Seasonal Changes in the Longitudinal Profile of Pavements Subject to Frost Action

EDWIN C. NOVAK, JR., AND LEO E. DEFRAIN, JR.

The use of profilometers for determining pavement surface roughness has been gaining favor because the results of profilometers are accurate and reproducible. It will be illustrated that using longitudinal profiles has far greater utility than simply determining pavement roughness. The winter and summer longitudinal profiles of three sites from each of three projects are presented to illustrate how these data can be used to determine cause of deterioration, appropriate maintenance, rehabilitation, and reconstruction treatments to improve ride quality, and cause of surface roughness. Another proposed use for longitudinal profile data is to estimate the ride quality that can be expected as a result of overlaying an existing pavement.

Response-type roughometers, contact and noncontact profilers, and a line of levels are all methods that can be used to establish the roughness of pavement surfaces. Generally, roughometers are least accurate and the line of levels is the most accurate. The cost of data collection, which should include the cost of equipment, has the roughometer as the least expensive method and the line of levels as the most expensive method. The result has been the increased use of profilometers for determining ride quality because of their intermediate cost and high level of accuracy and reliability. Highway agencies tend to key in on a subjective ride quality index such as the present serviceability index (PSI) or the international roughness index (IRI) as the most important pavement surface characteristic because it identifies pavement sections whose ride qualities are no longer acceptable. Whereas roughometers provide roughness index numbers only, profilometers provide a pavement surface's longitudinal profile, which can be used to determine what to do to correct unacceptable ride quality. Existing differences between winter and summer longitudinal profiles, the reasons for the differences, and the potential uses of such information are illustrated here.

INVESTIGATIVE PROCEDURE

The Michigan Department of Transportation (MDOT) uses a GM-type noncontact profilometer for establishing roughness and faulting characteristics of each 0.1-mi segment of its approximately 12,500 directional-mi trunkline system. The longitudinal profile is measured in the right wheelpath at 3-in. intervals. The elevation is measured to an accuracy of ±0.01 in. The profilometer was designed and constructed by the Instrumentation and Data Systems Unit and the Structures Research Unit of MDOT's Materials and Technology Division.

MDOT collects roughness data statewide once a year. Data collection begins in June and is completed in October. Several of the more northern districts indicated a need to establish the roughness of their pavements during the winter when frost heaves, tenting, and other factors were claimed to cause a seasonal decline in pavement ride quality. In response to this request, approximately 500 mi of longitudinal profile data were collected in February 1991 for comparison with profile data collected the previous summer.

The longitudinal profiles of pavements are plotted on grid paper. Winter profiles are always plotted above summer profiles. Although to view a roll of continuous longitudinal profile is most informative, the short 200-ft-long sections presented in this paper are suitable to illustrate the factors that influence the pavement's longitudinal profile. Presented are nine examples of important causes of composite pavement deterioration that can be identified by longitudinal profiles. Longitudinal profile data are equally useful for rigid and flexible pavements.

Figure 1 illustrates the overlay of unrepaired portland cement (PC) concrete pavement for which the transverse joints have deteriorated due to D-cracking. Figure 2 shows the winter cross section, when frost tenting action in the deteriorated PC concrete material causes a localized frost heave. Fines that form as a result of D-cracking pump on thawing, as shown in Figure 3. The loss of fines because of pumping causes summertime depressions, as shown in Figure 4. If the base layer is frost-susceptible, the PC concrete slabs may tilt or fault because of frost action. When the slabs tilt, the back slabs rise at the deteriorated joint, and the fore slabs depress (typical of faulting caused by pumping), as shown in Figure 5.

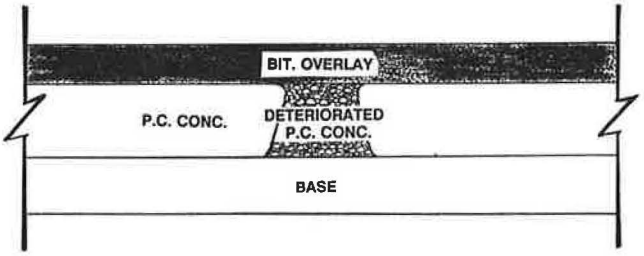

FIGURE 1 Typical overlay of unrepaired PC concrete pavement.

Materials and Technology Division, Michigan Department of Transportation, P.O. Box 30049, Lansing, Mich. 48909.

