there was little consistency in their lateral placement. The survey also showed no general agreement on the most desirable width of shoulders.

McKenzie (*7*) stated that, in Illinois, the search for inexpensive paving materials for heavy-duty shoulders led to four experimental studies using stabilizing binders to accompany the granular material. The studies included bituminous-aggregate mixtures, cement-aggregate mixtures, pozzolan-aggregate mixtures, and plain portland cement concrete. McKenzie concluded that well-documented construction costs, as well as shoulder maintenance costs, are badly needed to evaluate costs and benefits assignable to paved shoulder.

Murray (*8*) discussed shoulder maintenance considerations in Missouri. A variety of shoulder designs were constructed in the late 1950s to study their relative performance. Some of the findings after eight years of observation are given in Table 1.

Hutchinson summarized the 1972 conference session as showing a need for "1) construction of full depth monolithic pavements throughout the entire width of the shoulder area so as to avoid the costly problem of maintaining a longitudinal joint just outside the right-hand edge line, 2) eliminating the 'drop-off' or 'raised shoulder' at the right-

TABLE 1

SHOULDER STUDY FINDINGS (MISSOURI, 1970) (*5*)

Average Daily Traffic	Shoulder Type Justifiable	Cost per Mile	
		Initial	Annual Maintenance
Less than 750	Sod	$750	Mowing & blading
750 to 1,700	3" compacted granular	$6,000	$50
1,700 to 3,500	6" granular seal coat	$16,000	$220
3,500 to 20,000	Full-depth, sealed, dense graded granular	$25,000	$125
Over 20,000	2" AC surface course on 5" bit. stab. base on full-depth aggr. base	$37,000	Little

TABLE 2

ASPHALT CONCRETE SHOULDER SECTIONS, 1974 (*11*)

STATE	SURFACE COURSE		BASE COURSE		SUBBASE	
	MATERIAL TYPE	THICKNESS	MATERIAL TYPE	THICKNESS	MATERIAL TYPE	THICKNESS
ALABAMA	AC	approx 1"	AC	approx 3"	Select soil	4½"
ARIZONA	AC	4"	AB	4 - 5"	ASB	4 - 6"
CALIFORNIA	AC	3" to 5½"	AB	6"	ASB	variable
CONNECTICUT	AC	3"	SSB	6"	Material not specified	6" to 18"
GEORGIA	AC	1½"	CTB	6"	Select borrow	
FLORIDA	AC	1 "	SA	5 "	Sand-Clay	6"
IDAHO	AC	3.6"	AB	8.4"	ASB	2.4"
ILLINOIS	AC	1½"	CTB LTB ATB	6½" 6½" 6½"	ASB	4"
INDIANA	ST	-	ATB	6"	ATSB	4"
KENTUCKY	AC	2"	AB	variable		
KANSAS	-	9" tapered	AB	4"	LTS	6"
LOUISIANA	AC	8" to 10"	AC	3½"	LTS	
MAINE	AC	3"	AB	9"	ASB	9"
MICHIGAN	AC	1½"	ATB	6½" to 7½"	ASB	14"
MISSOURI	AC	2"	ATB CTB	5" 5"	ASB	5" to 7"
MINNESOTA	AC	1½" to 2"	AB	3"	ASB	9" to 11"
NEW YORK	AC or ST	approx 1"	Emulsion stab. gravel	3"	ASB	17"
NORTH CAROLINA	ST or AC	1"	AB	8"	ASB	4"
NORTH DAKOTA	AC	4"	ATB	4"	LTS	
	AC	2"	Emulsion or cutback treated	6"		
OHIO	AC	3"	ATB	5" to 6"	ASB	6"
OREGON	AC	Full pavt depth	CTB	4" to 6"	LTS CTS	6"
PENNSYLVANIA	AC or ST	4"	AB	6"	ASB	12"
SOUTH CAROLINA	AC	-	ATB	-	-	-
SOUTH DAKOTA	AC	2"	ATB LTB	6" 6"	AC	2"
TEXAS	AC	8"	ATB	4"	LTS	-
UTAH	AC	3"	AB	6"	ASB	8"
WASHINGTON	AC	2"	AB	3"	ASB	7"
WEST VIRGINIA	PM	3"	AB	6"	ASB	6"
WISCONSIN	AC	3"	AB	6"	ASB	15"

AB	Aggregate base	LTB	Lime-treated base
AC	Asphalt concrete	LTS	Lime-treated subgrade
ASB	Aggregate subbase	PM	Penetration macadam
ATB	Asphalt-treated base	SA	Sand asphalt
ATSB	Asphalt-treated subbase	SSB	Salt-stabilized base
CTB	Cement-treated base	ST	Surface treatment

1" = 25.4 mm

hand pavement edge and 3) eliminating shoulder structural distress due to traffic loadings" (*9*).

1975 SHOULDER STUDY—NCHRP PROJECT 14-3

A survey of shoulder practices was conducted as a part of NCHRP Project 14-3 (*10, 11*). Paved bituminous shoulder sections adjacent to PCC main-line pavement were quite varied, as evidenced by the data given in Table 2. The study found that trucks encroaching on the shoulder (2.4 percent of the mainline truck traffic in rural areas), water entering the longitudinal joint, and severe climatic conditions are the most important causes of shoulder deterioration. The study concluded that the shoulder within 2 ft (0.6 m) of the longitudinal joint should be structurally designed to withstand the wheel loadings from encroaching truck traffic.

1975 REVIEW OF PAVED SHOULDERS

Portigo summarized paved-shoulder information received as a result of a questionnaire sent to all the states in 1975 (*12*). As in earlier surveys, the report concluded that highway engineers recognize the advantages of paved shoulders and motorists show favorable response to them. The survey showed that 15 states had documented policies on when to use paved shoulders, 28 states had no separate policies but had shoulder paving standards, and 5 states paved shoulders integrally with the main-line pavement. Where paved shoulders were used, they were justified by (a) smoother traffic operations, (b) safer traffic operations, and (c) reduced maintenance requirements on shoulder and mainline pavements.

In many states, Portigo found, the decision to pave the shoulder was made on a project-by-project basis. Such decisions were usually dependent upon engineering judgment, past experience, and availability of funds. Nearly all the earlier surveys found the latter statement to be basically true.

CONCRETE SHOULDER STUDIES

The Portland Cement Association (PCA) reported that 30 states had installed nearly 17,000,000 sq yds (14 000 000 m²) of concrete shoulders in the period 1970-1978. Several states have built or awarded contracts for more than 1 million sq yds (840 000 m²) (*13*).

A computer analysis of continuously reinforced concrete pavements with and without concrete shoulders was performed by the Center for Highway Research at the University of Texas (*14*). The analysis showed that the concrete shoulder has a significant effect on the maximum deflections at the edge of a slab due to typical axle loadings of 18,000 lb (80 kN). Using a fatigue relationship, it was found that, for the values used, an 8-in. (200-mm) pavement with a concrete shoulder would have approximately 2½ times as long a service life as a conventional pavement without a shoulder or with an asphalt concrete shoulder (*14*).

The results of experimental concrete shoulder projects were presented by Lokken of PCA (*15*). Lokken's paper summarizes performance data, examines design details developed from the experimental projects, and makes recommendations for design and maximum safety and economy. Some conclusions regarding minimum design requirements for concrete shoulders, developed primarily from the experimental projects in Illinois from 1965 to 1972, include: (a) a 6-in. (150-mm) thickness is adequate; (b) tie bars should be placed between mainline and shoulder concrete; (c) use of a longitudinal joint key is recommended; and (d) corrugated rumble strips should be impressed into the surface of the plastic concrete.

Based on the summary prepared by Lokken (*15*) and on other research results, the PCA issued a bulletin that provides information on design and construction of concrete shoulders for major highways and expressways (*16*). It describes jointing designs and methods for distinguishing shoulder surface from adjacent roadway pavements. It illustrates innovative shoulder designs in use by state highway departments and the equipment used in their construction.

In 1974, FHWA removed concrete shoulders from experimental status, and in 1975 issued design criteria for use of concrete shoulders on federal-aid projects (*17*).

A structural evaluation of portland cement concrete (PCC) shoulders in Illinois showed that each of the variables (thickness, support, joint spacing, ties, width, etc.) can have a significant effect on PCC shoulder performance (*18*). The study recommended that required thickness be determined from a structural analysis. Tie bars should be used. Width should be at least 3 to 5 ft (0.9 to 1.5 m) to obtain significant structural benefit to both lane and shoulder. A follow-up study contains a structural design procedure for plain, jointed PCC shoulders (19). This study also gives recommendations on the design of the longitudinal joint between PCC shoulder and mainline pavement.

A study of instrumented pavements in Minnesota showed that concrete shoulders were effective in reducing the magnitude of strains and deflections in the pavements (*20*). Lane widening of about 16 in. (400 mm) was equally effective, but the concrete shoulder allowed water to drain further from the pavement.

SAFETY STUDIES

A number of studies on the safety aspects of shoulders were performed in the 1950s and are referred to in the report by Portigo (*12*) and in NCHRP Report 197 (*21*). The latter report found that accident rates were lower with wider shoulders and paved shoulders. A methodology was developed to determine an optimum pavement width, shoulder width, and shoulder type based on a safety-cost effectiveness evaluation (*21*).

A study in California showed that accident rates were reduced when shoulders were widened (*22* and Appendix B). Comparisons were made only on widening projects that were completed on existing alignment. Accident rate reductions were 16 percent for widening to a total width of 28 ft (8.5 m) with annual average daily traffic (AADT) less than 3000, 35 percent for 32 ft (9.8 m) and AADT less than 5000, and 29 percent for 40 ft (12.2 m) with AADT more than 5000. Each total width included a 24-ft

(7.3-m) travel way. Total widths before widening ranged from 18 to 26 ft (5.5 to 7.9 m). Although the study "attributes these accident rate reductions entirely to the shoulder widening, the reductions may in part be due to improved signing, striping, intersection geometrics, some small curve corrections and the new surfacing constructed concurrently with the widening" (*22*).

An analysis by FHWA showed that shoulder widening or improvement had the highest benefit/cost ratio of any safety improvement for which there was adequate data (*23*).

CHAPTER TWO

1977 QUESTIONNAIRE AND REPLIES

As mentioned previously, a questionnaire (Appendix A) regarding policy and procedures, design, and operations was sent to all the states early in 1977. At the same time, the states received a copy of the 1967 questionnaire results for their review and appropriate updating. This was done to determine what changes have occurred during the 10-year period. It is interesting to note that 20 states did not make any changes from their 1967 shoulder design standards.

POLICY AND PROCEDURES

Section A of the 1977 questionnaire requested information on policies and procedures used by the states in selecting a shoulder type, designing the shoulder, providing drainage, evaluating the condition of the shoulder, and upgrading the shoulder for use as a travel lane.

