**Design and Construction Guidelines for Thermally Insulated Concrete Pavements**

**TPF-5(149)**

**MnDOT Contract No. 89261**

**Task 2: TICP Life Cycle Cost Analysis**

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# introduction

A conceptual life cycle cost analysis (LCCA) sensitivity study was performed to evaluate the cost and structural reasonableness of thermally insulated concrete pavement (TICP) structures that are economically viable compared with jointed plain concrete pavement (JPCP).

Three cases were considered for this life cycle cost analysis of TICPs. The first two cases were based on California conditions. For these cases, the discount rate, LCCA periods, material costs, pavement designs, and maintenance and rehabilitation (M & R) practices were based on current Caltrans practices. Caltrans Case 1 involved reconstruction of truck lanes and maintenance of passenger lanes on an existing JPCP freeway. Caltrans Case 2 involved construction of two lanes on a new roadbed in order to convert a highway into a dual carriageway freeway. A spreadsheet was built so that, given an array of assumptions, the construction and maintenance costs of TICP could be considered relative to those of JPCP. Considered in this sensitivity analysis were the cost of HMA relative to the cost of PCC, traffic handling costs during construction, and different TICP designs. The layer types and thicknesses in the JPCPs and the underlying concrete layer in the TICP were based on the Caltrans Highway Design Manual. The third case, MN Case 3, considered construction of a new TICP on a major highway or Interstate. The pavement design was based on Minnesota climatic conditions and typical Minnesota Department of Transportation (MnDOT) design guidelines.

Within each case study, three measures were evaluated for reasonableness:

* PCC thickness requirement: the thickness of the portland cement concrete (PCC) in the TICP pavement that resulted in same net present value (NPV) for the TICP as for the JPCP. These thicknesses were compared with assumed plausible minimum thicknesses necessary to provide required service lives.
* TICP PCC cost reduction requirement: if the TICP and JPCP PCC thicknesses remained equal, the reduction in cost of the TICP PCC as a percentage of the cost of JPCP PCC that resulted in the same NPV for TICP and JPCP.
* Life extension: the increase of PCC life in the TICP pavement beyond the normal PCC service life caused by including a hot-mix asphalt (HMA) overlay from initial construction. The HMA overlay would be expected to reduce temperature gradients in the PCC, therefore reducing stresses and increasing the cracking life of the PCC. The PCC thickness in the TICP pavement was the normal PCC thickness for JPCP. The maximum reasonable life extension was assumed to be 70 percent.

It must be emphasized that the performance assumptions of TICPs are unverified. This was a conceptual study that intended to evaluate the plausibility of TICP PCC thickness reductions relative to JPCPs, TICP PCC cost reductions relative to JPCP PCC costs, and life extensions of PCC in TICPs that were economically competitive with JPCPs. The performance estimates may or may not be reasonable, which will need to be determined from later structural analyses.

# background information for caltrans case studies

A LCCA was considered for both TICPs and JPCPs in the context of the following two case studies:

* Case 1: Lane replacement of truck lanes in Southern California as TICP instead of JPCP. This project was based on the scope of a real project on I-15 near Devore (District 8).
* Case 2: Convert multi-lane highway in Northern California into divided highway by adding new direction with TICP instead of JPCP. This project was roughly based on the scope of a real project on State Route 70 near East Nicholas (District 3).

Two basic TICP designs were considered to represent different initial design lives. Design 1 was composed of a thicker concrete slab and a thicker asphalt overlay. Design 2 was composed of a thinner slab and thinner asphalt overlay. Based on the Caltrans LCCA Manual and Highway Design Manual, Design 1 was intended to provide 50 years of service until the first major intervention is required and is referred to as having a 40-year design life. Design 2 was intended to provide 30 years of service until the first major intervention is required and is referred to having a 20-year design life. Both conventional hot mix asphalt (HMA) and rubberized hot mix asphalt (RHMA) were considered as the top layer for the TICPs.

## Cost Data

All cost data for the initial construction were taken from the 2009 Caltrans Construction Cost Data Book, for the appropriate district, using data for similar size projects. The JPCP designs and the PCC and base thicknesses underlying the TICPs came from the current Caltrans Highway Design Manual. The annual maintenance costs, design lives, analysis periods, and future maintenance and rehabilitation treatments and costs were taken from the current version of the Caltrans Life Cycle Cost Analysis Manual for the appropriate climate region and design life for JPCP and Composite pavement types. The discount rate used was four percent, as required by the Caltrans Life Cycle Cost Analysis Manual. Traffic control costs for future annual maintenance, maintenance, and rehabilitation were assumed to be included in the costs used from the Caltrans LCCA Manual. Only costs for the mainline were considered, no shoulder costs were considered because it was assumed that shoulder reconstruction and maintenance would be similar for all alternatives. The following cost data apply to both Caltrans case studies:

### Asphalt and PCC Costs

Two scenarios were considered regarding the prices of asphalt and PCC for the LCCAs. The first, referred to as the 1:1 case, assumed that the HMA, RHMA, and PCC costs were those typical of these materials in California in 2009. The second scenario, referred to as the 0.8:1 case, assumed that HMA costs were 80 percent of the 2009 cost. The following values were used as the cost basis for HMA, RHMA, and PCC:

HMA overlays and HMA base:

* $80/tonne = $192/m3 for 1:1 case
* $154/m3 for 0.8:1 case

RHMA overlays:

* $100/tonne = $240/m3 for 1:1 case
* $192/m3 for 0.8:1 case

PCC: $190/m3

For the life extension cases where the PCC layer has equal thickness in both the new JPCP and TICP pavements, the cost of the PCC was assumed to be the same. This may be a conservative assumption because one of the benefits of TICP is that the PCC layer is not exposed to the extreme environmental stresses or tire wear that a typical JPCP surface must be durable against. This implies that it would be possible to decrease the cost of composite pavements by either decreasing the thickness of the PCC layer or by decreasing the cost of the cement or aggregates in the PCC layer. A reduction in cost of the TICP PCC layer could be accomplished by increasing the percentage of supplementary cementitious materials in the total cementitious volume, by substituting recycled concrete aggregates for conventional coarse aggregates, or by allowing a higher percentage of fine, soft, spall, or slate in the coarse aggregate.

