Design and Performance of Highway Shoulders

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RESEARCH REPORT
UKTRP-87-8

DESIGN AND PERFORMANCE OF HIGHWAY SHOULDERS

by

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in cooperation with
Kentucky Transportation Cabinet

and

Federal Highway Administration
US Department of Transportation

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March 1987
April 3, 1989

Mr. Robert E. Johnson  
Division Administrator  
Federal Highway Administration  
330 West Broadway  
Frankfort, Kentucky 40601

SUBJECT: IMPLEMENTATION STATEMENT  
RESEARCH STUDY KYHP R 82-89  
PAVEMENT AND SHOULDER PERFORMANCE

Dear Mr. Johnson:

Information gained during the course of the subject study provided valuable insight relative to the long-term performance of various mainline pavements and shoulders. The advantages of shoulders from the standpoint of safety and improved performance have been demonstrated. Minimum thickness requirements for both flexible and rigid shoulders were addressed and a rational methodology for the design of shoulders was developed.

Data collected and information gained during the study have been used extensively in the development of interim guidelines for design of pavements. The importance of subdrainage systems was emphasized and received considerable attention during development of the interim guidelines. Department officials are currently devoting considerable attention to the task of finalizing guidelines for pavement and shoulder designs and have made extensive use of the study findings. Final implementation will occur upon adoption of pavement design guidelines.

Sincerely,

O. G. Newman, P. E.  
State Highway Engineer
**Title and Subtitle**
Design and Performance of Highway Shoulders

**Author(s)**
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**Abstract**
This report summarizes findings of a long-term evaluation of the construction and performance of asphaltic concrete and portland cement concrete shoulders. Performance was used as the basis for the development of empirical criteria that permit the use of existing pavement thickness design procedures for the structural design of shoulders. Minimum thicknesses were determined on the basis of performance and review of literature.

**Key Words**
Highway Shoulder
Rigid Pavement
Flexible Pavement
Fatigue

**Distribution Statement**
Unlimited with approval of Kentucky Transportation Cabinet
TABLE OF CONTENTS

LIST OF TABLES ................................................................. ii
LIST OF FIGURES ............................................................... ii
INTRODUCTION ................................................................. 1
LITERATURE SEARCH ......................................................... 2
EXPERIMENTAL SHOULDERS ................................................ 5

PORTLAND CEMENT CONCRETE SHOULDERS ............................... 7
BITUMINOUS CONCRETE SHOULDERS ....................................... 18
CONCEPT AND DESIGN OF A TRUCK REST ............................... 22

PERFORMANCE OF SHOULDERS ............................................. 24
PORTLAND CEMENT CONCRETE SHOULDERS ............................... 24
BITUMINOUS SHOULDERS AND TRUCK REST ............................... 30

STRUCTURAL DESIGN OF SHOULDERS ..................................... 38
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS ......................... 43
REFERENCES ......................................................................... 48

APPENDICES

A. ANNOTATED BIBLIOGRAPHY ............................................... 49

B. PERFORMANCE SURVEYS

Portland Cement Concrete Shoulders; US 31W .......................... 68

  5-INCH NON-REINFORCED .................................................. 69
  5-INCH REINFORCED ......................................................... 75
  6-INCH NON-REINFORCED .................................................. 81
  6-INCH REINFORCED ......................................................... 87
  7-INCH NON-REINFORCED .................................................. 93
  7-INCH REINFORCED ......................................................... 98

C. PERFORMANCE SURVEYS

Bituminous Concrete Shoulders; US 31W ................................. 104

D. PERFORMANCE SURVEYS

Bituminous Concrete Shoulders; I 275 .................................. 113
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ingredient Proportions and Requirements for Class A Concrete</td>
</tr>
<tr>
<td>2</td>
<td>Construction and Experimental Cost Data -- US 31W</td>
</tr>
<tr>
<td>3</td>
<td>Construction and Experimental Cost Data -- I 275</td>
</tr>
<tr>
<td>4</td>
<td>Structural Features of Experimental Shoulder Sections</td>
</tr>
<tr>
<td>5</td>
<td>Shoulder Design ESAL's as a Function of Mainline ESAL's</td>
</tr>
<tr>
<td>6</td>
<td>Shoulder Thickness Designs Utilizing Developed Criterion</td>
</tr>
</tbody>
</table>

LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project Location; Experimental Portland Cement Concrete Shoulders, US 31W</td>
</tr>
<tr>
<td>2</td>
<td>Project Location; Experimental Bituminous Concrete Shoulders, I 275</td>
</tr>
<tr>
<td>3</td>
<td>Typical Cross Section, US 31W</td>
</tr>
<tr>
<td>4</td>
<td>Layout of Shoulder Section, US 31W</td>
</tr>
<tr>
<td>5</td>
<td>Joint Detail; Edge of Mainline Pavement and Shoulder, US 31W</td>
</tr>
<tr>
<td>6</td>
<td>Detail of Rumble Strip, US 31W</td>
</tr>
<tr>
<td>7</td>
<td>Shoulder Base Placed to Final Grade, US 31W</td>
</tr>
<tr>
<td>8</td>
<td>Straightening Tie Bars in the Keyway, US 31W</td>
</tr>
<tr>
<td>9</td>
<td>Straightened Tie Bars, US 31W</td>
</tr>
<tr>
<td>10</td>
<td>Paving Non-reinforced Shoulder Section, US 31W</td>
</tr>
<tr>
<td>11</td>
<td>Paving a Reinforced Section, US 31W</td>
</tr>
<tr>
<td>12</td>
<td>Forming Rumble Strip in Plastic Concrete, US 31W</td>
</tr>
<tr>
<td>13</td>
<td>Cleaning Saw Cut Prior to Installation of Neoprene Seal, US 31W</td>
</tr>
<tr>
<td>14</td>
<td>Installation of Neoprene Seal, US 31W</td>
</tr>
<tr>
<td>15</td>
<td>Compression Seal Protruding from Joint, US 31W</td>
</tr>
<tr>
<td>16</td>
<td>Workmen Manually Install Neoprene Seals, US 31W</td>
</tr>
<tr>
<td>17</td>
<td>Typical Cross Section, I 275</td>
</tr>
<tr>
<td>18</td>
<td>Typical Section; Corrugated Drain Pipe, I 275</td>
</tr>
<tr>
<td>19</td>
<td>Corrugated Drain Pipe Extending Through Shoulder to Headwall, I 275</td>
</tr>
<tr>
<td>20</td>
<td>Paving of the Bituminous Concrete Shoulder, I 275</td>
</tr>
<tr>
<td>21</td>
<td>Paving of the Bituminous Concrete Shoulder, I 275</td>
</tr>
<tr>
<td>22</td>
<td>Typical Plan for a Truck Rest Facility</td>
</tr>
<tr>
<td>23</td>
<td>Hairline Longitudinal Cracking Extending through Transverse Joint, US 31W</td>
</tr>
<tr>
<td>24</td>
<td>Longitudinal Cracking across Rumble Strip, US 31W</td>
</tr>
<tr>
<td>FIGURE</td>
<td>PAGE</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>25. Transverse Cracking Extending from a Transverse Joint / Failed Seal, US 31W</td>
<td>26</td>
</tr>
<tr>
<td>26. Rumble Strip Filled with Debris, US 31W</td>
<td>26</td>
</tr>
<tr>
<td>27. Rumble Strip Beginning to Collect Debris, US 31W</td>
<td>27</td>
</tr>
<tr>
<td>28. Wire Mesh Coming through the Concrete Surface, US 31W</td>
<td>27</td>
</tr>
<tr>
<td>29. Concrete Shoulder Showing Signs of Freeze-Thaw Damage, US 31W</td>
<td>28</td>
</tr>
<tr>
<td>30. Freeze-Thaw Damage on the Shoulder, US 31W</td>
<td>28</td>
</tr>
<tr>
<td>31. Spalling and D-Cracking on the Concrete Shoulder, US 31W</td>
<td>29</td>
</tr>
<tr>
<td>32. Hot-poured Sealant is Missing from Transverse Joint, US 31W</td>
<td>29</td>
</tr>
<tr>
<td>33. Medium Severity Alligator Cracking, US 31W</td>
<td>31</td>
</tr>
<tr>
<td>34. High Severity Alligator Cracking, US 31W</td>
<td>31</td>
</tr>
<tr>
<td>35. Edge Failure of the Bituminous Shoulder, US 31W</td>
<td>32</td>
</tr>
<tr>
<td>36. Pavement Edge Drop-off, US 31W</td>
<td>32</td>
</tr>
<tr>
<td>37. Longitudinal Joint between Mainline and Shoulder, I 275</td>
<td>33</td>
</tr>
<tr>
<td>38. Longitudinal Joint between Mainline and Shoulder, I 275</td>
<td>33</td>
</tr>
<tr>
<td>39. Pavement Edge Drop-off, I 275</td>
<td>34</td>
</tr>
<tr>
<td>40. Pavement Edge Drop-off, I 275</td>
<td>34</td>
</tr>
<tr>
<td>41. Sympathetic Cracking of Bituminous Shoulder, I 275</td>
<td>35</td>
</tr>
<tr>
<td>42. First Sign of Impending Base Failure, I 275</td>
<td>35</td>
</tr>
<tr>
<td>43. Trailer-jack Footprints, I 275</td>
<td>36</td>
</tr>
<tr>
<td>44. Typical Cross Section, KY 15, Whitesburg Bypass</td>
<td>36</td>
</tr>
<tr>
<td>45. Pull Cracks in Sandstone Base, Ky 15</td>
<td>37</td>
</tr>
<tr>
<td>46. Mountable Median at Truck Rest Facility, Ky 15</td>
<td>37</td>
</tr>
<tr>
<td>47. Shoulder Design ESAL's as a Function of Mainline Design ESAL's</td>
<td>41</td>
</tr>
<tr>
<td>48. Percent of Mainline ESAL's for Shoulder Design as a Function of Mainline Design ESAL's</td>
<td>42</td>
</tr>
</tbody>
</table>
INTRODUCTION

AASHTO (1) defines a highway shoulder as that "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." The basic functions of a highway shoulder are delineation, drainage, structural support, and emergency and safety uses (2). Regarding delineation, a highly visible, contrasting shoulder is necessary to enable motorists to clearly and easily discern proper paths in the travel lane. The shoulders, whether surfaced or not, should be designed, constructed, and maintained to insure that water will drain quickly from the pavement. The shoulder, when properly designed, furnishes structural support to the pavement base and surface courses by serving as a buttress along the edge. The emergency use function of a shoulder is the use most commonly cited. To serve that purpose, shoulders should be of adequate width and capable of supporting vehicles. Shoulders also improve sight distances in vertical cuts and provide space for lateral clearances to signs and guardrails and maintenance operations. Shoulders should meet the following requirements (3):

a) Maintain stability in all types of weather;
b) Prevent differential heave or settlement so as to maintain the same elevation as the adjacent traffic lanes;
c) Possess the ability to support axleloads permitted on traffic lanes, though fewer in number;
d) Provide for free cross drainage of surface water between driving lanes and ditch with minimal leakage into the subgrade;
e) Have a service life comparable to the mainline pavement; and,
f) Provide intended service at low annual cost.

Paved shoulders provide smoother and safer traffic operations, reduced maintenance requirements on both the shoulder and mainline pavements, and improved performance of the mainline pavement.

Geometric details for shoulder design should include width, cross slope, and continuity of the shoulder. Details will depend upon shoulder type and anticipated number and types of vehicles in the traffic stream. A wider shoulder is used on high-type facilities that carry large volumes of traffic. The cross slope of the shoulder enhances drainage for removal of water from the highway. Turf shoulders should have steeper cross slopes than paved shoulders. A continuous shoulder is usually provided on high-type facilities; however, on many low-type facilities, the shoulder is not
continuous, especially on bridges. Shoulders on long bridges may not be justified on accident-reduction or economical grounds when nominal traffic volumes are anticipated.