Criteria Used to Select Shoulder Type

The criteria used by the reporting states to select shoulder type are given in Table 3. The predominant criterion is the combination of highway classification and traffic volume. About 40 percent (17 of the 43 reporting) are in this category. Six states (14 percent) use a specified material, such as asphalt or PCC, for all their shoulders. Three states consider economics when determining shoulder type; however, they did not indicate what economic analysis they performed to determine the type of material to be used. Three states use the AASHTO policy in some form, one state bases the shoulder type on the percentage of trucks in the traffic stream, and two states select the shoulder type based on experience or by trial and error. Although these criteria are more detailed, they generally follow the results of the 1967 and 1975 surveys.

TABLE 3
POLICY AND PROCEDURES—CRITERIA USED TO SELECT SHOULDER TYPE

Criterion	States
AASHTO policy	1
AASHTO policy and facility type	2
Type of facility only	3
Highway classification and traffic volume	17
Traffic volume only	2
Truck traffic only	1
Specified material	6
Same as traffic lane	3
Economics (cost to construct and maintain)	3
Climate or availability of material	3
Experience and trial and error	2

Shoulder Design Criteria

The criteria used to determine shoulder thickness, width, and slope are given in Table 4. The predominant criterion for shoulder thickness and width, like shoulder type, is the combination of highway classification and traffic volume. Seventeen of the 43 states use this criterion for thickness. Six states use the same design procedure for shoulder thickness as for the travel lane, another 6 use past experience or trial and error, and 4 use a percentage of the traffic loading in the adjacent travel lane as the design criterion for shoulder thickness.

Width appears to be the most standardized element of shoulder design, as 41 states use either AASHTO policy or highway classification and traffic volume, which is, in effect, the basis for AASHTO policy.

Shoulder slope appears to be the most variable element of design. AASHTO policy is followed by 9 states, 15 states use a standard slope for all highways, and 16 vary the slope depending on highway classification or shoulder surface material.

TABLE 4

POLICY AND PROCEDURE FOR SHOULDER DESIGN

Criterion	States Using Criterion for Thickness	Width	Slope
AASHTO	2	16	9
Highway classification and traffic volume	17	25	11
Same as travel lane	6	-	3
Experience	6	-	-
State standards - specified for all conditions	1	1	15
No established policy	4	-	-
Percent of travel lane traffic	4	-	-
Soil support value	1	-	-
Surface material of shoulder or pavement	2	-	5

Policy for Treatment of Drainage

Surface drainage is accommodated by the cross-slope of the shoulder—most states replying specifically said this, and it was implied in the responses of the others. In addition, several states mentioned use of catch basins or inlets, particularly on curbed sections, and some said they use gutters, dikes, or curbs on fills (see section on curbs and dikes).

For subsurface drainage, the predominant policy is to use some form of underdrains or a free-draining base (Table 5).

Policy for Evaluating Shoulder Condition

Only five states use some kind of objective review or condition survey to evaluate shoulders. Of these five, one state specified the Dynaflect method, whereas the other four states just reported "condition survey" as their method. The predominant method of evaluating shoulder condition was reported as visual inspection, usually by a member of the maintenance crew. Nearly 75 percent of the states (32 of 43) rely on this method. Six states have no policy for evaluating shoulder condition.

TABLE 5

POLICY AND PROCEDURE FOR TREATMENT OF SUBSURFACE DRAINAGE

Criterion	States
Open-graded aggregate or granular base	19
Underdrains	18
Same as travel way	6

Policy for Upgrading the Shoulder to a Travel Lane

The criteria used by the states to upgrade the shoulder to a travel lane are given in Table 6. Fifteen states do not originally construct the shoulder for use as a travel lane; they reconstruct the shoulder when and if needed for use by traffic. Five states design and construct the shoulder to be adequate for a travel lane, but 23 states have no set provision or policy to upgrade the shoulder, even when needed as a travel lane.

TABLE 6

POLICY AND PROCEDURE FOR UPGRADING SHOULDERS TO TRAVEL LANE

Criterion	States
Shoulder constructed same as travel lane	5
Reconstructed as needed	15
No provision or policy	23

DESIGN PRACTICES

Section B of the questionnaire requested specific shoulder geometrics for concrete and bituminous roadway pavements. This information was requested for several classes of highways, ranging from Interstate to local roads. This section also asked several other questions on design and construction of shoulders.

Shoulder Geometrics and Materials

Generally, the states reported that shoulders adjacent to concrete pavements are of the same width and the same slope as those adjacent to bituminous pavements. The shoulder thicknesses are also very similar if not identical for the two types of pavements. Although the shoulder geometrics were requested according to the several types of highways (Interstate, arterials, ramps, etc.), the information received was quite fragmentary and variable, so that summaries could not be made. The most reliable data were for Interstate highways and freeways. Table 7 gives a summary of widths for the outside and median shoulders of these major highways.

The predominant outside shoulder width is 10 ft (3 m), but one state uses 11 ft (3.4 m), three use 12 ft (3.7 m), and four use an outside shoulder width from 10 to 12 ft depending upon the volume of traffic. The median shoulder width varies considerably more than the outside shoulder width. Although 16 of the 39 states reporting this information specify a 4-ft (1.2-m) median shoulder, the median shoulder width in the remaining 23 states varies from 2 to 10 ft (0.6 to 3.0 m), again depending on the traffic volume

TABLE 7

SHOULDER WIDTH ON MULTILANE FREEWAYS

Outside Shoulder Width (ft)	Outside Shoulder States	Median Shoulder Width (ft)	Median Shoulder States
10	31	3	2
11	1	4	16
12	3	6	5
10 to 12* (var.)	4	10	1
		11	1
		2 to 4 (var.)*	1
		3 to 10 "	1
		4 to 5 "	1
		4 to 6 "	1
		4 to 8 "	3
		4 to 10 "	2
		5 to 8 "	1
		5 to 10 "	1
		6 to 8 "	1
		6 to 10 "	1
		8 to 10 "	1.

* Shoulder width depends on traffic volume and/or truck volume, and on the number of traffic lanes for the median shoulder.

1 ft = 0.3048 m

and the number of traffic lanes. The 10-ft median shoulder is used for 4-lane pavements (one direction) and often also for 3-lane pavements.

The shoulder slope was reported to be usually the same for the median shoulder as for the outside shoulder. The basic slope specified by the states, however, varies from 2 percent to 8 percent (¼ in. to 1 in. per ft). The predominant slope reported was 4 percent or ½ in. per foot (Table 8).

Not all the states noted the type of material used as the top or wearing course for shoulders. Only 39 reported this information for Interstate, major highways, and highways other than local roads. The material used is usually the same for all the highways, except in many cases a less expensive material is used for local roads. Table 9 gives the materials used for major highways and for local roads. It should be pointed out that these materials are those used by the states in their *normal* construction and maintenance operations. For example, although the table shows that only 3 states normally use PCC shoulder, 30 states have constructed some concrete shoulder. Although 19 states reported normally using asphalt or bituminous concrete for shoulders, 11 states use variable materials depending upon local conditions, highway type, availability of material, and economics.

Many of the states supplied their standard drawings showing typical sections of the entire roadway including the travel lanes, shoulders, and ditches, but these drawings were so diversified that it was not feasible to categorize them. However, several typical sections are included in this report. Bituminous shoulder designs adjacent to rigid pavements are shown in Figure 1, and concrete shoulders adjacent to rigid pavements are shown in Figure 2. The bituminous shoulders have several layers—usually 2 to 4 in. (50 to 100 mm) of a bituminous wearing course and a base of several inches of crushed stone laid on a select soil—and the total prepared thickness in most cases is more than 12 in. (300 mm). The concrete shoulders have a thickness of 6 to 8 in. (150 to 200 mm) and are usually placed on an aggregate or lime-treated base.

TABLE 8

PREDOMINANT SHOULDER SLOPE

Slope Percent	Slope In./ft	No. of States Using on: Fwys.	Arterials	Local Roads
2.0		6	5	5
3.0 or	3/8	2	1	1
4.0 or	1/2	20	18	9
5.0 or	5/8	4	4	3
	3/4	4	5	3
8.0 or	1	-	-	2

TABLE 9

PREDOMINANT TYPE OF MATERIAL USED ON SHOULDERS

Shoulder Wearing Course	Interstate & Major Hwys	Local Roads
Asphalt or bituminous concrete	19	7
Portland cement concrete	3	-
Bituminous surface treatment	2	1
Aggregate	1	3
Same as travel lane	3	2
Earth or sod	-	5
Variable	11	11

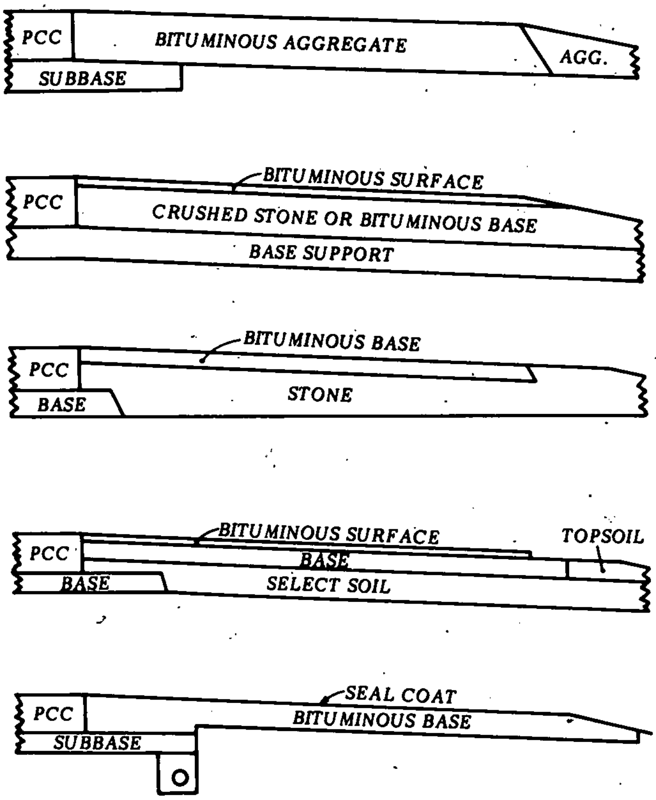


Figure 1. Typical bituminous shoulder designs adjacent to rigid pavements.

