Portland Cement Concrete Material Characterization for Pavement ME Design Implementation in Idaho

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IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

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RP 253

Portland Cement Concrete Material Characterization for Pavement ME Design Implementation in Idaho

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16. Abstract

The objective of this research project was to develop a concrete material database as the first step towards the implementation of Pavement ME for rigid pavement design in the state of Idaho. Eight concrete mixtures from five of Idaho Transportation Department (ITD) districts were reproduced at Washington State University's laboratory using the local aggregates and based on the corresponding field test results obtained from the respective district. Cast portland cement concrete (PCC) specimens were tested for compressive strength (f'_c), modulus of elasticity (E_c), Poisson's ratio (μ), modulus of rupture (*MR*), splitting tensile strength (f'_t), coefficient of thermal expansion (CTE) and ultimate drying shrinkage (ε_∞). All mechanical tests were repeated on 7-, 14-, 28- and 90-day ages. Based on the laboratory test results, proper values for all PCC Pavement ME material inputs at Levels 1 and 2 were recommended, wherever available. In other cases, Level 3 values were suggested for a few material inputs that were not the characterized in this project. Two case studies were developed for the rigid pavement highway sections in Idaho that are also part of the Long term Pavement Performance (LTPP) database. Pavement structure, general design inputs and traffic inputs were defined based on the LTPP data. In terms of material parameters, experimental data obtained as part of this study was utilized at input Levels 1 and 2 and compared to the default values at input Level 3. The case studies revealed that the usage of experimental data at Levels 1 and 2 results in lower distress predications and more economic design compared to Level 3. Beyond the mixtures tested in this project, tests of f'_c at all four required ages, CTE, and ε_∞ are recommended at minimum.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4		mm	mm	millimeters	0.039	inches	in
ft	feet	0.3048		m	m	meters	3.28	feet	ft
yd	yards	0.914		m	m	meters	1.09	yards	yd
mi	Miles (statute)	1.61		km	km	kilometers	0.621	Miles (statute)	mi
		AREA					AREA		
in^2	square inches	645.2	millimeters squared	cm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.0929	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	km^2	kilometers squared	0.39	square miles	mi^2
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g	g	grams	0.0353	Ounces (avdp)	oz
lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
^oF	Fahrenheit temperature	5/9 (^{o}F-32)	Celsius temperature	^oC	^oC	Celsius temperature	9/5 ^{o}C+32	Fahrenheit temperature	^oF
		ILLUMINATION					ILLUMINATION		
fc	Foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

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Technical Advisory Committee

Each research project is supervised by a technical advisory committee (TAC), led by an ITD project sponsor and project manager. The Technical Advisory Committee (TAC) is in charge of overseeing the project progress, reviewing deliverables and ensuring that study objective are met in a timely manner. The work of the following TAC members in guiding this research study is gratefully recognized.

Project Manager – Mike Santi, PE, Materials Engineer

TAC Members

Clint Hoops, PE, Concrete Material Engineer

Ron Wright, Laboratory Services Manager

Mark Wheeler, PE, Pavement Engineer

Jeff Drager, PE, District 1 Materials Engineer

Ned Parrish, Research Program Manager

FHWA-Project Advisor — Kyle Holman

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List of Acronyms

AADTT	Annual Average Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Standard for Testing and Materials
CC	Cementitious materials content
CRCP	Continuously Reinforced Concrete Pavement
CTE	Coefficient of thermal expansion
E_c	PCC modulus of elasticity
EICM	Enhanced Integrated Climatic Model
ESAL	Equivalent Single Axle Load
f'_c	Compressive strength of PCC
f'_t	Split tensile strength of PCC
FD	Fatigue damage
HMA	Hot Mix Asphalt
IRI	International Roughness Index
ITD	Idaho Transportation Department
JPCP	Jointed Plain Concrete Pavement
K	Heat capacity of PCC
LC	Local Calibration
LTPP	Long Term Pavement Performance
MAF	Monthly Adjustment Factor
ME	Mechanistic-empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
MMT	Mean monthly temperature
MR	Modulus of rupture of PCC
NCHRP	National Cooperative Highway Research Program
PCC	Portland Cement Concrete
Pavement ME	AASHTOWare Pavement Mechanistic Empirical Design
Q	Heat capacity of PCC
RH	Relative humidity
RP	Research project
SCM	Supplementary cementitious materials
T_Z	PCC zero-stress temperature
UI	University of Idaho
w/cm	Water-to-cementitious materials ratio
WSU	Washington State University
ε_∞	Ultimate drying shrinkage
μ	Poisson's ratio of PCC

Executive Summary

Introduction

State Departments of Transportation (DOT) and highway agencies are making the necessary efforts to transition from the American Association of State Highway and Transportation Officials (AASHTO) 1993 empirical Design Guide to the recently released AASHTOWare Pavement ME Design (hereafter Pavement ME.) This research project was the first preparatory work by Idaho Transportation Department (ITD) to implement the ME design software for the design of rigid pavements across the State of Idaho. This project encompassed tests of ITD's portland cement concrete (PCC) paving mixtures, which are used for road and highway paving. In addition, in the absence of concrete paving mixtures, some districts provided their structural mixtures that are primarily used for bridge decks and structures for the development of the required PCC material database for use in the Pavement ME software.

Overview of Experimental Work

A total of eight PCC mixtures (five paving and three structural mixtures) from five districts in Idaho were reproduced in Washington State University (WSU)'s laboratory as closely as possible to the mixtures used in the field. This was obtained by using each districts' local aggregates and batching the mixture based on the corresponding field test results obtained from ITD for slump and entrained air. Cast PCC specimens were used for mechanical tests including compressive strength (f'_c), modulus of elasticity (E_c), Poisson's ratio (μ), modulus of rupture (*MR)* and splitting tensile strength (f'_t). Other material performance tests included the determination of coefficient of thermal expansion (CTE) and ultimate drying shrinkage (ε_∞). All the mechanical tests were performed on 7-, 14-, 28- and 90-day ages, while the CTE was determined on specimens after 28-day age. Drying shrinkage was measured on the specimens exposed to air drying at a constant humidity up to 54 weeks, following the initial 28 days of moist curing.

Final Report Summary

Concrete Material Inputs Database

Pavement ME features three hierarchical input levels, based on project significance and reliability of the input data. Level 1 data is based on direct experimental characterization, Level 2 uses the data from comparable projects and empirical equations, while Level 3 relies on national and regional averages and empirical relations. Proper values are recommended in this report for all the PCC material inputs in Pavement ME at Levels 1 and 2, based on laboratory-obtained experimental results and regional averages, respectively. Moreover, the values of unit weight of fresh PCC, water-to-cementitious materials ratio (w/cm), and cementitious materials content, all of which are Pavement ME design inputs, are summarized for the tested mixtures and respective recommendations are provided for these inputs. Level 3 values are suggested for a handful of material inputs that were not encompassed in the scope of this project. These inputs are heat capacity, thermal conductivity, irreversible drying shrinkage, and permanent curl/warp temperature difference.

