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OPTIMIZATION OF AC SHOULDER DESIGN AND CONSTRUCTION FOR PCC PAVEMENTS

Study SD1998-07
Final Report

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16. Abstract

The performance of asphalt concrete (AC) shoulders adjacent to Portland cement concrete (PCC) pavements has been extremely variable throughout South Dakota, with relatively good performance on some projects and severe shoulder subsidence and shoulder joint seal failure occurring on others. The factors behind poor shoulder performance may be directly related to shoulder design and construction, combined with regional climatic and topographical features.

The research performed in this study sought to better define the causes of shoulder subsidence and joint seal failure, and to develop and implement a field study that tests the effectiveness of various design strategies and construction practices in reducing or minimizing settlement and seal failure. In the study, a total of 29 in-service shoulder structures located in the eastern half of the state were surveyed for condition and tested for load response characteristics using non-destructive deflection testing (NDT) techniques. The observations and resulting data were then used to formulate a set of shoulder design/construction strategies that could be tested as part of an actual paving project. Subsequently, a total of 11 different shoulder strategies were included in a mainline PCC paving project located on SD 37, north of Parkston. The construction of the test shoulders in fall 2001 were carefully monitored, and condition surveys and NDT testing of the shoulder sections were conducted at periods of 7 and 12 months following construction. This report discusses the results of the entire research effort and the recommendations made to the South Dakota DOT concerning their AC shoulder design and construction practices.

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Research Objectives

The overall objective of this research project (SD 1998-07) was to investigate the factors that cause poor performance of AC shoulders adjacent to PCC pavement and to identify changes in design and construction that will lead to substantially improved shoulder performance. The specific objectives were as follows:

- To explore technologies, construction practices, and design modifications that may improve AC shoulder performance adjacent to PCC pavements.
- To examine the need for different shoulder designs based on regional and climatic factors.
- To determine the effect of the time at which sealing occurs on PCC/AC shoulder joint performance.

Research Approach

To achieve the objectives of this research project, several individual tasks were initiated and completed by the research team, ERES Consultants Division of Applied Research Associates, Inc. (ARA–ERES). To begin with, a literature search and review was conducted, which provided valuable insight into past and current shoulder design and construction practices, as well as reported performance. Next, a comprehensive field evaluation of 29 highway shoulder sites throughout the eastern half of South Dakota was performed. This evaluation included both a detailed visual condition survey and falling-weight deflectometer (FWD) testing to determine shoulder structural characteristics. Results of both the literature search/review and the field evaluation were presented to the Technical Panel in September 1999, along with preliminary recommendations for shoulder strategies to be tested as part of a formal field experiment.

During and shortly after the search for a suitable highway construction project in which to implement the shoulder experiment, a set of construction plan notes was developed detailing how and where to build various shoulder test sections. The plan notes were then incorporated into the construction plans and specifications for Project No. NH 0037(75)43, an 18-mile long concrete pavement–asphalt shoulder construction project located on SD 37 near Parkston.

Construction of the SD 37 shoulder test sections took place in September and October 2001, under the field supervision and observation of the SDDOT Field Engineer and key members of the ERES research team. A total of 22, 500-ft-long test sections representing 11 different asphalt shoulder strategies were built for the field experiment. The sections were visually surveyed and FWD-tested at 7 and 12 months after construction.

Based on a thorough analysis of the data collected in the study and considerations of the level of performance, constructability, cost-effectiveness, and other factors, a set of practical implementation guidelines for improved shoulder design and construction practices was developed. Summaries of the key findings and recommendations of this research effort are provided below.

Key Findings

- Poor asphalt shoulder performance is experienced widely among midwestern states, with several key factors (inadequate thickness, truck encroachment, poor construction and treatment of the shoulder joint, and inadequate drainage) being cited.

- AC shoulder performance can be drastically reduced through high moisture infiltration rates, underscoring the importance of facilitating drainage, be it at the surface (adequate cross-slope, effective sealing of joints/cracks), below the surface (use of drainage systems and/or permeable layers), or both.

- Field evaluation of many different AC shoulders in South Dakota indicates a general relationship between shoulder drop-off and longitudinal joint seal failure. While it is not known for sure if one parameter is more dependent upon the other, it is believed that settlement of the shoulder occurs initially due to other factors (inadequate compaction of shoulder layers, presence of water in the shoulder structure) and that as the shoulder settles and/or widens, the joint seal becomes debonded. The failed joint seal allows more water to infiltrate the shoulder structure, which in turn facilitates shoulder drop-off and widening.

- While the effects of leveling aggregate base windrows within a 24-hour period could not be properly assessed in this study, it is believed that this simple practice can effectively safeguard against construction problems caused by ponded water.

- During shoulder joint routing operations, it is vital that the router operator cuts the joint reservoir so that it fully adjoins the edge of the mainline PCC. If slivers or remnants of AC shoulder surfacing exist between the inner sidewall of the reservoir and the PCC edge, the likelihood of an unsealed or poorly sealed at construction is very high.

- The overall performance of the SD 37 shoulder sections after 12 months is good, with the only notable distresses being shoulder settlement and longitudinal joint seal failure.

- Seven of the 11 shoulder strategies show significantly less shoulder settlement, on average, than the corresponding control sections after 12 months of service. The average settlements for these seven strategies, which include the thicker asphalt structures, the PCC beveled edge structures, and the windrow-leveled salvage and virgin aggregate base structures, are roughly one-half the average settlements of the controls, which range from 0.22 to 0.32 in. Given the substantially higher up-front costs of the thicker asphalt structures, they are likely to not be as cost-effective as the beveled edge and windrow-leveled structures.

- Average settlements for the two delayed sealing strategies (strategies 1a and 1b) and the longitudinal edge drain strategy (strategy 4) after 12 months are the highest of all strategies tested and are similar to settlements in corresponding control sections. The high settlement for the edge drain strategy is largely attributed to inadequate compaction of the backfill material during construction.

- Longitudinal joint seal performance in shoulder test sections is excellent after 12 months of service. For the eight shoulder strategies in which joint seal has been in place for 1 year, none have more than 5 percent of the seal length in a failed state. In contrast, the percent failure observed in the corresponding control sections ranges from 30 to 75 percent. Although it is believed that the use of low-modulus rubberized asphalt (modified SDDOT Standard Specification 870.1 A) instead of standard rubberized asphalt (SDDOT 870.1 A) is the primary reason for this difference in performance, construction quality and shoulder settlement are likely to be contributing factors.

- Three rounds (post-construction, 7 months after construction, and 9 months after construction) of FWD testing of the SD 37 shoulder sections show substantially lower deflections—and substantially higher effective pavement moduli (E_P)—for the full-depth AC, 5-in AC, and daylighted ATPB test strategies (strategies 3, 7, and 9), as compared to the other shoulder strategies.

- Although fairly good performance is being exhibited by the full-depth AC, 5-in AC, and daylighted ATPB strategies (3, 7, and 9, respectively), long-term performance data will be needed to assess whether their higher initial costs are offset by improved performance.

Recommendations for Shoulder Design/Specification Changes

1. Windrowed base material shall be leveled with a grader or other suitable equipment within 24 hours after mainline PCC paving, so as to prevent the potential ponding of water between the mainline PCC slab and the windrowed aggregate.

2. Placement and compaction of shoulder base material (salvaged or virgin aggregate), including trim material from the leveled windrow, shall be in 4-in maximum lifts. Compaction of shoulder base material shall begin no sooner than 3 days after PCC paving and each lift shall be compacted to a specified density by (a) mechanically tamping the base material along the PCC edge using a J-tamper, wacker-packer, or vibratory plate compactor, and (b) rolling the entire shoulder width with a pneumatic or vibratory roller, in accordance with SDDOT Standard Specification 260.3 B.

3. Salvaged/reclaimed aggregate used as shoulder base material shall be compacted to 95 percent of target dry density, as determined through nuclear density checks (SD Test Method 219).

4. Virgin aggregate used as shoulder base material shall be compacted to 97 percent of maximum dry density (SDDOT Standard Specification 260.3 A), as determined by modified Proctor tests (AASHTO T-180, Modified SD 104) or nuclear density tests (AASHTO T-238/239, SD 114).

5. The longitudinal lane–shoulder joint shall be sealed with hot-applied rubberized asphalt sealant conforming to SDDOT Standard Specification 870.1 A, with the following modifications: (a) sealant shall have cone penetration value between 90 and 150 when tested at 77°F, (b) sealant shall pass 3 cycles of the bond test with 200 percent extension at a temperature of -20°F, and (c) sealant shall weigh no more than 9.35 lb/gal.

6. The longitudinal lane–shoulder joint sealant shall be placed in a routed and thoroughly cleaned joint reservoir having width and depth dimensions between 0.5 and 0.75 in. The routed reservoir shall fully abut the mainline PCC edge, such that no slivers or remnants of AC exist between the inner sidewall of the reservoir and the mainline PCC edge. The sealant shall be allowed to overfill the reservoir, so that it can be struck off with a molded squeegee to create a 3-in wide by 0.2-in thick band centered over the PCC lane–AC shoulder interface.

7. One strategy that is highly recommended at this time involves constructing the mainline PCC slab with beveled/tapered edges at AC shoulder interfaces. The bevel/taper would have a horizontal-to-vertical ratio of between 3:1 and 4:1 (i.e., for an 8-in PCC slab, the bottom edge extends 2 to 2.5 in beyond the top edge), and would result in a mid-depth slab width equal to the standard specified width of 12 or 14 ft (i.e., the top edge extends inward the same amount as the bottom edge extends outward). Discussions with major PCC paving contractors in South Dakota indicate having such a requirement would entail them to make paver sideform adjustments, that range from relatively quick and easy to somewhat time-consuming and difficult, depending on the equipment make and model.

8. Although fairly good performance is being exhibited by the full-depth AC, 5-in AC, and daylighted ATPB strategies (3, 7, and 9, respectively), long-term performance data will be needed to assess whether their higher initial costs are offset by improved performance

9. It is strongly recommended that the existing specification for granular base construction (SDDOT 260.3) be fully enforced, particularly as it relates to specifying that shoulder base/subbase material be mixed with water at a central plant, prior to placement and compaction. This mixing requirement will help tremendously in achieving the required density levels.

1. INTRODUCTION

Problem Statement

Shoulders are an important part of a highway system, particularly for highways that experience appreciable volumes of traffic. Shoulders provide a safe haven for disabled vehicles and highway maintenance operations, act as a safety buffer between traveling vehicles and roadside obstacles (e.g., ditches, signs, guardrails), and aid in the preservation of the mainline pavement structure through lateral support and facilitation of drainage. Moreover, depending on the design, shoulders can represent a significant percentage of the total highway system investment.

Like most States, South Dakota's highway system consists of a myriad of mainline pavement designs supplemented with many different shoulder types (gravel, blotter, asphalt concrete [AC], recycled AC, portland cement concrete [PCC]) and designs. These different shoulder structures are largely the result of South Dakota Department of Transportation (SDDOT) design policies established according to facility type (e.g., interstate, principal arterial) and traffic level. According to SDDOT research report SD95-04 (Butt et al., 1997) and to SDDOT personnel, the four most common mainline pavement/shoulder combinations are as follows:

- PCC pavement with gravel shoulders.
- PCC pavement with AC shoulders.
- PCC pavement with PCC shoulders.
- AC pavement with AC shoulders.

The adequacy of a given shoulder structure can generally be judged according to its ability to fulfill safety and preservation functions, while maintaining the lowest possible total life cycle cost. Thus, when higher quality, higher initial cost shoulder designs like those given above are used instead of lower quality designs, good performance is paramount so that the savings associated with less future upkeep equals or exceeds the additional initial cost.

One particular shoulder type that has not consistently met its performance expectations in South Dakota is the AC shoulder that adjoins PCC pavement. Its performance has been extremely variable statewide, with relatively good performance occurring on some projects (primarily in the central and western portions of the State) and severe shoulder subsidence and shoulder joint seal failure occurring on others (primarily in the eastern portion of the State). Though several key factors, such as design, climate, topography, and construction techniques, are believed to have a significant effect on AC shoulder performance, the precise causes of the poor performance that has been observed have not been formally identified.

This research study (SD 98-07) set forth the challenge of determining the factors that are inhibiting the performance capabilities of the AC shoulder when constructed adjacent to PCC pavement. Through a comprehensive survey of existing, poorly performing AC shoulder projects and through controlled field experimentation of various shoulder design modifications, the

SDDOT desired to implement improved design and construction practices and specifications that will result in long-lasting and economical AC shoulders. Carrying out the much-needed research for the Department was the ERES Consultants Division of Applied Research Associates, Inc (ARA–ERES).

Research Objectives

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Based on a thorough analysis of the data collected in the study and considerations of the level of performance, constructability, cost-effectiveness, and other factors, a set of practical implementation guidelines for improved shoulder design and construction practices was developed and is reported herein.

2. LITERATURE SEARCH AND REVIEW (TASK 1)

Although highway shoulders research is minute compared to research on traffic lane pavement structures, a substantial amount of information on shoulder facilities exists that can help guide the conduct of this research study. Some of the information is specific to experiences and observations in the State of South Dakota, whereas the remaining information reflects the experiences of other highway agencies. Given that many of these outside agencies have also struggled with the issue of inferior performance from AC shoulders adjacent to PCC pavement, they are likely to have ideas that could be of benefit to this project.

This section provides an overview of the literature collected and reviewed under task 1 of the project. The information gleaned from the literature helped form the basis of project understanding.

National Cooperative Highway Research Program Synthesis on Shoulder Design (NCHRP, 1979)

One of the first major national assessments of AC shoulder design and use was reported in the National Cooperative Highway Research Program (NCHRP) *Synthesis of Highway Practice 63*. This report provided detailed information on highway shoulders, including several States' practices regarding policies and procedures, design, maintenance, and traffic operations. Much of the information contained in the report was derived from the responses of 43 States to a multifaceted questionnaire on shoulders. The report contained an excellent discussion of previous shoulder studies and forums, and several pointed recommendations concerning the areas of advancement needed at that time.

Interestingly, the most noteworthy problem identified in the 1977 NCHRP questionnaire survey was the lane–shoulder joint. More than half of the respondents reported having no effective method to overcome the deterioration at this joint. Another noted problem was surface deterioration as a result of inadequate materials and insufficient structural design. Key recommendations given in *Synthesis 63* included the formation of studies to examine the following:

- Shoulder type selection criteria and geometric and structural design criteria.
- Design of the PCC lane–AC shoulder joint.
- Subsurface drainage design.
- Effects of shoulder types on mainline pavement performance.
- Maintenance costs for various shoulder types and designs.

Federal Highway Administration (FHWA) Shoulder Joint Sealing Study (Carpenter et al., 1987)

A 1984 FHWA study of shoulder joint sealing methods investigated the interaction of the lane–shoulder joint integrity and the impact of this integrity on shoulder structural adequacy. In addition, shoulder design was investigated to determine if any factors could be improved to extend the life of the shoulder joint seal, and in turn, the shoulder itself. The study involved several tasks as a means of fulfilling the project objectives. These tasks included the following:

- Nationwide surveys to determine current practices in sealing the lane–shoulder joint.
- Nationwide surveys to determine current practices in shoulder design.
- Analytical studies of the joint to determine the impact of sealant type, reservoir dimension, and paving materials on the performance of the sealant.
- Analytical predictions of the impact of sealing effectiveness on the infiltration of moisture and the resulting deterioration of material and structural quality, resulting in shortened pavement life.
- Data collection from field installations throughout the U.S. showing actual movements at the lane–shoulder joint over a season.
- Development of a procedure by which the cost-effectiveness of a joint sealing project may be evaluated.
- Recommendations concerning improvements that can be made by agencies that would improve the potential for long-term performance in their joint sealing programs, thereby increasing pavement and shoulder life.

A survey of current practices conducted in the FHWA study indicated the use of a wide variety of PCC lane–AC shoulder joint sealing procedures throughout the U.S. Though the favored sealant materials were asphalt rubber and polymer-modified asphalt, the joint sizes and joint preparation techniques were found to vary considerably.

Two key highlights of the survey concerning AC shoulder design practices included the following:

- No definite patterns in AC shoulder thicknesses were apparent among the country's climatic regions. Though it was expected that colder and wetter areas of the country would have thicker shoulders, design thicknesses varied randomly from 1.5 in to 10 in.
- No State reported using truck traffic as the criterion for shoulder selection.

Finite-element computer analyses of various joint seal designs provided some general insight as to development of sealant stresses. The stress calculations provided validity to the thought that failure in the PCC lane–AC shoulder joint sealant originates in the AC shoulder material, not the sealant itself or the mainline concrete. Using joint movement data collected from several field locations throughout the U.S., it was found that vertical shear deformations at the shoulder joint generally reach critical levels (0.5 in) in the northern States only.

Using an established pavement drainage model and an array of rainfall and wet-/dry-day sequences data from several U.S. locations, a detailed analysis was conducted of moisture infiltration and the resulting percent reduction in load-carrying capacity for the year's rainfall activity. A dramatic difference in the life decrease for a given shoulder structure (figure 1) was found between eastern and western South Dakota. Table 1 summarizes the predicted life decreases for 20 cities located in 9 climatic zones in the U.S. Figure 2 shows the corresponding climatic zones. As can be seen, eastern South Dakota, located in the II-A climatic zone, was represented by shoulder life decreases of 5.39 and 0.33 percent, whereas central/western South Dakota, located in the III-A climatic zone, was represented by percentage decreases of 0.23 and 0.57.

The FHWA study included an example life cycle cost analysis (LCCA) using various shoulder rehabilitation strategies and estimated costs and service lives associated with each strategy. The LCCA example did not show a clear-cut advantage to routine shoulder joint resealing as compared to alternative inlay procedures. And, although it was not evaluated, it was suggested that the installation of drainage (accompanied by an open joint) during initial construction could be the most economic and beneficial to the overall structural adequacy of the pavement.

Overall recommendations of the 1984 FHWA shoulder joint sealing study included the following:

- Further study should be devoted to the determination of the moisture, suction, and modulus relationships for a wider variety of subgrade and base course materials.
- Added emphasis must be placed on ensuring acceptable sealant installation procedures.
- More accurate assessments of the total amount of traffic encroaching on the shoulder are needed to ensure the shoulder is designed to an adequate level.
- The inclusion of subsurface drainage should be given greater consideration as a cost-effective option for preserving the pavement–shoulder structure.
- Though the effects of moisture infiltration on the structural capacity of the shoulder were examined in great detail, the analysis did not include moisture's effects on AC shoulder material integrity. Because stripping of asphalt can be a major problem in areas where moisture is in prolonged contact with the AC, this issue needs to be fully addressed.

SDDOT Silicone Shoulder Joint Seal Study (Johnston, 1994)

In 1989, the SDDOT undertook a field performance evaluation of the Dow Corning 890-SL self-leveling silicone sealant. The sealant was installed in the PCC lane–AC shoulder joint along eastbound I-90 near the Tilford Weigh Station in western South Dakota. The objective of the research project was to determine:

- If Dow Corning 890-SL works.
- The optimum shape factor for the material using a minimum of material.
- Actual water infiltration at a treated joint in the field.

The 24-ft-wide pavement section consisted of 10 in of jointed plain concrete (JPC) pavement over a 4.5-in granular base with 4-in AC shoulders over a 6-in subbase. The sealant application involved the routing and sealing of a 450-ft stretch of the shoulder. Sealant depth varied between 0.75 and 1 in, with the seal recessed about 0.5 in below the pavement edge to avoid adhesion problems due to the residual hot-applied sealant remaining in the joint from a previous application.

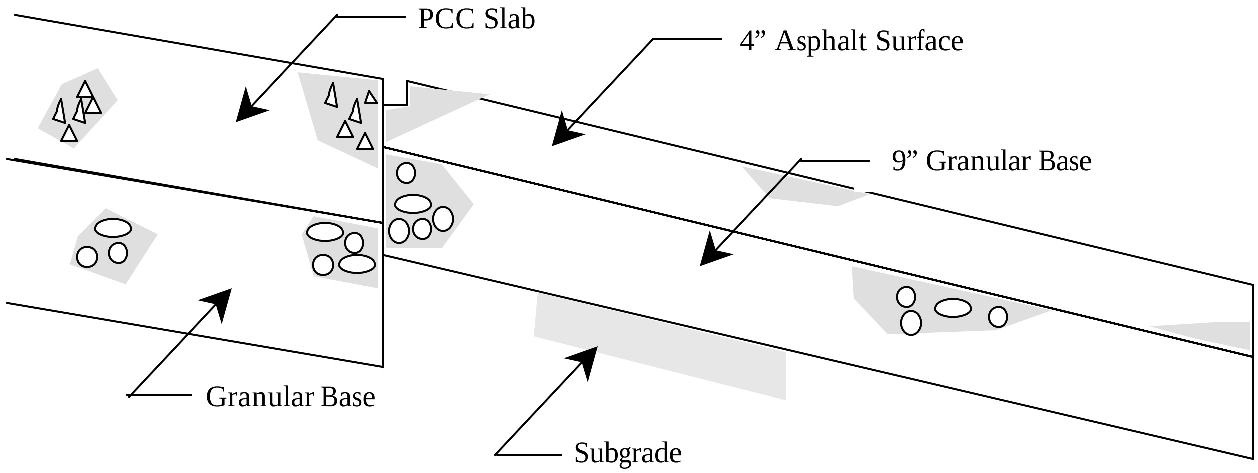

Figure 1. Shoulder structure used in shoulder analysis (Carpenter et al., 1987).

Table 1. Life decrease due to moisture infiltration (Carpenter et al., 1987).

Zone	City	Percent Total Yearly Decrease in Shoulder Life
I - A	1	1.32
I - A	2	2.50
I - B	3	1.66
I - B	4	0.81
I - C	5	2.57
I - C	6	1.85
I - C	7	12.49
II - A	8	5.39
II - A	9	0.33
II - B	10	4.01
II - B	11	4.02
II - C	12	2.54
II - C	13	1.23
III - A	14	0.23
III - A	15	0.57

III - B	16	2.58
III - B	17	2.36
III - C	18	12.73
III - C	19	3.91
III - C	20	1.34

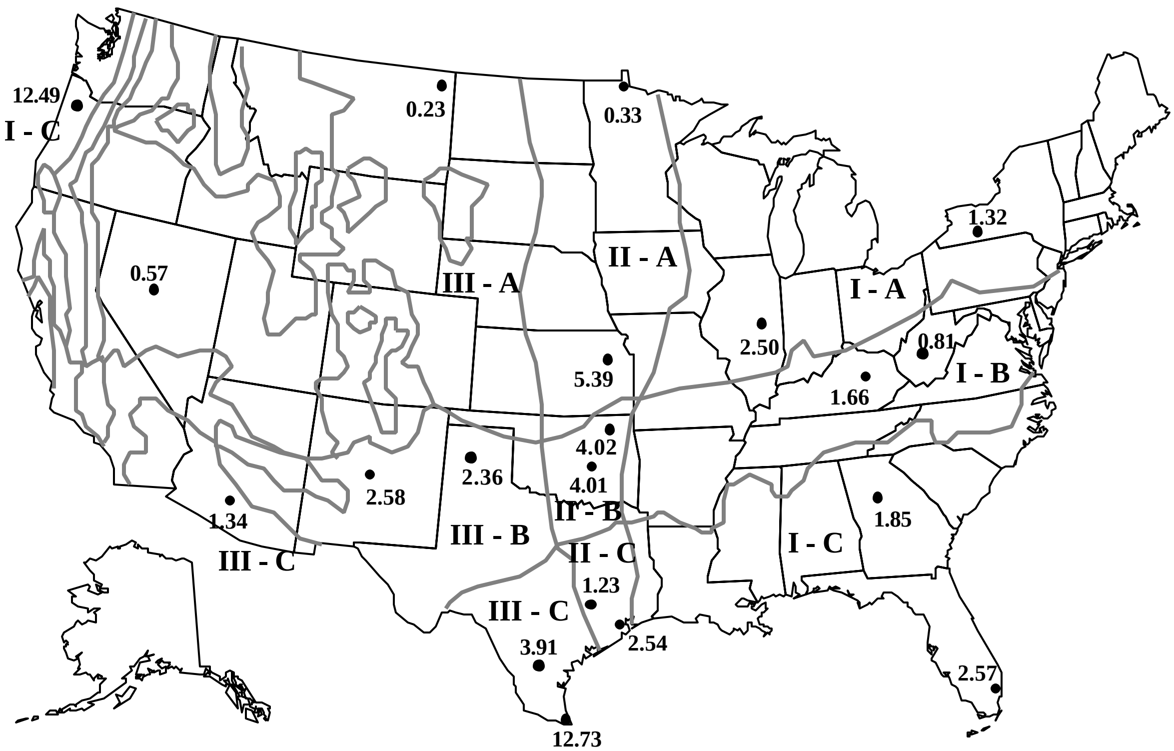

Figure 2. Calculated life decreases shown in the climatic zones (Carpenter et al., 1987).

The test section was monitored twice yearly over a 5-year period. The 890-SL sealant exhibited excellent performance over the course of the monitoring period, with no adhesion failures or distresses. However, the high cost of installing the sealant with the design parameters of the test section ($1.88/linear ft) precluded it from being a feasible alternative to the existing modified hot-pour seal system.

Evaluation of South Dakota Department of Transportation's Shoulder Surfacing on New Construction (Butt et al., 1997)

In 1995, the SDDOT began a research project to evaluate the State's shoulder surfacing on new construction. SDDOT constructs various types of shoulders, and there are problems associated with each. Furthermore, construction and maintenance costs of the different shoulder types vary widely. The DOT had shoulder construction cost data available, but without the maintenance cost data, the State could not evaluate the life cycle costs of the different shoulder types.

Research Approach

Shoulder surfacing data were collected from South Dakota and other State departments of transportation (DOTs). The data included current shoulder maintenance and construction guidelines, shoulder layout plans, traffic data, climatic data, and maintenance and rehabilitation cost data. Based on the information gathered, 67 representative pavement/shoulder sections in South Dakota were identified for field investigation.

The field investigation included both manual and video distress surveys, nondestructive deflection testing (NDT), and limited destructive testing (coring). The data were then analyzed to calculate pavement condition index (PCI) values, normalize the NDT data, and backcalculate layer moduli. Shoulder performance prediction models were also developed, and maintenance policies were developed to address the localized preventive maintenance requirements.

Once the maintenance policies were developed, the relationship between shoulder condition and maintenance cost could be determined and evaluated. Finally, shoulder surfacing guidelines were developed based on life cycle cost analysis, traffic loading, and safety requirements.

Research Results

Surprisingly, many factors were determined *not* to affect the performance of the various shoulder types. For example, shoulder performance did not vary significantly from one climatic zone to another, nor did pavement functional classification have a significant effect. In addition, the shoulder distress data showed no clear correlation with soil type, subgrade modulus, or shoulder thickness.

The mainline pavement type generally did not seem correlated with shoulder performance. The only situation that seemed to exhibit an increase in deterioration rate was asphalt overlays of AC shoulders located adjacent to PCC pavements. However, due to a limited number of data points, this deterioration trend could not be generalized. Moreover, there did not seem to be an increase in deterioration rate for AC shoulders adjacent to PCC pavements.

Most of the distresses noted on all shoulder types were climate-related, and lane–shoulder drop-off was observed frequently at the interface between the mainline pavement and the shoulder. In most cases, the mainline pavements had not been tapered properly to provide a smooth transition to the shoulder.

The results of the life cycle cost analysis showed that gravel shoulders are the most cost-effective option. However, because all the gravel shoulders evaluated in this study were located on two-lane highways, they are only recommended for this use. For all other highways (including PCC highways), blotter or AC shoulders are recommended, along with extending the mainline pavement by 24 in.

2002 Guide for Design of New and Rehabilitated Pavement Structures (ERES, 2002)

Part 3, Chapter 2 of the draft 2002 Design Guide provides both geometric and structural design guidelines for paved shoulders. In addition to referencing recommended shoulder widths and cross-slopes to the American Association of State Highway and Transportation Official's (AASHTO's) *A Policy on Geometric Design of Highways and Streets*, the Guide recommends the use of full-width paved shoulders, where the additional cost is warranted. It also recommends that widened lanes be given strong consideration, as they significantly reduce edge stresses, strains, and deflections (thus reducing structural damage), and the potential for dangerous edge drop-offs by increasing the distance from vehicle tires to the edge of the pavement.

The Guide emphasizes that shoulder structural design must be predicated upon the magnitude and frequency of loads to which the shoulder will be subjected. However, it acknowledges there are a large number of variables that affect the loadings it will receive, such as encroachment of trucks, night parking by trucks, and use of the shoulder as a temporary lane during rehabilitation or as a future permanent lane. Key recommendations given for the design of shoulders include the following:

- The shoulder should be constructed of the same materials as the mainline pavement to reduce maintenance problems at the mainline–shoulder joint.
- The same type and general thickness of base and subbase material should be used under the shoulder as under the mainline, particularly on high-volume facilities.
- Avoid the use of aggregate base courses having more than 6 percent minus 200 mesh sieve materials to provide at least some slow seepage of water out of the base to minimize pumping and clogging of the shoulder drainage system.
- On urban freeways and other routes carrying high truck volumes, the shoulders should be constructed to the same structural section as the mainline pavement to ensure adequate load capacity at the mainline–shoulder interface, to provide for ease and economy of construction, and to prevent a "bathtub" condition under the pavement.
- Widened PCC lanes should not be greater than 14 ft to minimize the possibility of longitudinal cracking.
- As a less costly option initially, a tapered PCC shoulder should be considered, with the thickness equaling the mainline slab thickness at the inside edge and a minimum of 6 in at the outside edge.
- PCC shoulders should be tied to the mainline concrete with properly spaced and sized tiebars, so as to maintain a tight joint and good load transfer.
- For the combination of JPC mainline and JPC shoulders, the mainline transverse joints should be extended continuously across the shoulder.
- For the combination of CRC mainline and JPC shoulders, the transverse joints in the shoulder should be sawed at 15-ft intervals.

- If full-width paving of asphalt shoulders is not used, consideration should be given to widening the AC mainline to reduce edge loading conditions.
- For other than urban freeways and expressways, a structural section less than that of the mainline may be warranted for the shoulder. Thickness determination should be based on an evaluation of life-cycle costs and past performance under similar conditions.
- For heavily trafficked highways, plant-mixed asphalt concrete should be used for shoulders instead of bituminous surface treatments, as the latter may not support the loads as well and may require much more maintenance.

Paved Shoulders Adjacent to Concrete Pavements: Synthesis of Current Practices in the Midwest (Owusu-Ababio et al., 2003)

A 2001 survey of highway engineers and managers at seven midwestern State DOTs—Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin—generated much useful information for the sponsoring organization (Wisconsin DOT) regarding the design, construction, and maintenance of asphalt and concrete shoulder structures. Based on responses from design personnel at six of the seven States and maintenance personnel from 22 of 54 districts representing the seven States, the following information was learned:

- Criteria for Paved Shoulder Type Selection and Thickness Determination—Policies and procedures for paved shoulder type selection (adjacent to concrete pavement) varied from State to State, with the primary decision factors consisting of functional classification, traffic/truck volume, construction and maintenance costs, and engineering judgment. Paved shoulder thickness determination is based on agency-specified standard thicknesses derived from past field observations, or on modified AASHTO design procedures.

    - Illinois requires PCC shoulders (JPC with 20-ft joint spacing and no dowels) for all mainline concrete pavement. The thickness tapers from the mainline thickness to 6 in at the outside edge.
    - Indiana uses bituminous base (minimum thickness of 2 in) over compacted aggregate for low-volume (average daily traffic [ADT] $\leq$ 5,000 for 2-lane facilities, ADT $\leq$ 7,000 for 4-lane roads) and medium-volume (5,000 $<$ ADT $\leq$ 20,000) concrete roads.
    - Iowa specifies that full-depth tied PCC (doweled JPC with 20-ft joint spacing) or full-depth AC be used if the shoulder is subjected to traffic during the construction stage; otherwise, an 8-in AC shoulder or 7-in PCC shoulder placed on granular base is specified.
    - For freeway projects in Michigan, the contractor is given the option of constructing either a full-depth tied PCC shoulder (doweled JPC or jointed reinforced concrete [JRC], with or without a taper to 7 in at the outside edge) or a full-depth AC shoulder (minimum of 5.5 in thick).

- Minnesota considers construction and maintenance cost in determining the type of shoulder to use. Tied PCC shoulders (non-doweled JPC with 15-ft joint spacing) are 6 in thick and are placed on aggregate base. Asphalt shoulders are a minimum of 3 in thick and are placed on dense aggregate base.
- In Wisconsin, 2-lane facilities with ADT > 1,250 are built with a 3-ft monolithic widened (concrete) lane, while 4-lane facilities with ADT > 1,250 are built with a 2-ft monolithic widened outside lane. Shoulders are designed using the AASHTO procedure and 2.5 percent of mainline design ESALs/day. The minimum PCC (non-doweled JPC with 15- or 18-ft joint spacing) thickness is 6 in and the minimum AC surface thickness is 2 in.

- Subsurface Design Practices—The two types of subsurface drainage systems commonly specified by States are (a) pipe in a geotextile-wrapped aggregate-filled trench and (b) graded aggregate around pipe in the trench without a geotextile filter. The systems are generally required with drainable or open-graded base layers.

  - Illinois specifies geotextile-wrapped aggregate with corrugated polyethylene pipe placed at the mainline pavement edge for a 20-year design and at the shoulder edge for a 30-year design.
  - Indiana uses graded aggregate around corrugated polyvinyl chloride (PVC) pipe placed at the mainline pavement edge.
  - Iowa specifies graded aggregate around polyethylene pipe placed at the mainline pavement edge.
  - Michigan uses stiff, smooth-walled PVC or corrugated PVC pipe in conjunction with geotextile-wrapped aggregate. The system is placed 2 ft off the mainline pavement edge, where curb-and-gutter are not present.
  - Minnesota uses both smooth-walled PVC and corrugated PVC in conjunction with geotextile-wrapped or unwrapped aggregate. The system is placed at the mainline pavement edge.
  - Wisconsin specifies corrugated polyethylene or smooth-walled PVC pipe contained in a geotextile-wrapped aggregate placed at the mainline pavement edge.

- Premature Failures in Paved Shoulders—Almost all of the 22 responding district maintenance personnel reported experiencing premature failure of concrete and asphalt shoulders. For concrete shoulders, more than 50 percent of the respondents did not attribute failure to thickness; rather, most indicated that the problems relate to inadequate drainage, inadequate treatment of the longitudinal shoulder joint, and poor shoulder joint construction. For asphalt shoulders, several factors were attributed to premature failure, most notably inadequate thickness, truck encroachment, inadequate treatment of the longitudinal shoulder joint, poor shoulder joint construction, inadequate drainage, and frost.

- Maintenance Treatment Practices—Although shoulder maintenance strategies vary amongst the States, several common practices were identified. For concrete shoulders, the predominant activities include patching, pothole repair, crack sealing, and shoulder joint repair. For asphalt shoulders, the predominant activities include crack sealing, patching/pothole repair, surface treatments, shoulder joint repair, wedging, and overlays.

