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LTPP Data Analysis: Factors Affecting Pavement Smoothness

An NCHRP digest of the findings from the final report on NCHRP Project 20-50(08/13), "LTPP Data Analysis: Factors Affecting Pavement Smoothness," conducted by Soil and Materials Engineers, Inc. Dr. Starr D. Kohn served as Principal Investigator.

INTRODUCTION

This digest highlights the factors affecting pavement smoothness, identified in NCHRP Project 20-50(08/13), on the basis of the data available from the Long-Term Pavement Performance (LTPP) studies.

Smoothness has been recognized as one of the measures of pavement performance. However, the contributions of pavement structure and features, rehabilitation techniques, climatic conditions, traffic levels, layer materials and properties, pavement distress, and other factors to changes in pavement smoothness are not well documented. Without this information, the selection of pavement structure, design features, and rehabilitation strategies that will ensure long-term smoothness is a difficult task. Therefore, there is a need to determine the factors that cause changes in pavement smoothness and to determine the extent of such short-term and long-term changes. A large amount of smoothness-related data has been collected as part of the LTPP studies. An analysis of this data will provide preliminary conclusions regarding the factors that affect pavement smoothness. NCHRP Project 20-50(08/13) was initiated to address this need.

The research was conducted under NCHRP Project 20-50(08/13), "LTPP Data Analysis: Factors Affecting Pavement Smoothness," by Soil and Materials Engineers. The research, completed in August 2001, provided preliminary conclusions regarding the factors affecting pavement smoothness of different types of new and rehabilitated pavement structures. This digest provides a summary of the work performed in this research. The materials in this digest are extracted from the project's final report.

FINDINGS

The analysis performed in this research used the data available in the LTPP Information Management System (IMS) database classified as "Level E" for the Specific Pavement Studies (SPS) and the General Pavement Studies (GPS). To accomplish the project objective, the LTPP IMS database was reviewed in early 2000. Data related to pavement structure and features, rehabilitation techniques, climatic conditions, traffic levels, layer materials and properties, pavement distress variables, and other factors that may contribute to changes in pavement smoothness were extracted from LTPP data tables and compiled in a project-specific database to facilitate the analysis. The International Roughness Index (IRI) was adopted as the measure of pavement smoothness. The smoothness of each pavement section was characterized by the mean IRI value for section (i.e., the average computed IRI value for the left and right wheel paths).

Specific Pavement Studies

The data available for the following four SPS experiments were analyzed to determine the factors affecting pavement smoothness and their contribution to pavement smoothness:

- SPS-1, Strategic Study of Structural Factors for Flexible Pavements,
- SPS-2, Strategic Study of Structural Factors for Rigid Pavements,
- SPS-5, Rehabilitation of Asphalt Concrete Pavements, and

- SPS-6, Rehabilitation of Jointed Portland Cement Concrete Pavements.

Because the SPS experiments were developed to investigate the effects of specific design and rehabilitation features on performance, data available from these experiments were analyzed with consideration of the factors included in the experiment design.

SPS-1 Experiment

The SPS-1 experiment examines the effects of climatic region, subgrade soil (fine and coarse grained), and traffic rate (as a covariate) on asphalt concrete (AC) pavement sections incorporating different levels of structural factors. These factors are drainage [presence or lack of it as provided by an open-graded permeable asphalt-treated (PATB) drainage layer and edge drains], AC thickness (100 and 175 mm), base type [dense-graded untreated aggregate (AB), dense-graded asphalt-treated (ATB), and combinations thereof], and base thickness (200 and 300 mm for undrained sections and 100, 200, and 300 mm for drained sections). The experiment design stipulates traffic loading in the study lane in excess of 100,000 equivalent single axle loads (ESAL) per year. The combinations of the study factors result in 24 different pavement structures. However, to enhance implementation, 12 test sections were constructed at one site and the complementary 12 sections were constructed at another site within the same climatic region on a similar subgrade type.

