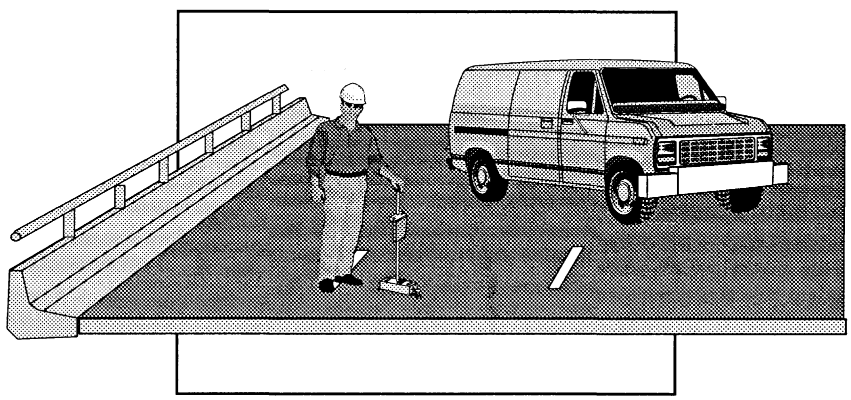
TECHNICAL ASSISTANCE
REPORT

PRESCRIBING A BRIDGE DECK RIDE QUALITY REPAIR USING THE SOUTH DAKOTA ROAD PROFILER AND THE DIPSTICK



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Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Transportation and the University of Virginia)

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ABSTRACT

This report describes how two sophisticated road roughness instruments were used to investigate the feasibility of a bridge deck ride quality repair. The instruments were the South Dakota Road Profiler (SDRP) and the Face Companies' Dipstick®. The bridge being repaired was on Interstate 95 over the Occoquan River in Northern Virginia. The repair being considered was a strategic grinding of the surface to remove high spots in the concrete. In addition to a badly formed profile, the top steel over much of the deck suffered from insufficient concrete cover. Using the SDRP and the Dipstick®, a research team was able to provide detailed illustrations of the repair strategy necessary to mitigate the significant rideability problem without exposing steel. Using the same equipment, this team was able to objectively monitor the progress and eventual success of the repair.

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BACKGROUND & PROBLEM STATEMENT

In June 1995, the Manassas Residency Construction Office and the Northern Virginia District Bridge Office accepted as complete a 4-lane, 264 meter (865 foot) plate girder bridge over the Occoquan River on I-95 South. Completion and opening to traffic was necessary for a number of costly reasons. Unfortunately, although steps were taken during placement to ensure that the deck adhered to VDOT's construction smoothness requirements, the final surface exhibited extremely poor ride quality. Several explanations have been offered to describe the phenomena that took place, seemingly entirely after the original placement of the deck. One explanation suggested that the combination of old and new steel (the new structure included recycled steel from the bridge that had previously stood at this location) produced inconsistent deflections, resulting in a collective distortion of the deck surface. A second interesting theory attributed the wave-like character of the surface to the pour sequence, suggesting that alternating pours were done while adjacent sections were still plastic. The continuous nature of the superstructure conveyed a ripple through adjacent spans, an effect that did not completely develop until the last pour was completed, screeding finished, and the 10-foot straightedge put away.

Corrective Options

Regardless of the reasons, the fact was that a new bridge deck on a major interstate highway in Virginia had an extremely poor, almost dangerous, ride quality. Two basic options were available to repair the ride quality of the deck. One was a thin overlay that would cover the entire deck to fill the troughs in the surface. The original engineer's estimate for this option, which included approximately $50,000 for scarification and $190,000 for latex concrete, was nearly $250,000. In addition to the expense, the drawbacks of this alternative included the need to maintain closed lanes during peak hours and the additional dead load.

Instead of filling the troughs, the second option involved removing the peaks through strategic grinding. The potential advantages included a significant cost savings over the first alternative (estimated at $60,000), the ability to conduct the work exclusively during off-peak hours, and no additional dead load added to the new structure. Of course, the feasibility of this approach hinged on the ability of the engineer and equipment to identify where and how deeply the concrete should be ground. To exacerbate matters, an earlier survey to locate reinforcing had indicated some potential complications due to insufficient top steel cover. Officials feared that the existing concrete would not sustain the necessary grinding without causing unacceptable cover conditions or even exposure of steel.

PURPOSE AND SCOPE

This technical assistance report describes a cooperative effort to determine the feasibility of a strategic grinding operation. This effort involved the Northern Virginia Structure and Bridge Office, the Manassas Residency Construction Office, the Materials Division's Non-Destructive Testing Section, and the Research Council. It involved two surveys to identify the roughness component, and a third survey to obtain steel cover information. In essence, the objective was to confirm that the phenomenon producing the undesirable ride quality could be dealt with by a grinding operation. Using sophisticated road roughness equipment, characteristic deck surface profiles were collected and analyzed to identify areas that needed to be ground. This allowed engineers to proceed with remedial actions with less fear of exposing steel and more confidence that the corrective measures would be successful.

