Development of Long-Life Overlays for Existing Pavement Infrastructure Projects with Surface Cracking in New Jersey

GEOFFREY ROWE
Abatech, Inc.

ROBERT SAUBER
New Jersey Department of Transportation

FRANK FEE
Citgo, Inc.

NASSEF SOLIMAN
Parsons-Brinckerhoff–FG, Inc.

Existing pavements represent significant capital expenditure on infrastructure. Appropriate maintenance insures that the existing pavement infrastructure is maintained in the most cost-effective manner. Pavements in New Jersey have been the subject of extensive evaluation to determine the best treatment options while making maximum use of the existing structure.

The interstate I-287 in Morris County, New Jersey was showing considerable signs of distress in the early 1990s. The rehabilitation of this highway followed an evaluation of the structure (*1*) that revealed both a hardened binder in the existing pavement layers and surface cracking. The degree of surface cracking was evaluated by extensive coring and materials testing and then confirmed through falling-weight deflectometer testing of all pavement travel lanes.

The existing pavement materials provided an excellent stiff-base structure utilizing the existing pavement infrastructure. The surface-cracked layers were removed to a depth consistent with the crack depth and replaced with a polymer modified asphaltic overlay. The pavement is currently performing in an excellent manner and is expected to give many years of surface before maintenance is required to restore riding quality.

The Interstate route 287 (I-287) at Morristown, New Jersey, is a north–south highway that provides a western bypass around New York City and local traffic movements through New Jersey along a very busy highway corridor. The road also intersects with three major east–west highways at this location: I-80, Route10, and Route 24. Due to the poor condition of the pavement and to the opening of I-287 north of I-80, linking to the New York Thruway (with increasing traffic volumes), this route became a priority for maintenance. The road was initially constructed in 1968 and was considered for rehabilitation design in 1993. The roadway geometry in the highway corridor in the Morristown vicinity was restricted in width due to numerous structures and the presence of the town of Morristown. The road typically carries 24,000 trucks/day (2 way) and the limits of the project were from Milepost 35.5 to 38.8 (Figure 1).

The reconstruction project included the construction of high occupancy vehicles (HOV)

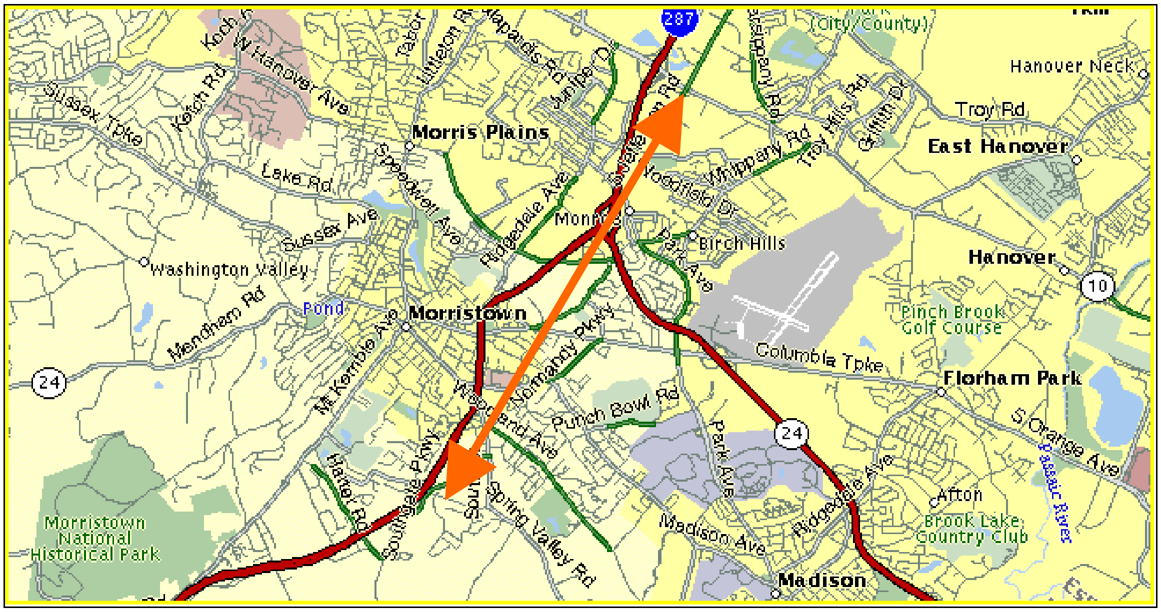

FIGURE 1 Project location.

lanes in both directions to increase capacity and coincide with the opening of I-287 to the north. In addition, it was a requirement that rehabilitation of the pavement structure must have minimal impact on roadway profile, provide a durable wearing surface, and maintain the existing number of travel lanes in peak traffic hours during the construction.