Mechanical properties for the PCC mix are recommended to be defined at Level 2, which includes f'_c at 7-, 14-, 28- and 90-day ages. This recommendation is due to the occasional decrease in some of the mechanical properties at later test dates, which will result in a user error when using Pavement ME. The two design case studies in this project showed that the effect of Level 1 versus Level 2 on the predicted distresses is negligible. Furthermore, strength growth curves for f'_c, E_c and *MR* based on the experimental results were developed for IDT mix designs and materials. Comparison with Pavement ME default growth curves shows that the strength gain for these three mechanical properties is underestimated in Pavement ME model and is therefore suggested to be replaced with the values developed in this project. Finally, an empirical relationship to obtain 28-day E_c and *MR* based on the 28-day f'_c was developed and compared to the corresponding default correlation coefficients incorporated in Pavement ME. Discrepancies between the experimentally established and the default correlation coefficients for *MR* and E_c were identified.

The experimental results, based on mixture design and respective district, were systematized in the PCC ME material database in Appendix D. The results were organized in the fashion that follows Pavement ME input order.

Design Case Studies

To evaluate the sensitivity of Pavement ME distress predictions to the experimentally-established material inputs in comparison to the default values, two existing rigid highway pavement sections in Districts 3 and 5 were designed using the software. The pavement structure, coordinates, general design inputs, and traffic data available in the Long Term Pavement Performance (LTPP) database were used. In terms of material inputs, three cases corresponding to the three input levels in Pavement ME were developed for each section: Level 3 with all Pavement ME default inputs, Level 2 and Level 1 with the input parameters based on the experimentally-determined PCC properties for the mixtures from the respective districts. For both sections design scenarios using Levels 1 and 2 provided similar results in terms of predicted distresses: joint faulting, transverse cracking and international roughness index (IRI). Further, the predicted distresses were markedly lower for the Level 1 and 2 scenarios compared to the Level 3 scenario, implying that using the national average default values in Pavement ME may result in an overestimation of the required slab thickness. Therefore, the implementation of parameter values specific to hierarchically higher input levels is recommended to obtain more realistic distress predictions and potential savings to the agency.

Conclusions and Recommendations

Based on testing of eight PCC mixtures from five districts of the ITD, a material input database for rigid pavement design using Pavement ME was developed in this project. Recommendations were provided for the appropriate values for each material input, specifically mechanical parameters (f'_c, E_c, μ and *MR*), CTE, ultimate drying shrinkage, and unit weight. For other PCC design inputs, recommendations were provided based on the mixture design (e. g. cementitious material content) or the default values (e. g. thermal conductivity, heat capacity, reversible shrinkage percentage). Two design case studies indicated that the implementation of the experimentally established material design inputs results in lower distress predictions in comparison with the usage of default values. It is thus, expected that the PCC material database will help ITD attain optimized pavement designs and potential savings on future projects. Based on the results of this study, the authors recommend f'_c tests on four test dates (7-, 14-, 28- and 90-days), tests of CTE and ε_∞ for the rigid pavement design using AASHTOWare Pavement ME.

Chapter 1
Introduction

Background

The Mechanistic-Empirical Pavement Design Guide (MEPDG) was developed as the outcome of the National Cooperative Research Program (NCHRP) 1-37A research project in 2002. [1] In the period between 2002 and 2011, several beta versions of the MEPDG went through extensive evaluations by academia and practitioners. The development of the MEPDG started an evolution in pavement design procedures across North America by transitioning the design from the empirical AASHTO 1993 design guide to the mechanistic-empirical based principles. [2] Today, a new version of the MEPDG software is commercially offered by the American Association of State Highway and Transportation Officials (AASHTO) as the AASHTOWare Pavement ME.

Pavement ME overcomes many limitations of the conventional AASHTO 1993 thickness design procedure, which relies upon the empirical serviceability loss-based design relationships developed based on the AASHO road experiment. Using Pavement ME, axle loads are no longer converted to one Equivalent Single Axle Load (ESAL's) value over the design life. Instead, distributions of the axle loads for different axle types (axle load spectra) are directly entered and used in the design. Moreover, hourly and monthly adjustment factors can be defined to the load distributions and truck classifications where needed. Layer coefficients for asphalt concrete (AC) and asphalt-treated bases (ATB) are replaced with direct values of mechanical properties, such as the dynamic modulus for asphalt concrete, and resilient modulus for unbound materials. The moduli are adjusted based on the effect of temperature and moisture for specified time increments over the design life. Modulus of rupture and modulus of elasticity for portland cement concrete (PCC) still have the significant effects on the thickness design. Additional PCC parameters such as thermal properties and ultimate drying shrinkage are incorporated in the new design guide.

One of the novel characteristics of Pavement ME is the three hierarchical input levels, which provide the user with flexibility in defining the design inputs based on availability of the data for a specific project. Level 1 utilizes the data obtained via direct experimental characterization, Level 2 combines the data from comparable projects and empirical equations, while Level 3 relies on default values (national and regional averages) and empirical relationships of these input variables. Defining the traffic and material inputs at Level 1 is suggested for the projects of highest significance where accurate and reliable predictions are required.

The effects of climate are incorporated in Pavement ME using the embedded Enhanced Integrated Climatic Model (EICM), which uses the embedded site-specific hourly climatic databases to predict the in-pavement temperature and moisture conditions for use in the mechanistic analysis. [3]

Advances in modeling and computational techniques made it possible to embed Pavement ME with finite element analysis models and neural networks to extract the pavement responses in terms of stresses, strains and deflections for the specific site's material, traffic, and climate conditions. Finally, embedded empirical models that are calibrated based on nation-wide field distress data are used to predict the in-field distress development over the design period in conjunction with reliability models to account for variability.

Detailed site and material-specific design inputs are required for the design using Pavement ME. Therefore, before Pavement ME can be implemented by highway agencies, the necessary preparation steps especially in terms of developing the required material input databases need to be taken. Development of a concrete material input database was the focus of the current project, which will be discussed further in detail as follows.

Project Scope

As stated earlier, the transition from AASHTO 1993 to Pavement ME demands extensive preparatory work by highway agencies. Pavement ME includes more than 100 design inputs and, therefore, a reliable design depends on the accuracy and reliability of the input parameters. Because mechanistic design procedures rely considerably on material parameters, the determination of appropriate material properties for use in Pavement ME represents a critical portion of the preparatory work. This project, *Portland Cement Concrete Material Characterization for Pavement ME Design Implementation in Idaho, RP 253* focused on characterization of typical concrete paving mixtures used in the State of Idaho.

The project started with correspondence between representatives of the six districts in Idaho to obtain concrete mixture designs and samples of respective aggregate sources from each district. Five of these six districts were able to provide samples of aggregate from their concrete mixtures for testing in this project. Eight PCC mixture designs representing five districts in Idaho were tested as presented in Table 1. Approximate geographical location of the eight projects correspondent to the tested mixtures is pretend on the map of the State of Idaho in Figure 1.

Copies of the original mixture designs are provided in Appendix A. A summary of the mixture constituents and proportioning are provided in Table 1. Please note that a few districts supplemented the project with their structural mixtures in the lack of concrete paving projects. Structural mixtures were used mainly for bridge decks and generally have higher w/cm, and workability and lower nominal maximum aggregate size comparing to paving mixtures. It is also expected that the structural mixture will demonstrate higher mechanical properties and higher drying shrinkage comparing to the paving mixtures. Due to these inherent differences between the two groups of PCC mixtures tested in the project, the test results in this report are mainly maintained in the two separate groups for comparisons. In addition to aggregates representing five IDT districts, other constituents including cement, supplementary cementitious materials (SCM), and admixtures necessary to reproduce the mixtures from each district were collected from respective suppliers according to each mixture design.

