The Canadian LTPP (C-LTPP) project was established in 1989 as a fifteen-year experiment to extend the US-LTPP concept to consider factors of particular interest to Canada. The overall goal of the C-LTPP project is to increase pavement life through the development of cost effective pavement rehabilitation procedures, based upon a systematic observation of in-service pavement performance. The decision to focus on rehabilitation practices (asphalt concrete overlays over existing asphalt concrete pavements) reflects the current trend in Canada toward rehabilitation of the existing infrastructure as opposed to new construction.

C-LTPP is truly a national and cooperative venture consisting of 24 test sites across all ten Canadian provinces. These sites were specifically selected to cover a wide range of environmental and traffic conditions, as well as various combinations of subgrade type and overlay material. Each site consists of two or more adjacent test sections, allowing the performance comparison of various rehabilitation strategies under identical environmental conditions and traffic loading. These strategies include variable overlay thicknesses, virgin asphalt vs. recycled asphalt pavement (RAP), milling or lack of milling prior to overlay, and the use of polymer-modified asphalts or other performance enhancing additives. A total of 65 test sections are included in the C-LTPP experiment.

BACKGROUND

Performance monitoring of the C-LTPP sites is completed by sponsoring agencies on an annual or biannual basis. The data collection effort includes extensive monitoring of surface distress, roughness, rutting, structural performance, traffic loading and climatic data. This data is stored in a central database for use by highway agencies, consultants, industry and researchers. In 1996/97, a series of data insight projects was initiated to establish performance trends, carry out comparative analyses and diagnostic evaluations, and also test the integrity of the C-LTPP database. The report entitled Roughness Trends at C-SHRP LTPP Sites [1] represents the second such data insight project, directed to establish roughness trends at both the national and provincial levels in general and at specific test sites or sections. This technical brief summarizes the findings of the report.

* The United States Long Term Pavement Performance (US-LTPP) project is a field experiment of unprecedented magnitude – consisting of over 2400 test sections representing various pavement structures under different loading and environmental conditions. Initiated in 1987 under the Strategic Highway Research Program (SHRP), the 20-year US-LTPP project represents a landmark opportunity to advance pavement technology to a more technically and economically sound basis.

The Strategic Highway Research Program (SHRP) was established by the United States Congress in 1987 as a five-year, $150-million research program to improve the performance and durability of highways and to make them safer for motorists and highway workers. As a follow-on program to SHRP, Congress established in the Intermodal Surface Transportation Efficiency Act of 1991 programs to implement SHRP products and to continue SHRP’s long-term pavement performance (LTPP) program. The Canadian Highway Research Program (C-SHRP) is directed at extracting the benefit of the US work for Canada.
Roughness and Pavement Serviceability

Road roughness is one of the most important components in a pavement management system (PMS) as it provides an indicator of pavement performance associated with driving comfort, vehicle operating costs and safety. The International Roughness Index (IRI) has become recognized as a general-purpose roughness measure that is strongly correlated to most kinds of vehicle response-type road roughness measuring systems. Specifically, IRI involves the simulation of a standard quarter car passing over a measured profile. The response of the vehicle is measured in m/km or mm/m. An IRI of 0.0 m/km means the profile is perfectly flat or smooth. There is no theoretical upper limit to roughness, although pavements with IRI values above about 8.0 m/km would be driven on at reduced speeds.

Roughness and Profile Data in the C-LTPP Database

A digital incremental profiler (Dipstick™) is used to collect longitudinal profile data in the inner and outer wheel paths at each test section. Presently there are two tables in the C-LTPP database for longitudinal profile data. The first contains pavement surface profile data of the wheel paths conducted in a continuous, closed loop fashion using the Dipstick™ at 300 mm foot spacing. The second contains the international roughness indices (IRI) calculated for each wheel path of individual sections. Although some variance may exist in the data since each province provides its own Dipstick™, proper calibration and closed-loop measurements should minimize this variability. As well, each section is measured in the fall so that variation due to weather conditions should be minimal. Seven years of profile data was available at the commencement of the project.