CONSTRUCTION AND DESIGN DATA

The original pavement section was of asphaltic materials that consisted of layers as follows:

- 3-in. hot-mix asphalt (HMA) surface course;
- 7-in. HMA base course (stone mix);
- 8-in. crushed stone base (dense graded);
- 10-in. subbase (graded sand); and
- Subgrade soil (silty sand).

No rehabilitation of the pavement was performed between construction and 1993 (26 years) with the exception of small patches in local areas required to maintain a safe running surface.

The traffic design data used for the pavement rehabilitation was as follows:

- 1993 average daily traffic$_2$ (ADT) = 110,190;
- 2013 ADT$_2$ = 170,830;
- 22 percent total trucks, 9 percent heavy trucks; and
- 20-year equivalent single-axle loads (ESALs) = 50,000,000.

Due to the heavy traffic volumes in this area, there is often the occurrence of slow or standing loads.

The depth of frost penetration at this location is estimated to be 36 in. during the winter months.

The project volumes for HMA were approximately 75,000 tons HMA surface mix and 225,000 tons HMA base mix.

PAVEMENT TESTING AND EVALUATION

A visual condition survey of the pavement was conducted during the design phase, concluding that all lanes had cracking, apparently typical bottom-up fatigue cracking (Table 1). The cracking was more evident in Lanes 2 and 3, which carry the higher truck volumes. The typical surface appearance at that time is illustrated in Figure 2.

TABLE 1 Results of Visual Condition Survey

Lane 1 (Fast Lane)	Lanes 2 and 3 (Middle and Slow Lane)
Low-severity cracking Rutting <1 in.	Moderate- to high-severity fatigue cracking Wheelpath longitudinal cracking Some high-severity patching Rutting > 1 in.

FIGURE 2 Typical surface appearance, 1993.

The initial indications were that cracks penetrated through all bound layers. Subsequently, a pavement coring survey was performed, which indicated that the cracks originated at surface with the majority stopping at the base layer (3-in. depth) (Figure 3). No cracks penetrated through entire layer. This was in contrast to the traditional concept used to design and evaluate pavements, the assumption that cracks start at the bottom of the pavement structure.

As a consequence of this finding it was decided to perform additional testing to determine the likely cause of the pavement distress and to evaluate the pavement for overlay design. The additional work consisted both of materials testing and pavement testing with the falling weight deflectometer (FWD).

Materials Testing

A total of 25 pavement cores were taken from the pavement structure. For each of these cores the gradation, binder content and properties were determined. The binder contents and grading indicated that the mixtures were consistent with the job mix formula for the original asphalt pavement. However, the binder properties, as measured by penetration and viscosity, indicated that significant hardening had taken place, particularly in the surface layers. The mean binder results (penetration test) and void content are illustrated versus their approximate position in the pavement structure in Figure 4.

The data from all the testing appeared to suggest that the degree of hardening in the binder (viscosity data) is related to the void content of the mixture with a regression coefficient r^2 of 0.6618. However, it should be noted that this data set is fairly limited with only five test results (Figure 5).

The data would suggest that the binder in the base has hardened partially due to the higher void content of these materials. The harder binder in the surface course is probably related to the exposure of the binder to oxidative aging due to its location at the surface.

REC. PEN	VOIDS
16	5.5%
40	4.9%
22	6.8%
25	9.3%

FIGURE 3 Example of surface cracking (REC. PEN = recovered penetration in units of mm/10, ASTM D5-97).

