# Lifecycle Cost Analysis of Internally Cured Jointed Plain Concrete Pavement

**Final Report**
**November 2017**

National Concrete Pavement Technology Center

CP Tech Center

IOWA STATE UNIVERSITY
Institute for Transportation

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The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.




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**16. Abstract**

Internal curing is a technique that has been developed to prolong cement hydration by providing internal water reservoirs in a concrete mixture that do not adversely affect the concrete mixture's fresh or hardened physical properties. Internal curing grew out of the need for more durable structural concretes that were resistant to shrinkage cracking.

This report covers an investigation into the relative costs and benefits of internal curing using a lifecycle cost analysis (LCCA) that compares internally cured (IC) jointed plain concrete pavement to conventionally cured (CC) pavement. This analysis was based on a pavement designed for use in Dubuque, Iowa.

According to the analysis, IC concrete makes it possible to design pavement with decreased thickness or increased joint spacing or to reduce the required maintenance over the analysis period, which results in savings in initial construction cost. Even if the thickness does not change, IC pavement requires less maintenance than a comparable CC pavement to provide satisfactory performance over its service life. However, the initial construction cost of IC pavement is about 3.2% higher than that of CC pavement with the same thickness. Considering all of the evidence, the net present value of IC pavement is less than that of CC pavement.


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# LIFECYCLE COST ANALYSIS OF INTERNALLY CURED JOINTED PLAIN CONCRETE PAVEMENT

**Final Report**
**November 2017**


**Principal Investigator**
Peter Taylor, Director
National Concrete Pavement Technology Center, Iowa State University

**Co-Principal Investigator**
Halil Ceylan, Director
Program for Sustainable Pavement Engineering and Research (ProSPER)
Institute for Transportation, Iowa State University

**Research Assistant**
Payam Vosoughi

**Authors**
Payam Vosoughi, Steven Tritsch, Halil Ceylan, and Peter Taylor



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A report from
**National Concrete Pavement Technology Center**
**Iowa State University**
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-5798 / Fax: 515-294-0467
www.intrans.iastate.edu

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## ACKNOWLEDGMENTS

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# INTRODUCTION

The road transportation system in the US plays a fundamental role for the traveling public and in the movement and exchange of goods. Therefore, it is essential to invest wisely in building new roads and maintaining the existing ones.

An approach to increasing the longevity of concrete pavements is to include lightweight fine aggregate (LWFA) in the mixture for the purpose of internal curing (Bentz and Snyder 1999, Cusson et al. 2010). This report covers an investigation into the relative costs and benefits of this approach using a lifecycle cost analysis (LCCA) that compares internally cured (IC) jointed plain concrete pavement to conventionally cured (CC) pavement. This analysis was based on a pavement designed for use in Dubuque, Iowa.

## Background

Water has two different roles in concrete. The first is to make the fresh concrete workable, and the second is the hydration of the cementitious system (Mehta and Monteiro 2013). The ratio of water to cementitious materials (w/cm) in the fresh mixture significantly affects the mechanical and durability properties of concrete (Mehta and Monteiro 2013); consequently, efforts are applied to ensure that the w/cm ratio does not exceed specified limits while still maintaining workability. However, if the w/cm ratio is below about 0.40, the water in the system is likely to be insufficient to fully hydrate all of the cementitious materials, and the pores may dry out prematurely, potentially leading to increased shrinkage and the associated risks of warping and cracking.

The main concept behind internal curing is to provide water reservoirs inside the concrete matrix (Villarreal 2008). Therefore, when water is required for hydration, it can be provided from the uniformly distributed, small, reservoirs (Cusson and Margeson 2010, Schlitter et al. 2010).

Cusson and Margeson (2010) demonstrated that internal curing might lead to 20% higher calcium silicate hydrate (C-S-H) content at 28 days using thermal gravimetric analysis (TGA). In addition, the modulus of elasticity (MOE) is decreased (Babcock and Taylor 2015) leading to reduced stresses under shrinkage strains (Shah and Weiss 2000).

The goal of internal curing is to provide the water needed to keep the internal moisture of early-age concrete above 90% by replacing about 20% to 25% of the fine aggregate with saturated LWFA (Bentur et al. 2001, Schlitter et al. 2010).

Reported benefits include the following:

- Reduced shrinkage
- Reduced moisture gradient (Jeong and Zollinger 2004, Wei and Hansen 2008) and so a reduced risk of warping
- Decreased fluid transport (Zhutovsky and Kovler 2012)

- Improved resistance to cycles of freezing and thawing (Cusson et al. 2010, Bentz and Weiss 2011, Schlitter et al. 2010, Zhutovsky and Kovler 2012)

LCCA is a tool to assist in decision-making between alternatives based on determining their relative costs over a period of time. It evaluates overall long-term costs including initial, maintenance, rehabilitation, user, and salvage costs (Walls and Smith 1998).

The work reported here is an analysis of the relative costs and benefits of using internal curing for local pavements with low and medium traffic in Iowa.

## MATERIALS AND PAVEMENT PROPERTIES

The proportions of the concrete mixtures used for this analysis are shown in Table 1.

**Table 1. Concrete mixture proportions**

| Materials | Value |
|---|---|
| Cementitious material content | 550 lb/yd$^3$ |
| Coarse aggregate content | 1,479 lb/yd$^3$ |
| Fine aggregate content | 1,490 lb/yd$^3$ |
| Water to cement ratio | 0.43 |

The proportions were assumed to be the same for both the IC and CC mixtures. Table 2 shows the properties of the CC and IC concrete mixtures used for the analysis.

**Table 2. Properties of CC and IC concretes**

| Concrete Properties | Conventionally Cured Concrete | Internally Cured Concrete |
|---|---|---|
| Concrete unit weight | 144 lb/ft$^3$ | 138.5 lb/ft$^3$ |
| Concrete coefficient of thermal expansion | 4.8 in./in./°F | 4.3 in./in./°F |
| Concrete modulus of elasticity | 4.3×10$^6$ psi | 3.95×10$^6$ psi |
| Concrete compressive strength | 6,050 psi | 6,070 psi |
| Ultimate shrinkage | 611×10$^{-6}$ in./in. | 592×10$^{-6}$ in./in. |
| Coarse aggregate type | Limestone | Limestone |
| Zero stress temperature | 101.9°F | 101.9°F |
| Concrete Poisson's ratio | 0.2 | 0.2 |
| Slump | 1–3 in. | 1–3 in. |

Based on reported data, the risk of early-age cracking in IC concrete is reduced in comparison to the risk in CC concrete.

The researchers conducted the LCCA for eight different pavements in Iowa: control and IC pavements, 15 and 20 ft joint spacings, and 400 and 1,500 average annual daily truck traffic (AADTT). The design of the pavements (selected based on the results of analyzing 220 pavements by AASHTOWare Pavement ME 2.3.1+66) is shown in Table 3. (Additional details are presented in the appendix).

**Table 3. Pavement designs**

| Code | Thickness (in.) | Joint Spacing (ft) | AADTT | Dowel Bar Diameter (in.) |
|---|---|---|---|---|
| CC-8-15 | 8 | 15 | 400 | 1.25 |
| CC-8-20 | 8 | 20 | 400 | 1.25 |
| CC-10-15 | 10 | 15 | 1,500 | 1.5 |
| CC-10-20 | 10 | 20 | 1,500 | 1.5 |
| ICC-7-15 | 7 | 15 | 400 | 1 |
| ICC-7-20 | 7 | 20 | 400 | 1 |
| ICC-9-15 | 9 | 15 | 1,500 | 1.5 |
| ICC-9-20 | 9 | 20 | 1,500 | 1.5 |

The properties used in the design of the pavements compared in this study are shown in Table 4.

**Table 4. Basic design properties of the pavements**

| Pavement Properties | Value |
|---|---|
| Location | Dubuque, IA |
| Design life | 30 yrs |
| Analysis period | 40 |
| Design reliability | 90 % |
| Base layer thickness | 10 in. |
| Joint spacing | 15 and 20 ft |
| Erodibility index | 2 |
| Subgrade layer resilient modulus | 10,000 psi |
| Base layer resilient modulus | 38,000 psi |
| Permanent curling and warping effective temperature gradient | -10°F |

The analysis period was selected to be longer than the pavement design life to see the benefits of utilizing IC concrete over the long-term. Joint spacing and dowel diameter were selected based on what are common in Iowa. An effective temperature gradient of -10°F was assumed to simultaneously simulate the effects of both curling and warping on the pavements. The schematic view of the intended pavement is illustrated in Figure 1.

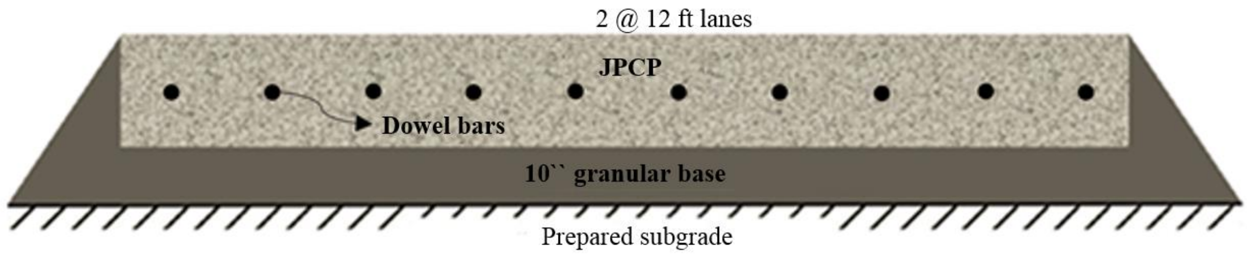



**Figure 1. Schematic view of the pavement**

As shown, the pavement included two 12 ft lanes.

## DESIGN AND ANALYSIS OF PAVEMENTS

Two hundred twenty different pavement designs were analyzed based on the mechanistic-empirical method using AASHTOWare Pavement ME software version 2.3.1+66 (AASHTO 2015). The materials and pavement structure discussed in the previous chapter were selected to investigate the effects of internal curing on the performance of pavements. Two different slab thicknesses (8 and 10 in.) were compared for two joint spacings (15 and 20 ft) and two different curing methods (CC and IC).

The pavement performance parameters assessed were International Roughness Index (IRI), joint faulting, and transverse cracking at two reliabilities (50% and 90%). The initial IRI value was assumed to be 63 in. per mile for 50% reliability and 85 in. per mile for 90% reliability in all analyses. All pavements were designed based on a 30-year analysis. The LCCA was conducted based on a 40-year analysis.

There are two main approaches to show the benefits of IC in the design of pavements. The first approach is to decrease the minimum thickness of pavements required to achieve the minimum performance at the end of the design period, leading to savings in materials and significantly decreasing the initial construction costs without compromising performance. The second approach is to assess the improvement in the overall performance of pavements constructed using IC concrete. Although the initial construction costs may be higher, less maintenance would be required over time, saving money over the analysis period.

### Design of Control and Internally Cured Pavements

Internal curing improves some hardened properties of concrete mixtures, leading to improved pavement performance. The performance measurements (IRI, joint faulting, and transverse cracking) of all conventionally and internally cured pavements at two reliabilities (50% and 90%) are shown in Table 5.