IRI values in the C-LTPP database are calculated in-house at C-SHRP using equations and relationships developed during the International Road Roughness Experiment funded by the World Bank. For verification purposes, a subset of IRI values were recalculated using RoadRuf software. Values of IRI calculated by C-SHRP and RoadRuf were extremely comparative, providing confidence in the C-LTPP database [1].

ROUGHNESS TRENDS

Effect of Overlay Construction

Prior to overlay construction in 1989/90, the existing longitudinal profile was measured at each site to observe the improvement in roughness provided by the rehabilitation. Figure 1 displays the average IRI values determined before and after overlay construction for each province. As shown, the reduction in IRI ranged between 0.43 m/km to 1.39 m/km. The greatest improvements were observed for sections with IRI values above 2 m/km prior to overlay construction.

![Figure 1: Improvement in Roughness Resulting from Overlay Construction](image)

Overall National and Provincial Trends

An investigation of the overall national range of roughness was conducted to provide a broad insight of roughness variation. As shown in Table 1, the average IRI directly after construction was 1.190 m/km and this value has risen to 1.494 m/km after 7 years. Table 1 also displays IRI values grouped by province and it appears that climate has a significant influence on roughness progression (IRI increase). All test sites in Quebec and two sites in Ontario are classified into Wet, High-Freeze zone; all test sites in the prairie provinces (Alberta, Manitoba and Saskatchewan) are defined as Dry, High-Freeze zones; the remaining sites are located in Wet, Low-Freeze zones.
Table 1: Changes in Average IRI for All Sites and By Province

<table>
<thead>
<tr>
<th>Location</th>
<th>Climatic Zone¹</th>
<th>IRI As-built in 1989/90</th>
<th>IRI in 1997</th>
<th>Δ IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1²</td>
<td>G3³</td>
<td>Mean</td>
<td>G1</td>
</tr>
<tr>
<td>All Sites</td>
<td>N/A</td>
<td>1.00</td>
<td>1.32</td>
<td>1.190</td>
</tr>
<tr>
<td>AB</td>
<td>III</td>
<td>1.148</td>
<td>1.281</td>
<td>1.220</td>
</tr>
<tr>
<td>BC</td>
<td>I</td>
<td>0.880</td>
<td>1.219</td>
<td>1.056</td>
</tr>
<tr>
<td>MB</td>
<td>III</td>
<td>1.092</td>
<td>1.347</td>
<td>1.246</td>
</tr>
<tr>
<td>NB</td>
<td>I</td>
<td>1.187</td>
<td>1.389</td>
<td>1.270</td>
</tr>
<tr>
<td>NF</td>
<td>I</td>
<td>0.930</td>
<td>1.531</td>
<td>1.231</td>
</tr>
<tr>
<td>NS</td>
<td>I</td>
<td>1.367</td>
<td>1.666</td>
<td>1.554</td>
</tr>
<tr>
<td>ON</td>
<td>I and II</td>
<td>0.827</td>
<td>1.045</td>
<td>0.978</td>
</tr>
<tr>
<td>PE</td>
<td>I</td>
<td>1.108</td>
<td>1.203</td>
<td>1.158</td>
</tr>
<tr>
<td>QC</td>
<td>II</td>
<td>1.109</td>
<td>1.254</td>
<td>1.181</td>
</tr>
<tr>
<td>SK</td>
<td>III</td>
<td>0.882</td>
<td>1.127</td>
<td>1.002</td>
</tr>
</tbody>
</table>

Notes: 1. Climate zone is classified into three categories: Wet, Low-Freeze Zone noted by I, Wet, High-Freeze Zone noted by II, and Dry, High-Freeze Zone noted by III.
2. The first quartile
3. The third quartile

A view of changes in average IRI with time for all provinces is shown in Figure 2. At first glance, there is a general overall progression of roughness with time. Sections in Alberta, Manitoba, Saskatchewan and Newfoundland have seen very little increase in average IRI over the seven years, while British Columbia, Ontario, Prince Edward Island and Nova Scotia show a definite roughness progression. No clear trends are evident in data from Quebec and New Brunswick at this point in time, however, it is important to note that these are aggregated values, which can mask the individual factors and provincial trends.