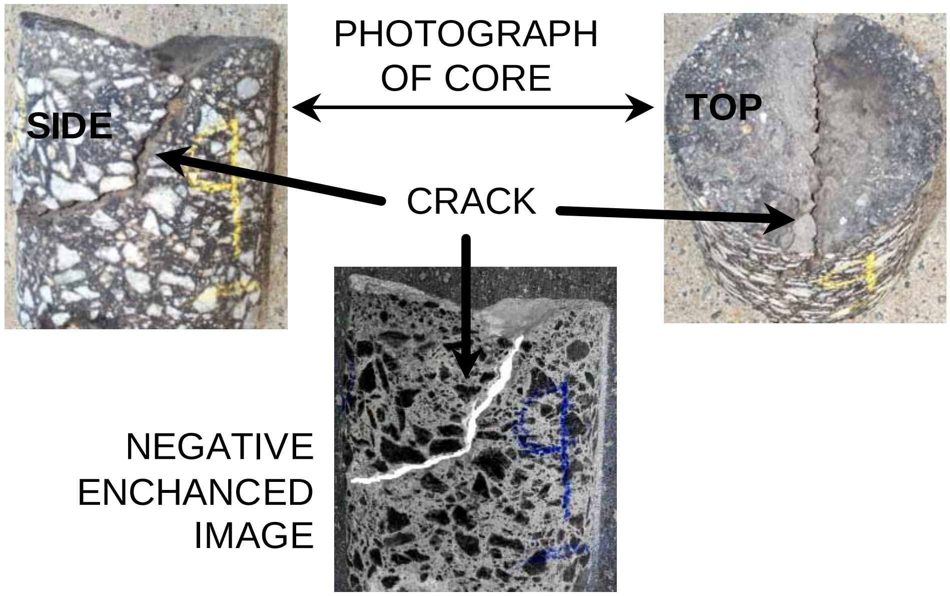

FIGURE 4 Penetration and air voids shown versus approximate depth of core

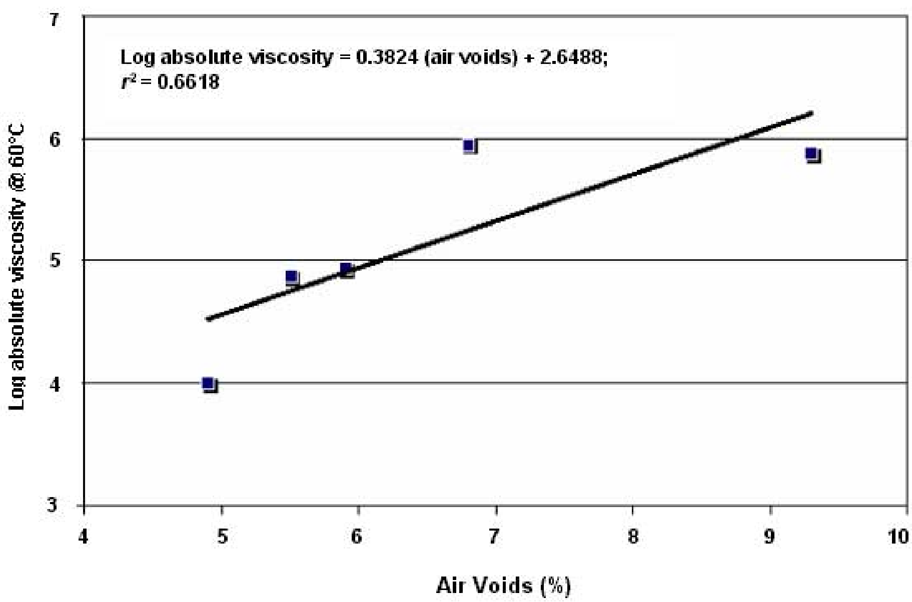

FIGURE 5 Log absolute viscosity versus air voids.

Falling-Weight Deflectometer Testing

The pavement was tested using a Dynatest FWD in the fall of 1993. The testing was conducted in all wheelpaths for the entire length of the project. After testing, the deflection data was analyzed (*2*) to determine the stiffness of the various pavement layers. The stiffness of the combined asphalt layer corresponding to the 85-percentile deflection values are presented in Table 2. Lane 1, which carries less traffic, had a considerably higher stiffness compared to lanes 2 and 3 which carry all the truck traffic.

TABLE 2 Stiffness Results from FWD Analysis

Lane	Northbound	Southbound
1—Fast	7,100 MPa	7,600 MPa
2—Middle	5,600 MPa	5,300 MPa
3—Slow	4,600 MPa	4,900 MPa

Using a simple layer equivalence approach it was demonstrated that the test results for lanes 2 and 3 would suggest that the lower stiffness is consistent with a cracked surface layer and a sound base. The results from the FWD testing thus supported the view that the base was in a sound condition while the reduced stiffness was associated with surface cracking as illustrated in Figure 6. Consequently, the pavement still contained a sound base of high stiffness that could be incorporated in the rehabilitated pavement structure.