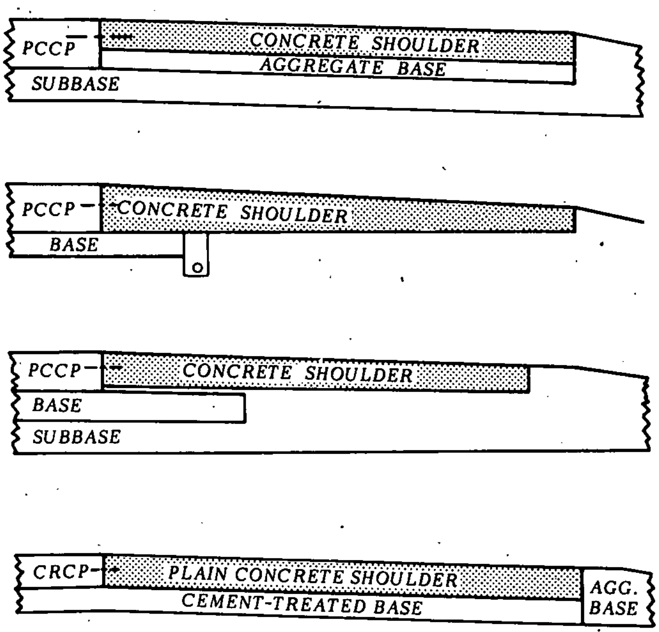


Figure 2. Typical concrete shoulders adjacent to rigid pavements.

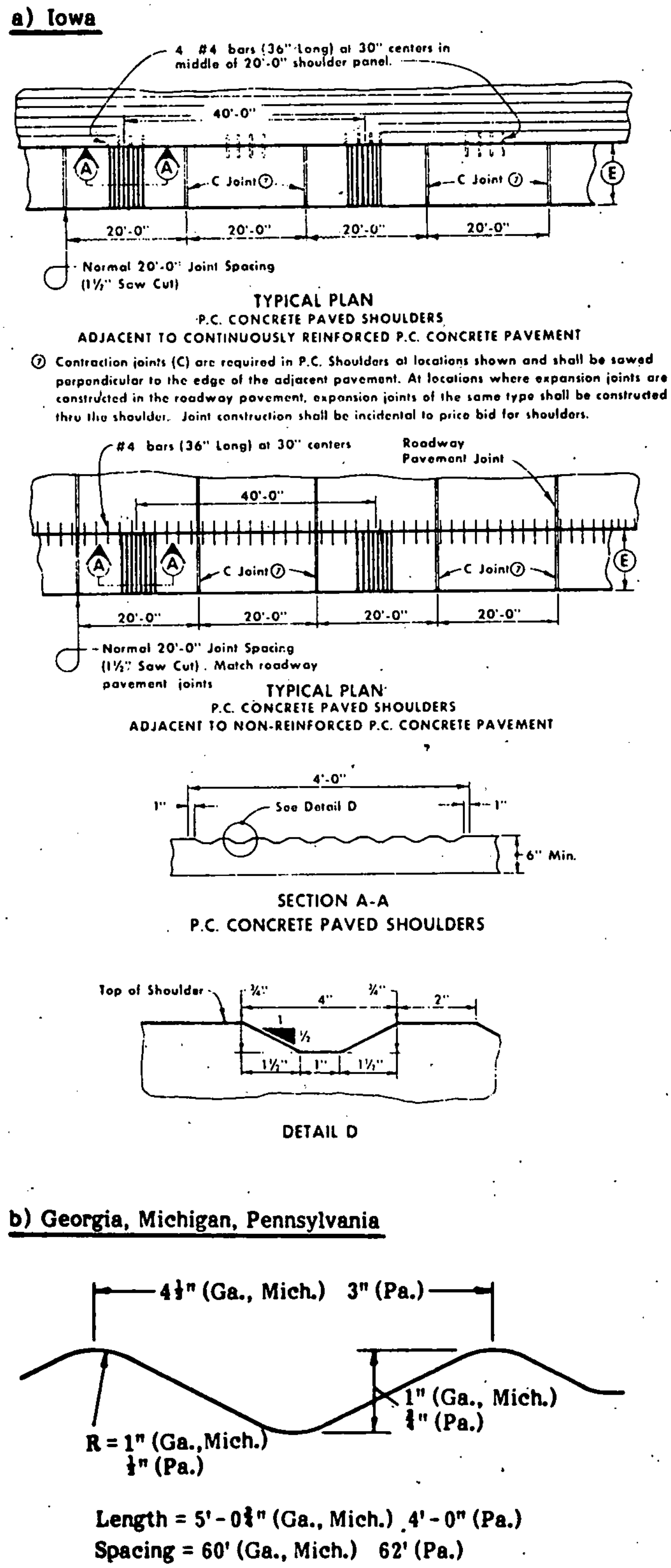


Figure 3. Details of concrete shoulders.

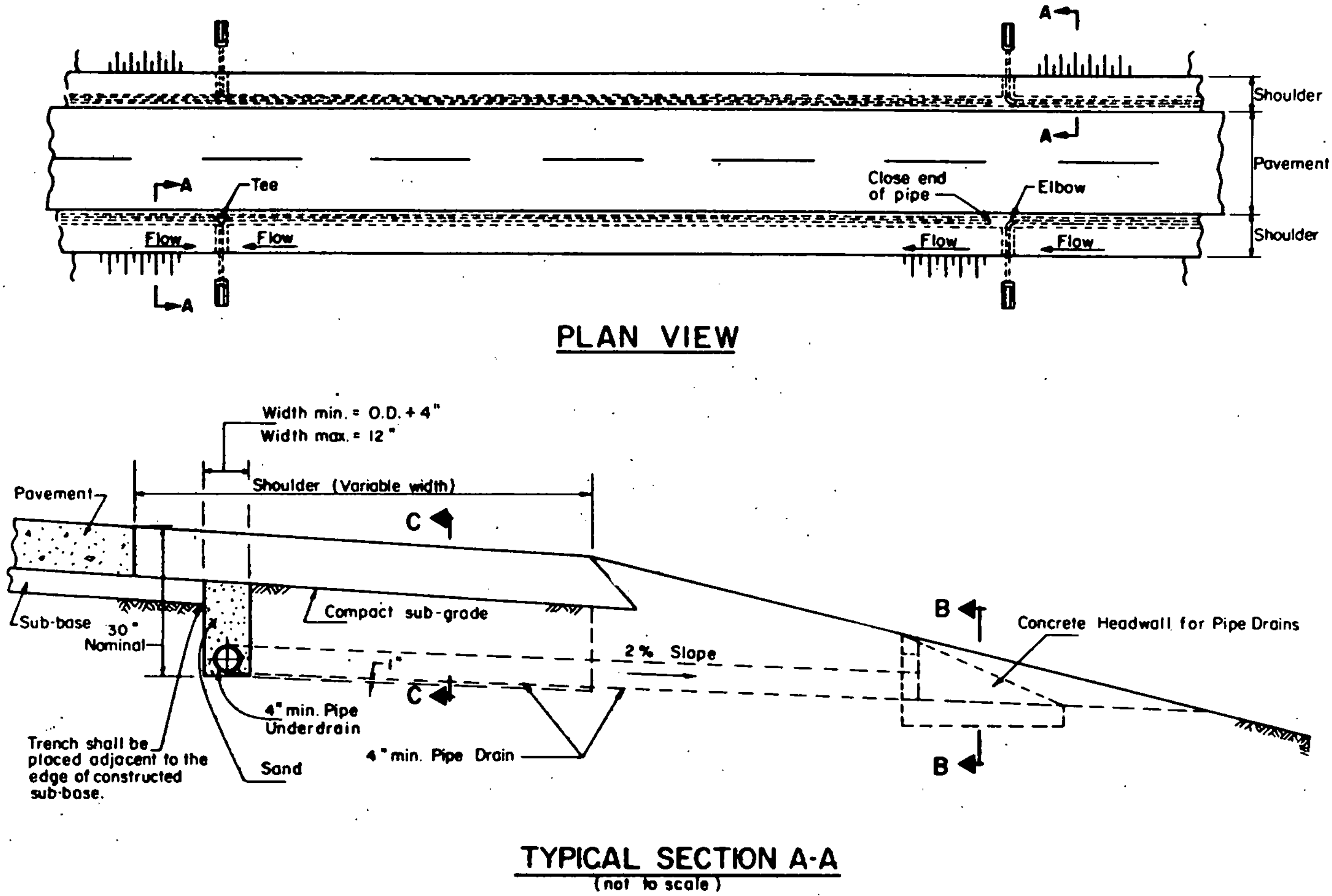


Figure 4. Standard design subsurface drains (Illinois).

Figure 3 shows details of concrete shoulders adjacent to concrete pavement. The "rumble strips" are typical in many states, although details and spacing may be different.

A standard design for subsurface drains is shown in Figure 4. A pipe underdrain having a minimum diameter of 4 in. (100 mm) is placed in a trench of sand on both sides of the pavement at the edge of the subbase. The pipe underdrains are outletted approximately every 500 ft (150 m).

Examples of shoulder treatment and designs in one state are shown in Figures 5 and 6.

Special Designs

Of the seven states that have special shoulder designs, three states are experimenting with special shoulder material and full-depth paved shoulders. Of the other four states, one (Minnesota) specifies "reinforced" shoulders in the vicinity of railroad crossings (Figure 7). The "reinforced" shoulder is designed to be comparable to the mainline pavement so it can carry the trucks or buses that would use the shoulder for stopping. A similar design is also employed where a shoulder is used as a turnout or deceleration lane for right turns at crossroads.

North Carolina now specifies that paved shoulders have a full depth the same as the travel lane; and South Carolina requires aggregate underdrains on some of its secondary roads. Pennsylvania now requires that shoulders on Interstate, major arterial, and collector roads be paved as a part of any reconstruction, rehabilitation, or resurfacing project.

Specifications

With regard to obtaining full specification compaction of shoulder material at the slab edge, 32 of the 43 states replied unequivocally that they do obtain the specified compaction; 8 states were not sure or did not know. One state had a problem, but a change in the specifications corrected it. Two states do not use concrete pavement.