### Traffic Control Costs

For second reconstructions only, two traffic control costs of 15% and 50% of the total pavement construction costs were considered, based on analyses of similar long-life pavement rehabilitation projects completed by the University of California Pavement Research Center (UCPRC), as follows:

* I-15 Devore, continuous closure, intermediate between rural and urban: 16%
* I-710 Long Beach, 55 hour weekends, urban: 63%
* I-80 Truckee, continuous closure, rural: 7%
* I-10 Pomona, 55 hour weekend and nighttime, urban: 12%

### Mobilization Costs

A mobilization cost of $400,000 was applied to the initial construction and to future reconstructions. Mobilization was assumed to be included in the costs for future annual maintenance, maintenance, and rehabilitation taken from the Caltrans LCCA Manual for those activities.

# caltrans CASE 1: RECONSTRUCTION OF TRUCK LANES ON I-15

## History

Caltrans Case 1 involved the lane replacement of truck lanes and rehabilitation or maintenance of the passenger lanes in an existing freeway. The existing JPCP pavement was approximately 40 years old and consisted of 230 mm (9 in) of non-doweled concrete slabs over 100 to 150 mm (2 in to 6 in) of cement-treated base on aggregate base.

## Project Scope

The total reconstruction project length was 4.5 km with 2 km with 3 lanes and 2.5 km with 4 lanes in each direction. Truck lanes consisted of 4-4.5 km lanes totaling 18 lane-km (11.2 lane-miles) and passenger car lanes consisted of 2-2 km lanes and 4-2.5 km lanes totaling 14 lane-km (8.7 lane-miles). It was assumed that the existing JPCP in the passenger car lanes never needed reconstruction, only normal maintenance for concrete (JPCP) or asphalt (TICP) surfaces, in perpetuity. In the passenger car lanes, it was assumed that a maintenance treatment other than annual maintenance was needed every 20 years for up to 100 years for PCC surfaces and then every 15 years, and every 15 years for HMA surfaces following the initial service life (50 or 30 years). The high annual maintenance cost of the TICP pavement reflects periodic asphalt resurfacing during the initial service life without explicitly identifying when these will occur.

The existing grade was maintained across all lanes for the JPCP designs. For the TICP designs, the new PCC surface in the truck lanes matched the grade of the existing JPCP in the passenger lanes, and all lanes were overlaid with the same thickness of HMA or RHMA. In the truck lanes, the existing pavement was excavated to the depth required for the new base and PCC layers, and the top of the remaining existing aggregate base layer was recompacted. The base was assumed to be HMA. The subgrade was assumed to be Type II soil (lean clay). Costs of constructing the base were the same for JPCP and TICP because the thicknesses were assumed equal for this case, although this assumption might not be true for all JPCP and TICP comparisons.

The passenger car lanes were 3.6 m (12 ft) wide and the truck lanes were 4.2 m (14 ft) wide. Caltrans designs assume joint spacings of 3.6, 3.9, 4.2, 4.5 m (12, 13, 14, 15 ft), with 11 dowels per joint for 3.6 m lanes and 13 dowels for 4.2 m lanes. Dowel costs were included in the PCC cost. The 40-year design ESALs were 55 million, and the traffic index was 14.5. The 20-year design ESALs were 22 million, and the traffic index was 13.

### JPCP Design

The JPCP design per Table 623.1G of the Highway Design Manual for doweled JPCP with a nominal 40-year design life was the following:

* 300 mm (12 in) PCC
* 150 mm (6 in) HMA base

The maintenance and rehabilitation schedule was assumed as shown in Table 1.

### TICP Design 1

The pavement design per Table 623.1G of the Highway Design Manual for doweled JPCP with a nominal 40-year design life was:

* 300 mm (12 in) PCC (PCC thickness was solved for in TICP PCC thickness analysis cases)
* 150 mm (6 in) HMA base

The following two asphalt overlays were considered:

* 105 mm (4 in) HMA
* 75 mm (3 in) RHMA

The maintenance and rehabilitation schedule was assumed as shown in Table 2.

### TICP Design 2

The pavement design per Table 623.1G of the Highway Design Manual for doweled JPCP with a nominal 20-year design life was:

* 255 mm (10 in) PCC (PCC thickness is solved for in thickness changes cases)
* 150 mm (6 in) HMA base

The following four asphalt overlays were considered:

* 30 mm (1.2 in) HMA
* 45 mm (1.8 in) HMA
* 30 mm (1.2 in) RHMA
* 45 mm (1.8 in) RHMA

The maintenance and rehabilitation schedule was assumed as shown in Table 3.