This report deals principally with the structural design of highway shoulders. Design criteria will be presented to encompass both flexible and rigid type shoulder pavements.

Kentucky's experience with experimental shoulder design has been concentrated on two applications. Portland cement concrete shoulders were constructed on US 31W in Meade and Hardin Counties in 1974. A section of bituminous concrete shoulder also was constructed on US 31W. Bituminous concrete shoulders were constructed on I 275 in Kenton and Campbell Counties in 1977. An experimental truck rest lane was designed and constructed on KY 15, Whitesburg Bypass, in 1983. Visual monitoring of these applications has continued throughout the study period.

Extensive literature search and review were conducted in conjunction with this study. Twenty-six articles concerning various aspects of portland cement concrete and bituminous concrete highway shoulders were obtained. Each article was reviewed and a short abstract was prepared. The era of the articles ranged from the late 1950's through the early 1980's. The literature contained considerable historical data concerning the development of highway shoulders.

LITERATURE SEARCH

As indicated in NCHRP Report 63 (4), the primary criteria used to select shoulder type are highway classifications and traffic volumes. In 40 percent of the reporting states, 14 percent used a specified material for all shoulders. Only one state of the 43 responding to a 1977 questionnaire based the shoulder type on the percentage of trucks in the traffic stream. The predominant criteria for shoulder thickness and width, like shoulder type, was the highway classification and traffic volume. Six states used the same design procedure for shoulder thickness as for the travel lane, and four states used a percentage of the traffic in the adjacent travel lane for shoulder thickness design. Shoulder width appeared to be the most standardized element of shoulder design. Forty-one states used either AASHTO recommendations or highway classifications and traffic volumes. Shoulder slopes were the most variable element of shoulder design. Fifteen states used a standard slope for all highways, while 16 states varied the slope depending on highway classification or shoulder surface material. Surface drainage was accommodated by the cross slope of the shoulder. For subsurface drainage, underdrains or free draining base courses were used by most states. Visual inspection was most often cited as the means to evaluate shoulder condition.
A summary of shoulder design policies for various agencies is included in NCHRP Report 254 (5), "Shoulder Geometrics and Use Guidelines." The three objectives of the report included the following: to identify highway shoulder design practices and operational uses of shoulders, to determine optimum utilization of highway shoulders, and to encourage greater uniformity in highway shoulder geometric design and use guidelines. Seventeen state, county, and city highway agencies were selected to represent all geographical and climatic conditions in both rural and urban locations. Agencies from the following locations were interviewed: Arkansas; Baltimore County, Maryland; California; Connecticut; Georgia; Idaho; Illinois; Lake County, Illinois; Maryland; Nebraska; New Jersey; New Mexico; New Orleans, Louisiana; New York; North Carolina; Texas; and West Virginia. Twenty-three uses of highway shoulders were identified in the report:

1. Emergency stopping (mechanical difficulty),
2. Parking,
3. Mail and other deliveries,
4. Turning and/or passing at intersections,
5. Routine maintenance,
6. Snow storage,
7. Arid areas,
8. Major reconstruction and maintenance activities,
9. Off-tracking,
10. Encroachment,
11. Slow moving vehicles,
12. Pedestrians,
13. Bicycles,
14. Full running lanes -- non freeways,
15. Full running lanes -- freeways,
16. Mass transit,
17. Errant vehicles,
18. Emergency vehicle travel,
19. Law enforcement,
20. Emergency call box service and public telephones,
21. Roadside sales,
22. Garbage pickup, and
23. Miscellaneous (funerals, snowmobiles).
A majority of the highway shoulder uses identified are adequately provided for by AASHTO design standards and policies. However, AASHTO's "A Policy on Geometric Design of Highways and Streets" (6) does not include a consideration of truck parking, turning and/or passing at intersections, major reconstruction and maintenance activities, slow moving vehicles, full running lanes on freeways, law enforcement, or roadside sales. According to the report, findings indicate a desirability to include these highway shoulder uses in AASHTO's design policy.

Each highway agency interviewed had established shoulder design policies that were in general conformance with AASHTO policies. However, those design policies also reflected special needs and conditions of each agency. Of the 17 agencies interviewed, five based the type of shoulders on highway classifications, six agencies designed their shoulders the same as the mainline pavement, and three based their designs on traffic volumes. One agency used a combination of highway classifications and traffic volumes and one agency designed highway shoulders based on their proposed usage. The remaining agency selected shoulder type through a special design committee.

Shoulder delineation practices were generally consistent. All agencies interviewed used a white edge line to delineate the shoulder from the mainline pavement, although there was some variance regarding placement of the edge line. The use of contrasting surface texturing to achieve shoulder delineation had been tried by nearly all agencies interviewed. Because of the additional initial construction costs and relatively short life of texturing, the practice was generally discontinued.

Roadway drainage was accommodated by increasing the cross slope of the shoulder. Agencies also reported using subsurface drains, shoulder drains, or extensions of the subgrade to the foreslope to improve the stability of mainline and shoulder pavements.

Portland cement concrete (PCC) shoulder designs have, for the most part, been based on engineering judgment. In 1978, Sawan and Darter (7) proposed a structural design procedure that considered all factors influencing highway shoulder design. Major variables included slab thickness and tapering of thickness, joint spacing, foundation support and loss of support, tie between the shoulder and traffic lane, width of the shoulder slab, and design and condition of the adjacent traffic lane.

Considering these variables, the following conclusions were drawn with respect to shoulder design and performance:

1. The two load positions that must be considered in determination of the required shoulder thickness are the inside edge near lane/shoulder joint (encroaching traffic) and the outside edge of the shoulder (parked traffic),

2. Minimum thickness of 6 inches for tied portland cement concrete shoulders,
3. Tapering of the thickness was not recommended,
4. Shoulder width should be at least 3 to 5 feet,
5. Tie systems that provide at least 50 percent load transfer greatly reduced critical stresses,
6. Moderate foundation support was justified, and,
7. Slab length should not exceed 15 feet.

Much of the report (7) focused on development of a computer program for the analysis of a shoulder defined by a given set of input design parameters. The program determined the fatigue damage to the shoulder due to specified loadings. Minimum design thicknesses were chosen for the given conditions by analyzing different thicknesses and relating allowable fatigue damage to the shoulder thickness.

Havens et al. (8) developed a "Design Guide for Bituminous Concrete Pavement Structures" in 1981. That report indicated that neither the design charts nor EAL parameters were discretely applicable to the structural design of bituminous concrete shoulder pavements. Shoulder pavements, in one sense, were considered analogous to "hard stands"; in another sense, shoulders might be compared to low-volume roads. Designs for $7.8 \times 10^3$ ESAL's (equivalent to 1.07 18-kip axles per day or 7,800 repetitions in 20 years) could result in over design. However, if it became necessary to divert traffic onto the shoulder to do maintenance on the mainline, the 20-year quota of repetitions would be accumulated in a matter of days. It was this reasoning that lead Havens to suggest that shoulder thickness design should include some reserve capabilities. Havens further suggested that design curves for $3.1 \times 10^4$ ESAL's be used until more definitive criteria became available. Reductions in thicknesses of flexible shoulders could be justified because they would be repairable.

Overall, 26 articles concerning all aspects of the history of shoulder design, construction, and performance were reviewed. Short abstracts were written for each article and are contained in Appendix A.

**EXPERIMENTAL SHOULDERS**

For the initial experimental shoulder construction in Kentucky, two sites were chosen, one for portland cement concrete shoulders, the other for bituminous concrete shoulders. Project SP 47-19-25, SP 82-3-16, F79(27), a 3.44-mile section of US 31W between Radcliff and Tiptop in Hardin and Meade Counties, was selected for construction of portland cement concrete shoulders (see Figure 1). Included with the experimental concrete shoulders was a 3,200-foot section of bituminous shoulder. Project I-275-
Figure 1. Project Location; Experimental Portland Cement Concrete Shoulders, US 31W.
PORTLAND CEMENT CONCRETE SHOULDERS

The US 31W project is a four-lane controlled-access facility having 10-foot shoulders in each direction. The mainline pavement consisted of 9 inches of portland cement concrete (PCC) on 4 inches of compacted densely graded aggregate. Three shoulder thicknesses (5, 6, and 7 inches) were specified. Compacted dense-graded aggregate base thicknesses were 8, 7, and 6 inches, respectively. Class A PCC concrete (6.0 bags/cubic yard) was used in both mainline and shoulder pavements. Ingredient proportions, according to 1965 Kentucky Standard Specifications for Road and Bridge Construction, are listed in Table 1. Cross slope for the concrete shoulder was 3/4 inch :: 1 foot. A typical cross section is shown in Figure 3. Reinforcement (WWF 6x12 - W4xW4) was included and excluded from each shoulder thickness. Figure 4 shows a layout of the experimental shoulder sections. The mesh was not continuous across transverse joints. Load transfer dowel assemblies were excluded from all transverse shoulder joints.

<table>
<thead>
<tr>
<th>TABLE 1. INGREDIENT PROPORTIONS AND REQUIREMENTS FOR CLASS A CONCRETE</th>
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<tr>
<td><strong>SAND</strong></td>
</tr>
<tr>
<td>Saturated Surface Dry Aggregate (lbs/bag)</td>
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<td>Approximate Percent Fine to Total Aggregate</td>
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<tr>
<td>Maximum Free Water (gal/bag)</td>
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<tr>
<td>Minimum Expected Compressive Strength at 28-Days (psi)</td>
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<tr>
<td>Slump (in.)</td>
</tr>
<tr>
<td>Minimum Cement Factor (bag/cu yd)</td>
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</tbody>
</table>
Figure 2. Project Location; Experimental Bituminous Concrete Shoulders, I 275.
Figure 3. Typical Cross Section, US 31W.

Figure 4. Layout of Shoulder Section, US 31W.
The longitudinal joint between the mainline pavement and shoulder was tied by deformed steel tie-bars, 1/2 inch in diameter, 30 inches in length, and placed transversely through the joint. The bars were positioned 3-1/2 inches below the concrete surface and spaced on 30-inch centers. Figure 5 typifies an acceptable joint.

Corrugated rumble strips were formed in the shoulder at 50-foot intervals to alert errant drivers. The rumble strips were 6 feet in length. They began 3 inches from the longitudinal joint and extended to the shoulder edge to provide drainage. The corrugations were rounded rather than peaked. They were 1 inch in depth and 4-1/2 inches from peak to peak or trough to trough. The cross slope of the rumble strip corresponded to that of the shoulder. Figure 6 illustrates the rumble strip details.

Shoulder sections containing reinforcement were jointed at 50-foot intervals to match the mainline pavement. Intermediate (25-foot spacing) joints was required in the sections without reinforcement. Standard joints, sawed 1/8 to 1/4 inch wide and 1/4 of the pavement thickness in depth, and filled with hot-poured rubberized asphalt, were used in shoulders and mainline pavement from Station 167+00 to Station 220+00.

A companion experimental feature on this project was the use of neoprene joint seals. All longitudinal joints from Station 220+00 to Station 302+50 were sawed 1/8 to 1/4 inch in width and required a 7/16-inch neoprene compression seal. Transverse joints from Station 273+00 to Station 302+50 were sawed 3/16 to 5/16 inch in width and required a 9/16-inch neoprene compression seal. Transverse compression seals were continuous from the centerline through the shoulder. Longitudinal seals were in 50-foot minimum lengths unless intersected by a transverse joint. Ends of the longitudinal seals were cemented to the transverse seals.