General Discussion

The current collection of literature clearly touches upon many of the factors involved in the poor performance observed of AC shoulders (next to PCC pavement) in South Dakota. These factors include climate (precipitation and temperature), design (geometric, structural, and drainage), construction (compaction, seal installation), materials (stripping, permeability), subgrade soils, and traffic. Determining the most critical factors or combination of factors is one of three keys to success of this study. A second key is to identify the design and/or construction methods that can largely overcome the root causes of shoulder failure. The third and final key is to determine the most cost-effective methods, so that in the future the SDDOT makes the best use of limited highway funds.

Some preliminary ideas on alternative design/construction methods include the following:

- Inclusion of a beveled edge on the PCC mainline slabs (figure 3)—This design has been tried on a very limited basis in South Dakota and the preliminary indication is that performance is benefited through additional compaction that can be achieved in the base and AC at the lane-shoulder interface.
- Inclusion of a full or partial drainage system, such as a drainable base or longitudinal edge drains, which could substantially reduce the amount of wet time the pavement and shoulder experience.
- Use of more stringent construction specifications, particularly as related to the placement and compaction of aggregate base materials in the shoulder.
- Innovative construction practices, whereby higher AC densities are achieved at the lane-shoulder interface.
- Use of thicker AC shoulder sections or tied PCC shoulders.
- Improved specifications regarding the types of sealant materials and sealant design configurations to be used for the longitudinal shoulder joint.

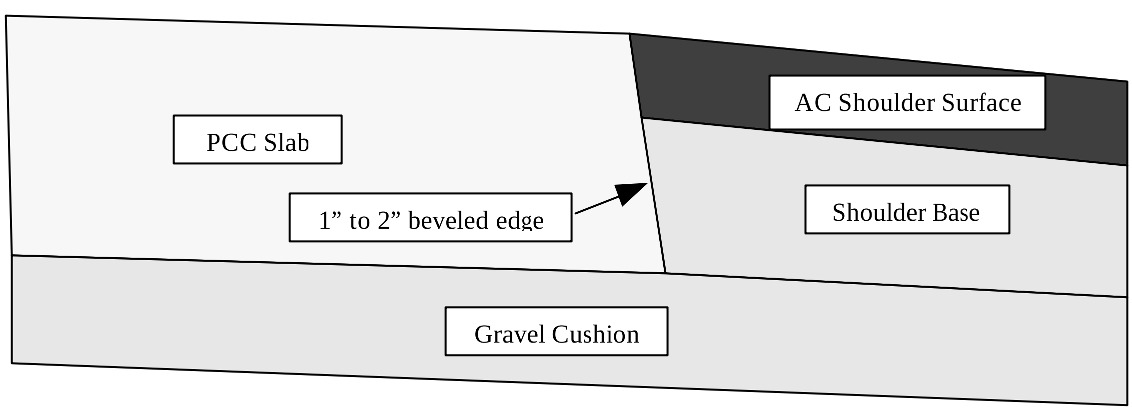

Figure 3. PCC beveled-edge design.

3. SURVEYS OF EXISTING HIGHWAY SHOULDERS (TASK 2)

To develop a better understanding of the problems afflicting asphalt shoulders adjoining concrete pavements, a comprehensive field evaluation of existing asphalt shoulders was undertaken in September 1999. This evaluation, representing task 2 of the project, centered around 29 different asphalt shoulder projects recommended for review by SDDOT Regional and Area Engineers. The projects were located in the eastern half of the State and consisted mostly of relatively young (less than 6 years) asphalt shoulders experiencing significant settlement. The field evaluation included both a detailed visual condition survey and falling-weight deflectometer (FWD) testing for assessment of structural characteristics. This chapter discusses the results of the condition surveys and FWD testing performed at the various shoulder locations.

Selection of Highway Shoulder Projects

To determine which existing highway shoulders should be examined in the field, the ERES research team contacted the following SDDOT representatives with inquiries about suitable candidates:

Mitchell Region
- Tom Week—Regional Engineer.
- Ron Gillen—Mitchell Area Engineer.
- Ron Peterson—Yankton Area Engineer.
- Jeff Senst—Sioux Falls Area Engineer.

Aberdeen Region
- Larry Afdahl—Regional Engineer.
- Gary DeJong—Aberdeen Area Engineer.
- Ron Sherman—Watertown Area Engineer.
- Wayne Cramer—Huron Area Engineer.

Although the study requirements focused on asphalt shoulders located on interstate routes, 4-lane divided highways, and 2-lane highways with ADT greater than 2,500 vehicles/day, some of the projects suggested for evaluation were on facilities that didn't satisfy the traffic requirement. These projects were included in the proposed field evaluation list, as they were expected to be of some value to the study.

Figure 4 shows the general locations of the 29 projects selected for field review, while tables 2 and 3 provide more detailed information about each project. About half of the projects were located on rural, 2-lane highways, whereas the other half were located on rural, 4-lane divided facilities. Outside shoulder widths ranged from 6 ft to 11 ft, while AC surface thicknesses ranged from 2 to

4.5 in. Although some shoulders had received an overlay, chip seal, or wedge patching, most were the original structure.

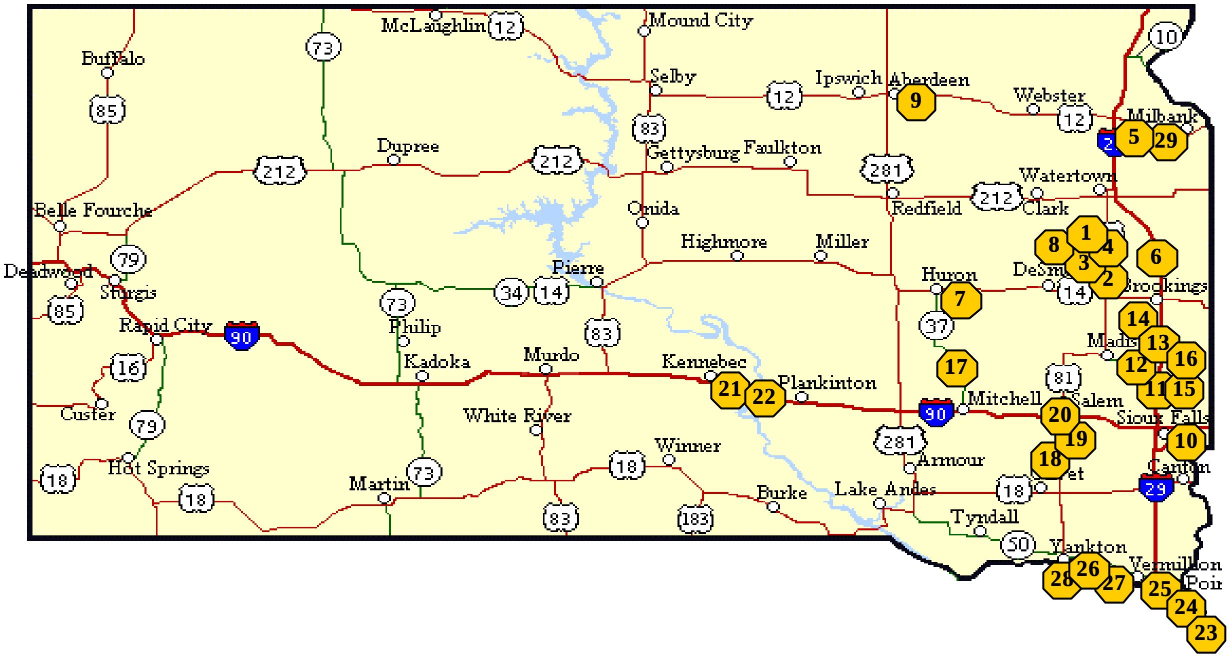

Figure 4. Map of surveyed highway shoulder projects.

Table 2. General information about highway shoulder projects.

Project No.	Highway No.	Location	Nearest City	Total Lanes	Mainline/ Shoulder Type	1999 2-Way ADT (% Trucks)
1	U.S. 81	Arlington (U.S. 14) to Kingsbury/Hamlin Co. Line	Arlington	2	JPC / AC	1,191 (14.9)
2	U.S. 81	Kingsbury/Lake Co. Line to 5 mi north	Arlington	2	JPC / AC	1,113 (15.4)
3	U.S. 81	5 mi north of Kingsbury/Lake Co. Line to 7 mi north	Arlington	2	JPC / AC	1,055 (16.2)
4	U.S. 81	7 mi north of Kingsbury/Lake Co. Line to U.S. 14	Arlington	2	JPC / AC	1,055 (16.2)
5	U.S. 12	Summit (I-29) to east of Marvin (SD 123)	Summit	2	JPC / AC	1,162 (27.2)
6a/b	I-29 NB/SB	SD 30 (Exit 140) to SD 28 (Exit 150)	Brookings	4 (div.)	Composite/AC[a]	6,672 (20.3)
7	U.S. 14	East of Huron (4-lane to 2-lane) to Iroquois	Huron	2	JPC / AC[a]	1,766 (15.9)
8	U.S. 14	Hetland to Arlington (U.S. 81)	Arlington	2	JPC / AC	2,445 (11.5)
9a 9b	U.S. 12 EB U.S. 12 WB	Bath to 5 mi east Bath to 7 mi east	Aberdeen	4 (div.)	JPC / AC JPC /AC	5,277 (12.9)
10a/b	I-90 EB/WB	Sioux Falls (I-229) to Minnesota State Line	Sioux Falls	4 (div.)	CRC / AC	12,089 (16.1)
11a/b	I-29 NB/SB	Sioux Falls (I-90) to Dell Rapids (SD 115)	Sioux Falls	4 (div.)	CRC / AC	13,264 (13.9)
12a/b	I-29 NB/SB	Dell Rapids (SD 115) to SD 34	Dell Rapids	4 (div.)	CRC / AC[a]	11,225 (16.8)
13a/b	I-29 NB/SB	SD 34 to Exit 121	Brookings	4 (div.)	CRC / AC	9,794 (16.5)
14a/b	I-29 NB/SB	Exit 121 to Brookings (U.S. 14B)	Brookings	4 (div.)	CRC / AC	9,858 (18.8)
15	SD 115	South of Renner to north of Baltic	Sioux Falls	2	JPC / AC	3,794 (6.4)
16	SD 115	North of Baltic to south of Dell Rapids	Sioux Falls	2	JPC / AC	3,180 (8.8)
17	SD 37	Davison/Sanborn Co. Line to SD 34	Mitchell	2	JPC / AC	1,760 (13.1)
18	U.S. 81	Freeman to Stanley Corner (SD 42)	Salem	2	JPC / AC	1,417 (12.3)
19	U.S. 81	Stanley Corner (SD 42) to 2 mi north	Salem	2	JPC / AC	572 (19.8)
20	U.S. 81	2 mi north of Stanley Corner to Salem (SD 38)	Salem	2	JPC / AC	673 (18.0)
21a/b	I-90EB/WB	SD 47 (Exit 251) to Oacoma	Chamberlain	4 (div.)	CRC / AC	6,590 (23.8)
22	I-90 WB	Exit 263 to Exit 265	Chamberlain	4 (div.)	CRC / AC	7,120 (23.8)
23	I-29 NB	N. Sioux City (Exit 4) to Elk Pt. (Exit 15)	N. Sioux City	4 (div.)	JRC / AC	9,677 (25.4)
24	I-29 NB	1.5 mi north of Elk Pt. to 4.0 mi north of Elk Pt.	N. Sioux City	4 (div.)	JRC / AC	9,750 (28.4)
25a/b	I-29 NB/SB	4.0 mi north of Elk Pt. to Junction City (Exit 50)	Junction City	4 (div.)	JRC / AC	9,514 (28.4)

26	SD 50 EB	Gayville to Mackling	Vermillion	4 (div.)	JPC / AC	4,310 (16.7)
27	SD 50 EB	Mackling to Vermillion	Vermillion	4 (div.)	JPC / AC	4,428 (16.7)
28	SD 50 WB	West of Gayville to east of Yankton/Clay Co. Line	Vermillion	4 (div.)	JPC / AC	5,070 (16.7)
29	U.S. 12	2 mi east of Marvin to Milbank	Milbank	2	JPC / AC[b]	1,374 (26.1)

[a] AC on AC. [b] AC along horizontal curves only; gravel elsewhere.

Table 3. Detailed information about highway shoulder projects.

Project No.	Year of Initial Construction	Year of Last Major Rehabilitation	Width—Outside/ Inside, ft	Current Structure	Current Sealant/ Configuration
1	1992	—	6 / —	3-in AC / 5-in gravel cushion[a] / 5-in gravel cushion	Hot-Pour/Flush
2	1990	Mid 1990s (chip seal)	4 / —	0.5-in chip seal / 3-in AC / 10-in aggregate	Hot-Pour/Flush
3	1990	Mid 1990s (chip seal)	8 / —	0.5-in chip seal / 3-in AC / 10-in aggregate	Hot-Pour/Flush
4	1990	Mid 1990s (chip seal)	4 / —	0.5-in chip seal / 3-in AC / 10-in aggregate	Hot-Pour/Flush
5	1995	—	6 / —	2-in AC / 6-in gravel cushion[a] / 6-in gravel cushion	Hot-Pour/Flush
6a/b	1972	1994 (4.5-in AC overlay)	10 / 4	4.5-in AC / 8-in AC	—
7	1966	1992 (2-in AC mill & replace, shoulder joint resealing)	10 / —	2-in AC / 5-in soil aggregate / 4-in sand	Hot-Pour/Flush ('92)
8	1991	—	9 / —	3-in AC / 5-in gravel cushion[a] / 5-in aggregate	Hot-Pour/Flush
9a 9b	1994 1975	— —	8 / 4 10 / 4	2-in AC / 6-in aggregate 2-in AC / 6-in aggregate	Hot-Pour/Flush
10a/b	1961	1997/98 (resurfacing)[b]	8 / 4	3-in AC / 5-in aggregate / 2-in AC	Hot-Pour/Flush ('97)
11a/b	1964	1999/2000 (resurfacing)	10 / 4	3-in AC / 5-in aggregate / 2-in AC	Hot-Pour/Flush ('99)
12a/b	1964	1997/98 (resurfacing)[b]	8 / 4	3-in AC / 5-in aggregate / 2-in AC	Hot-Pour/Flush ('97)
13a/b	1968	1990s (wedge patching, shoulder joint resealing)	10 / 4	2-in+ AC / 6-in gravel cushion / 6-in aggregate	Hot-Pour/Flush ('90s)
14a/b	1968	1990s (wedge patching, shoulder joint resealing)	10 / 4	2-in+ AC / 6-in gravel cushion / 8-in aggregate	Hot-Pour/Flush ('90s)
15	1988	—	6 / —	3-in AC / 5-in gravel cushion	Hot-Pour/Flush[c]
16	1953	1988 (remove top 3 in of gravel & replace w/ AC, shoulder joint resealing)	8 / —	3-in AC / 5-in gravel[d] / 18-in aggregate	Hot-Pour/Cap[e]
17	1993	—	6 / —	3-in AC / 5.5-in aggregate	Hot-Pour/Flush
18	1995	—	6 / —	3-in AC / 5-in salvage material / 5-in salvage material	Hot-Pour/Flush
19	1995	—	6 / —	3-in AC / 5-in salvage material / 5-in salvage material	Hot-Pour/Flush
20	1994	—	6 / —	3-in AC / 5-in salvage material / 5-in salvage material	Hot-Pour/Flush
21a/b	1996/97	—	10 / 4	3-in AC / 7-in aggregate / 7.5-in AC / 6-in aggregate	Hot-Pour/Flush
22	1995	—	10 / 4	3-in AC / 6.5-in aggregate / 6-in AC / 6-in aggregate	Hot-Pour/Flush
23	1961	1995 (2-in AC mill & replace, shoulder joint resealing)	10 / 6	3.5-in AC / 7.5-in aggregate	Hot-Pour/Flush ('95)
24	1961	1995 (2-in AC mill & replace, shoulder joint resealing)	10 / 6	3.5-in AC / 7.5-in aggregate	Hot-Pour/Flush ('95)
25a/b	1961	1995 (2-in AC mill & replace, shoulder joint resealing)	10 / 6	3.5-in AC / 7.5-in aggregate	Hot-Pour/Flush ('95)
26	1975	1991 (2-in AC recycling, shoulder joint resealing)	11 / 5	3-in AC / 8-in lime-treated aggregate	Hot-Pour/Flush
27	1975	1991 (2-in AC recycling, shoulder joint resealing)	11 / 5	3-in AC / 7-in lime-treated aggregate	Hot-Pour/Flush
28	1975	1991 (2-in AC recycling, shoulder joint resealing)	11 / 5	3-in AC / 8-in lime-treated aggregate	Hot-Pour/Flush
29	1998	—	6 / —	8-in aggregate	Hot-Pour/Cap[e]

[a] Thickness of layer is tapered.
[b] Mainline pavement received unbonded CRC overlay. Corresponding new shoulder (3-in AC, 7-in aggregate) built on top of existing AC shoulder.
[c] Unrouted sealant reservoir.
[d] Original shoulder structure was 8 in of gravel on 18 in aggregate. When mainline JPC was patched and diamond ground in 1988, the top 3 in of gravel shoulder were removed and replaced with AC.
[e] Cap = overbanded sealant not struck off to any particular dimensions.

Condition Surveys

Detailed condition surveys of the various shoulder projects were performed on September 14 through 16, 1999. The weather conditions during this field evaluation period ranged from cloudy and cool (45 to 50°F) to sunny and pleasant (65 to 70°F), with no precipitation occurring on any of the days.

For each shoulder project, a 500-ft-long section of shoulder, considered to be largely representative of the entire project length, was selected for evaluation. Each shoulder section was then evaluated for the following distresses, using the Long-Term Pavement Performance (LTPP) *Distress Identification Manual* (SHRP, 1990) as a general guide:

- Alligator cracking.
- Block cracking.
- Edge cracking.
- Longitudinal cracking.
- Transverse cracking.
- Potholes.
- Rutting.
- Raveling and weathering.
- Lane–shoulder drop-off.
- Lane–shoulder separation.
- Sealant damage.

Figure 5 shows the survey form used to collect the important field information. The dimensions of the shoulder and characteristics of the mainline pavement were verified, and the type and amount of shoulder maintenance was documented. PCI and remaining serviceable life were also estimated.

Results

Table 4 summarizes the conditions of the shoulders visually surveyed under Task 2 of the project. Although most of the asphalt shoulders showed considerable levels of drop-off and joint seal damage, as illustrated in figures 6 and 7, their overall condition was generally acceptable, with most shoulders receiving an estimated PCI greater than 70. Only a few shoulder pavements exhibited substantial levels of fatigue or other forms of cracking, and a few others had received maintenance in the form of surface treatments or wedge patching.

Of particular interest from the survey results is the apparent connection between shoulder drop-off and longitudinal joint seal failure, as illustrated in figure 8. While it is not known for sure if one parameter is more dependent upon the other, it is believed that settlement of the shoulder occurs initially due to other factors (inadequate compaction of shoulder layers, presence of water in the shoulder structure) and that as the shoulder settles and/or widens, the joint seal becomes debonded. The failed joint seal allows more water to infiltrate the shoulder structure, which in turn facilitates shoulder drop-off and widening.

SHOULDER PROJECT SURVEY

Date of Survey (month/day/year)	______	Highway:	______	Mainline Pavement Type:	______
Surveyor's Initials	______	Direction:	______	No. Mainline Lanes:	______
	______	From MP:	______	Outside Lane Width (ft):	______
Shoulder Project No.	______	To MP:	______	Opp. Dir. Mainline Pavement Type:	______
		MP of Detailed Survey:	______	Opp. Dir. No. Mainline Lanes:	______

	INSIDE SHOULDER (4-lane divided highway)			OUTSIDE SHOULDER		
Shoulder Type:	AC	Aggregate		AC	Aggregate	
Shoulder Width (ft):		______			______	
Overall Condition of Shoulder:	Good	Fair	Poor	Good	Fair	Poor
Prevailing Shoulder Maintenance Types:						
Degree of Shoulder Maintenance:	Low	Moderate	Extensive	Low	Moderate	Extensive
Estimated PCI:		______			______	
Distresses Present						
Alligator Cracking (ft^2)	Low =	Mod =	High =	Low =	Mod =	High =
Block Cracking (ft^2)	Low =	Mod =	High =	Low =	Mod =	High =
Edge Cracking (ft^2)	Low =	Mod =	High =	Low =	Mod =	High =
Longitudinal Cracking (ft)	Low =	Mod =	High =	Low =	Mod =	High =
Transverse Cracking (ft)	Low =	Mod =	High =	Low =	Mod =	High =
Potholes (#)	Low =	Mod =	High =	Low =	Mod =	High =
Rutting (in)	Avg. =	Min =	Max =	Avg. =	Min =	Max =
Raveling & Weathering (ft^2)	Low =	Mod =	High =	Low =	Mod =	High =
Lane-Shoulder Dropoff (in)	Avg. =	Min =	Max =	Avg. =	Min =	Max =
Lane-Shoulder Separation (ft)	Low =	Mod =	High =	Low =	Mod =	High =
Sealant Failure (ft), Mode(s) of Failure						
Remarks:						

Figure 5. Shoulder project condition survey form.

Table 4. Summary of shoulder pavement conditions.

Project No.	Highway No. and Direction, Location	Age at Time of Survey	Overall Condition	Estimated PCI	Average Drop-off, in	Fatigue Cracking, ft^2	Transverse Cracking, ft	Joint Seal Failure, % length
10a	I-90EB, Sioux Falls	1	Good	88	0.13	0	0	10
12a	I-29NB, Dell Rapids	1	Good	90	0.00	0	0	3
29	U.S. 12 EB, Milbank	1	Good	91	0.06	0	0	5
21a	I-90EB, Chamberlain	3	Good	84	0.56	0	0	7
5	U.S. 12EB, Summit	4	Good	83	0.13	0	25 (LS) 125 (MS)	5
18	U.S. 81NB, Salem	4	Good	82	0.38	0	100 (LS) 50 (MS)	25
19	U.S. 81NB, Salem	4	Good	84	0.56	0	80 (LS)	25
22	I-90WB, Chamberlain	4	Good	76	0.63	0	140 (LS)	20
23	I-29NB, N. Sioux City	4	Good	80	0.25	0	150 (LS) 20 (MS)	12
24	I-29NB, N. Sioux City	4	Good	82	0.19	0	130 (LS)	8
25a	I-29NB, Junction City	4	Good	72	0.63	0	120 (LS)	75
9a	U.S. 12EB, Aberdeen	5	Good	75	0.81	25 (LS)	30 (LS) 10 (MS)	45
20	U.S. 81NB, Salem	5	Good	74	0.50	30 (LS)	30 (LS)	65
17	SD 37NB, Mitchell	6	Good	70	0.75	10 (LS)	100 (LS) 160 (MS)	40
1	U.S. 81NB, Arlington	7	Fair	63	0.88	200 (LS) 50 (MS)	300 (LS)	90
7	U.S. 14EB, Huron	7	Good	78	0.25	20 (LS)	80 (LS) 100 (MS)	25
27	SD 50EB, Vermillion	7	Fair	53	0.25	1100 (LS) 275 (MS)	140 (LS) 40 (MS)	35
28	SD 50WB, Vermillion	7	Poor	38	0.38	1925 (LS) 330 (MS)	110 (LS) 50 (MS)	28
8	U.S. 14,WB Arlington	8	Good	72	0.63	250 (LS)	110 (LS)	95
2	U.S. 81NB, Arlington	9	Fair	53	1.13	50 (LS) 15 (MS)	100 (LS)	100
15	SD 115NB, Sioux Falls	11	Fair	62	0.81	0	210 (LS)	98
16	SD 115NB, Sioux Falls	11	Good	78	0.25	0	150 (LS)	10
13a	I-29NB, Brookings	31	Poor [a]	38	0.50	0	300 (LS) 500 (MS)	100
14a	I-29NB, Brookings	31	Fair [a]	50	0.31	150 (LS) 100 (MS)	200 (LS) 250 (MS)	No Seal

Note: For 4-lane divided facilities, reported conditions are for outside shoulder only.
LS = low severity; MS = medium severity, HS = high severity.
[a] Substantial wedge patches exist.

Figure 6. Approximate 1-in shoulder settlement on project 9a (US 12 EB, Bath).

Figure 7. Joint seal failure and inside edge fatigue cracking on project 1 (US 81, Arlington).

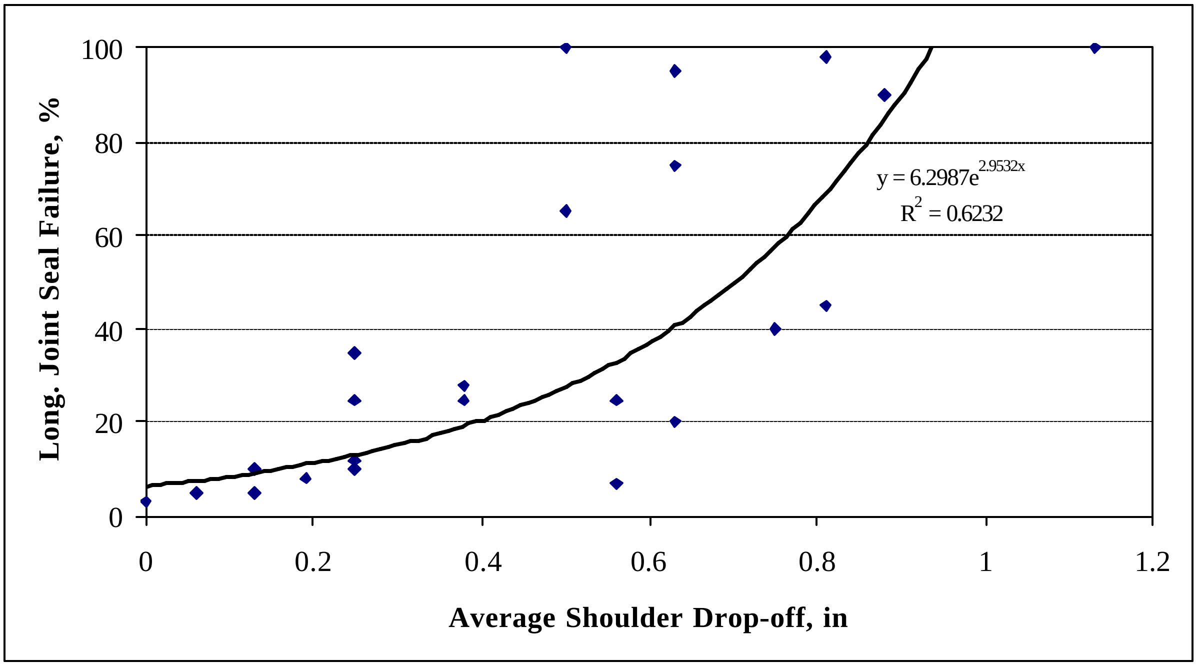

Figure 8. Shoulder drop-off versus joint seal failure, based on survey of 24 shoulder projects.

FWD Testing

On October 28, 1999, Department field crews performed FWD testing on shoulder projects 1, 5, 7, 8, 9a, 10a, 13a, 16, 17, 20, 22, 23, 28, and 29. The purpose of this testing was to assess the structural characteristics of the shoulder pavements and to identify any apparent factors contributing to the strength or weakness of the various shoulders.

For each project, a representative sample segment was identified for testing and assigned a starting location in terms of the mileage reference marker (MRM). As many as eight shoulder locations were tested with the Department's Dynatest 8000E FWD. As illustrated in figure 9, transverse locations included the inside edge of the shoulder (9-in offset from the PCC slab edge) and the center of the shoulder (typically, 3 to 4 ft from the PCC slab edge). Longitudinal locations included mid-slab of the 1st and 10th slabs from the specified beginning point of testing, and the interface of the 5th and 6th slabs. Each location received three sequential nominal load drops of 6,000, 9,000, and 12,000 lb. Following each drop, the pavement surface deflections at seven points offset from the center of loading were measured. These offsets were as follows:

- D_0—0 in.
- D_1—8 in.
- D_2—12 in.
- D_3—18 in.
- D_4—24 in.
- D_5—36 in.
- D_6—60 in.

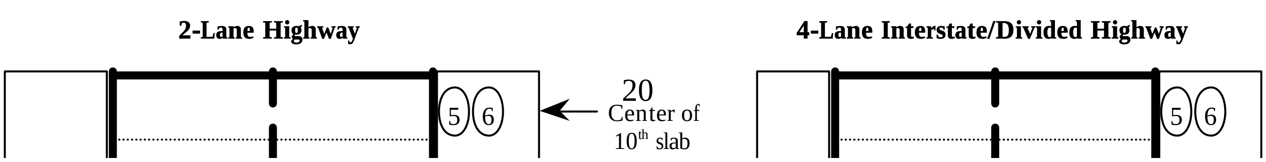

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Figure 9. FWD testing and coring layout for individual shoulder projects.

Deflection and Back-Calculation Analysis

Table 5 summarizes the maximum deflections recorded for each location of each shoulder project tested. For comparison sakes, the deflections were normalized to a 9,000-lb test load and an air temperature of 68°F (note: because pavement temperature readings were erroneous, the recorded air temperatures, which ranged from 60 to 75°F, were used to normalize the deflections). Although the shoulder structures vary somewhat in terms of layer material types and thicknesses, it can generally be seen that the older and/or thinner (particular the AC surface) sections exhibited higher maximum deflections. It can also be seen that the maximum deflections on the narrower inside shoulders (for 4-lane facilities with inside and outside shoulders) were often substantially greater than on the wider outside shoulders.

Using the FWD deflection data and the AASHTO structural capacity analysis procedures (AASHTO, 1993), the layer stiffness properties of each shoulder structure (including subgrade) were determined. Figures 10 and 11 show the back-calculated subgrade moduli (M_R) and effective pavement elastic moduli (E_P), respectively, for each project. Both the average modulus value and the range (minimum and maximum) in values are given, which are based on the deflections that occurred under 9,000-lb loadings applied at the center and inside edge of the outside shoulder.

Table 5. Maximum FWD deflections, normalized to 9,000-lb test load and 68°F.

Project No.	Project Location (FWD MRM Begin Point)	Shoulder Age and Cross-Section	Inside Edge of Shoulder (drop locations 1, 3, & 5)		Center of Shoulder (drop locations 2, 4, & 6)		Inside Edge of Alt. Shoulder (drop location 7)	Center of Alt. Shoulder (drop location 8)
			D_0, mils	Avg. D_0, mils	D_0, mils	Avg. D_0, mils	D_0, mils	D_0, mils
1	US 81 NB (121.00)	7 yrs 3 in AC 10 in granular	46.02 43.99 58.85	49.62	50.26 44.99 77.05	57.43	NA	NA
5	US 12 EB (371.80)	4 yrs 2 in AC 12 in granular	33.02 32.49 32.44	32.65	37.81 36.08 34.89	36.26	NA	NA
7	US 14 EB (355.75)	7 yrs 2 in AC 9 in granular	38.18 47.81 52.27	46.09	41.76 53.28 48.19	47.74	NA	NA
8	US 14 EB (399.00)	8 yrs 3 in AC 10 in granular	42.10 57.37 56.56	52.01	37.05 48.99 57.03	47.69	56.36	50.14
9a [a]	US 12 EB (301.00)	5 yrs 2 in AC 6 in granular	31.84 33.24 30.00	31.69	39.01 34.62 37.33	36.99	33.68	46.99
10a	I-90 EB (402.80)	2 yrs 3 in AC 7 in granular 2 in AC	36.97 56.67 32.37	42.00	30.42 48.00 30.90	36.44	NA	NA
13a [b]	I-29 NB (113.40)	31 yrs >2 in AC 12 in granular	53.14 49.28 46.53	49.65	56.06 57.43 52.28	55.26	NA	NA
16	SD 115 NB (102.40)	11 yrs 3 in AC 23 in granular	38.32 41.77 33.13	37.74	43.46 45.19 44.77	44.47	NA	NA
17 [a]	SD 37 NB (89.80)	6 yrs <3 in AC 5.5 in granular	58.92 67.40 65.92	64.08	55.44 62.58 64.26	60.76	63.84	62.82
20	US 81 NB (53.50)	5 yrs 3 in AC 10 in salvage	16.13 16.68 13.83	15.55	15.00 15.42 13.91	14.78	25.95	36.64
22 [a]	I-90 WB (264.90)	4 yrs 3 in AC 6.5 in granular	19.45 23.33 18.39	20.39	19.13 20.31 16.49	18.64	21.10	32.10
23	I-29 NB (7.50)	4 yrs 3.5 in AC 8 in granular	22.82 33.01 24.20	26.68	32.67 37.61 31.13	33.80	34.93	29.44
28	SD 50 WB (395.50)	8 yrs 3 in AC 8 in lime-agg	50.87 45.99 45.66	47.51	28.21 33.19 32.43	31.28	67.96	77.09
29 [a]	US 12 EB (378.90)	1 yr 8 in granular	28.87 24.64 23.06	25.52	28.47 29.54 24.65	27.55	28.87	53.28

NA: Not available.

[a] Actual layer thicknesses not known. Deflection values normalized according to assumed layer thicknesses of 3 in AC and 10 in granular.

[b] Project underwent wedge patching in 1990s.

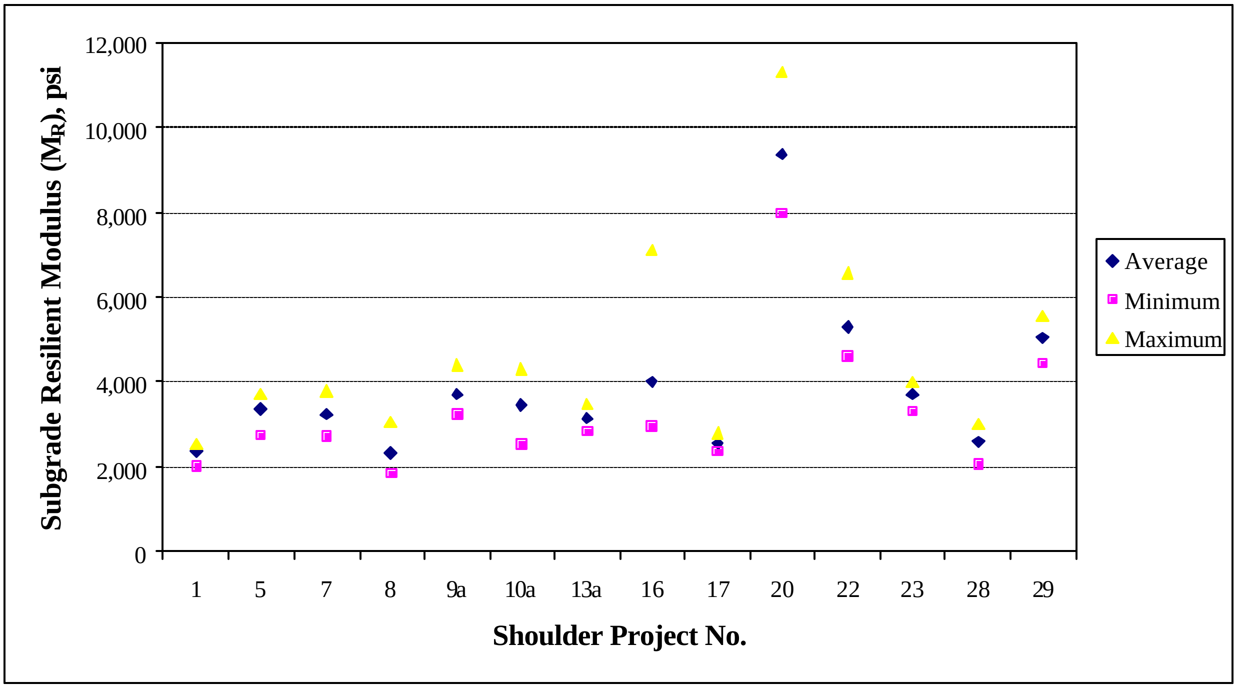

Figure 10. Back-calculated subgrade resilient moduli of tested shoulder projects.