Table 1a Caltrans Case 1 JPCP truck lane maintenance and rehabilitation schedule

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Annual Maintenance Cost/ln-mi** |
| Initial JPCP | 0 | Calculated elsewhere | 45 | $800 |
| CPR-C | 45 | $89,000 | 5 | $3000 |
| CPR-B | 50 | $106,000 | 10 | $1500 |
| Reconstruct JPCP \*\* | 60 | Same as Year 0 | 45 | $800 |

Table 1b Caltrans Case 1 JPCP passenger lane maintenance and rehabilitation schedule

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Annual Maintenance Cost/ln-mi** |
| CPR-C | 0 | $89,000 | 20 | $3000 |
| CPR-C | 20 | $89,000 | 20 | $3000 |
| CPR-C | 40 | $89,000 | 15\* or 20\*\* | $3000 |
| CPR-B\*\* | 60 | $106,000 | 15 | $1500 |

\* for 55 year analysis period for TICP PCC thickness analyses
\*\* for 75 year analysis period for life extension analyses

Notes:
1. Concrete Pavement Rehabilitation B involves pavement grinding, moderate slab replacement, spall repair, & joint seal repair. It is for JPCP projects with a total number of slabs in the lane that were replaced or exhibit third stage rigid cracking between 2 and 5%.
2. Concrete Pavement Rehabilitation C involves pavement grinding, minor slab replacement, spall repair, & joint seal repair. It is for JPCP projects with a total number of slabs in the lane that were replaced or exhibit third stage rigid cracking of 2% or less.

Table 2 Caltrans Case 1 TICP Design 1 maintenance and rehabilitation schedule

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Lanes** | **Annual Maintenance Cost/ln-mi** |
| Initial TICP | 0 | Calculated | 50 + LE\* | Reconstruct PCC/base in truck lanes (18 ln-km) and overlay all lanes (32 ln-km) | $4800\*\*  |
| FO+JPCP SR | 50 + LE\* | $91,000 | 8 | Truck lanes (18 ln-km) | $700 |
| 75 mm Overlay | 50 + LE\* | Calculated | 15 | Passenger lanes (14 ln-km) | $4800 |
| FO+JPCP SR | 50 + LE\* + 8 | $91,000 | 7 | Truck lanes (18 ln-km) | $700 |
| Repeat TICP | 50 + LE\* + 15 | Same as initial TICP | 50 + LE\* | Truck lanes (18 ln-km) | $700 |
| 75 mm Overlay | 50 + LE\* + 15 | Calculated | 15 | Passenger lanes (14 ln-km) | $4800 |

\* Life Extension (LE) additional years solved for in life extension analyses, equal to zero in TICP PCC thickness analyses.

\*\* Annual maintenance cost for TICP and other longer life overlays includes the cost of patching and other maintenance towards the end of life of the overlay, and includes the cost of periodic replacement of the overlay for the very long design lives of the TICP overlays. This value comes from the Caltrans LCCA Manual.

Table 3 Caltrans Case 1 TICP Design 2 maintenance and rehabilitation schedule

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Lanes** | **Annual Maintenance Cost/ln-mi** |
| Initial TICP | 0 | Calculated | 30 + LE\* | Reconstruct PCC/base in truck lanes (18 ln-km) and overlay all lanes (32 ln-km) | $4800\*\*\* |
| FO+JPCP SR | 30 + LE\* | $91,000 | 8 | Truck lanes (18 ln-km) | $700 |
| 30 or 45 mm Overlay\*\* | 30 + LE\* | Calculated | 15 | Passenger lanes (14 ln-km) | $4800 |
| FO+JPCP SR | 30 + LE\* + 8 | $91,000 | 7 | Truck lanes (18 ln-km) | $700 |
| Repeat TICP | 30 + LE\* + 15 | Same as initial TICP | 30 + LE\* | Truck lanes (18 ln-km) | $700 |
| 30 or 45 mm Overlay\*\* | 30 + LE\* + 15 | Calculated | 15 | Passenger lanes (14 ln-km) | $4800 |
| 30 or 45 mm Overlay\*\* | 30 + LE\* + 15 + 15 | Calculated | 15 | Passenger lanes (14 ln-km) | $4800 |

\* Life Extension (LE) additional years solved for in life extension analyses, equal to zero in TICP PCC thickness analyses.
\*\* Overlay thickness same as original TICP overlay thickness

\*\*\* Annual maintenance cost for TICP and other longer life overlays includes the cost of patching and other maintenance towards the end of life of the overlay, and includes the cost of periodic replacement of the overlay for the very long design lives of the TICP overlays. This value comes from the Caltrans LCCA Manual.

## Caltrans Case 1 Results

### TICP PCC Thickness Analyses

The results of the analyses of the thickness requirement for the TICPs PCC are shown for 1:1 cost scenarios in Table 4 and for 0.8:1 cost scenarios in Table 5. The tables show the TICP PCC thicknesses that make the NPV of the TICP pavements equal to the NPV of the JPCP pavement. It can be observed that the Design 2 TICPs resulted in a thicker allowable PCC layer than the Design 1 TICPs. This is because the lower initial cost of constructing Design 2 TICP more than compensates for the later cost of reconstructing the truck lanes a second time with the Caltrans official discount rate of four percent.

Assuming that an absolute minimum possible thickness for the PCC in the TICP pavements is 175 mm (7 in), it can be seen that most of the Design 2 TICPs are potentially viable when the costs are at 2009 levels for both HMA and PCC. If the cost of HMA drops to 80% of its 2009 cost with no change in the cost of PCC, then the results indicate that there is a significant improvement in the allowable PCC thicknesses in the TICPs.

Assuming that 70% is the minimum cost of TICP PCC relative to JPCP PCC, half of the TICPs have equal NPV to the JPCPs with 1:1 cost scenarios and two thirds of the TICPs have equal NPV to the JPCPs with 0.8:1 cost scenarios. An equal NPV between TICP and JPCP is more likely achieved with a thinner asphalt overlay and with an HMA rather than an RHMA overlay.