The experimental concrete shoulders were constructed separate from and after the mainline pavement. The shoulder base was placed to partial depth simultaneously with the mainline base. After the mainline section was paved, the shoulder base was placed to final grade (see Figure 7). Prior to placing the shoulder, tie bars bent into the keyway during construction of the mainline sections were straightened to proper positions (see Figures 8 and 9). Concrete in the shoulders was placed, consolidated, and finished in accordance with procedures outlined in the 1965 Kentucky Department of Highways Standard Specifications for Roads and Bridges. Both non-reinforced (see Figure 10) and reinforced (see Figure 11) sections were placed in one lift. The reinforcement was placed in the plastic concrete and positioned by mechanical means. After final finishing, the rumble strips were formed in the plastic concrete (see Figure 12).

Prior to the installation of the neoprene seals, the sawed joints were cleaned with compressed air (see Figure 13). The seals were installed by a mechanical extruder (see Figure 14) which lubricated the seals as they were forced into the joint. The mechanical extruder was furnished to the contractor by the manufacturer of the seals. Some problems occurred with the installation of the seals, eventually leading to manual installation (see Figures 15 and 16). Cost and project data are summarized in Table 2.
Figure 5. Joint Detail; Edge of Mainline Pavement and Shoulder, US 31W.
Figure 6. Detail of Rumble Strip, US 31W.
TABLE 2. CONSTRUCTION AND EXPERIMENTAL COST DATA -- US 31W

<table>
<thead>
<tr>
<th>Date Contract Let:</th>
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<tr>
<td>Date Contract Awarded:</td>
<td>February 26, 1973</td>
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<tr>
<td>Date Work Began:</td>
<td>March 14, 1973</td>
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<tr>
<td>Date Work Completed:</td>
<td>July 7, 1975</td>
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<td>Final Acceptance:</td>
<td>October 9, 1975</td>
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<td>Contractor:</td>
<td>Ruby Construction</td>
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<td>Neoprene Seals Manufacturer:</td>
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**EXPERIMENTAL COSTS:**

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<th>Item</th>
<th>Unit Price</th>
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<td><strong>CONCRETE SHOULDER</strong></td>
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<td>5-in. Reinforced</td>
<td>$5.20/sq yd</td>
<td>5,196 sq yd</td>
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<td>6-in. Reinforced</td>
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<td>1,774 sq yd</td>
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<tr>
<td>7-in. Reinforced</td>
<td>6.00/sq yd</td>
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</tr>
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<td>7-in. Non-reinforced</td>
<td>5.40/sq yd</td>
<td>5,117 sq yd</td>
<td>27,632</td>
</tr>
</tbody>
</table>

| **NEOPRENE COMPRESSION SEALS** | | | |
| 7/16 in. x 3/4 in. | 0.75/ft | 8,418 ft | 6,314 |
| 9/16 in. x 3/4 in. | 0.90/ft | 2,400 ft | 2,160 |

**TOTAL EXPERIMENTAL COSTS** | $136,891

**BITUMINOUS CONCRETE SHOULDERS**

The I 275 project is a four-lane, limited access interstate facility having 10-foot bituminous concrete shoulders in each direction. The mainline pavement consisted of 11 inches of concrete pavement on 6 inches of compacted dense-graded aggregate. The bituminous concrete shoulders consisted of 5 inches of compacted Class I base (AC-10) and 1 inch of compacted Class I surface, Type A, Modified (AC-10), on 11 inches of dense-graded aggregate. The cross slope of the bituminous concrete shoulder was 1/2 inch :: 1 foot. A typical cross section is shown in Figure 17.

Polyethylene plastic corrugated underdrain pipe was incorporated in the shoulder to facilitate subgrade drainage. The 6-inch slotted drain pipe was placed parallel to the pavement and was connected to box inlets in the median or to headwalls on the outside shoulder. The centerline of the pipe was positioned 21 inches from the pavement edge and the flowline of the pipe was 15 inches below the surface (see Figures 17 and 18).

The dense-graded aggregate base for the bituminous concrete shoulders was placed to partial depth simultaneously with the mainline base. Mainline paving was completed before excavation of the trench for the drainage system. After positioning the drain pipe, the trench was backfilled with No. 57 stone. Final grading of the base and placing of the bituminous concrete shoulder were normal. Figure 19 shows the drain pipe exiting the...
Figure 17. Typical Cross Section, I 275.

Figure 18. Typical Section; Corrugated Drainpipe, I 275.
CONCEPT AND DESIGN OF A TRUCK REST

A truck rest (or truck pull off or pull out) is a surfaced area outside the normal continuous shoulder to provide space for parking of one or more vehicles for semi-emergency stopping. Truck rests differ from a rest area in that they do not provide separated (from the mainline pavement) parking areas and additional facilities.

The need for truck rests depends to a large extent upon the character and volume of traffic, type of highway, and geographical location of the highway. Transportation engineers have become increasingly aware of shoulder failures as a result of the lack of such facilities. A warrant for such facilities would be a high percentage of heavy trucks. Two-lane facilities in mountainous terrain would be further warrant for the use of truck rests.

Investigations regarding reasons and the preferred location for truckers to stop falls into two general categories: safety and economy. Truckers most often stop at the crests of hills. Stops are made to inspect brakes, cooling systems, and cargo. Truckers use the stop to permit faster moving vehicles to pass and to rest. Crests of hills also permit the greatest sight distances and are generally free from restricting guardrails and/or bridge piers. However, in many instances, the crests of hills are often located in steep rock cuts and the width of the shoulder may be narrower. This tends to cause truck drivers to pull off on the shoulder on the down slope just past the rock cut and thus reduces the rear sight distance.

Stops may also be located in certain areas for economic reasons. Trucks hauling heavy cargoes are geared down and moving at a slow speed at the top of a hill, making a stop easy to accomplish and fuel efficient. Fuel economy also is achieved during a downhill start versus an uphill start. Another reason offered for stopping included waiting for other truckers.

The Kentucky Department of Highways constructed a truck rest facility on KY 15 (Whitesburg Bypass) in 1983. Structural design criteria normally would have been established by frequency of use. However, there were no estimates of the frequency that truckers would use the facility. Therefore, a pavement design equivalent to the mainline design was selected for the initial truck rest design. The structural design consisted of 7-1/2 inches of asphaltic concrete on 11 inches of dense-graded aggregate.

The truck rest was constructed at the crest of a hill in mountainous eastern Kentucky. The entire facility was constructed outside and not as part of the normal shoulder. The facility was designed to accommodate two to three trucks in one storage lane. Deceleration and acceleration lanes were provided. Signing of the truck rest was in accordance with the Manual on Uniform Traffic Control Devices (MUTCD). A typical truck rest design is shown in Figure 22.
TYPICAL TRUCK REST
2 OR 4 LANE FACILITY

NOT TO SCALE)
TRUCK STORAGE

TAPER
240°
320°
TAPER

NORMAL 10' SHOULDER

SOLID WHITE EDGE LINE

DASHED WHITE LINE

SIGN A
SIGN B
SIGN C
SIGN D
SIGN E

1. Construct pavement of same thickness and composition as mainline pavement. Width as per Plan: center
   slope 1/4" 1'.
2. Two-lane OCA shoulder. S2mple 1/4" 1'.
3. All safety modifications to be in accordance with the Standard Specifications.
4. For multilane access, a construction or two-lane facilities. Identify truck rest should be constructed
   for each traffic direction. When cut areas will not allow truck rest to be constructed on opposite sides of
   a roadway, median will be necessary to separate vehicles in same direction.
5. Sign A should be located at the beginning and at all access points of a limited access facility such as a toll
   road or freeway. For state or federal roads sign A should be located well in advance of any truck
   rest facility and preferably thereafter. Signs A will be located as directed by the Traffic and Projects
   Engineers.
6. Maintain entire facility within 50'/clear zone when necessary.

SIGNING

TRUCKS REST AT PULL-OFFS ONLY

TRUCKS REST 1 MILE

TRUCKS USE OUTER SHOULDER FOR STOPPING

WHITE ON GREEN

WHITE ON GREEN

WHITE ON GREEN

WHITE ON GREEN

WHITE ON GREEN

RED AND WHITE

Figure 22. Typical Plan for a Truck Rest Facility.
PERFORMANCE OF SHOULDERS

PORTLAND CEMENT CONCRETE SHOULDERS

Visual surveys of experimental portland cement concrete shoulders were conducted periodically since 1976. Until recently, the extent of distress was nominal. The most recent survey of the experimental concrete shoulders was conducted in the spring of 1986. The various sections were visually surveyed for common distresses. Approximately 3,000-foot sections were surveyed in each design section. All sections were performing well although discernible differences existed between the various design sections. Results of the visual crack survey are included in Appendix B.

All sections exhibited many of the same forms of distress. Distresses within the 5-inch sections were more pronounced than in the 6-inch sections and distresses within the 6-inch sections were more pronounced than in the 7-inch sections. The most common forms of distress observed were hairline cracking, rumble strips filled with debris, protruding mesh, and freeze-thaw damage to the concrete. The experimental neoprene seals were in fair condition overall.

Hairline cracking, both longitudinally and transversely, appeared frequently. Longitudinal cracking extended across transverse joints and rumble strips (see Figures 23 and 24). Many transverse cracks developed at mid-slab locations of the mainline pavement where transverse joints were provided for on the shoulder (see Figure 25). A failure of the neoprene seal also may be noted in Figure 25. The most likely cause of this failure of the seal was intrusion of incompressible fines from the side of the joint. Fine material collects at the shoulder pavement and slope interface and infiltrates into the saw cut. Eventually, the seal is forced from the joint.

Some debris had collected in the troughs of virtually all rumble strips (Figures 26 and 27). Many rumble strips exhibited hairline transverse cracking. However, these cracks seldom extended across the longitudinal joint into the mainline pavement.

There were instances where the wire mesh reinforcing steel was placed too close to the surface. Figure 28 shows a small piece of the wire mesh protruding through the concrete surface. Figures 29 and 30 show unmistakable evidence of freeze-thaw damage to the concrete shoulder. Spallling and D-cracking were observed as shown in Figure 31.

Other forms of distress or deficiencies noted on the visual survey data sheets included a shoulder edge drop off of 4 to 6 inches in one location and transverse seals where hot-poured sealant had been replaced largely with fine material (see Figure 32).
BITUMINOUS SHOULders AND TRUCK REST

Thirty-two hundred foot sections of bituminous concrete were used in both the northbound and southbound shoulders of US 31W. The thicknesses of those sections were 2 inches asphaltic concrete and 11 inches of dense-graded aggregate. The visual survey encompassed the entire control section. Results of the most recent visual crack survey are contained in Appendix C. The bituminous shoulders were badly deteriorated. The shoulders exhibited varying degrees of severity of alligator cracking (see Figures 33 and 34). There were numerous failures at the edge of the shoulder (see Figure 35). The shoulder had settled near the pavement-shoulder joint (see Figure 36). This distress was more prevalent in the northbound direction. There were only two instances where the base had actually failed. The asphaltic concrete showed signs of pushing and shoving in those areas. Water was observed migrating through the asphalt shoulder in two southbound locations.

The most recent visual survey (winter of 1986) of I 275 covered both northbound and southbound directions between the KY 17 and KY 16 interchanges. Results of the visual crack survey are contained in Appendix D. The most common distresses observed were separation of the bituminous shoulder from the mainline portland cement concrete pavement and settlement of the shoulder near the mainline pavement edge. The condition of asphaltic concrete at the longitudinal joint between the mainline pavement varied from fair to very poor (see Figures 37 and 38). It could not be determined whether the shoulder had settled or whether it had been compressed under the loading of encroaching vehicles (see Figures 39 and 40).