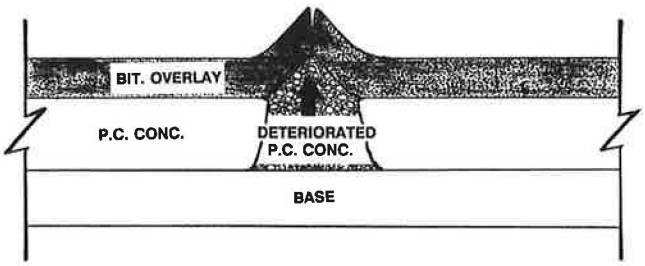

FIGURE 2 Localized frost-heave tenting of deteriorated PC concrete joints and cracks.

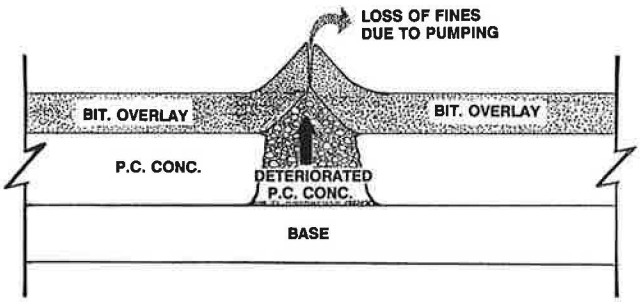

FIGURE 3 Loss of fines from deteriorated joints and cracks occurs during thawing when traffic recompacts frost-heaved joint or crack area.

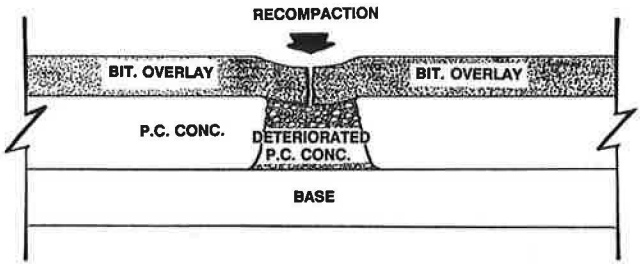

FIGURE 4 Loss of fines at deteriorated joints and cracks leads to surface depressions during summer.

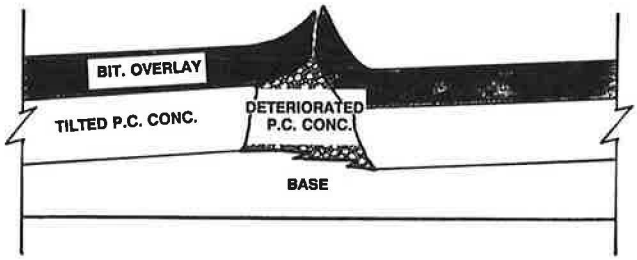

FIGURE 5 Bituminous overlays are also subject to differential frost heave in the base layer that causes PC concrete slabs to tilt.

Frost action in the base layer can also cause the fore slab to rise above the back slab at joints and cracks, as shown in Figure 6. The previously described causes of seasonal changes in longitudinal profiles can be seen in longitudinal profiles shown in Figures 10, 11, 12, 15, and 16.

Figure 7 illustrates the overlay of a PC concrete pavement for which the D-cracked material is removed and replaced with bituminous concrete patching material. In winter, the PC concrete slabs contract, and some lateral movement of the bituminous joint repair material may cause a depression in the repair area, as shown in Figure 8. In summer, expansion of the PC concrete slabs compresses the bituminous repair material, causing a bump to occur, as shown in Figure 9. The causes for seasonal changes in longitudinal profile are shown in Figures 13 and 14.

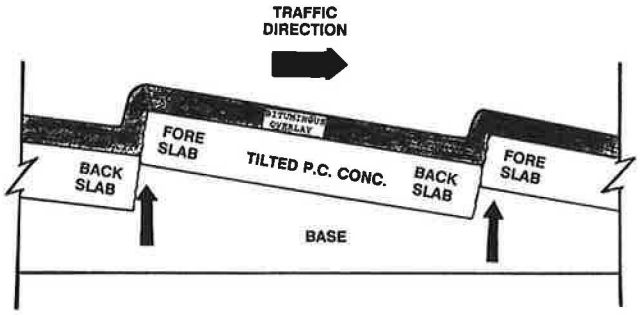

FIGURE 6 Tilting of PC concrete slabs caused by differential frost heave can be opposite tilting associated with faulting of joints and cracks.