METHODS

Diagnosis of Surface Profile Defects

In mid-July, the Project Engineer contacted the Non-Destructive Testing (NDT) Section of the Materials Division to determine what capabilities were available within the Virginia Department of Transportation (VDOT) for measuring the roughness of a highway riding surface. His intention was to determine exactly how rough the surface was, and precisely where the rideability problem existed.

South Dakota Road Profiler

After assessing the problem, the NDT section dispatched one of the two high-speed road profiling units that VDOT has been using for several years to inventory the State's pavement roughness. These units are referred to as South Dakota Road Profilers (SDRP). This specially equipped vehicle (Figure 1) can collect normalized road surface profiles at highway speeds and produce objective estimates of ride quality.

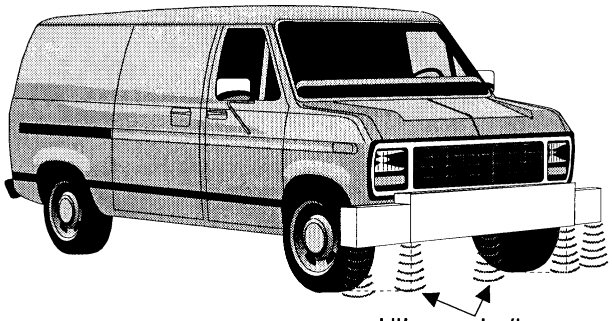

Figure 1. The South Dakota Hybrid Road Profiler.

Most commonly, the profiles collected by the SDRP are used to generate the International Roughness Index (IRI). The IRI provides a widely accepted measure of the simulated response of a standard vehicle to a measured profile. It is an accumulated index reported in units of slope (millimeters per meter or inches per mile). The higher the value, the higher the roughness and the worse the ride quality. For example, an IRI of 1.0 mm/m (64 in/mi) might describe a good to excellent riding surface. Few pavements in Virginia, much less bridge decks, yield IRIs of 1.0 mm/m or less. A more typical asphalt pavement in Virginia might exhibit an IRI of between 1.0 and 1.5 mm/m (64 to 100 in/mi). IRIs that exceed 2.5 mm/m (160 in/mi) are typical of deteriorated hot mix asphalt pavements or many surface-treated secondary roads. This probably represents the condition of many bridge decks. Surfaces with IRIs of 4.0 mm/m (250 in/mi) or greater are considered rough by most standards in developed countries. Highway surfaces that fall within this category are generally not well suited for significant high speed travel.

The SDRP equipment has been tuned to provide objective and repeatable roughness estimates in terms of IRI. To insure repeatability, certain characteristics of a profile must be measured accurately time after time. Unfortunately, these characteristics are not necessarily absolute elevations. Also, under normal operating conditions, it is rarely necessary to establish longitudinal distances with the degree of accuracy required in this case. Peculiarities of the accelerometer-based system require that it begin operating at least 100 meters (300 feet) in advance of the highway section being surveyed. The profile in Figure 2 shows the system stabilizing as it leads up to the bridge. Although the general portion of the profile associated with the bridge is recognizable, the exact beginning and ending of the slab are less obvious.

Face Companies' Dipstick®

The NDT section performed the surveys of the bridge with the SDRP, and contacted the staff at the Research Council to help interpret the collected information. To confirm and accurately locate the surface features detected by the high-speed profiler, a more precise device, the Dipstick® manufactured by the Face Companies (Figure 3), was recommended. The manually operated device accumulates elevation data along a survey line in precisely controlled steps. This information is recorded automatically using an on-

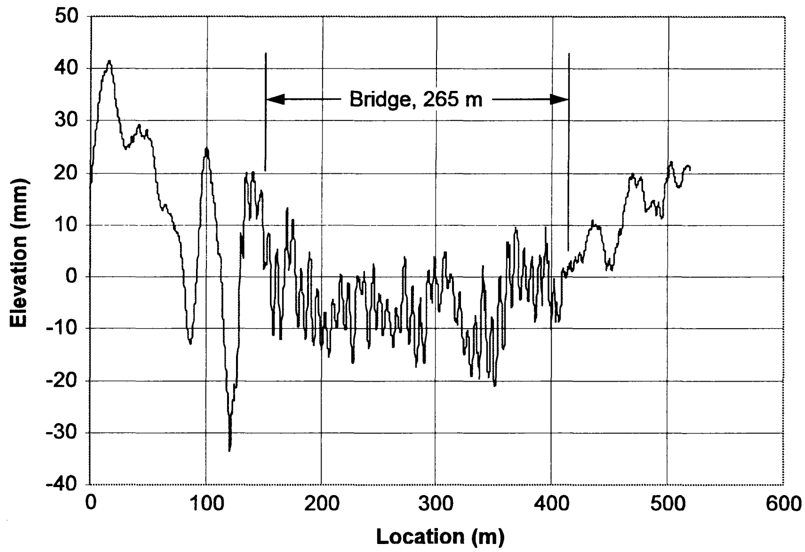

Figure 2. SDRP bridge profile.