Table 4 Caltrans Case 1: Change of PCC thickness in TICP pavement for same NPV as JPCP with 1:1 costs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **Max TICP PCC thickness for equal NPV (mm)** | **Cost of TICP PCC relative to JPCP PCC for equal NPV and PCC thickness in JPCP and TICP** |
| 15 | HMA 105 | 1 | 136 | 45% |
| 15 | RHMA 75 | 1 | 153 | 51% |
| 15 | HMA 30 | 2 | 207 | 81% |
| 15 | HMA 45 | 2 | 180 | 71% |
| 15 | RHMA 30 | 2 | 193 | 76% |
| 15 | RHMA 45 | 2 | 160 | 63% |
| 50 | HMA 105 | 1 | 141 | 47% |
| 50 | RHMA 75 | 1 | 159 | 53% |
| 50 | HMA 30 | 2 | 218 | 85% |
| 50 | HMA 45 | 2 | 192 | 75% |
| 50 | RHMA 30 | 2 | 205 | 80% |
| 50 | RHMA 45 | 2 | 173 | 68% |

Table 5 Caltrans Case 1: Change of PCC thickness in TICP pavement for same NPV as JPCP with 0.8:1 costs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **Max TICP PCC thickness for equal NPV (mm)** | **Cost of TICP PCC relative to JPCP PCC for equal NPV and PCC thickness in JPCP and TICP** |
| 15 | HMA 105 | 1 | 171 | 57% |
| 15 | RHMA 75 | 1 | 185 | 62% |
| 15 | HMA 30 | 2 | 217 | 85% |
| 15 | HMA 45 | 2 | 196 | 77% |
| 15 | RHMA 30 | 2 | 207 | 81% |
| 15 | RHMA 45 | 2 | 180 | 71% |
| 50 | HMA 105 | 1 | 175 | 58% |
| 50 | RHMA 75 | 1 | 190 | 63% |
| 50 | HMA 30 | 2 | 229 | 90% |
| 50 | HMA 45 | 2 | 208 | 82% |
| 50 | RHMA 30 | 2 | 218 | 85% |
| 50 | RHMA 45 | 2 | 192 | 75% |

### Life Extension Analyses

The results of the life extension analyses are shown for the 1:1 cost ratios between HMA and PCC in Table 6 and for the 0.8:1 cost ratios between HMA and PCC in Table 7. The results indicate that except for thin overlays on Design 2 TICPs, a more than 70% increase in the life of the PCC layer in the TICP must be achieved to be economically competitive with JPCP. This is because the initial cost of constructing a full scale PCC pavement with the additional overlay is not compensated for sufficiently in later years by the reduced maintenance and rehabilitation costs, with this discount rate. The results do not change significantly by reducing the HMA costs to 80% of 2009 values while holding PCC costs at 2009 values because most of the initial cost of the TICP is in the PCC layer.

Table 6 Caltrans Case 1: Change of PCC life in TICP pavement for same NPV as JPCP with 1:1 costs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **JPCP PCC thickness (mm)** | **TICP PCC thickness (mm)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **TICP % PCC life change for same NPV** |
| 15 | 300 | 300 | HMA 105 | 1 | >70% |
| 15 | 300 | 300 | RHMA 75 | 1 | >70% |
| 15 | 300 | 255 | HMA 30 | 2 | 37% |
| 15 | 300 | 255 | HMA 45 | 2 | 70% |
| 15 | 300 | 255 | RHMA 30 | 2 | 54% |
| 15 | 300 | 255 | RHMA 45 | 2 | >70% |
| 50 | 300 | 300 | HMA 105 | 1 | >70% |
| 50 | 300 | 300 | RHMA 75 | 1 | >70% |
| 50 | 300 | 255 | HMA 30 | 2 | 27% |
| 50 | 300 | 255 | HMA 45 | 2 | 64% |
| 50 | 300 | 255 | RHMA 30 | 2 | 44% |
| 50 | 300 | 255 | RHMA 45 | 2 | >70% |

Table 7 Caltrans Case 1: Change of PCC life in TICP pavement for same NPV as JPCP with 0.8:1 costs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **JPCP PCC thickness (mm)** | **TICP PCC thickness (mm)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **TICP % PCC life change for same NPV** |
| 15 | 300 | 300 | HMA 105 | 1 | >70% |
| 15 | 300 | 300 | RHMA 75 | 1 | >70% |
| 15 | 300 | 255 | HMA 30 | 2 | 24% |
| 15 | 300 | 255 | HMA 45 | 2 | 54% |
| 15 | 300 | 255 | RHMA 30 | 2 | 37% |
| 15 | 300 | 255 | RHMA 45 | 2 | >70% |
| 50 | 300 | 300 | HMA 105 | 1 | >70% |
| 50 | 300 | 300 | RHMA 75 | 1 | >70% |
| 50 | 300 | 255 | HMA 30 | 2 | 17% |
| 50 | 300 | 255 | HMA 45 | 2 | 44% |
| 50 | 300 | 255 | RHMA 30 | 2 | 30% |
| 50 | 300 | 255 | RHMA 45 | 2 | 67% |

# CALTRANS CASE 2: CONSTRUCTION OF NEW pavement lanes ON STATE ROUTE 70

## Project Scope

This case involved the construction of two new pavement lanes on virgin ground creating a dual carriageway where a two lane highway existed. The total project length was 10 km (6.2 miles). Truck lanes totaled 10 lane-km (6.2 lane-miles) and passenger car lanes totaled 10 lane-km (6.2 lane-miles). It was assumed that once the new JPCP was constructed, the passenger car lanes would never need reconstruction, only normal maintenance for concrete surfaces, in perpetuity. Similarly, it was assumed that the passenger car lanes for the TICP would only require normal maintenance for asphalt surfaces, in perpetuity. In the passenger car lanes, it was assumed that a maintenance treatment other than annual maintenance was needed every 20 years for up to 100 years for PCC surfaces, and every 15 years for HMA following the initial service life (50 or 30 years). The high annual maintenance cost of the TICP pavement reflects periodic resurfacing during the initial service life without explicitly identifying when these would occur during that initial period.