Profile data were available for 16 projects; most of which were relatively new (less than 3 years: 10 projects, 3 to 5 years: 2 projects, and greater than 5 years: 4 projects). The projects were generally profiled within 1 year after construction; the IRI value obtained at this time was referred to as the "early-age IRI." The average early-age IRI values were 0.88 and 0.82 m/km for the sections constructed with 100- and 175-mm AC layers, respectively, and the standard deviations were 0.21 and 0.18 m/km, respectively. The computed IRI values were less than 1.0 m/km for 70 percent of the sections with a 100- mm AC layer and 85 percent of the sections with a 175-mm AC layer. The average early-age IRI values were 0.94, 0.82, and 0.84 m/km for the sections constructed with AB, ATB, and PATB bases, respectively. Large increases in IRI values (more than 20 percent in 2.3 to 5.8 years) were computed for most sections of three of the SPS-1 projects.

SPS-2 Experiment

The SPS-2 experiment examines the effects of climatic region, subgrade soil (fine and coarse grained), and traffic rate (as a covariate) on doweled jointed plain concrete pavement sections incorporating different levels of structural factors. These factors are drainage (presence or lack of it as provided by an open-graded PATB drainage layer and edge drains), concrete thickness (200 and 275 mm), base type (AB and lean concrete base), concrete flexural strength (3.8 and 6.2 MPa), and lane width (3.66 and 4.27 m). The combinations of the study factors result in 24 different pavement structures; 12 test sections were constructed at one site and the complementary 12 sections were constructed at another site within the same climatic region on a similar subgrade type.

Profile data were available for 12 projects, most of which were relatively new (less than 3 years: 4 projects, 3 to 5 years: 5 projects, and greater than 5 years: 3 projects). Early-age IRI values were generally obtained within 1 year after construction. The average early-age IRI values were 1.27 and 1.30 m/km for the sections constructed with 200- and 275-mm concrete slabs, respectively and the standard deviations were 0.28 and 0.30 m/km, respectively. The average early-age IRI values were 1.27, 1.40, and 1.25 m/km for the sections constructed with AB, LCB, and PATB bases, respectively. Over the monitored period (1.6 to 6.6 years), 23 percent of the sections with a 200-mm concrete slab and 9 percent of the sections with a 275-mm concrete slab showed increases in IRI values of over 20 percent. The change in smoothness is attributed to changes in slab curvature and related curling.

SPS-5 Experiment

The SPS-5 experiment examines the effects of climatic region, condition of existing pavement (fair and poor), and traffic rate (as a covariate) on AC pavement sections incorporating different methods of rehabilitation with AC overlays. These rehabilitation methods consist of surface preparation (minimum surface preparation by patching distressed areas and intensive preparation with cold milling and associated repairs) and resurfacing with asphalt overlays of different types (virgin and recycled) and thickness (50 and 125 mm). The experiment design stipulates traffic loading level in the study lane in excess of 100,000 ESAL/year. The combinations of the study factors result in eight different rehabilitation options at each test site.

Profile data were available for 17 projects. The computed IRI values shortly after overlay were less than 1.0 m/km for 80 percent of the sections that had IRI values less than 1.5 m/km prior to overlay and ranged from 0.8 to 1.2 m/km for most sections that had IRI values of more than 1.5 m/km prior to overlay. The 50-mm AC overlay reduced the IRI of some sections by 0.5 to 1.0 m/km. An analysis of all available data indicated that the IRI value after overlay placement did not depend on the IRI value prior to rehabilitation, overlay thickness, milling prior to overlay, or AC type. Data from the sections that had IRI values greater than 1.5 m/km indicated that milling prior to overlay placement results in a smoother pavement with an IRI value on the average 0.07 m/km less than that for a non-milled section. Generally, the IRI values for all test sections in a project fell within a relatively narrow range irrespective of the IRI

values prior to overlay. However, the change over time in the smoothness of resurfaced pavements depended on IRI value prior to overlay and overlay thickness. When all projects were considered, the average rates of increase in IRI values were 0.042, 0.050, 0.025, and 0.028 m/km/year for the sections rehabilitated with a 50-mm overlay with milling prior to overlay, a 50-mm overlay without milling prior to overlay, a 125 mm overlay with milling prior to overlay, and a 125-mm overlay without milling prior to overlay, respectively.