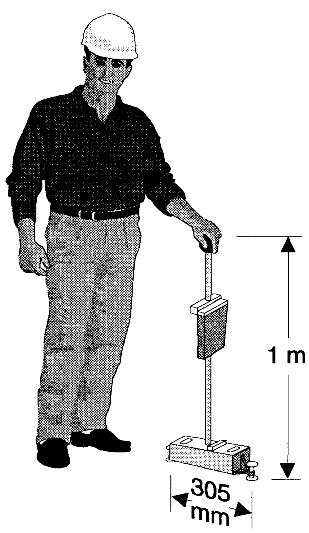

Figure 3. Dipstick®.

board palmtop computer. Once field work is complete, the collected data can be uploaded to a personal computer for more involved analysis. The Dipstick® system includes a series of PC-compatible software routines that can perform a variety of useful analyses (including IRI calculation, straight-edge simulation and grind schedule development).

After some discussion with the project engineer and engineers from the Northern Virginia District Bridge office and other experts at the Research Council, additional surveys were conducted using the Dipstick®. While the lanes were closed for profiling, a more rigorous steel cover survey was also be conducted with a profometer, a Swiss-made instrument used specifically for locating reinforcing steel in concrete.

On the nights of August 15 and 16, beginning at approximately 10:00 pm, one very precise profile was collected for each of the four lanes of the I-95 southbound bridge. On the night of the 15th and the morning of the 16th, a profile was recorded down the center of each of the two inside lanes. On the night of the 16th and morning of the 17th, the profiles for the centers of the outside travel lane and an exit lane were collected. To maximize accuracy, the profiles were collected using a "boxing" technique. Much like closing a traverse when surveying, boxing a run involves completing the profile collection as nearly as possible to the identical location upon which it was started (Figure 4). In addition to providing a convenient method of collecting two lanes of data in a single run, it ensures that the unavoidable error associated with these procedures is minimized and equitably distributed.

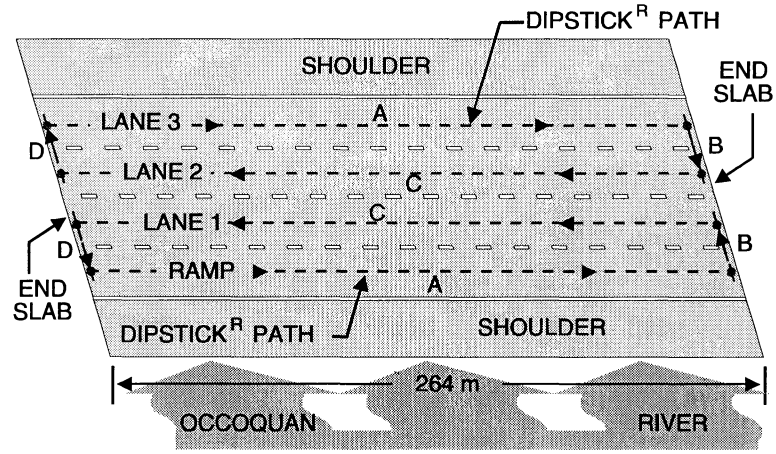

Figure 4. Dipstick® deck survey.

RESULTS AND DISCUSSION

SDRP Findings

The SDRP succeeded in collecting profiles illustrating the fundamental wave-form responsible for the unsatisfactory ride (Figure 5). For the reasons cited previously, a literal interpretation would have been ill-advised. It was possible, however, to generate reliable IRI values and establish the relative rideability of the bridge deck. This was important for two reasons. First, it verified that the ride quality was indeed extremely poor in objective terms, which gave concerned officials a justification for pursuing corrective actions. Second, it provided a baseline from which to assess the improvement, once corrective activities began.

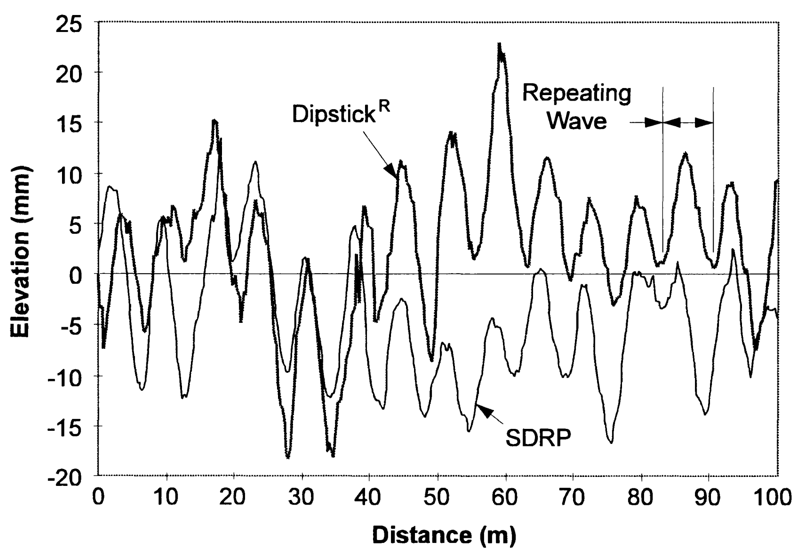

Figure 5. Deck surface wave characteristic.