The subgrade is assumed to be Type II soil (lean clay). Site preparation costs were ignored for Case 2 as the cost were similar for both JPCPs and TICPs.

The passenger car lanes were 3.6 m (12 ft) wide and the truck lanes were 4.2 m (14 ft) wide. Caltrans designs assume joint spacings of 3.6, 3.9, 4.2, 4.5 m (12, 13, 14, 15 ft), with 11 dowels per joint for 3.6 m lanes and 13 dowels for 4.2 m lanes. Dowel costs were included in the PCC cost. The 40-year design ESALs were 55 million, and the traffic index was 14.5. The 20-year design ESALs were 22 million, and the traffic index was 13.

### JPCP Design

The pavement design per Table 623.1G of the Highway Design Manual for doweled JPCP with a nominal 40-year design life was the following:

* 255 mm (10 in) PCC
* 150 mm (6 in) lean concrete base (LCB)
* 210 mm (8.5 in) aggregate subbase (ASB)

The maintenance and rehabilitation schedule was assumed as shown in Table 8.

### TICP Design 1

The pavement design per Table 623.1G of the Highway Design Manual for doweled JPCP with a nominal 40-year design life was the following:

* 255 mm PCC (10 in) (PCC thickness is solved for in thickness changes cases)
* 150 mm (6 in) LCB
* 210 mm (8.4 in) ASB

The following two asphalt overlays were considered:

* 105 mm (4 in) HMA
* 75 mm (3 in) RHMA

The maintenance and rehabilitation schedule were assumed as shown in Table 9.

### TICP Design 2

The pavement design per Table 623.1G of the Highway Design Manual for doweled JPCP with a nominal 20-year design life were the following:

* 225 mm (9 in) PCC (PCC thickness is solved for in TICP PCC thickness analyses)
* 120 mm (4.7 in) LCB (assumed to be 150 mm (6.0 in) for cost calculations)
* 180 mm (7 in) ASB (assumed to be 210 mm (8.3 in) for cost calculations)

The following four asphalt overlays were considered:

* 30 mm (1.2 in) HMA
* 45 mm (1.8 in) HMA
* 30 mm (1.2 in) RHMA
* 45 mm (1.8 in) RHMA

The maintenance and rehabilitation schedule were assumed as shown in Table 10.

Table 8a Caltrans Case 2 JPCP truck lane maintenance and rehabilitation schedule

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Annual Maintenance Cost/ln-mi** |
| Initial JPCP | 0 | Calculated elsewhere | 45 | $800 |
| CPR-C | 45 | $89,000 | 5 | $3000 |
| CPR-B | 50 | $106,000 | 10 | $1500 |
| Reconstruct JPCP \* | 60 | Same as Year 0 | 45 | $800 |

Table 8b Caltrans Case 2 JPCP passenger lane maintenance and rehabilitation schedule

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Annual Maintenance Cost/ln-mi** |
| Initial JPCP | 0 | Calculated elsewhere | 45 | $800 |
| CPR-C | 45 | $89,000 | 20 | $3000 |
| CPR-C \* | 65 | $89,000 | 20 | $3000 |

\* for 75 year analysis period for life extension analyses

Notes:
1. Concrete Pavement Rehabilitation B involves pavement grinding, moderate slab replacement, spall repair, & joint seal repair. It is for JPCP projects with a total number of slabs in the lane that were replaced or exhibit third stage rigid cracking between 2% and 5%.
2. Concrete Pavement Rehabilitation C involves pavement grinding, minor slab replacement, spall repair, & joint seal repair. It is for JPCP projects with a total number of slabs in the lane that were replaced or exhibit third stage rigid cracking of 2% or less.

Table 9 Caltrans Case 2 TICP Design 1 maintenance and rehabilitation schedule

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Lanes** | **Annual Maintenance Cost/ln-mi** |
| Initial TICP | 0 | Calculated | 50 + LE\* | Construct TICP pavement in all lanes (20 ln-km) | $4800\*\* |
| FO+JPCP SR | 50 + LE\* | $91,000 | 8 | Truck lanes (10 ln-km) | $700 |
| 75 mm Overlay | 50 + LE\* | Calculated | 15 | Passenger lanes (104 ln-km) | $4800 |
| FO+JPCP SR | 50 + LE\* + 8 | $91,000 | 7 | Truck lanes (10 ln-km) | $700 |
| Repeat TICP | 50 + LE\* + 15 | Same as initial TICP | 50 + LE\* | Truck lanes (10 ln-km) | $700 |
| 75 mm Overlay | 50 + LE\* + 15 | Calculated | 15 | Passenger lanes (10 ln-km) | $4800 |

\* Life Extension (LE) additional years solved for in life extension analyses, equal to zero in TICP PCC thickness analyses.

\*\* Annual maintenance cost for TICP and other longer life overlays includes the cost of patching and other maintenance towards the end of life of the overlay, and includes the cost of periodic replacement of the overlay for the very long design lives of the TICP overlays. This value comes from the Caltrans LCCA Manual.