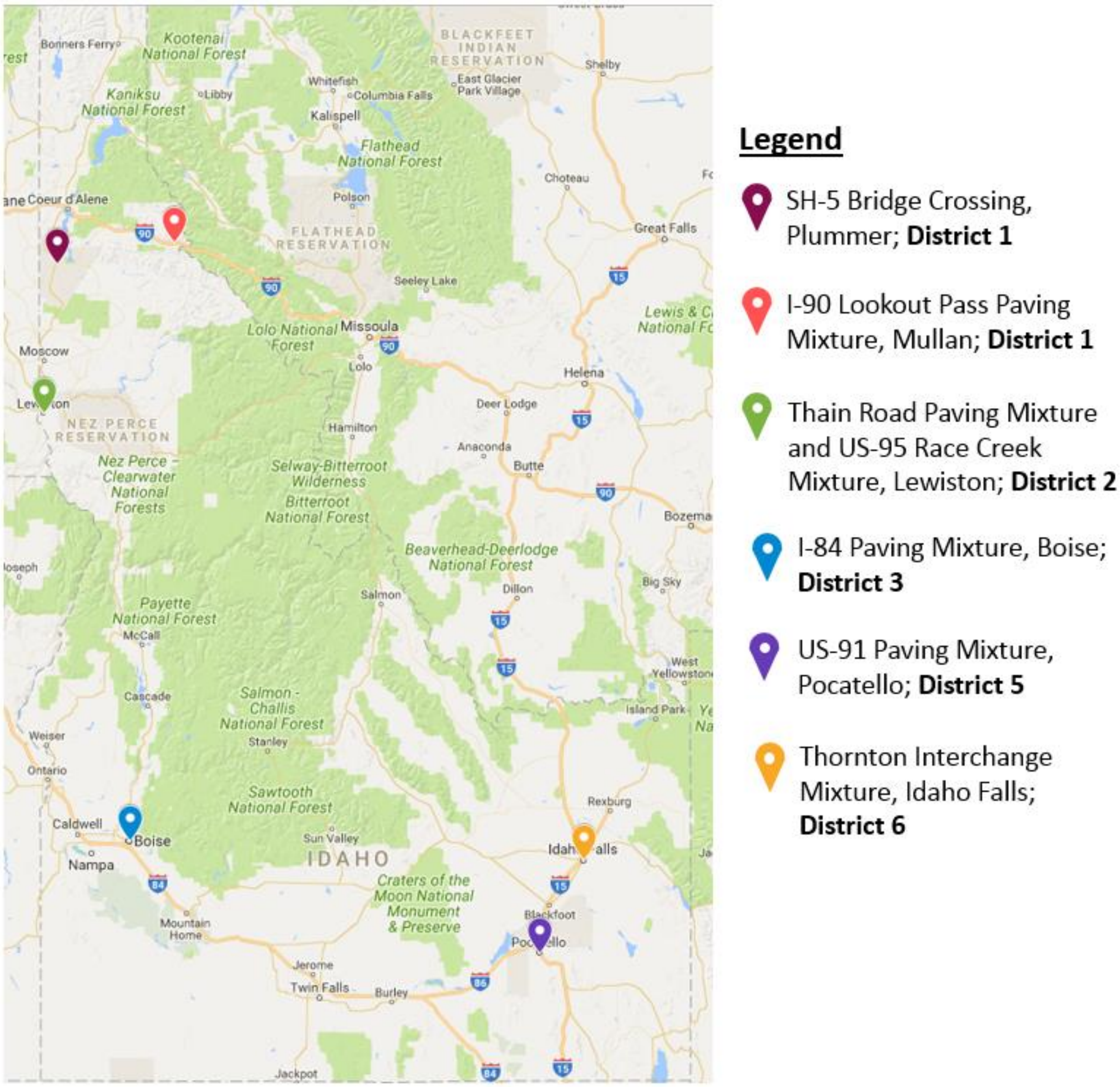


Figure 1. Geographical Distribution of the Eight Projects for Mixtures Tested in the Project

Table 1. PCC Mixture Designs Tested in RP 253 and Included in the Study

District	Mixture ID	Mixture Type	Coarse Agg. Content [lbs/yd3]	Fine Agg. Content [lbs/yd3]	Nominal Max Agg. Size [in]	w/cm	Cementitious Material Content [lbs/yd3]	Slump * [in]
1	SH-5 Bridge Crossing, Plummer	Structural	1,850	1,081	¾	0.42	611	3 ½
	I-90 Lookout Pass Paving Mixture 2015, Mullan	Paving	1,803	1,154	1 ½	0.38	688	1 ½
	I-90 Lookout Pass Paving Mixture 2016, Mullan	Paving	1,745	1,126	1 ½	0.40	688	1 ½
2	Thain Road Paving Mixture, Lewiston	Paving	1,721	1,246	¾	0.43	611	4 ½
	US-95 Race Creek Mixture, Lewiston	Structural	1,660	1,350	¾	0.40	625	5 ¾
3	I-84 Paving Mixture, Boise	Paving	1,751	1,167	1 ½	0.40	625	1 ¾
5	US-91 Paving Mixture, Pocatello	Paving	1,720	1,043	1 ½	0.39	729	3 ¼
6	Thornton Interchange Mixture, Idaho Falls	Structural	1,762	1,005	¾	0.39	658	4 ¾

*Values of slump are based on ITD' on-site tests during paving.

Upon material collection, batching and testing of mixtures was initiated at WSU's concrete material characterization laboratory (CMCL) in May 2016. Prior to laboratory mixing, ITD's field test results corresponding to each mixture were compiled and laboratory mixtures were reproduced so that fresh parameters, slump and air content, closely followed field results. Mixing procedures, as well as casting and curing of the specimens, were conducted per the requirements of ASTM C192. [4] Performed fresh concrete quality control tests with corresponding standardized procedures are listed as follows:

- Slump "Standard Test Method for Slump of Hydraulic-Cement Concrete" ASTM C143 [5]
- Air content "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method" ASTM C231 [6]
- Unit weight "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete" ASTM C138 [7]
- Concrete temperature "Standard Test Method for Temperature of Freshly Mixed Hydraulic Cement Concrete" ASTM C1064 [8]

Slump and the temperature of concrete were monitored for every batch, while the unit weight and air content were determined for every other batch. The following mechanical tests were conducted on four types of specimens:

- Compressive strength (f'_c), modulus of elasticity (E_c), Poisson's ratio (μ), and splitting tensile strength (f'_t) on 6" by 12" cylinders
- Modulus of rupture (*MR*) on 6" by 6" by 20" beams
- Coefficient of thermal expansion (CTE) 4" by 8" cylinders
- Ultimate drying shrinkage (ε_∞) on 2" by 2" by 11" prisms

Table 2 presents the number of specimens used for each test. All the mechanical tests were performed on 7-, 14-, 28- and 90-day ages for the number of specimens shown in Table 2. Coefficient of thermal expansion was established on specimens after 28-days, while the ultimate drying shrinkage (ε_∞) was characterized for specimens exposed to extended air drying (up to 50 weeks) after the initial 28 days of moist curing. More details on the test procedures can be found in subsequent chapters.