Dipstick® Findings

A single field profile, as collected with the Dipstick®, contained the profiles from the center of two lanes, and the two short transverse profiles at the beginning and end of the deck slab. The first step of an analysis involved "unboxing" the field profile to separate the two lanes, box legs A and C, from the two box legs at the bridge ends, legs B and D (Figure 4). Figure 6 plots the first 100 meters of a single-lane profile. Unlike those collected with the SDRP, this profile clearly illustrates the 2 % design slope. Intuitively, a 2 % slope over 264 meters will have little effect on ride quality. To discern the features that are adversely affecting rideability, the design slope can be factored, or "rotated," out. This is also the method used to make the Dipstick®-based profile comparable to that collected with the SDRP. Figure 5 shows the same first 100 meter profile with the design slope removed. Notice that the combination of Figure 6 and Figure 5 also illustrates the "near-sightedness" of the SDRP, which is incapable of reliably measuring features much longer than 100 meters (such as a 2 % design slope).

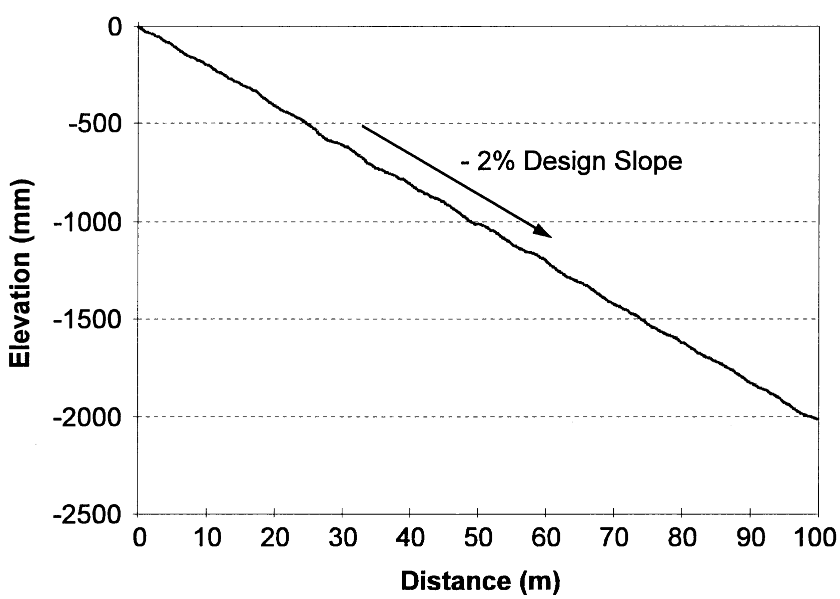

Figure 6. Unrotated Dipstick® profile.

Once the individual lane profiles were available, a battery of calculations were performed, including estimates of IRI, a simulation of a California profilograph analysis, and a "gap under an unleveled straight edge" simulation. Figure 7 reports the IRIs as generated from the Dipstick® profiles. It shows remarkable consistency in ride quality (or lack of ride quality) from one lane to the next. For comparison, the figure also includes the IRI values as determined earlier by the SDRP equipment.

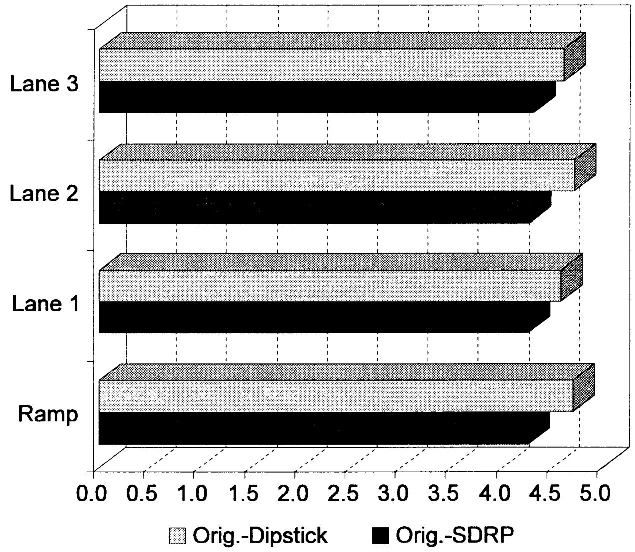

Figure 7. Ride quality summary, before correction.

Next, an attempt was made to emulate the inspection activity that would normally have prevented the problematic surface from being constructed. Accordingly, a 3.3 meter (10 foot) perfectly rigid straight edge with a 3.2 millimeter (1/8 inch) maximum allowable gap (VDOT Road and Bridge Specifications, Section 404.04) was applied to each profile. Figure 8 illustrates a step in a typical straight edge simulation. The black down-pointing triangles along the top of the figure indicate locations where the gap under the straight edge exceeds the maximum allowable. The simulation suggested that approximately 70% of every lane failed the specification. Unfortunately, the ability of the simulated straight edge to react to and measure the slightest surface imperfections far exceeds the capabilities of even the most talented and experienced "human" straight edge operators. The exercise was interesting, but the precision was considered excessive and not particularly applicable for helping to prescribe milling needs.

