# Smoothness Control in Asphalt Pavement Construction: Development of Specifications, Implementation, and Results

MUSTAQUE HOSSAIN AND WILLIAM H. PARCELLS, JR.

Surface smoothness on newly constructed pavement is a major concern of the highway industry. This smoothness, or riding comfort, is an indication of the quality of the newly constructed pavements since it affects road users directly. Smoothness specifications for asphalt concrete (AC) pavements now in effect in Kansas have evolved over the past few years through a number of revisions. Pavement profiles with short wavelengths and smaller amplitudes than the industry-accepted 5.1 mm (0.2 in.) can harm the ride quality of pavements. This experience has led the Kansas Department of Transportation to eliminate the blanking band width in the profilograph trace reduction process. The implementation of this zero, or null, blanking band was successful and has resulted in smoother asphalt pavements in Kansas. The currently used specifications for AC pavements have been based on the consideration of a number of factors related to the construction of and the measurement of smoothness on AC pavement. The incentive payment amounts have been calculated to make these compatible with the incentive payments for concrete pavement. The results show that these smoothness specifications can be achieved by contractors, and the number of sections in the bonus range indicates that the incentive payments encouraged better-quality paving. These results should have a positive impact on AC paving in Kansas. Overall, an increasing number of miles of pavements with lower profile index values are being constructed since the implementation of smoothness specifications for AC pavements.

Pavement smoothness and roughness can be described by the magnitude of profile irregularities and their distribution over the measurement interval. The road surface smoothness on newly constructed pavement is a major concern of the highway industry. This smoothness, or riding comfort, is a measure of the quality of the newly constructed pavements since it affects the road users directly. According to Hudson (*1*), the primary purpose for smoothness measurement is to maintain construction quality control.

It is accepted that there is a growing interest in the highway industry for attaining smoother and smoother pavement surfaces. Results from a 1992 NCHRP study show that of the 22 states reporting, 91 percent used smoothness criteria on new pavement construction (*2*). In 1990 NCHRP reported that of 36 states reviewed, 80 percent utilized smoothness criteria on new pavement construction (*3*). The increasing trend in the use of ride quality specifications is also evidenced by the 1992 study, in which 21 states out of 25 queried believe that there will also be a future increase in ride quality requirements. A 1987 AASHTO survey showed that 53 percent of the states using profilographs for acceptance of concrete pavements used incentive and disincentive specifications (*4*). The incentive and disincentive values in smoothness specifications typically ranged from 1 to 5 percent of the bid item price, with 31 percent of the states reporting allowable incentives up to 5 percent. The relatively high incentives now possible with many of the profilograph specifications place an ever-increasing burden on the measurement process and data reduction process. Variability in test results can substantially affect contractor payments (*2*).

Mustaque Hossain, Department of Civil Engineering, Kansas State University, Manhattan, Kan. 66506. W. H. Parcells, Kansas Department of Transportation, Bureau of Materials and Research, Materials and Research Center, 2300 Van Buren, Topeka, Kan. 66611.

## DEVELOPMENT OF AC PAVEMENT SMOOTHNESS SPECIFICATIONS

### Factors Considered

In 1985 the Kansas Department of Transportation (KDOT) selected a 7.63-m (25-ft) California-type profilograph and a 5.1-mm (0.2-in.) blanking band for evaluation of the profilogram for determining the smoothness of portland cement concrete (PCC) pavement construction (*5*). In 1985 the first three PCC pavement projects with smoothness requirements were constructed. However, the incentive clauses were not exercised. Profilograph measurements were taken on each wheel path. The profilograph results in terms of profile roughness index (PRI) on 0.16-km (0.1-mi) intervals on these projects were analyzed. The first two projects had a high percentage of sections in the bonus range indicating that smoothness of 0 to 63 mm/km (0 to 4 in./mi) was practical and achievable. In 1990 the specifications given in Table 1 were adopted as standards for controlling concrete pavement smoothness in Kansas.