**Table 5. Distress performance of the designed pavements at the age of 30 years**

| Code | 90% Reliability | | | 50% Reliability | | |
|---|---|---|---|---|---|---|
| | IRI (in./mile) | Joint Faulting (in.) | Transverse Cracking (%) | IRI (in./mile) | Joint Faulting (in.) | Transverse Cracking (%) |
| CC-8-15 | 158 | 0.05 | 1.9 | 113 | 0.02 | 0.0 |
| CC-8-20 | 160 | 0.06 | 4.1 | 115 | 0.02 | 0.3 |
| CC-10-15 | 168 | 0.06 | 1.0 | 119 | 0.03 | 0.0 |
| CC-10-20 | 174 | 0.09 | 4.3 | 125 | 0.05 | 0.3 |
| ICC-7-15 | 171 | 0.07 | 3.3 | 121 | 0.03 | 0.1 |
| ICC-7-20 | 170 | 0.08 | 4.6 | 122 | 0.04 | 0.4 |
| ICC-9-15 | 165 | 0.06 | 1.0 | 117 | 0.02 | 0.0 |
| ICC-9-20 | 168 | 0.08 | 2.4 | 120 | 0.04 | 0.0 |

The minimum thicknesses satisfying the required performance limits for 30 years were determined. The results indicated that internal curing may allow a decrease in the minimum thickness from 8 and 10 in. to 7 and 9 in., respectively. Figure 2 and Figure 3 illustrate the increase in the IRI value over the design life for both CC and IC concrete, respectively.

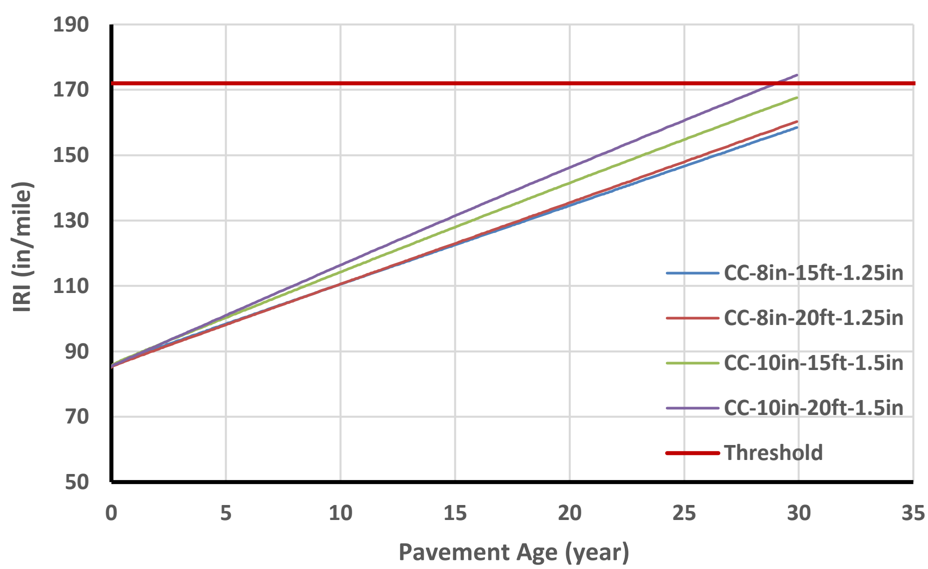



**Figure 2. IRI of conventionally cured pavements over design life**

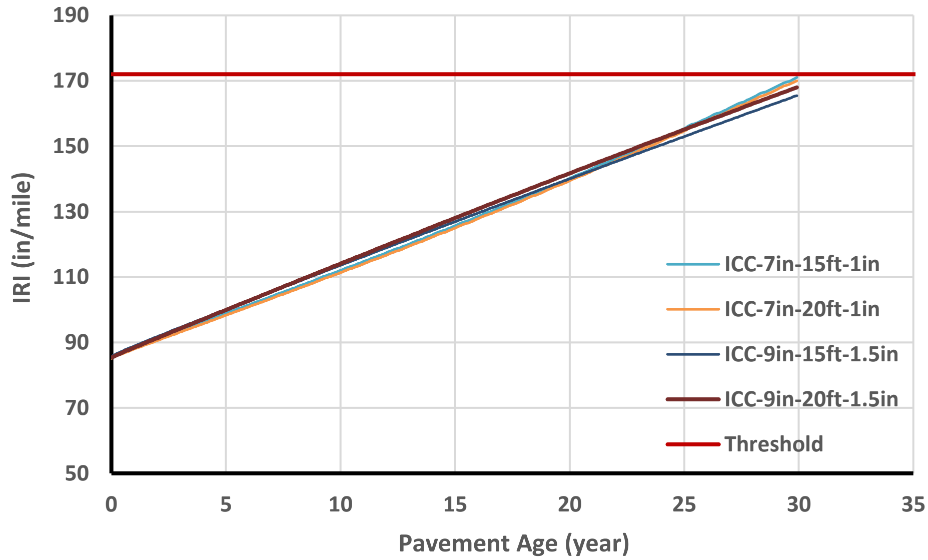



**Figure 3. IRI of internally cured pavements over design life**

The results demonstrate that using IC concrete slightly compensates for the effect of increasing joint spacing from 15 to 20 ft on the ultimate IRI value.

Slab transverse cracking is significantly dependent on both joint spacing and thickness. As the results demonstrate, IC can mitigate some transverse cracking as the joint spacing is increased from 15 to 20 ft.

## Improving the Performance of Pavements by Utilizing IC Concrete

Internally cured concrete typically has a lower coefficient of thermal expansion (CTE), lower modulus of elasticity (MoE), higher compressive strength, lower unit weight, and lower ultimate shrinkage. Better overall distress performance is therefore expected for IC pavements over their design life. The results shown in Figure 4 through Figure 7 show that using IC concrete leads to higher overall performance and a decreasing ultimate IRI value.

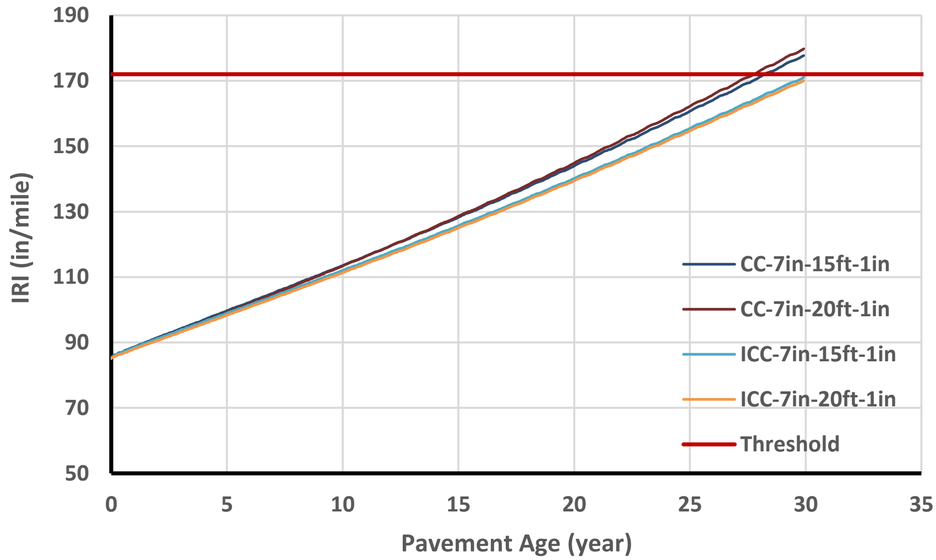



**Figure 4. 7 in. thick conventionally and internally cured pavement**

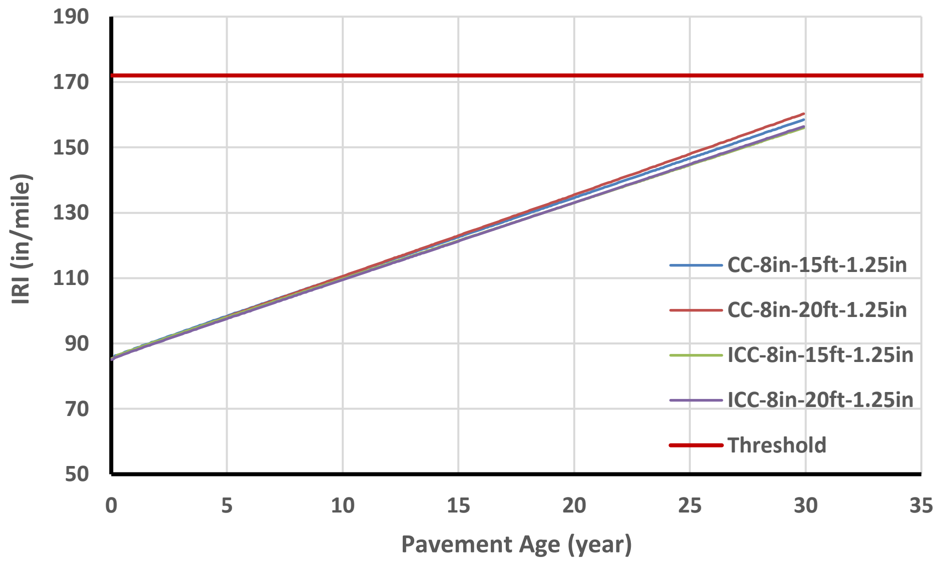



**Figure 5. 8 in. thick conventionally and internally cured pavement**

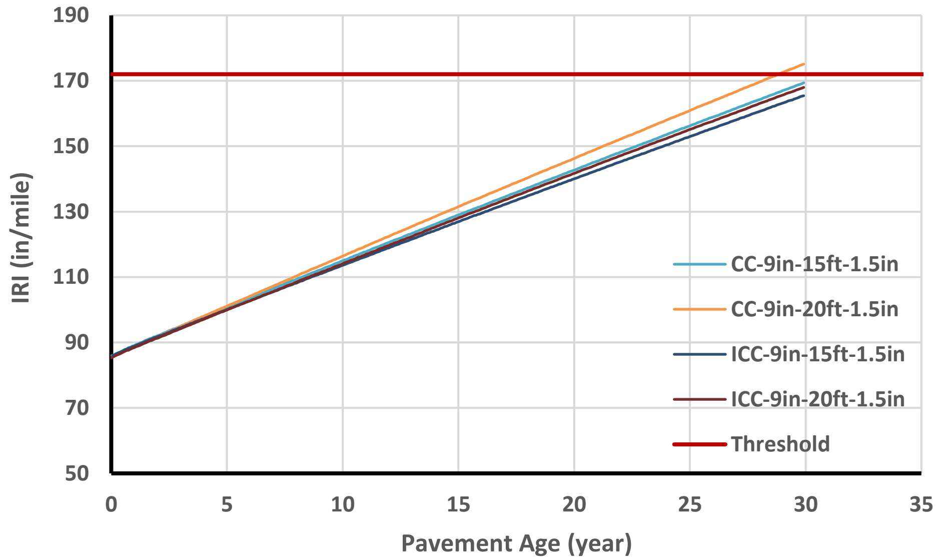



**Figure 6. 9 in. thick conventionally and internally cured pavement**

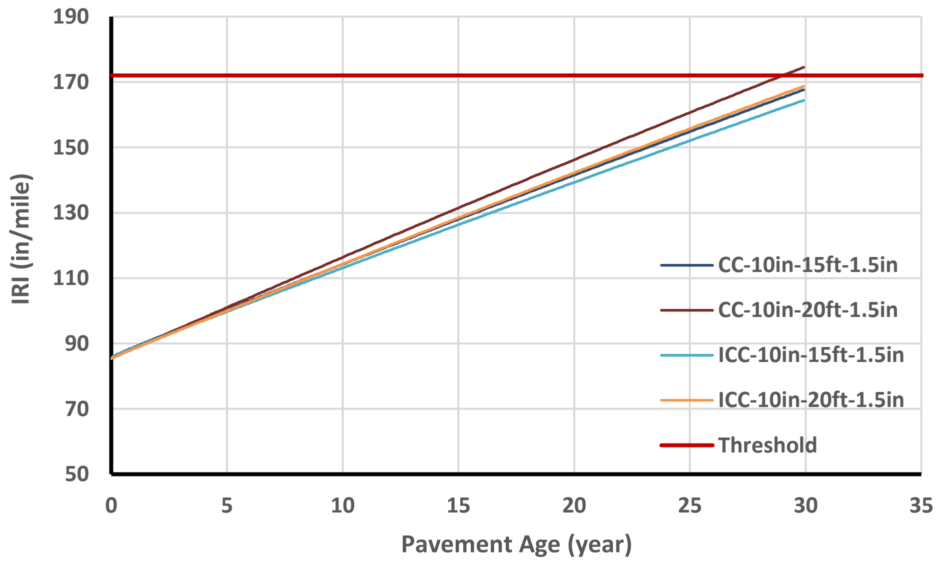



**Figure 7. 10 in. thick conventionally and internally cured pavement**

## LIFECYCLE COST ANALYSIS OF PAVEMENTS

LCCA started to be used by state agencies in the 1950s for cost evaluations and to compare proposed pavement systems (AASHTO 1960). LCCA is a form of economic analysis used to evaluate long-term economic efficiency among alternative investment options. Different pavement types, qualities of pavement, effects on the motoring public, and maintenance and rehabilitation costs should be considered in this type of analysis (Wilde et al. 1999).