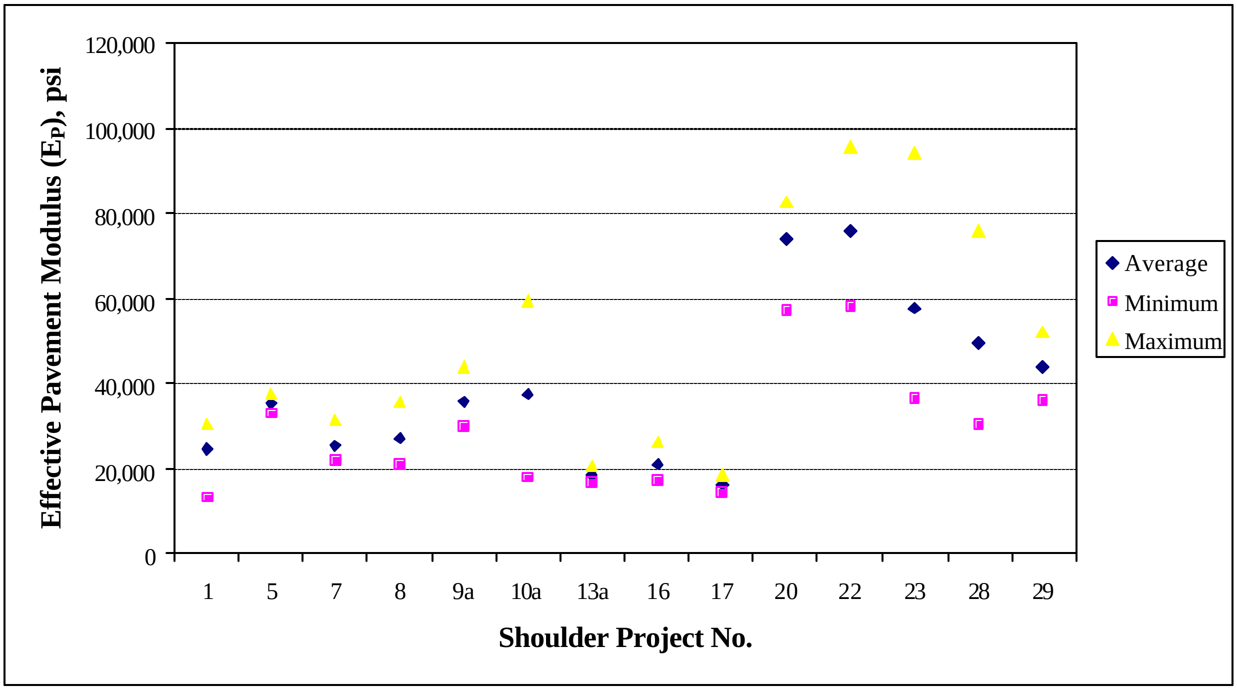

Figure 11. Back-calculated effective pavement moduli of tested shoulder projects.

As seen in figure 10, with the exception of Project 22 (US 81 NB, Salem), the back-calculated resilient moduli ranged from about 2,000 to 6,000 psi. These values are fairly typical of the silt–clay soils that comprise most of the shoulder projects surveyed and tested under Task 2 of the study.

As seen in figure 11, the effective pavement moduli range from 15,000 to 95,000 psi. However, it should be pointed out that the older and/or thinner shoulder sections (projects 1, 5, 7, 8, 9a, 13a, 16, and 17) generally had much lower moduli (15,000 to 40,000 psi) than the newer, more highly stabilized sections (projects 10a, 20, 22, 23, 28, and 29). For instance, project 20, which is one of only three projects known to include salvaged gravel cushion (i.e., gravel with reclaimed asphalt), had an average E_P of 73,898 psi. Also, project 23, which included a thicker AC surface (3.5 in), had an average E_P of 57,656 psi.

As a final step in the analysis and back-calculation of FWD data, the elastic moduli of the AC surface and granular base were estimated using predictive equations developed for the Washington DOT (FHWA, 1993). These equations are as follows:

$$\log E_{AC} = -4.13464 + 0.25726*(5.9/h_{AC}) + 0.92874*(5/9/h_B)^{0.5} - 0.69727*(h_{AC}/h_B)^{0.5} - 0.96687*\log(E_{SG}) + 1.88298*\log(PA/D_0^2) \quad \text{Eq. 1}$$

$$\log E_B = 0.50634 + 0.03474*(5.9/h_{AC}) + 0.12541*(5/9/h_B)^{0.5} - 0.09416*(h_{AC}/h_B)^{0.5} + 0.51386*\log(E_{SG}) + 0.25424*\log(PA/D_0^2) \quad \text{Eq. 2}$$

where:
- E_{AC} = Elastic modulus of AC surface layer, psi.
- E_B = Elastic modulus of base layer, psi.
- h_{AC} = Thickness of AC surface layer, in.
- h_B = Thickness of base layer, in.
- E_{SG} = Subgrade modulus, psi.
- P = Applied load on a 11.8-in plate, lb.
- A = Approximate area under deflection basin out to 3 ft.
  = $4D_0 + 6D_{0.67} + 8D_1 + 12D_2 + 6D_3$
- D_0 = Deflection under center of applied load, in.
- $D_{0.67}$ = Deflection at 8 in from center of applied load, in.
- D_1 = Deflection at 12 in from center of applied load, in.
- D_2 = Deflection at 24 in from center of applied load, in.
- D_3 = Deflection at 36 in from center of applied load, in.

The results of this back-calculation effort are presented in figures 12 and 13. With the exception of a few shoulder projects, the AC surface moduli seem fairly reasonable, given the temperatures encountered during testing (55 to 75°F). It is probable that the very high modulus values computed for projects 5 and 22 are the result of using AC thickness values that were less than the actual in-place thicknesses. In other words, the AC thickness of shoulder project 5 is likely to be greater than the 2 in documented in construction plans and used in the back-calculation. Also, the AC thickness of shoulder project 22 is likely to be greater than the 3 in that was assumed in the back-calculation.

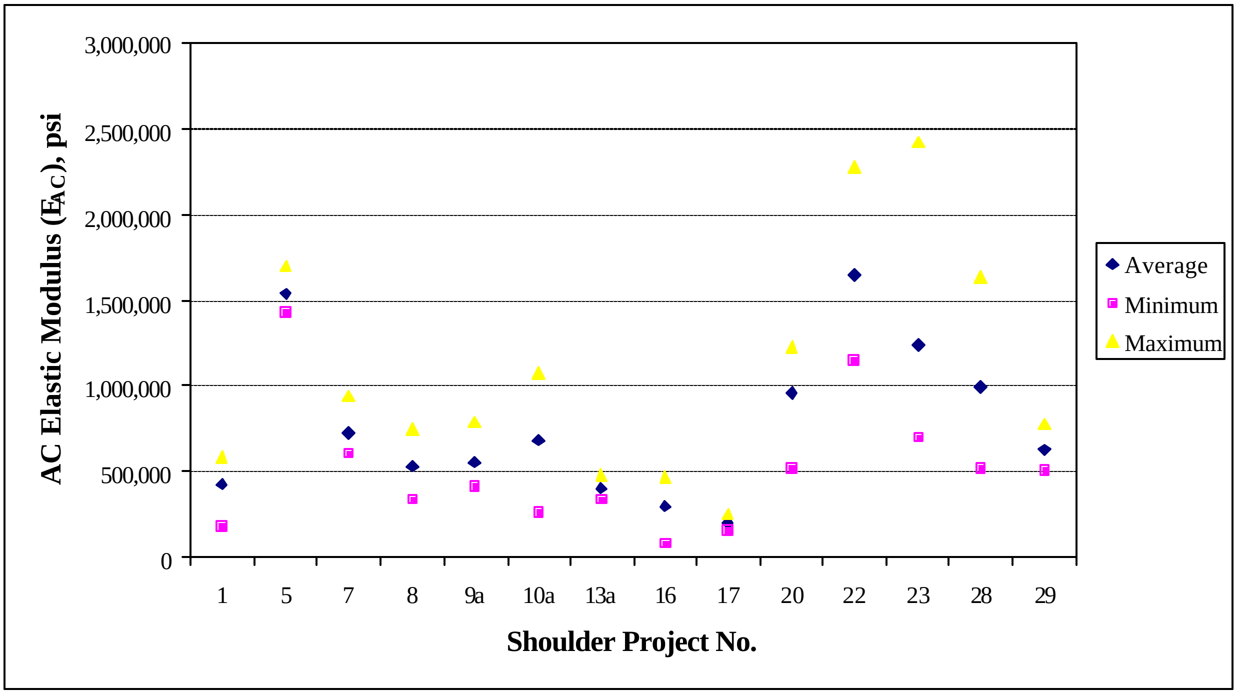

Figure 12. Back-calculated AC elastic moduli of tested shoulder projects.

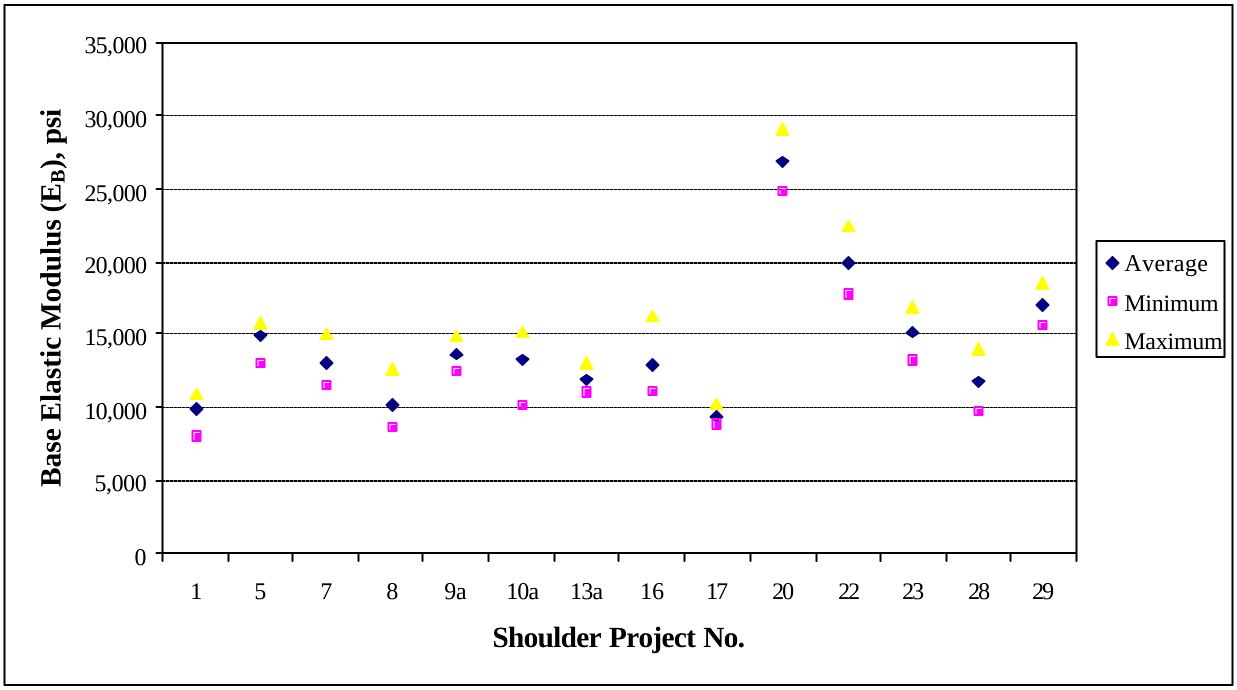

Figure 13. Back-calculated granular base elastic moduli of tested shoulder projects.

Although it is possible that the very low modulus values seen in figure 12 (e.g., projects 1, 13a, 16, and 17) are the result of using higher than actual thicknesses, it is likely that the values are simply reflective of the fair to poor conditions observed for these projects in the distress survey (see table 4).

Finally, in figure 13, it can be seen that base moduli generally vary between 9,000 and 17,000 psi. These values, at first glance, seem to be lower than ordinary for granular materials. However, a review of the base moduli computed for many shoulder sections tested in the mid-1990s (Butt et al., 1997) indicates otherwise. The majority of the asphalt shoulders tested in that study had base moduli between 7,500 and 15,000 psi.

4. DEVELOPMENT OF HIGHWAY SHOULDER EXPERIMENT PLAN (TASKS 3 AND 4)

Task 3 Technical Panel Meeting

Immediately following the completion of the task 2 shoulder surveys in September 1999, the ARA–ERES research team made a presentation to the SDDOT Technical Panel summarizing the results of the task 1 literature review and task 2 field surveys. During the presentation, it was reported that the two key ingredients for poor asphalt shoulder performance are extended periods of moisture presence and insufficient density/compaction of the shoulder structure layers. It was pointed out that the typical shoulder failure scenario is as follows:

1. Moisture penetrates into the base, subbase, and subgrade layers, which remain saturated for long periods due to low permeability levels and the absence of drainage features.
2. Traffic loading on insufficiently compacted and moisture-laden shoulder results in permanent strain/settlement, especially at the inside edge of the shoulder where traffic mostly encroaches.
3. Increased shoulder settlement leads to increased stress on joint sealant, and subsequent adhesive or cohesive failure in sealant.
4. More joint seal failure results in the entry of more water into shoulder structure, thereby weakening the shoulder and/or increasing the time it is in a weakened state.
5. Additional loading of weakened shoulder results in AC fatigue cracking, particularly at the inside edge and at locations with thinner amounts of AC.

Several potential design/construction remedies for poor shoulder performance were offered for consideration by the Technical Panel. These included the following:

- PCC beveled edge design: 3-in AC surface abutting mainline PCC slab with a tapered edge.
- Drainable base: 3-in AC surface placed on asphalt-treated permeable base (ATPB) that is either daylighted or is equipped with edge drains.
- Delayed joint seal application: 3-in AC surface, with longitudinal shoulder joint sealed 6, 12, or 18 months after construction (i.e., after shoulder subsidence has occurred).
- Delayed shoulder surfacing: Gravel surface initially, replaced with 3-in AC surface 6, 12, or 18 months after construction.
- Different joint seal materials: 3-in AC surface, with longitudinal shoulder joint sealed using standard- and low-modulus hot-applied sealants and asphalt-compatible, self-leveling silicone sealant.
- Different joint seal configurations: 3-in AC surface, with longitudinal shoulder joint sealed using band-aid and flush-fill seal configurations.
- Porous concrete base: 3-in AC surface, with porous concrete edge-drain system tied into drainable concrete base beneath mainline PCC.
- PCC shoulder: 6-in tied PCC shoulder.

After a period of collaboration among Panel members, a shortlist of shoulder strategies to be scientifically tested in the field was developed. The shortlist included all of the strategies listed above, except the last two, which were deemed too expensive, in terms of initial costs. Also included in the shortlist were partial-depth (5 in) and full-depth (8 in) AC shoulder strategies, as well as virgin-aggregate and salvaged-aggregate base strategies. Lastly, recommendations were made that the field study should address certain shoulder construction practices, including the immediate leveling of windrowed base material and the assurance of adequate base layer compaction.

Task 4 Development of Construction Plan Notes

In the months following the task 3 Technical Panel meeting, the research team prepared a draft set of construction plan notes, detailing the procedures for constructing the various shoulder test sections and providing a general layout of the sections. The plan notes were submitted to the Department in December 1999 for review by the Panel.

Based on comments received back from the Panel and information obtained from SDDOT concerning a potential project in which the shoulder study could be implemented, a revised set of construction plan notes was prepared and resubmitted for review. During this review, it was determined that the location and geometrics of the project (U.S. 12/281 Bypass in Aberdeen) were not compatible with the requirements of the proposed shoulder study (the project was located in an urban area and was not long enough to include all the shoulder test sections). Thus, the project was rejected and the search for a suitable paving project continued.

In fall 2000, an 18-mi-long pavement reconstruction project located on SD 37 near Parkston (figure 14) was offered up by the Mitchell Region Engineer (Mr. Tom Weeks) for implementation of the highway shoulder study. This JPC paving project was scheduled for construction in summer 2001 and, following an on-site review in October 2000, was deemed to be very conducive to the physical and logistical requirements of the shoulder experiment.

The SD 37 project was subsequently approved by the Technical Panel and appropriate revisions were immediately made to the construction plan notes, so they could be quickly incorporated into the SD 37 construction plans/specifications. A copy of the final construction plan notes is provided in appendix A.

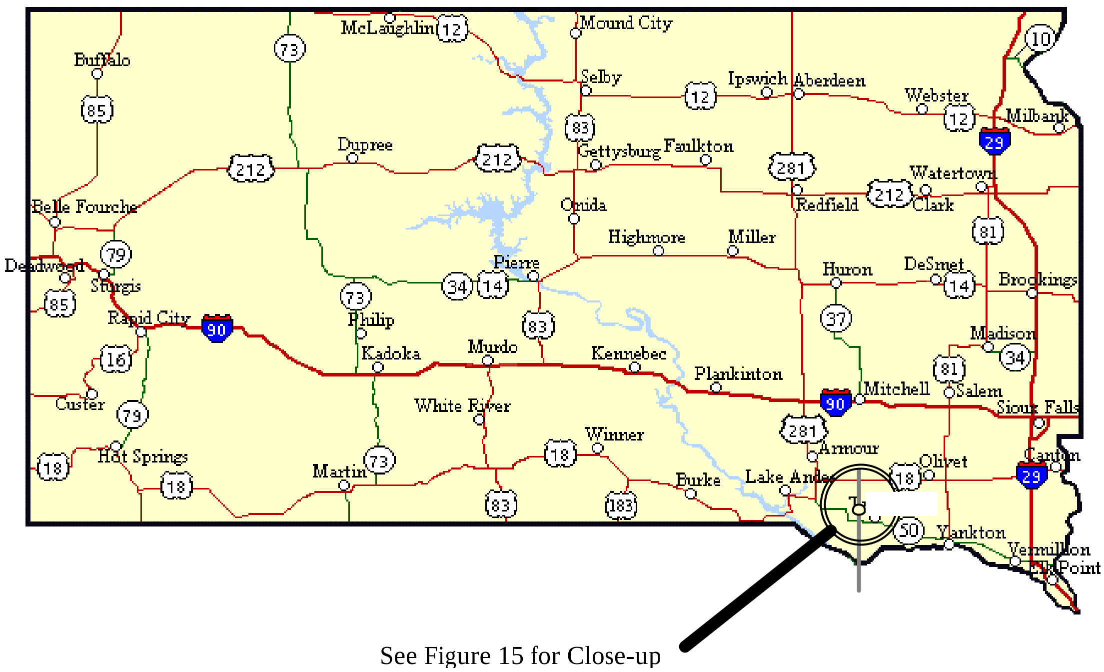

Figure 14. Location of SD 37 reconstruction project.

5. HIGHWAY SHOULDER TEST SITE CONSTRUCTION (TASK 5)

Overview of SD 37 Reconstruction Project

The SD 37 reconstruction project, in which the experimental shoulder sections were built, consisted of two sections: a north section, extending from the north edge of Parkston (MRM 52.42 + 0.328) to SD 42 (MRM 62.00 + 0.530), and a south section, extending from the south edge of Parkston (MRM 51.00 + 0.422) to approximately 8 mi south (MRM 43.00 + 0.585). These sections can be seen in the project plan view provided in figure 15. Because only the north section was programmed to include asphalt shoulders, it was chosen as the location for the shoulder experiment.

Prior to its 2001 reconstruction, this stretch of SD 37 consisted of multiple layers of chip seal and thin AC applications on top of aggregate or asphalt-stabilized base. Some areas of both sections were surface patched in 1997. The 1998 2-way ADT ranged from 1,895 to 2,399, with approximately 12 percent trucks. The topography along the site is slightly rolling and includes several small- to medium-sized sloughs, some of which extend up to the roadside ditch line.

The basic design of the SD 37 pavement consists of two 14-ft-wide by 8-in-thick JPC slabs tied together with No. 5 epoxy-coated deformed tie bars. Transverse joints are spaced at 20-ft intervals and are equipped with 18-in-long by 1.25-in-diameter dowel bars on 12-in centers. The slabs are placed on 5 in of salvaged gravel cushion material and are supported by 6-ft-wide by 3-in-thick AC shoulders (the shoulders actually extend out to 10 ft, but the thickness tapers from 3 in to 0).

Figure 16 shows the layout of the experimental shoulder sections within the SD 37 reconstruction project. As can be seen, the experiment consists of 11 different shoulder strategies, with each strategy tested twice along SD 37 in the form of 500-ft-long test sections located on each side of the road. Although the majority of test sections were established in the eighth, ninth, and tenth miles north of Parkston, a few sections—those involving the beveled PCC edge concept (strategies 8a and 8b)—had to be located along the southbound lane within the first mile north of Parkston. As will be discussed later, this occurrence had to do with the contractor’s logistics for the paving operation.

SD 37 Construction—Phase I

The first phase of the SD 37 reconstruction project was begun in spring 2000. Involved in this phase were the reclamation and stockpiling of existing asphalt-bound materials, grading and reshaping of roadside ditches and the roadbed, and placement of 6 in of salvage cushion base and an asphalt blotter to carry traffic through the winter and spring of 2001.

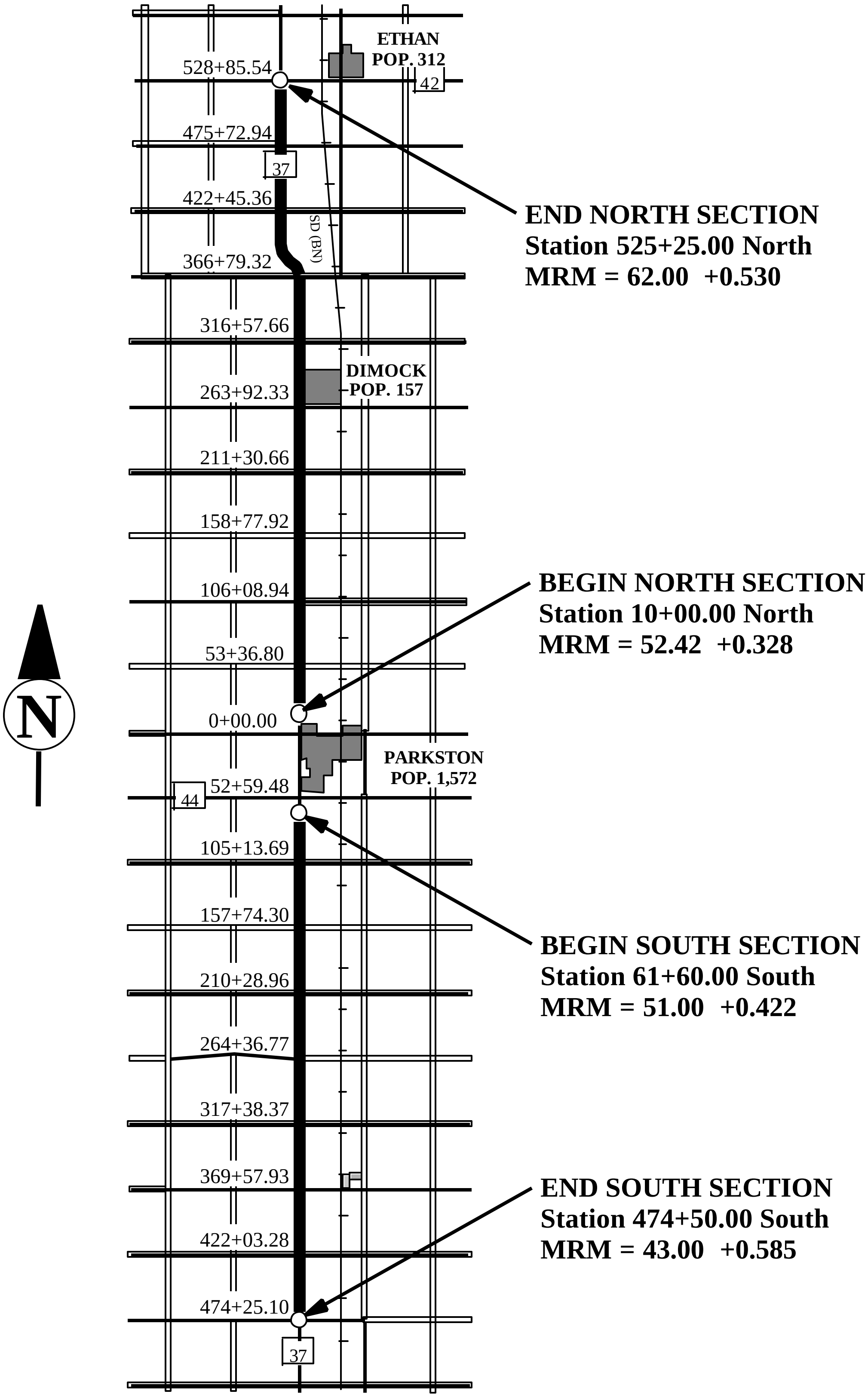

Figure 15. Plan view of SD 37 reconstruction project.

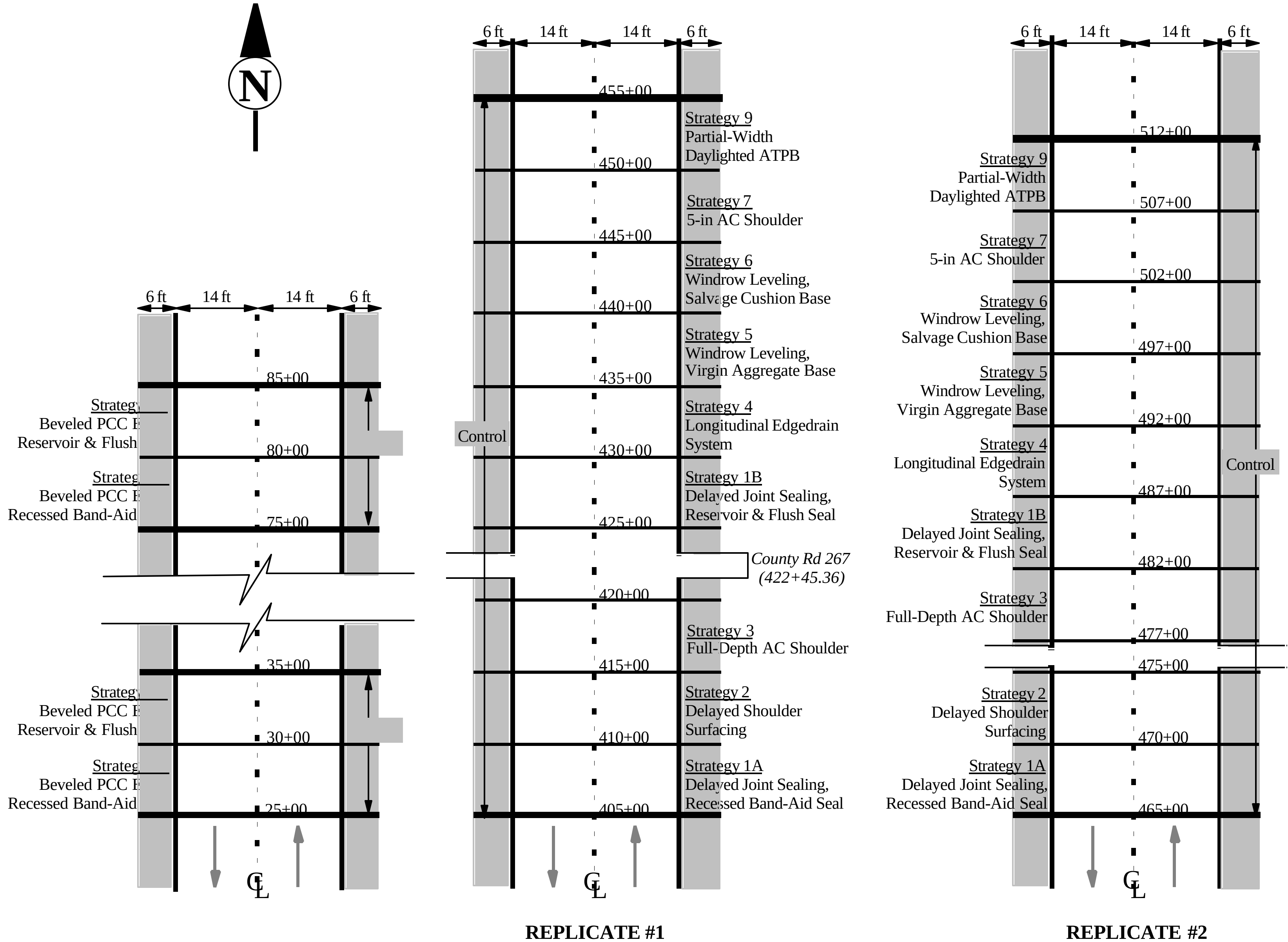

Figure 16. Layout of SD 37 shoulder test site.

SD 37 Construction—Phase II

Phase II of the SD 37 reconstruction project, which entailed roadway base reshaping and construction of the pavement surface and shoulder, began with the establishment of detour routes in July 2001. These detours allowed for a full closure of both the north and south sections of the SD 37 project.

Roadway Base Course Reshaping

Roadway base course reshaping began in July 2001 and simply involved reworking the top 3 in of salvage cushion base, adding water and additional salvage material as needed, and recompacting the base to slightly above grade for final trimming.

Prior to final trimming, however, two areas of the compacted salvage cushion were removed and replaced with a virgin aggregate (quartzite), in accordance with the research construction plan notes. These areas were as follows:

- Sta. 435 + 00 to 440 + 00, right of centerline (strategy 5 in replicate 1).
- Sta. 492 + 00 to 497 + 00, left of centerline (strategy 5 in replicate 2).

The quartzite was placed and compacted in 2- to 3-in lifts to a depth of 6 in. Because the sand cone density tests prescribed in the research construction plan notes could not be completed on the material (the material lacked the fines needed to lock-up and allow for determination of maximum dry density), each lift of material was watered and then rolled with numerous passes until a solid and tightly knit layer was achieved.

A 30-ft-wide fine-grading machine was used to bring the base course to its final grade. This machine trimmed off excess cushion material and deposited it in a windrow on the left shoulder throughout the length of the project.

PCC Paving

Once the roadway base course was trimmed, dowel baskets and bars were assembled for load transfer across transverse contraction joints. The epoxy-coated dowel bars were 1.25 in diameter by 18 in long, and were placed 12 in apart along each contraction joint. The spacing of each dowel assembly, and hence each contraction joint, was 20 ft.

PCC paving began in mid-August of 2001. The paving operation began at the south end of the south section (Station 474 + 50 South), proceeded in the northbound lane to the north end of the north section (Station 525 + 25 North), and returned in the southbound lane to the point of origin. A Gomaco slipform paver was used to pave the 14-ft-wide slabs predominant throughout the project. Number 5 epoxy-coated, deformed tie bars were installed at 30-in intervals across the adjacent slabs.

Although the four shoulder test sections involving a beveled PCC slab edge were to be constructed between Stations 450 + 00 and 460 + 00 and between Stations 507 + 00 and 517 + 00, the lateness of the construction season caused these four sections to be relocated several miles south of the shoulder test site—specifically, stations 25 + 00 to 35 + 00 and 75 + 00 to 85 + 00, just north of Parkston. This is because several hours were required by the contractor to flare the right side panel on the slipform paver to a 4:1 taper, so as to create the required 2-in beveled PCC edge. Many more hours of valuable paving time would have been lost had the contractor been required to change the panel back and forth throughout the paving operation.

Shoulder Base Course Construction

As mentioned previously, all excess roadway cushion material was deposited onto the left shoulder. As a result, only the test sections in replicate 2 required windrow leveling (replicate 1 test sections had no windrows, as they were located on the right shoulder).

In accordance with the research construction plan notes, the windrowed cushion material in 9 of the 11 test sections in replicate 2 was leveled within 24 hours of PCC paving to minimize the possibility of rainwater ponding between the windrow and the PCC edge. In the other 2 sections, the windrowed material was removed to allow for construction of the full-depth AC shoulder (strategy 3) and the daylighted asphalt-treated permeable base shoulder with an AC surface (strategy 9).

All leveled cushion material (salvage and quartzite) was compacted in the days to follow using a pneumatic roller. Water was added as appropriate to achieve the required density levels. During this same period, salvaged and quartzite cushion materials were hauled in and placed as specified in the replicate 1 test sections, located on the right shoulder. These materials were spread and compacted in 3- to 4-in lifts to the required density levels. Moreover, the edge of each lift adjacent to the concrete slab was mechanically tamped using a vibratory plate compactor or a whacker-packer compaction device.

Because the contractor ran out of salvage material while nearing completion of the shoulder bases, small amounts of quartzite (1 to 2 in) had to be used at various locations in replicate 2 to bring the shoulder base course to grade. Also, for the two delayed shoulder surfacing (strategy 2) test sections, salvaged cushion material was used for surfacing in replicate 2, whereas a sandy gravel was used for surfacing in replicate 1. Both surfaces were allowed to remain in service for about 1 year, at which time they were replaced with 3 in of AC (additional discussion on this matter is provided later).

Longitudinal Edge Drain Strategy

Construction of the two longitudinal edge drain test sections (strategy 5) took place primarily on October 1, 2001. An integral trenching and drain installation machine was used to sequentially install the geotextile filter, 4-in diameter flexible perforated drainpipe, and permeable backfill. A backhoe tractor was used to dig the trench for the outlet pipes and then backfill around those pipes.

Material from the trenching operation was windrowed atop the PCC slab and the shoulder, about 1 ft from the edge. Although trench depth was maintained at 21 to 22 in below the PCC surface, the lateral position of the trench varied considerably. In some locations, the inside trench wall abutted the PCC slab, whereas at other locations, it was offset as much as 5 in from the PCC slab edge.

Because the gradation specified in the construction plans would have allowed the use of concrete sand for backfill for the edge drain, a construction change order was issued having the following gradation requirements:

Sieve	% Passing
0.375	100
#4	20 - 70
#16	0 - 50
#50	0 - 30
#100	0 - 10
#200	0 - 2

The actual backfill material used consisted of 0.25-in quartzite chips, containing very few fines. The chips were placed in one lift to between 3 and 6 in below the top of the PCC slab. One to two passes of the whacker-packer compaction device were made to compact and seat the chips around and atop the 4-in drainpipe.