Curbs and Dikes at Shoulder Edge

Although some engineers consider curbs and dikes at the shoulder edge a necessary design feature from the standpoint of drainage, only 6 states reported that they normally use them (Table 10). Twenty states use them under certain circumstances, usually for erosion control on high fills or in urban areas. One of these states reported that the dikes are removed after vegetation has grown on the slopes. The curbs or dikes are usually located under or behind a guardrail, and the states reported no safety problem in this loca-

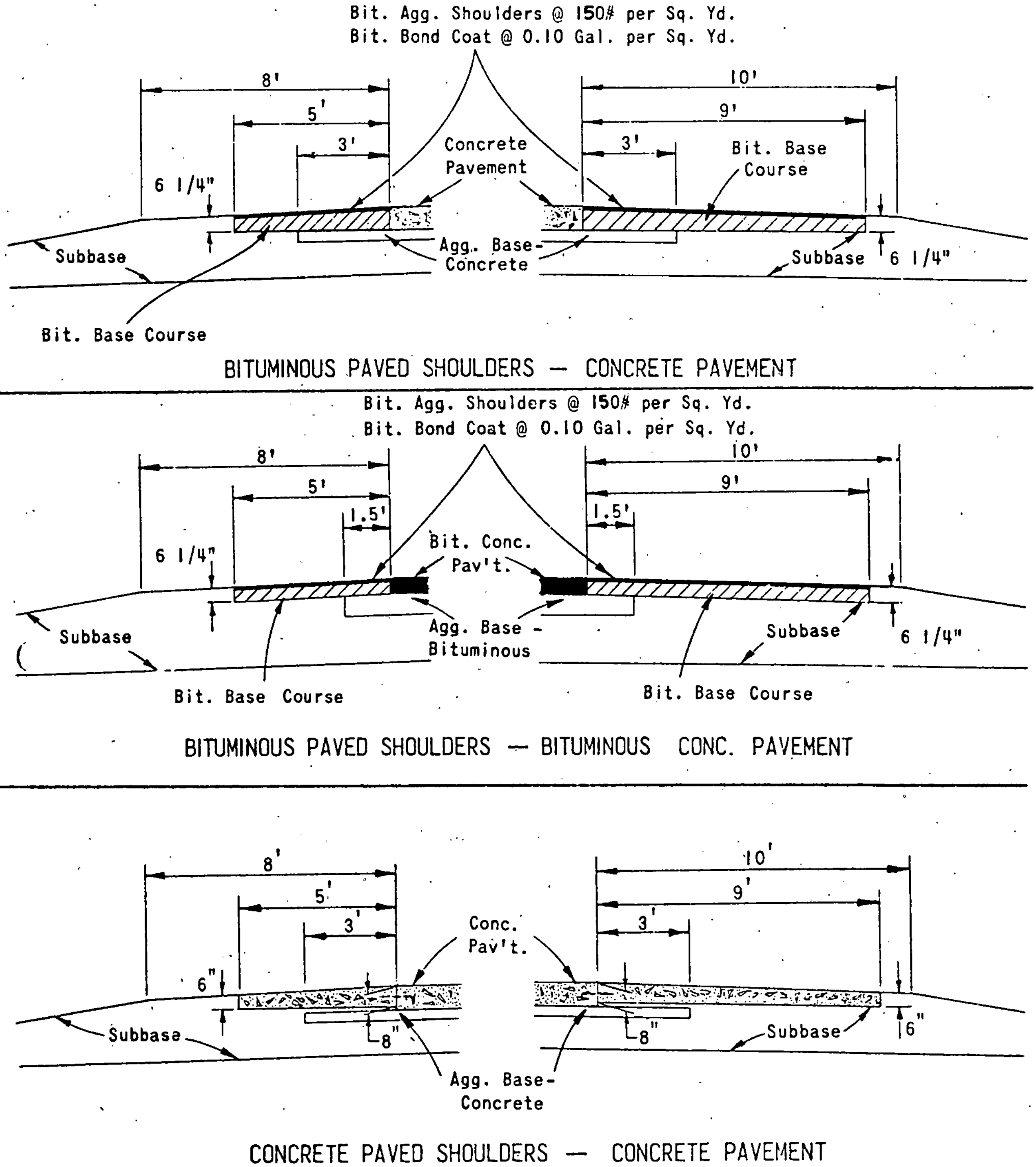
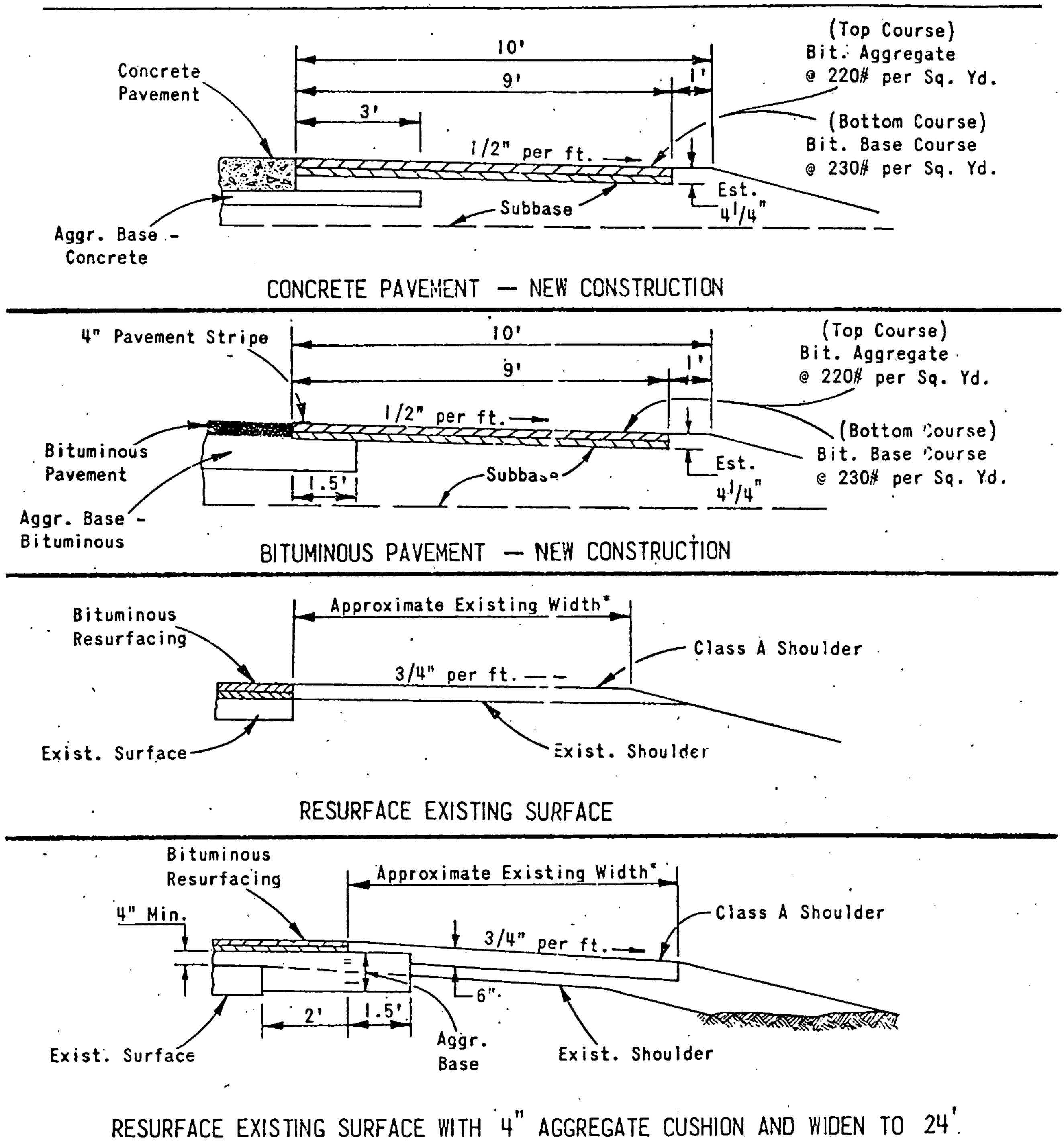


Figure 5. Shoulders for rural dual roadways (Michigan).



*Narrower shoulders may be permitted on widening and/or resurfacing projects that would require major grading and additional R.O.W. to provide the required width shown in table.

Figure 6. Shoulders for rural two-way trunklines (Michigan).

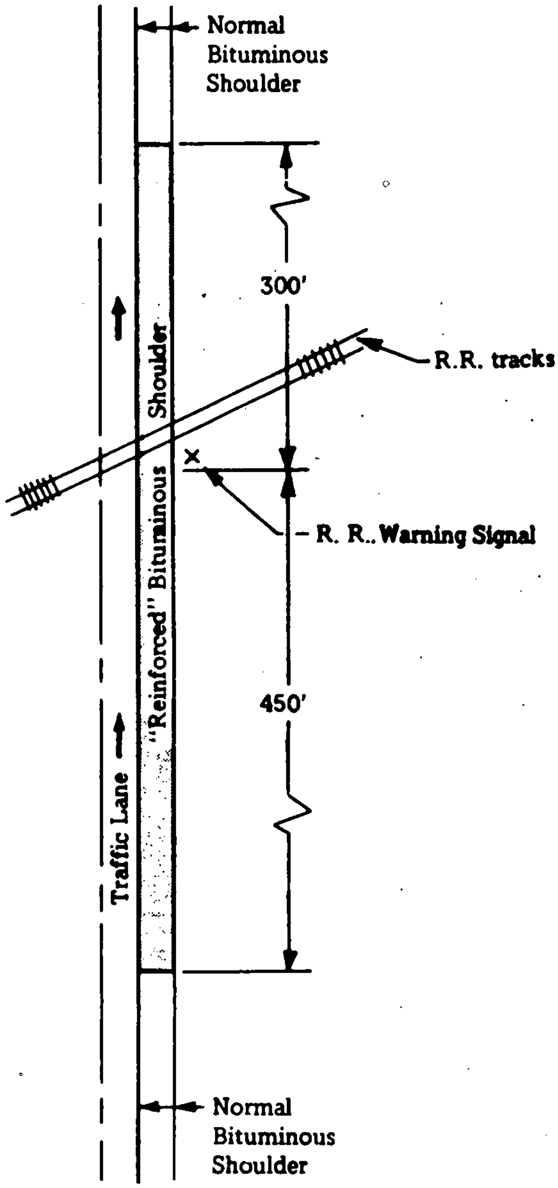


Figure 7. "Reinforced" bituminous shoulder (Minnesota). The "reinforced" shoulder at railroad crossings is designed the same as the traffic lane if the traffic lane is a flexible pavement. For rigid pavements, this shoulder is designed to be comparable to a flexible mainline pavement.

TABLE 10

USE OF CURBS AND DIKES AT EDGE OF SHOULDER

Use	States
Sometimes	20
Used generally	6
When slopes or grade exceed specified value	3
Do not use	14

tion. A vaulting problem was reported in one state where curbs were used without guardrail.

One state that does not use curbs or dikes does use a shallow concrete gutter in front of the guardrail.

Methods of Maintaining the Joint Between Shoulder and Pavement

One of the biggest problems of shoulder maintenance is the joint between the shoulder and the travel lane. Table 11 gives a summary of the states' practices to solve this problem. The questionnaire did not specify pavement or shoulder type; however, most of the answers were directed to the joint between a PCC pavement and a bituminous shoulder. Although only 17 states specifically stated that they have no effective method to maintain the joint, several of those that are using a joint sealer or filler were not sure if their method was really effective.

TABLE 11

METHODS USED TO MAINTAIN JOINT BETWEEN SHOULDER AND PAVEMENT

Method	States*
No effective method	17
Use same material for shoulder as for pavement	8
Joint sealer or filler	19
Slurry seal	1
Edge seal and 2 ft overlay	1
Wedge patch	1
No problem	2

*Some states gave more than one reply.

OPERATIONS (TRAFFIC AND MAINTENANCE)

This portion of the report discusses the operational feature of shoulders, how they perform, to what uses they are subjected, and the maintenance practices reported by the 43 responding states.

How Are Shoulders Used?

This question was divided into several parts in an attempt to more clearly define shoulder use.

Only 5 states permit the use of shoulders for slow-moving vehicles at all times. Ten states permit such use under certain conditions (Table 12).