Note there is also an approach called benefit/cost (B/C) analysis; however, it is not generally recommended for pavement analysis because of the difficulty of determining the benefits and costs for use in developing B/C ratios (Walls and Smith 1998).

Economic analysis focuses on the relationship between construction, maintenance, and rehabilitation costs; timings of costs; and discount rates employed. Once all costs and their timings have been determined, future costs are discounted to the base year and added to the initial cost to determine the net present value (NPV) for the LCCA alternatives. The basic NPV equation for discounting discrete future amounts at various points in time back to some base year is as follows (West et al. 2013):

$$NPV = Initial\ Construction\ Cost + \sum_{k=1}^{N} Rehabilitation\ Cost_k \left[\frac{1}{(1+i)^{n_k}}\right] - Salvage\ Value \left[\frac{1}{(1+i)^{n_k}}\right] \quad \textbf{(1)}$$

where:

i = discount rate
n = year of expenditure

The same concept is demonstrated in Figure 8, which shows how NPV decreases as additional years of spending are applied.

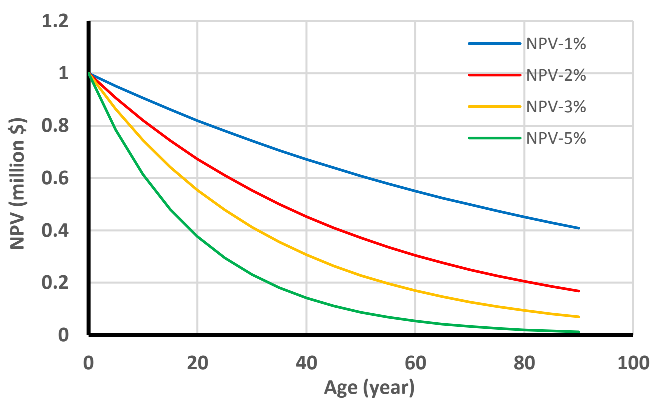
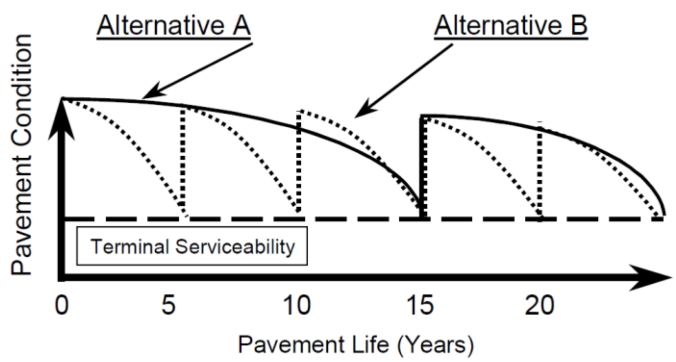



**Figure 8. Net present value of $1 million over the long term**

The discount rates employed in LCCA should reflect historical trends over long periods of time. The US Office of Management and Budget (OMB) has suggested that the real discount rate, which can be used for discounting constant-dollar flows, for 30-year cost-effectiveness analysis can be assumed to be equal to 0.7 (Darman 1992). In this investigation, the discount rate was selected to be equal to 1%, but a sensitivity analysis was also performed to see the effects of different discount rates because some other discount rates are also recommended for conducting LCCAs of pavements in the US (Walls and Smith 1998, Jawad and Ozbay 2006).

The LCCA period is the period over which future costs are evaluated. This period should be long enough to reflect long-term cost differences associated with reasonable design strategies. The analysis period should generally be long enough to see at least one maintenance or major rehabilitation activity over the pavement life, and the period can also be selected based on the requirements of the department of transportation. Figure 9 demonstrates the lifecycles of two different pavements over an analysis period; Alternative A has a higher initial cost but lower maintenance expenses than Alternative B.




Walls and Smith 1998

**Figure 9. Lifecycles of two pavements over an analysis period**

Routine annual maintenance costs usually do not change significantly and have a marginal effect on the total NPV of pavements compared to initial construction or major rehabilitation costs, particularly when discounted over 30- to 40-year analysis periods.

Salvage value represents the value of an investment alternative at the end of the analysis period. Residual value and residual serviceable life are two essential components of salvage value.

Residual value refers to the net value from recycling the pavement material. The differential residual values among pavement design strategies are usually not very significant and tend to have little effect on LCCA results when discounted over the entire analysis period.

Residual serviceable life represents the more significant component of salvage value and is the remaining life in a pavement alternative at the end of the analysis period. Residual serviceable life is primarily used to account for differences in remaining pavement life between alternative pavement design strategies at the end of the analysis period.

Figure 10 depicts the entire pavement cost stream over the analysis period, including initial construction, minor and routine maintenance, and major rehabilitation costs, as well as salvage value at the end of the period.

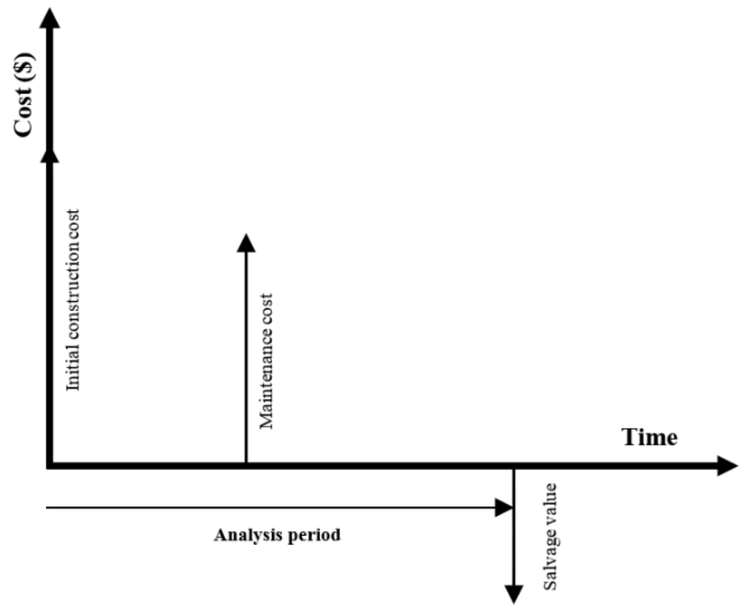



**Figure 10. Cost stream over the lifecycle of a pavement**

All of these values should be estimated and discounted to calculate NPV in the base year. Then, using the NPV, alternatives can be compared with each other.

For this study, all phases of the pavement lifecycle were considered (and costs included raw material costs) to find the differential costs among all CC and IC pavements where previously indicated.

A performance parameter of a pavement that can be used to study how the pavement behaves over the analysis period is IRI. The threshold value at which the pavement is assumed to have failed is 172 in. per mile. Maintenance should be conducted well before the pavement reaches the threshold value because delayed maintenance significantly increases maintenance costs. Therefore, it is assumed that major maintenance is required when the IRI value of the pavement reaches a specific threshold. This threshold is assumed to be 130 and 140 in. per mile for pavements with 1,500 and 400 AADTT, respectively, because a higher IRI value is acceptable for county roads with lower traffic levels.

The smoothness of the pavement would be significantly improved after conducting major maintenance, so it is assumed that the IRI value will decrease to half (65 and 70 in. per mile for pavements with 1,500 and 400 AADTT, respectively). The IRI value after maintenance may be lower than the initial value because maintenance may mitigate some of the initial curling and warping that may occur at very early ages.

The lifecycle of pavements with low AADTT that are designed for low-volume primary routes and county roads is illustrated in Figure 11.

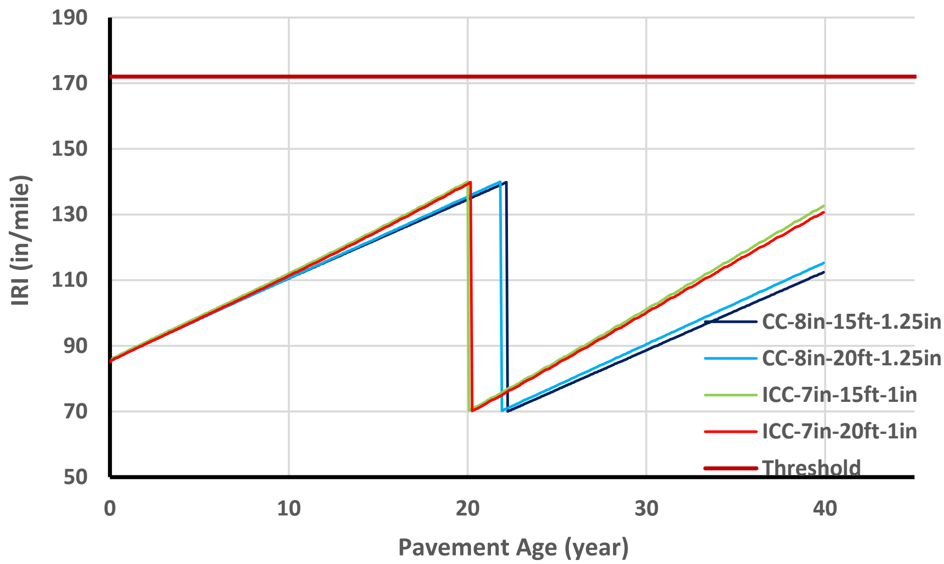



**Figure 11. Lifecycle of pavements with low AADTT**

The lifecycle of pavements designed for higher AADTT is represented in Figure 12.