With a considerable longitudinal slope present in each edge drain test section, only two of the three outlet pipes specified for each section were installed. In the replicate 1 test section (right shoulder), which sloped downward from the north end (Station 435 + 00) to the south end (Station 430 + 00), outlets were installed at the middle (Station 432 + 50) and at the south end. In the replicate 2 test section (left shoulder), which sloped downward from the south end (Station 487 + 00) to the north end (Station 492 + 00), outlets were installed at the middle (Station 489 + 50) and at the north end.

As specified in the research construction plan notes, each outlet pipe consisted of 4-in-diameter rigid PVC pipe, placed at a 3 to 4 percent slope down to the ditch line, and secured to a concrete headwall (figure 17). With the exception of the outlet at the south end of replicate 1 (Station 430 + 00), each outlet pipe was connected to the longitudinal drainpipe using flexible, non-perforated pipe bent to a 2-ft radius. The outlet pipe at Station 430 + 00 was connected to the longitudinal drainpipe with angled PVC also having a 2-ft radius.

After the top flaps of the geotextile filter were folded over one another, the windrowed trench material (a combination of soil and salvage material) on top of the PCC slab was bladed back onto the shoulder using a motor grader. Additional salvage material was placed as needed to bring the shoulder base closer to final grade. Most of the salvage and trench material that got deposited on top of the edge drain was then bladed to the outer portion of the shoulder, where it was compacted with a pneumatic roller.

Figure 17. Longitudinal edgedrain outlet and headwall for shoulder strategy 4.

Because additional granular backfill was needed to bring the edge drain system to grade, the top flaps of the geotextile filter were manually cleared of remaining debris. Quartzite chips were added such that the surface was a little more than 3 in below the top of the PCC slab. As with the first lift of chips, several passes of the whacker-packer were made to compact and seat the chips. To finalize edge drain installation, the top flaps of the geotextile fabric were again folded over one another.

Asphalt-Treated Permeable Base Strategy

Construction of the daylighted ATPB layers (strategy 5) took place on October 10, 2001. In the replicate 1 test section, 12-ft wide rolls of non-woven geotextile separator fabric (LinQ Industrial Fabrics 225EX) were laid along the 500-ft length of the graded shoulder. The inside edge of the fabric was positioned vertically along the edge of the PCC slab; however, some difficulty was encountered in keeping the edge secured against the face of the concrete. To keep the fabric held in place during placement of the ATPB, small amounts of quartzite aggregate were placed on the entire fabric at various locations. In the replicate 2 test section, a slightly heavier fabric was installed and fewer problems were had with keeping it secured against the PCC slab edge.

The ATPB material brought to the job site consisted of crushed quarry stone with a 0.75-in nominal top size, blended and well coated with about 3 percent asphalt cement (PG 58-28) by weight. The ATPB mixture was put down with a shouldering machine in one lift. Because of the limited width of the shouldering machine, the 3- to 4-ft-wide taper on the outside edge of the

ATPB had to be placed and screeded manually. Some problems were also experienced by the machine in maintaining a constant depth along the PCC edge; as much as 3 in of variation in depth were observed in one of the test sections.

Compaction of the ATPB layers was accomplished with 2 to 3 passes of a 7.5-ton steel-wheeled roller. Although the ATPB mix appeared to be slightly tender, no serious problems were incurred with rolling the material and proper care was taken not to over-compact it.

<u>Shoulder Surfacing</u>

Class E, Type I AC was used as surfacing (figure 18) for all shoulder test sections, except those representing strategy 2 (delayed shoulder surfacing). It was also used as base material for the full-depth and 5-in thick AC test sections (strategies 3 and 7).

Asphalt paving for the shoulder test sections was performed on October 12, 13, and 16, 2001. The paving operation commenced at the start of the first replicate (Station 405 + 00, right shoulder) and proceeded north to the end of that replicate (Station 455 + 00). Replicate 2 test sections were then paved, beginning at the north end of the replicate (Station 512 + 00) and moving to the south end (Station 465 + 00). Strategy 8A and 8B test sections were likewise paved from north to south.

Figure 18. Completed AC-surfaced shoulder section.

As per the research construction plan notes, the full-depth AC shoulders (strategy 3) were paved in three consecutive lifts, while the 5-in AC shoulders (strategy 7) were paved in two lifts. The thickness of each lift ranged from 2 to 3 in, and nuclear density checks were made to ensure that the specified 92 percent of target dry density (Rice Method) was achieved.

In paving the various shoulder surfaces, the paver screed was positioned partly over the PCC slab, so as to leave a narrow swath (≈6 in wide and 0.5 in deep) of AC mix on the slab edge. This material was immediately windrowed back onto the shoulder along the joint, where it was then compacted with the rest of the surfacing using multiple passes of a steel-wheeled breakdown roller and a steel-wheeled finish roller. Again, nuclear density tests were performed to ensure that the specified density was attained.

Paving in both ATPB test sections was slowed somewhat, as the paving crew had to trim excess separator fabric from the PCC–ATPB interface. Also, at the start of the replicate 1 ATPB test section, a 200-ft stretch of the shoulder had to be repaved, because the cross-slope on the first attempted surface mat was more than twice the specified 4 percent slope.

Sealing of Longitudinal Shoulder Joint

Rout and seal operations took place October 17 through 19, 2001. With the exception of the strategy 1 (delayed joint sealing) and strategy 2 (delayed shoulder surfacing) test sections, the longitudinal shoulder joint in each test section was routed and then sealed with the hot-applied, low-modulus rubberized asphalt product Crafco RS 231 (an SDDOT-approved product that conforms to the modified ASTM D 3405 standard). A carbide-tipped rotary impact router was used to form the 0.75-in by 0.75-in joint reservoir, and high compressed air was used to clean it and the surrounding surface area (in the last few sections of replicate 2, a broom was used in conjunction with the high compressed air to remove the dust and debris from the routing operation).

The asphalt sealant was heated and dispensed into the joint using a large (at least 400 gal) melter-applicator unit. The material was heated and applied at the recommended safe heating and application temperatures, respectively. A steel-plated squeegee with a 3-in by 0.2-in cutout was used to form the overfilled joint sealant into the required band-aid dimensions. In some locations, where the elevations of the PCC edge and the AC shoulder edge were mismatched, problems were encountered in achieving a properly shaped overband. It should be noted that the replicate 2 strategy 1A (delayed joint sealing, recessed band-aid sealant) test section located between stations 465 + 00 and 470 + 00, were inadvertently routed and sealed (flush) by the sealing crew. This section was supposed to have been left unsealed at construction and then sealed 1 year later under a separate contract.

Delayed Shoulder Surfacing

On October 2, 2002, the gravel surfaces of the two delayed shoulder surfacing test sections (strategy 2) were removed and replaced with AC. A motor grader operated by Loiseau was used to remove the gravel surfaces, and after removal the remaining aggregate base was reportedly watered and rolled for proper compaction. The contractor, Commercial Asphalt, used an asphalt paver to place (in one lift) SDDOT class E hot-mix to a nominal depth of 3 in. Several passes of a static steel-wheeled roller were then made to compact the AC. Density tests on the compacted asphalt were not performed for either section.

Delayed Sealing

Rout-and-seal operations for the delayed joint sealing test sections (strategies 1a and 1b) and the delayed shoulder surfacing test sections (strategy 2) were conducted on October 9, 2002 by Midwest Coatings. Only three of the four delayed sealing test sections were sealed, since, as mentioned earlier, one of the sections had been inadvertently sealed at the time of initial construction (i.e., October 2001).

Although initially, the operator of the rotary-impact router did not run the cutters up against the concrete and had too narrow of a cut, adjustments were quickly made that resulted in the correct cutting position and the approximate specified reservoir dimension of 0.75 in wide. Following high-pressure airblasting of the joint reservoirs, a standard-modulus rubberized asphalt sealant (manufacturer and make unknown) was then installed. The heated sealant was struck-off according to the configurations specified for each section—flush for strategy 1b (figure 19), overbanded for strategies 1a and 2 (figure 20).

Figure 19. Longitudinal joint seal in standard reservoir-and-flush configuration.

Figure 20. Longitudinal joint seal in recessed band-aid configuration.

Post-Construction Testing

Following the completion of the SD 37 shoulder test sections, ERES researchers took measurements of lane–shoulder elevation differentials, which could serve as a baseline for monitoring shoulder settlement over time. Arrangements were also made with the SDDOT to conduct NDT tests on the shoulder sections using the Department’s Dynatest 8000E FWD. The results of these measurements and FWD tests are presented in chapter 6 as part of the shoulder performance evaluations.

6. PERFORMANCE OF SD 37 SHOULDER TEST SECTIONS (TASK 6)

Each of the 11 shoulder strategies put to test on SD 37 was evaluated for performance on two separate occasions. The first evaluation was conducted approximately 7 months after construction, and the second evaluation occurred approximately 12 months after construction. Each evaluation consisted of a detailed visual condition survey performed by ERES researchers and FWD testing performed by SDDOT field personnel. This chapter discusses the evaluation methodology and presents the evaluation results, which are representative of short-term shoulder performance.

Condition Surveys

Detailed condition surveys of the SD 37 shoulder test sections were performed on April 30, 2002, and October 28, 2002. The weather conditions during the first survey (7-month evaluation) were cloudy and cool (40 to 54°F), with light rain and drizzle occurring in the morning. The weather conditions during the second survey (12-month evaluation) were cloudy and cold (35 to 42°F), with no precipitation. Each 500-ft shoulder test section was evaluated for distresses in a manner similar to the Task 2 shoulder project surveys. However, given the need to track performance consistently over time, the LTPP distress survey procedures were followed much more closely.

Results

Complete results of the two shoulder condition surveys are provided in appendix B. In general, the sections were in very good condition after 7 and 12 months of service. The predominant forms of deterioration observed during the surveys were shoulder settlement (figure 21) and longitudinal joint seal failure (figure 22). All other forms of distress, such as alligator cracking and edge cracking, were non-existent or very minimal in severity and amount. It should be noted, however, that while snowplow damage to the band-aid seals (figure 23) was not largely prevalent in the shoulder sections, it did contribute to some seal failure and will need to be closely monitored in future surveys. Likewise, although only small amounts of sediment have been observed in the longitudinal edgedrain outlets, they will need to be routinely evaluated for clogging.

Figure 24 shows the average shoulder settlement (after 7 and 12 months) for each of the 11 shoulder strategies, based on vertical differential measurements taken along each strategy's two replicate test sections. It also shows the average shoulder settlement for the adjacent (across the road) control sections, which represent current shoulder design and specifications.

As can be seen, with the exception of the delayed sealing and longitudinal edge drain strategies (strategies 1a, 1b, and 4), each test strategy has exhibited significantly less settlement, on average, than the control. The strategies with the lowest average settlement are the PCC beveled

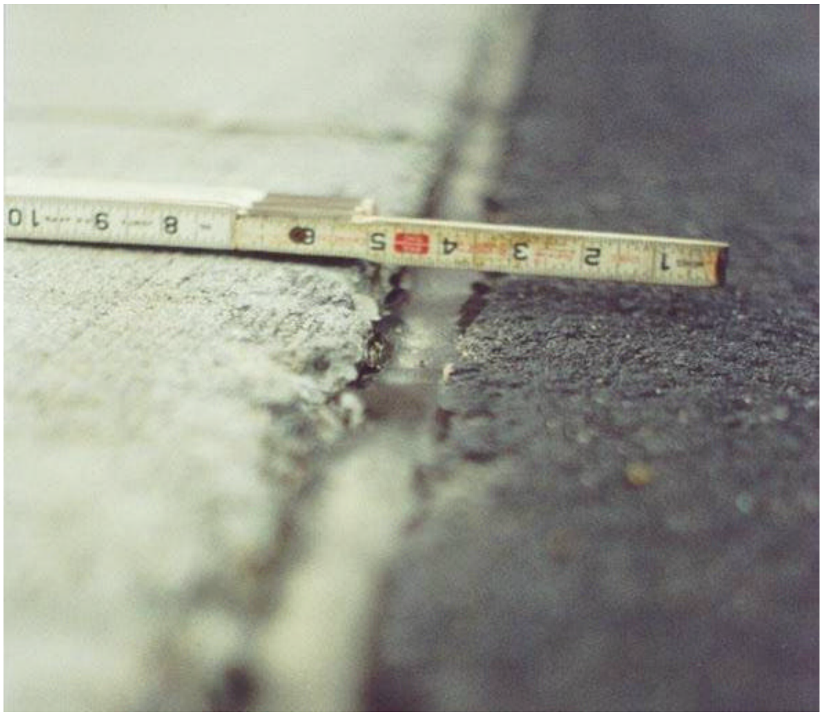

Figure 21. Approximate 0.2-in shoulder settlement in windrow-leveled salvage aggregate test section (strategy 6).

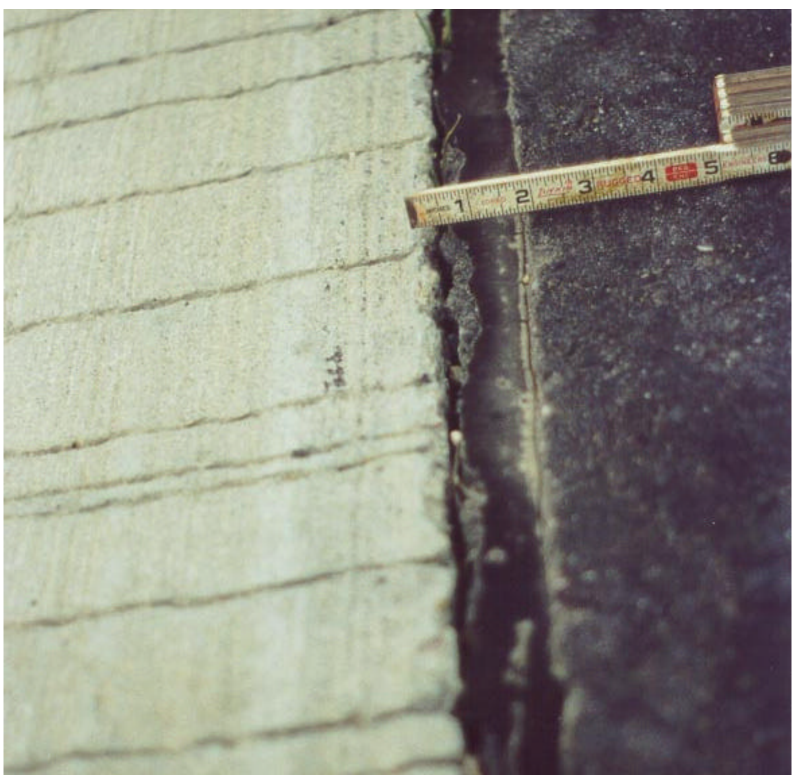

Figure 22. Longitudinal joint seal failure in one of the control sections.

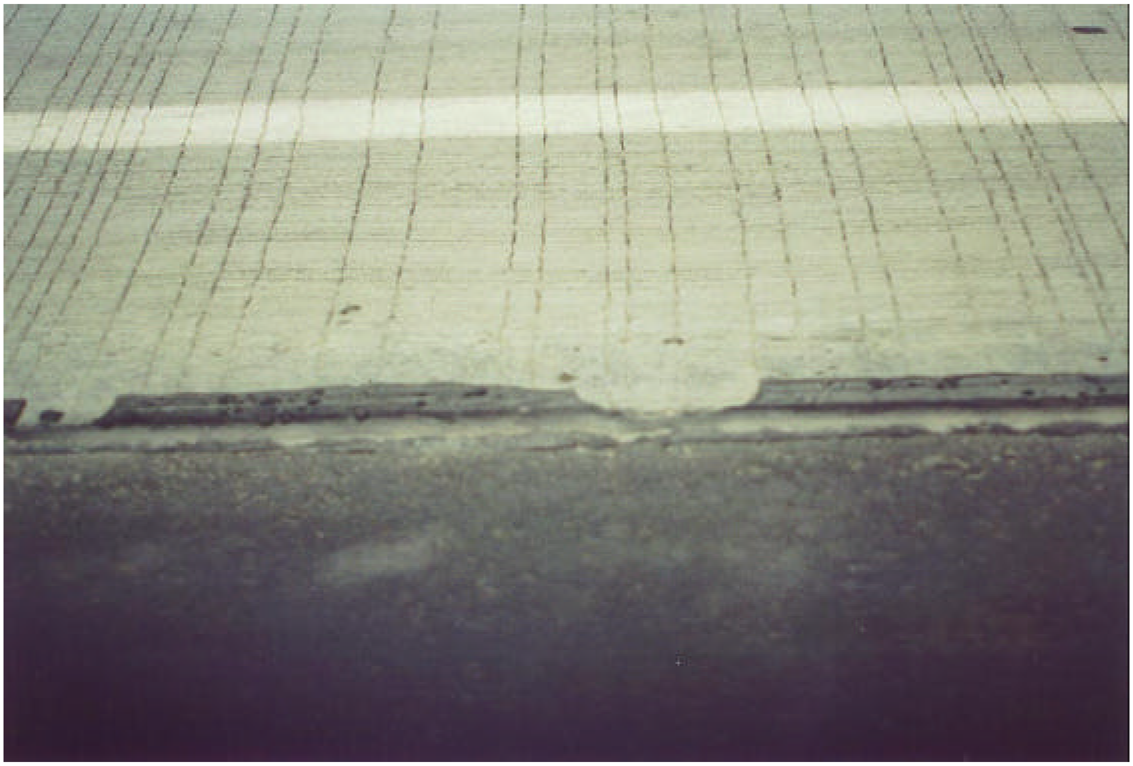

Figure 23. Snowplow damage to band-aid seal in daylighted ATPB test section (strategy 9).

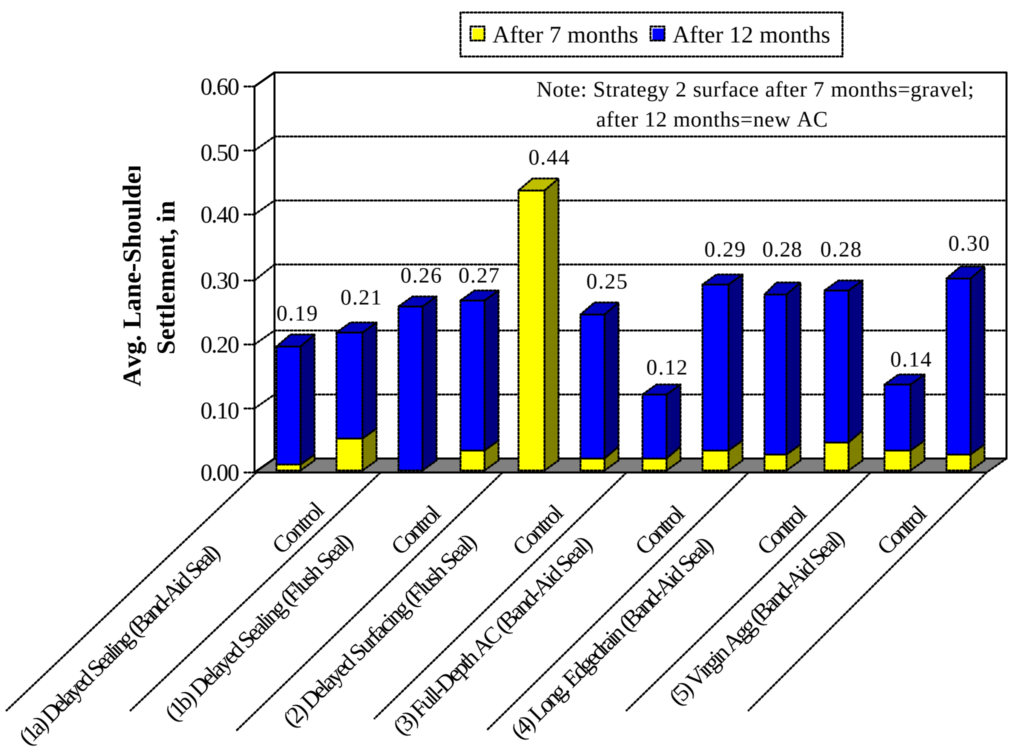

Figure 24. Shoulder settlements at 7 and 12 months after construction.

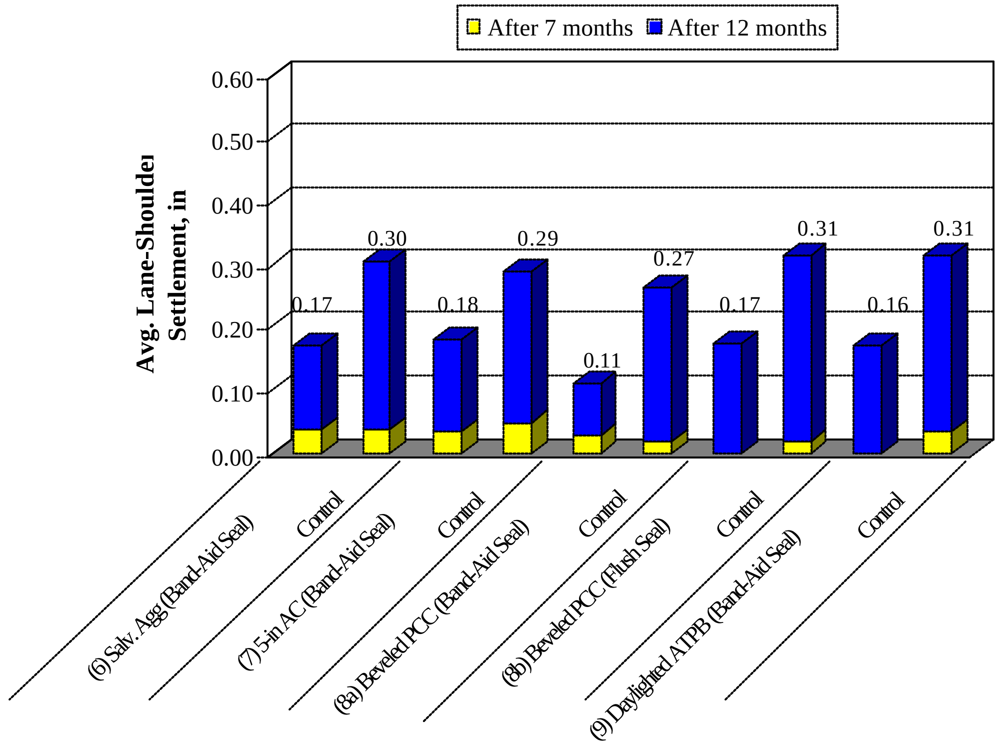

Figure 24. Shoulder settlements at 7 and 12 months after construction (continued).

edge/recessed band-aid seal strategy (strategy 8a), the full-depth AC strategy (strategy 3), and the windrow-leveled virgin aggregate base strategy (strategy 5). Slightly higher levels of settlement were experienced by four other strategies (strategies 6, 7, 8b, and 9). It should be noted that no settlement is shown for strategy 2 after 12 months because the two sections representing this strategy were just resurfaced with AC at the time of the 12-month survey.

The strategies with the greatest benefit in terms of short-term settlement, are the thicker asphalt shoulder structures (5-in AC, full-depth AC, and daylighted ATPB), the PCC beveled edge structures, and the windrow-leveled salvage and virgin aggregate base structures. Given the substantially higher up-front costs of the thicker asphalt structures, however, they are likely to not be as cost-effective as the beveled edge and windrow-leveled structures.

The high settlement in the longitudinal edge drain strategy (strategy 4) is largely attributed to the fact that the quartzite backfill material was placed and compacted in one 8- to 10-in lift during construction. Had two lifts been used, as specified, the settlement after 12 months would not have been as high.

Figure 25 shows the condition/performance of the longitudinal lane–shoulder joint seals for each strategy, and their counterpart controls. This figure clearly shows that the seal system used in the control sections (standard-modulus rubberized asphalt placed in the reservoir-and-flush

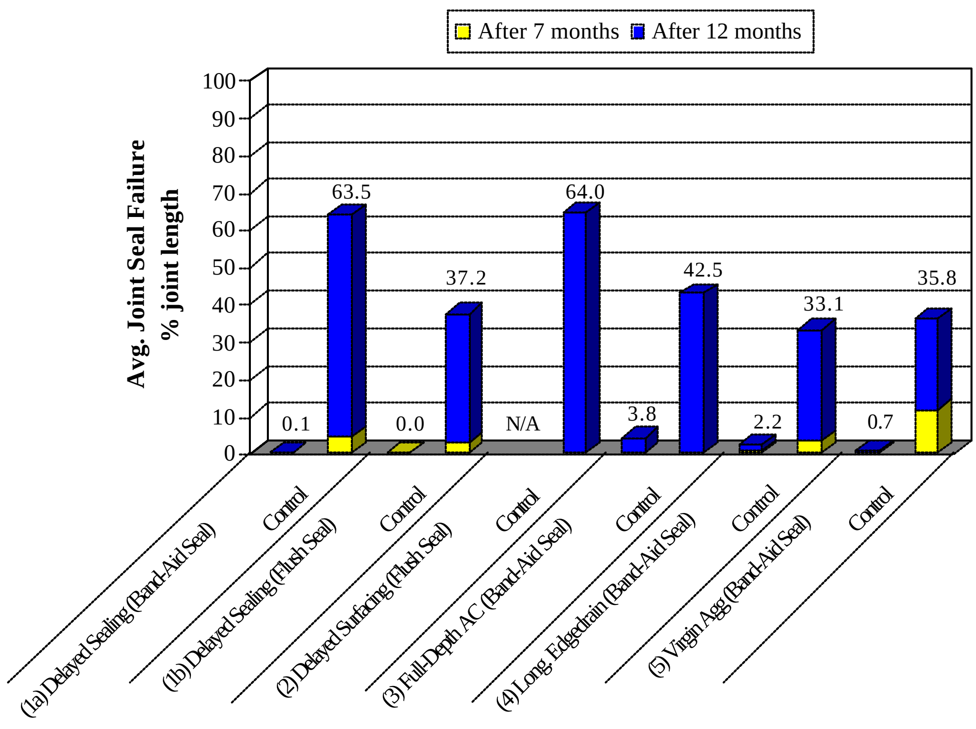

Figure 25. Lane–shoulder joint seal performance after 7 and 12 months of service.

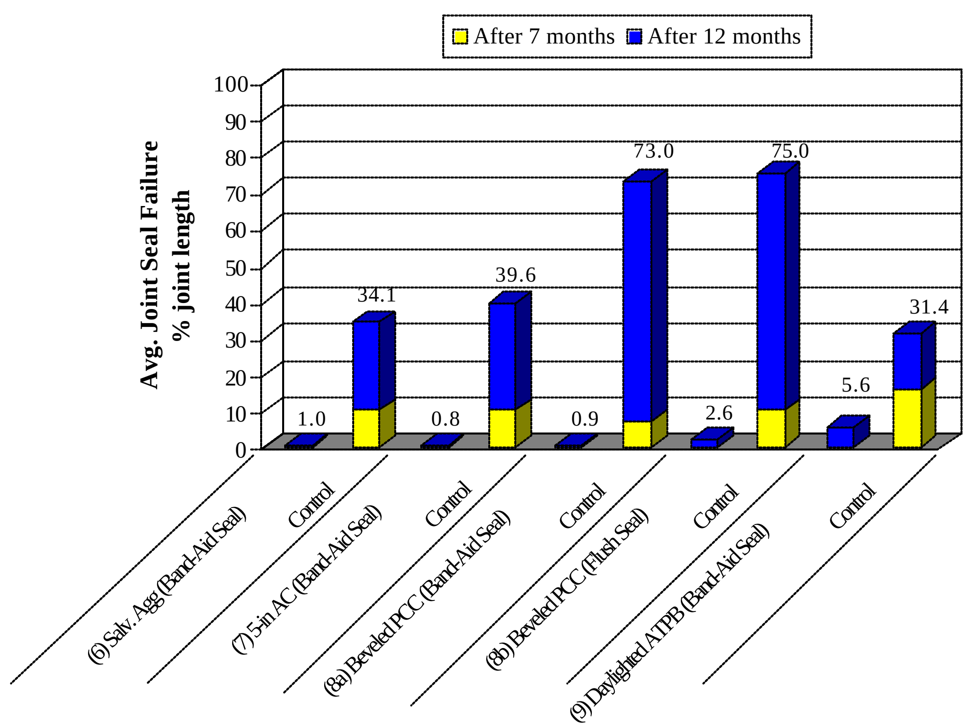

Figure 25. Lane–shoulder joint seal performance after 7 and 12 months of service (continued).

configuration) is performing much worse than the seal systems used in the experimental shoulder sections. Only 2 of the 22 control sections had less than 10 percent of the joint seal length in a failed condition after 12 months of service (failure being defined as full-depth adhesion or cohesion loss or other seal-system damage that allows the infiltration of water into the joint).

Among the experimental shoulder sections (for which all but the delayed sealing sections used low-modulus rubberized asphalt), there may be a slight advantage in performance for the recessed band-aid seal configuration, as evidenced by the head-to-head comparison between the two PCC beveled edge strategies (strategies 8a and 8b). Although the advantage over the reservoir-and-flush configuration is not statistically significant at this time, the band-aid seal has greater potential to provide better long-term performance than the flush seal (as long as snowplow damage to the overband remains minimal), due to the additional bonding area.

The primary modes of sealant failure observed in the 12-month survey were as follows:

- Standard-modulus rubberized asphalt placed in reservoir-and-flush configuration (control sections): Full-depth adhesion loss due to horizontal opening of the joint and settlement of shoulder.
- Low-modulus rubberized asphalt placed in reservoir-and-flush configuration (strategy 8b): Full-depth adhesion loss due to horizontal opening of the joint.

Figure 26 shows the relationship between shoulder drop-off and longitudinal joint seal failure at the SD 37 test site. Although the trend is not nearly as strong as the one established in the Task 2 field surveys (chapter 3), it does generally indicate that the higher the drop-off, the more seal failure likely to be incurred. This figure also shows a considerable difference in the settlement–seal failure trend of the test shoulders versus the trend for the control sections. Although the control

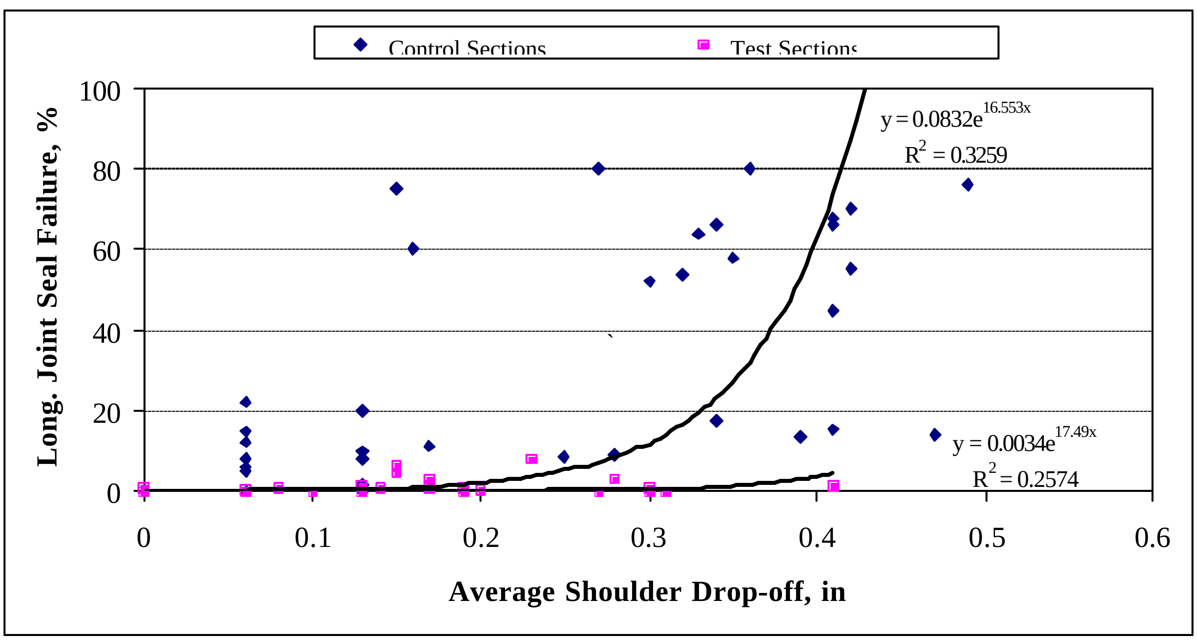

Figure 26. Shoulder drop-off versus joint seal failure at SD 37 shoulder test site.

sections had higher levels of settlement than the test sections, it would seem that the low-modulus, primarily overbanded sealants used in the test sections hold up better under vertical displacement than the standard-modulus, flush-filled sealants used in the control sections.

FWD Testing

As was done for the various shoulder projects surveyed in Task 2, each SD 37 shoulder test section was deflection tested by SDDOT personnel using the Department's Dynatest 8000E FWD. The purpose of this testing was to assess the initial and short-term load-response characteristics of the shoulder sections and get a better indication of future performance.

The shoulder sections were tested at three different times following construction:

- Post construction (November 6, 2001).
- 7 months after construction (May 3, 2002).
- 12 months after construction (November 7, 2002).

As shown in figure 27, each test section and corresponding control section (located on the opposite

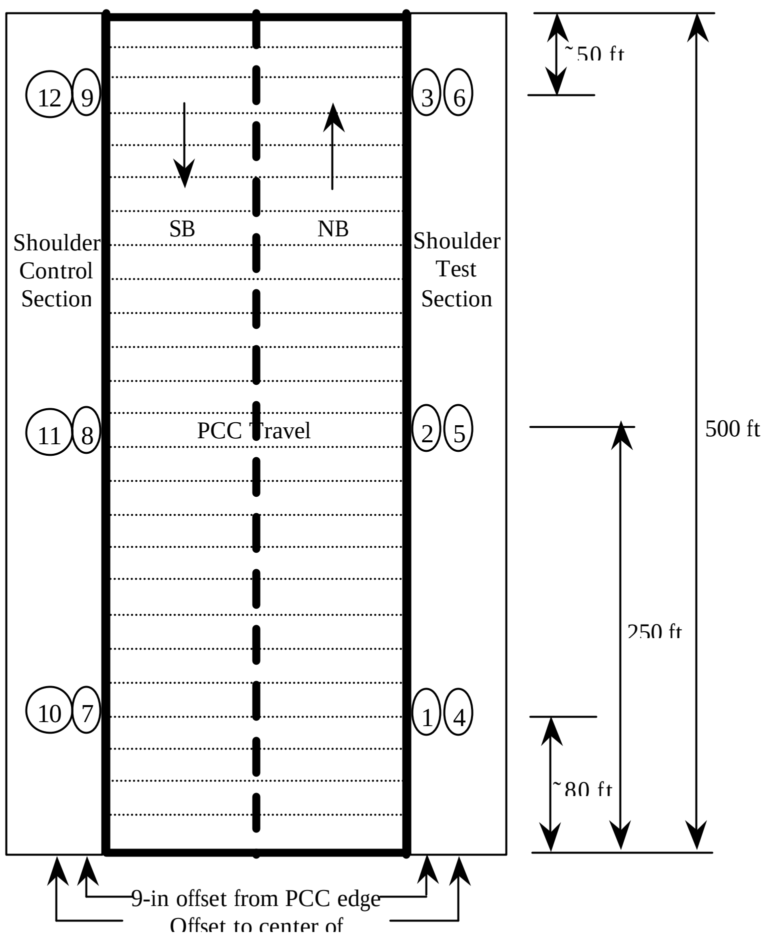

Figure 27. FWD testing plan for SD 37 shoulder sections.

side of the road) was tested at six locations—three at the inside edge of the shoulder (9-in offset from the PCC slab edge) and three at the center of the shoulder (5 ft from the PCC slab edge).