Thirty-seven states allow temporary use of shoulders by traffic during maintenance, construction, or emergencies (Figure 8), four states use shoulders for this purpose sometimes, and two do not use the shoulder for this purpose.

The use of the shoulder as a temporary lane during peak traffic is generally allowed in 3 states (Figure 9), is some-

TABLE 12

ARE SHOULDERS USED FOR SLOW-MOVING VEHICLES?

Reply	States
Yes	5
No	28
Sometimes	7
For farm vehicles only	2
On climbing lane only	1

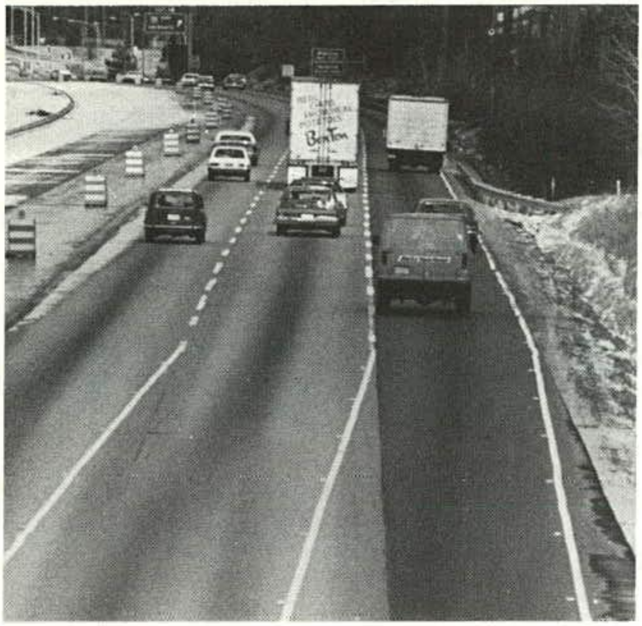


Figure 8. Shoulder used as travel lane during median construction (Maryland).

Figure 9. Signing for peak hour use of shoulder as a travel lane (California).

times allowed in 3 other states, and is prohibited in 36 states. Practically all the states prohibit regular use of the shoulder as a traffic lane. Only one state permits it, although 3 states permit its use in certain areas only, for example, as a turning lane at an intersection. On the other hand, nearly all the states permit the shoulder to be used for disabled vehicles, usually specifying a time limit for the length of such use. However, no signs are posted to indicate to the motorist how long the disabled vehicle can remain on the shoulder.

Nine states permit bicycle use on shoulders, but 22 states prohibit bicycles on shoulders. Four states permit bicycle use on shoulders of local streets only, and 8 states reported such use under certain conditions (Table 13).

The states were asked whether they have uses for shoulders other than those stated above. Only a few states listed other uses. Among them were drainage assistance, safety zones, fire lane, snow storage, and use by pedestrians and farm equipment.

Shoulder Delineation

Although all the states reported using a 4-in. (100-mm) white edgeline at the right pavement edge, a number of states reported using additional methods to better delineate the shoulder. Information on edge striping of the median shoulder on divided highways was not sufficient to permit any meaningful summary. Table 14 summarizes the states' practice of outside shoulder delineation. The predominant delineation is by edgeline only (17 states use this method), although 22 states supplement the edgeline with contrasting color or texture or both. Four states indicated they use rumble strips with concrete shoulders; one also uses diagonal striping on the concrete shoulder.

Delineation at Bridge Approaches

It is generally accepted that approaches to bridges, especially narrow ones, are more hazardous than sections of

TABLE 13

ARE SHOULDERS USED FOR BICYCLES?

Reply	States
Yes	9
No	22
On local streets only	4
Not on freeways	1
If signed only	1
Sometimes	6

TABLE 14

HOW ARE SHOULDERS DELINEATED FROM TRAVEL LANE?

Reply	States
Edgeline only	17
Edgeline plus contrasting color	7
Edgeline plus texture	4
Edgeline plus texture and color	11
Edgeline plus other treatment	4
Edgeline plus rumble strips on PCC	4

highway without bridges. The 1977 survey indicated that most states recognized this hazard by giving additional information to motorists approaching bridges. Of the 42 states reporting, 21 use edge striping plus delineators, hazard markers, transverse striping, wide striping, flared shoulders, rumble strips, or some combination of these (Table 15). In several of these states, the treatment used depends on the width of the bridge. Twenty-six states treat the bridge approaches the same as where there are no bridges, particularly if the shoulder is continuous across the bridge. A few of these reported using a special treatment or combination of treatments on narrow bridges.

The survey did not provide any information for shoulders on bridges. However, a five-year study completed in West Virginia in 1975 was directed toward determining whether providing full-width shoulders across a long-span bridge would improve traffic and safety. The study concluded that 6-ft (1.8-m) outside shoulders on rural freeway bridges would not seriously affect the operational characteristics of vehicles as they crossed the bridge (*24*).

Placement of Edge Stripes

The position of the reflectorized edge stripes used to delineate the shoulder from the traveled way is given in

TABLE 15

HOW ARE SHOULDERS DELINEATED AT BRIDGE APPROACHES?

Reply	States*
Same as travel way	26
Delineators	8
Hazard markers	4
Other special treatment	9

* Some states use more than one method, depending on bridge width.

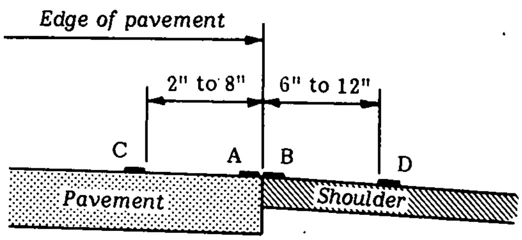
Table 16. Most of the states (28 of 40 responding) paint the stripe on the pavement, either at the edge or 2 to 8 in. (50 to 200 mm) in from the edge. Another four states paint the stripe on the pavement unless there is a paved shoulder.

Shoulder Maintenance Practice and Experience

The question on maintenance practices brought a variety of replies (Table 17). The majority of the states (23) indicated that they had no regular schedule for shoulder maintenance. Of those with a regular schedule, several indicated

TABLE 16

WHERE ARE EDGE STRIPES PLACED?



Stripe Location (see sketch)	States
A	15
B	2
C	13
D	3
A - Unpaved shoulder; B - paved	2
A - Interstate; B - others	1
B - Interstate; A - others	1
C - Interstate; D - others	1
C - Unpaved shoulder; D - paved	2

TABLE 17

SHOULDER MAINTENANCE PRACTICES

Reply	States
Regular maintenance schedule	12
No schedule; maintain as needed	17
Specified operation but no schedule	6
Maintain same as travel way	1
Perform maintenance before edge striping or resurfacing	2
Information not available	5

that the schedule only applied to unpaved shoulders and that paved shoulders were maintained as needed.

It is obvious that too little attention is given by most states to such an important operation as keeping the shoulders in good condition. Most officials recognize this problem, but budgetary limitations put the maintenance department in a very difficult position as to where funds are to be expended.

Shoulder Maintenance Costs

Thus far, very little information has been available on shoulder maintenance costs. The 1977 survey certainly verified this fact. Thirty-three states said cost data were not available. Only 10 states provided some limited cost data, and these were quite variable. For example, the cost of maintaining unpaved shoulders ranged from $38 to $170 per mile of shoulder ($24 to $106/km) per year, whereas bituminous shoulder maintenance costs ranged from $40 to $200 per mile ($25 to $124/km) per year. One state reported that costs vary between $105 and $335 per mile ($65 to $208/km) per year depending on the highway classification; two other states indicated averages for all types of shoulders were $115 and $330 per mile ($71 and $205/km) per year. No state reported maintenance costs of PCC shoulders.

Table 18 gives the shoulder maintenance work performed in 1977 in one urban district of a state department of transportation. Also given are the costs of labor and materials to do the work.

RESEARCH REPORTS

The 1977 questionnaire requested that the states supply research reports, published or unpublished, on any phase of shoulder use. Fifteen reports were received from seven states; a summary of each is presented in Appendix B. This appendix also contains reports from other sources.

COMPARISON OF 1967 AND 1977 RESULTS

A state-by-state comparison of the 1967 and 1977 survey results revealed that more than half of the states (24 of 43) did not indicate any change in their criteria, standard designs, research activities, or safety features relating

TABLE 18

SHOULDER MAINTENANCE COSTS FOR ONE DISTRICT OF A STATE DEPARTMENT OF TRANSPORTATION

Shoulder Type	Inventory Quantity	Work Functions Performed	Accomplished Quantity	Accom % of Inv.	Material Cost	Labor Cost
SURFACED	4,882,120 s.y.	Shoulder Rep. Bit.	6,710 s.y.	.1%	$ 11,400	$ 19,142
	1163 miles	Shoulder Edge Seal	125.5 miles	11%	$ 7,045	$ 28,286
TOTAL					$ 18,445	$ 47,428
AGGREGATE	827 miles	Shoulder Wedging	17 miles	2%	$ 30,675	$ 26,639
		Shoulder Stone M	131 miles	16%	$ 14,520	$ 18,517
		Shoulder Stone H	890 miles	108%	$ 53,400	$103,660
		Shoulder Rehabil M	181 miles	22%	$ 23,415	$ 29,366
		Shoulder Blad Drag	4275 miles	517%	--------	$ 46,178
TOTAL					$122,010	$224,360
TURF	2,344 miles	Shoulder Cutting	50 miles	2%	--------	$ 34,023
TOTAL					--------	$ 34,023
SHOULDER WORK FUNCTION TOTALS:					$140,455	$305,811
DISTRICT TOTALS: ALL FUNCTIONS					$556,930	$4,615,456

COST FIGURES 1977

Asphalt Ave. $15.00/Ton

Stone Ave. $3.00/Ton

PAF-2 Ave. $.63/Gal.

to shoulders. Of the remaining 19 states, there were minor changes in the shoulder design standards of 9 and major changes in 10. The major changes were all in the area of strengthened or improved structural sections.

Construction Costs

Most states reported that construction costs have increased considerably since 1967. However, only 16 states supplied estimated cost data; a comparison of their reported shoulder construction costs for 1967 and for 1977 is given in Table 19. The costs have more than doubled in most states, and in some states they increased four-fold or more. For example, Ohio reported that construction costs in 1967 were less than $2,000 per mile ($1,200/km) for four-lane primary roads whereas in 1977 the reported costs were about $30,000 per mile ($19,000/km). Much of the increased cost is obviously due to inflation, but in some states better accounting methods may have been responsible for more up-to-date data. During the time between the two surveys, the FHWA price index for unit cost of highway construction has doubled: from 100 in 1967 to 202.2 in 1977 (*25*).

Shoulder Problems Identified by the States

The 1967 questionnaire asked what problems had been encountered in the serviceability and maintenance of shoulders. About half of the respondents listed joint failure at the pavement edge. Twelve states indicated that maintenance of unpaved shoulders was a problem. Other problems included surface deterioration, control of plant growth, and maintenance of color contrast. In 1977, most states indicated that the problems were still the same.