Table 2. Material Properties, Standards, and Test Dates for Concrete Material Characterization in RP 253

Material Test	Corresponding Standard	Number of Specimens for Testing			
		7-day	14-day	28-day	90-day
Modulus of Elasticity (E_c) & Poisson's Ratio	ASTM C469	3	3	3	3
Compressive Strength (f'_c)*	ASTM C39	4	4	4	4
Split Tensile Strength (f'_t)	ASTM C496	3	3	3	3
Modulus of Rupture (*MR*)	ASTM C239	3	3	3	3
Coefficient of Thermal Expansion (CTE)	AASHTO T-336	-	-	2	-
Drying shrinkage (ε_∞)	ASTM C157	6			

**Three of the specimens on each test date were also used in elastic modulus testing.*

During the course of the project, seven project deliverables were submitted to ITD. Deliverable 1 contained the review and summary of ITD material specifications, as well as a report of the collected concrete mixture designs from six districts of ITD. Deliverable 2 presented a detailed experimental plan and the respective schedule as well as a detailed description of the test procedures. Deliverables 3 and 4 focused on the material collection status, as well as a summary of the aggregate testing and mixing efforts. Deliverable 5 summarized the latest test results, while Deliverable 6 was the in-progress version of Pavement ME material database developed for ITD. Deliverable 7 was a follow-up to Deliverable 5 as it provided the most recent report of the test results since Deliverable 5, as well as a tentative outline for the final report. Final report draft was submitted as Deliverable 8, the current document represents the project final report after ITD review and commenting.

Report Organization

Following this introductory chapter, Chapters 2, 3 and 4 present the material input database for concrete pavement design using Pavement ME. These chapters are organized to follow the same order that the material inputs are required to be defined when using Pavement ME. Proper values at mainly Level 1 and 2 are recommended for all the PCC material input parameters included in Pavement ME based on the experimental results, where available. In other cases, Level 3 values are suggested for a few material inputs that were not the focus of this project, specifically thermal properties of the concrete including thermal conductivity, heat capacity, etc.

Chapter 5 contains a more in-depth discussion of the mechanical parameters. Strength growth curves and inter-correlations between the different parameters are also provided.

Chapter 6 presents two case studies of highway sections in Idaho that are part of the Long Term Pavement Performance (LTPP) studies. For each of the two highway sections, two Pavement ME design scenarios comparing the recommended input values in Chapter 2 to the national defaults are discussed. The distress predictions from these scenarios with respect to the material parameters at the two hierarchal levels are compared and discussed.

Finally, the conclusions and recommendations for future research are summarized in Chapter 7.

Chapter 2
General Properties

The following three successive chapters will introduce Pavement ME PCC material inputs, in the order of appearance in the software. The methods of characterization for each parameter will be explained briefly along with the impact of each parameter on distresses predictions. Proper values of material inputs, either experimentally established as a part of this study or based on the literature will be recommended for each input parameter as a function of mixture design.

Slab Thickness

Using Pavement ME software, a reasonable value for rigid pavement slab thickness needs to be defined by the designer in the first trial run as this program is an analysis tool that can be used for design purposes. Alternatively, the Pavement ME's specified default value of 10-inch for the slab thickness can be used for the first trial run. Based on the predicted performance over the design life, more trial runs should be conducted with increased or decreased slab thickness until a required pavement thickness that achieves the desired predicted performance is obtained. The final rigid pavement design satisfies the criteria for each performance indicator accounted for in Pavement ME: transverse fatigue cracking, joint faulting, and international roughness index (IRI) for the duration of the design life and at the required reliability level.

PCC Unit Weight

An independent review of Pavement ME in an NCHRP 1-40A (02) project indicated that the prediction of transverse cracking for jointed plain concrete pavements (JPCP) using Pavement ME is significantly impacted by the PCC unit weight. [(9)] Unit weight of PCC at input Level 1 should be determined experimentally for the fresh concrete, following the procedure in ASTM C138, "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete". [(7)] At input Level 3, historical data from the agency should be used. Alternatively, MEPDG documentation specifies the default range of unit weight from 140 to 160 pcf, with a default value of 150 pcf.

Table 3 presents the unit weight of PCC based on laboratory testing in RP 253, as well as the ITD's on-site test results for all tested mixtures. Note that the results provided in Table 1 are the averages of four to six unit weight tests in the laboratory. The number of ITD in-field testing varied from five to nine for most projects, with two mixtures that had exceptionally high number of field test results of 350 for I-90 Lookout Pass 2016 Paving Mixture from District 1 and 107 for I-84 Paving from District 3. Table 1 shows that the differences between the laboratory and field results for unit weight range from 0.04 to 4 percent. It is hypothesized that slight differences between the laboratory and field values may be due to the different environmental conditions during placement in the field and laboratory conditions resulting in different implemented w/cm.

Table 3. PCC Unit Weight Based on Laboratory Experiments and ITD's On-Site Test Results

District	Mixture	Average Unit Weight from RP 253 Testing (Standard Deviation)[pcf]	Average Unit Weight from ITD On-Site Testing (Standard Deviation) [pcf]
1	SH-5 Bridge Crossing, Plummer	142.9 (1.4)	140.7 (Not available)
	I-90 Lookout Pass 2015, Mullan	148.1 (1.0)	144.0 (1.8)
	I-90 Lookout Pass 2016, Mullan	142.8 (2.7)	148.6 (2.0)
2	Thain Road Paving, Lewiston	144.6 (1.8)	143.7 (3.0)
	US-95 Race Creek, Lewiston	145.6 (1.4)	142.5 (2.4)
3	I-84 Paving, Boise	140.2 (0.9)	143.3 (2.2)
5	US-91 Paving, Pocatello	140.2 (4.6)	143.2 (1.4)
6	Thornton Interchange, Idaho Falls	139.1 (1.6)	139.2 (1.5)

Table 4 provides the statewide average values. Based on the results in Table 4, statewide average values obtained in the field are recommended at input Level 3.

Table 4. State-wide Average PCC Unit Weight for Paving and Structural Mixtures

Mixture	Unit Weight from RP 253 Testing [pcf]	Unit Weight from ITD On-Site Testing [pcf]
Statewide Average-Paving mixtures	143.2	144.6
Statewide Average-Structural mixtures	142.5	141.6
All Mixtures Average	142.9	143.7

Poisson's Ratio

Poisson's ratio (μ) is the ratio of the lateral strain to longitudinal strain when loading is in the longitudinal direction. This parameter is determined experimentally in parallel with PCC's elastic modulus (E_c). Sensitivity studies have shown that the impact of μ on the structural responses of PCC pavement used for distress prediction is negligible. [(10)] At input Level 1, μ is obtained simultaneously with E_c and the software requires one single input for μ. According to the MEPDG documentation, at input Levels 2 and 3, it is recommended to use a value within the typical range of 0.15-0.18.

In this study, μ was experimentally characterized for all tested mixtures following ASTM C469. [(11)] This parameter was established at all test dates. However, since only one value of μ is required as Pavement ME input, the 28-day results from three samples are provided herein. Average 28-day values of μ along with the respective standard deviations are provided in Table 5. As seen in Table 5, values of μ for most of the mixtures falls within the recommended 0.15-0.18 range. These values are suggested to be used at Level 1 for these mixtures. An average value of 0.16 and 0.18 is recommended at Level 3 for the paving and structural mixtures, respectively.

Table 5. Experimentally Determined 28-Day Age Poisson's Ratio for All Tested Mixtures

District	Mixture	Mean 28-day μ (Standard Deviation)
1	SH-5 Bridge Crossing, Plummer	0.16 (0.04)
	I-90 Lookout Pass Paving Mixture 2015, Mullan	0.14 (0.01)
	I-90 Lookout Pass Paving Mixture 2016, Mullan	0.16 (0.01)
2	Thain Road Paving Mixture, Lewiston	0.18 (0.02)
	US-95 Race Creek Mixture, Lewiston	0.20 (0.03)
3	I-84 Paving Mixture, Boise	0.15 (0.03)
5	US-91 Paving Mixture, Pocatello	0.16 (0.01)
6	Thornton Interchange Mixture, Idaho Falls	0.16 (0.02)

General properties of each mixture can be found in the PCC ME Material Database, provided in Appendix D.