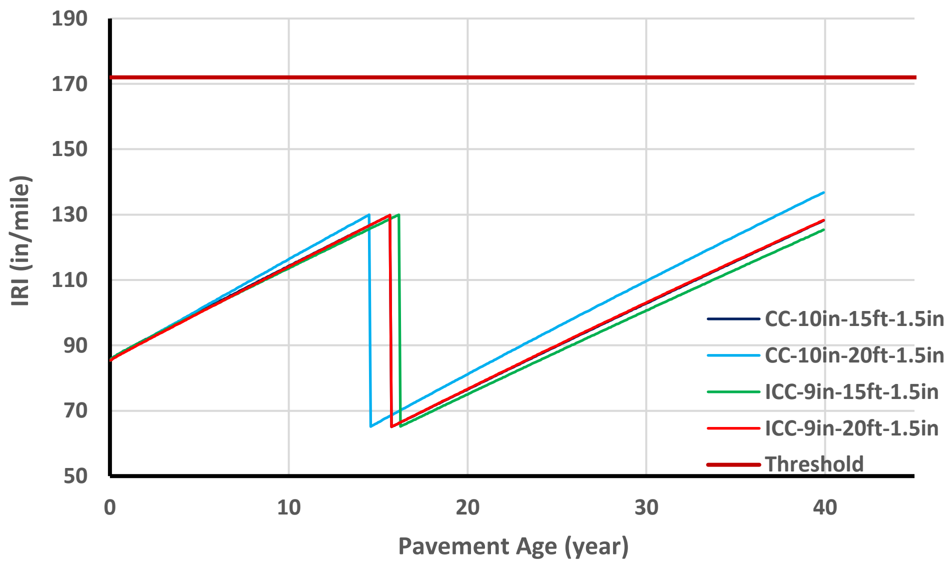



**Figure 12. Lifecycle of pavements with high AADTT**

The figures indicate that all eight pavements are in acceptable condition over the entire analysis period with one major maintenance activity.

Regarding the 7 in. thick IC pavement in Figure 11, the rate of increase of the IRI value is higher than that of an 8 in. thick CC pavement requiring major maintenance about 1.5 years sooner, and the ultimate IRI value is higher (yielding a lower salvage value).

However, decreasing the thickness of a 10 in. thick CC pavement by 1 in. using IC concrete will not reduce the performance, as demonstrated in Figure 12. In other words, a 9 in. thick IC pavement has a lower rate of increase of the IRI value, leading to maintenance being required at later ages, and the ultimate IRI value is even less than that of a 10 in. thick CC pavement.

Table 6 summarizes the time of the first major maintenance for each pavement as well as the residual serviceable life after the analysis period (40 years).

**Table 6. Maintenance time and residual serviceable life of all pavements**

| | Low AADTT | | | | High AADTT | | | |
|---|---|---|---|---|---|---|---|---|
| | CC Pavement | | IC Pavement | | CC Pavement | | IC Pavement | |
| | Joint Spacing (ft) | | | | | | | |
| | 15 | 20 | 15 | 20 | 15 | 20 | 15 | 20 |
| First major maintenance | 22.25 | 21.92 | 20.08 | 20.25 | 15.75 | 14.58 | 16.25 | 15.75 |
| Residual serviceable life | 25.25 | 22.92 | 12.75 | 14.00 | 17.67 | 13.17 | 19.25 | 17.90 |

Because the residual value at the end of the analysis period is not very significant and is almost constant for all scenarios, it was not considered in this study. Figure 13 and Figure 14 demonstrate the distress performance of pavements over a long time.

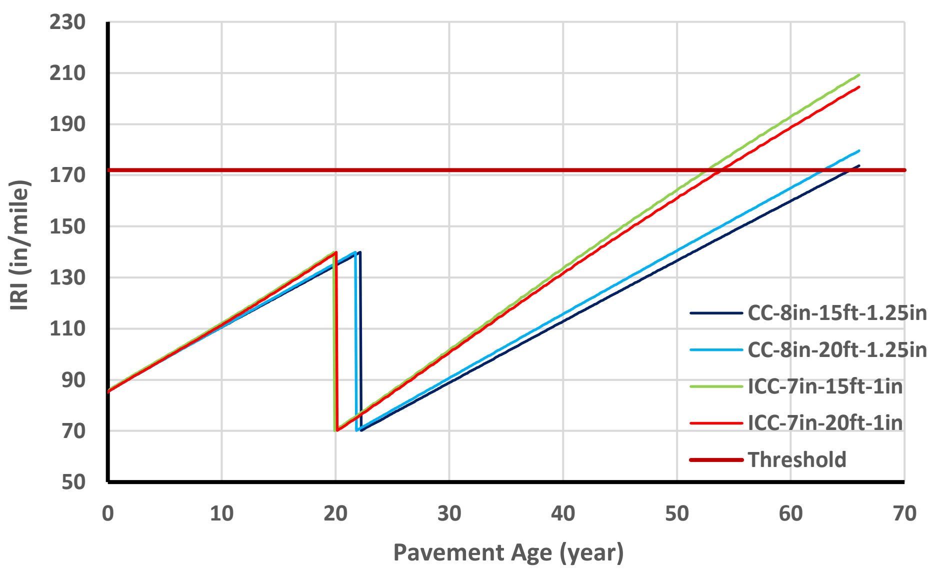



**Figure 13. Distress performance of the pavements with low AADTT over a long time**

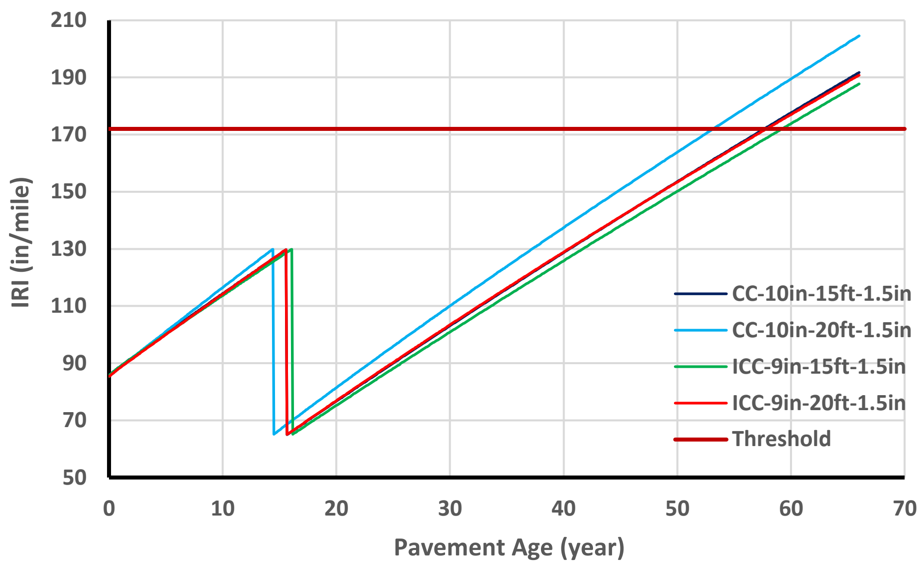



**Figure 14. Distress performance of the pavements with high AADTT over a long time**

The ideal maintenance schedule incurs the minimum cost while letting the pavement reach the maximum allowable distress (in terms of IRI) at the end of the analysis period. The extra paid for maintenance that results in a higher residual serviceable life should be refunded so that all pavements can be evaluated in a comparable condition. For this purpose, the salvage value at the end of the analysis period can be calculated by considering the maintenance cost in proportion to the ratio of the residual service life to the serviceable life after the maintenance.

To internally cure the concrete, 20% of the normal-weight fine aggregate (NWFA) had been replaced by the same volume of LWFA, which was about 0.126 $yd^3$ of LWFA per $yd^3$ of IC concrete (170 $lb/yd^3$).

Considering all expenses (including transportation and presaturation of LWFA), the total cost of NWFA and LWFA were estimated to be $\$24/yd^3$ and $\$54/yd^3$, respectively, in Iowa. Therefore, the incremental cost for the construction of a unit area of pavement was assumed to be as shown in Table 7.

**Table 7. Total construction costs of pavements**

| Total Construction Cost ($\$/yd^2$) | 7 in. Thickness | 8 in. Thickness | 9 in. Thickness | 10 in. Thickness |
|---|---|---|---|---|
| CC pavement | 28 | 30 | 32 | 34 |
| IC pavement | 29 | 31 | 33 | 35 |

The total construction cost of a pavement with 15 ft joint spacing is 0.5 $\$/yd^2$ more expensive than that of a pavement with 20 ft joint spacing.

It was assumed that the costs of transporting, placing, and externally curing the two different mixtures would be almost equal.

The initial construction costs of the pavements were estimated based on the surface area of the roadway using Equation 2.

$$Initial\ construction\ cost\ =\ Number\ of\ lanes\ \times\ Lane\ width\ \times\ Length\ of\ the\ pavement\ \times\ \text{Total}\ construction\ cost \quad \textbf{(2)}$$

The investigated pavement has two 12 ft lanes, and the total length of the pavement is equal to 1 mile.

As a practical assumption, it was assumed that maintenance would be the same for both the conventionally and internally cured pavements. Diamond grinding should be conducted on the whole area of the pavement when programming major maintenance, and 1% of the area should be considered for patching at the same time. The cost of diamond grinding and patching were assumed to be \$3 and \$100, respectively, per $yd^2$ of the surface of the pavements.

Initial construction and maintenance costs, as well as the salvage and net present values, are shown in Table 8.

**Table 8. Construction and maintenance costs and NPVs of alternatives**

| | Initial Construction Cost ($) | Major Maintenance | | Residual Value | | Net Present Value ($) |
|---|---|---|---|---|---|---|
| | | Cost ($) | Discounted Cost ($) | Value ($) | Discounted Value ($) | |
| CC-8in-15ft-1.25in | 429,440 | 56,320 | 45,135 | 39,460 | 26,504 | 448,071 |
| CC-8in-20ft-1.25in | 422,400 | 56,320 | 45,283 | 37,690 | 25,314 | 442,369 |
| CC-10in-15ft-1.5in | 485,760 | 56,320 | 48,151 | 27,978 | 18,792 | 515,119 |
| CC-10in-20ft-1.5in | 478,720 | 56,320 | 48,714 | 30,086 | 20,207 | 507,227 |
| ICC-7in-15ft-1in | 415,360 | 56,320 | 46,120 | 28,944 | 19,440 | 442,040 |
| ICC-7in-20ft-1in | 408,320 | 56,320 | 46,042 | 23,395 | 15,713 | 438,649 |
| ICC-9in-15ft-1.5in | 471,680 | 56,320 | 47,912 | 31,934 | 21,449 | 498,143 |
| ICC-9in-20ft-1.5in | 464,640 | 56,320 | 48,151 | 30,445 | 20,448 | 492,342 |

As shown, the initial construction costs of the IC pavements are about 3.2% more expensive on average than the initial construction costs of the CC pavements with the same thickness. However, IC concrete has improved hardened properties, which allows for the use of a reduced thickness. Therefore, the initial construction cost of IC pavement with a reduced thickness may be decreased by a total of 3.1%.

Table 9 shows the percent savings in NPV when using IC concrete and a reduced thickness in the design of the pavement.

**Table 9. Savings in NPV when using IC concrete**

| | ICC-7in-15ft-1in | ICC-7in-20ft-1in | ICC-9in-15ft-1.5in | ICC-9in-20ft-1.5in |
|---|---|---|---|---|
| Savings in NPV (%) | 1.35 | 0.84 | 3.30 | 2.93 |

According to the literature, some researchers (Rao and Darter 2013) have assumed that the rehabilitation and maintenance expenses of IC pavements are about 15% lower than those of comparable CC pavements of the same thickness; however, to be on the safe side, this study assumes the same maintenance costs for all pavements.

Although the NPVs of the CC and IC pavements are nearly the same, other key benefits of IC pavements that cannot be accounted for in LCCA should also be considered. These include improving F-T resistance, impermeability, curling and warping behavior, and plastic shrinkage.