Sympathetic transverse cracking of the bituminous shoulder was also evident (see Figure 41). Sympathetic cracking is caused by the movement of the portland cement concrete pavement at the joints. The expansion and contraction of the slabs induces a transverse crack in the bituminous shoulder. Joint spacing of the mainline portland cement concrete pavement was 50 feet. There was one 50-foot section showing the first signs of impending base failure (see Figure 42). There were visual signs that truckers had dropped their load on the shoulder at several locations. These were evidenced by trailer-jack foot prints on the shoulder (see Figure 43).

A truck rest was constructed as part of the Whitesburg Bypass in 1983. Trucks were estimated as being 8 percent of the total traffic at the time of the original design. There were no cost estimates available relative to construction of the truck rest. The truck rest has performed well. A typical section is depicted in Figure 44.

The truck pull off was most recently visually surveyed for signs of distress during the winter of 1986. The most observable distress was pull cracks produced by the roller during compaction of the base material (see Figure 45). The truck pull off did not have a final wearing surface. The curb of the mountable median was nearly 2 inches above the sandstone base material (see Figure 46). There were no major distresses observed at the truck pull off even though the wearing course had not been placed.
STRUCTURAL DESIGN OF SHOULDERS

The primary function of highway shoulders has long been associated with safety by providing motorists a location for emergency stopping and storage of disabled vehicles. More recently, the shoulder has taken on added significance. Shoulders have been used as temporary driving lanes during peak hours, in times of emergency, and during rehabilitation activities. It also has been demonstrated that shoulders improve pavement performance by providing additional lateral support to assist in distribution of induced stresses resulting from applied loads.

In those situations where shoulders have served as travel lanes, the shoulders have functioned as low-volume roads. Conversely, for those situations where shoulders have served only to provide space for emergency stopping and/or storage of disabled vehicles, the shoulders functioned essentially as a hardstand or parking lot. Given these two events, the structural design of shoulders may be addressed from two perspectives: 1) from a fatigue perspective and 2) from a static load or hardstand perspective. Literature indicated the design of shoulders from the perspective of fatigue or application of a specific volume of vehicles as being the more prevalent design consideration. Generally, designs have been based upon some portion of the mainline design ESAL's (equivalent axleloads) or some portion of the average daily traffic (ADT) for the adjacent mainline pavement. Given the variability of vehicle classifications within a traffic stream, design on the basis of some portion of the design ESAL's for the mainline pavement appears more appropriate. Design of a hardstand requires determination of the highest levels of stress induced by a parked vehicle. Prediction of these stresses is much more difficult than use of some portion of the design ESAL's for the mainline pavement. A "design" vehicle must be selected and that may be difficult.

Using a portion of the projected accumulation of fatigue for the mainline pavement offers the additional advantage of designing the shoulder as a low-volume road. This permits use of existing design procedures with a "scale down" on the basis of a reduction in the design fatigue level. It also allows the designer flexibility to use various design procedures.

There are, however, disadvantages for this particular design concept. First, the design ESAL's must be either estimated or determined by experiment and observation of performance. Second, designs are subject to the same limitations associated with the specific design procedure used for design of the mainline pavement.

A more recent approach to the design of shoulders involves using a specific mechanistic approach. Elastic layer and/or finite element concepts (7) have been used for some time for the thickness design of pavements. In
the literature review, an adaptation of finite element concepts to the
structural design of portland cement concrete shoulders was discussed. One
procedure permitted the designer to consider such factors as encroachment
of moving trucks, supporting capacity of the subgrade, and transfer of
loads from the mainline pavement to the shoulder. Mechanistic procedures
provide the flexibility to address specific considerations unique to each
design section. Perhaps the single most disadvantage of such procedures is
their complexity and the need for more than a casual understanding of layer
elastic or finite element principles. As a result, the use of mechanistic
procedures for shoulder design has been somewhat limited.

Thickness design procedures for both rigid and flexible pavements in
Kentucky have been developed on the basis of elastic layer concepts and
empirical correlations with observed pavement performance. Given this and
the observations of shoulder and pavement performance of the experimental
shoulder sections discussed previously, it was determined that the more
efficient design concept would be to use existing design procedures and
design shoulders on the basis of some portion of the design ESAL's for the
mainline pavement. Structural features for these experimental sections are
summarized in Table 4.

**TABLE 4. STRUCTURAL FEATURES OF EXPERIMENTAL SHOULDER SECTIONS**

<table>
<thead>
<tr>
<th>LAYER</th>
<th>THICKNESSES</th>
<th>AGE</th>
<th>JOINT SPACING</th>
<th>REINFORCEMENT</th>
<th>DESIGN ESAL'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>5.0, 8.0</td>
<td>13</td>
<td>25</td>
<td>No</td>
<td>6.5, 0.2</td>
</tr>
<tr>
<td>5.0</td>
<td>8.0, 13</td>
<td>50</td>
<td>Yes</td>
<td>6.5, 0.2</td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>7.0, 13</td>
<td>25</td>
<td>No</td>
<td>6.5, 0.7</td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>7.0, 13</td>
<td>50</td>
<td>Yes</td>
<td>6.5, 0.7</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>6.0, 13</td>
<td>25</td>
<td>No</td>
<td>6.5, 1.8</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>6.0, 13</td>
<td>50</td>
<td>Yes</td>
<td>6.5, 1.8</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAYER</th>
<th>THICKNESSES</th>
<th>DESIGN ESAL'S</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>2.0, 11.0</td>
<td>6.5, 0.04</td>
</tr>
<tr>
<td>6.0</td>
<td>11.0, 10</td>
<td>20.0, 0.20</td>
</tr>
<tr>
<td>7.5</td>
<td>11.0, 4</td>
<td>3.0, 3.00</td>
</tr>
</tbody>
</table>
A detailed summary of distress surveys is presented in Appendices B, C and D. Generally, mid-panel cracking was observed in all sections of the portland cement concrete shoulders where temperature reinforcement was used and joint spacing was 50 feet. Similar cracking was typically observed in mainline sections. Very little mid-panel cracking was observed in non-reinforced sections having joint spacings of 25 feet. The 5.0-inch thick sections had considerably more deterioration in the vicinity of joints than did the other sections. The 7.0-inch section, as expected, had the least distress. It was further speculated that the thinner sections might be more susceptible to freeze-thaw damage. Also, compression failures were associated with failure of joint seals and filling of joints with incompressibles. None of these shoulder sections has been removed for detailed inspection, although it is recommended as a task for long-term monitoring.

The asphaltic concrete shoulders on I 275 have experienced a small amount of fatigue and have also shown signs of aging due to the environment. With the exception of problems associated with separation of the bituminous shoulder from the mainline concrete pavement and the pavement/shoulder edge drop off, the asphaltic concrete shoulders have performed fairly well during the study period. Conversely, the asphaltic concrete shoulders on US 31W have failed sections throughout. Given the thicknesses of the two sections, it may be deduced that the minimum thickness of asphaltic concrete should be between 2 and 6 inches. A further analysis using the AASHTO structural numbers approach \((SN = a_1D_1 + a_2D_2)\) and assuming \(a_1 = 0.44\) (for asphaltic concrete) and \(a_2 = 0.14\) (crushed stone base) gives \(SN\)'s of 4.2 for the I 275 shoulders and 2.6 for the shoulders on US 31W. There was considerably more structural integrity for the I 275 sections than for the US 31W sections. This is supported by observations of distress and performance.

Performance of the portland cement concrete shoulders suggests 6.0 inches as the minimum thickness for high-type pavements. Five-inch sections would likely provide acceptable performance for lesser traveled routes. Literature indicates the minimum thickness of asphaltic concrete should be 4.0 inches \((9)\), regardless of the thickness of crushed stone. This is at least generally consistent with observed performances.

Given the performance of the experimental shoulders as described previously, results of the literature search, and review previously discussed, criteria for the selection of shoulder design ESAL's were determined and are illustrated in Figures 47 and 48. Figure 47 presents a log-log plot of shoulder design ESAL's as a function of mainline design ESAL's. Data points shown on the graph correspond to those listed in Table 4. The design curve provides a smooth, ever-increasing function from a 100 percent design when mainline design ESAL's are less than \(2 \times 10^5\) to a two percent design when mainline design ESAL's exceed \(1 \times 10^8\). More
Figure 47. Shoulder Design ESAL's as a Function of Mainline Design ESAL's.
5-inch non-reinforced
5-INCH REINFORCED
Figure 48. Percent of Shoulder Design ESAL's for Shoulder Design as a Function of Mainline Design ESAL's.
specifically, for mainline design ESAL's less than or equal to $2 \times 10^5$, shoulder design ESAL's and mainline design ESAL's are equivalent. For mainline design ESAL's greater than $2 \times 10^5$ but less than or equal to $1 \times 10^8$, shoulder design ESAL's are determined by the following equation:

$$\log(Y) = -69.675 + 39.989(\log(X)) - 7.8298(\log(X))^2 + 0.66516(\log(X))^3 - 0.020347(\log(X))^4$$  (1)

where $Y =$ shoulder design ESAL's, and

$X =$ mainline design ESAL's.

The recommended minimum shoulder design ESAL's for situations where mainline design ESAL's exceed $1 \times 10^8$ is 2 percent of the mainline design ESAL's. This is supported by performance evaluations and literature. Although the I 275 asphaltic concrete shoulders (1% design) exhibited only a small amount of fatigue, the design was considered weak primarily due to the presence of a shoulder/pavement edge drop off of an inch or more.

Figure 48 presents the same relationship in semi-log format where the percent of the mainline design ESAL's for shoulder design is presented on the arithmetic scale and the mainline design ESAL's are presented on the logarithmic scale. The curves presented in Figures 47 and 48 indicate shoulder thickness will approach the thickness of the mainline pavement as the mainline design ESAL's decrease.

Table 5 presents the relationship given in Equation (1) in tabular form. The proposed criteria for shoulder design may be utilized in combination with any pavement thickness design system wherein equivalent axleloads (ESAL's) are a basic factor. Applications of these criteria with the Kentucky pavement thickness design procedure (8, 13) are summarized in Table 6.

**SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

The shoulder has become an integral component of the pavement system. Safety aspects have received more attention, generally, than structural design aspects. Literature as well as performance observations support the contention that shoulders do improve pavement performance by providing lateral support for pavement sections, thereby reducing critical stresses and strains at pavement edges. Additionally, shoulders provide positive drainage of surface water from the pavement and improves safety and also may reduce the rate of moisture infiltration into the foundation material.
<table>
<thead>
<tr>
<th>MAINLINE DESIGN ESAL’S X 10^6</th>
<th>SHOULDER DESIGN ESAL’S X 10^6</th>
<th>PORTION OF MAINLINE ESAL’S FOR SHOULDER DESIGN (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.200</td>
<td>0.200</td>
<td>99.96</td>
</tr>
<tr>
<td>0.300</td>
<td>0.279</td>
<td>92.99</td>
</tr>
<tr>
<td>0.400</td>
<td>0.336</td>
<td>83.93</td>
</tr>
<tr>
<td>0.500</td>
<td>0.378</td>
<td>75.65</td>
</tr>
<tr>
<td>0.600</td>
<td>0.411</td>
<td>68.55</td>
</tr>
<tr>
<td>0.700</td>
<td>0.438</td>
<td>62.52</td>
</tr>
<tr>
<td>0.800</td>
<td>0.459</td>
<td>57.40</td>
</tr>
<tr>
<td>0.900</td>
<td>0.477</td>
<td>53.03</td>
</tr>
<tr>
<td>1.000</td>
<td>0.493</td>
<td>49.25</td>
</tr>
<tr>
<td>2.000</td>
<td>0.576</td>
<td>28.78</td>
</tr>
<tr>
<td>3.000</td>
<td>0.615</td>
<td>20.50</td>
</tr>
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<td>4.000</td>
<td>0.642</td>
<td>16.06</td>
</tr>
<tr>
<td>5.000</td>
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<td>13.30</td>
</tr>
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<td>6.000</td>
<td>0.685</td>
<td>11.42</td>
</tr>
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<td>7.000</td>
<td>0.704</td>
<td>10.06</td>
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<tr>
<td>8.000</td>
<td>0.722</td>
<td>9.02</td>
</tr>
<tr>
<td>9.000</td>
<td>0.739</td>
<td>8.22</td>
</tr>
<tr>
<td>10.000</td>
<td>0.756</td>
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</tr>
<tr>
<td>20.000</td>
<td>0.918</td>
<td>4.59</td>
</tr>
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<td>30.000</td>
<td>1.074</td>
<td>3.58</td>
</tr>
<tr>
<td>40.000</td>
<td>1.229</td>
<td>3.07</td>
</tr>
<tr>
<td>50.000</td>
<td>1.384</td>
<td>2.77</td>
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<td>60.000</td>
<td>1.540</td>
<td>2.57</td>
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<td>70.000</td>
<td>1.698</td>
<td>2.43</td>
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<td>80.000</td>
<td>1.859</td>
<td>2.32</td>
</tr>
<tr>
<td>90.000</td>
<td>2.021</td>
<td>2.25</td>
</tr>
<tr>
<td>100.000</td>
<td>2.186</td>
<td>2.19</td>
</tr>
</tbody>
</table>
A major problem of shoulder maintenance is the joint between the shoulder and the mainline pavement. For portland cement concrete pavements, tied portland cement concrete shoulders are recommended. Tied portland cement concrete shoulders significantly reduce development of an open longitudinal joint between the mainline and shoulder and minimizes development of pavement edge drop off that is common with other shoulder types. Tied portland cement concrete shoulders appear to demonstrate increased service life without the need for any special maintenance. For asphaltic concrete pavements, asphaltic concrete shoulders over the entire
width of the shoulder area are recommended. Again, this appears to minimize development of edge drop off and development of an open longitudinal joint between the mainline and shoulder.

For lower classes of highways, shoulder types have historically ranged from sod to compacted full-depth aggregate to compacted aggregate with a bituminous seal, depending upon the traffic volumes anticipated. Maintenance activities on sod or turf shoulders typically consist of mowing and blading. Compacted granular shoulders generally require mowing, blading, and adding aggregate to maintain proper elevation. Seal-coated shoulders are difficult to maintain and require frequent resealing. Granular shoulders stabilized with asphalt hot plant mix cost approximately fifty percent more than the conventional seal-coated shoulders but are more easily maintained and are often maintenance free during the early stages of their service life. Maintenance consists of sealing the longitudinal joint between the mainline and shoulder and spot sealing and patching of raveled and map cracked areas.

When considering the several types of shoulder material, the basic definition of the function of a highway shoulder should not be overlooked; that is, the shoulder must be sufficiently stable to support occasional or periodic loads in all types of weather without catastrophic failure. In view of this function and past experiences of shoulder performance, it is recommended that the shoulder material type be consistent with the mainline pavement material type.

Performance was used as a basis for development of empirical criteria that permit the use of existing pavement thickness design procedures for the structural design of shoulders, considering shoulders as "low-volume" roads. Minimum thicknesses were determined on the basis of performance and review of literature. A minimum thickness of 5 inches for tied portland cement concrete shoulders is recommended for use with portland cement concrete pavements. The minimum thickness of asphaltic concrete shoulders is recommended as 4 inches or 33 percent of the total shoulder thickness required when based upon the Kentucky design method with traffic input from Figure 47. The criterion, while recommended for implementation, also should be monitored over the long term to permit refinement and modification with experience.

Truck rests, climbing lanes, and paved shoulders are all vital elements of a complete transportation facility. The addition of truck rest areas may serve to compliment the others. Use of truck rests may reduce present shoulder thickness requirements in those areas where truck rests are provided. Consideration should be given to the use of intermittent truck rests placed at favorable locations. Implementation with new construction could be achieved at relatively nominal additional cost. Retrofitting existing facilities may be difficult due to the limited space available in rock cuts. Reduced thickness and maintenance required for
shoulders may provide an overall economic benefit. With adequate signing and encouragement by enforcement officials, intended use of truck rests may be expected.

Another phase of this study involved an investigation of various joint sealing systems for rigid pavements. Performance information presented in Appendix B indicates superior performance of neoprene compression seals relative to hot-poured asphalt rubber seals. Neoprene seals have provided satisfactory service for a period of 13 years with only localized failures. Hot-poured asphalt rubber seals are badly deteriorated and are missing in many locations. Performance of silicone seals for rigid pavements is addressed elsewhere (10). That report indicates that the service life of silicone seals is on the order of 10 to 15 years. At this time, there is not sufficient performance information to differentiate between neoprene and silicone seals. Recent cost data indicate silicone seals were bid on the order of $1.10 per lineal foot for longitudinal seals and $2.40 per foot for transverse seals. Unfortunately, recent costs for neoprene seals have been bid as incidental to pavement construction. As such, direct cost comparisons are not available.

Other reports (11, 12) summarize the performance of a subsurface drainage blanket and the variations in pavement performance with changing gradations of aggregate bases. Pavement sections having a coarse-graded aggregate subsurface drainage system have performed well (11). Subsequent inspections support those observations. In general, there was very little change in pavement performance with minor variations in gradations in the crushed-stone base (12). Additional investigation is required to study the extent of variations permitted without significant changes in performance.

Testing of material properties for various pavement layers was not addressed in this study. Instead, they are being addressed in Research Study KYHPR 86-115, "Laboratory and Field Evaluations and Correlations of Properties of Pavement Components". This study, however, has contributed to a better understanding of long-term pavement performance. Benefits of shoulders have been demonstrated. The effectiveness of a subsurface drainage system has been demonstrated.
REFERENCES


APPENDIX A

ANNOTATED BIBLIOGRAPHY
To meet the demand for increased traffic volumes, weights, and speeds, design for paved shoulders should include:

1. A means for alerting a drowsy driver that he is straying off traffic lane (rumble strips); and,

2. An appearance that invites use in emergencies when traveling at high speed.

Shoulders also should meet the following requirements:

1. Maintain stability in all types of weather;

2. Prevent differential heave or settlement so as to maintain same elevation as adjacent traffic lanes;

3. Possess the ability to carry axle loads permitted on traffic lanes, though fewer in number;

4. Provision for free cross-drainage of surface water between driving lanes and ditch with minimal leakage into subgrade;

5. Have a service life consistent with that of the traffic pavement; and,

6. Provide intended service at low annual cost.

Experimental work by the Illinois Division of Highways involved many different shoulder designs. The performance of concrete shoulders meet all the requirements for efficient paved shoulders.

A study in South Dakota revealed that motor vehicles stopped on the shoulder once for each 1,800 vehicle-miles of travel; trucks or buses stopped about every 800 miles.

The California Division of Highways Planning Manual on the Structural Design of the Roadbed specifies that a shoulder design should be based on one percent of the equivalent wheel-load repetitions used in design for the adjacent main travel lane. A 6-inch thickness of plain pavement would be adequate for normal shoulder use. To increase the load carrying capacity of the shoulder, a cement-stabilized subbase is used.

Field research in Illinois indicated it was advantageous to tie shoulders to the mainline pavement to prevent separation. Also, the joint should minimize water infiltration. Eliminating this infiltration into the longitudinal joint, migration of subbase material and possible faulting of joints is minimized.

To provide for safety during times of poor visibility, edge delineation that combines paint striping with rumble strips should be provided. By painting a stripe on the shoulder next to the traffic lane, the corrugations of the rumble strip will reflect the headlight beams. Corrugated rumble strips serve two purposes. When placed at intervals, an audio-vibratory disturbance is produced that alerts drivers when they stray from traffic lanes. Also, they are an effective means of discouraging traffic from using the shoulder unless needed for emergency use.
As of 1973, only California and Iowa had a design load criterion for paved shoulders. California's Department of Transportation bases shoulder designs on one percent of the equivalent wheel loads in the adjacent lane with no traffic index less than 5.0. Iowa, on the other hand, designs shoulders on the assumption the paved strip must carry the heaviest wheel load.

States that pave full width have their shoulders built to 100 percent the structural strength of the mainline pavements.

Vehicles typically do not track in the exact same wheel paths; thus, not all passes of vehicles apply a fully effective stress repetition. Here, the concept of coverages of a lane by wheel passes is used to treat this factor. It is generally sufficient to equate 2 2/3 axle passes to the production of one coverage.

Two figures in this article provide a procedure to estimate equivalent 18-kip single axle loads.

Two load positions must be considered to determine required thicknesses: (1) the inside edge near the lane/shoulder longitudinal joint and (2) the outside free edge. The outer free edge may control design thickness when a lane/shoulder tie is provided. A minimum thickness of 6 inches is recommended. Thicker shoulders may be required depending on truck traffic, the level of structural support for the edge of the traffic lane desired, foundation support, load transfer at joints, and shoulder width. Critical stresses occurring from parked trucks on the shoulder make the use of uniform-equivalent thickness more favorable.

Tied shoulder width should be at least 3 to 5 feet to provide maximum structural benefits. A narrower shoulder could be used, but requires a thicker PCC shoulder slab.

The provision of a tie system extends the endurance of aggregate interlock and keyed joint under repeated loads. Increasing the number of tie bars provides greater load transfer reliability and minimizes separation.
FOUNDATION SUPPORT

The PCC shoulder may be placed directly on the subgrade soil, a granular subbase, or a stabilized subbase. Field studies indicate that a granular subbase should be used. However, drainage continuity considerations and the effect of moisture on the types of materials used should be considered when selecting the subbase.

SLAB LENGTH

A maximum slab length of 15 feet is recommended. Short slab lengths eliminate the need for steel reinforcement.

EFFECT OF SHOULDER ON TRAFFIC LANE

The effect the shoulder has on stress and deflection of the traffic lane is through load transfer at the longitudinal joints and by minimizing edge pumping potential. To improve the performance of the traffic lane, the optimum design of a shoulder should provide a maximum load transfer across the longitudinal joint with a thickness greater than or equal to 6 inches, width greater than 3 feet, and foundation support approximately equal to 200 pci.

"DESIGN GUIDE FOR BITUMINOUS CONCRETE PAVEMENT STRUCTURES"
J. H. Havens, R. C. Deen, and H. F. Southgate, UKTRP-81-17, Kentucky Transportation Research Program, August 1981

Design of shoulder pavements for nominal traffic would permit maintenance of traffic during lane closures due to wrecks or pavement repairs. Neither the design charts nor the EAL parameters are discretely applicable to the structural design of shoulder pavements. Shoulder pavements, in one sense, are analogous to hardstands; in another sense, they might be compared to low-class roads. Designs for 7.8 x 10^3 EAL's (equivalent to 1.07 18-kip axles per day or 7,800 repetitions in 20 years) may result in "overdesign." On the other hand, if it were necessary to divert traffic onto the shoulder to do maintenance on the mainline, the 20-year quota of repetitions might be accumulated in a few days. For this reason, thickness design of the shoulder should include some reserve capabilities. However, in the absence of more definitive criteria, it is suggested that designs for 3.1 x 10^4 ESAL's be used for guidance. Further reductions in thickness may be justified on the basis that shoulders are repairable. Design practices involving "daylighting" base courses to the embankment slopes, inside and outside, are overriding considerations.