Although smoothness specifications with profilograph measurements were implemented on PCC pavements in 1985, new bituminous pavements had surface tolerance requirements as measured by a 3.05-m (10-ft) straight edge or a 7.62-m (25-ft) stringline at selected locations. The maximum variation of the surface in 3.05 m (10 ft) was not allowed to exceed 4.76 mm (3/16 in.); the maximum for 7.62 m (25 ft) was 7.94 mm (5/16 in.) (*6*). Evidently these requirements were not sufficient for constructing smooth-riding bituminous pavements, and public complaints about the quality of rides on newly paved asphalt concrete (AC) pavements were rampant. By 1990 KDOT was very successful in controlling concrete pavement smoothness. This success led to the development of profilograph-based specifications for AC pavements in 1990. The major elements of the smoothness specifications for asphalt pavements evolved through consideration of the following:

- The roadway elements that normally would be included in the smoothness specifications for bituminous pavements are finished surfaces of the mainline pavement, side roads, auxiliary lanes, and ramps. Each of these elements should have a minimum paving depth of 102 mm (4 in.). This minimum thickness was selected because of economics. All of KDOT's substantial maintenance projects have actions that are less than 102 mm (4 in.) thick. Because of budget restraints on the substantial maintenance program money, it was believed that this money should not be spent on incentives.
- Unlike concrete pavements, there are no hand-poured sections on any of the elements described previously. Thus, a single set of specifications would be developed irrespective of the posted speed limit on the roadway.
- Specifications would be developed for statewide application regardless of route type or functional classification. This should encourage the contractors to pave uniformly throughout the state.
- The following would be excluded from pay adjustments under the terms of the smoothness specifications:
  - –Bridge decks unless to be overlaid,
  - –Acceleration and deceleration lanes for at-grade intersections,
  - –Shoulders,
  - –Pavement on horizontal curves that have a 304.8-m (1,000-ft) or less centerline radius of curvature and pavement within the superelevation transition of such curves,
  - –Pavements consisting of new or recycled bituminous concrete surfacing 102 mm (4 in.) or less in plan thickness,
  - –County secondary and federal aid urban projects unless specified otherwise on the plans, and
  - –Projects less than 0.5 mi in length (excluding bridge lengths).
- The California-type profilograph would be used for as-constructed smoothness measurements, and the schedule for adjusted payment would be fashioned after that for concrete pavements. Doing this will bring some kind of parity between the specifications for these competing types of pavements. It was accepted that during paving of bituminous pavements, contractors had a better opportunity to meet smoothness requirements than during paving of concrete pavements, so the disincentive payments would be much higher for bituminous pavements. The specification for the "bumps" would be similar to that for concrete pavements (deviations in excess of 10.2 mm in a length of no more than 7.6 m, or 0.4 in. in 25 ft).
- The pavement smoothness would be established as a separate pay item with a zero-bid item amount. The pay schedule would then include incentives or disincentives in accordance with the pay schedule that will be added to or subtracted from the total contract amount through this pay item.

**TABLE 1 Schedule for Adjusted Payment for PCC Pavements, 1990 Specification 502.06 with 5.1-mm or 0.2-in. Blanking Band**

| Profile Index millimeter per kilometer per 0.16 kilometer segment | Price Adjustment Percent of Contract unit bid price |
|---|---|
| 48 or less | 106 |
| 48.1 to 64 | 103 |
| 64.1 to 159 | 100 |
| 159.1 to 191 | 96 |
| 191.1 to 222 | 92 |
| 222.1 to 238 | 90 |
| 238.1 or more | 88 (Corrective Work required or replace) |

**TABLE 2 Schedule for Adjusted Payment for AC Pavements, Special Provision 90P-39 with 5.1-mm or 0.2-in. Blanking Band**

| Profile Index (mm per km per 0.16 lane-km) | Contract Price Adjustment per 0.16 lane-km (Dollars) |
|---|---|
| 32 or less | + 152.00 |
| 32.1 to 47 | + 76.00 |
| 47.1 to 142 | 0.00 |
| 142.1 to 174 | -102.00 |
| 174.1 to 205 | -203.00 |
| 205.1 to 237 | -254.00 |
| 237.1 or greater | -305.00 |

- The incentive or disincentive amounts would be determined on a 0.16-km (0.1-mi) basis, which would be summed to an aggregate amount on a lane-mile basis. There should be a threshold target that when exceeded would require specific remedial action by the contractor such as that in the concrete pavement specification (i.e., grinding).
- The test method and trace reduction procedures would be similar to those used for concrete pavements.
- The contractor would be responsible for determining the smoothness of pavement by operating a profilograph. KDOT may perform profilograph testing on the surface for monitoring and comparison purposes and during disputes over test results.