SPS-6 Experiment

The SPS-6 experiment examines the effects of climatic region, type of pavement (plain and reinforced), condition of existing pavement (fair and poor), and traffic rate (as a covariate) on jointed portland cement concrete (JPC) pavement sections incorporating different methods of rehabilitation with and without AC overlays. These rehabilitation methods are surface preparation (limited preparation (joint sealing, crack sealing, partial depth and full depth patching) and full concrete pavement restoration (including diamond grinding)(with a 100-mm thick AC overlay or without an overlay, crack/break and seat with different AC overlays (100 and 200 mm), and limited surface preparation with a 100-mm thick AC overlay with sawed and sealed joints. The experiment design stipulates traffic loading level in the study lane in excess of 200,000 ESAL/year. The combinations of the study factors result in seven different rehabilitation options at each test site, five of which involve resurfacing with an AC overlay.

Profile data were available for 10 projects. Because intensive restoration by diamond grinding was performed on some of the sections designated for minimum restoration without an overlay, a valid evaluation of the influence of this rehabilitation treatment on pavement smoothness could not be made. The average rates of increase of IRI values were 0.058 m/km/year for the sections rehabilitated with minimum restoration and a 100-mm overlay, 0.057 m/km/year for the sections rehabilitated with minimum restoration and a 100-mm overlay with sawed and sealed joints, 0.200 m/km/year for the sections rehabilitated with intensive restoration with diamond grinding without an overlay, 0.054 m/km/year for the sections rehabilitated with intensive restoration and a 100-mm overlay, 0.032 m/km/year for the sections rehabilitated with crack/break seat and a 100-mm AC surface, and 0.013 m/km/year for the sections rehabilitated with crack/break seat and a 200-mm AC surface. The rate of increase of IRI for the diamond-ground sections was statistically different from that of the other sections; it was generally higher for sections that had higher IRI values prior to rehabilitation.

General Pavement Studies

The data available for the following seven GPS experiments were also analyzed to determine the factors affecting pavement smoothness and their contribution to pavement smoothness:

- GPS-1, Asphalt Concrete Pavements on Granular Base,
- GPS-2, Asphalt Concrete Pavements on Stabilized Base,
- GPS-3, Jointed Plain Concrete Pavements,
- GPS 4, Jointed Reinforced Concrete Pavements,
- GPS 5, Continuously Reinforced Concrete Pavements,
- GPS 6, Asphalt Concrete Overlay of Asphalt Concrete Pavements, and
- GPS 7, Asphalt Concrete Overlays of Portland Cement Concrete Pavements.

Because the GPS experiments do not deal with the effects of specific design and rehabilitation features on performance in the controlled manner provided by the SPS experiments, certain parameters were selected to evaluate their influence on pavement smoothness. These parameters were selected with consideration to the purpose of the experiment and the data available in the LTPP IMS database. For each GPS experiment, the relationships between the IRI values and each selected parameter were evaluated for all sections in each environmental zone (i.e., wet-freeze, wet no-freeze, dry freeze, and dry no-freeze) and for all sections in the experiment.

GPS-1 Experiment

The GPS-1 experiment deals with the performance of AC pavements on granular base. The effect of subgrade on smoothness was evaluated with consideration to the percent material passing the No. 200 sieve in three ranges (i.e., less than 20 percent, between 20 and 50 percent, and greater than 50 percent). For each range, the change in IRI values was generally different for the different environmental zones. When considering all data, the material in base passing the No. 200 sieve, the freezing index of the subgrade, and the plasticity index (PI) of subgrade were found to have a strong effect on smoothness; higher values resulted in lower smoothness.

GPS-2 Experiment

The GPS-2 experiment deals with the performance of AC pavements on asphalt and cement-stabilized bases. A variety of materials were used in these bases (e.g., hot mix AC, AC-treated mixtures, sand asphalt, cold mix, cement-aggregate mixtures, soil cement, and lean concrete). Because of the large variations in base materials, very few relationships could be observed. When all data were considered, it appeared that the sections with higher AC air voids exhibited a higher rate of smoothness reduction than the sections with lower AC air voids. The sections with cement-treated bases in warmer climates exhibited a higher rate of smoothness reduction than the sections in colder climates.