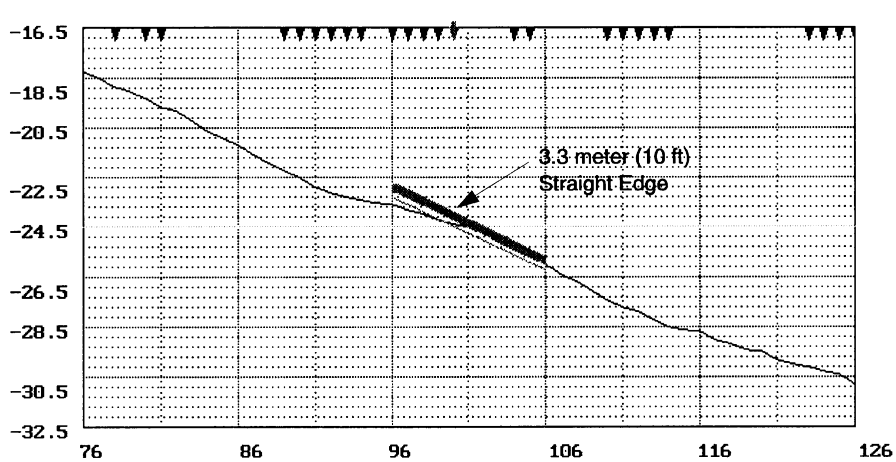

Figure 8. Straight edge simulation.

Ultimately, the simulation that proved most useful was the one emulating a profilograph. The profilograph is a profiling device that predates the Dipstick® and the inertial profilers. It works much like a sophisticated rolling straight-edge (Figure 9). The reduction of a profilograph survey is called a profilogram. It consists primarily of a graphical "trace" of the vertical displacements of the center wheel. Because the instrument has a fixed running length of about 7.5 meters (25 feet), some wave-forms are simply unmeasurable with it. There are also certain surface characteristics that the 7.5 meter length will tend to magnify. This indeed was the case in this situation. It can be illustrated and mathematically shown that a dominant harmonic approximately 6 to 7.5 meters (20 to 25 feet) in length was present in the surface.

The profile collected by the Dipstick® was not subject to the constraints of a conventional profilograph. That is, the character of the measured profile was not truncated by a fixed running length. Therefore, meaningful analysis of features of varying length was possible. As these analyses concluded, what seemed to be a relatively mild undulation viewed through a 3.33 m (11 ft) typical wheelbase of passenger vehicle, could be fairly severe at lengths in the range of 6 to 7.5 meters as seen by a rolling straight edge. Ultimately, it was determined that the controlling length for analysis should reflect the response of a critical vehicle. Several minutes of observing the bridge under traffic revealed that the critical vehicle was a typical road tractor pulling an unloaded trailer. Correspondingly, a 9 meter (30 ft) rolling straight edge was used to best simulate the response of the rear wheelbase of a standard HS truck. The contention in this instance was that 9 meters would be long enough to appropriately interpret the dominating surface harmonic, but short enough to empathize with a typical truck suspension.

Given a bump specification (10 mm or 0.4 inches to agree with the VDOT specification for PCC pavements, Section 316.04), a series of profilograms were generated. Figure 10 illustrates a portion of a typical profilogram. Within the development of these profilograms, grind schedules were generated. The grind schedules indicate proposed locations for beginning and ending a bump grind, as well as the maximum depth of grind necessary for that location.

Table 1 is a portion of a grind schedule for one lane of the bridge.

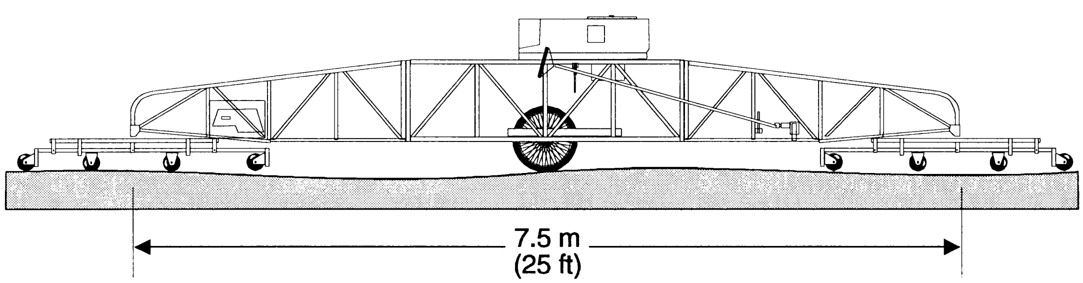

Figure 9. California profilograph.