The mode of pavement distress identified on this project is currently not supported by design methods. No classical models exist to enable the prediction of this form of distress. The occurrence of the surface cracking is considered to be a function of the hard binder in the surface combined with load-associated effects since the cracking was more evident in heavily traveled lanes 2 and 3.

With stiff pavement layers, surface cracking can be predicted to occur at the edge of the loaded area using sophisticated pavement models that are based upon dissipated energy or damage mechanics. The example shown in Figure 7 illustrates the case of a thick pavement structure made with a dense asphaltic material similar to that laid on I-287 and for which the highest value of dissipated energy occurs at the top of the pavement structure (*3*). This type of analysis will show that the dissipated energy will also be highest at the surface for thick pavement even if a wearing course with higher binder content is used. The analysis concluded that to limit cracking in the wearing course it is necessary to design the surface course mixture for high fatigue life, with as little age-hardening susceptibility as possible.

As a consequence of the analysis, a polymer-modified asphalt surface course was selected for the final surface. The surface cracks were removed by milling out the top 3 in. of pavement structure and then laying down two 2-in. layers, consisting of an HMA base course followed by a polymer-modified surface course.

TESTING DURING CONSTRUCTION

A planned program of testing was organized during the construction project, which had the objectives of (1) assessing the as-built pavement structure and (2) determining how the proposed mixtures compare to the Superpave asphalt specifications.

During the construction period a test area with 1200 tons of New Jersey's first Superpave mix was identified. This area was chosen for both mixture and pavement structural evaluation.

FWD Testing

The section was tested with the FWD after milling (December 1996) and after the final resurfacing (April 1997). The stiffness modulus values corresponding to the 85-percentile deflection values were the transposed into structural numbers using the procedures contained within the AASHTO Pavement Design Manual. This resulted in structural numbers for the slow lane of 5.7 in. before construction, 4.5 in. after milling, and 7.6 in. after final overlay. The existing structural capacity before overlay, using this approach, is a remaining pavement life of

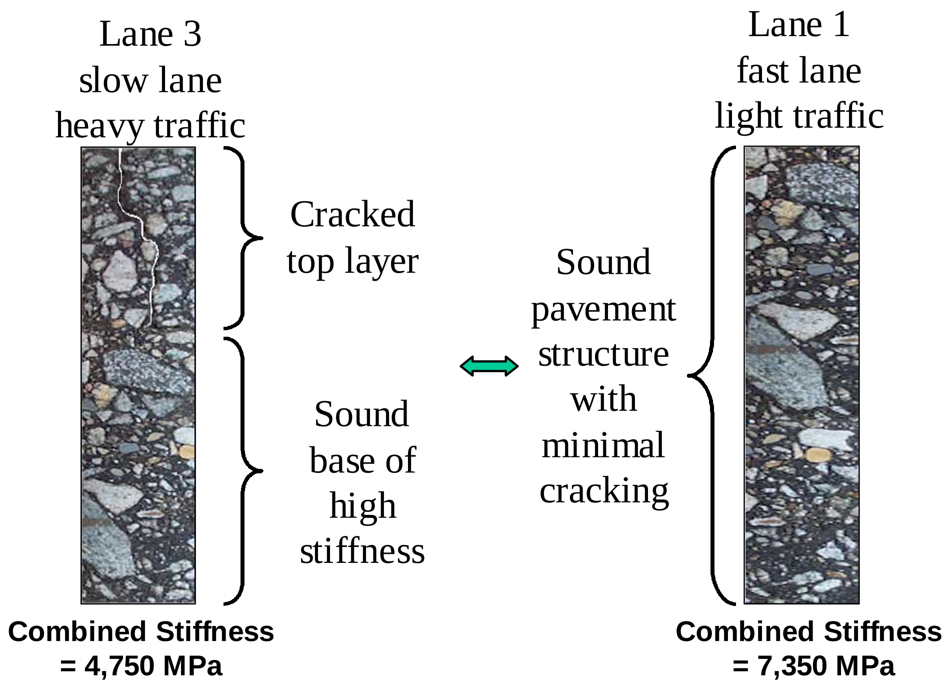

FIGURE 6 Average FWD results. [Combined stiffness refers to the stiffness modulus obtained from back analysis when the asphaltic layers (base and wearing course) have been combined into a single layer.]