"CURRENT PRACTICES IN SHOULDER DESIGN, CONSTRUCTION, MAINTENANCE AND OPERATION"
Highway Research Circular No. 142, Transportation Research Board, April 1973

To determine current practices in shoulder design, a survey was conducted. Questions were selected to obtain comparable data on shoulder design characteristics relating to warrants and guidelines, natural contrast, use of edge lines, shoulder widths, and structural quality of
shoulders as compared with that of the main lanes. Results indicated a
general agreement on the basic need for good shoulders. Thirteen percent
of the 47 respondents indicated they did not have any design criteria.
Also, four states permitted slower traffic to use the shoulder area to
facilitate a passing maneuver. All respondents endorsed the use of edge
lines. Seventy-seven percent of the respondents endorsed natural
contrasting. There was no agreement on the desirable widths of shoulders.
Thus, it is apparent that a standardization of shoulder design process is
in order.

The basic functions of a highway shoulder are (a) delineation, (b)
drainage, (c) structural support, and (d) emergency and safety uses.
Delineation is required so drivers may easily discern their proper paths in
the travel lane. The shoulders, whether surfaced or not, must insure that
water will drain rapidly from the pavement. The shoulder strip, if
properly designed, furnishes structural support to the pavement base and
surface courses by serving as a buttress along its edge. The emergency-use
function of a shoulder is the one most commonly cited. To serve this
purpose, the shoulder should be of adequate width and capable of supporting
the vehicle (including large trucks).

Geometric details of shoulder design include the width, cross slope,
continuity of the shoulder, and delineation and contrast of the shoulder
from the mainline. Recommendations for width include (a) 10 to 12 feet of
surfaced right shoulders for high-type facilities (where the desired cannot
be obtained, a width of at least 8 feet appears to be needed) and (b) on
highways carrying low volumes and/or lower-speed traffic, 4 feet is minimum
and the desired width is 6 to 8 feet. Widths of the left shoulder vary,
according to the class of highway, from 2 to 10 feet.

Recommendations for cross slopes on shoulders were

a) Hard surfaced 0.03 to 0.05 foot/foot
b) Gravel or crushed stone 0.04 to 0.06 foot/foot
c) Turf 0.08 foot/foot

It also is recommended that shoulders be continuous; this principle is
now being applied widely on high-type highways. Delineation also must be
provided.

Studies in Illinois indicate that shoulders may be designed less
strong than pavements with respect to axleload repetitions, but they must
be capable of supporting the same axle weights as the pavement without
structural damage. The study showed that a 3-inch thickness was not
sufficient to serve without early distress. The 6-inch thickness of
portland cement concrete appears adequate and maintenance requirements
would be minimal.

Missouri relates type of shoulder to the ADT of the highway. A sod
shoulder would be used when traffic is below 750 vehicles per day. A full-
deep granular shoulder (sealed dense-graded granular surface on an open-
graded aggregate base with 2-foot-x-2-inch edge strip of asphaltic
concrete) is considered useful for an ADT range from 3,500 to 20,000. These
shoulders, for ADT's greater than 1,700, are for concrete pavement.
Missouri constructs flexible pavement full width from in slope to in slope.
For less than 1,800 ADT, the designs are nearly the same.

Shoulder design recommendations also are given by the Texas Highway
Department.
In summary, a need has been shown for construction of full-depth monolithic pavements throughout the entire width of the shoulder area so as to avoid the costly problems of 1) maintaining a longitudinal joint just outside the right-hand edge line, 2) eliminating the drop off or raised shoulder at the right-hand pavement edge, and 3) eliminating shoulder structural distress due to traffic loadings.

"EXPERIMENTAL PORTLAND CEMENT CONCRETE SHOULDERS: DESIGN AND CONSTRUCTION"
J. H. Havens and A. Rahal, Report 403, Kentucky Department of Transportation, 1974

Kentucky's first Portland cement concrete shoulder project was constructed in 1970. A 3.4-mile section of US 31W, between Radcliff and Tiptop, was scheduled for reconstruction and was chosen for implementation. The mainline concrete pavement is 9 inches thick on 4 inches of dense-graded aggregate. Normal design of shoulders for this type of project would have been full-depth dense-graded aggregate daylighted through the shoulder slope and covered with a double inverted seal extending 10 feet from the pavement edge.

Five-, 6-, and 7-inch shoulders, with and without wire mesh, were thought to encompass shoulder structural requirements. A tied longitudinal joint was provided between the mainline pavement and the shoulder slabs to prevent faulting and to permit separate construction of the shoulder. A companion feature on this project was the use of neoprene joint seals. To prevent or deter use of the shoulders as traveling lanes, heavily corrugated rumble strips were formed into the shoulder concrete.

It was thought that the structural design of shoulders should be at least equal to that of concrete streets in residential areas and withstand legal axle loads and occasional overloads. In June 1974, the FHWA recommended not less than 6-inch-thick shoulder slabs, without steel reinforcement, on a stabilized base course. Further study is indicated with regard to the experimental sections.

"STRUCTURAL DESIGN OF PCC SHOULDERS"
J. S. Sawan and M. I. Darter, Annual Meeting, Transportation Research Board, January 1979

Because of the lack of a comprehensive structural design procedure, most PCC highway shoulder designs have been based on engineering judgment. This study developed and proposed a structural design procedure considering most factors that affect the design. Most experimental data used in this study were obtained from previous studies on the field performance of PCC shoulders.

The major variables influencing PCC shoulder design include the following:

1. Slab thickness and tapering of thickness;
2. Joint spacing;
3. Foundation support and loss of support;
4. Tie between shoulder and traffic lane;
5. Width of shoulder slab; and,
6. Design and condition of adjacent traffic lane.

Considering these variables, the following conclusions were indicated with respect to shoulder design and performance:
1. Two load positions must be considered in determining required thicknesses:
   a. Inside edge near lane/shoulder joint (encroaching traffic); and,
   b. Outside edge of shoulder (parked traffic).
2. Minimum thickness of 6 inches is recommended;
3. Tapering of thickness is not recommended;
4. Shoulder width should be at least 3 to 5 feet;
5. Tie systems that provide at least 50 percent load transfer greatly reduce critical stresses;
6. Moderate foundation support is justified; and,
7. Slab length should not exceed 15 feet.

Much of the report focuses on the development of a computer program to analyze a given set of input design parameters. The program determines the fatigue damage due to the specified loadings. A minimum thickness may be chosen for the given conditions by analyzing different thicknesses and relating allowable fatigue damage to shoulder thickness. This program appears to be useful in that many different designs may be analyzed quickly, and it is more likely that an optimum design may be determined.

"WHAT WE HAVE LEARNED TO DATE FROM EXPERIMENTAL CONCRETE SHOULDER PROJECTS"
E. C. Lokken, Record 434, Highway Research Board, 1973

This paper summarizes performance, examines design details developed from experimental projects, and makes recommendations for design for maximum safety and economy. Concrete shoulders in urban areas have functioned primarily to furnish additional emergency parking or travel area and to improve surface drainage facilities. In general, the same thickness has been used for the shoulder as for the main roadway. Several states now include concrete shoulders as a standard shoulder design; details of concrete shoulder standards may be obtained from Illinois and Pennsylvania.

From a structural standpoint, the 6-inch thickness used on projects to date has shown excellent performance. Several projects have used a wedge-shaped shoulder section, meeting the roadway pavement thickness at its edge and thinning to 6 inches at the outer shoulder edge.

There has been little evidence from experimental projects that a subbase of any kind has contributed to concrete shoulder performance. The small reduction in cracking that resulted where a subbase was used appears to be insignificant. Because shoulders carry no sustained load, the cracks are subject to little traffic-induced deterioration.
In an experimental shoulder section in Illinois, it was shown that longitudinal joint sealing was not needed. However, some states have felt that sealing, because of its relatively low cost, is additional insurance against leakage of water to the subgrade at this critical point.

The need for deformed tie bars or tie bolts between roadway and shoulder slabs definitely has been established. During the life of the shoulder, the low relative cost of tie steel and the advantage of positive prevention of separation at the critical joint between the two slab makes its use a wise investment.

The effectiveness of transverse contraction joints at short spacings in reducing cracking in shoulders has been demonstrated. There is no indication that contraction joints need to be uniformly spaced or that 20 feet should be the minimum spacing. Depth of the contraction joint has been normally a fourth of the depth of the shoulder slab; most contraction joints have been sealed with a low-cost rubber asphalt compound.

Corrugations have been built into most concrete shoulders. The rumble effect is a distinct safety feature, and corrugations have served to delineate lateral roadway limits.

With one exception, all concrete shoulders have been built without reinforcement. Performance does not indicate a need for steel reinforcement in concrete shoulders.

There is no mention in this report concerning the ability of the shoulder to carry a specific sustained load. It is further suggested that shoulder design standards be obtained from Illinois and Pennsylvania for comparison.

"SHORT-SLAB UNREINFORCED CONCRETE PAVEMENT AND SHOULDERS: A FIVE-YEAR PERFORMANCE SUMMARY"
J. M. Vyce, Research Report 95, New York Department of Transportation, 1982

In 1975, two pavements on I-88 were constructed with short non-reinforced concrete slabs and concrete shoulders. They were separated by a section with standard 63-foot 6-inch mesh reinforced slabs and asphalt shoulders, used for control purposes. Two portions on each short-slab project were built with slab lengths of 23 feet 4 inches and 26 feet 8 inches, and one of these sections on each contract was constructed with no longitudinal joint between lanes. In addition, a concrete secondary road relocated as part of another nearby I-88 contract was placed 7 inches thick with reinforcement, with slab lengths in the pattern of 18-22-16-20 feet. After one year of service, one of the short-slab pavements on the mainline exhibited an unusual amount of deterioration. Random and longitudinal cracks were present in several areas, as were spalls over the tie bars across the pavement-shoulder longitudinal joint. This situation led to more intensive monitoring and observation on the experimental and control pavements than had been anticipated during the initial years of service.

Relatively substantial distress was occurring on only one of the experimental contracts, indicating that several material, design, and construction variations were responsible for a significant portion of the distress. These included the quality of subgrade material, subbase thickness, and treatment of the longitudinal pavement-shoulder joint. Several changes have been made and applied to subsequent contracts, but these experimental contracts will continue to be monitored to determine the consequence of having no mesh to control cracking.
"IMPROVING SUBDRAINAGE AND SHOULDERS OF EXISTING PAVEMENTS"

The objective of research was to determine whether or not moisture is accelerating the deterioration of the pavement and, if so, at what rate? Deterioration of the shoulder in the vicinity of the pavement-shoulder joint is considerably more severe when a significant quantity of water is present beneath the pavement and shoulder structures. The magnitude of the severity depends on amount and distribution of rainfall, temperature, expansive clay subgrades, and the strength and type of structural shoulder section.

Not much is known about stress and strain levels in shoulders due to the lack of information on the exact moisture and temperature condition of the materials.

The first step in the design procedure is to estimate the variation of moisture content and temperature (shoulder) over the life of the shoulder. Once these are known, calculated stresses and strains may be used to predict the life of the shoulder.

The shoulder-pavement joint is critical to the performance of the shoulder. Technology to minimize water infiltration into joints has been poor. Improving the pavement-shoulder joint will improve performance of the shoulder.

Shoulders have essentially the same problems as the mainline pavement. However, they are amplified by two major factors:

1. The shoulder is commonly a thinner structural section; and,

2. Moisture is concentrated at both edges of shoulders as constructed on today's highways.

Moisture affects the behavior of the materials used in shoulder design. Performance deteriorates rapidly when the materials are exposed to moisture.