Table 10 Caltrans Case 2 TICP Design 2 maintenance and rehabilitation schedule

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Item** | **Year** | **Cost/ln-mi** | **Design Life** | **Lanes** | **Annual Maintenance Cost/ln-mi** |
| Initial TICP | 0 | Calculated | 30 + LE\* | Construct TICP pavement in all lanes (20 ln-km) | $4800\*\*\* |
| FO+JPCP SR | 30 + LE\* | $91,000 | 8 | Truck lanes (10 ln-km) | $700 |
| 30 or 45 mm Overlay\*\* | 30 + LE\* | Calculated | 15 | Passenger lanes (10 ln-km) | $4800 |
| FO+JPCP SR | 30 + LE\* + 8 | $91,000 | 7 | Truck lanes (10 ln-km) | $700 |
| Repeat TICP | 30 + LE\* + 15 | Same as initial TICP | 30 + LE\* | Truck lanes (10 ln-km) | $700 |
| 30 or 45 mm Overlay\*\* | 30 + LE\* + 15 | Calculated | 15 | Passenger lanes (10 ln-km) | $4800 |
| 30 or 45 mm Overlay\*\* | 30 + LE\* + 15 + 15 | Calculated | 15 | Passenger lanes (10 ln-km) | $4800 |

\* Life Extension (LE) additional years solved for in life extension analyses, equal to zero in TICP PCC thickness analyses.
\*\* Overlay thickness same as original TICP overlay thickness

\*\*\* Annual maintenance cost for TICP and other longer life overlays includes the cost of patching and other maintenance towards the end of life of the overlay, and includes the cost of periodic replacement of the overlay for the very long design lives of the TICP overlays. This value comes from the Caltrans LCCA Manual.

## Caltrans Case 2 Results

### TICP PCC Thickness Analyses

The results of the thickness change analyses for the 1:1 cost scenario are shown in Table 11 and for the 0.8:1 cost scenario in Table 12. The results show that Design 2 TICP resulted in a thicker allowable PCC thickness in the TICPs than the Design 1 TICP. This is because the lower initial cost of constructing Design 2 TICPs more than compensated for the later cost of reconstructing the truck lanes a second time with the Caltrans official discount rate of four percent.

Assuming that an absolute minimum thickness for the PCC in the TICPs was 125 mm (5 in), it can be seen that most of the Design 2 scenarios were potentially viable when the HMA and PCC costs were at 2009 levels. If the cost of the HMA droped to 80% of its 2009 costs and the PCC costs remained the same, then the results indicated that there could be a significant improvement in the allowable TICP PCC thicknesses. The Design 1 TICP PCC thicknesses were generally below a reasonable minimum thickness for the PCC layer.

Assuming that 70% is the minimum cost of TICP PCC relative to JPCP PCC, none of the TICPs had equal NPV to the JPCPs with 1:1 cost scenarios, and none of the TICPs had equal NPV to the JPCPs with 0.8:1 cost scenarios.

Table 11 Caltrans Case 2 Change of PCC thickness in TICP pavement for same NPV as JPCP with 1:1 costs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **Min. TICP PCC thickness for equal NPV (mm)** | **Cost of TICP PCC relative to JPCP PCC for equal NPV and PCC thickness in JPCP and TICP** |
| 15 | HMA 105 | 1 | 91 | 36% |
| 15 | RHMA 75 | 1 | 103 | 40% |
| 15 | HMA 30 | 2 | 144 | 56% |
| 15 | HMA 45 | 2 | 126 | 49% |
| 15 | RHMA 30 | 2 | 135 | 53% |
| 15 | RHMA 45 | 2 | 113 | 44% |
| 50 | HMA 105 | 1 | 111 | 44% |
| 50 | RHMA 75 | 1 | 123 | 48% |
| 50 | HMA 30 | 2 | 166 | 65% |
| 50 | HMA 45 | 2 | 149 | 58% |
| 50 | RHMA 30 | 2 | 158 | 62% |
| 50 | RHMA 45 | 2 | 136 | 53% |

Table 12 Caltrans Case 2 Change of PCC thickness in TICP pavement for same NPV as JPCP with 0.8:1 costs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **Min. TICP PCC thickness for equal NPV (mm)** | **Cost of TICP PCC relative to JPCP PCC for equal NPV and PCC thickness in JPCP and TICP** |
| 15 | HMA 105 | 1 | 113 | 44% |
| 15 | RHMA 75 | 1 | 122 | 48% |
| 15 | HMA 30 | 2 | 151 | 59% |
| 15 | HMA 45 | 2 | 137 | 54% |
| 15 | RHMA 30 | 2 | 144 | 56% |
| 15 | RHMA 45 | 2 | 126 | 49% |
| 50 | HMA 105 | 1 | 133 | 52% |
| 50 | RHMA 75 | 1 | 142 | 56% |
| 50 | HMA 30 | 2 | 173 | 68% |
| 50 | HMA 45 | 2 | 159 | 62% |
| 50 | RHMA 30 | 2 | 166 | 65% |
| 50 | RHMA 45 | 2 | 149 | 58% |

### Life Extension Analyses

The results of the life extension analyses are shown for the 1:1 cost scenarios in Table 13 and for the 0.8:1 cost scenarios in Table 14. The results indicate that life extension, even up to 70%, for the TICP PCC layer did not result in them being economically competitive. This is because, with the assumed discount rate, the initial cost of constructing equal amounts of PCC in both the JPCP and TICP pavements overwhelmed any future maintenance and rehabilitation savings. The primary difference between Case 1 and Case 2 in this regard was that in Case 1, the passenger lanes made use of existing JPCP lanes which were simply overlaid and did not include the cost of constructing new PCC layers for the TICP in the passenger lanes.