On the basis of these considerations, profilograph results for ensuring smoothness on bituminous pavements with greater than 102 mm (4 in.) paving depth were implemented through Special Provision 90P-39 as given in Table 2, where the roughness limits established were somewhat similar to the PCC pavement schedule.

## Calculation of Incentive Payments

The highest incentive payment of $152/0.16-km (0.1-mi) section as presented in Table 2 for the profile index of 32 mm/km (2.0 in./mi) or less was based on the average cost of an AC overlay 89 mm (3.5 in.) thick, 161 m (528 ft) long, and 3.66 m (12 ft) wide. Many states pay for AC paving by the square yard paved; KDOT pays for AC paving by the tons of mix and again for the asphalt binder. For the Kansas condition, there was no direct correlation between pay items for AC and PCC pavements. Therefore, a direct conversion of PCC incentive payments for smoothness to AC condition was not possible. The 89-mm (3.5-in.) AC pavement thickness was arbitrarily selected because it was thought that the incentive payment should be compared with that for PCC pavement at this thickness level. Details of this incentive payment calculation are as follows:

- The amount of AC in an overlay section 89 mm (3.5 in.) thick, 161 m (528 ft) long, and 3.66 m (12 ft) wide (unit weight = 145 pcf):

$$0.2917 \times 145 \times 12 \times 528/2{,}000 = 134 \text{ tons}$$

- The cost of this section of overlay (based on the price of AC, BM-2 for KDOT):

$$134 \text{ tons} \times \$18.90/\text{ton} = \$2{,}532$$

• The price of this section including incentive payment (maximum 106 percent, based on then-current PCC pavement payment adjustment schedule):

$2,532 × 1.06 = $2,684

• The maximum amount of incentive for a 0.16-km (0.1-mil) section =

$2,684 − $2,532 = $152.00

The payment schedule for the profile/index 33.1 to 47 mm/km (2.1 to 3.0 in.) was established to be half the amount for 0 to 32 mm/km (0 to 2.0 in./mi) (i.e., $76/0.16-km or 0.1-mi section). The disincentive amounts were made progressively higher (up to $305/0.16-km or 0.1-mi section) to discourage contractor negligence.

## IMPLEMENTATION OF AC PAVEMENT SMOOTHNESS SPECIFICATIONS

As mentioned earlier, the profilograph results for ensuring smoothness on AC pavements with greater than 102-mm (4-in.) paving depth were implemented through Special Provisions 90P-39 (as given in Table 2) during 1990. During this year, the incentive and disincentive clauses were not enforced. The profilograph results were collected and analyzed using the 5.1-mm (0.2-in.) blanking band. Table 3 gives the specification compliance for the 5.1-mm (0.2-in.) blanking band. Out of 851 sections (0.16-km or 0.1-mi) constructed in 1990, there were 547 sections (64 percent) in the bonus range, 226 sections (27 percent) in the full-pay range, and 78 sections (9 percent) in the penalty zone. Figure 1 illustrates the results; no specific statistical distribution is obvious. Most of the sections were lumped in the bonus range. However, the data contained some sections on which profilograph specifications were not required but were considered rough and measurements were made.

**TABLE 3 Profilograph Results on AC Pavements Using 5.1-mm Blanking Band for 1990 Special Provision 90P-39**

| Roadway | No. of 0.16 kilometer sections | Compliance with specified PRI (mm/km) | | | | | |
|---|---|---|---|---|---|---|---|
| | | PRI (0 - 47) Bonus | (%) | PRI (47.1 - 142) Full-pay | (%) | PRI (>142) Penalty | (%) |
| All 1990 | 851 | 547 | 64 | 226 | 27 | 78 | 9 |

## REVISED PROFILOGRAPH TRACE REDUCTION PROCEDURE

In 1990 there was a noticeable high-frequency vibration on a concrete pavement reconstruction project on I-70. This vibration was not noticed for another concurrent new PCC pavement project on I-470, however. A closer review of the profilograph traces on these projects showed that on the I-70 project, there was a consistent sine-wave cyclic oscillation of about 2.44-m (8-ft) spacing and with 5.1-mm (0.2-in.) amplitudes. Most of these surface deviations were covered up by the 5.1-mm (0.2-in.) blanking band during trace reduction. On the I-470 project, the oscillation waves were of about 9.14-m (30-ft) spacing and about 5.1-mm (0.2-in.) amplitude, which were, again, covered up by the 5.1-mm (0.2-in.) blanking band during trace reduction (*7*). This issue of the effects of short wavelengths on PRI was tied to the question about the proper blanking band width.