GPS-3 Experiment

The GPS-3 experiment deals with the performance of jointed plain concrete pavements (JPCP), either doweled or non-doweled. Because few doweled sections were located in the dry zone (dry-freeze and dry no-freeze), an evaluation of the effects of dowels on smoothness in this zone could not be made. However in the wet-freeze zone, the change in IRI over the monitored period (average of 7 years) was of less than 0.1 m/km for 60 percent of sections with dowels and 18 percent of sections without dowels. Also, a change in IRI of over 0.5 m/km was observed for 6 percent of sections with dowels and 36 percent of sections without dowels; a similar observation was noted in the wet no-freeze zone. Higher annual precipitation, faulting, moisture content of subgrade, clay content of subgrade, and PI of subgrade, and lower mean temperatures have contributed to higher IRI values of non-doweled pavements. For doweled pavements, higher IRI values were associated with a greater number of wet days and a higher freezing index.

GPS-4 Experiment

The GPS-4 experiment deals with the performance of jointed reinforced concrete pavements (JRCP) located in the wet-freeze and wet no-freeze zones. Higher IRI values were associated with higher moisture, clay content, and PI of the subgrade; annual precipitation; mean temperature; number of wet days; slab thickness; and joint spacing.

GPS-5 Experiment

The GPS-5 experiment deals with the performance of continuously reinforced concrete pavements (CRCP). Most of the GPS-5 sections showed little change in IRI over the monitored period (average of 7 years); a change of less than 0.1 m/km was recorded for 64 percent and 75 percent of the sections in the wet-freeze and wet no-freeze zones, respectively.

GPS-6 Experiment

The GPS-6 experiment deals with the performance of AC overlays of AC pavements and includes GPS-6A and GPS-6B; pavement condition prior to overlay is available for GPS-6B sections but not for GPS-6A sections. No relationship was observed between the IRI values obtained before overlay and those obtained shortly after overlay; most sections yielded IRI values ranging from 0.8 to 1.2 m/km after resurfacing. For most of the sections that had an IRI value less than 2.0 m/km before overlay, IRI value for the resurfaced sections increased by 0.04 m/km/yr in a 7-year period. Thin overlays have resulted in large reductions in IRI values. For example, the IRI value for one section was reduced from 3.4 m/km to 0.7 m/km after resurfacing with a 76-mm thick AC overlay.

GPS-7 Experiment

The GPS-7 experiment deals with the performance of AC overlays of portland cement concrete pavements (JPC, JRCP, or CRCP) and includes GPS-7A and GPS-7B; pavement condition prior to overlay is available for GPS-7B sections but not for GPS-7A sections. No relationship was observed between the IRI values obtained before overlay and those obtained shortly after overlay; the IRI values obtained for all sections after overlay fell within a relatively narrow range. The change in smoothness of the resurfaced pavements is likely to be influenced by the factors affecting the roughness development of the specific underlying pavement (i.e., JPC, JRCP, or CRCP).

CONCLUSIONS

An analysis was made of the data available in the LTPP IMS database classified as “Level E” for four SPS experiments and seven GPS experiments. This analysis took into account the time-sequence nature of the data at the test sections and used the IRI as the measure of pavement smoothness. Through this analysis, the factors related to pavement structure and features, rehabilitation techniques, climatic conditions, traffic levels, layer materials and properties, and pavement distress variables that contribute to changes in pavement smoothness were identified for each type of pavement structure. Because limited data were available for many of the SPS experiments, the findings of this research should be regarded as preliminary. Additional data have been collected since the conduct of this research and more data will be collected in the coming years; thus a much larger database should be available in a few years. A similar research effort would be warranted at some time in the future. Such an effort would refine the findings of this research and contribute to an improved understanding of the factors affecting pavement smoothness and their relative effects.

FINAL REPORT

The agency’s final report, titled “LTPP Data Analysis: Factors Affecting Pavement Smoothness,” gives a detailed account of the project, findings, and conclusions. The report, which was distributed to NCHRP sponsors (i.e., the state departments of transportation), is available as *NCHRP Web Document 40* on the NCHRP website at http://www4.nationalacademies.org/trb/crp.nsf; copies are available for loan on request to the National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, DC 20418.

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