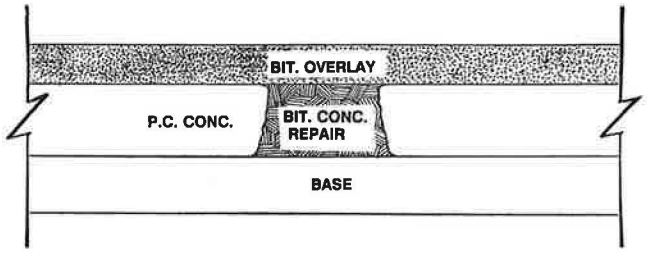

FIGURE 7 Typical bituminous joint repair before bituminous overlay.

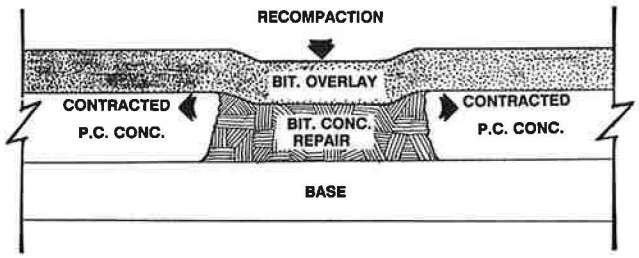

FIGURE 8 Expansion of PC concrete slabs compresses bituminous repairing material, causing it to form a bump in pavement surface.

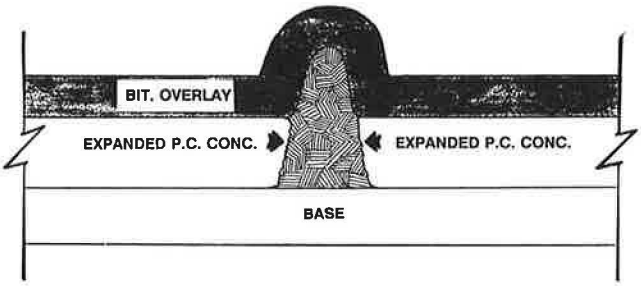

FIGURE 9 A depression may form in repair areas when PC concrete slabs contract in winter.

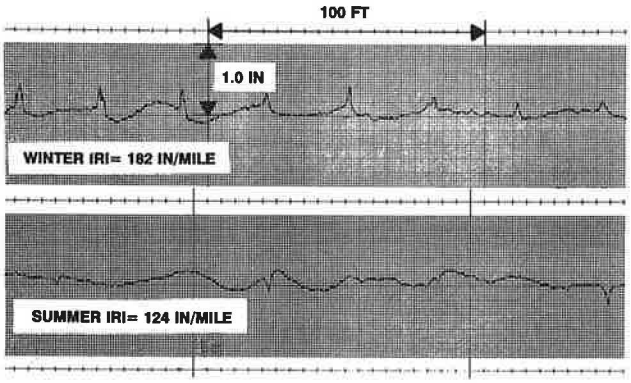

FIGURE 10 M-115 eastbound; rigid pavement 1940; overlaid with bituminous concrete in 1987; distress condition = 36 points.

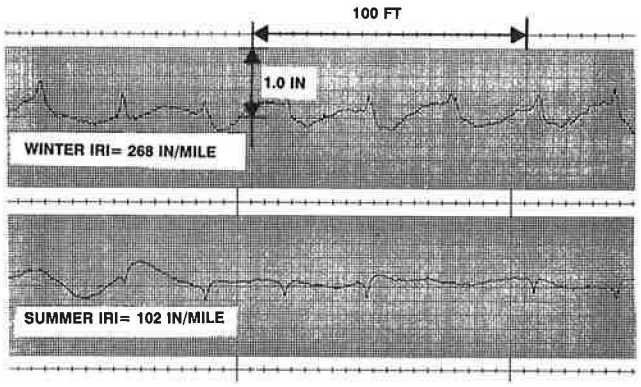

FIGURE 11 M-115 eastbound; rigid pavement 1940; overlaid with bituminous concrete in 1987; distress condition = 65 points.