Table 13 Caltrans Case 2 Change of PCC life in TICP pavement for same NPV as JPCP with 1:1 costs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **JPCP PCC thickness (mm)** | **TICP PCC thickness (mm)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **TICP % PCC life change for same NPV** |
| 15 | 255 | 255 | HMA 105 | 1 | >70% |
| 15 | 255 | 255 | RHMA 75 | 1 | >70% |
| 15 | 255 | 225 | HMA 30 | 2 | >70% |
| 15 | 255 | 225 | HMA 45 | 2 | >70% |
| 15 | 255 | 225 | RHMA 30 | 2 | >70% |
| 15 | 255 | 225 | RHMA 45 | 2 | >70% |
| 50 | 255 | 255 | HMA 105 | 1 | >70% |
| 50 | 255 | 255 | RHMA 75 | 1 | >70% |
| 50 | 255 | 225 | HMA 30 | 2 | >70% |
| 50 | 255 | 225 | HMA 45 | 2 | >70% |
| 50 | 255 | 225 | RHMA 30 | 2 | >70% |
| 50 | 255 | 225 | RHMA 45 | 2 | >70% |

Table 14 Caltrans Case 2 Change of PCC life in TICP pavement for same NPV as JPCP with 0.8:1 costs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Traffic Handling Cost on M&R (% pave cost)** | **JPCP PCC thickness (mm)** | **TICP PCC thickness (mm)** | **HMA/RHMA type, thickness (mm)** | **TICP Design No.** | **TICP % PCC life change for same NPV** |
| 15 | 255 | 255 | HMA 105 | 1 | >70% |
| 15 | 255 | 255 | RHMA 75 | 1 | >70% |
| 15 | 255 | 225 | HMA 30 | 2 | >70% |
| 15 | 255 | 225 | HMA 45 | 2 | >70% |
| 15 | 255 | 225 | RHMA 30 | 2 | >70% |
| 15 | 255 | 225 | RHMA 45 | 2 | >70% |
| 50 | 255 | 255 | HMA 105 | 1 | >70% |
| 50 | 255 | 255 | RHMA 75 | 1 | >70% |
| 50 | 255 | 225 | HMA 30 | 2 | >70% |
| 50 | 255 | 225 | HMA 45 | 2 | >70% |
| 50 | 255 | 225 | RHMA 30 | 2 | >70% |
| 50 | 255 | 225 | RHMA 45 | 2 | >70% |

# minnesota CASE 3: CONSTRUCTION OF TWO LANES ON A MAJOR HIGHWAY OR INTERSTATE

## Background, Assumptions, and Scope

This LCCA focused on construction, maintenance, and rehabilitation costs of TICPs and JPCPs. Similar to the Caltrans case studies, this LCCA was completed with a NPV calculation that considered life cycle costs that were unique to each pavement type and disregarded costs that were common across all pavement types. The following inputs, typical of Minnesota, were considered for this LCCA, which compared the economic viability of TICP and JPCP:

* Analysis period (total years of pavement life with typical maintenance and rehabilitation (M & R) schedules)
* Discount rate
* Pavement lane-miles
* Pavement lane width
* JPCP concrete thickness
* TICP concrete thickness
* TICP asphalt thickness
* Mobilization charges that reflect the difference in mobilizing equipment for composite pavement construction
* M & R schedules for the average rigid and asphalt pavements
* Unit cost of concrete
* Unit cost of asphalt

The following items were not considered for this LCCA:

* Removal of existing pavement
* Subgrade and base preparation
* Shoulder construction, including preparation and materials
* Dowel bars
* Jointing
* Concrete or asphalt placement costs
* Engineering costs

Additionally, items that could vary depending on the length of time for pavement construction and/or location of construction (urban vs. rural) were not considered in the LCCA:

* Traffic handling
* User costs

Finally, costs of annual maintenance performed on the pavements between minor and major rehabilitation projects were not considered.

The assumptions for the LCCA inputs were based on values provided by the Minnesota Department of Transportation (MnDOT) and information collected from construction of a test section of TICP at the Minnesota Road Research Center (Mn/ROAD) in May of 2010. The inputs for the LCCA are shown below, and each is followed by an explanation or reference. Four of the inputs were varied to show their impacts on total NPV, and these were discount rate, cost of concrete, cost of asphalt, and cost of concrete in TICP relative to the cost of concrete in JPCP.

* Analysis period = 50 years (typical LCCA period for MnDOT projects)
* Discount Rates = 2.8 and 5.0 (Survey of Caltrans, MnDOT, and Washington State Department of Transportation indicated discount rates of 4.0 and 2.8 for a given year. 5.0 was assumed to be a maximum discount rate and 2.8 was considered to be a minimum discount rate.)
* Design lane length = 6.2 mi (10 km) (Similar to the lane length in Case 2 by Caltrans)
* Truck lane width = 13.5 ft (4.1 m) (MnDOT standard truck lane width)
* Passenger lane width = 12 ft (3.6 m) (MnDOT standard passenger lane width)
* JPCP concrete thickness = 9 in (229 mm) (typical MnDOT JPCP thickness)
* TICP concrete thickness = 7 in (178 mm) which is a typical concrete thickness used in European composite pavements
* TICP asphalt thickness = 3 in (76 mm)
* Mobilization charges:

JPCP = $107,000

TICP = $157,000

The $50,000 premium for TICP mobilization is based on a recommendation from the Minnesota contractor who built the TICP test section. The additional cost is attributed to additional pavers and/or additional aggregate silos for mobile concrete batch plants required for composite pavement construction.

* Minor and major maintenance and rehabilitation costs:

Tables 15 and 16 show M & R schedules for high-volume bituminous and concrete pavements based on MnDOT’s recommendations (MnDOT Engineering Services Technical memorandum No. 04-19-MAT-02, September 7, 2004) and M & R data provided by MnDOT’s pavement management division from 30 years of MnDOT’s experience with minor and major M&R projects on JPCPs and JPCPs with asphalt overlays. It was assumed that the TICP required the same M & R procedures as a high-volume, conventional bituminous pavement.