Chapter 3
Thermal Material Parameters

PCC Coefficient of Thermal Expansion

Concrete's CTE is an estimate of the PCC's length change, when exposed to a uniform temperature change. CTE is a critical material parameter in PCC pavement design, since it substantially affects curling stresses, and joint/crack opening. Therefore, CTE plays an important role in the determination of distresses in Pavement ME, such as transverse fatigue cracking, and joint faulting of JPCP, as well as punchouts in continuously reinforced concrete pavements (CRCP). Several sensitivity analysis studies emphasized the significance of CTE on distress predictions, particularly on fatigue cracking and joint faulting for JPCP. [9, 10, 12] This parameter is a function of several mixture design parameters, but primarily of coarse aggregate type and content. At input Level 1, Pavement ME requires experimental determination of CTE by direct measurements of a specimen's length change due to exposure to temperature changes. At input Level 2, CTE is estimated based on a linear weighted average of the CTE's of the cement paste and coarse aggregate:

$$\alpha_{pcc} = \alpha_{agg} * V_{agg} + \alpha_{paste} * V_{paste}$$

Figure 2. Estimation of CTE Based on Mixture Constituents at Input Level 2

where α_{pcc}, α_{agg} and α_{paste} denote the CTE of concrete, aggregate and paste respectively, while V_{agg} and V_{paste} denote the volumetric proportions of aggregate and paste in the concrete mixture. Pavement ME documentation includes typical ranges for CTE of the paste and various aggregate types. Level 3 inputs use the CTE of concrete based on historical averages from the LTPP database. The default mean for CTE is set at $5.5x10^{-6}$ in/in/ ˚F in the Pavement ME. This value originates from hundreds of experiments conducted on cores from the LTPP PCC pavement sections and is considered a national average. [1] LTPP CTE data varies from $4\text{-}7.2\times10^{-6}$ in/in/ ˚F in this database.

In this study, CTE was established per AASHTO T 336-15, "Standard Method of Test for Coefficient of Thermal Expansion of Hydraulic Cement Concrete". [13] As per this standard, tests were performed on two 4-inch cylindrical specimens per mixture, at 28 days of age or later. Details of the experimental procedures were previously discussed in Deliverables 2 and 5. The experimentally-determined CTE based on mixture design is provided in Table 6. Geological composition of aggregates used in the tested mixture designs determined as a part of RP 212, using a quadrat inventory method is presented in Table 6. [14] As seen in Table 6, each aggregate contained a composition of four or more different rocks, type of most of which appears to be igneous rocks. This multi-rock composition makes it difficult to establish any potential patterns between the composition of the rocks and the established CTE values. The comparison between mixtures containing quartzite reveals that with increased contents of quartzite CTE values also increases. The four mixtures that contain quartzite are I-90 Lookout Pass 2015 and 2016, with approximately 36 percent quartzite and a CTE of 3.75 and 3.78 $\times$and 10^{-6} in/in/˚F, respectively.

These values are followed by the next mixture, SH-5 bridge Crossing Mixture from District 1 with 45 percent quartzite and a CTE of 4.83×10^{-6} in/in/˚F), and finally US-95 Race Creek from District 2 with 55 percent quartzite and the highest CTE at 5.38×10^{-6} in/in/˚F. A comparison of CTE values for Thain Road Paving Mixture from District 2 and Thornton Interchange from District 6 reveals that increase in basalt content from 30 to 50 percent yields increase in CTE from 3.83 to 4.51 $\times 10^{-6}$ in/in/˚F. The comparison between I-90 Lookout Pass Paving mixtures from 2015 and 2016 indicates comparable CTE values due to the same aggregate source and similar mixture design.

Table 6. Geological Composition of Coarse and Fine Aggregate for Tested Mixtures

District	Mixture	Aggregate Content			Mean CTE (Standard Deviation) [$\times 10^{-6}$ in/in/˚F]
		Coarse Agg. (Max Size 1 ½”)	Coarse Agg. (Max Size 3/4”)	Fine Agg.	
1	SH-5 Bridge Crossing, Plummer	Not Applicable (NA)	Quartzite (45%), Argillite (30%), Calcareous Siltstone (10%), Granodiorite (10%)		4.83 (0.13)
	I-90 Lookout Pass Paving 2015, Mullan	Quartzite (50%), Argillite (40%)	Quartzite (30%), Basalt (25%), Calcareous Siltstone (20%), Granodiorite (15%)	Quartzite (30~40%), Basalt (25~30), Calcareous Siltstone (10~20%), Granodiorite (10~15%) *	3.75 (0.18)
	I-90 Lookout Pass Paving 2016, Mullan				3.79 (0.10)
2	Thain Road Paving, Lewiston	NA	Basalt (50%), Ryolite/Dacite (25%), Siltstone (10%), Opal (3%)		4.51 (0.19)
	US-95 Race Creek, Lewiston	NA	Quartzite (55%), Basalt (20%), Andesite (10%), Rhyolite (5%), Opal (3%)		5.38 (0.04)
3	I-84 Paving, Boise	Granodiorite (30%), Rhyolite/Dacite (25%), Basalt (20%), Andesite (15%)			5.08 (0.04)
5	US-91 Paving, Pocatello	Information Not Available			3.08 (0.16)
6	Thornton Interchange, Idaho Falls	NA	Basalt (30%), Rhyolite (25%), Andesite (15%), Granite (10%), Quartzite (10%)	Rhyolite (30%), Quartz (25%), Granite (10%), Obsidian (10%), Opal (5%), Basalt (5%)	3.83 (0.18)

* Fine aggregate for I-90 Paving mixture consists of two fractions from two sources with the same aggregate types in slightly different quantities. Hence, the percentages are given as ranges.

For comparisons, Table 7 presents the experimentally determined average CTE and the respective CTE range for the LTPP rigid pavement sections in Idaho and Washington within geographical proximity. All the CTE measurements available from the LTPP database is provided in Appendix B. As seen in Table 7, the range of CTE measurements in LTPP database extends from 3.44 to 8.89×10-6 in/in/˚F and the most of the experimentally determined CTE values shown in Table 6 fall within that range. It can be observed, however, that CTE of several tested mixture designs is below the ranges from LTPP database. Lower CTE values should be beneficial from distress prediction standpoint, since CTE substantially influences curling and fatigue cracking for JPCP. Several unknowns regarding the exact geological composition of the aggregate, paste content and age of the samples at the time of testing makes it difficult to compare the test results in this project to those from the LTPP database. Therefore, CTE values determined in this project should be used at input Level 1, with respect to the location and mixture design.