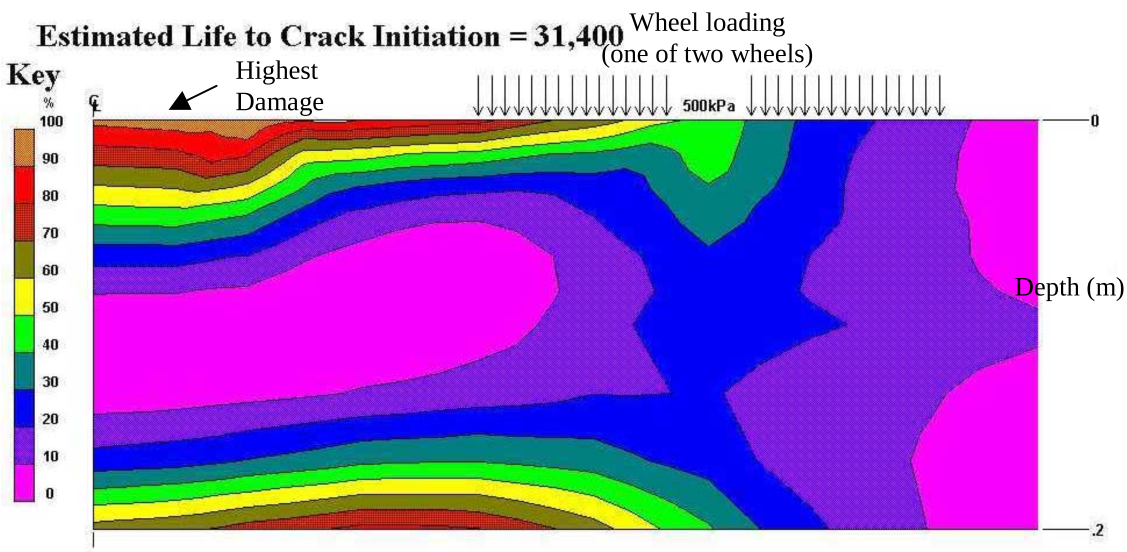

FIGURE 7 Surface-cracking calculations: pavement of 8 in. dense bitumen macadam with applications of a 40-kN duel wheelload; contours of relative (percent) fatigue damage; cross section from center line of loaded area with position of one wheel indicated (*3*).

7,000,000 ESALs compared to the rehabilitated structural capacity of 69,000,000 ESALs. The rehabilitated structure essentially offers an indeterminate pavement life that will need only periodic resurfacing to restore the ride quality.

Mix Testing

The objective of the mixture testing was to test the materials being used in accordance with the Superpave standards to determine what changes may be needed to NJDOT's standard I-4 surface course mix for compliance with the new standards. When this mixture was compared to the Superpave requirements it was observed that only a very minor change to the gradation was required to convert existing mixture to meet 12.5 mm Superpave requirements (*4*). The majority of NJDOT's standards for consensus properties were previously specified at the same or at higher quality values than used in the Superpave specifications.

The binder used in the surface course corresponds to a PG76-22 (see Table 3). This would compare to a PG58-22, which would be used for the region as per the standard Superpave procedures. The PG76-22 represents 3-grade bumps (e.g. PG58-22 to PG76-22) to consider heavy and slow traffic loads.

CURRENT PERFORMANCE

The project was inspected in January 2001 and is illustrated in Figure 8. Currently, after 4 years of traffic, the project is performing to acceptable standards with little signs of distress.

The most recent pavement management data available for this project is presented in Figures 9 and 10 that illustrate the pavement rating and skid properties.

The pavement rating data was obtained on December 11, 1998 (approximately 2 years after surfacing). The pavement rating is presented as both a Ride Quality Index (RQI) and Surface Distress Index (SDI) as measured with the ARAN profile device. (ARAN is the trade name for the equipment manufactured by Roadware of Paris, Ontario.) The pavement ratings (RQI and SDI) are related to the condition as indicated in Table 4.