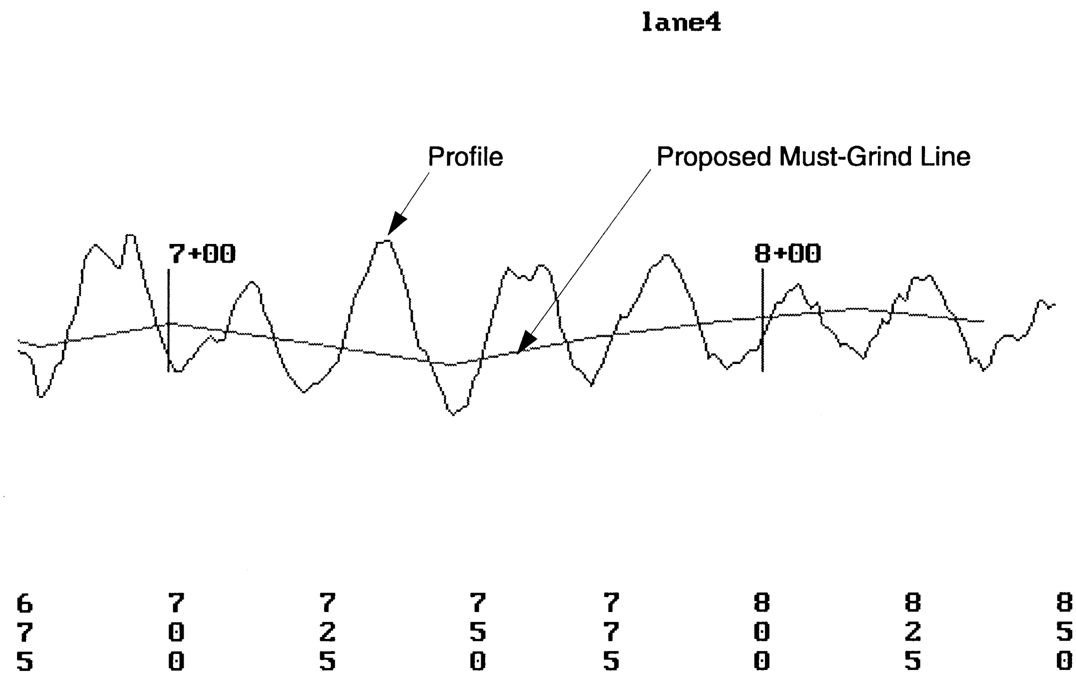

Figure 10. Example of profilogram.

Table 1

Must Grind Analysis for D:\ROADFACE\DATA\95BRDG\lane3
(Number of Grinding Locations: 34)

Location No.	Grinding Location	Grind Depth (mm)	Grind Depth (inches)
36	31 - 39	2.0	0.08
56	51 - 60	9.7	0.38
79	72 - 86	16.0	0.63
102	94 - 110	21.1	0.83
128	118 - 133	13.0	0.51
148	143 - 154	11.9	0.47
170	163 - 179	18.8	0.74
194	189 - 201	17.3	0.68
218	212 - 224	7.4	0.29
237	236 - 242	2.0	0.08
260	257 - 265	3.0	0.12
283	279 - 288	6.4	0.25
306	301 - 312	9.1	0.36
313	312 - 314	0	0

Corrective Activity

Grinding schedules were produced for all four lanes using the described profile data. These schedules were based on profilogram analyses using a 9 meter (30 foot) wheel base, a 25 mm = 7.5 m (1 inch = 25 feet) profilogram scale, and a maximum bump height of 10 mm (0.4 in.). To better illustrate the proposed grinding scheme and to verify the reasonableness of the methodology, the grind locations for each lane were individually mapped onto a copy of the deck plan. Figure 11 illustrates the resulting proposed grinding plan for the part of the deck leading up to the first expansion joint. It shows quite vividly the banded surface character that was producing the ride problems with this deck. It also succinctly communicates where grinding would be most beneficial.

An overlay of the proposed grinding plan with the steel cover survey did not expose any significant conflicts. Fortunately, none of the locations where steel cover deficits were most severe coincided with areas where deep grinding was required.

The correction was carried out in four stages. The first step was the grinding of the deck with a self-leveling grinder. The second stage re-grooved the surface where grinding had removed the original tining, to restore skid resistance and insure appropriate drainage. The third step was a light sand-blasting, and the last step was an application of deck sealer to compensate for lost and shy cover resulting from the combination of grinding and high steel. At 10:00 pm on Monday, October 16, the corrective operation began. The final inside lane and shoulder were completed on the night of Monday, October 30. The final cost, including materials and labor, was $64,000.