Research Suggested by the States to Solve Shoulder Problems

The research suggested by 18 states in 1967 included development of adequate joint seals; development of materials to reduce deterioration, bleeding, and discoloration; study of existing shoulders to solve the problems; development of chemicals to control plant growth; and development of rational design procedures. In 1977, few states indicated any change in their suggested research. One state suggested research to eliminate differential frost action; another state changed its previous reply to development of adequate joint seals.

TABLE 19

SUMMARY OF CONSTRUCTION COSTS PER SHOULDER MILE FOR 1967 AND 1977 (FOR THOSE STATES REPORTING SUCH DATA)

State	Type of hwy*	Construction Cost Per Mile: Shoulder adjacent to rigid 1967	Shoulder adjacent to rigid 1977	Shoulder adjacent to flexible pvt. 1967	Shoulder adjacent to flexible pvt. 1977
Conn.	I	16,000	44,500	17,500	62,000
	4P	15,500	43,500	16,000	50,000
	2P&S			16,000	50,000
Fla.	I	10,000 to 12,000	16,000 to 27,000	10,000 to 11,000	21,000 to 28,000
Ill.	I&4P	25,585	70,700	-	-
	2P	-	56,400	-	-
Ind.	I	24,700	31,000[1]	(Generally same as PCC)	
	4P	23,600	31,000[1]		
	2P		25,000		
Iowa	I	29,186	48,700	(Same as PCC)	
	2P&4P	NA	6,383		
	S	3,700	1,400		
Kansas	all types	7,000	20,000 to 56,000		
Maine	I	-	50,000	27,000	50,000
	4P	-	-	-	50,000
	2P	-	-	-	30,000
	S	-	-	-	15,000
Md.	I	NA	47,000	NA	47,000
Mich.	I-4P	11,500 for all types	34,000	11,500 for all types	28,000
	I urban		33,000		-
	2P&S		19,600		19,000
Neb.	I&4P	15,000	45,000	-	-
N.C.	I,4P,2P	18,500	40,000	18,500	40,000
	S	-	-	7,100	15,000
Ohio	I	1,850	36,600	-	36,600
	4P	1,850	29,300[2]	-	29,300[2]
	2P	1,500[2]	7,200[3]	1,500[2]	7,200[3]
	S	1,500[2]	2,900	1,500[2]	2,900
Oregon	I-4P	29,000	130,000	29,000	130,000
	2P	-	-	24,500[2]	104,000
	S	-	-	13,000[3]	52,000
Pa.	I-4P	17,000	41,000	-	
	2P-S	6,500	23,500	6,500	23,500
Texas	all	10,000	25,000	10,000	25,000
Wisc.	I	12,450 to 16,800	52,000 to 97,000	-	-
	2P,4P,S	6,740	37,000	6,740	37,000

*I = Interstate P = Primary S = Secondary

[1,2,3]: Construction cost for 10' shoulder except [1]=11 ft, [2]=8 ft, and [3]=4 ft.

CHAPTER THREE

CONCLUSIONS AND RECOMMENDATIONS

Shoulders are an important element of a highway system. They provide structural support for the pavement and improve traffic operations. Moreover, the safety benefits usually far exceed the costs of providing shoulders.

Some shoulder problems still remain, particularly on rural two-lane roads that have not been upgraded to present-day standards, but many of the problems have been solved by the use of wider, full-depth paved shoulders and adequate subsurface drainage. However, the joint between a concrete pavement and a bituminous shoulder is still a prevalent problem as noted by the responses to the questionnaire. The use of PCC shoulders is one attempt to solve this problem.

Based on a review of the literature and the several surveys relating to highway shoulders, the following recommendations are offered:

- Consideration should be given to the relative safety effect of various types of shoulders. Many studies have approached the subject but without much success, and usually the researchers have recommended further research.
- It is important to remember that accident research is a difficult and time-consuming effort. Past research has indicated that a number of factors could have been responsible for a particular mishap. The driver, the vehicle, the highway, and the environment are usually all contributing factors. The effect of any one element of the system, such as shoulders, on accident experience can only be correctly evaluated when all other elements of the system are included in the research. Such a research effort requires a comprehensive program involving researchers of many disciplines, a program that should be well-planned, organized, and executed in several parts of the country.
- The joint between the shoulder and travel lane has been a difficult problem to solve. More than half of the states reported having no effective method to overcome this problem. NCHRP Project 14-3 [Report 202 (*10*)] was directed toward finding an improved design for the joint between concrete pavement and a bituminous shoulder. The conclusions contained in NCHRP Report 202 as to design, sealing, sealants, and drainage should be tested in controlled experimental studies as recommended in the report.
- A study and appropriate recommendations should be made regarding shoulder type selection criteria and geometric and structural design criteria to supplement the AASHTO Geometric Design policies. These criteria should lead to economy, safety, and efficiency of operation.
- Subsurface drainage systems are such an important part of shoulder and pavement design that they should be given special emphasis.
- Various types of shoulders should be evaluated for their effects on pavement performance. There is evidence that paved shoulders improve pavement behavior and in the long run may be more economical than unpaved shoulders (*12*). However, nearly half the states do not use paved shoulders as a standard even on high-volume roads, except on Interstate highways.
- It is important that more attention be given to evaluating shoulder condition, as good maintenance will protect not only the initial investment in the shoulders but will provide greater benefits to the travel lane and to the motoring public.
- Little data are available on maintenance costs for various types and designs of shoulders. A study to evaluate maintenance costs and to relate these costs to the effectiveness of various types of shoulders under different traffic conditions is needed.
- Shoulder construction costs need to be more definitive so that administrators will have the necessary tools for selecting the appropriate shoulder type for given conditions.

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APPENDIX A

1977 QUESTIONNAIRE SENT TO STATE HIGHWAY AGENCIES

A. POLICY AND PROCEDURES

1. What criteria are used to select a shoulder type?

2. What shoulder design procedure is used?

    a. For thickness - structural requirement

    b. Width

    c. Slope

3. How is surface and subsurface drainage of the shoulder treated and what criteria is used for such treatment?

4. How is condition of shoulders evaluated?

5. Do you have provisions for upgrading the shoulder when it is determined that the shoulder should be used as a travel lane? If so, please explain.

B. DESIGN (geometric and structural)

1. What are your shoulder section geometrics for concrete and bituminous roadway pavements?

    a. Horizontal dimensions - width and slope with or without guardrails or concrete barrier

    b. Depth (thickness and types of material)

Supply the above information for the following classes of highways:

1) Interstate
2) Expressway
3) Major Arterial
    a) Principal
    b) Intermediate
    c) Noncontinuous
4) Collector Roads
5) Ramps
6) Auxiliary Lanes
7) Local Roads

If design is different for urban and rural classes of roads, or for different traffic volumes, please supply information for each. You may use the sketch on the back or supply copies of standard section.

2. Do you have any special shoulder design not covered above that would be of interest for inclusion in the synthesis? If so, please supply a sketch and relevant design characteristics.

3. Are shoulders constructed as per specifications? If not, please explain.

4. Do you obtain full specification compaction of shoulder material at the slab edge?

5. If eventual use of shoulders as traffic lanes is planned, are standard horizontal and vertical clearances and sight distance provided initially based upon ultimate use of the shoulder as a traffic lane?

6. Are curbs and dikes provided at the edge of shoulders? If so, are safety problems created by vehicles being trapped by the curb or dike?

7. What effective method have you found to maintain joint between shoulder and pavement?

8. If you have any research reports (published or unpublished) for any of the above please supply.

C. OPERATIONS (traffic and maintenance)

1. Are shoulders as presently designed and constructed suitable to traffic operation, for example: width, slope, drainage, maintainability?

2. Aside from emergency stopping, what uses are made of shoulders?

    a. Travel lane for slow moving vehicles?

    b. Temporary use during maintenance, construction, or emergencies?

    c. As a temporary lane during peak traffic periods?

    d. Permanent traffic lane?

    e. Parking of disable vehicles?

    f. Bicycle lanes?

    g. Other uses?

3. How are shoulders delineated from travel lane?

4. How are shoulders delineated at approaches to bridges?

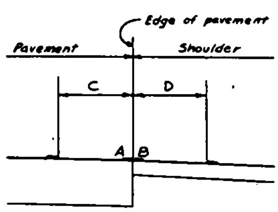
5. Where do you place edge striping to delineate the shoulder (see sketch below)? Is position of stripe determined by state policy or individual guidelines? Please discuss.

6. What are shoulder maintenance practices and experience with regard to schedule of maintenance for different types of shoulders?

7. Do you have any maintenance costs for shoulders classified by type of shoulder, traffic volume, percent of trucks, and/or class of highway?

8. Please supply any reports you may have evaluating first cost versus service costs; accident data; and maintenance cost.

9. Please supply any other research reports on any phase of shoulder use.



Class of Highway	Stripe Width	Location of stripe A	B	C	D

Note: Check A or B if edge stripe is immediately adjacent to pavement edge. If stripe is offset, give distance C or D.

APPENDIX B

SUMMARIES OF RESEARCH REPORTS

"Paved Shoulder Problem--Stevenson Expressway." Research and Development Report No. 19, Illinois Division of Highways (July 1967).

Soon after the fall 1964 opening of the Stevenson Expressway (I-55), an extreme upward displacement was noted in the bituminous paved shoulder adjacent to the portland cement concrete pavement. The vertical displacement was accompanied by some lateral displacement, by longitudinal cracks about one foot from the pavement edge, and by a considerable amount of random cracking. On this 16-1/2 mile section of highway, three kinds of material were used in the shoulder base course: (a) cement-aggregate mixture; (b) pozzolan-aggregate mixture; and (c) bituminous-aggregate mixture. The failures occurred primarily on sections having the cement-aggregate and the pozzolan-aggregate mixtures.

Field and laboratory tests found that several factors, either acting separately or in combination, seemed to have caused the failures. The factors were: (a) an embankment soil especially susceptible to frost expansion when exposed to large quantities of water; (b) a subbase material susceptible to frost expansion when exposed to water; and (c) base material lacking adequate durability when exposed to freeze-thaw cycles in the presence of water or brine.

The research indicated that (a) on new construction of the shoulder base, use should be made of mixtures more resistant to freezing and thawing deterioration in the presence of water and brine than cement-aggregate and pozzolan-aggregate mixtures; (b) structural design should provide more positive sealing against and removal of surface water and brine; and (c) for existing construction, steps should be taken to improve drainage of the subbase and to seal any cracks or joints in the shoulder against the entrance of surface water and brine.

RINDE, E. A., "Accident Rates vs. Shoulder Width." Report No. CA-DOT-TR-3147-1-77-01, California Dept. of Transp. (Sept. 1977) 57 pp.