Table 15 MN Case 3 bituminous pavement M & R schedule for ESALs > 7 million

|  |  |
| --- | --- |
| **Pavement Age** | **Treatment** |
| 0 | initial construction |
| 7 | crack fill |
| 15 | mill and overlay |
| 20 | crack fill |
| 27 | mill and overlay |
| 32 | crack fill |
| 40 | mill and overlay |
| 45 | crack fill |
| 50 | end of analysis period (no residual value) |

Table 16 MN Case 3 concrete pavement M & R schedule

|  |  |
| --- | --- |
| **Pavement Age** | **Treatment** |
| 0 | initial construction |
| 17 | minor re-seal and minor CPR (partial depth repairs) |
| 27 | Minor CPR (partial depth repairs) and some full depth repairs |
| 40 | major CPR (Full depth repair and diamond grind) |
| 50 | end of analysis period (no residual value) |

CPR=concrete pavement restoration

* Unit costs of concrete and asphalt:

Three levels of material cost were assumed for both concrete and asphalt. The potential range of costs was based on typical MnDOT estimating quantities as well as bid prices provided by contractors who submitted bids to build the TICP test section. Concrete and asphalt costs and their designations as low, medium, or high are shown in Table 17:

Table 17 MN Case 3 range of concrete and asphalt costs used for the LCCA

|  |  |
| --- | --- |
| **Concrete or Asphalt $ per yd3 (m3)** | **Price designation** |
| 38 (50) | Low |
| 115 (150) | Medium |
| 230 (300) | High |

* Cost of TICP concrete as a percentage of JPCP concrete:

One of the benefits of composite pavements is that the concrete layer has an HMA layer protecting it to some degree from the extreme environmental stresses and tire wear that a typical JPCP surface must endure. This implies that it would be possible to decrease the cost of composite pavements by either decreasing the thickness of the concrete layer or by decreasing the cost of the cement or aggregates in the concrete layer. A reduction in cost of the TICP PCC layer could be accomplished by increasing the percentage of supplementary cementitious materials in the total cementitious volume, by substituting recycled concrete aggregates for conventional coarse aggregates, or by allowing a higher percentage of fine, soft, spall, or slate in the coarse aggregate. Decreasing the cost of concrete is not limited to these examples. In a region with low aggregate quality where it is necessary to haul aggregates long distances from an acceptable source, TICP pavement construction could potentially allow the use of aggregates closer to the construction site, which would decrease the project’s cost.

## Minnesota Case 3 Results

The Minnesota LCCA analysis considered the economic viability of building TICPs if the cost of the TICP concrete was 25%, 50%, 75%, or 100% the cost of the JPCP concrete.

Figure 1 shows how the ratio of NPV of TICP to JPCP depended on asphalt cost, JPCP concrete cost, TICP concrete cost as a percentage of JPCP concrete cost, and discount rate. The low, medium and high designations in the top left plot indicate the cost of JPCP concrete, and these designations are typical for all plots. The data in the top row of plots was calculated with a discount rate of 2.8, and the data in the bottom row of plots was calculated with a discount rate of 5.0. The horizontal line in all the plots at a TICP/JPCP ratio of 1.0 indicates that the NPVs of TICP and JPCP were equal. Ratios above this line indicate it is more cost competitive to build JPCPs and ratios below this line indicate that it is more cost competitive to build composite TICPs. The following trends can be observed in Figure 1:

* As the cost of JPCP concrete increases, TICP become more cost competitive with JPCP.
* If the cost of JPCP concrete is low, it is almost never cost competitive to build TICP instead of JPCP pavements. This remains true despite the discount rate, cost of asphalt, and decrease in concrete cost for TICP concrete.
* If the cost of TICP concrete is equal to 100% of the cost of JPCP concrete, it is almost never cost competitive to build TICPs rather than JPCPs. At best, the NPV of the TICP equals the NPV of the JPCP.
* As the cost of asphalt increases, the cost of TICP concrete must decrease relative to the cost of JPCP concrete in order for TICP to remain cost competitive with JPCP. Table 18 shows the NPV breakeven range for the cost of TICP concrete relative to JPCP concrete for asphalt and JPCP concrete costs that are low, medium, and high. Realistically, if the cost of TICP concrete must be less than 60% of the cost of JPCP concrete in order for TICP to be cost competitive with JPCP, it is an unrealistic cost to achieve.
* An increase in discount rate increases the likelihood that TICP will be cost competitive with JPCP. In Table 18, the range of TICP concrete costs as a percentage of JPCP concrete costs results from the two discount rate values.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | Asphalt Cost: Low | Asphalt Cost: Medium | Asphalt Cost: High |
| NPV Project Cost of TICP/JPCP | DR = 2.8 |  |  |  |
| DR = 5.0 |  |  |  |
|  |  | Cost of TCIP Concrete as a Percentage of the Cost of JPCP ConcreteFigure 1: The ratio of the NPV of TICP to the NPV of JPCP, which are dependent on asphalt cost, JPCP concrete cost, TICP concrete cost as a percentage of JPCP concrete cost, and discount rate.  |

Table 18 MN Case 3 breakeven range for the cost of TICP concrete as a percentage of JPCP concrete

|  |  |
| --- | --- |
|  | **Asphalt Cost** |
| **Concrete Cost** | **Low** | **Med** | **High** |
| **Low** | 20-25% | Never | Never |
| **Med** | 86-92% | 58-64% | <25% |
| **High** | > 100% | 92-96% | 72-67% |

In summary, this Minnesota-based case study presented a LCCA that investigated when it would be economically feasible to build TICP in lieu of JPCP based on the NPV of initial construction costs and the costs of minor and major maintenance and rehabilitation regimens. The initial construction costs were calculated based on mobilization costs and the volume of concrete and asphalt used to build the pavements. The initial cost of JPCP construction was considered with low, medium, and high concrete costs, and the initial cost of TICP construction was considered with low, medium, and high asphalt costs and concrete costs that were between 25%-100% the cost of the JPCP concrete. The M & R schedule was based on the experience of MnDOT.