The I-70 and I-470 projects of 1990 prompted KDOT to experiment with the blanking band width in order to quantify the apparent visual difference of profilograph traces on these projects. It was decided to use a zero blanking band width, or null blanking band. The null blanking band is nothing but a reference line usually placed approximately at the center of the trace having the line equally dividing the scallops above or below the centerline. The null blanking band was also extended to cover profilograms from bituminous pavements.

Reanalysis of the profilograms from the AC pavement projects of 1990 was done using the null blanking band. Table 4 presents the

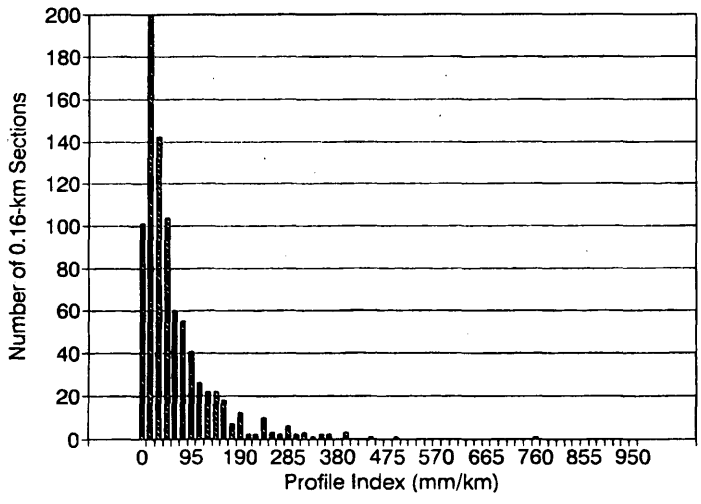


**FIGURE 1 Specification compliance of AC pavement sections with Special Provision 90P-39 (0.2-in. or 5.1-mm blanking band).**

**TABLE 4 Profilograph Results on AC Pavements Using Null (0.254-mm) Blanking Band for 1990 Special Provision 90P-39**

| Roadway | No. of 0.16 kilometer sections | Compliance with specified PRI (mm/km) | | | | | |
|---|---|---|---|---|---|---|---|
| | | PRI (0 - 158) Bonus | (%) | PRI (158.1 - 631) Full-pay | (%) | PRI (>631) Penalty | (%) |
| All 1990 | 842 | 71 | 8 | 753 | 90 | 18 | 2 |

specification compliance for the null blanking band. Out of 842 sections analyzed, 71 sections (8 percent) were in the bonus range, 753 sections (90 percent) in the full-pay range, and 18 sections (2 percent) in the penalty range; Figure 2 illustrates the results. The distribution of the measurements is somewhat normal, which should be expected for a set of engineering measurements. It appears that the null blanking band has enhanced the ability of the profilograph to measure the smoothness of newly constructed AC pavements. However, these results made it obvious that the specifications of Special Provision 90P-39 needed to be changed in order to interpret null blanking band results (*5*).

## REVISION OF AC PAVEMENT SMOOTHNESS SPECIFICATIONS

In 1991 Special Provision 90P-39-R1 was incorporated for AC pavement projects that also required the use of the null blanking band for mechanical profilographs or 0.25-mm (0.01-in.) blanking band for computerized profilographs. The corrective action for a rough section was modified slightly, eliminating the requirement to reseal the diamond-ground pavement, and incorporated in Special Provision 90P-39-R2 in 1992. The schedule for adjusted payments in this special provision at various levels of smoothness achieved in construction is given in Table 5. This requirement was applicable to all projects with multiple paver passes including cold milling with overlay or cold recycle with an overlay. The working depth in those cases might be less than 102 mm (4 in.). However, pay adjustment did not apply if the plan thickness is less than 102 mm (4 in.) on the existing surfaces (*6*).