Climate Effects

The majority of the C-LTPP test sections fall into the wet and low freeze zones climate category. This includes all sections built in British Columbia, New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland and some of the sections in Ontario. Figure 3 presents the overall trends of roughness progression in the three climatic zones (all levels of overlay thickness, traffic level, subgrade type and overlay material combined) and reveals that a higher rate of roughness progression takes place in wet, low freeze zones. Roughness trends for pavements in high freeze zones are relatively flat, especially in dry, high freeze zones. Climatic effects as a function of pavement thickness were also examined. Within the same climatic zone, thick pavements appear less affected by climate than medium and thin pavements.

Overlay Thickness Effects

Figure 4 compares the thickness effects on roughness progression for the two levels of traffic, the two types of subgrade (fine and coarse), and the three types of climatic zones combined. It is clear that the thinner overlays are deteriorating at a significantly higher rate than the medium and thick overlays. Highest IRI's of about 1.8 m/km after 7 years occur for the lowest overlay thickness level of 30-60 mm for both high and low traffic, while the lowest IRI's after 7 years, about 1.35 m/km, occur for the highest overlay thickness level of 100-185 mm. However, the average IRI difference between the medium and high thickness overlays after 7 years is only 0.1
m/km. Continued observations should reveal when and/or if they will diverge in the future.

**Thin Overlays (30-60mm)**

Illustrated in Figure 5 are comparisons of roughness progression for the pavements with thin overlay in the three climatic zones for the high traffic level. It is apparent that the pavements with thin overlays deteriorate the fastest in the wet, low freeze zones. However, the thickness effect on roughness is substantially reduced in dry, high freeze zones. For pavements in wet and high freeze zones, roughness levels are intermediate between the other two zones.

**Medium Overlays (60-100mm)**

In comparison to the thin overlays, the average IRI increase for the medium overlay thickness was lower. Figure 6 shows the roughness progression for the medium overlay thickness (60-100 mm) in the three climate zones.
climatic zones for the high traffic level. Obviously, the largest changes in IRI over the seven years occurred in the in wet, low freeze zones, for a net increase in IRI of about 0.4 m/km. In both the dry and wet, high freeze zones there were only slight increases in IRI of about 0.1 m/km over the 7 years.

*Thick Overlays (100-185mm)*

Figure 7 shows the roughness trends for thick overlays (100-185 mm) in the three climatic zones for the high traffic level. It is apparent that roughness trends for thick overlays are relatively flat for all climatic zones.

Comparing Figures 5, 6 and 7, it can be seen that overlay thickness is significant in controlling roughness progression in all types of climatic zones. Nevertheless, pavements in low freeze zones are more likely to increase in IRI than those in high freeze zones. It may be concluded that if a pavement is built with extra thickness of asphalt concrete (overlay or total thickness of a pavement structure), then the thickness factor can become dominant in relation to the other factors involved in roughness progression. Of course, life cycle economic analysis should indicate what the optimum overlay thickness is for any given situation.

In summary, the combination of thin overlay with climatic condition of wet, low freeze zones has the highest rate of deterioration in comparison to all other combinations of factors.

*Traffic Effects*

At present, there are two level traffic levels included in the C-SHRP experimental design matrix. The boundary is 200,000 Equivalent Single Axle Load (ESAL) applications per year. Thus, low traffic is designated as a section with less than 200,000 ESALs per year while high traffic is greater than 200,000 ESALs per year. In order to examine whether traffic level had any effects on roughness trends, sixteen different scenarios of roughness progression, were considered. Based on the analysis and for the traffic levels selected in the experiment, there does not appear to be any significant traffic effect to date on roughness trends of overlays constructed in high-freeze zones, for both dry and wet areas. In the case of pavements in wet and low freeze zones, the traffic factor also did not seem have a significant effect on roughness trends. However, this does not mean that traffic has no effect on pavement deterioration. It simply means that the traffic level boundary selected did not enable detection of a traffic level effect.
Subgrade Effects

C-LTPP subgrade soils are classified into two categories: fine grained and coarse grained. The coarse grained subgrade soils include sands and gravels while the fine grained subgrade soils are mainly composed of silts and clays. It has long been known that pavement deterioration is influenced to a considerable extent by the type of subgrade soil on which it is built. Generally, pavements on fine-grained subgrade soils will deteriorate significantly faster than pavements on coarse-grained subgrade soils in terms of average IRI progression within the same period of time. This factor effect is significant when examining thin overlays.