The test load sequence and deflection sensor spacings were the same as those used in the Task 2 surveys.

Deflection and Back-Calculation Analysis

Figures 28 through 30 show the average maximum deflections (normalized to a 9,000-lb test load and an air temperature of 68°F) for each shoulder strategy at 0, 7, and 12 months after construction. These averages are based on 12 individual deflection measurements (six at the inside edge and six at the center of the shoulder) taken over both replicate sections of a given shoulder strategy at a given time. For comparison sakes, the average maximum deflections of the corresponding control sections are also shown.

As these figures indicate, the lowest deflections were experienced by the full-depth AC strategy (strategy 3), followed closely by the 5-in AC and daylighted ATPB strategies (strategies 7 and 9). The average maximum deflections for these strategies were less than half those of the corresponding control sections. The remaining eight strategies (excluding the delayed surfacing strategy [strategy 2], which was not tested) had deflection levels relatively comparable to each other, however only the longitudinal edge drain strategy and the windrow-leveled salvage aggregate strategies (strategies 4 and 6) showed considerably better load response than the corresponding control sections.

The time of FWD testing had a notable effect on deflections. Conditions during post-construction testing were dry, with temperatures ranging from 58 to 73°F. Temperatures during the 7-month and 12-month test rounds were similar (46 to 65°F), but moisture conditions ranged from relatively wet during the 7-month test to dry during the 12-month test. The wet conditions at 7 months are the primary reason for the peaks in the curves in figures 28 through 30. Interestingly, no such peaks occurred for the PCC beveled edge strategies (strategies 8a and 8b), as the post-construction (0 months) deflections were the highest of any test period. A review of the post-construction deflection data for these strategies indicated considerably higher deflections at both the center and inside edge, as compared to the control sections. However, it also indicated considerably higher deflections at the inside edge, as compared to the shoulder center. Although these high inside-edge deflections are of concern from a potential settlement standpoint, the average settlements after 12 months for these two strategies are amongst the lowest of all strategies and are about half the settlement of the corresponding controls.

As figure 31 shows, the effect of test location (inside edge versus center) on maximum deflection was only significant under the relatively wet conditions of the 7-month test round. Based on data from all test and control sections, except those associated with the delayed surfacing strategy

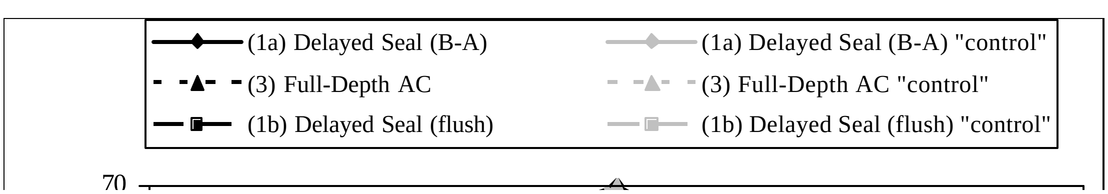

Figure 28. Average maximum deflections over time for shoulder strategies 1a, 3, and 1b.

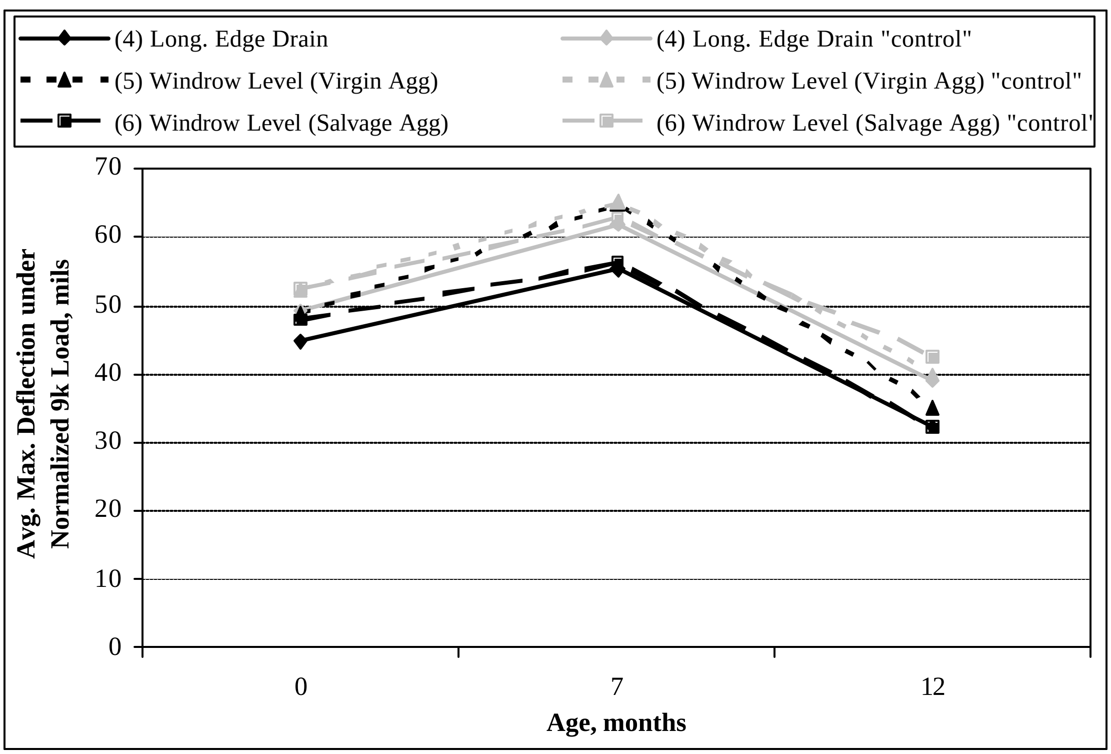

Figure 29. Average maximum deflections over time for shoulder strategies 4, 5, and 6.

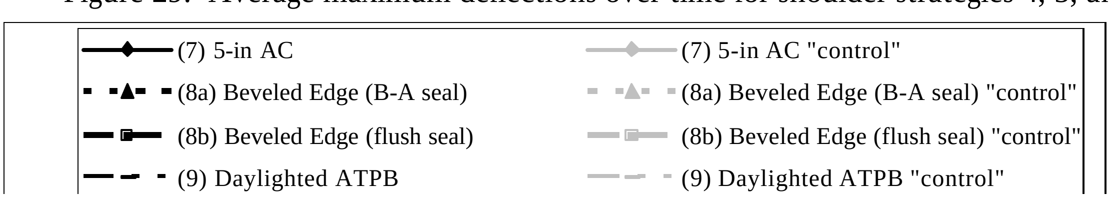

Figure 30. Average maximum deflections over time for shoulder strategies 7, 8a, 8b, and 9.

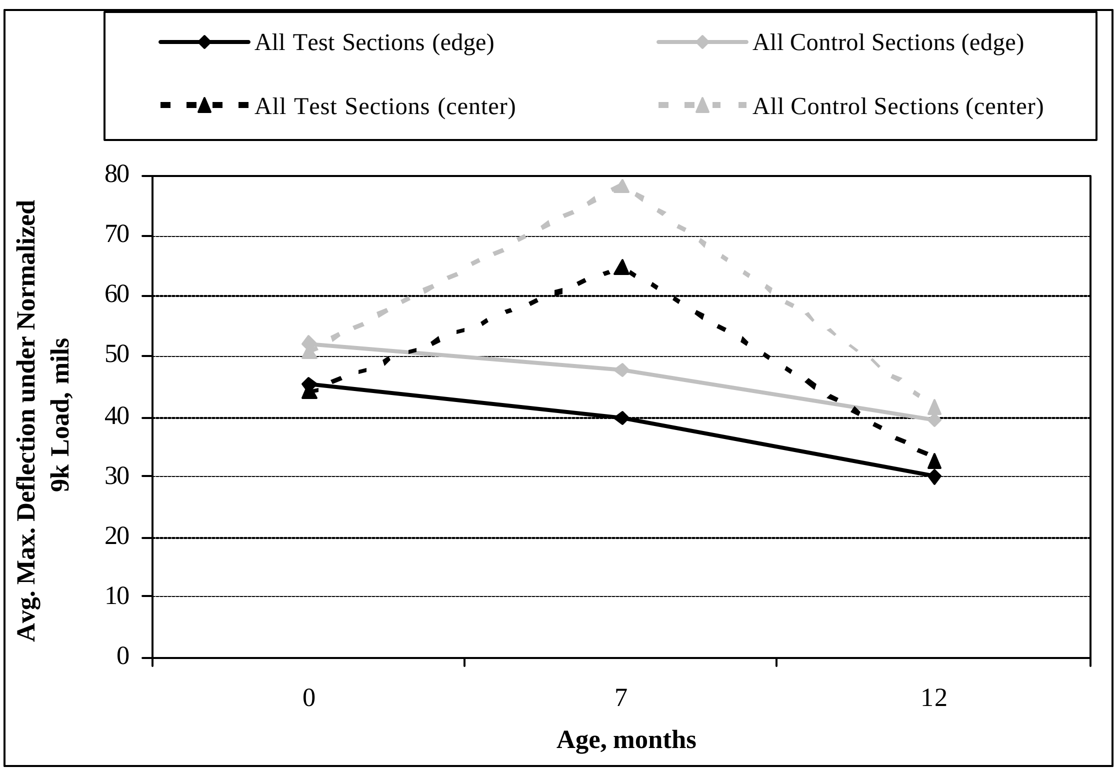

Figure 31. Average maximum deflections at inside edge and center—all shoulder sections.

(strategy 2), the average maximum deflection at the shoulder center was approximately 60 percent higher than the average maximum deflection at the inside edge. Under the dry conditions of the post-construction and 12-month test rounds, very little difference was observed between the maximum deflections recorded at the inside edge and those at the shoulder center.

Figure 32 shows the average back-calculated subgrade moduli (M_R) for the SD 37 shoulder sections at 0, 7, and 12 months. These modulus values were determined using the AASHTO structural capacity analysis procedures and the individual deflections (under nominal 9,000-lb loading) recorded for each test and control section. As can be seen, under the dry conditions of the post-construction and 12-month FWD tests, the average stiffness of the underlying foundation material (silty clay) ranged from about 3,600 to 4,200 psi, whereas under the relatively wet conditions of the 7-month survey, a considerable reduction in stiffness (average M_R between 3,000 and 3,400 psi) occurred.

Figures 33 through 35 show the average back-calculated effective pavement moduli (E_P) for each shoulder strategy and corresponding control sections at 0, 7, and 12 months. These values were determined using the AASHTO structural capacity analysis procedures, the design layer thicknesses for each shoulder section, and the individual recorded deflections. Clearly, the full-depth AC shoulder structure possessed the highest stiffness, followed by the daylighted ATPB and 5-in AC structures. The back-calculated moduli for these strategies far exceeded the moduli of the thin-surfaced (3-in AC) shoulder test and control sections, giving them a distinct advantage in terms of traffic loading capacity and potential settlement.

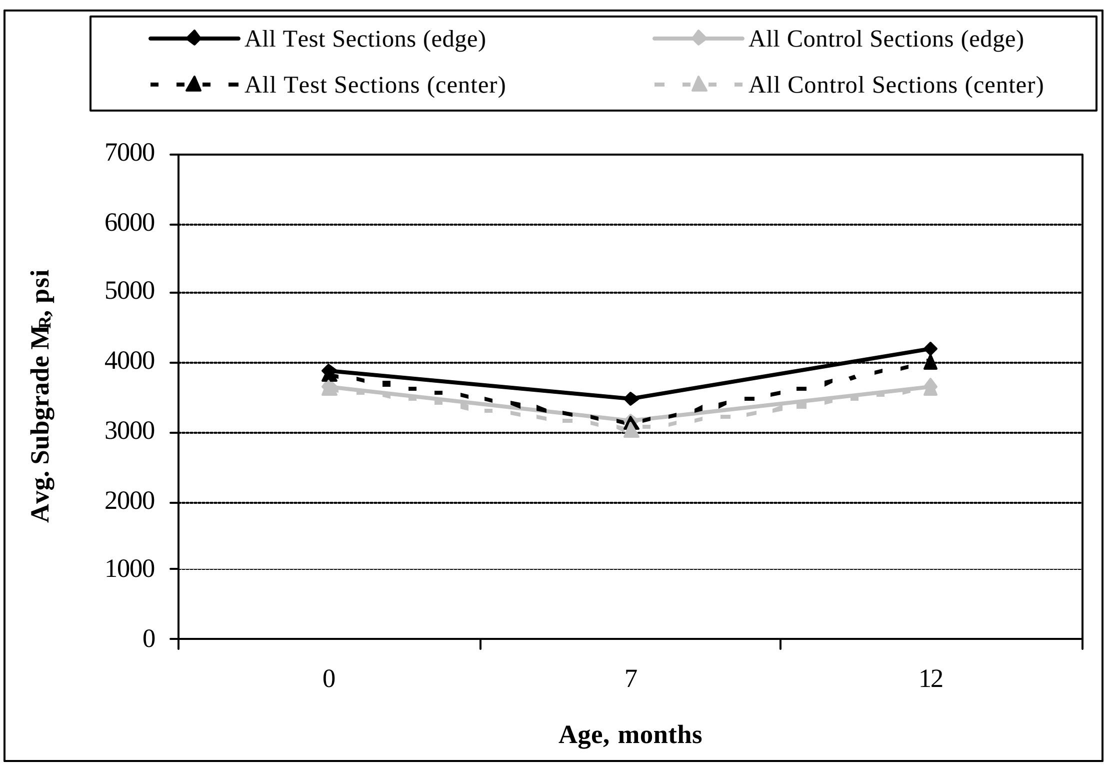

Figure 32. Average back-calculated subgrade resilient moduli—all shoulder sections.

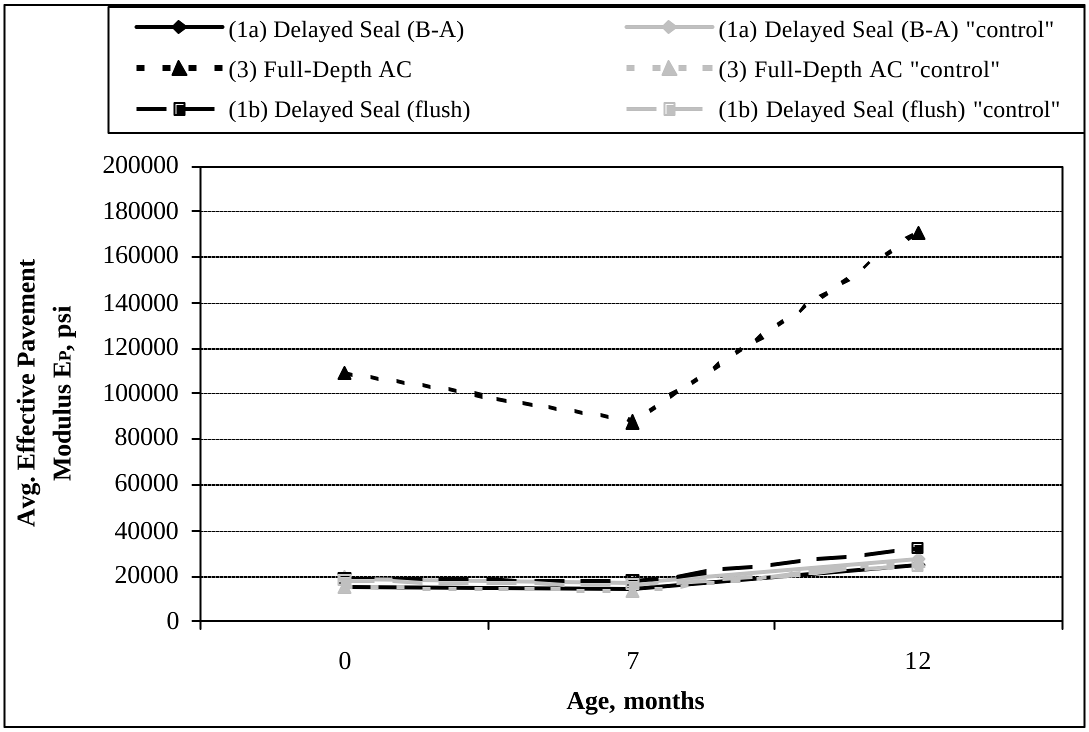

Figure 33. Average back-calculated effective pavement moduli for shoulder strategies 1a, 3, and 1b.

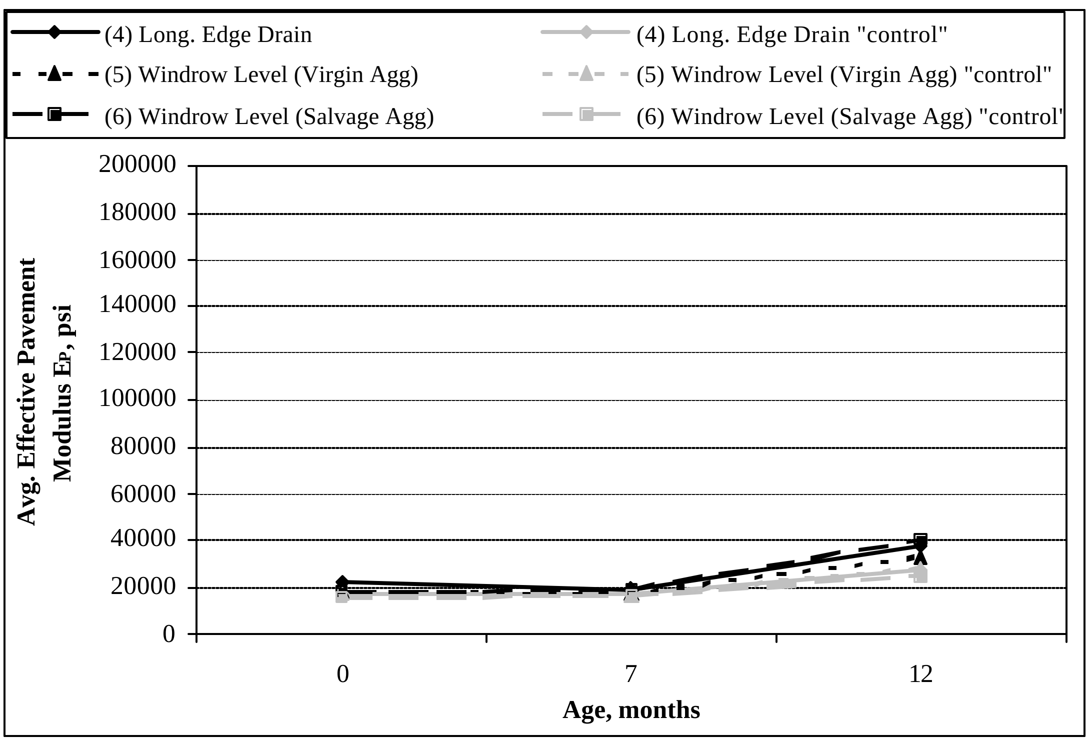

Figure 34. Average back-calculated effective pavement moduli

for shoulder strategies 4, 5, and 6.

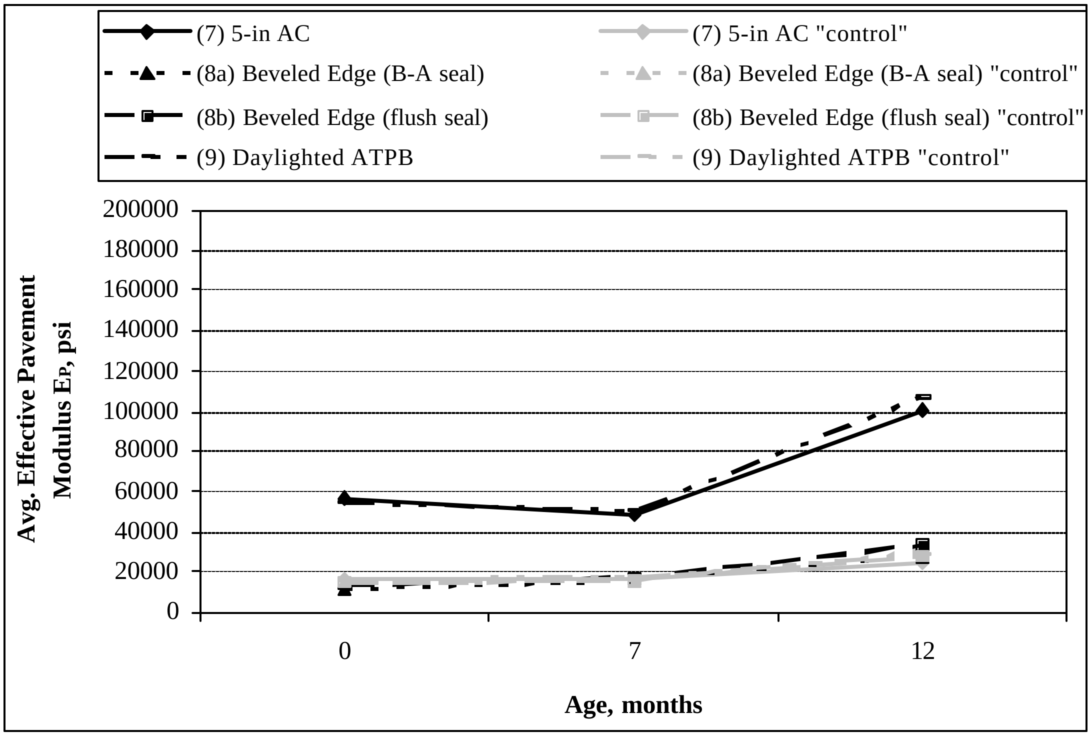

Figure 35. Average back-calculated effective pavement moduli for shoulder strategies 7, 8a, 8b, and 9.

As a check on the reasonableness of the back-calculated M_R and E_P values, the Washington DOT predictive equations presented in chapter 3 were used with design layer thicknesses and FWD load and deflection data to compute the elastic moduli of the AC surface and granular base in each shoulder section. Although the results of these computations (figures 36 and 37) are generally reflective of the temperature and moisture conditions experienced during testing, the back-calculated AC moduli (E_{AC}) are highly variable and may be somewhat low, on average. This is primarily attributed to the thickness of the AC surface layer, which for most of the shoulder sections was designed to be 3 in.

For thin (<3 in) AC pavements, the reliability of using FWD data to determine E_{AC} is significantly reduced, since thin layers contribute only a small portion to the overall deflection. Since most shoulder sections were borderline "thin," the back-calculated E_{AC} values could be considerably different from the actual E_{AC}. It should also be pointed out that the possibility exists that actual AC thickness was less than the design thickness (3 in) at many locations. If this was the case and if actual thicknesses were to be used in the back-calculations, then the resulting E_{AC} values would be much higher than those shown in figure 36.

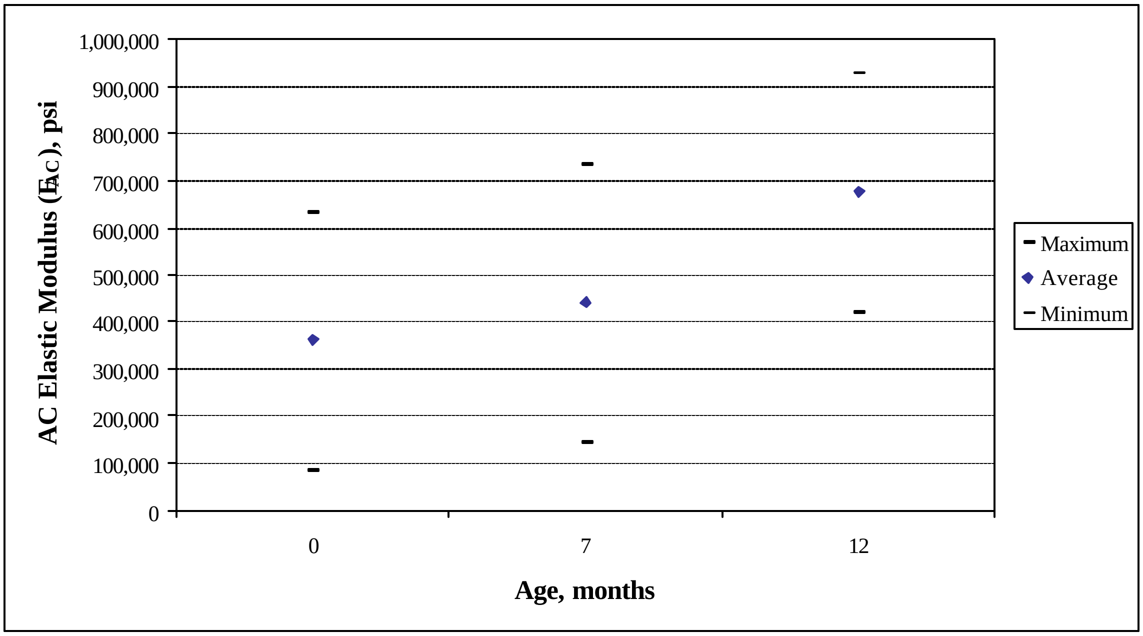

Figure 36. Back-calculated AC elastic moduli of SD 37 shoulder sections.

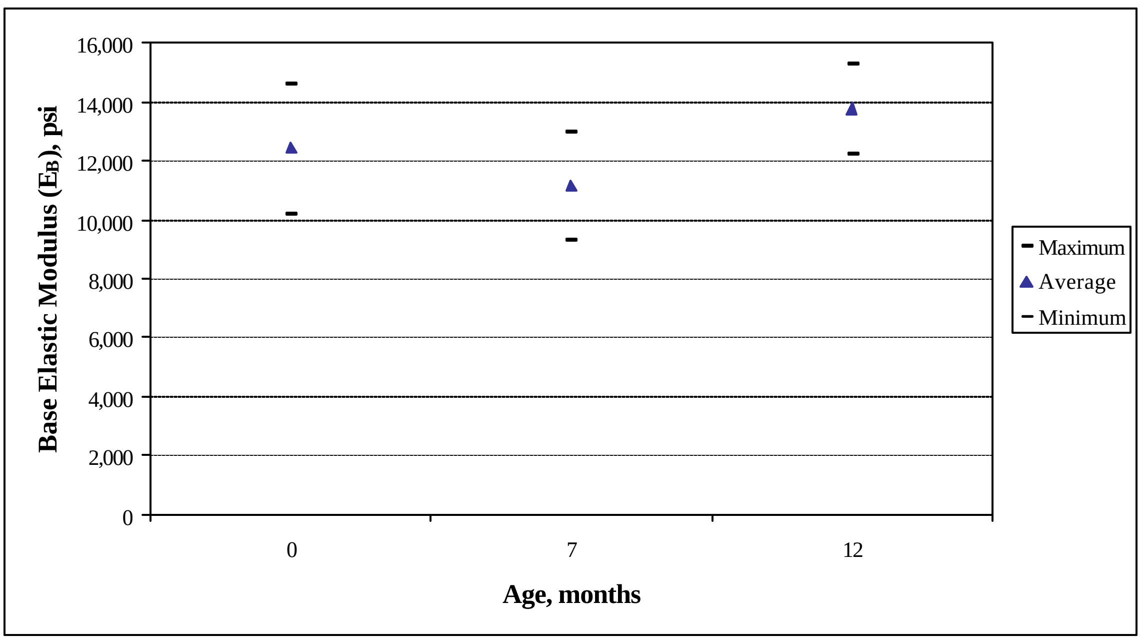

Figure 37. Back-calculated granular base elastic moduli of SD 37 shoulder sections.

7. FINDINGS AND RECOMMENDATIONS (TASK 7)

The primary objectives of this project were to investigate the factors that cause poor performance of AC shoulders adjacent to PCC pavement and to identify changes in design and construction that will lead to substantially improved shoulder performance. To achieve these objectives, three different areas of investigation were undertaken. First, a detailed literature search and review was performed, focusing on shoulder issues and remedies reported by highway researchers and practitioners nationwide. Second, a comprehensive set of condition surveys of AC shoulder projects throughout eastern South Dakota were conducted, focusing on the perceived causes of poor shoulder performance. And, lastly, a relatively large-scale field experiment was initiated, in which 22 AC shoulder test sections were constructed (as part of programmed construction project on SD 37 near Parkston) and evaluated for short-term performance.

Presented in the sections below are the various key findings of the SD 1998-07 research investigation and a detailed list of recommended design/specification changes. Also presented are suggestions for the continued performance monitoring and data assessment of the SD 37 shoulder sections towards the identification of the optimal shoulder strategy.

Key Findings

- Maintenance personnel in midwestern States overwhelmingly reported experiencing premature failure of concrete and asphalt shoulders. Key factors attributed to asphalt shoulder failure include inadequate thickness, truck encroachment, inadequate treatment of the longitudinal shoulder joint, poor shoulder joint construction, inadequate drainage, and frost.

- Policies and procedures for paved shoulder type selection (adjacent to concrete pavement) vary from State to State, with the primary decision factors consisting of functional classification, traffic/truck volume, construction and maintenance costs, and engineering judgment.

- Predominant asphalt shoulder maintenance activities in midwestern States include crack sealing, patching/pothole repair, surface treatments, shoulder joint repair, wedging, and overlays.

- AC shoulder performance can be drastically reduced through high moisture infiltration rates, underscoring the importance of facilitating drainage, be it at the surface (adequate cross-slope, effective sealing of joints/cracks), below the surface (use of drainage systems and/or permeable layers), or both.

- Field evaluation of many different AC shoulders in South Dakota indicates a general relationship between shoulder drop-off and longitudinal joint seal failure. While it is not known for sure if one parameter is more dependent upon the other, the phenomenon is such that settlement of the shoulder occurs initially due to other factors (inadequate compaction of shoulder layers, presence of water in the shoulder structure), and as the shoulder settles and/or separates from the PCC, the joint seal becomes debonded. The failed joint seal allows more water to infiltrate the shoulder structure, which in turn facilitates shoulder drop-off and widening.

- The effects of leveling aggregate base windrows within a 24-hour period could not be properly assessed, since no rain took place during the construction process. Nevertheless, prompt windrow leveling should become standard construction practice.

- The sand cone density tests prescribed in the construction plan notes for the virgin aggregate base material could not be completed, because the material, quartzite, lacked the fines needed to "lock-up" and allow for determination of maximum dry density. Quartzite, however, is very rarely used because of its much higher cost compared to other aggregate types (primarily gravels). And, since the other aggregates are generally conducive to sand-cone testing, this test and the 97 percent density requirement specified in the study should be utilized, as appropriate, in future construction projects.

- When installing longitudinal edgedrains, it was observed that the shoulder base should be completed to grade prior to trenching, so that the edgedrain system can be constructed to the proper grade in just one pass. In some areas of the longitudinal edgedrain sections, crews had to make a second pass of adding granular backfill material to bring the edgedrain system to proper grade.

- During edgedrain construction, it was also observed that all trench material that is deposited to the sides (either on the concrete or the finished shoulder base) by the integral trenching drain installation machine should be removed without covering or spilling onto the completed edgedrain system. Significant portions of the edgedrain system had trench material bladed onto it, which when the motor grader tried to remove it, resulted in some tearing of the edgedrain's geotextile fabric.

- The need for paving equipment that can place up to 5 in of ATPB material, while attaining the 6-ft shoulder width and 3- to 4-ft taper width is recognized. Because of the limited width of the shouldering machine used to place ATPB on this project, the taper had to be placed and screeded manually, which made for a ragged edge.

- During shoulder joint routing operations, it is vital that the router operator cuts the joint reservoir so that it fully adjoins the edge of the mainline PCC. When slivers or remnants of AC shoulder surfacing are allowed to remain between the inner sidewall of the reservoir and the PCC edge, the shoulder joint ends up either unsealed or poorly sealed, leading to early seal failure.

- The overall performance of the SD 37 shoulder sections after 12 months is good, with the only notable distresses being shoulder settlement and longitudinal joint seal failure.

- Seven of the 11 shoulder strategies show significantly less shoulder settlement, on average, than the corresponding control sections after 12 months of service. The average settlements for these seven strategies, which include the thicker asphalt structures, the PCC beveled edge structures, and the windrow-leveled salvage and virgin aggregate base structures, are roughly one-half the average settlements of the controls, which range from 0.22 to 0.32 in. Given the substantially higher up-front costs of the thicker asphalt structures, they are likely to not be as cost-effective as the beveled edge and windrow-leveled structures.

- Average settlements for the two delayed sealing strategies (strategies 1a and 1b) and the longitudinal edge drain strategy (strategy 4) after 12 months are the highest of all strategies tested and are similar to settlements in corresponding control sections. The high settlement for the edge drain strategy is largely attributed to inadequate compaction of the backfill material during construction.

- Average settlement for the delayed surfacing strategy (strategy 2) is insignificant after 12 months, since new AC surface was just placed.

- Longitudinal joint seal performance in shoulder test sections is excellent after 12 months of service. For the eight shoulder strategies in which joint seal has been in place for 1 year, none have more than 5 percent of the seal length in a failed state. In contrast, the percent failure observed in the corresponding control sections ranges from 30 to 75 percent. Although it is believed that the use of low-modulus rubberized asphalt (modified SDDOT Standard Specification 870.1 A) instead of standard rubberized asphalt (SDDOT 870.1 A) is the primary reason for this difference in performance, construction quality and shoulder settlement are likely to be contributing factors.

- Head-to-head performance comparison of the recessed band-aid and reservoir-and-flush seal configurations shows a slight advantage for the former. Although the advantage is not statistically significant at this time, the band-aid seal has the potential to provide better long-term performance than the flush seal (as long as snowplow damage to the overband remains minimal), due to the larger bond area.

- Three rounds (post-construction, 7 months after construction, and 12 months after construction) of FWD testing of the SD 37 shoulder sections show substantially lower deflections—and substantially higher effective pavement moduli (E_p)—for the full-depth AC, 5-in AC, and daylighted ATPB test strategies (strategies 3, 7, and 9), as compared to the other shoulder strategies. The average maximum deflections for these three strategies were less than half those of the corresponding control sections. The remaining eight strategies (excluding the delayed surfacing strategy [strategy 2], which was not tested) had deflection levels relatively comparable to each other and to the corresponding control sections.

- The effect of FWD test location (i.e., inside edge of shoulder versus shoulder center) on maximum deflection is generally significant under wet conditions only. SD 37 FWD test results showed that average maximum deflections at the shoulder center were approximately 60 percent higher than the average maximum deflection at the inside edge during the relatively wet conditions of the 7-month test round. Under dry conditions, very little difference was observed between the maximum deflections recorded at the inside edge and those at the shoulder center.

Recommendations

Recommendations for shoulder design/specification changes (based on the three areas of investigation undertaken in this study) and continued research and analysis, include the following:

1. Windrowed base material shall be leveled with a grader or other suitable equipment within 24 hours after mainline PCC paving, so as to prevent the potential ponding of water between the mainline PCC slab and the windrowed aggregate. The base material shall be leveled as close to the PCC slab as possible, without disturbing or damaging the pavement.