In 1993 the results of profilograph testing on 5,866 0.16-km (0.1-mi) sections from 30 paving projects in 1992 were analyzed using the null blanking band and compared with the results from the sections of 1990 and 1991. Table 6 gives the results. The 1992 results showed an increased percentage of sections in the bonus range with a similar reduction in the full-pay group. It is apparent that the smoothness limits in Special Provision 90P-39-R2 were achievable (*8*).

During the implementation of Special Provision 90P-39-R2, some contractors complained that requiring all pavement sections to be profiled on the same day they were placed was causing the contractors to stop paving earlier during afternoon hours in order to have time to finish rolling and profiling before reopening the highway to traffic.

Special Provision 90P-39-R3 contains an option allowing the contractor to delay profiling the final portion of a day's paving (not to exceed five 0.16-km or 0.1-mi sections) until the first working day that production is continued on the same lane. When deciding whether to exercise this option, the contractor should be aware that the profile index of the pavement will probably be higher after it has been opened to traffic than it would have been if profiled as soon as rolling was completed.

As more and more AC pavement projects were being built with these smoothness specifications, the clauses of grind-back provisions to profile index of 394 mm/km (25 in./mi) or less in Special Provision 90P-39-R3 were disputed by the contractors. They argued that if they had achieved a profile index of 473 mm/km (30.0 in./mi) then no grinding would have been necessary but that a profile index of 473.1 mm/km (30.1 in./mi) would require grinding back to 394 mm/km (25 in./mi). Special Provision 90P-39-R4 and subsequent revision 90P-39-R5 now require grind-back to 473 mm/km (30.0 in./mi) or less in case of a measured profile index greater than 473 mm/km (30.0 in./mi) along with the penalty payment, if any.

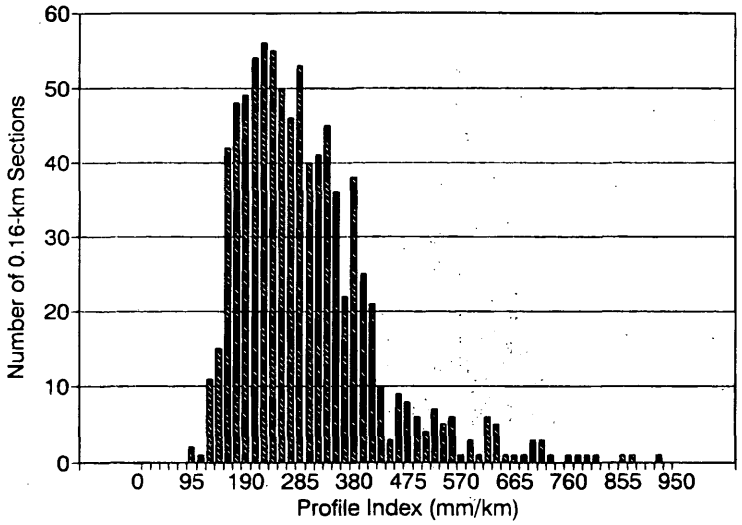


**FIGURE 2 Specification compliance of AC pavement sections with Special Provision 90P-39 (null blanking band).**

**TABLE 5 Schedule for Adjusted Payment for AC Pavements, Special Provision 90P-39-R2**

| Profile Index (mm per km per 0.16 lane-km) | Contract Price Adjustment Per 0.16 Lane-km (Dollars) |
|---|---|
| 110 or less | + 152.00 |
| 110.1 to 158 | + 76.00 |
| 158.1 to 473 | 0.00 |
| 473.1 to 631 | 0.00 (correct back to 394 mm/km or less) |
| 631.1 to more | -203.00 (correct back to 394 mm/km or less) |

**TABLE 6 Profilograph Results on AC Pavements Using Zero (0.254-mm) Blanking Band for 1993 Special Provision 90P-39-R2**

| Roadway | No. of 0.16 kilometer sections | Compliance with specified PRI (mm/km) | | | | | |
|---|---|---|---|---|---|---|---|
| | | PRI (0 - 158) Bonus | (%) | PRI (158.1 - 631) Full-pay | (%) | PRI (>631) Penalty | (%) |
| 1990 (reanalysis) | 842 | 71 | 8 | 753 | 90 | 18 | 2 |
| 1991 (reanalysis) | 1890 | 57 | 3 | 1796 | 95 | 37 | 2 |
| 1992 | 5866 | 1467 | 25 | 4341 | 74 | 58 | 1 |
| 1993 | 4166 | 625 | 15 | 3499 | 84 | 42 | 1 |