## SENSITIVITY ANALYSIS

Sensitivity analysis is a tool to study the effects of any uncertainty in the defining input parameters on the results. This chapter looks at the effects of changing the total construction cost, discount rate, and maintenance costs on the LCCA results.

Total construction cost covers all the expenses to build the pavements, including raw materials, transportation, placement, and curing. Table 7 shows the assumed total construction costs for CC and IC pavements with different thicknesses. A sensitivity analysis, presented in Table 10, helps to elucidate the effects of any uncertainty in the evaluation of these values.

**Table 10. Sensitivity of the savings in NPV to total construction cost**

| | Relative Total Construction Cost | | | | |
|---|---|---|---|---|---|
| | **0.8** | **0.9** | **1** | **1.1** | **1.2** |
| ICC-7in-15ft-1in | 0.89 | 1.14 | 1.35 | 1.52 | 1.66 |
| ICC-7in-20ft-1in | 0.25 | 0.58 | 0.84 | 1.06 | 1.24 |
| ICC-9in-15ft-1.5in | 3.39 | 3.34 | 3.30 | 3.26 | 3.23 |
| ICC-9in-20ft-1.5in | 2.93 | 2.93 | 2.93 | 2.94 | 2.94 |

The results indicate that although any variation in the total construction cost does not have a significant effect on the savings in NPV of the pavements with higher AADTT values, the savings in NPV of the 7 in. thick pavements were significantly affected by variations in the total construction cost. Savings in NPV resulting from the use of IC concrete may be increased by 2 to 5 times if the total construction cost is varied ±20% from the original assumption.

The discount rate suggested by the OMB for an LCCA with a 30-year analysis period is equal to 0.7%. As shown in Table 11, increasing the discount rate leads to a significant increase in savings if IC concrete is used for pavements with low AADTT values. The reason is that reducing the thickness of pavements with a low initial thickness leads to a relatively lower level of performance over the pavement's lifetime. Therefore, maintenance is required earlier, and the discounted cost of maintenance is reflected in the NPV.

**Table 11. Sensitivity of the savings in NPV to discount rate**

| | Net Present Value ($) | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **0.7** | **1** | **2** | **3** | **5** |
| ICC-7in-15ft-1in | 1.05 | 1.26 | 1.35 | 1.61 | 1.84 | 2.22 |
| ICC-7in-20ft-1in | 0.41 | 0.72 | 0.84 | 1.21 | 1.53 | 2.04 |
| ICC-9in-15ft-1.5in | 3.33 | 3.31 | 3.30 | 3.26 | 3.23 | 3.17 |
| ICC-9in-20ft-1.5in | 2.86 | 2.91 | 2.93 | 2.99 | 3.03 | 3.08 |

Another important parameter that can significantly affect LCCA results is the maintenance cost, which is difficult to estimate accurately. IC concrete is generally considered to have greater durability and need less maintenance than CC concrete; nevertheless, to be on the safe side, this study assumed that maintenance costs are the same for both alternatives. Table 12 shows the savings in NPV due to the use of IC concrete for different relative maintenance costs (relative to the maintenance cost assumed for this study).

**Table 12. Sensitivity of the savings in NPV to maintenance cost**

| | **Relative Maintenance Cost** | | | | |
|---|---|---|---|---|---|
| | **0.8** | **0.9** | **1** | **1.1** | **1.2** |
| ICC-7in-15ft-1in | 1.72 | 1.53 | 1.35 | 1.16 | 0.98 |
| ICC-7in-20ft-1in | 1.32 | 1.08 | 0.84 | 0.60 | 0.37 |
| ICC-9in-15ft-1.5in | 3.22 | 3.26 | 3.30 | 3.33 | 3.37 |
| ICC-9in-20ft-1.5in | 2.94 | 2.94 | 2.93 | 2.93 | 2.93 |

This analysis demonstrates that the maintenance cost has a more significant effect on the savings in NPV of pavements with lower thicknesses (and lower AADTT values). The savings that result from using IC pavements are substantially decreased by the increase in maintenance cost, but the minimum savings are still positive even for a 20% higher maintenance cost.

## CONCLUSIONS

Internal curing is an approach that allows concrete mixtures to deliver improved mechanical and durability properties that can be accounted for in the pavement design. IC concrete makes it possible to design pavement with decreased thickness or increased joint spacing or to reduce the required maintenance over the analysis period.

A variety of different alternatives were studied in this investigation to determine the advantages and disadvantages of using IC concrete in pavements. Based on the data collected, the following conclusions can be drawn:

- It is possible to design 8 and 10 in. thick pavement with 1 in. reduced thickness using IC concrete compared to conventionally cured concrete.

- IC pavement with the same thickness as CC pavement exhibits improved distress performance over time and requires less maintenance at later ages to provide satisfactory performance over its service life.

- Using IC concrete reduces the negative effects of increasing joint spacing on the distress performance of pavement over time by decreasing CTE, MoE, and ultimate shrinkage while at the same time increasing the concrete’s strength.

- The initial construction cost of IC pavements in Iowa may be about 3.2% higher than that of CC pavements with the same thickness. However, the initial construction cost can be reduced by 3.1% by decreasing the thickness of the pavement when utilizing IC concrete.

- The NPV of IC pavement is slightly lower than that of CC pavement, between 0.84% and 3.3% for different scenarios. These values exclude potential savings due to improvements in plastic shrinkage, F-T resistance, impermeability, moisture, and thermal gradient over the depth of the pavement.

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# APPENDIX: PAVEMENT DESIGN USING AASHTOWARE-PAVEMENT ME DESIGN V2.3.1+66

## CC-8in-15ft-1.25in

File Name: C:\Users\IPDC\Documents\Pavement ME runs, May 2017\Nov. 6th\Final\Design\Control concrete\CC-8in-15ft-1.25in.dgpx

## Design Inputs

Design Life: 30 years
Design Type: JPCP

Existing construction: -
Pavement construction: June, 2019
Traffic opening: July, 2019

Climate Data Sources (Lat/Lon): 42.398, -90.704

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 8.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 15.0 |
| Dowel diameter (in) | 1.25 |
| Slab width (ft) | 12.0 |

### Traffic

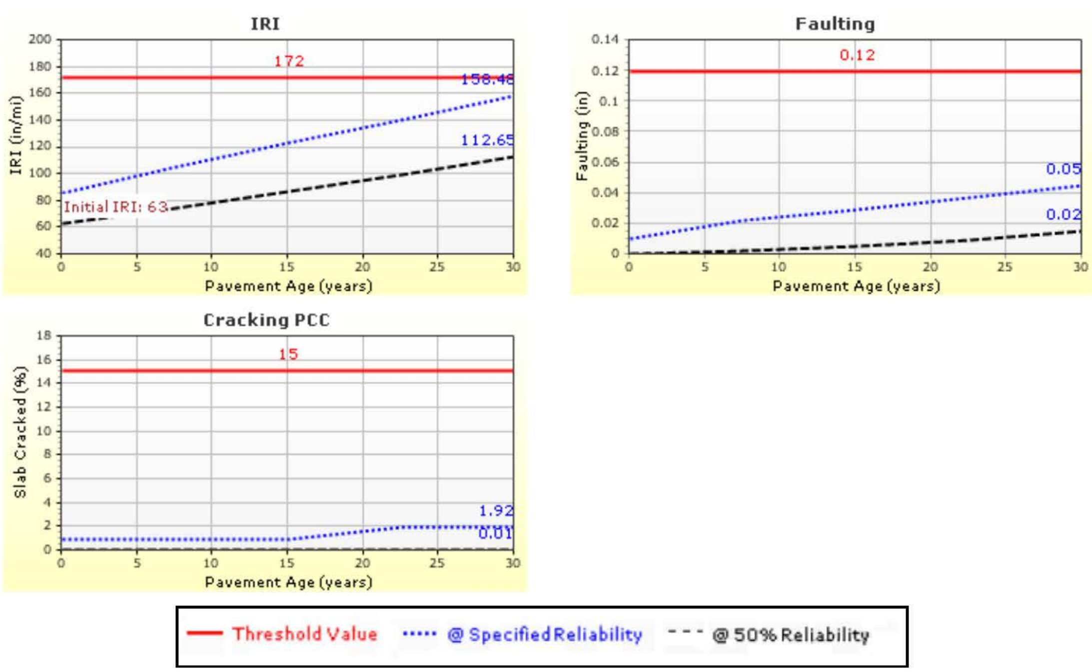
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 400 |
| 2034 (15 years) | 1,259,560 |
| 2049 (30 years) | 2,987,560 |

## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 158.48 | 90.00 | 95.15 | Pass |
| Mean joint faulting (in) | 0.12 | 0.05 | 90.00 | 100.00 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 1.92 | 90.00 | 100.00 | Pass |

### Distress Charts



# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.25 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 15.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| | |
|---|---|
| **Sealant type** | Preformed |

| | |
|---|---|
| **Erodibility index** | 2 |

| | |
|---|---|
| **Permanent curl/warp effective temperature difference (ºF)** | -10.00 |

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 8.0 |
| Unit weight (pcf) | 144.0 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.8 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 611.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Curing Compound |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6050.0 |
| **28-Day PCC elastic modulus (psi)** | 4300000.0 |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

**PCC Faulting**

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |

**PCC Reliability Faulting Standard Deviation**

0.07162 * Pow(FAULT,0.368) + 0.00806

**IRI-jpcp**

| | | |
|---|---|---|
| C1 - Cracking<br>C2 - Spalling<br>C3 - Faulting<br>C4 - Site Factor | C1: 0.8203 | C2: 0.4417 |
| | C3: 1.4929 | C4: 25.24 |
| | **Reliability Standard Deviation** | |
| | 5.4 | |

**PCC Cracking**

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$
$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |

**PCC Reliability Cracking Standard Deviation**

3.5522 * Pow(CRACK,0.3415) + 0.75

# CC-8in-20ft-1.25in

File Name: C:\Users\IPDC\Documents\Pavement ME runs, May 2017\Nov. 6th\Final\Design\Control concrete\CC-8in-20ft-1.25in.dgpx

## Design Inputs

| | | | | | |
|---|---|---|---|---|---|
| Design Life: | 30 years | Existing construction: | - | Climate Data Sources (Lat/Lon) | 42.398, -90.704 |
| Design Type: | JPCP | Pavement construction: | June, 2019 | | |
| | | Traffic opening: | July, 2019 | | |

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 8.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 20.0 |
| Dowel diameter (in) | 1.25 |
| Slab width (ft) | 12.0 |