The California Department of Transportation used a before-and-after technique to evaluate 37 widening projects representing 143 mi (230 km) of improved road. The projects were completed essentially on existing alignment. Accident rates were reduced for each of the three new widths studied: 28 ft (8.5 m), 32 ft (9.8 m), and 40 ft (12.2 m). These represent shoulder widths of 2 ft (0.6 m), 4 ft (1.2 m), and 8 ft (2.4 m), respectively. Previous widths ranged from 20 to 24 ft (6.1 to 7.3 m) for the 28-ft widening, 18 to 24 ft (5.5 to 7.3 m) for the 32-ft, and 20 to 26 ft (6.1 to 7.9 m) for the 40-ft. Accident reductions were 16 percent for the 28-ft widening with less than 3,000 AADT, 35 percent for 32-ft with less than 5,000 AADT, and 29 percent for 40-ft with more than 5,000 AADT. Reductions were statistically significant for the 32- and 40-ft widths.

The study recommended paving widths of 40 ft (12.2 m) for AADT of more than 5,000; 32 ft (9.8 m) for AADT between 3,000 and 5,000; and either 28 or 32 ft (8.5 or 9.8 m) for AADT less than 3,000, depending on an economic analysis, except that existing 24-ft (7.3-m) roads should be widened to 32 ft.

Although the accident rate reductions were attributed entirely to the shoulder widening, the reductions may, in part, be due to improved signing, striping, intersection geometrics, some small curve corrections, and the new surfacing constructed concurrently with the widening.

SHANNO/! Patrick, and STANLEY, Alohn, "Pavement Width Standards for Rural Two-Lane Highways." Research Project 80, Idaho Transportation Department (December 1976).

The Idaho Division of Highways standard practice is to pave the entire roadway including shoulders. Until recently, no visible distinction existed between the driving lane and the shoulder on most low-volume, two-lane roads in Idaho. The use of paint striping for lane-shoulder delineation is increasing, but during the period of study (1972-1974) few low-volume roads had shoulder striping. The research included an analysis of traffic accident rates on more than 1,000 sections having a total length of more than 5,000 miles of rural Idaho and Washington two-lane paved highways. The research also included an economic analysis comparing long-term monetary effects associated with several pavement widths.

The results showed that if a slight increase in pavement maintenance costs and slight increases in accident rates are acceptable, reductions can be made in Idaho's width standards, assuming a 30-year life of the pavement. The study recommended that a minimum total pavement width of 20 feet would be acceptable for ADT volumes of less than 400, 24 feet for 400 to 800; 28 feet for 800 to 1,000; 34 feet for 1,000 to 2,000; and 40 feet for 2,000 to 3,000.

McKENZIE, Lloyd J., "Experimental Paved Shoulders on Frost Susceptible Soils." Research and Development Report No. 24, Illinois Division of Highway (December 1969).

The research conducted was on a 3.9-mile section of I-80 east of Joliet, Illinois. Instrumentation was placed in the shoulder and pavement during construction to develop data permitting selection of those alternative shoulder designs and materials that will afford the best service and overall economy of construction and maintenance. Measurements were made of vertical pavement and shoulder movements, frost penetration, and embankment soil moisture contents and densities. In addition, condition and roughness surveys were made of the shoulder performance.

Four material types were used in the shoulder bases: (a) bituminous-aggregate mixture (BAM); (b) cement-aggregate mixture (CAM); (c) pozzolan-aggregate mixture (PAM); and (d) portland cement concrete (PCC). A bituminous-concrete surfacing course was placed on the CAM and PAM; no additional surfacing was placed on the BAM and PCC .

The BAM performance was found inferior to that experienced elsewhere in Illinois. The sections with CAM and PAM showed extensive longitudinal cracking near the pavement-shoulder joint. The performance of the PCC was found to be significantly better than the other types used.

The presence of open-graded subbase materials placed under some shoulders and extended through the side slopes for drainage contributed to better overall performance of the shoulders.

Hot-poured rubber-asphalt sealant was effective in retarding the development of longitudinal cracks at the pavement-shoulder joint of CAM and PAM sections, although it had no measurable effect on the behavior of the BAM and PCC sections.

McKENZIE, Lloyd J., "Final Report, Experimental Paved Shoulders on Frost Susceptible Soils." Research and Development Report No. 39, Illinois Department of Transportation, Bureau of Research and Development (March 1972).

This is the final report of the research summarized earlier in Research and Development Report No. 24 by the same author. Whereas the interim report covered two years of data, the final report includes three years of observation; the final conclusions are the same as those stated in the interim report.

Based on the results of this research, corroborated in some instances by additional observations made elsewhere in the state, the Illinois Department of Transportation has incorporated the following in its shoulder design and construction:

1. Continued using the bituminous aggregate mixture (BAM) as a shoulder material.
2. Increased the specified thickness of BAM shoulders at the outer edge by one inch, and revised the specification for thickness tolerance to assure less deviation from the intended thickness.
3. Continued using an open-graded drainage course under shoulder structures.
4. Rejected cement-aggregate mixture (CAM) and pozzolan-aggregate mixture (PAM) as shoulder-base material.
5. Accepted CAM and PAM as pavement subbase alternatives along with the previously used BAM.

ZAPATA, C. A., "Effectiveness of Sawed-Sealed Longitudinal Joints Between Bituminous Shoulders and Rigid Pavement in Reducing Longitudinal Cracking." First Progress Report, Research Report No. R-637R, Michigan Department of State Highways (August 1967).

A 4.9-mile test section of a four-lane divided highway, US 10, west of Sanford, Michigan, was constructed with a sealed joint between the rigid pavement and the bituminous-aggregate shoulders. The joints were 1/8 to 1/4 inch wide and 1-1/4 to 1-3/4 inches deep, and the grooves were filled with cold-applied solvent mastic sealer. This experimental section was compared with conventional shoulders over an 18-month period. It was found that elevation changes due to frost heaving were greater in the conventional shoulders with unsealed joints than shoulders having sawed-sealed joints.

Four additional test sections having a total length of about 28 miles were also studied. Measurements were made of extent and severity of longitudinal, transverse, diagonal, and alligator cracking and durability of the sealant material. Data were recorded for elevation change, lateral joint displacement, and extent of cracking.

The researcher concluded that it is very unlikely that frost heave caused the longitudinal cracking observed within two months after construction and observed that during the first two months of service, the sawed joint opened about 44 percent more than the original width. Michigan specifies a 50 percent stretch limit for solvent-type mastic compound.

ZAPATA, C. A., "Evaluation of Sawed-Sealed Longitudinal Joints Between Bituminous Shoulders and Rigid Pavement as a Means of Reducing Longitudinal Shoulder

Cracking." Research Report No. R-683, Michigan Department of State Highways (September 1969).

The performance of seal-treated joints was compared with several types of conventional joints. The test section was constructed on 3.3 miles of US 127 near Mason, Michigan. Test procedures, construction, and result of preliminary surveys were presented in Research Report No. R-637R, cited above.

The conclusions reached from this research were:

1. Seal-treated interface joints do not completely prevent longitudinal shoulder cracking, although during the 20 months of testing, they did, at least temporarily, reduce the cracking.
2. Longitudinal shoulder cracking can result from frost heave followed by traffic loading. Frost heave may occur (a) almost immediately after construction due to water in the shoulder material when a wearing surface is applied, or (b) during years after construction as surface water enters the shoulder material through cracks or an open interface joint.
3. Although cutting and sealing should prevent water entering shoulder material through the interface joint, field observations indicate that the major length of joint sealer soon fails due to excessive tension or spalling so very little protection is afforded.

The researcher recommended discontinuing sawing or cutting and sealing the shoulder-pavement interface. Even though the seal-treated joint sometimes effectively reduces shoulder cracking a small percent, the effectiveness is soon lost because of joint sealer failure. Consequently, the additional cost of this operation is not justified.

CHIUNTI, M. A., "Bulkhead Joints for Concrete Base Shoulders." Research Report No. R-1002, Michigan Department of State Highways and Transportation (May 1976).

This study investigated whether the addition of lane ties deterred differential movement between the roadway and concrete base shoulders. Hook-bolt lane ties were installed in the concrete base course widening for ramps at a rest area and for two of the ramps at the LaPorte Interchange on I-94. Three other ramps at the interchange had no lane ties and were used as control sections.

The report indicated that the openings established in untied ramps will continue to increase. Joint openings in ramps with lane ties, however, appear to stop at an average opening of 0.02 to 0.03 in. The report concludes that lane ties are beneficial in maintaining tight joints. Because the cost of ties is minimal, lane ties are recommended for all future concrete base course shoulders or widenings.

BANCROFT, K. S., "Experimental Concrete and Bituminous Shoulders." Research Report No. 1035, Michigan State Department of Highways and Transportation (December 1976).

This study evaluated the cost and performance of experimental concrete and bituminous shoulders in comparison with the standard shoulder used on Interstate construction in Michigan. An experimental PCC shoulder, two experimental bituminous shoulders, and the standard Interstate shoulder were constructed in 1971 and 1972 on I-69 between Charlotte and Olivet, Michigan. Each section was one-half mile in length and only the outside shoulder was used in these tests. Construction details, procedures, initial costs, instrumentation, and methods of measurement were given in Research Report Nos. 844 and 898.

The average cost of concrete shoulders is 50 percent higher than the experimental bituminous shoulder for the 20 projects covered by the report. However, the 1976 projects show only slightly higher costs for concrete than for bituminous shoulders because bituminous prices increased and concrete prices were lower. Condition and performance will be evaluated later.

(However, later information from Michigan indicates that (a) all the bituminous shoulders show separation from the concrete slab of 1/8 to 1/4 in. and have settled slightly; (b) the standard shoulders have longitudinal cracking over 100 percent of their length; (c) seal-coated shoulders show some signs of the seal coat wearing off, possibly during snow removal; and (d) concrete shoulders are performing satisfactorily.)

"I-96 at Creyts Road--Accident Study." Traffic and Safety Division, Surveillance Unit, Michigan Department of State Highways (November 1972).

The purpose of this study was to determine accident causation factors. Accident data for 5-1/2 years (1967-1972) were examined to determine the relation between accident and road characteristics. It was found that on the curve the ran-off-road type accident was the most prevalent (65%). It was also found that westbound traffic was involved in more accidents than the eastbound traffic. Shoulder design was apparently the major contributor to the larger westbound accident occurrence. The shoulders on the outside of the curve sloped away from the roadway. Vehicles drifting off the pavement onto the outer shoulder quickly lost the benefit of the superelevation. The westbound shoulder (outside of curve on median side) was only 3 feet wide, while the eastbound shoulder was 9 feet wide. This difference in shoulder width, and thus the lower westbound recovery distance, might explain why there was a greater number of westbound accidents.

Reconstruction of the shoulders on the outside of the curve was completed in 1974. The effect of this improvement has not as yet been determined.

"Shoulder Design Study." Research Investigation 62-1, Division of Materials and Research, Missouri State Highway Department (June 1973).