TABLE 3 Superpave Binder Test Results

Test Parameter	Results	Specification Requirement
Safety/Handling		
Flash Point (Cleveland Open Cup)	318°C	>230°C
Viscosity @ 135°C	1.55 Pa-s	<3 Pa-s
Loss on heating	0.25%	<1%
High Temperature		
$G^*/\sin\delta$, Original	1.56 @ 76°C	>1 kPa
$G^*/\sin\delta$, RTFOT	3.04 @ 76°C	> 2.2 kPa
Intermediate Temperature		
$G^*/\sin\delta$	3550 kPa @ 22°C	<5000 kPa
Low Temperature		
Creep Stiffness, S	220 MPa @ -12°C	<300 MPa
m-value	0.315 @ -12°C	>0.300

Based on the above definitions the pavement rating is in a “good” to “very good” condition with few (if any) visible signs of deterioration.

The average skid number obtained for the site on September 6, 2000, was 49.6 and with a standard deviation of 3.3 (see Figure 10). This would meet the requirements for a traffic speed of approximately 70 mph and is considered acceptable.

Further long-term monitoring of the project is planned during years ahead to determine the effectiveness of the treatments used.

The value of the engineering approach to this pavement structure has been demonstrated via the efficiencies in the pavement structural design compared to a full reconstruction option that would have been used based upon a limited visual survey.

CONCLUSIONS

The study of the pavement structure at Morristown, New Jersey, illustrated the need to consider the occurrence of surface cracking in the design and execution of pavement rehabilitation projects in New Jersey. The specific findings obtained during this study are as follows:

- This project illustrated the need to develop pavement solutions with adequate consideration to the mode of distress occurring on site.
- The surface cracking appears to be associated with a hard binder in the surfacing materials.
- FWD tests confirm that the base is of adequate stiffness for the overlay design.
- The developed solution involved evaluation with a FWD and the use of polymer-modified binders in the surface course.

FIGURE 8 Current condition.

TABLE 4 Ride Quality and Surface Distress Categories

RQI/SDI	Visual Category	Remarks
0.0 to 1.0	Very Poor	Pavements that are in an extremely deteriorated condition. The facility is passable only at reduced speeds, and with considerable ride discomfort. Large potholes and deep cracks exist. Distress occurs over 75 percent or more of the surface.
1.0 to 2.0	Poor	Pavements that have deteriorated to such an extent that they affect the speed of free flow traffic. Flexible pavements may have large potholes and deep cracks. Distress includes raveling, cracking, and rutting that occurs over 50 percent or more of the surface. Rigid pavement distress includes joint spalling, faulting, patching, cracking, and scaling, and may include pumping and faulting.
2.0 to 3.0	Fair	The riding qualities of pavements in this category are noticeably inferior to those of new pavements, and may be barely tolerable for high-speed traffic. Surface defects of flexible pavements may include rutting, map cracking and extensive patching. Rigid pavements in this group may have a few joint failures, faulting and cracking, and some pumping.
3.0 to 4.0	Good	Pavements in this category, although not quite as smooth as those described above, give a first class ride and exhibit few, if any, visible signs of surface deterioration. Flexible pavements may be beginning to show evidence of rutting and fine random cracks. Rigid pavements may be beginning to show evidence of slight surface deterioration as well as minor cracks and spalling.
4.0 to 5.0	Very Good	Only new (or nearly new) pavements are likely to be smooth enough and sufficiently free of cracks and patches to qualify for this category. All pavements constructed or resurfaced during the date year would normally be rated very good.

- Adequate service life was achieved with only a relatively thin overlay.
- This approach had significant cost benefits (savings) for the project.
- Superpave mixes were not significantly different from New Jersey's current I-4 HD (Heavy Duty) mixes.
- The pavement management information collected to date indicates that the surface is performing adequately.

Planned monitoring of performance over the following years will further assist with the development of a rational approach to the design of pavements which exhibit severe surface cracking.