### Traffic

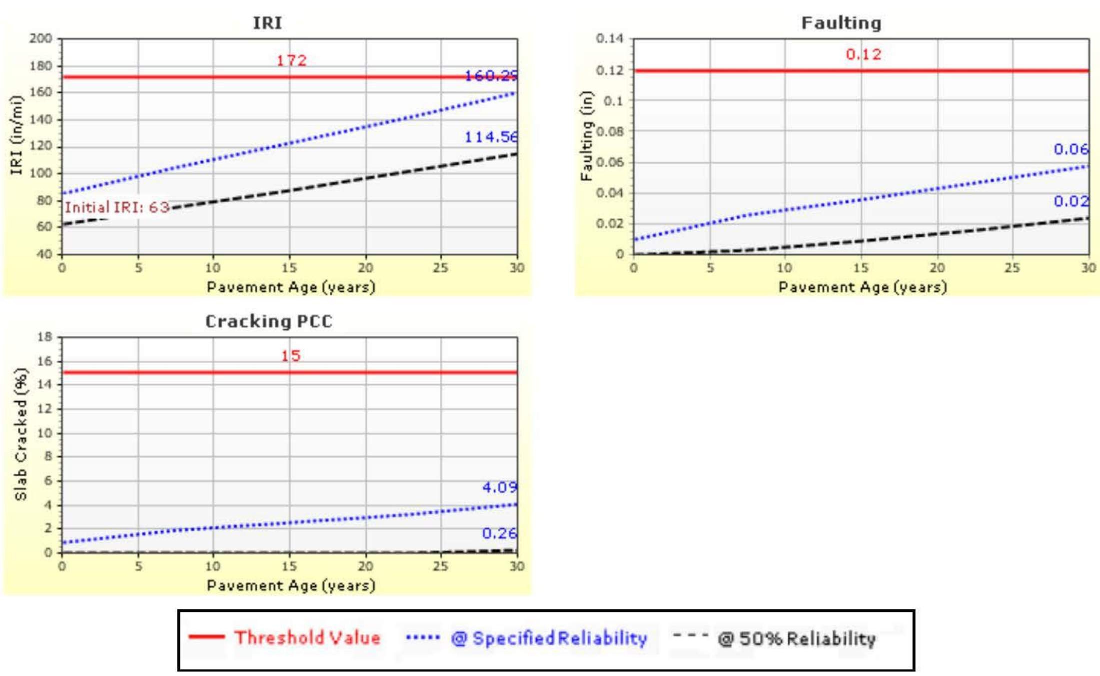
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 400 |
| 2034 (15 years) | 1,259,560 |
| 2049 (30 years) | 2,987,560 |

## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 160.29 | 90.00 | 94.63 | Pass |
| Mean joint faulting (in) | 0.12 | 0.06 | 90.00 | 99.99 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 4.09 | 90.00 | 100.00 | Pass |

### Distress Charts



# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.25 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 20.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| | |
|---|---|
| Sealant type | Preformed |

| | |
|---|---|
| Erodibility index | 2 |

| | |
|---|---|
| Permanent curl/warp effective temperature difference (ºF) | -10.00 |

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 8.0 |
| Unit weight (pcf) | 144.0 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.8 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 611.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Curing Compound |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6050.0 |
| **28-Day PCC elastic modulus (psi)** | 4300000.0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

**PCC Faulting**

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |
| **PCC Reliability Faulting Standard Deviation** | | | |
| 0.07162 * Pow(FAULT,0.368) + 0.00806 | | | |

**IRI-jpcp**

| | | |
|---|---|---|
| C1 - Cracking | C1: 0.8203 | C2: 0.4417 |
| C2 - Spalling | C3: 1.4929 | C4: 25.24 |
| C3 - Faulting | **Reliability Standard Deviation** | |
| C4 - Site Factor | 5.4 | |

**PCC Cracking**

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$

$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |
| **PCC Reliability Cracking Standard Deviation** | | | |
| 3.5522 * Pow(CRACK,0.3415) + 0.75 | | | |

# CC-10in-15ft-1.5in

File Name: C:\Users\IPDC\Documents\Pavement ME runs, May 2017\Nov. 6th\Final\Design\Control concrete\CC-10in-15ft-1.5in.dgpx

## Design Inputs

| | | | | | |
|---|---|---|---|---|---|
| Design Life: | 30 years | Existing construction: | - | Climate Data Sources (Lat/Lon) | 42.398, -90.704 |
| Design Type: | JPCP | Pavement construction: | June, 2019 | | |
| | | Traffic opening: | July, 2019 | | |

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 10.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 15.0 |
| Dowel diameter (in) | 1.50 |
| Slab width (ft) | 12.0 |

### Traffic

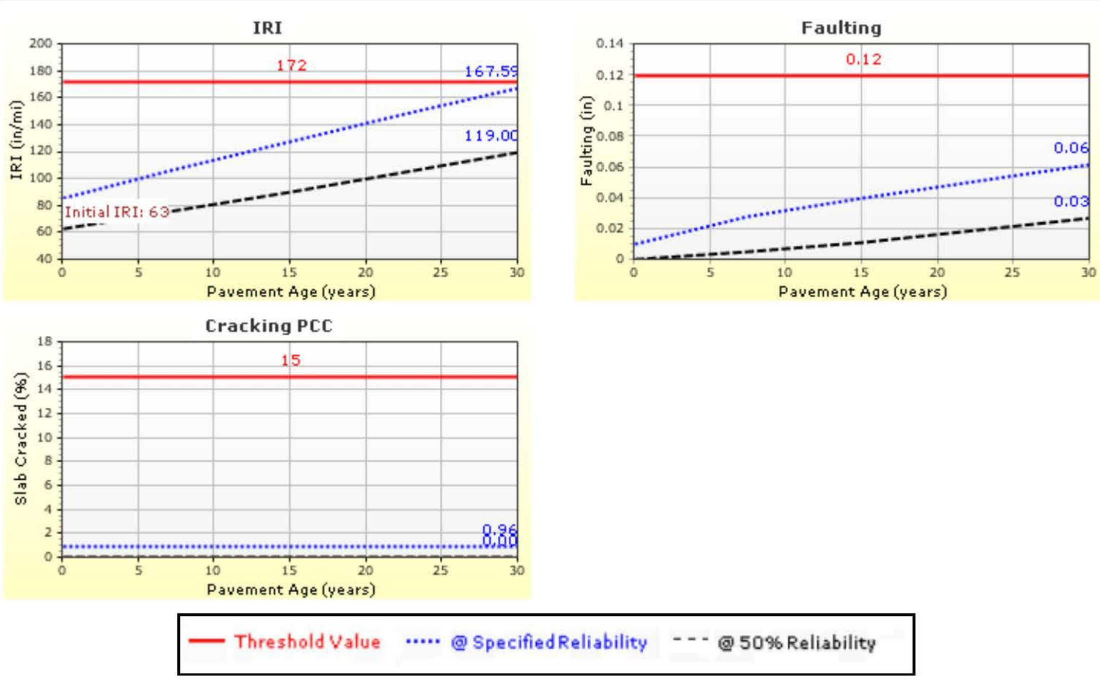
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 1,500 |
| 2034 (15 years) | 4,723,370 |
| 2049 (30 years) | 11,203,400 |

## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 167.59 | 90.00 | 91.89 | Pass |
| Mean joint faulting (in) | 0.12 | 0.06 | 90.00 | 99.97 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 0.96 | 90.00 | 100.00 | Pass |

### Distress Charts



# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.50 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 15.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| | |
|---|---|
| Sealant type | Preformed |

| | |
|---|---|
| Erodibility index | 2 |

| | |
|---|---|
| Permanent curl/warp effective temperature difference (ºF) | -10.00 |

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 10.0 |
| Unit weight (pcf) | 144.0 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.8 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 611.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Curing Compound |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6050.0 |
| **28-Day PCC elastic modulus (psi)** | 4300000.0 |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

**PCC Faulting**

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |
| **PCC Reliability Faulting Standard Deviation** | | | |
| 0.07162 * Pow(FAULT,0.368) + 0.00806 | | | |

**IRI-jpcp**

| | | |
|---|---|---|
| C1 - Cracking | C1: 0.8203 | C2: 0.4417 |
| C2 - Spalling | C3: 1.4929 | C4: 25.24 |
| C3 - Faulting | **Reliability Standard Deviation** | |
| C4 - Site Factor | 5.4 | |

**PCC Cracking**

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$
$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |
| **PCC Reliability Cracking Standard Deviation** | | | |
| 3.5522 * Pow(CRACK,0.3415) + 0.75 | | | |

# CC-10in-20ft-1.5in

File Name: C:\Users\IPDC\Documents\Pavement ME runs, May 2017\Nov. 6th\Final\Design\Control concrete\CC-10in-20ft-1.5in.dgpx

## Design Inputs

Design Life: 30 years
Design Type: JPCP

Existing construction: -
Pavement construction: June, 2019
Traffic opening: July, 2019

Climate Data Sources (Lat/Lon): 42.398, -90.704

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 10.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 20.0 |
| Dowel diameter (in) | 1.50 |
| Slab width (ft) | 12.0 |

### Traffic

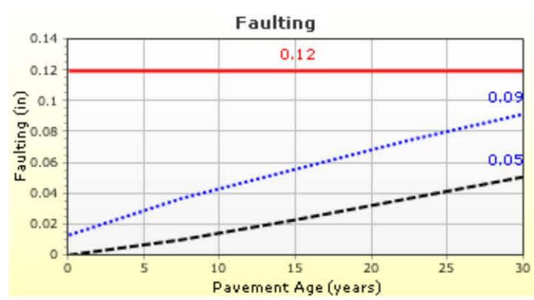
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 1,500 |
| 2034 (15 years) | 4,723,370 |
| 2049 (30 years) | 11,203,400 |

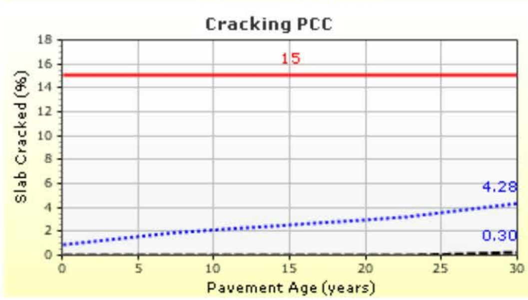
## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 174.51 | 90.00 | 88.81 | Fail |
| Mean joint faulting (in) | 0.12 | 0.09 | 90.00 | 98.49 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 4.28 | 90.00 | 100.00 | Pass |

### Distress Charts


Threshold Value — @ Specified Reliability — @ 50% Reliability

# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.50 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 20.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| Sealant type | Preformed |
|---|---|

| Erodibility index | 2 |
|---|---|

| Permanent curl/warp effective temperature difference (°F) | -10.00 |
|---|---|

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 10.0 |
| Unit weight (pcf) | 144.0 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.8 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 611.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Curing Compound |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6050.0 |
| **28-Day PCC elastic modulus (psi)** | 4300000.0 |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

**PCC Faulting**

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |
| **PCC Reliability Faulting Standard Deviation** | | | |
| 0.07162 * Pow(FAULT,0.368) + 0.00806 | | | |

**IRI-jpcp**

| | | |
|---|---|---|
| C1 - Cracking<br>C2 - Spalling<br>C3 - Faulting<br>C4 - Site Factor | C1: 0.8203 | C2: 0.4417 |
| | C3: 1.4929 | C4: 25.24 |
| | **Reliability Standard Deviation** | |
| | 5.4 | |

**PCC Cracking**

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$
$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |
| **PCC Reliability Cracking Standard Deviation** | | | |
| 3.5522 * Pow(CRACK,0.3415) + 0.75 | | | |

## Design Inputs

Design Life: 30 years
Design Type: JPCP

Existing construction: -
Pavement construction: June, 2019
Traffic opening: July, 2019

Climate Data Sources (Lat/Lon): 42.398, -90.704

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 7.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 15.0 |
| Dowel diameter (in) | 1.00 |
| Slab width (ft) | 12.0 |