Figures 10 through 18 show the winter (*top*) and summer (*bottom*) profiles of selected composite pavements. The route, pavement type, age of layers, and current distress conditions are presented in each figure's title. The IRI of each profile is presented adjacent to the profile. Note that no attempt was made to determine the IRI value from the approximately 200-ft-long profile shown. MDOT reports roughness for each contiguous 0.1-mi segment for the entire trunkline system. The

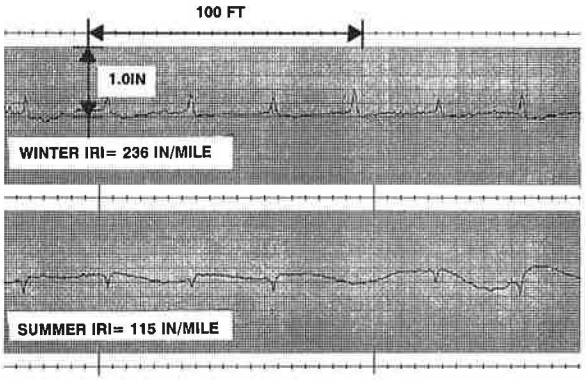

FIGURE 12 M-115 eastbound; rigid pavement 1940; overlaid with bituminous concrete in 1987; distress condition = 70 points.

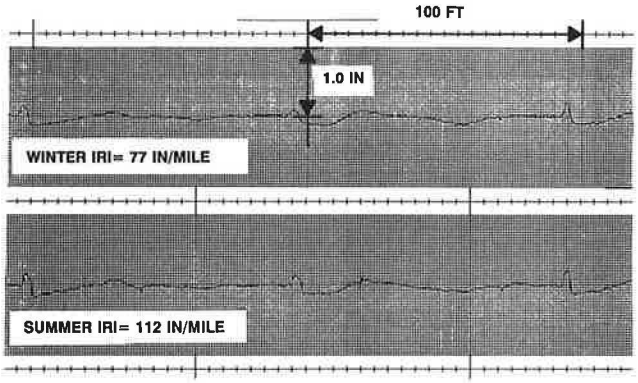

FIGURE 13 M-50 westbound, rigid pavement 1953; overlaid with bituminous concrete in 1985; joint repairs (Details 7 and 8) completed before overlay; distress condition = 18 points.

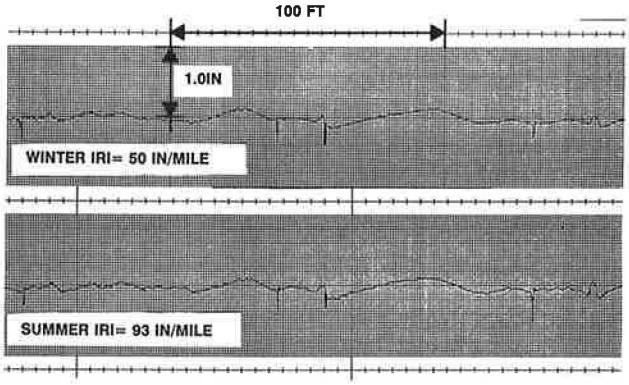

FIGURE 14 M-50 westbound; rigid pavement 1953; overlaid with Tensar-reinforced bituminous concrete in 1985; joint repairs (Details 7 and 8) completed before overlay; distress condition = 14 points.

IRI value indicated is the IRI value for the 528-ft segment that includes more than half the 200-ft-long profile shown. MDOT uses a distress point system for indicating pavement surface condition (*1*). A new pavement free of distress starts with 0.0 distress points. When 50 distress points have been accumulated, the pavement is considered to be in unaccept-

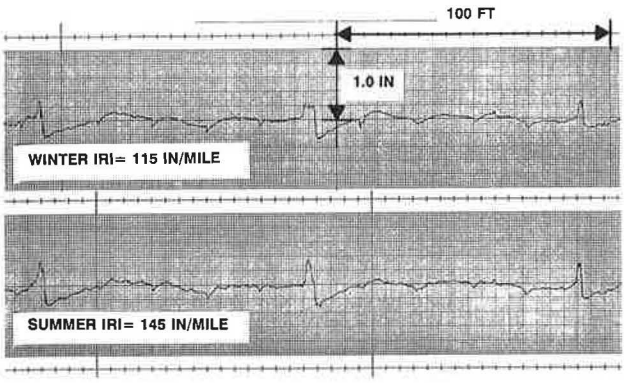

FIGURE 15 M-50 westbound; rigid pavement 1953; overlaid with bituminous concrete in 1985; cracked and severed at 20-ft centers; distress condition = 20 points.