## CURRENT SITUATION

In 1994 the results of profilograph measurements on 4,166 sections of AC pavement were collected from 24 paving projects completed in 1993. Table 6 presents the trace reduction results. Figure 3 illustrates the results graphically, and a normal distribution of the results is apparent. The traces were reduced using a null blanking band and the results were compared with those of 1990, 1991, and 1992. There is a decreased percentage of sections in the bonus range with a similar increase in the full-pay group (*9*). The results show that although the incentive payments have decreased, the currently used specifications for AC pavements are achievable by the contractors. The results should establish that under current specifications, bonus can be achieved through better-quality paving rather than by chance.

## COST ANALYSIS OF AC PAVEMENT SMOOTHNESS SPECIFICATIONS

The incentive and disincentive payments made to the contractors in 1991, 1992, and 1993 were analyzed to determine a trend in such payments. Table 7 provides the results of this analysis, and Figure 4 illustrates the results graphically. The incentive payments were much higher during the second year of the implementation of smoothness specification. The incentive to lane-kilometer-paved ratios were 14.07, 203.59, and 129.25 (22.5, 325.7, and 206.8 for lane miles) for 1991, 1992, and 1993, respectively. As illustrated in Figure 4, the incentive payments were showing trends of stabilization after a sharp increase in 1992. The disincentive payments were very minimal compared with the incentive payments in 1992 and 1993; they were somewhat stable then, also. However, the opposite was true in 1991. This indicates that the new specifications have made a positive impact on the overall quality of AC paving over the past 3 years.

**TABLE 7 Results of Cost Analysis of AC Pavement Smoothness Specifications**

| Year | No. of 0.16-km Sections | Bonus ($) | Bonus/ Lane-km Paved ($/km) | Penalty ($) | Penalty/ Lane-km Paved ($/km) |
|---|---|---|---|---|---|
| 1991 | 1890 | 4256 | 14.07 | 7919 | 26.19 |
| 1992 | 5866 | 191084 | 203.59 | 4060 | 13.43 |
| 1993 | 4568 | 94468 | 129.25 | 3857 | 12.75 |