### Traffic

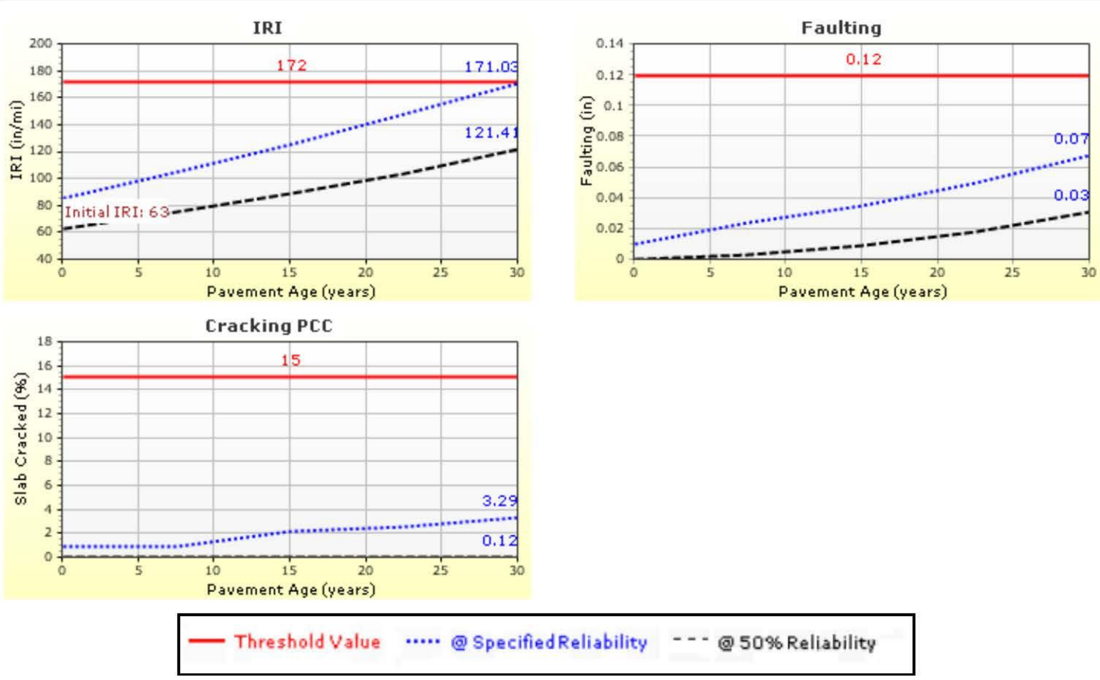
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 400 |
| 2034 (15 years) | 1,259,560 |
| 2049 (30 years) | 2,987,560 |

## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 171.03 | 90.00 | 90.43 | Pass |
| Mean joint faulting (in) | 0.12 | 0.07 | 90.00 | 99.91 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 3.29 | 90.00 | 100.00 | Pass |

### Distress Charts



# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.00 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 15.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| Sealant type | Preformed |
|---|---|

| Erodibility index | 2 |
|---|---|

| Permanent curl/warp effective temperature difference (°F) | -10.00 |
|---|---|

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 7.0 |
| Unit weight (pcf) | 138.5 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.3 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 592.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Wet Curing |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6070.0 |
| **28-Day PCC elastic modulus (psi)** | 3950000.0 |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

**PCC Faulting**

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |
| **PCC Reliability Faulting Standard Deviation** | | | |
| 0.07162 * Pow(FAULT,0.368) + 0.00806 | | | |

**IRI-jpcp**

| | | |
|---|---|---|
| C1 - Cracking | C1: 0.8203 | C2: 0.4417 |
| C2 - Spalling | C3: 1.4929 | C4: 25.24 |
| C3 - Faulting | **Reliability Standard Deviation** | |
| C4 - Site Factor | 5.4 | |

**PCC Cracking**

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$

$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |
| **PCC Reliability Cracking Standard Deviation** | | | |
| 3.5522 * Pow(CRACK,0.3415) + 0.75 | | | |

# ICC-7in-20ft-1in

File Name: C:\Users\IPDC\Documents\Pavement ME runs, May 2017\Nov. 6th\Final\Design\IC concrete\ICC-7in-20ft-1in.dgpx

## Design Inputs

| | | | | | |
|---|---|---|---|---|---|
| Design Life: | 30 years | Existing construction: | - | Climate Data Sources (Lat/Lon) | 42.398, -90.704 |
| Design Type: | JPCP | Pavement construction: | June, 2019 | | |
| | | Traffic opening: | July, 2019 | | |

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 7.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 20.0 |
| Dowel diameter (in) | 1.00 |
| Slab width (ft) | 12.0 |

### Traffic

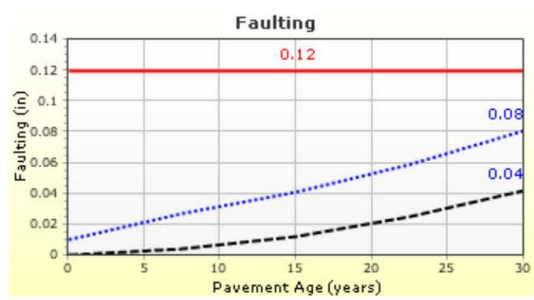
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 400 |
| 2034 (15 years) | 1,259,560 |
| 2049 (30 years) | 2,987,560 |

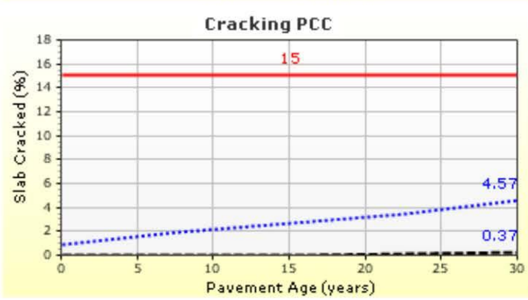
## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 169.99 | 90.00 | 90.90 | Pass |
| Mean joint faulting (in) | 0.12 | 0.08 | 90.00 | 99.48 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 4.57 | 90.00 | 100.00 | Pass |

### Distress Charts


# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.00 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 20.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| Sealant type | Preformed |
|---|---|

| Erodibility index | 2 |
|---|---|

| Permanent curl/warp effective temperature difference (°F) | -10.00 |
|---|---|

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 7.0 |
| Unit weight (pcf) | 138.5 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.3 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 592.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Wet Curing |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6070.0 |
| **28-Day PCC elastic modulus (psi)** | 3950000.0 |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

### PCC Faulting

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |

**PCC Reliability Faulting Standard Deviation**

0.07162 * Pow(FAULT,0.368) + 0.00806

### IRI-jpcp

C1 - Cracking
C2 - Spalling
C3 - Faulting
C4 - Site Factor

| | |
|---|---|
| C1: 0.8203 | C2: 0.4417 |
| C3: 1.4929 | C4: 25.24 |

**Reliability Standard Deviation**

5.4

### PCC Cracking

$$\log(N) = C1 \cdot (\frac{MR}{\sigma})^{C2}$$
$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |

**PCC Reliability Cracking Standard Deviation**

3.5522 * Pow(CRACK,0.3415) + 0.75

# ICC-9in-15ft-1.5in

File Name: C:\Users\IPDC\Documents\Pavement ME runs, May 2017\Nov. 6th\Final\Design\IC concrete\ICC-9in-15ft-1.5in.dgpx

## Design Inputs

Design Life: 30 years
Design Type: JPCP

Existing construction: -
Pavement construction: June, 2019
Traffic opening: July, 2019

Climate Data Sources (Lat/Lon): 42.398, -90.704

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 9.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 15.0 |
| Dowel diameter (in) | 1.50 |
| Slab width (ft) | 12.0 |

### Traffic

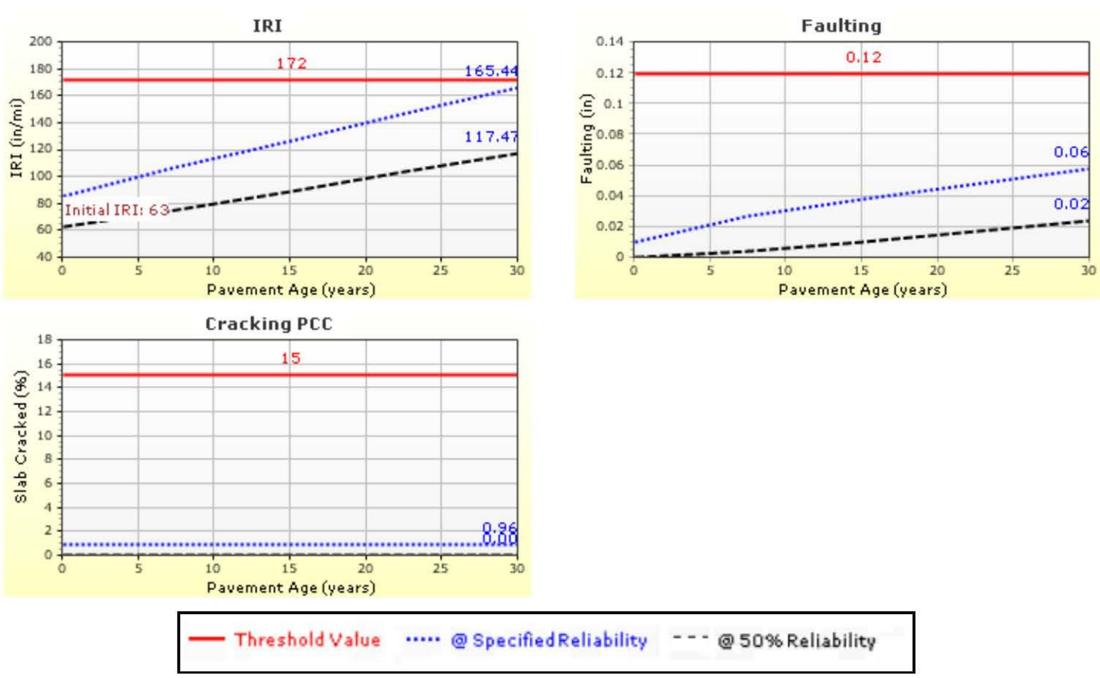
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 1,500 |
| 2034 (15 years) | 4,723,370 |
| 2049 (30 years) | 11,203,400 |

## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 165.44 | 90.00 | 92.74 | Pass |
| Mean joint faulting (in) | 0.12 | 0.06 | 90.00 | 99.99 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 0.96 | 90.00 | 100.00 | Pass |

### Distress Charts



# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.50 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 15.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| Sealant type | Preformed |
|---|---|

| Erodibility index | 2 |
|---|---|

| Permanent curl/warp effective temperature difference (°F) | -10.00 |
|---|---|

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 9.0 |
| Unit weight (pcf) | 138.5 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.3 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 592.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Wet Curing |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6070.0 |
| **28-Day PCC elastic modulus (psi)** | 3950000.0 |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

**PCC Faulting**

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |

**PCC Reliability Faulting Standard Deviation**

0.07162 * Pow(FAULT,0.368) + 0.00806

**IRI-jpcp**

| | | |
|---|---|---|
| C1 - Cracking<br>C2 - Spalling<br>C3 - Faulting<br>C4 - Site Factor | C1: 0.8203 | C2: 0.4417 |
| | C3: 1.4929 | C4: 25.24 |
| | **Reliability Standard Deviation** | |
| | 5.4 | |

**PCC Cracking**

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$
$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |

**PCC Reliability Cracking Standard Deviation**

3.5522 * Pow(CRACK,0.3415) + 0.75

# ICC-9in-20ft-1.5in

File Name: C:\Users\IPDC\Documents\Pavement ME runs, May 2017\Nov. 6th\Final\Design\IC concrete\ICC-9in-20ft-1.5in.dgpx