2. Placement and compaction of shoulder base material (salvaged or virgin aggregate), including trim material from the leveled windrow, shall be in 4-in maximum lifts. Compaction of shoulder base material shall begin no sooner than 3 days after PCC paving and each lift shall be compacted to a specified density by (a) mechanically tamping the base material along the PCC edge using a J-tamper, wacker-packer, or vibratory plate compactor, and (b) rolling the entire shoulder width with a pneumatic or vibratory roller, in accordance with SDDOT Standard Specification 260.3 B.

3. Salvaged/reclaimed aggregate used as shoulder base material shall be compacted to 95 percent of target dry density, as determined through nuclear density checks (SD Test Method 219).

4. Virgin aggregate used as shoulder base material shall be compacted to 97 percent of maximum dry density (SDDOT Standard Specification 260.3 A), as determined by modified Proctor tests (AASHTO T-180, Modified SD 104) or nuclear density tests (AASHTO T-238/239, SD 114).

5. The longitudinal lane–shoulder joint shall be sealed with hot-applied rubberized asphalt sealant conforming to SDDOT Standard Specification 870.1 A, with the following modifications: (a) sealant shall have cone penetration value between 90 and 150 when tested at 77°F, (b) sealant shall pass 3 cycles of the bond test with 200 percent extension

at a temperature of -20°F, and (c) sealant shall weigh no more than 9.35 lb/gal. (Note: The current SDDOT sealant specification requires a cone penetration less than or equal to 90, and passing of 3 cycles of the bond test performed with either 100 percent extension at 0°F or 50 percent extension at -20°F).

6. The longitudinal lane–shoulder joint sealant shall be placed in a routed and thoroughly cleaned joint reservoir having width and depth dimensions between 0.5 and 0.75 in. The routed reservoir shall fully abut the mainline PCC edge, such that no slivers or remnants of AC exist between the inner sidewall of the reservoir and the mainline PCC edge. The sealant shall be allowed to overfill the reservoir, so that it can be struck off with a molded squeegee to create a 3-in wide by 0.2-in thick band centered over the PCC lane–AC shoulder interface.

7. Construction of the mainline PCC slab shall include beveled/tapered edges at AC shoulder interfaces. The bevel/taper shall have a horizontal-to-vertical ratio of between 3:1 and 4:1 (i.e., for an 8-in PCC slab, the bottom edge extends 2 to 2.5 in beyond the top edge), and shall result in a mid-depth slab width equal to the standard specified width of 12 or 14 ft (i.e., the top edge extends inward the same amount as the bottom edge extends outward).

   This strategy is highly recommended, as it shows the potential for very good performance with little added expense. Moreover, it should be noted that all four major PCC paving contractors in South Dakota were contacted about their ability to make paver modifications to produce the beveled PCC edge. Two of the contractors, Upper Plains and Stanley Johnsen, indicated they use Gomaco pavers and that the paver side forms can be adjusted easily to achieve the 2-in bevel tested in the study. In fact, the owner of Upper Plains indicated that one of his paving supervisors preferred paving with a bevel instead the standard vertical edge. A third contractor, Irving Jensen, indicated that they use new CMI pavers and that making the side form adjustment is very difficult. It was stated that, while older CMI pavers used to be equipped with hydraulic rams that would easily make the side form adjust, the new pavers have the forms permanently bolted in place. Nevertheless, the company's owner indicated that despite the significant work that would be involved in modifying their paver for a beveled edge project, they would do what is necessary to build a pavement that produces an overall cost savings. Finally, the fourth contractor, Progressive Contractors, indicated using different makes and models of pavers in their projects. Although no specific feedback was provided regarding the adjustment, a general impression was given that side form adjustment would probably not be an issue.

8. Although fairly good performance is being exhibited by the full-depth AC, 5-in AC, and daylighted ATPB strategies (3, 7, and 9, respectively), long-term performance data will be needed to assess whether their higher initial costs are offset by improved performance.

9. It is strongly recommended that the existing specification for granular base construction (SDDOT 260.3) be fully enforced, particularly as it relates to specifying that shoulder

base/subbase material be mixed with water at a central plant, prior to placement and compaction. This mixing requirement will help tremendously in achieving the required density levels.

10. Although the preliminary results of this study suggest better overall performance by the full-depth AC, 5-in AC, and daylighted ATPB shoulder strategies, more time and continued field evaluations are needed to produce definitive answers about performance. In addition, a detailed analysis of life-cycle costs must be performed to identify the most cost-effective strategy.

    It is therefore recommended that each of the SD 37 shoulder sections (test and control) be condition-surveyed every 2 years, beginning in fall 2004. The surveys should be performed in the same manner as was done in this study, with the LTPP distress survey procedures being the primary protocol. Data from these surveys can be combined with the 7- and 12-month data collected in this investigation, to develop distress progression curves that better define performance.

    It is also recommended that FWD testing of all sections be done concurrently with the distress surveys. The deflection data and back-calculated moduli can also be combined with data from this study to examine shoulder structural integrity over time.

    Using the performance trends developed through continued field evaluations and FWD testing, the types and timings of maintenance and rehabilitation (M&R) treatments over a nominal period of time (say, 20 to 25 years) should be estimated for each shoulder strategy. The projected sequence of M&R treatments should then be fitted with appropriate cost information which, in conjunction with the actual construction costs incurred in the SD 37 project, can be used to conduct a life-cycle cost analysis (LCCA) to determine the most cost-effective shoulder strategy.

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APPENDIX A
CONSTRUCTION PLAN NOTES FOR
SD 37 SHOULDER EXPERIMENT

South Dakota Highway Shoulder Study

CONSTRUCTION PLAN NOTES FOR STATE ROUTE 37—PARKSTON, SOUTH DAKOTA

Prepared for:

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Revised October 2000

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South Dakota Highway Shoulder Study

CONSTRUCTION PLAN NOTES FOR STATE ROUTE 37—PARKSTON, SOUTH DAKOTA

1. DESCRIPTION OF EXPERIMENTAL PROJECT

This document describes the work to be performed in constructing a series of experimental shoulder test sections on project NH 0037(75)43, State Route 37, Parkston, from Station 405+00 to Station 522+00. The sections will be constructed and monitored for performance as part of SDDOT research project SD 98-07, the objectives of which are to identify effective and cost-efficient AC shoulder practices and to subsequently improve AC shoulder design and construction standards. Areas not otherwise described in the following are to be treated as described in other parts of the contract.

Unless otherwise stated, specification section references are from the version of the South Dakota Standard Specifications for Highway Construction and its supplements in effect at the time of this contract.

2. GENERAL

To achieve the experimental objectives, it is mandatory that a specific order of work be carried out within the limits of these test sections.

Contract-specified tests and procedures will govern the Contractor's operations and the acceptance of the completed work. However, due to the research nature of this project, some additional testing of the materials and procedures will be required during the construction process. These additional tests are described in section 3 of this document. The Contractor is advised that this testing and data collection could affect work scheduling. Possible interruptions will be discussed as part of the pre-construction meeting and are to be included as part of the Contractor's required written work schedule.

The Contractor shall keep the engineer advised of all work schedules and changes. A written schedule of work order in the area specified in section 1 shall be provided 7 days prior to work beginning, and any changes except those caused by weather or the engineer shall be transmitted to the engineer in writing 3 days prior to the change in the work schedule occurring.

If the written work schedule and/or change in work schedule is not received in the required time period, the Contractor shall cease work as necessary until the required testing or data collection can be completed by the Department or other interested parties.

The Department and other interested parties shall be allowed access to all operations and be given the full cooperation of the Contractor and subcontractors, whether work is accomplished on the project site or at an off-site location.

3. TESTING

In addition to routine sampling and testing, the engineer and other parties will be performing additional tests for research purposes. These tests include, but are not limited to, the following.

- Gradation analysis of all granular materials including those comprising the asphalt-treated permeable base (ATPB).
- Density determinations of the compacted Gravel Cushion base layer using the nuclear meter (SD 219) for salvaged material and the sand-cone test (SD 105) for virgin aggregate material.
- Density determinations of the ATPB material using a nuclear density gage or equivalent.
- Asphalt content and percent air voids determination for the ATPB material.
- Falling weight deflectometer (FWD) testing to assess the structural integrity of the various shoulder sections.

4. FIELD LAYOUT OF TEST SECTIONS

Field test sections will be constructed as part of this project to evaluate the performance and cost-effectiveness of different shoulder design and construction strategies. Several strategies are proposed for testing and the length and uniformity of the Route 37 construction project allows for a statistically based experiment consisting of 500-ft test sections and test section replication.

Included in the experiment are control test sections that represent the standard shoulder design specified for the northern section of the Route 37 construction project, and 11 alternative shoulder strategy test sections. Table 1 lists the various shoulder strategies to be tested in the field and provides the locations (station boundaries and direction) in which each strategy shall be tested. The test sections shall be laid out and constructed in the field in accordance with figure 1. Note that in both replicates the control design is located across the road from each alternative design, and that in replicate 1 the control is located along the southbound (SB) lane and in replicate 2 it is located along the northbound (NB) lane.

5. CONSTRUCTION OF TEST SECTIONS

This section discusses the details concerning the design and construction of the alternative shoulder strategies listed in table 1. All test sections shall be constructed in accordance with the specifications and design details specified for the northern section of the Route 37 project, with the exceptions noted herein.

Table 1. South Dakota experimental highway shoulder strategies.

Strategy Number	Strategy Title	Replicate 1 Location (Direction)	Replicate 2 Location (Direction)
—	Control (normal design and specifications)	Sta 405+00 to 465+00 (SB)	Sta 465+00 to 322+00 (NB)
1	Windrow Leveling (Salvaged Material)	Sta 440+00 to 445+00 (NB)	Sta 497+00 to 502+00 (SB)
2	Windrow Leveling (Virgin Aggregate Material)	Sta 435+00 to 440+00 (NB)	Sta 492+00 to 497+00 (SB)
3	Delayed (1 year) Shoulder Surfacing	Sta 410+00 to 415+00 (NB)	Sta 470+00 to 475+00 (SB)
4a	Delayed (1 year) Joint Sealing (Reservoir & Flush Sealant Configuration)	Sta 425+00 to 430+00 (NB)	Sta 482+00 to 487+00 (SB)
4b	Delayed (1 year) Joint Sealing (Recessed Band-Aid Sealant Configuration)	Sta 405+00 to 410+00 (NB)	Sta 465+00 to 470+00 (SB)
5a	Beveled PCC Edge (Reservoir & Flush Sealant Configuration)	Sta 455+00 to 460+00 (NB)	Sta 512+00 to 517+00 (SB)
5b	Beveled PCC Edge (Recessed Band-Aid Sealant Configuration)	Sta 450+00 to 455+00 (NB)	Sta 507+00 to 512+00 (SB)
6	Longitudinal Edgedrain	Sta 430+00 to 435+00 (NB)	Sta 487+00 to 492+00 (SB)
7	Partial-width, Daylighted Asphalt-Treated Permeable Base (ATPB)	Sta 460+00 to 465+00 (NB)	Sta 517+00 to 522+00 (SB)
8	Full-depth asphalt concrete (FDAC) Shoulder	Sta 415+00 to 420+00 (NB)	Sta 477+00 to 482+00 (SB)
9	5-in asphalt concrete (AC) Shoulder	Sta 445+00 to 450+00 (NB)	Sta 502+00 to 507+00 (SB)

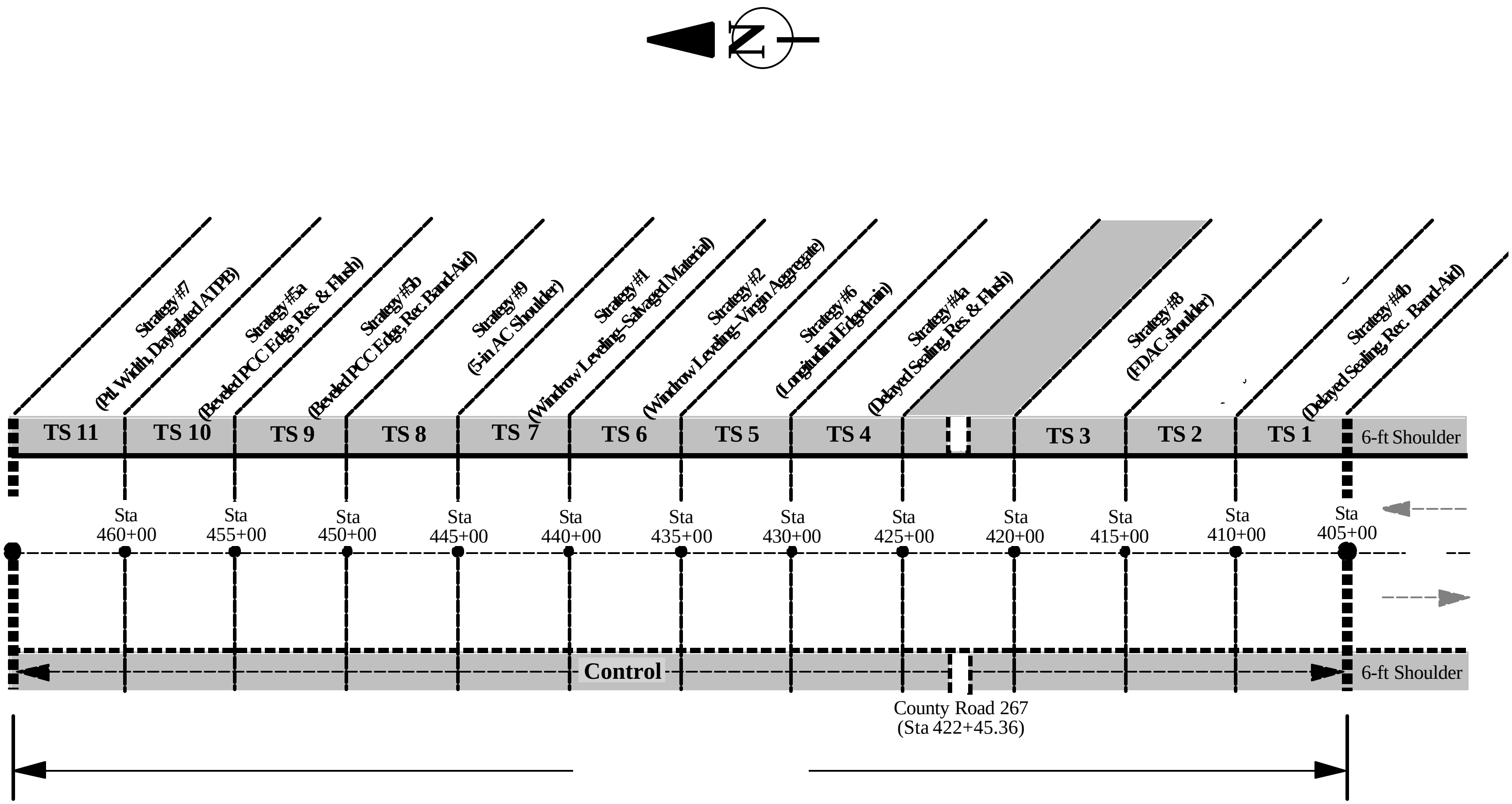


Figure 1. Shoulder test site layout for State Route 37 construction project.

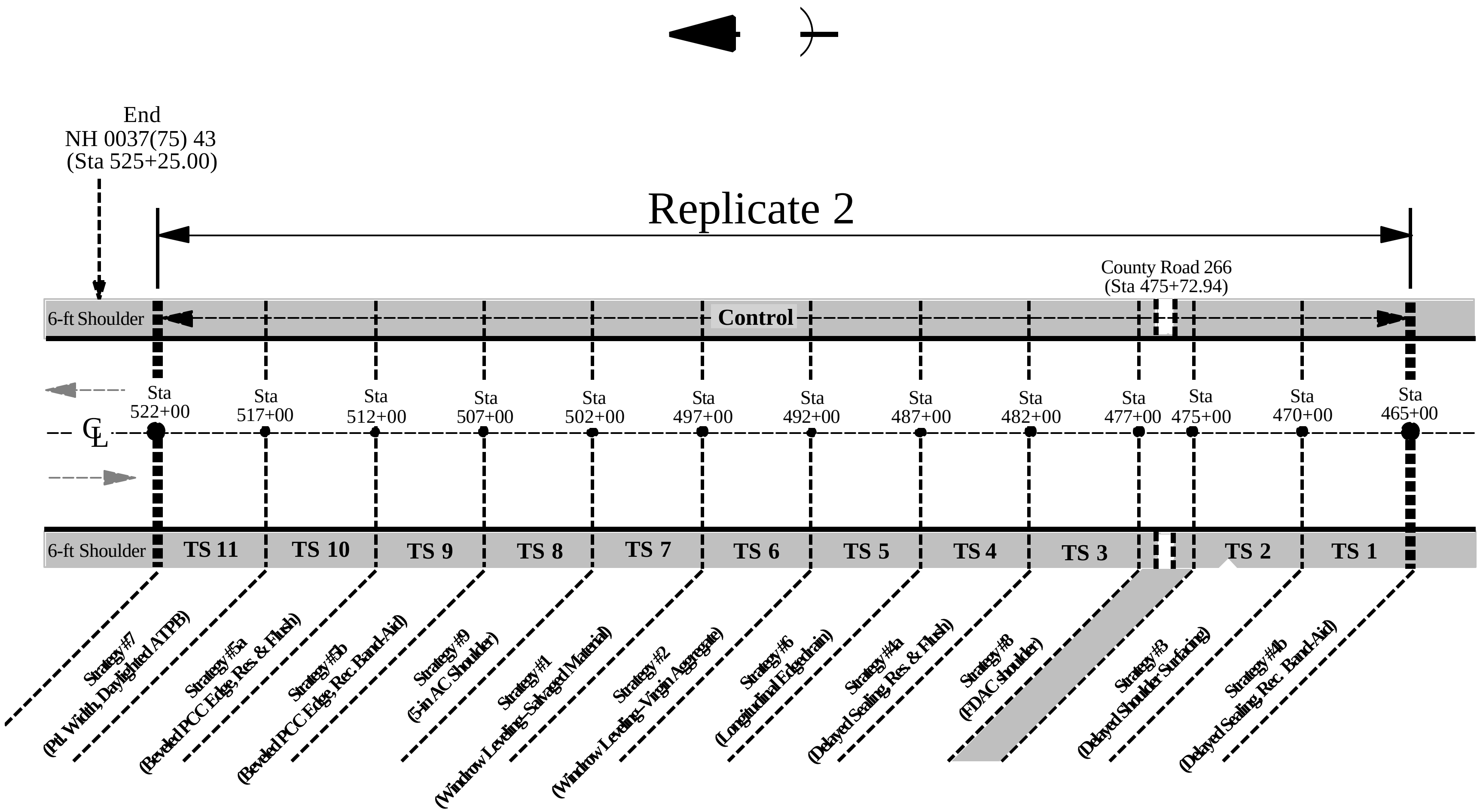


Figure 1. Shoulder test site layout for State Route 37 construction project (continued).

5.1 Control (Normal Design and Specifications)

Control test sections shall be constructed in full accordance with the specifications and design details specified for the northern section of the Route 37 construction project (NH 0037[75] 43). In brief, a 3-in Class E, Type 1 AC shoulder shall be constructed atop 5 in of trimmed and compacted salvage material. Hot-applied rubberized asphalt sealant conforming to SDDOT Standard Specification 870.1 A (modified ASTM D 3405) shall be placed in a 0.75-in x 0.75-in routed reservoir along the longitudinal PCC lane–AC shoulder interface using the procedures specified for the project. Material test requirements for this sealant are provided in section 6.

5.2 Strategy 1—Windrow Leveling (Salvaged Material)

Strategy 1 test sections shall be constructed in full accordance with the specifications and design details specified for the northern section of the construction project, with the exception that windrowed salvage material must be leveled within 1 day after mainline PCC paving and the material must subsequently be compacted to a specified density. In addition, a different sealant configuration shall be used for the longitudinal lane–shoulder joint.

As illustrated in figure 2, excess salvage material that is windrowed just outside of the PCC paver tracklines must be leveled within the 1-day time frame, so as to prevent the potential ponding of water between the mainline PCC slab and the windrowed aggregate. The Contractor shall level the material as close to the PCC slab as possible, without disturbing or damaging the green concrete.

The Contractor may begin compacting the shoulder base material a minimum of 3 days after the placement of the mainline PCC. The Contractor shall be required to first mechanically tamp any leveled salvage material along the PCC edge using a vibratory-plate compactor. The entire shoulder width must then be rolled with a pneumatic or vibratory compaction roller, in accordance with SDDOT Standard Specification 260.3 B. To ensure adequate in-place density of this initial lift of salvage material, nuclear density checks shall be made by South Dakota DOT representatives in accordance with SD 219, "Method of Test for Determining Target Dry Density and In-Place Density of Salvaged/Recycled Materials Using the Nuclear Meter." Each nuclear density measurement must be within 95 percent of the target dry density determined from the project test strip.

Once the initial lift has met the 95 percent requirement, the Contractor may place and compact subsequent lifts of salvaged material, with each lift not to exceed 4 in of thickness. Nuclear density measurements (in accordance with SD 219) shall also be made on each compacted lift, with no lift achieving less than 95 percent of the target dry density.

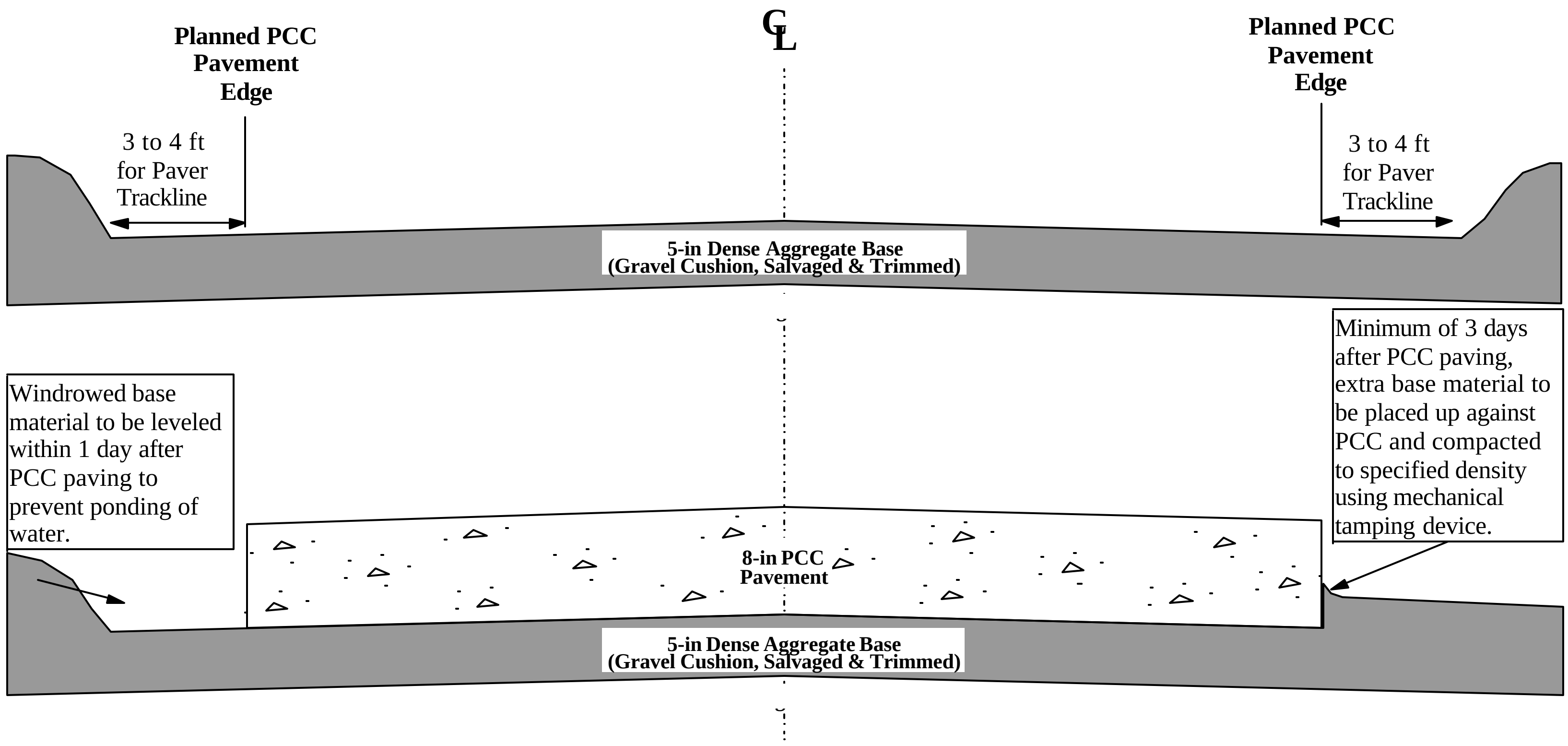


Figure 2. Illustration of 1-day windrow leveling.

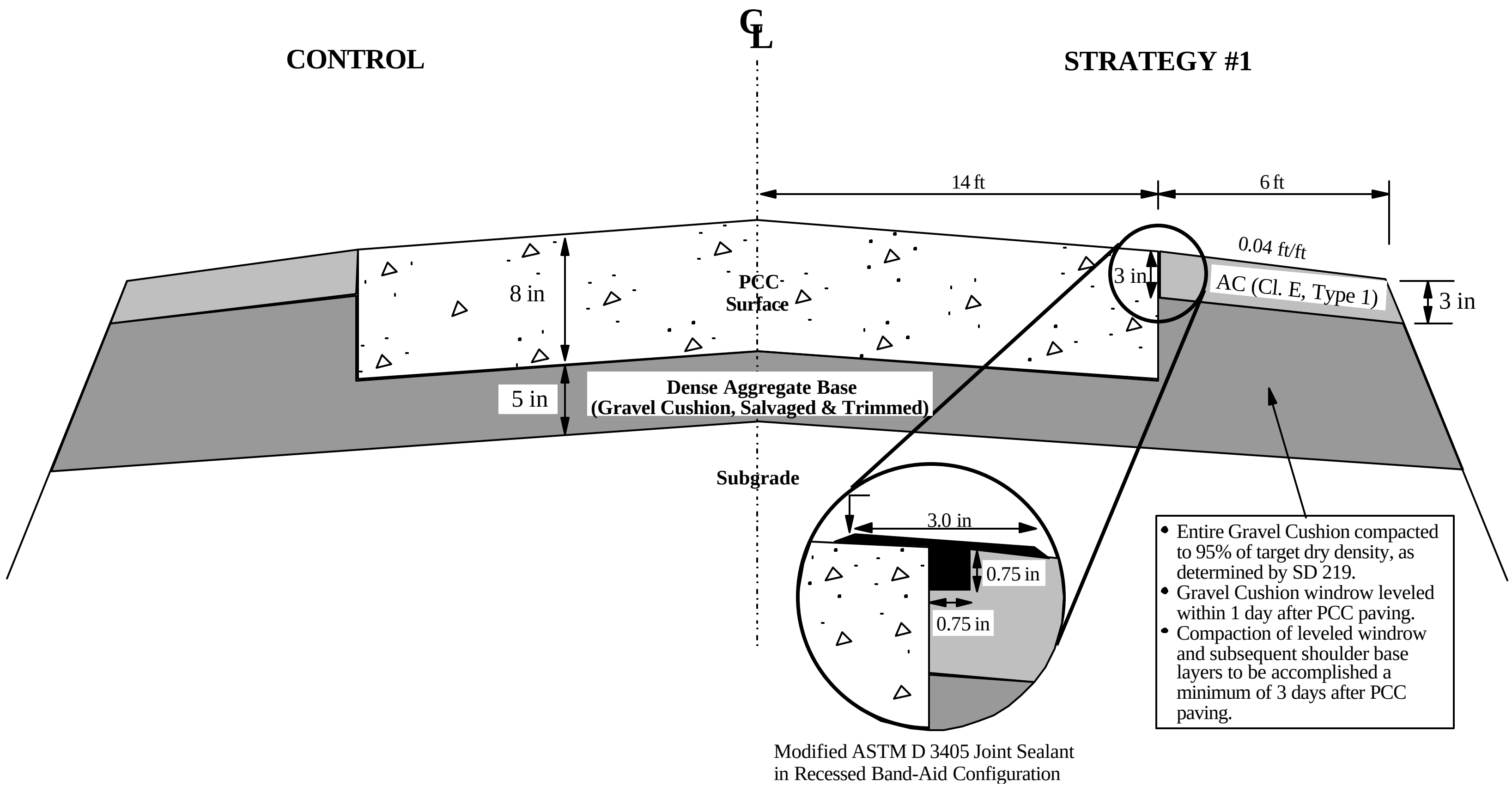


Figure 3. Cross-section of salvaged material windrow-leveling strategy (as viewed NB in replicate 1 and SB in replicate 2).

Following the placement of the AC shoulder surface, the Contractor shall rout and seal the longitudinal lane–shoulder joint using hot-applied rubberized asphalt sealant (modified ASTM D 3405, conforming to SDDOT Standard Specification 870.1 A). Material test requirements for this sealant are provided in section 6. The sealant shall be applied using the procedures specified for the northern section of the construction project, except that the material shall be placed in the recessed band-aid configuration shown in figure 3.

5.3 Strategy 2—Windrow Leveling (Virgin Aggregate Material)

Strategy 2 test sections shall be constructed using virgin aggregate for the gravel cushion base, instead of the salvaged material used throughout the project and in other test sections. As illustrated in figure 4, the cross-sectional thicknesses of this design are the same as those of the Control and Strategy 1 test sections. In addition, like Strategy 1, windrowed virgin aggregate material must be leveled within 1 day after mainline PCC paving, the material must subsequently be compacted to a specified density, and a different sealant configuration is to be used for the longitudinal lane–shoulder joint. It should be noted that if some salvaged base material is in-place prior to construction of the Strategy 2 test sections, only the material on one side of the roadway must be excavated in preparation for the placement of the virgin aggregate. This is because the other side of the roadway represents the Control, which uses salvaged material for the base.

As illustrated previously in figure 2, excess aggregate that is windrowed just outside of the PCC paver tracklines must be leveled within the 1-day time frame, so as to prevent the potential ponding of water between the mainline PCC slab and the windrowed aggregate. The Contractor shall level the material as close to the PCC slab as possible, without disturbing or damaging the green concrete.

As with Strategy 1, the Contractor may begin compacting the shoulder base material 3 days after the placement of the mainline PCC. The Contractor shall be required to first mechanically tamp any leveled virgin aggregate material along the PCC edge using a J-tamper or wacker packer compaction device. The entire shoulder width must then be rolled with a pneumatic or vibratory compaction roller, in accordance with SDDOT Standard Specification 260.3 B. This initial lift shall be compacted to 97 percent of maximum dry density (SDDOT Standard Specification 260.3A), as determined by modified Proctor tests (AASHTO T-180, modified SD 104) or nuclear density tests (AASHTO T238/239, SD 114). To ensure adequate in-place density of this initial lift, density checks shall be made by SDDOT representatives in accordance with SD 105, “Density of Soils In-place by the Sand-Cone Method.”

Once the initial lift has met the 97 percent requirement, the Contractor may place and compact subsequent lifts of aggregate base, with each lift not to exceed 4 in of thickness. Density measurements (in accordance with SD 105) shall also be made on each compacted lift, with no lift achieving less than 97 percent of the maximum dry density.

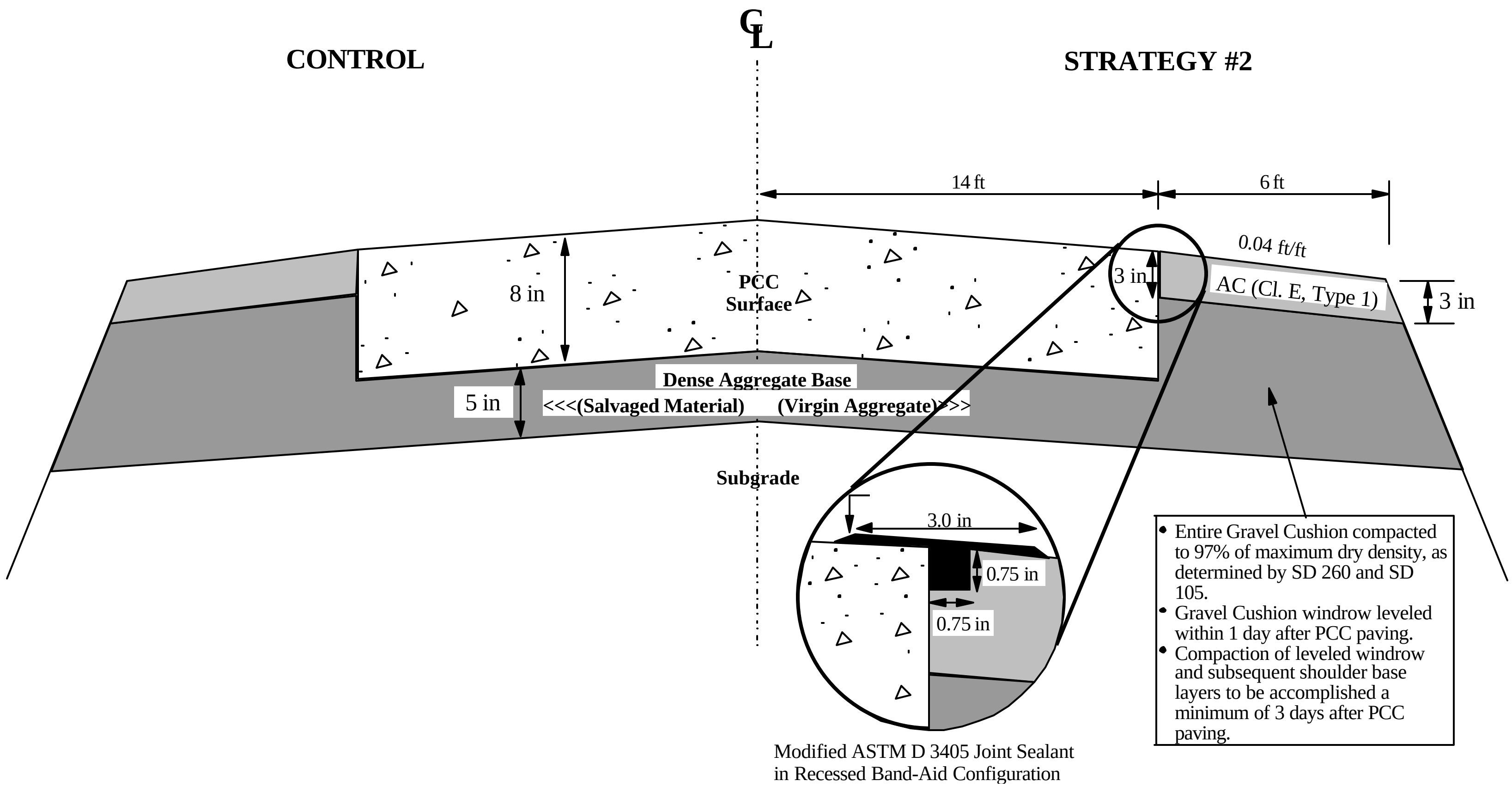


Figure 4. Cross-section of virgin aggregate windrow-leveling strategy (as viewed NB in replicate 1 and SB in replicate 2).