Temperature variations in the shoulders are different than those in the adjoining pavement. Thus, different stress conditions exist. Here, the performance of the shoulders suffer the most as a result of these differences.

"A SYMPOSIUM ON HIGHWAY SHOULDERS"
Bulletin 151, Highway Research Board, 1957

The following conclusions and recommendations were offered:

SHOULDER WIDTHS

Four to 10 feet

TURF SHOULDERS

Have problems with rutting due to moisture and poor surface run-off. These conditions greatly degrade the stability of the shoulder. A method to improve stability of ALL shoulders was the practice of placing a permeable subbase under the pavement and extending it through the shoulder to the ditch.
SHOULders for Flexible Pavement

A type of shoulder pavement support used was one which had multilayers from ditch line to ditch line. Of 43 states, the following statistics were found:

(1) Eighteen states used base courses extending the full width of section. The remainder widened the base course beyond the width of traffic lane from 1/4 to 1 1/2 feet.

(2) Twenty-five states used a bituminous surface course on the shoulders. Thirteen of those states used a bituminous surface treatment mixed in place.

Heavy Duty highways

Shoulders should consist of hot-mix asphaltic concrete or penetration macadam.

Secondary roads

Shoulder pavement should consist of surface treatment or mixed-in-place surface courses.

Geometric design

Shoulder should be continuous with a usable width of 8 to 12 feet.

Cross slopes

One-quarter to 1 inch per foot.

Relationship of Accident Rate to Highway Shoulder Width

Accident data on two-lane highways in Connecticut with paved shoulder widths ranging from 0 to 10 feet were tabulated. The average daily traffic volumes had a general relationship to the pavement, shoulder, and total surface widths. However, no relationship was found to exist with the accident rate.

Policy for construction (Ohio) provided stabilized shoulders along the outside pavement edge of all divided highways and along each edge of all two-lane pavements with more than 200 heavy commercial vehicles per day. Some turf shoulders (limited to low-volume roads) were still used.

"Shoulder Use on an Urban Freeway"


The single most frequent reason to use the shoulder was "to offer assistance." However, this use would not have occurred if there had not been an earlier use for some reason. The most frequent reasons for an initial usage were motor trouble or tire trouble. Uses involving accidents do not seem disproportionately great nor do uses for roadway maintenance.
However, no usage was recorded unless the maintenance vehicle moved back and forth into the traffic stream. The median length of stay was under 5 minutes. A great number of vehicles pull onto the shoulder for a few minutes and then leave, and these represent a major usage of shoulders.

Results of the study indicated that the percentage of vehicles using the shoulder that were trucks was consistently higher than the percentage of trucks in the traffic stream as a whole. The reverse was generally true for passenger cars.

"USE OF TOTAL BENEFIT ANALYSIS FOR OPTIMIZING LANE WIDTH, SHOULDER WIDTH, AND SHOULDER SURFACE TYPE ON TWO-LANE RURAL HIGHWAYS"

The objective is to balance the various costs of design parameters so the total safety benefit is maximized. A procedure called total benefit technique is used to approach the problem. Four phases of the technique are as follows:

Phase 1: Determine construction costs.
Phase 2: Determine accident costs.
Phase 3: Determine candidate designs.
Phase 4: Select the final design.

Results of the analysis allow an agency to select designs of pavement width, shoulder width, and shoulder type that are optimum from a safety standpoint.

"CONCEPT AND DESIGN OF TRUCK RESTS"
Memo from J.H. Havens to W. B. Drake, August 19, 1980 (File H.3.27, P.3.9).

A truck rest (or truck pull-off) is a surface area, separate from the normal continuous shoulder, designed to provide space for parking of one or more vehicles for semi-emergency stopping. A truck rest differs from a rest area in that they do not provide separated parking areas and additional facilities (i.e., restrooms), and they are used for relatively short periods of time.

The need for truck rests depends on the character and volume of traffic and the type of highway and its geographical location. Only a high percentage of heavy trucks would warrant such facilities. Two-lane roads in mountainous terrain further warrant the use of truck rests.

Truckers stop most often at the crests of hills. This provides the optimum combination of safety and economy.

The entire truck rest facility should be designed to be separate from the normal shoulder. For those classes of highways requiring a 30-foot clear zone, the entire facility could be constructed within that zone but outside the normal shoulder. Structural design criteria for the pavement would be established by the volume and character of the traffic. EAL parameters would not be entirely applicable. Estimates of the frequency of use would be desirable. However, pavements equivalent to the mainline
should provide adequate performance. More conservatively, the pavement should be designed to withstand the static weight of the truck plus reserve strength for fatigue. Geometrics are partially established by the necessity and function of the truck rest. A storage area 320 feet long is proposed; however, further investigation may alter this. Deceleration and acceleration tapers should be in accordance with the AASHTO blue book. Signing should be in accordance with MUTCD.

Most shoulders are not designed to handle the load of heavy vehicles. They are usually thin overlays to accommodate cars and light trucks adequately, but do not perform well when heavy vehicles travel over them. Unsurfaced aggregate shoulders and soils tend to frost heave, rendering them unstable upon melting. These exposed shoulders also wash and erode, thus causing further burden on maintenance.

All advantage should be taken in design and retrofitting to utilize rock subgrade to bring the shoulder embankment up to the foundation elevation for the desired pavement template. Soil should not be used unless trench-type construction is sought. Edge drains or french drains might be needed if there is a porous draining base beneath the mainline pavement. There, a thicker pavement would be needed.

By implementing the truck rest, present shoulder thickness requirements could be designed only for their intended use. If the need arises to divert traffic to the shoulders, the shoulders could be strengthened in advance or repaired afterwards. An overall benefit (economic) may be realized by reducing the mileage of heavy-duty shoulders.

"OPERATIONAL AND SAFETY EFFECTS OF DRIVING ON PAVED SHOULDERS IN TEXAS"

The objective of this study was to quantify benefits and/or disbenefits associated with shoulder usage in Texas. Uses of paved shoulders include pulling onto them to let faster vehicles pass on rural two-lane roads, to bypass left-turning vehicles at driveways or non-channelized intersections, or as an auxiliary lane.

A combination questionnaire and personal interview technique was used to obtain additional insight. The most common responses were as follows:

a) Intended Function -- for emergency stops;

b) Operational Problems -- usage as a passing lane (passing on right);

c) Safety Problems -- usage near narrow bridges; and,

d) Field Experience -- most drivers will use a paved shoulder.

The addition of paved shoulders to a two-lane roadway is effective in reducing the total number of accidents. The conversion of a shoulder to an additional travel lane increases the total number of accidents on low-volume facilities.

Two separate accident investigations were conducted as a portion of this research. Their objectives were to determine the safety effects of paved shoulders on three types of rural highways. The initial
investigation was an analysis of accident rates, patterns, and characteristics on roadways with and without paved shoulders. The second was a before-and-after study to determine the change in safety characteristics caused by the addition of paved shoulders. The most significant results from these analyses are as follow:

a) The accident rate for each roadway type increases as the volume increases;

b) Two-lane highways without paved shoulders have the highest accident rates and are most sensitive to changes in traffic volume;

c) "Poor-Boy" roadways have an accident rate in between the other two types (two-lane highways with paved shoulders and two-lane highways without paved shoulders) of roads and are least sensitive to volume changes;

d) Construction of full-width paved shoulders at rural intersections may be effective in reducing the number of accidents on high-volume roadways;

e) The addition of full-width paved shoulders to a two-lane roadway is effective in reducing the total number of accidents that occur; and,

f) Conversion of a shoulder to an additional travel lane results in fewer total accidents only if the volume is greater than 3,000 vehicles per day.

Field measurements were made to quantify operational characteristics on three types of rural highways. Significant findings are as follow:

a) Operational benefits derived from a full-width paved shoulder increase as the volume increases;

b) These benefits are minimal at low and moderate volumes; however, at volumes greater than 200 vehicles per hour, a paved shoulder will increase the speed on the roadway by at least 10 percent;

c) Only about 5 percent of the traffic actually uses the shoulder;

d) Conversion of the shoulder to an additional travel lane offers no apparent operational benefits until the volume reaches about 150 vehicles per hour; and,

e) Such a conversion will result in more than two-thirds of the traffic using the outside or "shoulder" lane.

Recommendations from this study included the following:

a) A paved shoulder should not be considered a part of the roadway;

b) Paved shoulders should probably be added to all two-lane roads with traffic volumes in excess of 200 vehicles per hour; and,
c) Conversion of a paved shoulder to an additional travel lane probably should not be considered unless the volume on the roadway exceeds 3,000 vehicles per day.

"EFFECT OF SHOULDER WIDTH AND CONDITION ON SAFETY: A CRITIQUE OF CURRENT STATE OF THE ART"

Shoulder-widening projects should not be selected randomly but should be based primarily on the incidence of run-off-the-road and head-on accidents. Widening should be given a higher preference on moderate and high volume roads and where related accident numbers are abnormally high. Shoulder widening of horizontal curves and winding sections should be given higher priority over level tangent sections. On rural two-lane roads, optimal shoulder widths are 6 to 9 feet.

"THE EFFECT OF LANE AND SHOULDER WIDTHS ON ACCIDENT REDUCTIONS ON RURAL, TWO-LANE ROADS"
C. V. Zegeer, R. C. Deen, and J. G. Mayes, Research Report 561, Kentucky Department of Transportation, October, 1980.

A study in Oregon concluded that total accidents increase with increasing shoulder width (except for roads with AADT's of 3,600 to 5,500). Most other study's have revealed a decrease in accidents with an increase of shoulder width for highways with an AADT's of 3,000 to 5,000. In a North Carolina study, it was found that paved shoulders had a significantly lower traffic experience and severity index. In Ohio, shoulder stabilization resulted in a 38-percent reduction in all accidents and a 46-percent reduction in fatal accidents. Cost of widening and stabilization of shoulders depends on the amount of widening to be done and techniques used.

"PAVEMENT AND SHOULDER MAINTENANCE PERFORMANCE GUIDES"

This was a joint effort by eight states that centered on the following seven pavement and shoulder maintenance activities:

1. Crack sealing of bituminous pavements;
2. Crack and joint sealing of concrete pavements;
3. Shoulder maintenance -- bituminous shoulders with bituminous pavements;
4. Shoulder maintenance -- bituminous shoulders with concrete pavement and concrete shoulders with concrete pavements;
5. Seal coating;
6. Repair of concrete joints and spalled areas; and,
7. Bridge approach settlement correction.

Elements of each maintenance activity included the types of distresses, probable causes, criteria or warrants, materials used, frequency, expected life, and cost per unit.

Performance guides to follow were field tested for only a 12-month period; however, the performance guide for each maintenance activity is considered to be the state-of-the-art on existing materials, equipment, and procedures. Of interest to this study are the following:

MAINTENANCE OF BITUMINOUS SHOULDERS WITH BITUMINOUS PAVEMENT

Performance guides for crack sealing are applicable to bituminous shoulder maintenance. Probable or root causes for shoulder deterioration may be different than the roadway proper; however, corrective or preventive maintenance should be essentially the same.

When weeds are visible in cracks, a good herbicide should be used promptly to preclude further accelerated deterioration of the paved shoulder. Depending on environmental surroundings, a good herbicide should last one to three years. Shoulder turf and/or gravel build-up should be removed when the build-up restricts shoulders from draining freely, normally every two or three years.