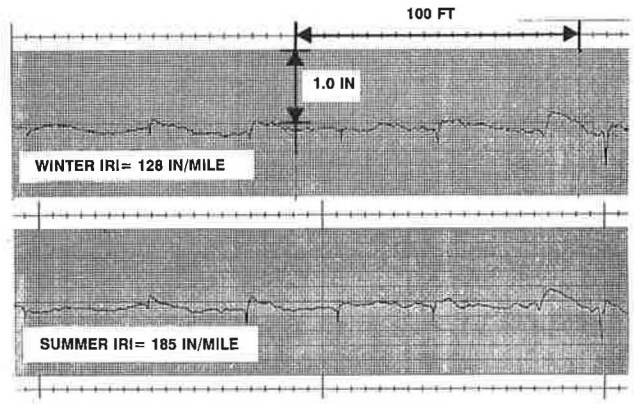

FIGURE 17 US-2 westbound; rigid pavement 1936; overlaid with bituminous concrete in 1952 and 1976; distress condition = 71 points.

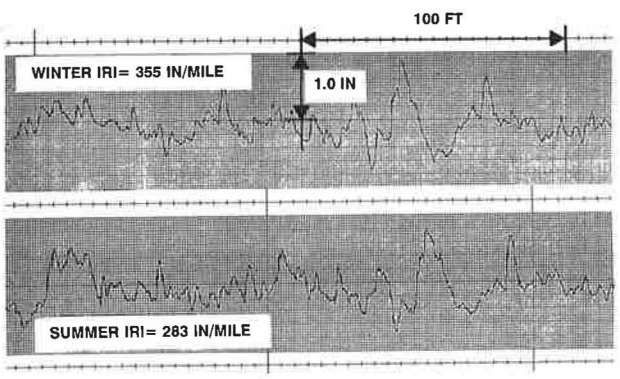

FIGURE 16 US-2 westbound; rigid pavement 1936; overlaid with bituminous concrete in 1952 and 1976; distress condition = 24 points.

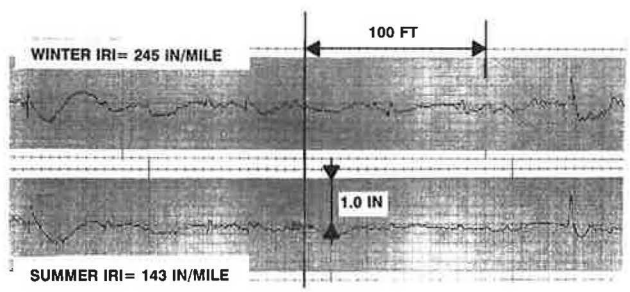

FIGURE 18 US-2 westbound; rigid pavement 1936; overlaid with bituminous concrete in 1952 and 1976; distress condition = 37 points.

able distress condition. MDOT also considers an IRI of less than 100 in./mi to be of excellent ride quality and one greater than 250 in./mi to be of poor ride quality.

From Figures 1 through 9, the pavement performance characteristics illustrated by each profile are briefly explained. The seasonal effects on longitudinal profiles are also discussed in terms of difference in winter and summer ride quality.

EVALUATION OF LONGITUDINAL PROFILES

Figures 10 through 12 are taken from the Michigan Test Road constructed in 1940 (*2,3*). Since then the pavement has been overlaid twice. Two frost effects are illustrated. The first is a frost tenting action that occurs at the joints. The PC concrete deteriorates to a dense-graded gravel (Figure 2), which in turn frost heaves in the winter and returns, on thawing, to its original surface level as a result of traffic compaction. Usually fines are lost through transverse cracks (Figure 3) as a result of frost heave and recompaction cycles. Hence, in summer, the area about the joints is depressed (Figure 4) in comparison with the adjacent pavement. The other frost effect is frost heaving of the supporting material, usually a base layer. Frost heave usually causes a tilting of PC concrete slabs of the type shown in Figure 5.

The winter longitudinal profile of Figure 10 shows that joint spacing is 30 ft and that all joints are tenting in the winter but only two joints are depressed in the summer. The left half of the winter profile indicates that the slabs are tilting as a result of frost heave in the slab support material (base), whereas the slabs in the right half are not tilting. The right half of the profile indicates that frost action in the support material smooths the somewhat irregular summer profile. The tenting and slab tilting caused by frost action make winter ride quality worse than that of the summer but the difference, in this case, is not large. Profiles such as Figure 10 illustrate the nonuniform performance of pavement sections as short as 200 ft.