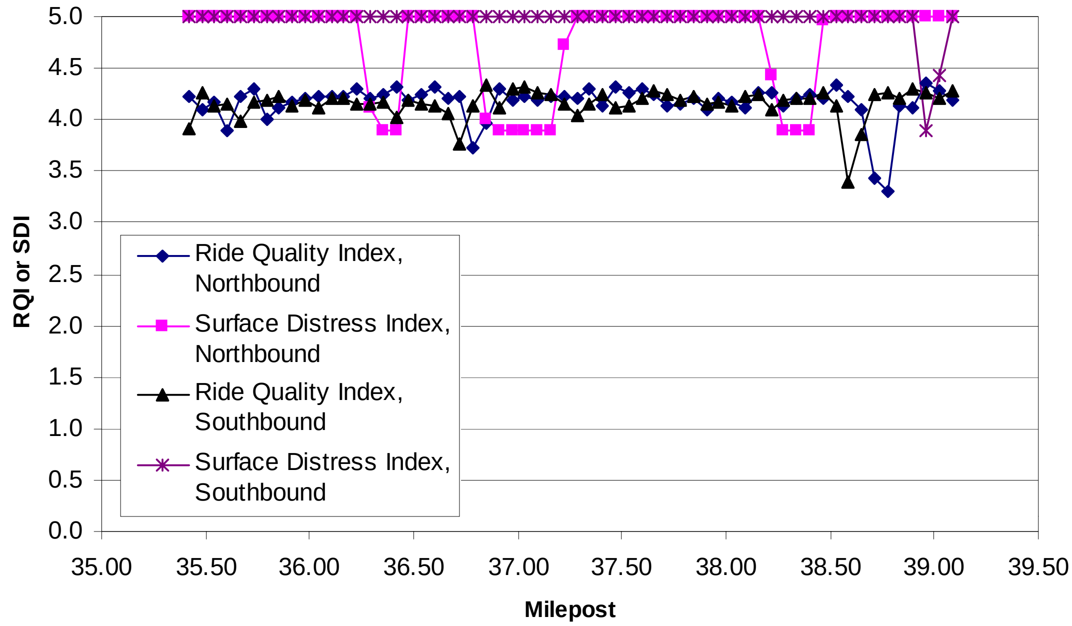

FIGURE 9 Pavement ratings (RQI and SDI) versus Milepost I-287.

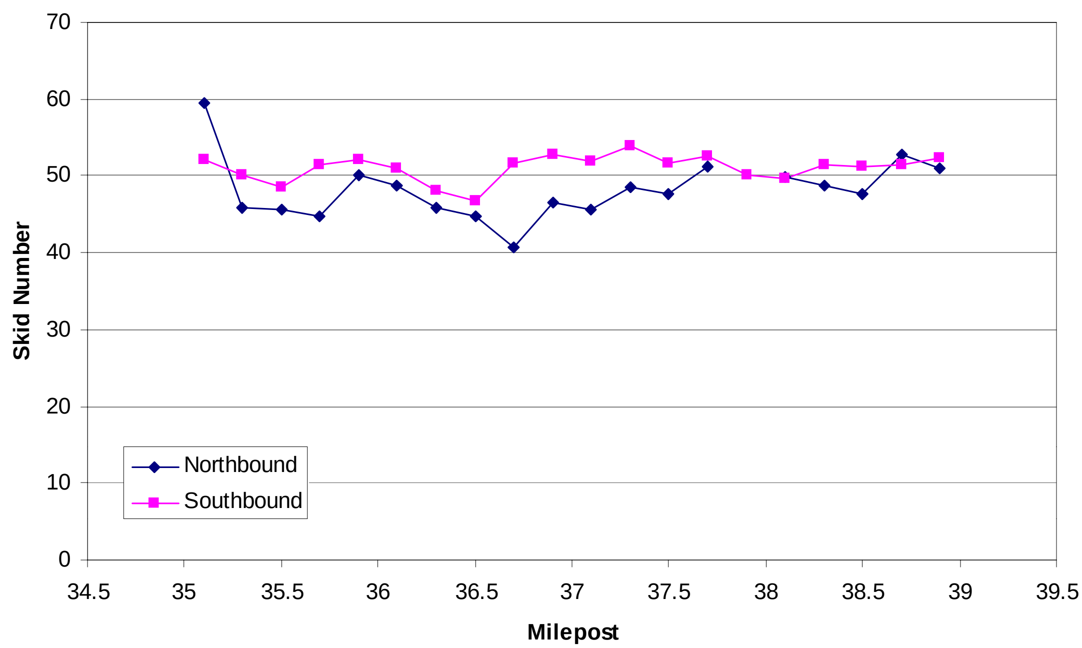

FIGURE 10 Skid numbers versus Milepost I-287.

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ADDITIONAL RESOURCE

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