Following the placement of the AC shoulder surface, the Contractor shall rout and seal the longitudinal lane–shoulder joint using hot-applied rubberized asphalt sealant (modified ASTM D 3405, conforming to SDDOT Standard Specification 870.1 A). Material test requirements for this sealant are provided in section 6. The sealant shall be applied using the procedures specified for the northern section of the construction project, except that the material shall be placed in the recessed band-aid configuration shown in figure 4.

5.4 Strategy 3—Delayed Shoulder Surfacing

The delayed surfacing test sections shall be constructed in full accordance with the specifications and design details specified for the northern section of the construction project, with the exception that the shoulder shall be constructed full-depth with aggregate instead of having a 3-in AC surface (figure 5). Approximately 1 year after construction of these sections, the shoulder will be resurfaced with AC under a different contract.

The aggregate shoulder shall be constructed using the same salvaged material used for the pavement/shoulder base. As with Strategies 1 and 2, aggregate windrows shall be leveled within 1 day after mainline PCC paving and shoulder base compaction may begin 3 days after PCC paving. Maximum lifts of 4 in are required, with each lift compacted to 95 percent of target dry density, as determined through nuclear density checks (SD 219).

5.5 Strategies 4a and 4b—Delayed Joint Sealing

Delayed joint sealing test sections shall be constructed in full accordance with the specifications and design details specified for the northern section of the construction project, with the exception that the longitudinal lane–shoulder joint shall be left unsealed at the time of construction (figure 6). Approximately 1 year after construction of these sections, the lane–shoulder joints will be sealed under a different contract.

As with Strategies 1 through 3, aggregate windrows shall be leveled within 1 day after mainline PCC paving and shoulder base compaction may begin 3 days after PCC paving. Maximum lifts of 4 in are required, with each lift compacted to 95 percent of target dry density, as determined through nuclear density checks (SD 219).

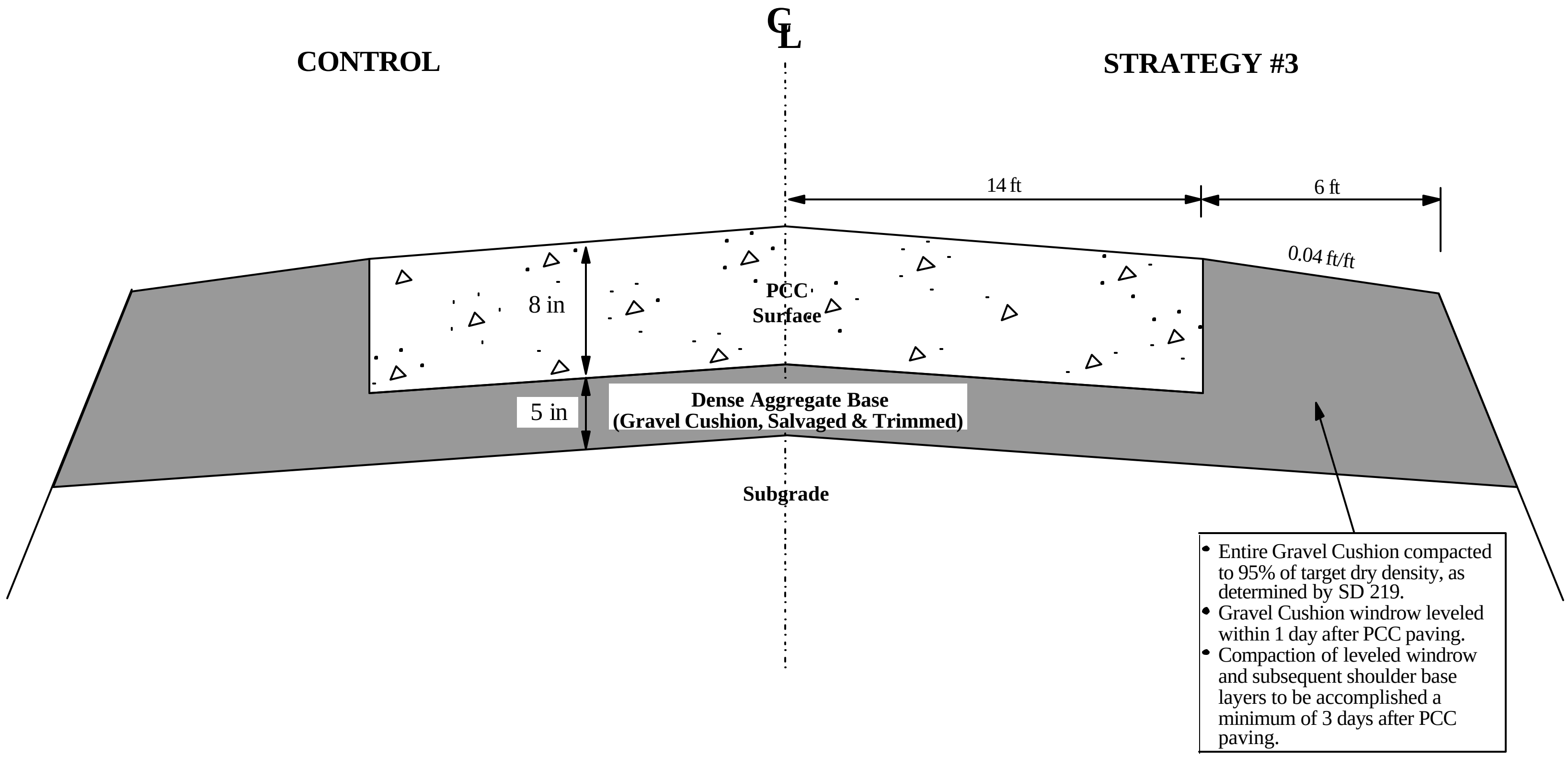


Figure 5. Cross-section of delayed shoulder surfacing strategy (as viewed NB in replicate 1 and SB in replicate 2).

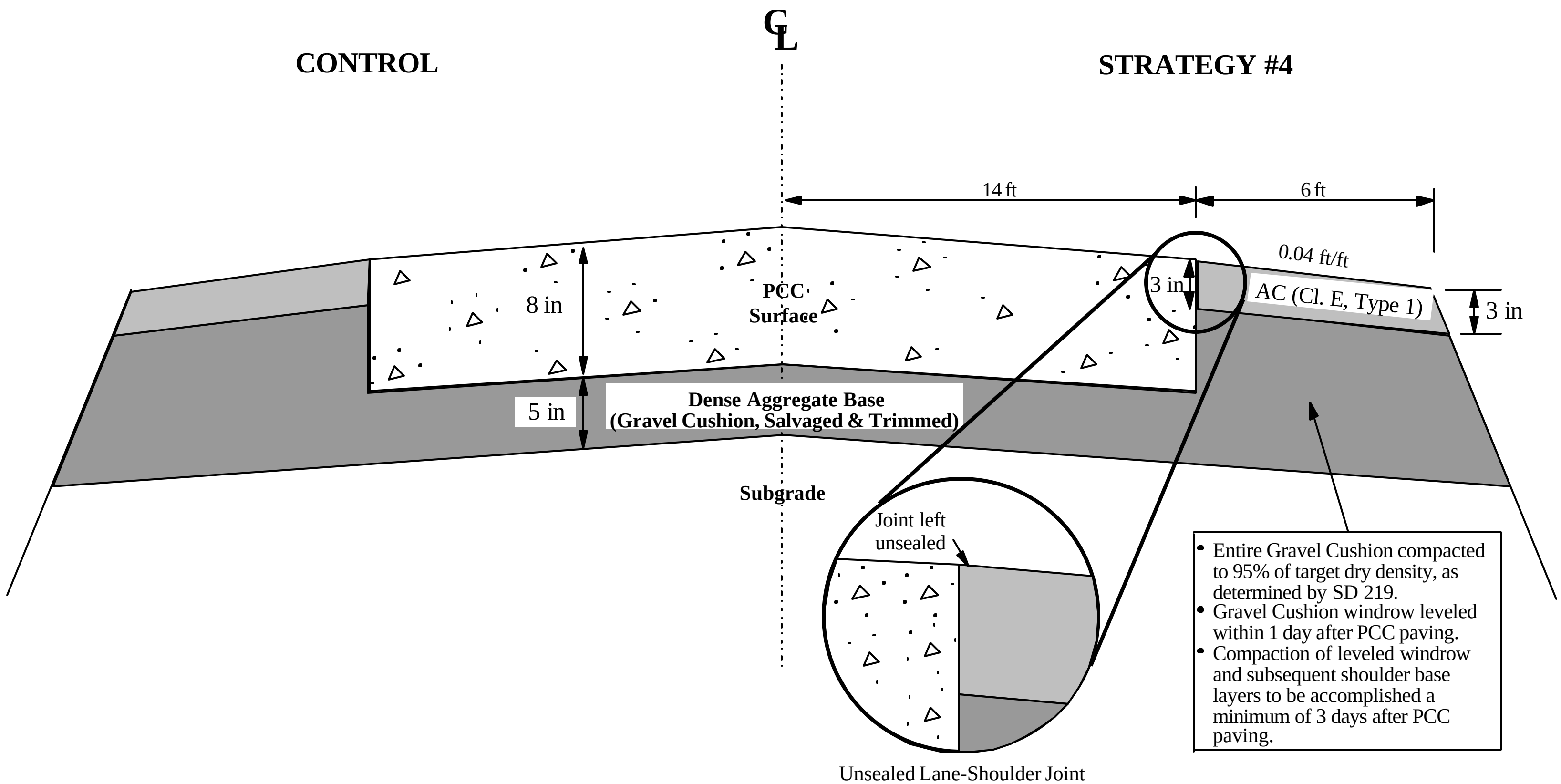


Figure 6. Cross-section of delayed joint sealing strategy (as viewed NB in replicate 1 and SB in replicate 2).

5.6 Strategies 5a and 5b—Beveled PCC Edge

The beveled PCC edge test sections shall be constructed in full accordance with the specifications and design details specified for the northern section of the construction project, except that the outside edge of the 8-in thick PCC slab shall be tapered according to the dimensions shown in figure 7. In addition, although Strategy 5a will use the normal longitudinal lane–shoulder joint seal configuration (reservoir-and-flush), Strategy 5b will use a recessed band-aid configuration. Both strategies will require that the Contractor make physical adjustments to the sideforms of the PCC paver, in a manner that is approved by SDDOT representatives. In essence, the sideforms will have to be rotated outward to achieve the approximate 4:1 taper on the PCC edge.

Visual checks shall be made of the beveled PCC edge during paving operations to ensure that proper consolidation is achieved and that the correct taper is created.

As with Strategies 1 through 4, aggregate windrows shall be leveled within 1 day after mainline PCC paving and shoulder base compaction may begin 3 days after PCC paving. Maximum lifts of 4 in are required, with each lift compacted to 95 percent of target dry density, as determined through nuclear density checks (SD 219).

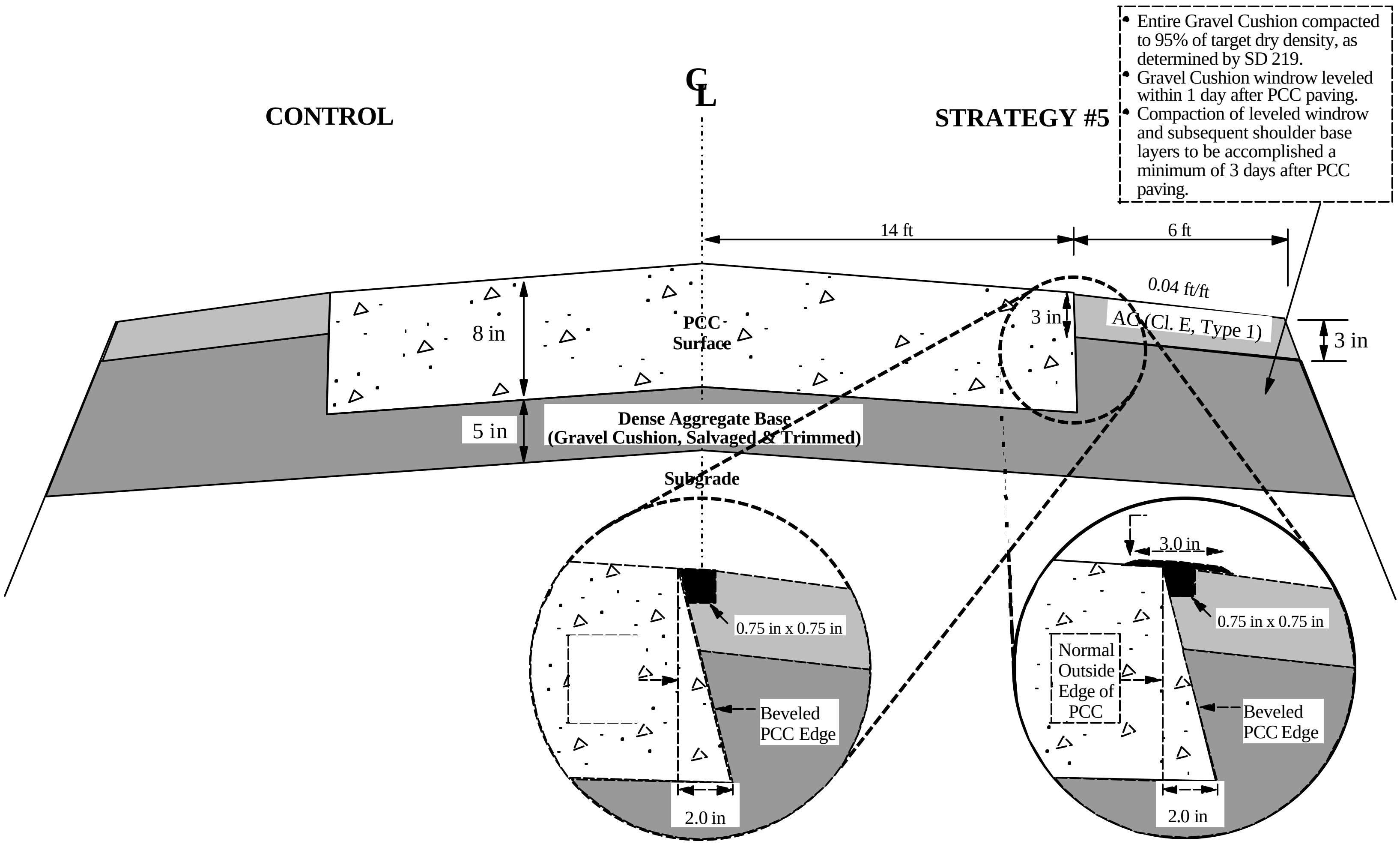
Following the placement of the AC shoulder surface, the Contractor shall rout and seal the longitudinal lane–shoulder joints using hot-applied rubberized asphalt sealant (modified ASTM D 3405, conforming to SDDOT Standard Specification 870.1 A) placed in the two specified sealant configurations (reservoir-and-flush for Strategy 5a sections and recessed band-aid for Strategy 5b sections). Material test requirements for this sealant are provided in section 6.

5.7 Strategy 6—Longitudinal Edgedrain

As illustrated in figure 8, this strategy involves the installation of a longitudinal edgedrain system beneath the lane–shoulder interface as a means of collecting surface water and conveying it to the ditches. The system consists of a 4-in diameter perforated pipe embedded in permeable aggregate, and encapsulated with a geotextile filter fabric. To carry the water from the edge drain to the ditch, outlet pipes with headwalls at the ends are required on 250-ft intervals. This strategy also entails the use of a different longitudinal lane–shoulder joint sealant configuration than the one specified for the northern section of the Route 37 construction project.

Construction of this design shall follow normal construction practices up to the point that the mainline PCC pavement has been paved and the aggregate base windrow has been leveled. The installation of the pipe edgedrains is next and involves the following steps:

1. Trenching.
2. Placing the geotextile.
3. Placing the drains and outlet pipes and backfilling with permeable aggregate.
4. Connecting the headwalls to the outlet pipes.



Strategy 5a: Modified ASTM D 3405 Joint Sealant in Reservoir & Flush Configuration

Strategy 5b: Modified ASTM D 3405 Joint Sealant in Recessed Band-Aid Configuration

Figure 7. Cross-section of beveled PCC edge strategy (as viewed NB in replicate 1 and SB in replicate 2).

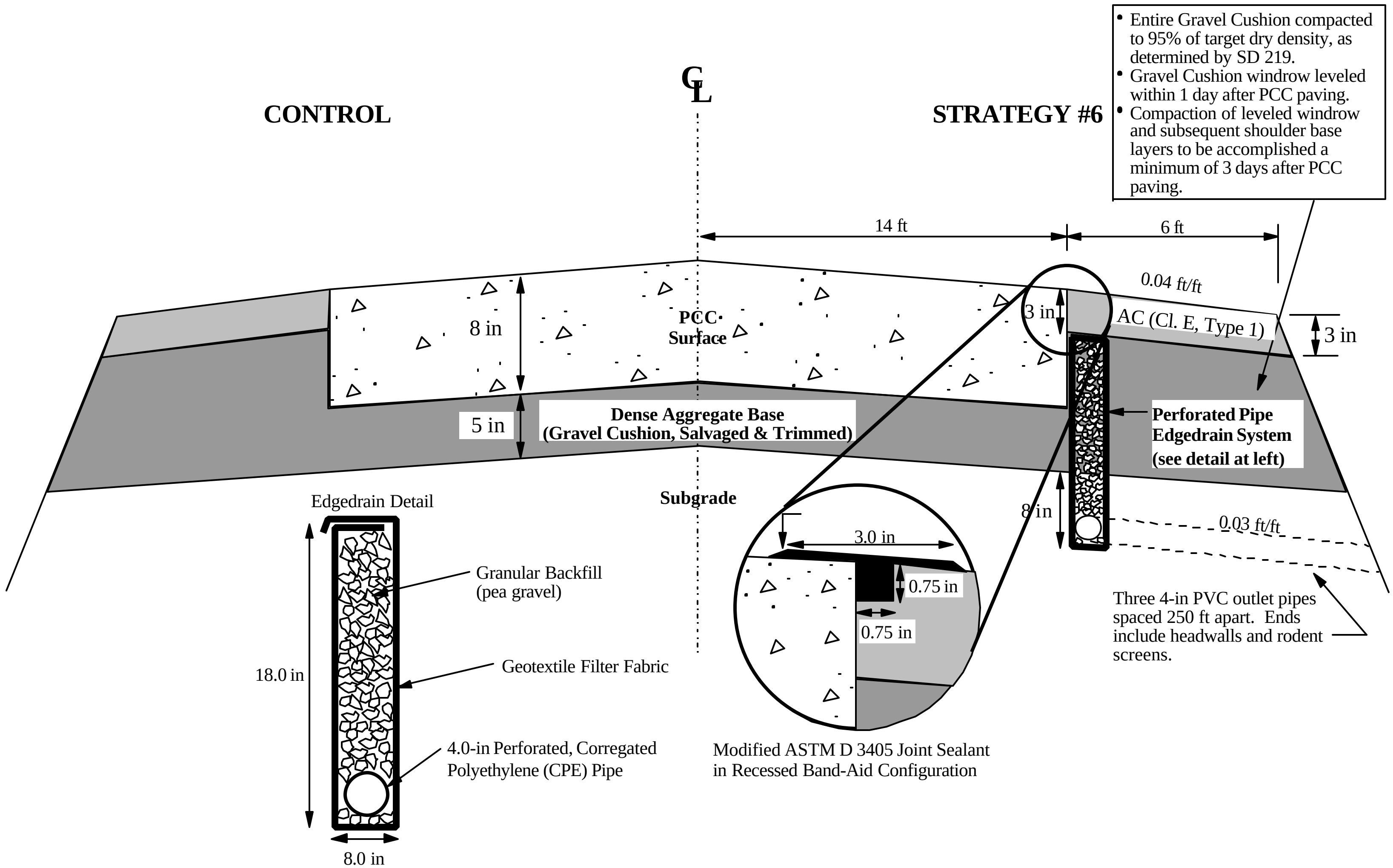


Figure 8. Cross-section of longitudinal edgedrain strategy (as viewed NB in replicate 1 and SB in replicate 2).

Edgedrain trenches shall be cut 8 in wide and to a depth of 8 in below the dense aggregate base (i.e., 13 in below the bottom of the PCC slab).

Specifications for the geotextile fabric to be installed are provided in section 6. Placement of the fabric shall extend from the top of the PCC slab, downward along the inside wall of the trench, across the trench bottom, back up the outside wall, and across the trench top (see the edgedrain detail in figure 8). The ends of the fabric shall be folded over one another at the top of the trench, so that the entire edgedrain system is fully encapsulated by the geotextile.

Flexible, perforated corrugated polyethylene (CPE) pipe, having a diameter of 4 in, shall be used for the longitudinal drains. The CPE pipe shall conform to the requirements for Type E Drainage Tubing given in SDDOT Standard Specification 990. Just prior to its placement, a thin layer of bedding material (i.e., about 1 to 2 in of the permeable backfill discussed below) must be installed at the trench bottom. The bedding material should be partly shaped such that the drainage pipe rests snugly atop it.

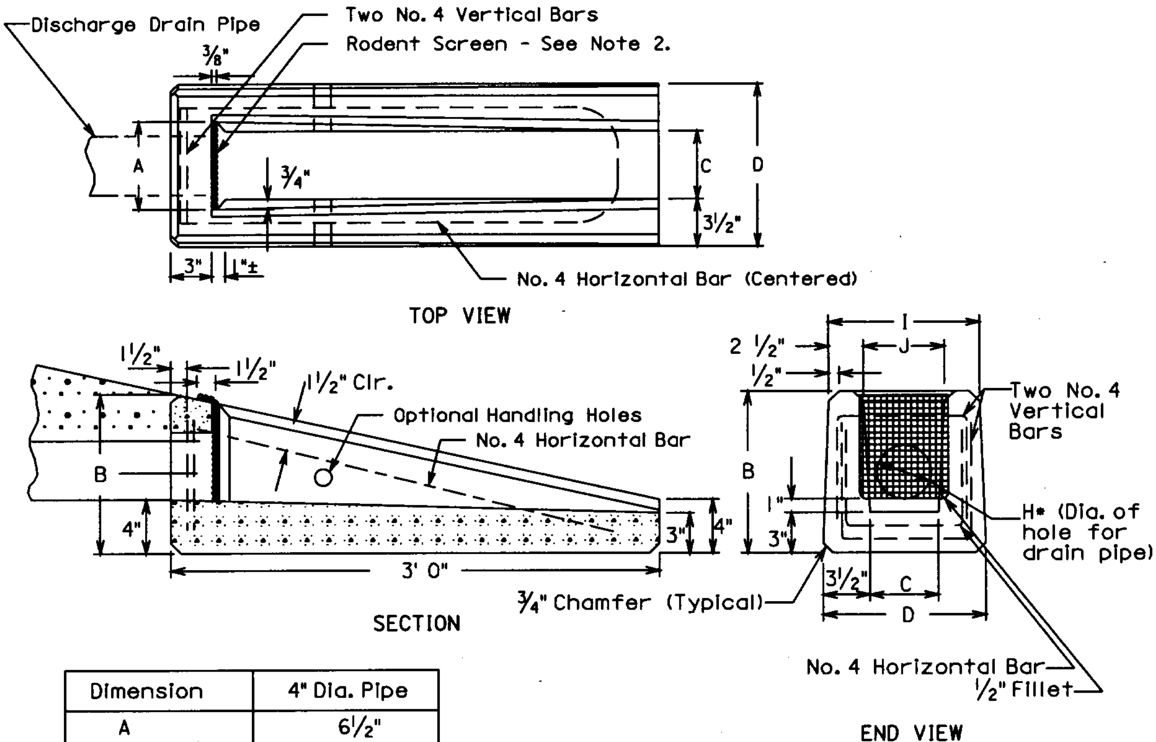
The permeable backfill for the edgedrain system shall consist of pea gravel meeting the requirements of SDDOT Standard Specification 881.2, Type 1B (see section 6 for specification details).

To avoid damage to the CPE pipe during compaction, at least 6 in of backfill must be placed over the drainage pipe prior to compaction. At least two lifts of backfill shall be placed, with each lift compacted using one pass of a high-energy vibratory wheel.

The CPE pipe shall be connected to 4-in diameter solid-walled, polyvinyl chloride (PVC) outlet pipes, conforming to the requirements of ASTM D-3033 and ASTM D 3034. A total of three outlet pipes shall be installed at 250-ft intervals within each test section. Long radius bends of the CPE just prior to connection with the outlet pipes are required to help facilitate routine pipe cleaning. The outlet pipes shall be sloped at approximately 3 percent (0.03 ft/ft) downward to the ditch. Precast concrete headwalls shall be placed on the ends of the outlet pipes to prevent erosion of the ditch slopes and to protect the pipes from damage. Removable rodent screens shall be installed on each headwall. Figure 9 illustrates the headwall and rodent screen details.

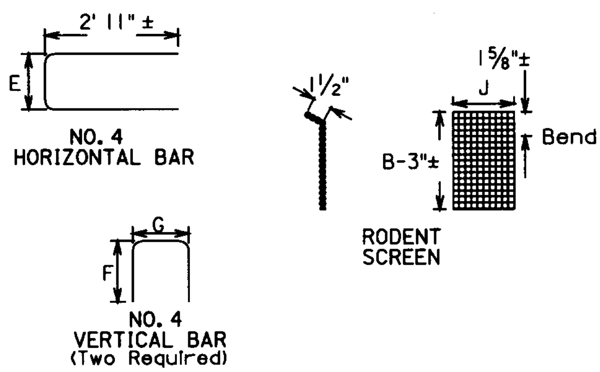
Once the edgedrain system has been constructed, the remaining part of the shoulder can be constructed. This includes 4-in maximum lifts of compacted (95 percent of target dry density, as per SD 219) salvage material and the placement and compaction of the 3-in Class E Type 1 AC surface.

Following the placement of the AC shoulder surface, the Contractor shall rout and seal the longitudinal lane–shoulder joint using hot-applied rubberized asphalt sealant (modified ASTM D 3405, conforming to SDDOT Standard Specification 870.1 A). Material test requirements for this sealant are provided in section 6. The sealant shall be applied using the procedures specified for the northern section of the construction project, except that the material shall be placed in the recessed band-aid configuration shown in figure 8.



Dimension	4" Dia. Pipe
A	6½"
B	1'0"
C	5"
D	1'0"
E	8½"
F	9"
G	9½"
H•	5"
I	11"
J	6"
Approx. Wt.	210 lbs.

• Exact dimension dependent on coupling method.



GENERAL NOTES:

1. Concrete for headwalls shall meet requirements for Class M6. Reinforcing bars shall conform to ASTM A615 Grade 60, be epoxy coated and securely retained so they are not displaced during concrete placement.

2. The rodent screen shall be fabricated from flattened expanded metal, style ½" No. 13F and hot dip galvanized. Actual screen dimensions shall be such that it will snugly fit the provided slot.

3. Radii may be substituted for the upper ¾ inch chamfers shown in the END VIEW. The lower chamfers shown in the END VIEW and those in the SECTION are optional.

September 17, 1998

Figure 9. Precast concrete headwall and rodent screen design illustration.

5.8 Strategy 7—Partial-width, Daylighted Asphalt-Treated Permeable Base

As illustrated in figure 10, this strategy involves the construction of a 5.0-in asphalt-treated permeable base (ATPB) layer located in the shoulder structure between the 5-in dense aggregate base and the 3-in AC surface. A geotextile fabric is placed at the ATPB's side interface with the mainline PCC and its bottom interface with the salvaged gravel cushion. This strategy also entails the use of a different longitudinal lane–shoulder joint sealant configuration than the one specified for the northern section of the Route 37 construction project.

Construction of this design shall follow normal construction practices up to the point that the mainline PCC pavement has been paved. Unless needed in reshaping the aggregate base layer following PCC paving, windrowed salvage material shall be removed from the roadbed to allow for placement of the geotextile separator fabric and the ATPB material.

The geotextile shall be of woven or nonwoven type and shall conform to the requirements given in section 6. An 8- to 10-ft wide strip of the geotextile seperator fabric shall be lain across the periphery of the PCC sidewall and aggregate base surface. The fabric shall be secured in place by approved means, so that it is not damaged or shifted out of place during placement of the ATPB material.

The ATPB course material shall consist of a mixture of crushed quarry stone and PG 58-28 asphalt binder, and shall conform to the requirements given in section 6. An asphalt paving machine or hopper-type spreader box shall be used to place the ATPB material, as long as segregation is kept to a minimum. Construction of the ATPB can be done in one 5-in lift, provided segregation is kept to a minimum and that the mix is sufficiently stable for compaction equipment. Compaction of the ATPB layer shall be accomplished using 2 to 3 passes of a 5- to 10-ton steel-wheeled roller. Care must be taken not to overcompact the material, so that adequate permeability is maintained.

After the ATPB layer is placed and compacted, the Contractor shall trim the ends of the geotextile so that excess fabric does not protrude from the ATPB–PCC interface and the ATPB–Gravel Cushion interface at the end slope. The shoulder shall then be surfaced with 3 in of Class E Type 1 AC, as per the details and standard specifications of the northern section of the project.

Following the placement of the AC shoulder surface, the Contractor shall rout and seal the longitudinal lane–shoulder joint using hot-applied rubberized asphalt sealant (modified ASTM D 3405, conforming to SDDOT Standard Specification 870.1 A). Material test requirements for this sealant are provided in section 6. The sealant shall be applied using the procedures specified for the northern section of the construction project, except that the material shall be placed in the recessed band-aid configuration shown in figure 10.

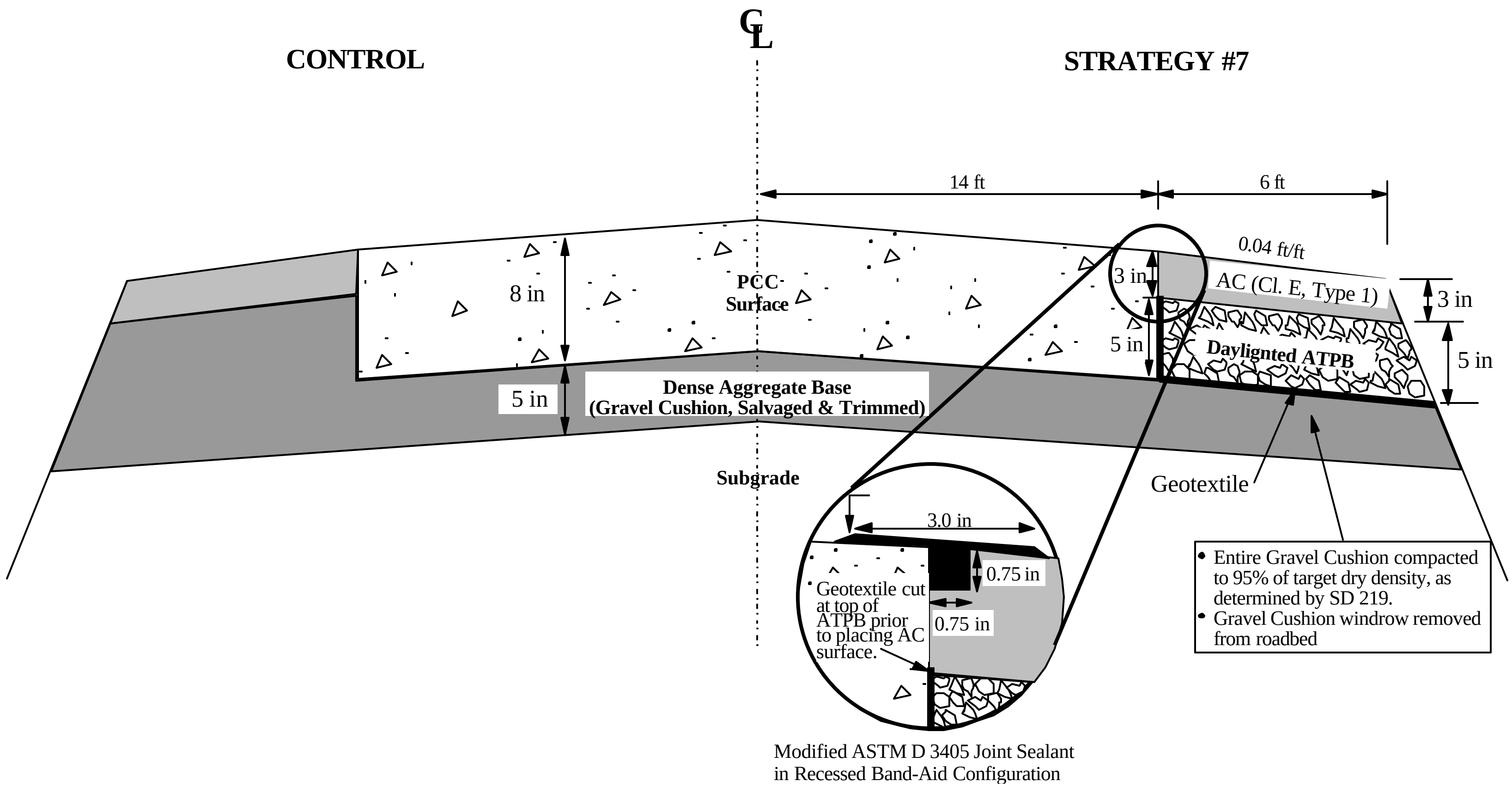


Figure 10. Cross-section of partial-width, daylighted ATPB (as viewed NB in replicate 1 and SB in replicate 2).

5.9 Strategy 8—Full-Depth Asphalt Concrete Shoulder

The full-depth asphalt concrete (FDAC) shoulder strategy consists of placing AC full depth (8.0 in) at the PCC interface and tapering it to a thickness of 6.5 in at the shoulder edge, as shown in figure 11. This strategy also entails the use of a different longitudinal lane–shoulder joint sealant configuration than the one specified for the northern section of the Route 37 construction project.

Construction of the FDAC design shall follow normal construction practices up to the point that the mainline PCC pavement has been paved. At this point, windrowed salvage material shall be removed from the roadbed to allow for placement of the AC structure. A total of three lifts of Class E, Type 1 AC shall be placed and compacted, with each lift not exceeding a thickness of 3 in. The final AC shoulder structure shall have a thickness of 8.0 in at the PCC edge and 6.5 in at the shoulder edge.

Following the placement of the AC shoulder surface, the Contractor shall rout and seal the longitudinal lane–shoulder joint using hot-applied rubberized asphalt sealant (modified ASTM D 3405, conforming to SDDOT Standard Specification 870.1 A). Material test requirements for this sealant are provided in section 6. The sealant shall be applied using the procedures specified for the northern section of the construction project, except that the material shall be placed in the recessed band-aid configuration shown in figure 11.

5.10 Strategy 9—5-in Asphalt Concrete Shoulder

Test sections using this strategy shall be constructed in full accordance with the specifications and design details specified for the northern section of the Route 37 construction project, with the exception that the shoulder shall be constructed with 5 in of AC instead of 3 in. This strategy also entails the use of a different longitudinal lane–shoulder joint sealant configuration than the one specified for the construction project. Figure 12 shows the cross-sectional design for Strategy 9.