MAINTENANCE OF BITUMINOUS SHOULDERS WITH CONCRETE PAVEMENTS AND CONCRETE SHOULDERS WITH CONCRETE PAVEMENT

Performance guides for crack sealing, seal coating, and shoulder maintenance of bituminous shoulders with bituminous pavement are applicable to maintenance of bituminous shoulders with concrete pavements. The performance guide for crack and joint sealing for concrete pavement is applicable to maintenance of concrete shoulders with concrete pavements.

For lane/shoulder joint separation (PCC pavements with bituminous shoulders), the joint should be sealed when visual inspection indicates water is infiltrating the lower layers. A rubber asphalt is recommended to seal the longitudinal shoulder joint.

For lane/shoulder drop off (PCC pavements with bituminous shoulders) the warrant for repair states that, when the drop off is 1 inch or more for 50 percent or more of a mile, build-up of the shoulders is necessary. To correct lane/shoulder drop off, bituminous hot-mix, bituminous cold-mix, slurry seals, or chip seals have been used successfully.

Likewise, lane/shoulder heaves (PCC pavements with bituminous shoulders), should be removed with a motor grader when the differential is 1 inch or more for 50 percent or more of any mile. However, safety is the prime consideration with regard to shoulder drop off and shoulder heave and corrective work should be done even though less than 50 percent of any one mile may be heaved or sagged 1 inch.

Expected performance is 4 to 5 years for joint, drop off, and heave repairs of shoulders.
"IMPROVED DRAINAGE AND FROST ACTION CRITERIA FOR NEW JERSEY PAVEMENT DESIGN - VOLUME II, EXPERIMENTAL SUBSURFACE DRAINAGE APPLICATIONS"


The fundamental objective of this research project was to document design methods and construction and maintenance procedures for a subsurface drainage system. In the initial report on pavement underdrainage, the extent of water-induced distress in New Jersey highways was described. The report identified an urgent need for better internal drainage. Theoretical assessments and laboratory investigations were undertaken to develop a drainage layer design. This report describes efforts to verify the effectiveness and practicality of that design through test-track and field trials.

A circular test track at the University of Illinois was used to evaluate small-scale sections of pavement containing a drainage layer of either bituminous-stabilized open-graded (BSOG) aggregate material or a non-stabilized open-graded (NSOG) aggregate. This work also involved evaluation of filter cloth and lime-fly ash stabilization to prevent intrusion of fines into the open-graded material.

The Illinois test-track results indicate the inclusion of the NJDOT's open-graded layer in a pavement above dense-graded granular material will not prevent the saturation of that material. However, the layer will tend to accelerate drainage of the underlying dense-graded material. Placing an open-graded course immediately below the lowest bound layer of a pavement provides an effective medium to carry away infiltrated surface water. Also, if the open-graded layer is properly designed, it will transmit and distribute applied traffic loads to an underlying subbase material without deteriorating consolidation or reorientation of the aggregate matrix.

A surprising finding was that no infiltration of fines into the open-graded layer from the underlying material was observed. This applied equally to sections having filter cloth, subbase stabilization, and no protective medium other than the subbase's own filtering ability.

Field trials of the drainage system were completed near the end of the study period, and performance data of any significance will not be available for a number of years. Therefore, emphasis in this report is placed on defining construction sequences and methods for underdrainage components.

The proposed New Jersey internal drainage design is a finely tuned balance of functional surface drainage, a subsurface drainage layer, and longitudinal edge drains. A drainage layer immediately below the lowest bound layer of pavement has the greatest potential for eliminating water build-up. This layer of either BSOG or NSOG material, when combined with appropriate edge drains and outlets, can remove intruded surface water before it damages the pavement structure.

"DESIGN AND USE OF HIGHWAY SHOULDERS"

Shoulders are an important element in the highway. They give structural support, and the safety benefits far exceed the cost of shoulders.
Many problems still remain, especially with shoulders on rural roads that have not been upgraded to today's standards. The joint between a concrete pavement and a bituminous shoulder is still a prevalent problem. Conclusions contained in NCHRP Report 202 as to design, sealants, and drainage should be tested in controlled environments.

Studies should be conducted to improve drainage systems. More attention should be given to the evaluation of shoulder conditions. An analysis by the Federal Highway Administration showed that shoulder widening or improvement had the highest benefit/cost ratio of any safety improvement for which there is adequate data.

"DESIGN PRACTICES FOR PAVED SHOULDERS"

Deterioration of asphaltic concrete shoulders normally occurs at the joint between the pavement and shoulder. This deterioration not only affects structural strength of the shoulder but also leads to faulting, cracking, spalling, and settlement of the pavement and/or shoulder surfaces. Hence, deterioration of this sort may prove to be a serious safety hazard.

The main cause of joint deterioration is water infiltration. If water penetrates into unsealed joints, it will flow through the subbase and subgrade of the shoulder. Coupling this with repeated traffic loads, the subbase beneath the shoulder and concrete slab can be pumped, causing the failure of the slab and cracking and/or settlement of the shoulder.

Attempts to prevent water infiltration have been made by sealing the longitudinal joints. However, it has been conceded that no joint can be watertight for the life of the pavement. Thus, steps should be made to minimize the amount of water that flows through the joint and to design stronger pavement-shoulder structures that utilize drainage and base treatment.

Shoulders constructed with 1 1/2 to 2 inches of asphaltic concrete and 6 inches of granular base have performed poorly due to gross underdesign. In addition, sections having deep granular bases have experienced settlement problems caused by one or a combination of the following factors:

1. Inadequate compaction;
2. Use of frost susceptible material;
3. Poor gradation and/or small maximum size aggregate; and,
4. Use of low-quality uncrushed gravel aggregate.

"CURRENT DESIGN POLICIES OF VARIOUS AGENCIES"

Arkansas Shoulder strengths, while a major concern, are not specifically designed, but rather are based on previous experience.
<table>
<thead>
<tr>
<th>State</th>
<th>Shoulder specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltimore County,</td>
<td>Shoulder strengths are not designed, but all Maryland shoulders are either stabilized (double surface treatment on 6 inches of crusher-run stone) or paved full mainline depth if used as a parking lane/off peak-running lane/peak.</td>
</tr>
<tr>
<td>California</td>
<td>Shoulder strengths are designed on the basis of two percent of equivalent axleloads (EAL) on the adjacent lane, with a minimum traffic index of 5.0. Use of two percent of EAL was established after in-house research and discussions with other states. (That research also determined that about three percent of the truck traffic encroaches 1 to 2 feet onto the shoulder in rural areas.)</td>
</tr>
<tr>
<td>Connecticut</td>
<td>All shoulders are paved to the same design strength as mainline pavements.</td>
</tr>
<tr>
<td>Georgia</td>
<td>Shoulder widths and strengths are determined considering truck and vehicle volumes.</td>
</tr>
<tr>
<td>Idaho</td>
<td>Shoulder strengths are typically designed the same as mainline pavements.</td>
</tr>
<tr>
<td>Illinois</td>
<td>Shoulder design is empirical, except where anticipated shoulder uses require greater shoulder strengths (such as in the vicinity of weigh stations, at locations of repetitive truck parking, and where shoulders will be used for maintenance of traffic during construction).</td>
</tr>
<tr>
<td>Lake County, Illinois</td>
<td>Shoulder strengths are based on standard designs and are not normally designed for each project.</td>
</tr>
<tr>
<td>Maryland</td>
<td>Shoulder strengths are primarily designed on the basis of truck volumes. For less than 500 trucks per day, one-way in 10th year, a 1-year life as a through-lane is used for shoulder thickness design. Where more than 500 trucks per day one-way in 10th year, a 2-year life as a through-lane is used for shoulder thickness design. On bituminous concrete paving projects with greater than 500 trucks per day in 10th year, the mainline pavement section (i.e., full depth) is extended 2 feet into the shoulder area to compensate for vehicles tracking beyond the striping at the road's edge. On low-type facilities, a lesser (thinner) section is provided. Where shoulders are to serve as through lanes, bypass lanes, turning lanes, or extra paving at turning radii, the same paving sections as the mainline are provided.</td>
</tr>
<tr>
<td>Nebraska</td>
<td>Shoulder widths and strengths are based on traffic volumes, highway classifications, and proposed uses.</td>
</tr>
<tr>
<td>State</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Shoulder strengths are typically designed to be 10 percent of the mainline pavement design. The use of 10 percent is based on previous poor experience with shoulders of lesser strength.</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Shoulders are constructed of the same materials as the mainlines. For concrete pavements with concrete shoulders, the shoulder is tapered from the traffic lane depth to 6 inches or 1/2 mainline thickness, whichever is greater, at the outer edge of the shoulder. For flexible pavements on roadways with a curving and rolling alignment and/or where the truck volume is 12 percent or more of the traffic stream, the shoulder is of the same thickness as the mainline. For flexible pavements on roadways where sight distances are good and truck volumes are less than 12 percent of the traffic stream, 80 percent less ADT is used for design of the shoulder strength.</td>
</tr>
<tr>
<td>New York</td>
<td>Shoulder strength is designed on the basis of traffic volumes and expected truck loads.</td>
</tr>
<tr>
<td>North Carolina</td>
<td>Shoulder widths and strengths are determined using traffic volumes and highway classifications.</td>
</tr>
<tr>
<td>Texas</td>
<td>Shoulder strengths are typically the same as the mainlines.</td>
</tr>
<tr>
<td>West Virginia</td>
<td>Shoulder strength is normally not designed. Normal practice is to provide aggregate and paving in the same overall thickness as the mainlines.</td>
</tr>
</tbody>
</table>
APPENDIX B

PERFORMANCE SURVEYS

Portland Cement Concrete Shoulders
US 31W
31 W
W/41/47
Shoulder Sung
N.8 lane
walking south

(w)

Note
This Report

Hair line
Cracks
in shoulder

(PS)

Evident
Patches

Raveling

Louisiana

Main Line

5' Concrete
With Wire Mesh

Shoulder

Main Line

Station Numbers were checked out in North
Bound Lane. These Station Numbers correspond
with South Bound Lane.

All joints in shoulder were filled with
Sandy Sports were depressed as much as 3/4
to finish below Surface.
...
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>82</td>
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<td>282+00</td>
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**Notes:**
- Shoulder:
  - Shoulder 82 near shoulder:
    - Shoulder 413 east shoulder:
- Main Line:
  - 413 west side:
  - 413 east side:
  - 413 west side:
  - 413 east side:
  - 413 west side:
  - 413 east side:
  - 413 west side:
  - 413 east side:
  - 413 west side:
  - 413 east side:
  - 413 west side:
  - 413 east side:
  - 413 west side:
  - 413 east side:
  - 413 west side:
  - 413 east side:
6-INCH REINFORCED
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<th>4+05</th>
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<td>6-534-535</td>
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<td>1+15</td>
<td>6-477-483</td>
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- 6" CONCRETE WITH WIRE MESH
- B+15, STA 328+00
- 6-310-369
- 6-328-374
- 3+15 STA 325+00
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**Note:**
- 1B+15 foritched
- 1B+15 for parallel
- 1B+15 for through

**Bean Curran Ave:**

- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15

**8F+15:**
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
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- 8F+15

**8F+15:**
- 8F+15
- 8F+15
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- 8F+15

**8F+15:**
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- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
- 8F+15
7-INCH NON-REINFORCED
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Shoulder Main Line
7-INCH REINFORCED
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<tr>
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190+02 started ground curve.

Shoulder Main Line

100
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<td>+99</td>
<td>204411</td>
</tr>
<tr>
<td>+61</td>
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</tr>
</tbody>
</table>

No N-1
APPENDIX C

PERFORMANCE SURVEYS

Bituminous Concrete Shoulders
US 31W
APPENDIX D

PERFORMANCE SURVEYS

Bituminous Concrete Shoulders
I 275