## Design Inputs

Design Life: 30 years
Design Type: JPCP

Existing construction: -
Pavement construction: June, 2019
Traffic opening: July, 2019

Climate Data Sources (Lat/Lon): 42.398, -90.704

### Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| PCC | JPCP Default | 9.0 |
| NonStabilized | Crushed gravel | 10.0 |
| Subgrade | A-7-6 | Semi-infinite |

| Joint Design: | |
|---|---|
| Joint spacing (ft) | 20.0 |
| Dowel diameter (in) | 1.50 |
| Slab width (ft) | 12.0 |

### Traffic

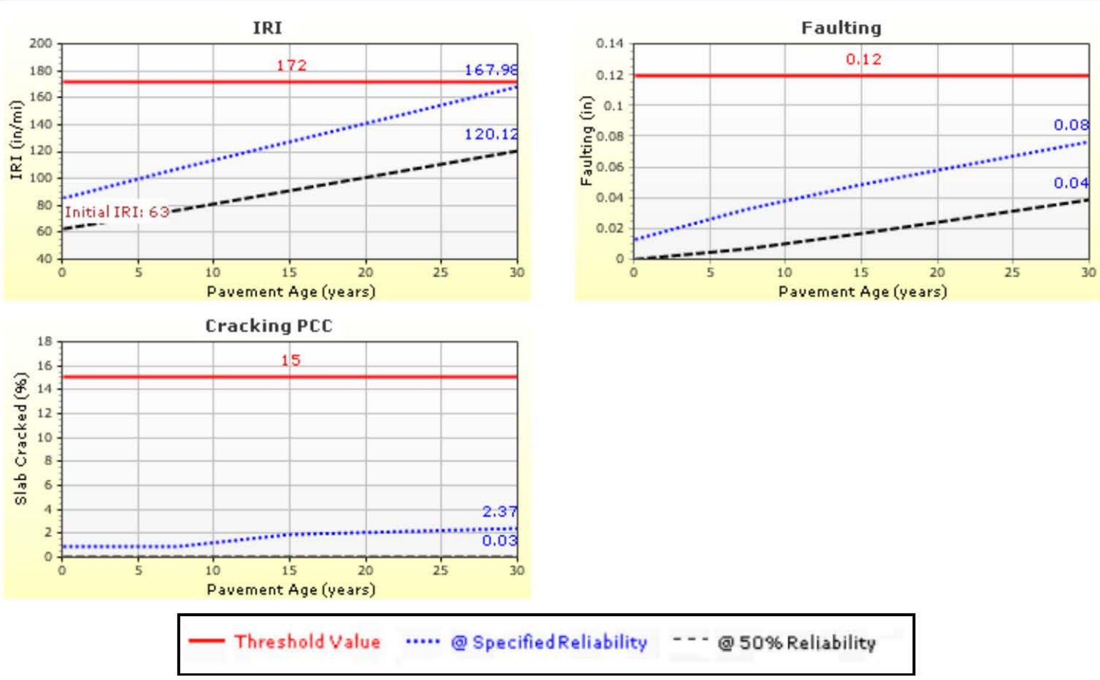
| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2019 (initial) | 1,500 |
| 2034 (15 years) | 4,723,370 |
| 2049 (30 years) | 11,203,400 |

## Design Outputs

### Distress Prediction Summary

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 167.98 | 90.00 | 91.76 | Pass |
| Mean joint faulting (in) | 0.12 | 0.08 | 90.00 | 99.66 | Pass |
| JPCP transverse cracking (percent slabs) | 15.00 | 2.37 | 90.00 | 100.00 | Pass |

### Distress Charts



# Design Properties

## JPCP Design Properties

| Structure - ICM Properties | |
|---|---|
| PCC surface shortwave absorptivity | 0.85 |

| Doweled Joints | |
|---|---|
| Is joint doweled ? | True |
| Dowel diameter (in) | 1.50 |
| Dowel spacing (in) | 12.00 |

| Tied Shoulders | |
|---|---|
| Tied shoulders | True |
| Load transfer efficiency (%) | 40.00 |

| PCC joint spacing (ft) | |
|---|---|
| Is joint spacing random ? | False |
| Joint spacing (ft) | 20.00 |

| Widened Slab | |
|---|---|
| Is slab widened ? | False |
| Slab width (ft) | 12.00 |

| PCC-Base Contact Friction | |
|---|---|
| PCC-Base full friction contact | True |
| Months until friction loss | 240.00 |

| Sealant type | Preformed |
|---|---|

| Erodibility index | 2 |
|---|---|

| Permanent curl/warp effective temperature difference (°F) | -10.00 |
|---|---|

# Layer Information

## Layer 1 PCC : JPCP Default

| PCC | |
|---|---|
| Thickness (in) | 9.0 |
| Unit weight (pcf) | 138.5 |
| Poisson's ratio | 0.2 |

| Thermal | |
|---|---|
| PCC coefficient of thermal expansion (in/in/°F x 10^-6) | 4.3 |
| PCC thermal conductivity (BTU/hr-ft-°F) | 1.25 |
| PCC heat capacity (BTU/lb-°F) | 0.28 |

| Mix | | |
|---|---|---|
| Cement type | | Type I (1) |
| Cementitious material content (lb/yd^3) | | 550 |
| Water to cement ratio | | 0.43 |
| Aggregate type | | Limestone (1) |
| PCC zero-stress temperature (°F) | Calculated Internally? | False |
| | User Value | 101.9 |
| | Calculated Value | - |
| Ultimate shrinkage (microstrain) | Calculated Internally? | False |
| | User Value | 592.0 |
| | Calculated Value | - |
| Reversible shrinkage (%) | | 50 |
| Time to develop 50% of ultimate shrinkage (days) | | 35 |
| Curing method | | Wet Curing |

### PCC strength and modulus (Input Level: 3)

| | |
|---|---|
| **28-Day PCC compressive strength (psi)** | 6070.0 |
| **28-Day PCC elastic modulus (psi)** | 3950000.0 |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | JPCP Default |
| Description of object | |
| Author | |
| Date Created | 5/9/2017 12:58:38 PM |
| Approver | |
| Date approved | 5/9/2017 12:58:38 PM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

## Layer 2 Non-stabilized Base : Crushed gravel

| Unbound | |
|---|---|
| Layer thickness (in) | 10.0 |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 38000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | Crushed gravel |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 6.0 |
| **Plasticity Index** | 1.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 127.2 |
| Saturated hydraulic conductivity (ft/hr) | False | 5.054e-02 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 7.4 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 7.2555 |
| bf | 1.3328 |
| cf | 0.8242 |
| hr | 117.4000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 8.7 |
| #100 | |
| #80 | 12.9 |
| #60 | |
| #50 | |
| #40 | 20.0 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 33.8 |
| #8 | |
| #4 | 44.7 |
| 3/8-in. | 57.2 |
| 1/2-in. | 63.1 |
| 3/4-in. | 72.7 |
| 1-in. | 78.8 |
| 1 1/2-in. | 85.8 |
| 2-in. | 91.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 97.6 |

## Layer 3 Subgrade : A-7-6

| Unbound | |
|---|---|
| Layer thickness (in) | Semi-infinite |
| Poisson's ratio | 0.35 |
| Coefficient of lateral earth pressure (k0) | 0.5 |

### Modulus (Input Level: 3)

| | |
|---|---|
| **Analysis Type:** | Modify input values by temperature/moisture |
| **Method:** | Resilient Modulus (psi) |

| Resilient Modulus (psi) |
|---|
| 10000.0 |

| | |
|---|---|
| **Use Correction factor for NDT modulus?** | - |
| **NDT Correction Factor:** | - |

### Identifiers

| Field | Value |
|---|---|
| Display name/identifier | A-7-6 |
| Description of object | Default material |
| Author | AASHTO |
| Date Created | 1/1/2011 12:00:00 AM |
| Approver | |
| Date approved | 1/1/2011 12:00:00 AM |
| State | |
| District | |
| County | |
| Highway | |
| Direction of Travel | |
| From station (miles) | |
| To station (miles) | |
| Province | |
| User defined field 1 | |
| User defined field 2 | |
| User defined field 3 | |
| Revision Number | 0 |

### Sieve

| | |
|---|---|
| **Liquid Limit** | 51.0 |
| **Plasticity Index** | 30.0 |
| **Is layer compacted?** | False |

| | Is User Defined? | Value |
|---|---|---|
| Maximum dry unit weight (pcf) | False | 97.7 |
| Saturated hydraulic conductivity (ft/hr) | False | 8.946e-06 |
| Specific gravity of solids | False | 2.7 |
| Water Content (%) | False | 22.2 |

| User-defined Soil Water Characteristic Curve (SWCC) | |
|---|---|
| Is User Defined? | False |
| af | 136.4179 |
| bf | 0.5183 |
| cf | 0.0324 |
| hr | 500.0000 |

| Sieve Size | % Passing |
|---|---|
| 0.001mm | |
| 0.002mm | |
| 0.020mm | |
| #200 | 79.1 |
| #100 | |
| #80 | 84.9 |
| #60 | |
| #50 | |
| #40 | 88.8 |
| #30 | |
| #20 | |
| #16 | |
| #10 | 93.0 |
| #8 | |
| #4 | 94.9 |
| 3/8-in. | 96.9 |
| 1/2-in. | 97.5 |
| 3/4-in. | 98.3 |
| 1-in. | 98.8 |
| 1 1/2-in. | 99.3 |
| 2-in. | 99.6 |
| 2 1/2-in. | |
| 3-in. | |
| 3 1/2-in. | 99.9 |

## Calibration Coefficients

**PCC Faulting**

$$C_{12} = C_1 + (C_2 * FR^{0.25})$$
$$C_{34} = C_3 + (C_4 * FR^{0.25})$$
$$FaultMax_0 = C_{12} * \delta_{curling} * \left[\log(1 + C_5 * 5.0^{EROD}) * \log\left(P_{200} * \frac{WetDays}{p_s}\right)\right]^{C_6}$$
$$FaultMax_i = FaultMax_0 + C_7 * \sum_{j=1}^{m} DE_j * \log(1 + C_5 * 5.0^{EROD})^{C_6}$$
$$\Delta Fault_i = C_{34} * (FaultMax_{i-1} - Fault_{i-1})^2 * DE_i$$
$$C_8 = DowelDeterioration$$

| | | | |
|---|---|---|---|
| C1: 0.595 | C2: 1.636 | C3: 0.00217 | C4: 0.00444 |
| C5: 250 | C6: 0.47 | C7: 7.3 | C8: 400 |
| **PCC Reliability Faulting Standard Deviation** | | | |
| 0.07162 * Pow(FAULT,0.368) + 0.00806 | | | |

**IRI-jpcp**

| | | |
|---|---|---|
| C1 - Cracking | C1: 0.8203 | C2: 0.4417 |
| C2 - Spalling | C3: 1.4929 | C4: 25.24 |
| C3 - Faulting | **Reliability Standard Deviation** | |
| C4 - Site Factor | 5.4 | |

**PCC Cracking**

$$\log(N) = C1 \cdot \left(\frac{MR}{\sigma}\right)^{C2}$$
$$CRK = \frac{100}{1 + C4\ FD^{C5}}$$

| Fatigue Coefficients | | Cracking Coefficients | |
|---|---|---|---|
| C1: 2 | C2: 1.22 | C4: 0.52 | C5: -2.17 |
| **PCC Reliability Cracking Standard Deviation** | | | |
| 3.5522 * Pow(CRACK,0.3415) + 0.75 | | | |

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