Construction of the 5-in AC shoulder design shall follow normal construction practices up to the point that the mainline PCC pavement has been paved. At this point, the aggregate windrows must be leveled within 1 day of mainline PCC paving. Compaction of this leveled material can begin 3 days after PCC paving, and the compacted material must have a density of at least 95 percent of target dry density, as determined through nuclear density checks (SD 219). If needed, an additional lift of salvage material shall be placed, shaped, and compacted (same density as above) in preparation for the 5-in AC surface.

Two lifts of Class E, Type 1 AC shall be placed and compacted, with each lift not exceeding a thickness of 3 in. The final AC shoulder structure shall have a uniform thickness of 5.0 in from PCC edge to shoulder edge.

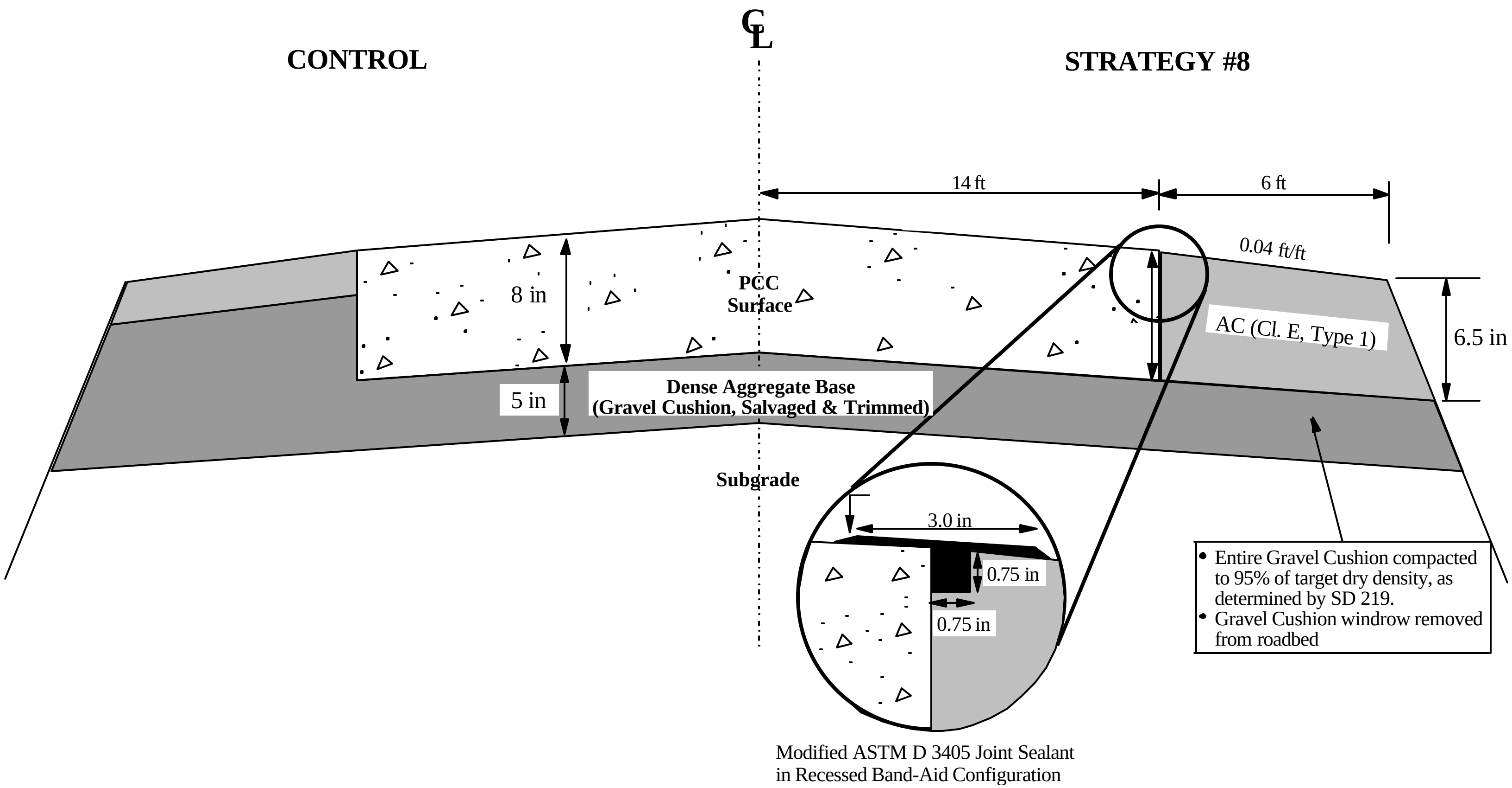


Figure 11. Cross-section of FDAC shoulder strategy (as viewed NB in replicate 1 and SB in replicate 2).

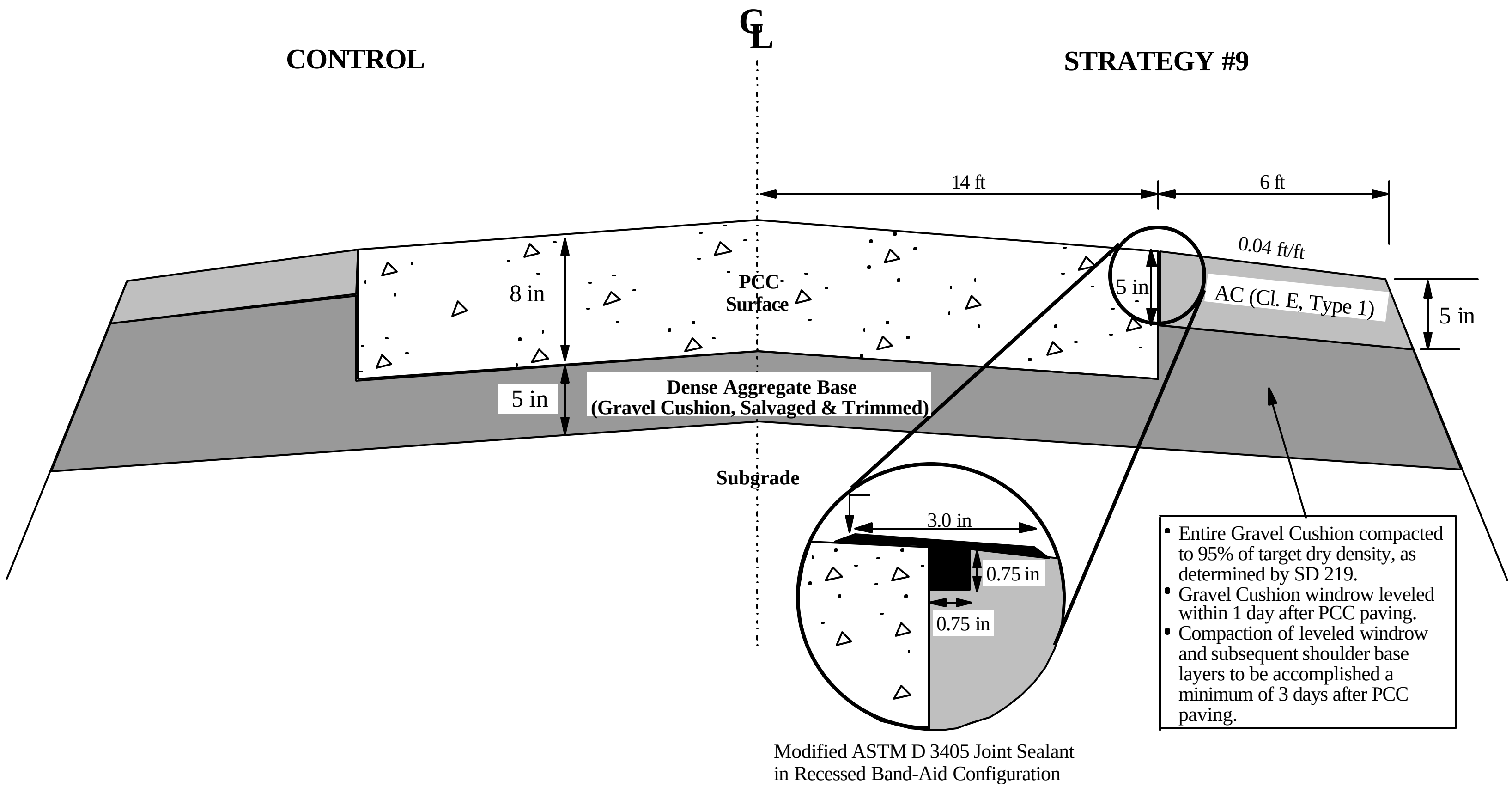


Figure 12. Cross-section of 5-in AC shoulder strategy (as viewed NB in replicate 1 and SB in replicate 2).

Following the placement of the AC shoulder surface, the Contractor shall rout and seal the longitudinal lane–shoulder joint using hot-applied rubberized asphalt sealant (modified ASTM D 3405, conforming to SDDOT Standard Specification 870.1 A). Material test requirements for this sealant are provided in section 6. The sealant shall be applied using the procedures specified for the northern section of the construction project, except that the material shall be placed in the recessed band-aid configuration shown in figure 12.

6. MATERIALS

6.1 Joint Sealant

The hot-applied rubberized asphalt sealant to be used in sealing the longitudinal lane–shoulder joint of most test sections shall conform to SDDOT Standard Specification 870.1 A, with the following modifications:

- Sealant shall have cone penetration value between 90 and 150 when tested at 77^{o}F.
- Sealant shall pass 3 cycles of the bond test with 200 percent extension at a temperature of -20^{o}F.
- Sealant shall weigh no more than 9.35 lb/gal.

6.2 Geotextile Filter Fabric

Longitudinal Edgedrain Application—The geotextile filter fabric to be used in the longitudinal edgedrain test sections shall be a Type A Drainage Fabric conforming to SDDOT Standard Specification 831.

ATPB Application—The geotextile fabric to be used as a separator layer in the partial-width ATPB test sections shall of woven or nonwoven type conforming to the requirements provided in SDDOT Standard Specification 831.

6.3 Permeable Backfill Material for Edgedrain

The permeable backfill for the edgedrain system shall consist of pea gravel meeting the requirements of SDDOT Standard Specification 881.2, Type 1B. This material has a maximum plasticity index of 3 and has the following gradation requirements:

Sieve	% Passing
0.375-in	100
#4	10 - 90
#10	0 - 30
#40	0 - 4

6.4 Asphalt-Treated Permeable Base (ATPB)

The ATPB course material shall consist of a mixture of PG 58-28 asphalt binder (3 percent by weight of mix) and crushed quarry stone meeting the gradation requirements for course aggregate 1A in SDDOT Standard Specification 820. That gradation is as follows:

Sieve	% Passing
1-in	100
0.75-in	90 - 100
0.375-in	20 - 55
No. 4	0 - 10
No 8	0 – 5

6.5 Gravel Cushion Using Virgin Aggregate

Aggregate base material to be used in Strategy 2 shall consist of crushed aggregate Gravel Cushion material conforming to the requirements of SDDOT Standard Specification 882.

APPENDIX B
SD 37 SHOULDER PERFORMANCE DATABASE

Table B-1. Condition survey data for SD 37 shoulder sections.

Replicate	Strategy No.	Strategy Name	Survey	General Condition	Estimated PCI	Lane-Shoulder Differential, in			Lane-Shoulder Separation, ft			Alligator Cracking, ft^2		
						Average	Minimum	Maximum	Low	Moderate	High	Low	Moderate	High
1	1a	Delayed Sealing	Construction			0.03	-0.06	0.13						
		(Std RA, Recessed BA Seal)	7-month	Good	98	0	0	0.13						
			12-month	Good	98	0.19	0.06	0.31						
2	1a	Delayed Sealing	Construction			0.08	0	0.19						
		(Std RA, Recessed BA Seal)	7-month	Good	100	0.13	0.06	0.25						
			12-month	Good	96	0.31	0.25	0.5						
1	1a-Con	Control	Construction			0.05	0	0.13						
			7-month	Good	99	0.06	0	0.13						
			12-month	Good	93	0.3	0.19	0.31						
2	1a-Con	Control	Construction			-0.03	-0.13	0.06						
			7-month	Good	97	0.06	0	0.19						
			12-month	Good	90	0.15	0	0.38						
1	1b	Delayed Sealing	Construction			0.06	0	0.13						
		(Std RA, Reservoir/Flush Seal)	7-month	Good	99	0.06	0	0.19						
			12-month	Good	99	0.3	0.25	0.44						
2	1b	Delayed Sealing	Construction			0.02	-0.06	0.13						
		(Std RA, Reservoir/Flush Seal)	7-month	Good	100	0	0	0.13						
			12-month	Good	96	0.27	0	0.5						
1	1b-Con	Control	Construction			0.06	-0.06	0.13						
			7-month	Good	98	0.06	0	0.13						
			12-month	Good	97	0.34	0.06	0.56						
2	1b-Con	Control	Construction			0	-0.06	0.06						
			7-month	Good	99	0.06	0	0.13						
			12-month	Good	95	0.25	0.19	0.38						
1	2	Delayed Shoulder Surfacing	Construction			0.19	0.13	0.25						
		(Std RA, Reservoir/Flush Seal)	7-month	Good	---	0.5	0.25	0.38	---	---	—	---	---	---
			12-month	Good	100	0.08	-0.06	0.25						
2	2	Delayed Shoulder Surfacing	Construction			0.19	0.06	0.31						
		(Std RA, Reservoir/Flush Seal)	7-month	Good	---	0.75	0.5	1.25	---	---	—	---	---	---
			12-month	Good	100	0.07	0	0.13						
1	2-Con	Control	Construction			0.13	0.06	0.25						
			7-month	Good	98	0.06	0	0.25						
			12-month	Good	93	0.41	0.31	0.56						
2	2-Con	Control	Construction			-0.05	-0.13	0.06						
			7-month	Good	99	0.06	0	0.13						
			12-month	Good	92	0.16	0.06	0.25						
1	3	Full-Depth AC	Construction			0.08	0	0.19						
		(LM RA, Recessed BA)	7-month	Good	95	0.06	0	0.31						
			12-month	Good	96	0.17	0.06	0.25						
2	3	Full-Depth AC	Construction			0	-0.13	0.06						
		(LM RA, Recessed BA)	7-month	Good	100	0.06	0	0.19						
			12-month	Good	97	0.15	0	0.25						
1	3-Con	Control	Construction			0.16	0.06	0.25						
			7-month	Good	97	0.19	0	0.31						
			12-month	Good	92	0.49	0.31	0.56						
2	3-Con	Control	Construction			0.03	-0.06	0.13						
			7-month	Good	98	0.06	0	0.19						
			12-month	Good	96	0.28	0.06	0.44						
1	4	Longitudinal Edge Drain	Construction			0.09	0	0.19						
		(LM RA, Recessed BA)	7-month	Good	99	0.13	0	0.19						
			12-month	Good	96	0.41	0.25	0.5						
2	4	Longitudinal Edge Drain	Construction			0.05	-0.06	0.13						
		(LM RA, Recessed BA)	7-month	Good	98	0.06	0	0.25						
			12-month	Good	96	0.28	0.13	0.44						
1	4-Con	Control	Construction			0.06	0	0.13						
			7-month	Good	97	0.06	0	0.19						
			12-month	Good	94	0.42	0.25	0.63						
2	4-Con	Control	Construction			-0.03	-0.13	0.13						
			7-month	Good	98	0.06	0	0.13						
			12-month	Good	96	0.17	0.06	0.25						
1	5	Windrow Leveling--Virgin Agg	Construction			-0.02	-0.06	0.13						
		(LM RA, Recessed BA)	7-month	Good	100	0	0	0.06						
			12-month	Good	100	0.1	0	0.19						
2	5	Windrow Leveling--Virgin Agg	Construction			0.02	-0.06	0.13						
		(LM RA, Recessed BA)	7-month	Good	99	0.06	0	0.13						
			12-month	Good	98	0.17	0.06	0.25						
1	5-Con	Control	Construction			0.06	0	0.13						
			7-month	Good	96	0.06	0	0.19						
			12-month	Good	93	0.35	0.25	0.5						
2	5-Con	Control	Construction			0.08	0	0.13						
			7-month	Good	99	0.13	0	0.19						
			12-month	Good	94	0.39	0.25	0.5						

Table B-1. Condition survey data for SD 37 shoulder sections (continued).

Replicate	Strategy No.	Strategy Name	Survey	General Condition	Estimated PCI	Lane-Shoulder Differential, in			Lane-Shoulder Separation, ft			Alligator Cracking, ft^2		
						Average	Minimum	Maximum	Low	Moderate	High	Low	Moderate	High
1	6	Windrow Leveling--Salvaged Agg	Construction			0	-0.13	0.13						
		(LM RA, Recessed BA)	7-month	Good	99	0.06	0	0.19						
			12-month	Good	99	0.13	0.06	0.19						
2	6	Windrow Leveling--Salvaged Agg	Construction			-0.02	-0.13	0.13						
		(LM RA, Recessed BA)	7-month	Good	99	0	-0.06	0.19						
			12-month	Good	98	0.19	0.06	0.31						
1	6-Con	Control	Construction			0.09	0	0.19						
			7-month	Good	98	0.13	0	0.25						
			12-month	Good	93	0.32	0.19	0.44						
2	6-Con	Control	Construction			0.09	0	0.19						
			7-month	Good	98	0.13	0	0.19						
			12-month	Good	95	0.47	0.31	0.56						
1	7	5-in AC	Construction			0.08	0	0.13						
		(LM RA, Recessed BA)	7-month	Good	100	0.13	0.06	0.25						
			12-month	Good	96	0.3	0.25	0.38						
2	7	5-in AC	Construction			-0.08	-0.19	0						
		(LM RA, Recessed BA)	7-month	Good	100	-0.06	-0.13	0.06						
			12-month	Good	99	0.06	-0.06	0.25						
1	7-Con	Control	Construction			0.08	0	0.19						
			7-month	Good	98	0.13	0	0.19						
			12-month	Good	92	0.33	0.13	0.56						
2	7-Con	Control	Construction			0.08	0	0.13						
			7-month	Good	99	0.13	0	0.19						
			12-month	Good	95	0.41	0.38	0.44						
1	8a	PCC Beveled Edge	Construction			-0.03	-0.13	0.06						
		(LM RA, Recessed BA)	7-month	Good	100	0	0	0.13						
			12-month	Good	99	0.08	0	0.19						
2	8a	PCC Beveled Edge	Construction			0.03	0	0.06						
		(LM RA, Recessed BA)	7-month	Good	100	0.06	0	0.13						
			12-month	Good	100	0.14	0.06	0.25						
1	8a-Con	Control	Construction			0.06	-0.06	0.13						
			7-month	Good	97	0.06	0	0.19						
			12-month	Good	92	0.41	0.31	0.5						
2	8a-Con	Control	Construction			0.09	0	0.19						
			7-month	Good	100	0.13	0.06	0.19						
			12-month	Good	90	0.27	0.06	0.31						
1	8b	PCC Beveled Edge	Construction			0.02	-0.06	0.13						
		(LM RA, Reservoir/Flush Seal)	7-month	Good	100	0	0	0.06						
			12-month	Good	98	0.15	0.06	0.38						
2	8b	PCC Beveled Edge	Construction			0.02	-0.06	0.06						
		(LM RA, Reservoir/Flush Seal)	7-month	Good	100	0	0	0.13						
			12-month	Good	100	0.2	0.06	0.25						
1	8b-Con	Control	Construction			0.09	0	0.19						
			7-month	Good	99	0.13	0	0.25						
			12-month	Good	92	0.42	0.19	0.56				1		
2	8b-Con	Control	Construction			0.06	0	0.13						
			7-month	Good	100	0.06	0	0.19						
			12-month	Good	90	0.36	0.19	0.5						
1	9	Partial-Width Daylighted ATPB	Construction			0.02	-0.06	0.13						
		(LM RA, Recessed BA)	7-month	Good	98	0	0	0.25						
			12-month	Good	97	0.17	0.06	0.31						
2	9	Partial-Width Daylighted ATPB	Construction			0.05	-0.06	0.13						
		(LM RA, Recessed BA)	7-month	Good	100	0.06	0	0.13						
			12-month	Good	97	0.23	0.13	0.31						
1	9-Con	Control	Construction			0.09	0	0.13						
			7-month	Good	96	0.06	0	0.13						
			12-month	Good	95	0.41	0.19	0.56						
2	9-Con	Control	Construction			0.03	-0.06	0.13						
			7-month	Good	98	0.13	0	0.25						
			12-month	Good	94	0.34	0.25	0.5						

Table B-1. Condition survey data for SD 37 shoulder sections (continued).

Replicate	Strategy No.	Strategy Name	Survey	Block Cracking, ft^2			Edge Cracking, ft			Longitudinal Cracking, ft			Transverse Cracking, # and ft Pat		
				Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
1	1a	Delayed Sealing (Std RA, Recessed BA Seal)	Construction												
			7-month												
			12-month												
2	1a	Delayed Sealing (Std RA, Recessed BA Seal)	Construction												
			7-month												
			12-month												
1	1a-Con	Control	Construction												
			7-month												
			12-month												
2	1a-Con	Control	Construction												
			7-month												
			12-month												
1	1b	Delayed Sealing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month												
			12-month												
2	1b	Delayed Sealing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month												
			12-month												
1	1b-Con	Control	Construction												
			7-month												
			12-month												
2	1b-Con	Control	Construction												
			7-month												
			12-month												
1	2	Delayed Shoulder Surfacing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month	---	---	---	---	---	---	---	—	—	---	---	---
			12-month												
2	2	Delayed Shoulder Surfacing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month	---	---	---	---	---	---	---	—	—	---	---	---
			12-month												
1	2-Con	Control	Construction												
			7-month												
			12-month												
2	2-Con	Control	Construction												
			7-month												
			12-month												
1	3	Full-Depth AC (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
2	3	Full-Depth AC (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
1	3-Con	Control	Construction												
			7-month												
			12-month												
2	3-Con	Control	Construction												
			7-month												
			12-month												
1	4	Longitudinal Edge Drain (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
2	4	Longitudinal Edge Drain (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
1	4-Con	Control	Construction												
			7-month												
			12-month												
2	4-Con	Control	Construction												
			7-month												
			12-month												
1	5	Windrow Leveling--Virgin Agg (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
2	5	Windrow Leveling--Virgin Agg (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
1	5-Con	Control	Construction												
			7-month										1, 6		
			12-month												
2	5-Con	Control	Construction												
			7-month						3						
			12-month						3						

Table B-1. Condition survey data for SD 37 shoulder sections (continued).

Replicate	Strategy No.	Strategy Name	Survey	Block Cracking, ft^2			Edge Cracking, ft			Longitudinal Cracking, ft			Transverse Cracking, # and Pat		
				Low	Moderate	High	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
1	6	Windrow Leveling–Salvaged Agg	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
2	6	Windrow Leveling–Salvaged Agg	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	6-Con	Control	Construction												
			7-month												
			12-month												
2	6-Con	Control	Construction												
			7-month				10								
			12-month				10								
1	7	5-in AC	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
2	7	5-in AC	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	7-Con	Control	Construction												
			7-month												
			12-month												
2	7-Con	Control	Construction												
			7-month												
			12-month												
1	8a	PCC Beveled Edge	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month	25											
2	8a	PCC Beveled Edge	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	8a-Con	Control	Construction												
			7-month												
			12-month												
2	8a-Con	Control	Construction												
			7-month												
			12-month												
1	8b	PCC Beveled Edge	Construction												
		(LM RA, Reservoir/Flush Seal)	7-month												
			12-month												
2	8b	PCC Beveled Edge	Construction												
		(LM RA, Reservoir/Flush Seal)	7-month												
			12-month												
1	8b-Con	Control	Construction												
			7-month												
			12-month												
2	8b-Con	Control	Construction												
			7-month												
			12-month												
1	9	Partial-Width Daylighted ATPB	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
2	9	Partial-Width Daylighted ATPB	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	9-Con	Control	Construction												
			7-month												
			12-month												
2	9-Con	Control	Construction												
			7-month												
			12-month												

Table B-1. Condition survey data for SD 37 shoulder sections (continued).

Replicate	Strategy No.	Strategy Name	Survey	Patch/Patch Deterioration, # and ft^2			Potholes, #			Rutting, in			Raveling/Loss of Cover Agg, ft^2		
				Low	Moderate	High	Low	Moderate	High	Average	Minimum	Maximum	Low	Moderate	High
1	1a	Delayed Sealing (Std RA, Recessed BA Seal)	Construction												
			7-month												
			12-month						1						
2	1a	Delayed Sealing (Std RA, Recessed BA Seal)	Construction												
			7-month												
			12-month												
1	1a-Con	Control	Construction												
			7-month												
			12-month												
2	1a-Con	Control	Construction												
			7-month												
			12-month												
1	1b	Delayed Sealing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month												
			12-month												
2	1b	Delayed Sealing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month												
			12-month												
1	1b-Con	Control	Construction												
			7-month												
			12-month												
2	1b-Con	Control	Construction												
			7-month												
			12-month												
1	2	Delayed Shoulder Surfacing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month	---	---	---	---	---	---	---	---	---	---	---	---
			12-month												
2	2	Delayed Shoulder Surfacing (Std RA, Reservoir/Flush Seal)	Construction												
			7-month	---	---	---	---	---	---	---	---	---	---	---	---
			12-month												
1	2-Con	Control	Construction												
			7-month												
			12-month												
2	2-Con	Control	Construction												
			7-month												
			12-month												
1	3	Full-Depth AC (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
2	3	Full-Depth AC (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
1	3-Con	Control	Construction												
			7-month												
			12-month												
2	3-Con	Control	Construction												
			7-month												
			12-month												
1	4	Longitudinal Edge Drain (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
2	4	Longitudinal Edge Drain (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
1	4-Con	Control	Construction												
			7-month												
			12-month												
2	4-Con	Control	Construction												
			7-month												
			12-month												
1	5	Windrow Leveling--Virgin Agg (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
2	5	Windrow Leveling--Virgin Agg (LM RA, Recessed BA)	Construction												
			7-month												
			12-month												
1	5-Con	Control	Construction												
			7-month												
			12-month												
2	5-Con	Control	Construction												
			7-month												
			12-month												

Table B-1. Condition survey data for SD 37 shoulder sections (continued).

Replicate	Strategy No.	Strategy Name	Survey	Patch/Patch Deterioration, # and ft^2			Potholes, #			Rutting, in			Raveling/Loss of Cover Agg, ft^2		
				Low	Moderate	High	Low	Moderate	High	Average	Minimum	Maximum	Low	Moderate	High
1	6	Windrow Leveling–Salvaged Agg	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
2	6	Windrow Leveling–Salvaged Agg	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	6-Con	Control	Construction												
			7-month												
			12-month												
2	6-Con	Control	Construction												
			7-month												
			12-month												
1	7	5-in AC	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
2	7	5-in AC	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	7-Con	Control	Construction												
			7-month												
			12-month												
2	7-Con	Control	Construction												
			7-month												
			12-month												
1	8a	PCC Beveled Edge	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
2	8a	PCC Beveled Edge	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	8a-Con	Control	Construction												
			7-month												
			12-month												
2	8a-Con	Control	Construction												
			7-month												
			12-month												
1	8b	PCC Beveled Edge	Construction												
		(LM RA, Reservoir/Flush Seal)	7-month												
			12-month												
2	8b	PCC Beveled Edge	Construction												
		(LM RA, Reservoir/Flush Seal)	7-month												
			12-month												
1	8b-Con	Control	Construction												
			7-month												
			12-month												
2	8b-Con	Control	Construction												
			7-month												
			12-month												
1	9	Partial-Width Daylighted ATPB	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
2	9	Partial-Width Daylighted ATPB	Construction												
		(LM RA, Recessed BA)	7-month												
			12-month												
1	9-Con	Control	Construction												
			7-month												
			12-month												
2	9-Con	Control	Construction												
			7-month												
			12-month												

Table B-1. Condition survey data for SD 37 shoulder sections (continued).

Replicate	Strategy No.	Strategy Name	Survey	Long. Joint Seal Condition	% Length of Failed Seal	General Remarks
1	1a	Delayed Sealing (Std RA, Recessed BA Seal)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.0	The noted pothole was located on outside edge of shoulder and was due to truck or tractor damage.
2	1a	Delayed Sealing (Std RA, Recessed BA Seal)	Construction			Lane-shoulder joint was inadvertently sealed (LM RA, recessed band-aid) at time of initial construction (Oct 2001).
			7-month	Good	0.0	
			12-month	Good	0.2	Primary mode of seal failure is adhesion loss due to snowplow damage to overband, and cohesion loss.
1	1a-Con	Control	Construction			
			7-month		0.0	
			12-month	Poor	52.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	1a-Con	Control	Construction			
			7-month	Good	8.0	Primary mode of seal failure is adhesion loss.
			12-month	Poor	75.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
1	1b	Delayed Sealing (Std RA, Reservoir/Flush Seal)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.0	
2	1b	Delayed Sealing (Std RA, Reservoir/Flush Seal)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.0	
1	1b-Con	Control	Construction			
			7-month	Good	5.0	Primary mode of seal failure is adhesion loss.
			12-month	Poor	66.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	1b-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Good	8.4	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in).
1	2	Delayed Shoulder Surfacing (Std RA, Reservoir/Flush Seal)	Construction			Gravel shoulder.
			7-month	---	---	Gravel shoulder.
			12-month	Good	0.0	New AC shoulder surface (placed 10/02/02).
2	2	Delayed Shoulder Surfacing (Std RA, Reservoir/Flush Seal)	Construction			Gravel shoulder.
			7-month	---	---	Gravel shoulder.
			12-month	Good	0.0	New AC shoulder surface (placed 10/02/02).
1	2-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Poor	68.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	2-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Poor	60.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in).
1	3	Full-Depth AC (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	A 25-ft segment from 419+75 to 420+00 is settled up to 0.5 in, possibly due to poor subgrade or nearby slough).
			12-month	Good	1.2	Primary mode of seal failure is adhesion loss attributed to snowplow damage to overband.
2	3	Full-Depth AC (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	6.4	Primary mode of seal failure is adhesion loss due to snowplow damage to overband.
1	3-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Poor	76.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	3-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Good	9.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
1	4	Longitudinal Edge Drain (LM RA, Recessed BA)	Construction			
			7-month	Good	1.2	Edgedrain outlet @ 430+00 is slightly obstructed with dirt. Edgedrain outlet @ 432+50 is halfway plugged with dirt.
			12-month	Good	1.2	Primary mode of seal failure is adhesion loss due to shoulder settlement. Both edgedrain outlets slightly obstructed by dirt.
2	4	Longitudinal Edge Drain (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	Both edgedrain outlets partially clogged with dirt, but water flowing through them.
			12-month	Good	3.2	Primary mode of seal failure is adhesion loss due to snowplow damage to overband.
1	4-Con	Control	Construction			
			7-month	Good	6.0	Primary mode of seal failure is adhesion loss.
			12-month	Poor	55.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	4-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Fair	11.2	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in).
1	5	Windrow Leveling--Virgin Agg (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.2	
2	5	Windrow Leveling--Virgin Agg (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	1.1	Primary mode of seal failure is adhesion loss due to snowplow damage to overband.
1	5-Con	Control	Construction			
			7-month	Fair	15.0	Primary mode of seal failure is adhesion loss.
			12-month	Poor	58.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	5-Con	Control	Construction			
			7-month	Good	8.0	Primary mode of seal failure is adhesion loss.

Table B-1. Condition survey data for SD 37 shoulder sections (continued).

Replicate	Strategy No.	Strategy Name	Survey	Long. Joint Seal Condition	% Length of Failed Seal	General Remarks
1	6	Windrow Leveling--Salvaged Agg (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	1.2	Primary mode of seal failure is adhesion loss due to shoulder settlement.
2	6	Windrow Leveling--Salvaged Agg (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.7	Primary mode of seal failure is adhesion loss due to snowplow damage to overband.
1	6-Con	Control	Construction			
			7-month	Fair	20.0	Primary mode of seal failure is adhesion loss.
			12-month	Poor	54.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	6-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Fair	14.2	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
1	7	5-in AC (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.9	Primary mode of seal failure is adhesion loss, caused by snowplow damage to overband.
2	7	5-in AC (LM RA, Recessed BA)	Construction			Shoulder constructed noticeably higher than mainline PCC.
			7-month	Good	0.0	
			12-month	Good	0.6	Primary mode of seal failure is adhesion loss due to snowplow damage to overband.
1	7-Con	Control	Construction			
			7-month	Good	10.0	Primary mode of seal failure is adhesion loss.
			12-month	Poor	64.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	7-Con	Control	Construction			
			7-month	Good	10.0	
			12-month	Fair	15.2	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
1	8a	PCC Beveled Edge (LM RA, Recessed BA)	Construction			
			7-month	Good	0.8	
			12-month	Good	1.0	Primary modes of seal failure are cohesion loss and adhesion loss attributed to snowplow damage.
2	8a	PCC Beveled Edge (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.7	
1	8a-Con	Control	Construction			
			7-month	Good	12.0	Primary mode of seal failure is adhesion loss, caused in part by shoulder settlement.
			12-month	Poor	66.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	8a-Con	Control	Construction			
			7-month	Good	2.0	
			12-month	Good	80.0	Primary seal failure mode is adhesion loss caused by opening of joint (about 0.1 in) and shoulder settlement. Also, some failure due to poorly routed joints (AC not routed fully up to PCC edge).
1	8b	PCC Beveled Edge (LM RA, Reservoir/Flush Seal)	Construction			
			7-month	Good	0.0	
			12-month	Good	4.6	Primary mode of seal failure is adhesion loss, caused by opening (about 0.1 in) of joint
2	8b	PCC Beveled Edge (LM RA, Reservoir/Flush Seal)	Construction			
			7-month	Good	0.0	
			12-month	Good	0.5	Primary mode of seal failure is adhesion loss, caused by opening (about 0.1 in) of joint
1	8b-Con	Control	Construction			
			7-month	Fair	20.0	Primary mode of seal failure is adhesion loss, caused in part by shoulder settlement.
			12-month	Poor	70.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	8b-Con	Control	Construction			
			7-month	Good	0.0	
			12-month	Poor	80.0	Primary seal failure mode is adhesion loss caused by opening of joint (about 0.1 in) and shoulder settlement. Also, some failure due to poorly routed joints (AC not routed fully up to PCC edge).
1	9	Partial-Width Daylighted ATPB (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	3.1	Primary mode of seal failure is adhesion loss, caused by snowplow damage to overband.
2	9	Partial-Width Daylighted ATPB (LM RA, Recessed BA)	Construction			
			7-month	Good	0.0	
			12-month	Good	8.0	Primary mode of seal failure is adhesion loss due to snowplow damage to overband.
1	9-Con	Control	Construction			
			7-month	Poor	22.0	Primary mode of seal failure is adhesion loss.
			12-month	Poor	45.0	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.
2	9-Con	Control	Construction			
			7-month	Good	10.0	
			12-month	Fair	17.8	Primary mode of seal failure is adhesion loss, caused by opening of joint (about 0.1 in) and shoulder settlement.