A shoulder design study, initiated in 1962 and completed in 1973, examined the relative performance of standard, nonstandard, and experimental shoulder designs throughout the State of Missouri. Cost and performance data were obtained for 21 projects with different shoulder designs adjacent to concrete pavements. Flexible pavements did not lend themselves to this type of study and were excluded. The performance of these projects was surveyed semiannually, and construction and maintenance costs were carefully examined.

The study developed a system of evaluating shoulder performance based upon the shoulder drop-off, amount of loose material, color contrast, roughness, rutting, and depressions. The guidelines established offer a means of control and uniformity for the surveillance of test sections by different personnel.

Construction and maintenance costs were developed on a per mile and annual basis, thus eliminating the variation in years of service life of each section. Annual total costs per mile varied from a low of $318 for a 3-inch stabilized gravel shoulder to a high of over $3,500 for a calcium chloride-treated aggregate shoulder. The calcium chloride-treated shoulder had a lower construction cost than a high-type standard design shoulder, but the maintenance costs were much higher. This study indicated that a shoulder design consisting of six inches of calcium chloride-treated rolled stones could be expected to give satisfactory performance only in areas of low traffic volumes.

This study was instrumental in eliminating the color coat design as a standard intermediate-type design in the state. The Missouri 1971 shoulder design manual revision upgraded the intermediate shoulder design by specifying six inches of rolled stone or stabilized aggregate with a seal coat as the minimum design on roads having average daily traffic volumes greater than 1,700.

BARKSDALE, R. D., and HICKS, R. G., "Improved Pavement-Shoulder Joint Design." NCHRP Report 202 (June 1979).

The objectives of this study were: (a) to determine the most suitable procedures for alleviating the problems associated with the joint between a portland cement concrete roadway and a bituminous surfaced shoulder; (b) to develop and experimentally evaluate improved systems for minimizing the passage of water through the joint; and (c) to develop a plan for a field study for evaluating promising procedures for sealing the longitudinal joint.

As part of this project, a survey of 1975 shoulder practices was conducted. The survey form was designed to (a) identify problems associated with the pavement-shoulder joint; (b) evaluate existing design, construction, and maintenance; and (c) evaluate the performance of the sealant in the joint.

The following are the major conclusions reached in this study:

1. Field observation showed that shoulder distress in the form of excessive cracking, breakage, and settlement occur primarily within 24 inches of the longitudinal pavement-shoulder joint. Design approaches that can be taken to minimize the paved shoulder problem include either one or a combination of the following: (a) select an adequate structural section; (b) saw and seal the longitudinal joint; and (c) provide a positive means of water removal from the vicinity of the longitudinal joint. Typical improved shoulder designs are given in the report.

2. Proper sealing of the longitudinal pavement-shoulder joint can minimize infiltration of water through the joint. Sealant performances tested in the laboratory in decreasing order of acceptance were polyurethane, improved rubber asphalt, polyvinyl chloride, and regular rubber asphalt. The laboratory and field testing indicated that current (1974) laboratory testing procedures do not give a true indication of sealant performance in the field. The report gives sealant specifications which may be used until more realistic procedures are developed.

3. The occurrence of significant ground-water quantities should be controlled by using a drainage blanket and/or an interceptor drainage trench. Recommendations include a high-permeability, granular drainage blanket stabilized with 1.5 to 2.0 percent asphalt.

4. Several improved designs were developed using sealed longitudinal joints and/or permeable asphalt concrete shoulder drains to minimize roadway and paved shoulder deterioration caused by water.

5. Recommendations are given for an experimental shoulder field study to evaluate the most promising design alternatives.

HEIMBACH, C. L., and VICK, H. D., "The Exploration of Economic, Safety, Maintenance and/or Operations on Paved Versus Unpaved Shoulders." Project ERD-110-P-1, Highway Research Program, North Carolina State University at Raleigh (June 1966).

This exploratory project investigated the feasibility of studying paved versus unpaved shoulders in North Carolina. This project reviewed the state-of-the-art and examined states' policy on shoulder pavement and how it was derived.

The major conclusions were:

1. The effect of paved shoulders on safety and traffic flow is a technically feasible area for investigation, but this effect can only be determined if all other roadway and traffic characteristics are studied at the same time.

2. A maintenance and economic study of paved versus unpaved shoulders cannot be initiated until a maintenance cost accounting system is adopted.

3. Other research projects found that benefits will, in fact, be derived from shoulder pavement.

The findings of this study were used as a basis for the following study.

"Portland Cement Concrete Shoulders." Research and Development Report No. 27, Illinois Division of Highways (July 1970).

As part of the reconstruction and rehabilitation program in Illinois, experimental portland cement concrete shoulders were constructed in 1965, 1966, and 1967. These shoulders, all of which were constructed of full-length, plain concrete without reinforcing, have been placed adjacent to conventionally reinforced pavement, continuously reinforced pavement, and a bituminous concrete overlay system. Other variables studied were: (a) the presence or absence of tie bars; (b) the presence or absence of granular subbase; (c) the spacing of transverse joints; and (d) warning rumble strip treatments.

The following are the results of this research on PCC shoulders:

1. A 6-in. thickness of plain concrete is adequate.

2. Tiebars are necessary.

3. Transverse joint spacing of about 20 feet is desirable for the control of intermediate cracking.

4. Using a good grade of joint sealant is important in controlling spalling of transverse joints.

5. The need for subbase under the PCC shoulders was not established.

6. Rumble strips in 4 to 6-foot wide groupings, one inch deep, and with the groupings spaced 60 to 100 feet apart, were effective as a traffic warning measure.

McCASLAND, William R., "The Use of Freeway Shoulders to Increase Capacity." Transportation Research Record 666 (1978) pp. 46-51.

Temporary relief to traffic congestion on a section of Texas freeway was obtained by adding another lane. This was accomplished by narrowing the existing lane widths and using part of the shoulder as a travel lane. Lane widths were reduced to 10.5 ft (3.2 m), and shoulder widths were reduced from 10 ft (3.0 m) to 5.5 ft (1.7 m) where 4 lanes were changed to 5 and to 4 ft (1.2 m) where 3 lanes became 4.

The expected improvements in capacity were achieved. There was a significant decrease in accident rates, and the benefit/cost ratio was very attractive. Additional maintenance was required for lane delineation and for the turf area beyond the shoulder.

MILLER, C. L., BILLER, R., and PORTER, D. A., "Value Engineering Study of Selected Maintenance Activities--Shoulder Maintenance." Maintenance Division, West Virginia Department of Highways (December 1976).

A value engineering study of shoulder maintenance activities was conducted in 1976 in Arizona, Idaho, Iowa, and West Virginia. Three standard maintenance activities on unpaved shoulders were selected for study: (a) blade and shape shoulders, (b) aggregate stabilization of shoulders, and (c) pull shoulders and ditches. These activities represent 98 percent of the annual maintenance budget expended on shoulders of all types in West Virginia.

The study was to determine if more efficient methods (equipment, manpower, or materials) could be utilized in the three activities. It was concluded that more than $750,000 per year could be saved through the acquisition of some additional equipment or modification of existing equipment for the first two activities and only a modification of the maintenance technique for the third activity (pull shoulder and ditches).

The data developed in this study allow the concept of value engineering to be applied to total highway planning, design, construction, and maintenance functions.

"Commercial Vehicles in Collisions Involving Vehicles Parked or Stopped on Highway Shoulders." Special Study, U. S. Department of Transportation, FHWA, Bureau of Motor Carrier Safety (June 1977).

This report points out the causes and results of moving vehicles colliding with vehicles parked on shoulders of Interstate and other highways, and stresses the importance of motorists stopping on highway shoulders only for motor vehicle breakdowns or other emergency situations. The report covers accidents involving commercial and noncommercial vehicles parked on shoulders of highways during 1967 through 1975.

Of 400,000 accident reports, in-depth investigations were made of 2,006 (0.5%). Fifty-eight (3%) of the accidents investigated involved commercial and/or noncommercial vehicles stopped on the shoulders. Forty-seven (81%) of these shoulder accidents occurred on Interstate highways, 8% on U. S. highways, and 3% on state routes and city streets. Negligent and nonemergency parking of vehicles were contributing factors in 21% of the accidents. Ninety percent of the accidents investigated occurred between 11:31 p.m. and 5:30 a.m., during the hours of darkness.

Among the conclusions in the report are:

1. Apparently drivers disregard the "Emergency Stopping Only" signs along Interstate highway shoulders. The report states that "if these shoulders are used by motorists only for the purpose for which they are intended, there is reason to believe that the number of accidents occuring at these locations would decrease."

2. The primary cause in 53% of the accidents was drivers dozing at the wheel and allowing their vehicles to encroach on the shoulder. The question arises whether the paved texture of the highway shoulders effectively produces a "rumble effect" to awaken the driver once the vehicle starts to leave the travel lane. Rumble strips on shoulders should be given serious consideration. The strong stimulus produced by rumble strips is especially important where distractions are present and where boredom and fatigue exist after long stretches of easy driving.

This study is not intended to identify the scope of the problem in highway shoulder accidents, but to establish the fact that there are contributing problems.

HEIMBACH, C. L., et al., "Investigation of the Relative Cost-Effectiveness of Paved Shoulders on Various Types of Primary Highways in North Carolina for the Purpose of Establishing Priority Warrants." Project ERD-110-71-1, Highway Research Program, North Carolina State University at Raleigh (June 1972).

This research compared accident rates for highways having paved shoulders with accident rates for similar highways having only grass or gravel shoulders. The study utilized an analysis of covariance to identify the highway classification variables sensitive to accident rate differences between highway sections with paved and unpaved shoulders. The methodology involving the detailed classification of homogenous highway sections, alike in all respects except for the presence or absence of a paved shoulder, is a workable technique for the testing of differences in accident experience between these two types of highways.

The conclusions were:

1. When four-lane, divided and undivided highways, and two-lane, two-way highways are treated as two composite groups, each group identical except for the presence or absence of a paved shoulder, the average accident rate for the paved shoulder highway group is significantly less than the average accident rate for the unpaved shoulder group.

2. A significantly lower accident rate and severity index is associated with homogenous highway sections having predominantly 3- to 4-ft. paved shoulder, when compared with identical highway counterpart having unpaved shoulders.

3. Combinations of the variables for (a) the cost per mile for paving shoulders on two-lane, two-way roadways, (b) the desired rate of return on the investment, and (c) the estimated rate of yearly growth for the average daily traffic were formulated in which the investment costs for the paved shoulder can be recovered in 7 to 20 years.

4. For two-lane, two-way roadways, the maximum paved shoulder cost-effectiveness occurred for traffic volumes in the 3,000 to 4,000 vehicles-per-day category; the minimum cost-effectiveness occurred within the 2,000 to 3,000 vehicles-per-day category.

5. The investment return analysis showed that for two-lane highways, paving shoulder costs as high as $14,000 per highway mile can be recovered in 20 years or less when the lower accident rate on paved shoulders is translated into dollar benefits.

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