Figure 11 is taken in another location in which tenting and differential frost heave of slab support material are occurring as shown in Figure 5. It can also be seen that most joints are losing fines, hence upon thawing are depressed, adding to summer roughness. The winter to summer change in roughness of 268 to 102 in./mi is highly significant since winter ride quality is in the unacceptable range (> 250) while the summer ride quality is near the excellent (< 100) range.

Figure 12 is taken in yet another location in which tenting and loss of fines at the joints are the only major causes for differences in winter and summer profiles. However, note that the irregular summer profile in the area of the second and third joint from the right is leveled by frost action in the slab

support material. As with the Figure 11 profiles, winter roughness is near the unacceptable level, yet the summer ride quality is very good. A pavement such as that shown in Figure 12 would be a good candidate to replace deteriorated joints with dowelled PC concrete patches. The resulting ride quality should be somewhat improved over its current summer ride quality. However, with the joint spacing of 30 ft and a cost of roughly $1,000/patch the repair cost would be $176,000/lane-mi. If the joint spacing were 99 ft, as in Figure 13, the cost to repair would be one-third as much. The shorter the joint spacing, the less repairable the pavement and the higher the cost of preventive and routine maintenance.

Figures 13, 14, and 15 come from an experimental test road on which various methods of overlaying PC concrete pavement were studied (*4*). The sections of pavement shown in Figures 13 and 14 were repaired with bituminous Detail 7 and 8 joint repairs before being overlaid. Detail 7 and 8 repairs consist of removing loose and deteriorated PC concrete and replacing it with a bituminous concrete mixture (Figure 8). For the Figure 14 section, Tensar reinforcing was added to attenuate reflective cracking. For Figure 15, the PC concrete was cracked and severed into 20-ft lengths before overlay.

Figure 13 (Detail 7 and 8 joint repairs before overlay) shows that winter's ride quality is better than summer's. The reason is that Detail 7 and 8 were completed in cooler weather; as the slabs warm, they increase in length and the bituminous joint repair material is squeezed together to form a mound, as Figure 9 illustrates. In winter, the mound is recompacted somewhat by traffic, but at low temperatures the bituminous concrete joint repairs are too stiff for traffic to recompact completely. The base layer provides good all-season support for the PC concrete slabs that, by measuring the distance between bumps, have 99-ft joint spacing. With time, slab length should increase, thus increasing the bump's amplitude until causing serious ride quality problems. The 18-distress-point condition of this section indicates there are 18 transverse cracks per 528 ft. However, the cracks are too fine to show up on the profile.

Figure 14 (Tensar-reinforced bituminous overlay) shows that the winter ride quality is better than the summer ride quality, and there is little change in winter and summer profiles. This indicates that the base layer is frost-free and provides good all-season support. It is interesting to see that the joint cracks have nevertheless penetrated Tensar-reinforced bituminous concrete. The distress condition, in which 14 points have been accumulated, indicates there are 14 pronounced transverse cracks per 528 ft for an average spacing of a little more than 35 ft.

Figure 15 (cracked and severed at 20-ft centers) further shows that the winter ride quality is better than that in summer. The cracking of slabs and severing at 20-ft centers provides the roughest and most distressed alternative of the three test sections shown in Figures 13 through 15. The 20-ft spacings at which the slabs were severed are easily seen in the profile, as are the 99-ft joint spacings. The primary reason for improved winter ride quality is the reduced amplitude of the profile at the joint areas, presumably due to shrinkage of the PC concrete slabs.

Figures 16, 17, and 18 are all profiles from same project or pavement section. The old PC concrete, which was constructed in 1936, was overlaid with bituminous concrete in 1952 and again in 1976. The pavement is in an urban area that has a speed limit of 35 mph. The three profiles illustrate how much change there can be in the longitudinal profile within the limits normally considered as a homogeneous project length. The degree of variation in ride quality and distress condition from profile to profile should be noted.

Figure 16 (old PC concrete pavement twice overlaid) shows that the winter ride quality is much worse than that in summer and that in both seasons it is unacceptable. The highly irregular profile, the good distress condition, and the irregular nature of frost heave does not fit a recognizable pattern. In this case the longitudinal profile would simply indicate that to determine the cause of deterioration and the difference between winter and summer profiles would require detailed distress data. The profile gives no evidence that there is an underlying PC concrete pavement, which could indicate that it has significantly deteriorated to gravel. Distress data would indicate such an occurrence.