Figure 8 shows the roughness trends for thin overlays (30-60 mm) in wet, low freeze zones. The effect of fine subgrade, for either level of traffic, is quite apparent. This might be expected because in this type of climatic zone with more moisture, more freeze-thaw cycles and a lower depth of frost penetration, a thin overlay on a fine subgrade should deteriorate more rapidly. However, the subgrade type factor effect becomes less significant or has little influence on roughness trends of the pavements constructed in dry or wet but high freeze zones. For thicker overlays, subgrade strength effects are reduced due to increased structural strength.

Overlay Materials Effects

Among the 65 C-LTPP sections, 10 were constructed with recycled asphalt pavement (RAP), or bottom lift(s) were paved with RAP and the top lift was paved with virgin hot mix asphalt concrete (HMAC). In addition, two sections in Quebec were overlaid with polymer modified HMAC, two sections in Nova Scotia were overlaid with HMAC and then treated with high friction chips on the surface, and one section in Ontario was overlaid with HMAC plus additives. Considering that overlay materials could affect roughness progression of a pavement, comparisons of roughness trends were made between the pavements with different paving materials but having the same thickness and climatic conditions.

At this time, it is clear that RAP overlays have performed similar to virgin HMAC overlays. It is difficult to identify any factor effect played by polymer modified HMAC overlays because the net IRI increase in seven years for each section in this test site is too small. However, overlays with HMAC plus high friction (HF) treated surface appear to have significant effects in controlling roughness progression as shown in Figure 9. This certainly warrants close observation in future years to determine whether the effect will continue.

![Figure 8: Roughness Trends for Thin Overlays in Wet, Low Freeze Zones](image-url)
Traffic effect on roughness progression was not significant in most cases. In order to obtain further insight on the traffic factor effect, at least three traffic levels (low, medium and high) should be defined. In other words, only two traffic levels (low and high with 200,000 ESALs per year being the boundary) in C-LTPP is too wide to conduct sensitivity analysis. As well, comparisons between design traffic levels and actual traffic levels for the various sites may provide more insight on the traffic effect on roughness progression.

The influence of overlay materials (polymer modified asphalt concrete and reclaimed asphalt pavement) and overlay construction (milling and milling depth) did not appear to influence roughness progression at this time. However, this may be explained by the limited comparative test sections and observations. The high friction treated surface did appear to control roughness during the first 7 years.

**MAJOR CONCLUSIONS**

While this study was not intended to produce performance models for design purposes, the roughness progression relationships developed can serve as checks or approximate verification of more complex or comprehensive overlay design models. The caveat, however, is that only seven years of data have been used and any extrapolation to lives beyond this may be subject to considerable error.

Overlay thickness and climatic conditions are two major factors that have a significant influence on roughness progression. Subgrade type is also a factor that can have substantial influence in certain circumstances. The worst situation (fastest increase in pavement roughness) would be the combined effect of thin overlay thickness, wet, low-freeze zone, fine-grained subgrade and high traffic volume. On the other hand, the combination of thick overlay, dry, high-freeze zone, and coarse-grained subgrade would minimize roughness progression.

**SUMMARY**

This technical brief summarizes the results of an initial analysis of C-LTPP test site roughness trends during the first seven years of service. Most of the trends observed are logical and definite, however, there are cases where definitive trends have yet to be defined. At this time, the worst performing test sections (in roughness progression) are those with thin overlay thickness, fine-grained subgrade and high traffic volume within wet, low-freeze zones. It is apparent that continued monitoring of all sites is crucial to provide additional data for long-term trends. Since road roughness is often used as a trigger for pavement rehabilitation, continued monitoring will also allow the development of pavement performance models to better predict the service life and cost effectiveness of asphalt pavement overlays – the fundamental goal of the Canadian Long Term Pavement Performance program.
References


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