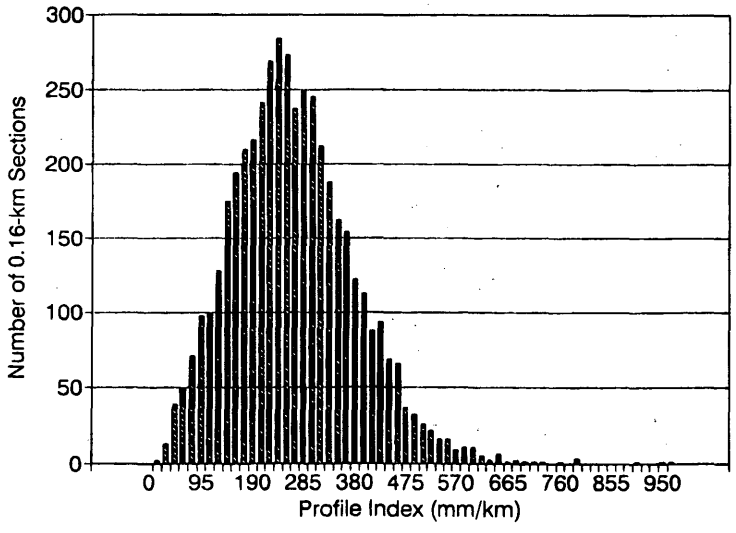


**FIGURE 3 Specification compliance of AC pavement sections with Special Provision 90P-39-R2 (null blanking band).**

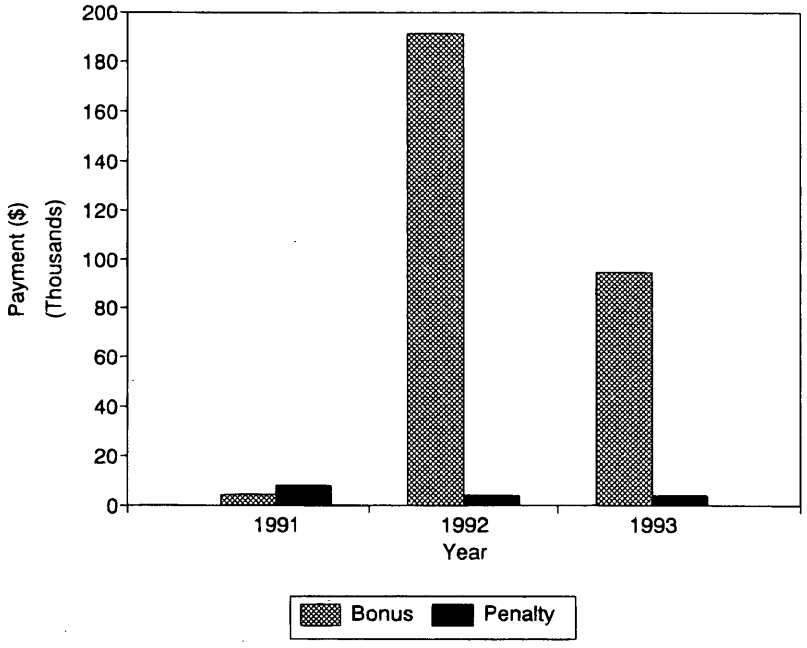


**FIGURE 4 Incentive and Disincentive Payments for AC Paving in 1991, 1992, and 1993.**

## CONCLUSIONS

Smoothness specifications for AC pavements now in effect in Kansas have evolved over the past few years through a number of revisions. Pavement profiles with short wavelengths and smaller amplitudes than the industry-accepted 5.1 mm (0.2 in.) can harm the ride quality of pavements. This experience has led KDOT to eliminate the blanking band width in the profilograph trace reduction process first for concrete pavements, then for bituminous pavements. The implementation of this zero, or null, blanking band was successful and has resulted in better-quality pavements in Kansas. The currently used specifications for AC pavements can be achieved by contractors, and the number of sections in the bonus range indicates that incentive payments have encouraged better paving than in the past. This should have a positive impact on asphalt pavement paving in Kansas. In general, an increasing number of miles of pavement with low profile index are now being constructed since smoothness specifications for bituminous pavements were implemented.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the financial support provided by KDOT for this study. Thanks are due to Ron Harvey, Construction Engineer of Bureau of Construction and Maintenance; Lon Ingram, Chief of Bureau of Materials and Research; and Dick McReynolds, Engineer of Research, for their continued interest in and support of smoothness research.

## REFERENCES

1. Hudson, W. R. Road Roughness: Its Elements and Measurement. In *Transportation Research Record 836,* TRB, National Research Council, Washington, D.C., 1981, pp. 1–7.
2. Scofield, L. A. *Profilograph Limitations, Correlation, and Calibration Criteria for Effective Performance-Based Specifications.* Final Report, NCHRP Project 20-7, Task 53. TRB, National Research Council, Washington, D.C., Dec. 1992.
3. Woodstrom, J. H. *NCHRP Report 167: Measurement, Specifications, and Achievement of Smoothness for Pavement Construction.* TRB, National Research Council, Washington, D.C., Nov. 1990.
4. *Summary of Results of the 1987 AASHTO Rideability Survey.* Highway Subcommittee on Construction, AASHTO, Washington, D.C., 1988.
5. Parcells, W. H., Jr. *Control of Pavement Trueness in Kansas.* Interim Report. Kansas Department of Transportation, Topeka, Jan. 1992.
6. *Standard Specifications for State Road and Bridge Construction.* Kansas Department of Transportation, Topeka, 1990.
7. Parcells, W. H., Jr., and M. Hossain. Kansas Experience with Smoothness Specifications for Concrete Pavements. In *Transportation Research Record 1435,* TRB, National Research Council, Washington, D.C., 1994, pp. 115–123.
8. Parcells, W. H., Jr. *Control of Pavement Trueness in Kansas.* Interim Report. Kansas Department of Transportation, Topeka, May 1992.
9. Parcells, W. H., Jr. *Control of Pavement Trueness in Kansas.* Interim Report. Kansas Department of Transportation, Topeka, May 1994.

*Publication of this paper sponsored by Committee on Flexible Pavement Construction and Rehabilitation.*