Table 7. CTE from the LTPP Sections in Idaho and Washington for Comparisons

SHRP ID	State, District	Aggregate Type	Mean CTE (Range) [$\times 10^{-6}$ in/in/˚F]
16-3017	ID, 5	Gravel, Igneous Sedimentary, Limestone	4.92 (4.56~5.28)
16-3023	ID, 3	Gravel, Igneous Sedimentary, Chert or Diabase	4.36 (3.83~5.0)
16-5025	ID, 5	Gravel, Igneous Sedimentary, Quartzite	5.56 (5.28~5.72)
53-3011	WA, Not available (NA)	Gravel, Igneous Plutonic, Granite or Basalt	5.09 (4.56~5.89)
53-3013	WA, NA	Gravel, Igneous Extrusive or Plutonic, Andesite or Granite	5.28 (4.83~6.11)
53-3014	WA, NA	Gravel, Igneous Extrusive, Basalt or Andesite	4.29 (3.89~4.78)
53-3019	WA, NA	Gravel, Igneous Extrusive, Basalt	4.46 (4.11~4.72)
53-3812	WA, NA	Gravel, Igneous Plutonic, Basalt or Andesite	5.03 (4.28~8.89)
53-3813	WA, NA	Gravel, Igneous Extrusive, Basalt	4.00 (3.44~4.67)
53-7409	WA, NA	Gravel, Igneous Extrusive, Basalt	4.03 (3.83~4.22)
53-A800	WA, NA	Gravel, Igneous Extrusive, Basalt	3.94 (Not Available)

PCC Thermal Conductivity

Thermal conductivity (*K*) and heat capacity (*Q*) are the material properties that define the heat flow through PCC and are used to estimate temperature profiles in pavement. The suggested range at Level 3 is 1.0-1.5 Btu/(ft)(h)(˚F), with a default value 1.25 Btu/(ft)(h)(˚F). This property needs to be accounted for as a default, as it was not experimentally established in this project. Nevertheless, previous sensitivity studies have shown that this parameter does not significantly affect the performance predictions of concrete pavement. [(10)]

PCC Heat Capacity

Heat capacity (*Q*) is equivalent to the ratio of the amount of heat added to (removed from) the unit mass of the material in response to a temperature change. Similar to *K*, the *Q* of PCC determines the amount of heat transfer between the slab and the surroundings and is used in temperature profile predictions in the EICM. Typical value of *Q* for PCC recommended in Pavement ME documentation at input Level 3 ranges from 0.20 to 0.28 Btu/(lb)(˚F), and the default value in Pavement ME is 0.28 Btu/(lb)(˚F). Experimental determination of Q was outside the scope of this study and therefore the use of Level 3 default *Q* is recommended. Past sensitivity-analysis studies of Pavement ME consistently indicate that Q does not significantly affect distress predictions. [9, 10, 12]

Thermal properties for each mixture design are listed as a part of the PCC ME Database, provided in Appendix D.

Chapter 4
Mixture Design Parameters

Cement Type

The cement type is a mixture design parameter that is used primarily to estimate the ultimate drying shrinkage strain in Pavement ME. Literature indicates that cement type does not highly influence distress predictions. [9, 10, 12] Regardless, the cement type and producer for the eight mixtures tested in this project are listed in Table 8. Based on this record, it is recommended that cement is defined as Type I when using Pavement ME. Mill certificates for implemented portland cement and fly ashes are provided in Appendix C.

Table 8. Cement Type and Producer for the Tested Mixtures

District #	Mixture	Cement Type	Cement Producer
1	SH-5 Bridge Crossing, Plummer	Type I	Lafarge
	I-90 Lookout Pass Paving Mixture 2015, Mullan	Type I	Lafarge
	I-90 Lookout Pass Paving Mixture 2016, Mullan	Type I	Lafarge
2	Thain Road Paving Mixture, Lewiston	Type I/II	Ash Grove
	US-95 Race Creek Mixture, Lewiston	Type I/II	Ash Grove
3	I-84 Paving Mixture, Boise	Type I/II	Ash Grove
5	US-91 Paving Mixture, Pocatello	Type I/II	Ash Grove
6	Thornton Interchange Mixture, Idaho Falls	Type I/II	Lafarge

Cementitious Material Content

Cementitious material content is the total content of portland cement and SCM in the unit volume of concrete. Cement content is used to estimate the ultimate drying shrinkage and the zero-stress temperature among other parameters in Pavement ME. Earlier studies demonstrated that the predictions of joint faulting and IRI may be sensitive to the cementitious materials content. [9]

The default value of the cementitious material content in Pavement ME is 600 lbs/yd^3. Cementitious material content for the eight mixtures tested in this study is provided in Table 9, while Table 10 shows state-wide average cementitious material contents for different mixture types. As seen in Table 9, all tested mixtures had higher content of cementitious materials compared to the default amount.

Table 9. Cementitious Material Content for Tested Mixtures

District #	Mixture	Cementitious material content [lbs/yd^3]
1	SH-5 Bridge crossing, Plummer	611
	I-90 Lookout Pass Paving Mixture 2015, Mullan	688
	I-90 Lookout Pass Paving Mixture 2016, Mullan	688
2	Thain Road Paving Mixture, Lewiston	611
	US-95 Race Creek Mixture, Lewiston	625
3	I-84 Paving Mixture, Boise	625
5	US-91 Paving Mixture, Pocatello	729
6	Thornton Interchange Mixture, Idaho Falls	658

Table 10. State-wide Average Cementitious Material Content for Tested Mixtures

Mixture Type	Cementitious Material Content [lbs/yd^3]
Statewide Average-Paving Mixtures	668
Statewide Average- Structural Mixtures	631
All Mixtures Average	654

Water-to-cementitious Ratio

Water-to-cementitious materials ratio (w/cm) is a critical mixture design parameter, which impacts mechanical and durability properties of PCC. Mixtures with higher w/cm have higher porosity and permeability in the cement paste, which in turn reduces the mechanical properties. The effect of w/cm on Pavement ME design is accounted for through the computation of the ultimate drying shrinkage. Based on the literature, w/cm significantly affects the prediction of joint faulting and therefore IRI. (9) The default w/cm in Pavement ME software is 0.42.

In this project, the moisture absorption, moisture content, and specific gravity for coarse and fine aggregate were determined in accordance to ASTM C127, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate" (15) and ASTM C128, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate" (16), respectively. Based on the moisture content of the aggregate, the water was adjusted from the suggested amount in the mixture design to bring the aggregate to surface saturated dry (SSD) conditions.

ITD's on-site slump and entrained air test results were collected from each district. The mixtures were batched to reproduce the same slump and air content as those obtained in the field. Target slump was typically achieved with the water content lower than that specified in the mixture design. Since the actual water contents used during paving were not available, w/cm specified in the mixture design as well as those implemented in the laboratory are provided in Table 11. The slightly lower values of w/cm required in the laboratory compared to the mixture design to obtain the same slump is expected. This is most likely because in laboratory's controlled ambient conditions, less water will provide the same workability that may decrease in the field, depending on delivery distance and ambient conditions. Values of w/cm ratios specified in mixture design should correspond to field conditions and are hence recommended to be used in Pavement ME. Table 12 presents the statewide average w/cm for structural and paving mixtures.