Figure 17 (old PC concrete pavement twice overlaid) indicates the winter ride quality is better than that in summer, although both are good. Here again, the better winter ride quality is associated with the apparent absence of frost action. However, the distress condition (71 points) is unacceptable. This profile was selected because the PC concrete slabs are apparently tilted the wrong way [i.e., the fore slabs (at cracks and joints) are higher than are the back slabs, as shown in Figure 6]. The cause for this unusual behavior cannot be determined on the basis of profile data alone. However, it is clear from the profiles that the PC concrete slabs are not deteriorated.

Figure 18 (old PC concrete pavement twice overlaid) indicates that winter ride quality is worse than the summer ride quality. The middle 250 ft have a fairly smooth profile compared with the 50-ft-long right and left ends of the profile. The 250-ft-long flat profile is a grade lift in which a granular separation course is placed over the existing pavement surface before resurfacing. This is a standard practice that produces the erratic profile illustrated by Figure 18. The Michigan practice of reporting roughness data for each 528-ft segment tends to mask the true variability of pavement surface roughness. Nevertheless, the difference in ride quality of the direct PC concrete overlays compared with that of overlay on the separation course, which removes irregularities in the profile of old PC concrete surface, is obvious from the profile itself.

SUMMARY

Three sections of pavement were selected from each of three different projects to illustrate the seasonal change in roughness and the utility of using the longitudinal profile to determine why the ride quality seasonally changes and deteriorates with time. This information should be valuable to any agency that seeks to provide uniformly good ride quality.

It is suggested that longitudinal profile data be available for an agency's entire highway system. For a state such as Michigan, the 12,500 mi. of summer and 12,500 mi. of winter longitudinal profile data would require approximately 2,000 M of data storage. Data could be stored on 15 M cartridges that cost about $25 each, or $350 of profile data for the year.

Profile data has several potential uses. One use is for the development of maintenance, rehabilitation, and reconstruction (MR&R) projects. The theory is to identify the MR&R treatment that has the lowest life-cycle cost. Using M-50, Figures 13, 14, and 15, for example, dowelled joint repairs at an average of 55 repairs per lane-mile would cost approximately $55,000/lane-mi. A thin overlay should cost about $30,000/lane-mi. Such a treatment may be reasonable from the standpoint that the existing pavement is not subject to frost action and that, although deterioration of the transverse joints is the primary cause of surface roughness, the rate of deterioration is slow. Even the length of patches can be determined as shown in Figure 13. The two joint areas shown should be replaced with about 15-ft patches to provide a smooth longitudinal profile.

Another use is to determine the type of pavers and number of layers that must be specified if the as-constructed pavement is to meet or exceed minimum required ride quality. MDOT has developed software that, given existing profile, type of paver, and layer thickness, will simulate the resulting profile for each of any designated number of layers. Utility software could be written to give pavement design engineers the ability to predict ride quality and to specify types of acceptable pavers and number of layers. This information is essential to management systems for estimating the improvement in ride quality provided by alternative MR&R treatments.

A third use is to develop software that would automate the analysis of winter with summer profiles. Sections of pavement subject to each major cause of frost action could be identified, as could sections that are not affected. The data could then be reported in any way that would most help the MR&R program or project development process.

CONCLUSIONS

1. Profilometers are significantly underutilized if their only purpose is to calculate a roughness index.
2. Pavements subject to frost action are rougher in the winter than in the summer.
3. Pavements that are not subject to frost action tend to be rougher in the summer than in the winter.
4. The longitudinal profile provides a means of determining cause of pavement deterioration and surface roughness.
5. Pavement surface roughness and distress condition are not necessarily correlated.
6. Longitudinal profile data should be available to aid the MR&R program and project development process.
7. The longitudinal profile should be used to estimate roughness of the surface of proposed bituminous concrete overlay projects.

REFERENCES

1. *Pavement Management System (PMS) Distress Survey Manual.* Michigan Department of Transportation, Lansing, 1989.
2. *The Michigan Test Road, Design Project.* Michigan Department of Transportation, Lansing, Aug. 1950.
3. C. C. Rhodes and E. A. Finney. *The Michigan Test Road Durability Project.* Michigan Department of Transportation, Lansing, Jan. 1960.
4. J. H. Defoe. *Evaluation of Tensar Bituminous Pavement Reinforcement.* Michigan Department of Transportation, Lansing, Aug. 1990.

Publication of this paper sponsored by Committee on Frost Action.