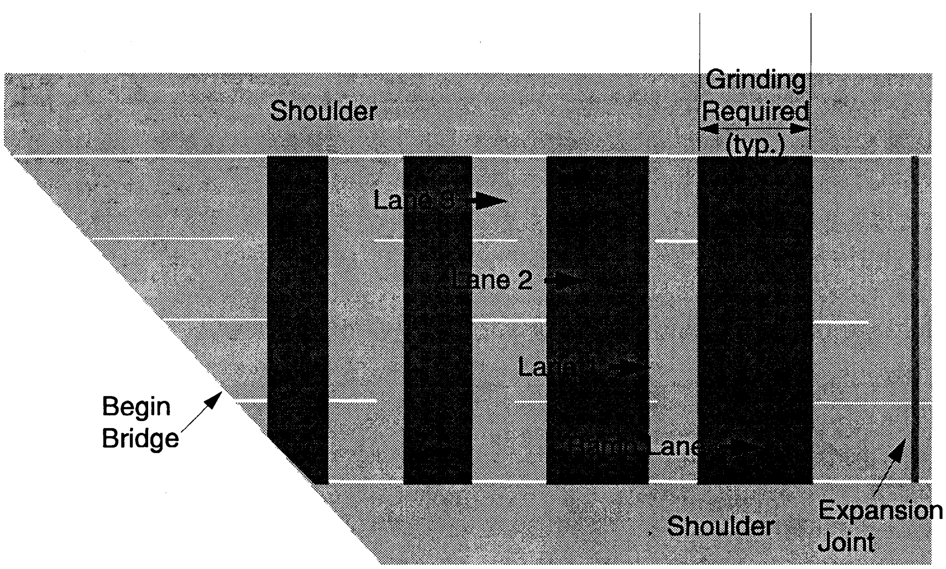

Figure 11. Partial grind schedule plan.

Grinding

The primary grinding mechanism was a diamond-bit drum approximately 1 meter (38 inches) in width. The wheelbase of the self-leveling machine was approximately 6 meters (20 feet). Much like the profilograph, this fixed length means that there is some limit to the device's "vision." This deficiency is mitigated somewhat by arranging the rear wheels to follow completely within the fresh cut.

The cutting depth of the machine was set so the first peak in the first grind path was cut just shy of the depth proposed by the profilogram analysis. Understandably, the first and the remaining peaks in the deck were cut shallower than proposed, considering the difficulty with insufficient steel cover. The first pass of the grinder was critical, since all other passes were cut to match. Once the first pass was complete, a guide wheel was extended from the right-hand side of the machine, and the remaining passes were cut to match the depths and locations of the first pass. With a 1 meter cutting swath and a 75 mm (3 inch) overlap, a lane could be completed in just over 4 passes.

Grooving

Once grinding was essentially complete on three of the four lanes, grooving began. The grooving depth was intentionally set to the shy side of the Department's groove specification, in the effort to avoid worsening the steel cover deficiencies. The 3 mm deep (1/8") grooves were only applied to those areas that had been affected by grinding.

Sand Blasting and Sealing

When all grinding and grooving operations were finished, a very modest sand blasting and sealing operation began. Areas of the surface that had been ground and grooved were accordingly blasted clean, and a light penetrating sealer applied. Standard 12 liter (3 gallon) garden sprayers were used to apply the silicone-based sealant at a rate of 4.6 square meters per liter (200 square feet per gallon).

Success of Corrective Actions

Although the Dipstick® performed well in helping to confirm a viable corrective approach, it was not a convenient tool for monitoring the progress and eventual success of the operation. The speed of the SDRP, however, made it an ideal alternative. The reasonable agreement in profiles, at least in terms of IRI (Figure 7), suggested that the SDRP would easily do the job.

Figure 12 is a plot of the original and corrected profiles for the first 100 meters of the inside lane. Apart from a fairly severe spike near the beginning, the post-correction profile is markedly less active. Again, plotting the two profiles together demonstrates the difficulty with absolute elevation. The significant thing to note, in terms of rideability, is the reduction in relative magnitude between the peaks and troughs in the profile. Figure 13 summarizes the accomplished improvements in terms of IRI. The roughness in every lane was better than halved. During the assessment of this procedure, several casual tests were conducted on the accompanying northbound bridge. Based on the results of those tests, it would appear that the ride quality of the corrected deck now exceeds that of the companion bridge, for which no problems were reported.

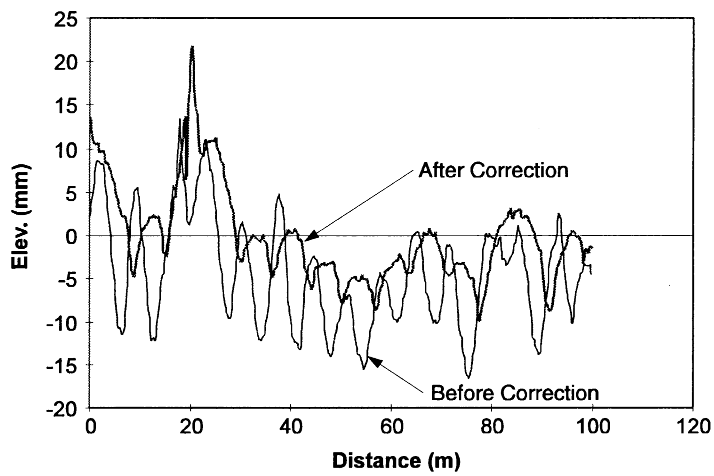

Figure 12. Corrected and original profile (SDRP).