Table 11. Water-to-cementitious Material Ratios Based on Mixture Design and Incorporated Water in the Laboratory to Achieve Target Slump

District	Mixture	W/cm According to Mixture Design	Laboratory W/cm to Achieve Target Slump
1	SH-5 Bridge Crossing, Plummer	0.42	0.41
	I-90 Lookout Pass Paving Mixture 2015, Mullan	0.38	0.35
	I-90 Lookout Pass Paving Mixture 2016, Mullan	0.39	0.37
2	Thain Road Paving Mixture, Lewiston	0.43	0.40
	US-95 Race Creek Mixture, Lewiston	0.40	0.35
3	I-84 Paving Mixture, Boise	0.40	0.36
5	US-91 Paving Mixture, Pocatello	0.39	0.34
6	Thornton Interchange Mixture, Idaho Falls	0.39	0.38

Table 12. State-Wide Average Water-to-cementitious Material Ratios for Structural and Paving Mixtures

Mixture type	w/cm according to mixture design	Laboratory w/cm to achieve target slump
State-wide Paving mixtures average	0.40	0.36
State-wide Structural mixtures average	0.40	0.38
All mixtures	0.40	0.37

Aggregate Type

Aggregate type and size influence mechanical and durability parameters of concrete, as well as the CTE and drying shrinkage. Aggregate is volumetrically stable over a wide range of environmental conditions and serves as an internal restraint for concrete undergoing autogenous and drying shrinkage. Aggregate type is one of Pavement ME inputs intended to be used for the estimation of CTE, however this parameter is not linked to any other input in software and therefore does not have any influence on the design. It is hence recommended to directly use the experimental values of CTE.

PCC Zero-stress Temperature

PCC zero-stress temperature (T_z) is defined as the PCC temperature after placement and during curing at which PCC slab exhibits no thermal stresses. This temperature is used as the baseline to compute the contraction and expansion of the slab over the design life. This parameter is particularly effective in the case of CRCP, since it impacts the crack width and consequently punchouts. (9) This parameter can be entered directly or estimated using the embedded empirical relationship based on cementitious materials content (CC) and month of construction:

$$T_z = CC * 0.59328 * H * 0.5 * 1000 * 1.8 / (1.1 * 2400) + MMT$$

Figure 3. Equation for PCC Zero-stress Temperature

where H is an empirical parameter calculated based on mean monthly temperature (MMT) as follows:

$$H = -0.0787 + 0.007 * MMT - 0.00003 * MMT^2$$

Figure 4. Equation for Empirical Parameter H Used in PCC Zero-stress Temperature Calculation

Determination of T_z was beyond the scope of this research project. It is thus recommended to use the existing Pavement ME relationship at all input levels.

Ultimate Drying Shrinkage

Concrete goes under volumetric reduction due to exposure to drying. In CRCP, drying shrinkage impacts crack development, while in JPCP the primary effect of drying shrinkage is slab warping due to differential shrinkage throughout the PCC depth. This in turn affects transverse fatigue cracking and joint faulting. Additionally, drying shrinkage influences joint opening, which is an important factor in joint faulting characterization. The magnitude of ultimate drying shrinkage depends on the mixture design parameters, such as aggregate and cement type and content, w/cm, environmental conditions, such as ambient temperature and relative humidity (RH). Curing method also highly influences the ultimate drying shrinkage.

Pavement ME documentation defines the ultimate shrinkage as a shrinkage strain that will develop in the concrete exposed to prolonged drying conditions with ambient RH at 40 percent. At input Level 1, the magnitude of total drying shrinkage should be established in the laboratory. However, the results of field studies indicated that it may take up to five years for drying shrinkage to stabilize. (17) The current laboratory test procedures may not provide an adequate estimation of ultimate drying shrinkage due to the relatively short duration of testing in this project. It is still recommended for agencies to perform laboratory evaluation of drying shrinkage as a baseline for the evaluation of ultimate shrinkage calculated by Level 2 and 3 relationships. At input Level 2 ultimate shrinkage (ε_{su}) is calculated as:

$$\varepsilon_{su} = C_1 C_2 \left\{ 26 * w^{2.1} (f'_c) - 0.28 + 270 \right\}$$

Figure 5. Equation for Ultimate Drying Shrinkage at Level 2 and 3

Where, C_1 and C_2 are constants dependent on cement and curing type, w stands for the water content of concrete mixture and f'_c for the 28-day compressive strength. Input Level 3 relies on the same equation with the difference in typical inputs from the agency for w and f'_c as opposed to mixture specific values at input Level 2.

In this study, free drying shrinkage test was performed based on ASTM C157, "Standard Test Method for Length Change of Hardened Hydraulic-Cement mortar and Concrete". [18] Tests were performed on 2" by 2" by 11" prisms on six specimens from each mixture. After initial 28-days of moist curing, specimens were exposed to drying environment with ambient RH at 40 percent over a 64-week period. Figure 6 presents the comparison of drying shrinkage strains for all tested mixtures, with positive values of strain showing swelling during the moist curing and negative values indicating shrinkage. Whisker bars correspond to the standard deviations of shrinkage observed among the six tested specimens. Figure 6 encompasses the final drying shrinkage measurements recorded in the last week of June, correspondent to nine to 54 weeks of drying, depending on the mixture batching date. As seen in Figure 6, the development of shrinkage has stabilized for most mixtures and it is therefore safe to assume that the latest measurements correspond well with the ultimate shrinkage and can be used as Pavement ME input. Based on Figure 6, mixtures with relatively high drying shrinkage from District 2 also demonstrate higher variability among the specimens in comparison to mixtures with lower shrinkage (the first two mixtures from Districts 1 and mixtures from District 3 and 6). Relatively high shrinkage of mixtures from District 2 may be related to the high slumps of these two mixtures, as well as low maximum aggregate size ¾ in. Other mixtures with high drying shrinkage are US-91 Paving mixture from District 5, followed by I-90 Lookout Pass Paving Mixture 2016 from District 1. UI will continue recording the length change until the end of 64-week drying period and will report the final results.