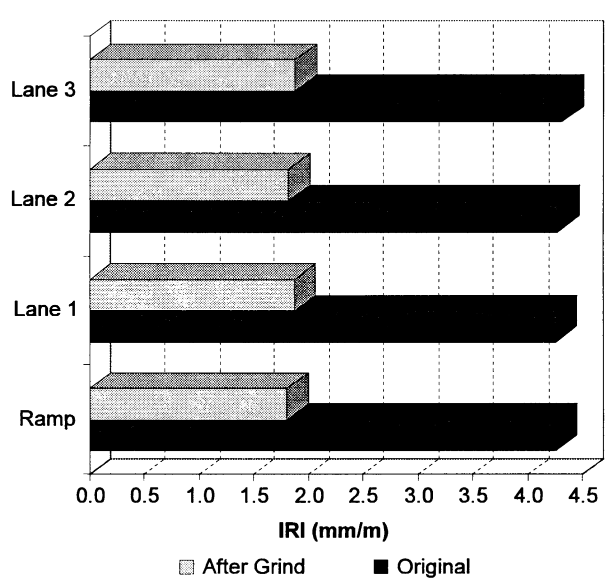

Figure 13. Results of corrective action.

Suitability of IRI for Assessing Degree of Success

The very real "seat-of-the-pants" improvement was obvious. Nonetheless, it was important to report the success of the procedure in unbiased terms. Because the profiles generated by the SDRP can be lengthy and difficult to interpret, the IRI was selected to summarize the completed ride quality. Unfortunately, the IRI is also complex and not widely understood. Naturally, this provoked an appropriate level of skepticism regarding its ability to adequately account for much of what caused the initial rideability problem.

A full explanation of the origins of the IRI calculation is beyond the scope of this document. However, scientists familiar with fine points of the IRI simulation have shown that the 5.0 to 7.5 meter (15 to 25 foot) repeating wavelength observed in this case falls well within the wavelengths that contribute to significant roughness *(1)*. However, the ride simulation that produces the IRI is not tuned specifically to be sensitive to tractor trucks with semi-trailers. The vehicle mass, stiffness and damping terms incorporated into the IRI vehicle model were developed to provide the best correlation with older response type roughness meters (Mays meters and the Bureau of Public Roads Roughometer) *(2,3)*. No explicit effort was made to model the ride characteristics of any particular vehicle type. It is safe to say, however, that the suspensions of the first road roughness meters were much closer to mid-to-large passenger vehicles than to tractor trailers.

CONCLUSIONS

The reader is encouraged to draw his or her own conclusions from the findings and discussions in this report. The author reached the following conclusions:

1. The SDRP can detect and report most of the physical features responsible for undesirable ride quality.
2. Profiles collected by the Dipstick® (or similar device) are necessary if absolute elevation and longitudinal distance information is critical.
3. If the engineer is familiar with its limitations, the SDRP can be an effective tool to assess the feasibility of remedial activity of this nature.
4. The SDRP is an adequate instrument for measuring the relative ride quality of bridge decks.

Some very sophisticated tools can be used to help highway engineers clearly define and address rideability problems on today's highways and bridges. With a fairly high degree of accuracy, and within a very reasonable period of time, modern road roughness equipment can assess a potential problem and confirm potential remedial actions. These findings are expected to prove increasingly useful as VDOT moves forward in implementing new smoothness specifications for highway surfaces.

RECOMMENDATIONS

This paper reported the application of modern, relatively complex equipment to a common problem. Agency officials who have rideability problems on new construction projects or on existing surfaces should take advantage of these tools. On highway riding surface where construction practices simply failed to adequately address smoothness (and no major structural problems or other factors contribute to the ride problem), these tools can verify the potential for correction. This I-95 bridge deck project illustrates the degree of success possible.

Recently, renewed emphasis has been placed on the constructed smoothness of new roadway pavements. In the 1996 construction season, a new smoothness specification is being piloted on selected asphalt concrete overlays. This draft provision will be administered using the SDRP. It includes the payment of bonuses for smooth riding pavement, disincentives for pavements that exhibit a less than satisfactory ride, and a requirement for corrective action if roughness exceeds a preset limit. Perhaps this is an appropriate time for bridge engineers to revisit their own requirements for smoothness, and the methods they use for controlling it. The SDRP is probably not an appropriate instrument for administering a smoothness specification for bridge decks. It may be, however, that an instrument like the Dipstick® could be used to supplement the straight-edge.

REFERENCES

1. Sayers, M. W. 1995. *On the Calculation of International Roughness Index from Longitudinal Road Profile*. Report No. TRR 1501. Washington, D.C.: Transportation Research Board.

2. Sayers, M. W., Gillespie, T. D., and Queiroz, C. 1986. *International Experiment to Establish Correlations and Standard Calibration Methods for Road Roughness Measurements*. World Bank Technical Paper No. 45. The World Bank, Washington, D.C.

3. McGhee, K. K. 1996. *Assessment of Virginia's Hybrid South Dakota Road Profiling System*. VTRC Report No. 96-R20. Charlottesville, Virginia.