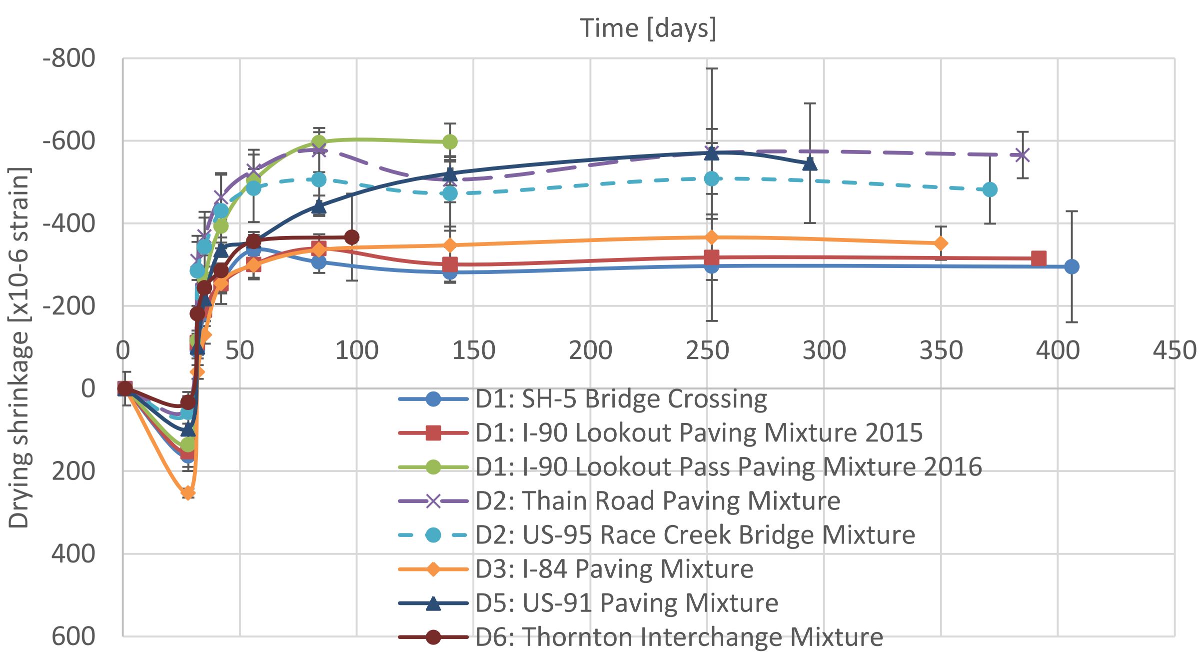


Figure 6. Average Drying Shrinkage Development for All Tested Mixtures to Date

Table 13 presents the last recorded measurements with the corresponding time for the ultimate drying shrinkage. Note that the time of the last measurement includes the initial 28-days of moist curing. Upon the completion of drying shrinkage recordings, the experimentally determined values will be compared with that obtained using empirical relationship given in Figure 5. Based on the experiment's schedule, the final 64-week shrinkage measurements for the first two mixtures from District 1 and Thain Road Paving Mixture will be reached during September 2017. Corresponding measurements for US-95 Race Creek Mixture will be recorded in October 2017, followed by the measurements for I-84 Paving Mixture and US-91 Paving Mixture in November and December 2017, respectively. The ultimate 64-week drying shrinkage measurements for I-90 Lookout Paving Mixture 2016 are scheduled for May 2018, while Thornton Interchange Mixture will be characterized for ultimate drying shrinkage on June 2018. The final measurements will be provided to ITD in the updated materials database spreadsheet.

Table 13. Last Recorded Drying Shrinkage Strains with the Corresponding Test Date

District	Mixture	Last Recorded Drying Shrinkage [x10^{-6} strain]	Time of Last Measurement (days)
1	SH-5 Bridge Crossing, Plummer	295.00	405
	I-90 Lookout Pass Paving Mixture 2015, Mullan	315.00	392
	I-90 Lookout Pass Paving Mixture 2016, Mullan	597.50	140
2	Thain Road Paving Mixture, Lewiston	565.67	385
	US-95 Race Creek Mixture, Lewiston	481.67	371
3	I-84 Paving Mixture, Boise	352.00	350
5	US-91 Paving Mixture, Pocatello	545.83	294
6	Thornton Interchange Mixture, Idaho Falls	366.67	98

Reversible Shrinkage

A portion of drying shrinkage of concrete is reversible upon rewetting. Pavement ME recommends reversible shrinkage of 50 percent as a default material input, unless more accurate information is available. A study by Lederle and Hiller (2013) indicated that approximately 30 percent of the ultimate drying shrinkage is reversible for common paving mixtures, however prolonged moisture curing may increase that value up to 80 to 100 percent. (19) Reversible drying shrinkage characterization was not encompassed in this study and the use of the default value is recommended. Sensitivity studies consistently pointed out that reversible shrinkage percentage does not exhibit significant effect on distress predictions. (9, 10, 12)

Time to Develop 50 Percent of Ultimate Shrinkage

The time to develop 50 percent of the ultimate shrinkage is recommended as 35 days at all input levels, unless more reliable information is available. (20) If the laboratory shrinkage characterization is conducted, which is the case in this study; it is recommended to estimate the time to 50 percent of drying shrinkage based on the experimental data.

Table 14 presents the estimation of time to 50 percent drying shrinkage for the tested mixtures, based on the latest shrinkage measurement presented earlier in Table 14. As seen in Table 14, the estimated values correspond well with the default of 35 days. The final values of time to develop 50 percent shrinkage will be updated when the ultimate drying shrinkage values for all mixtures become available. Literature suggests that this parameter does not impact distress predictions significantly. [9, 10, 12]

Table 14. Time to Develop 50 Percent of Ultimate Drying Shrinkage Based on Current Test Results

District	Mixture	Time to Develop 50 Percent of Ultimate Shrinkage (Days)
1	SH-5 Bridge Crossing, Plummer	33
	I-90 Lookout Pass Paving Mixture 2015, Mullan	33
	I-90 Lookout Pass Paving Mixture 2016, Mullan	35
2	Thain Road Paving Mixture, Lewiston	31
	US-95 Race Creek Mixture, Lewiston	31
3	I-84 Paving Mixture, Boise	37
5	US-91 Paving Mixture, Pocatello	36
6	Thornton Interchange Mixture, Idaho Falls	31

Curing Method

Appropriate curing method is critical to provide desirable curing conditions for satisfactory development of mechanical properties. Pavement ME allows two types of curing: wet curing and curing compound. One of these two options should be selected based on the practice in the field. Sensitivity studies of Pavement ME predictions suggested that both curing methods result in comparable distress projections. [9, 10, 12] Nevertheless, curing compound is recommended to be used as the method of curing as it represents the state of concrete paving practice.

Mixture design parameters for all of the mixtures are organized and provided in Appendix D, as a part of the PCC ME Material Database.

Chapter 5
Mechanical Properties

Compressive Strength

Compressive strength (f'_c) of PCC, typically tested at twenty eight-day age, is most commonly used for quality control. Input Level 2 of Pavement ME requires 7-, 14-, 28- and 90-day values of f'_c, which are further used to estimate the modulus of elasticity and modulus of rupture. Further, at input Level 2, the ratio of the 20-year to 28-day f'_c is a required Pavement ME input, with a maximum recommended value of 1.35. Input Level 3 utilizes 28-day f'_c to establish other mechanical properities of PCC.

In this study, f'_c test was performed per requirements of ASTM C39, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens”. [21] The tests were conducted on 6-inch diameter and 12-inch high cylinders, at 7-, 14-, 28- and 90-day ages, on four specimens on each test day. The details of f'_c testing were provided previously in the project Deliverables 2 and 5. Table 15 presents the average f'_c test results with the corresponding standard deviations, based on the mixture design and test date. Based on ASTM C39, experimental results were rounded to closest 10 psi. [21]

Table 15. Values of f'_c for All Tested Mixtures on 7-, 14-, 28- and 90-day Ages

District	Mixture	f'_c [psi] (Standard Deviation [psi])			
		7-day	14-day	28-day	90-day
1	SH-5 Bridge crossing, Plummer	4,040 (180)	4,630 (200)	4,870 (160)	5,270 (180)
	I-90 Lookout Pass Mixture 2015, Mullan	4,830 (130)	5,470 (210)	5,510 (240)	6,560 (230)
	I-90 Lookout Pass Mixture 2016, Mullan	3,500 (110)	4,360 (260)	4,640 (210)	5,560 (400)
2	Thain Road Mixture, Lewiston	3,760 (200)	5,130 (180)	5,160 (260)	5,830 (170)
	US-95 Race Creek Mixture, Lewiston	5,340 (190)	5,610 (300)	6,900 (130)	7,560 (410)
3	I-84 Paving Mixture, Boise	3,890 (170)	4,510 (200)	5,590 (220)	6,400 (350)
5	US-91 Paving Mixture, Pocatello	4,540 (170)	4,850 (100)	5,080 (120)	5,930 (280)
6	Thornton Interchange, Idaho Falls	2,800 (140)	3,400 (90)	4,310 (150)	5,260 (180)

To investigate the effect of mixture constituents on the compressive strength, Figure 7 shows the relationships between the 90-day f'_c and unit weight, w/cm, coarse and fine aggregate contents. The value of f'_c slightly increases with increased unit weight and drops with increase in w/cm ratio. Increase in coarse aggregate content results in a drop in f'_c, while the opposite trend can be seen in relationship between f'_c and fine aggregate content. The relationships with other parameters such as slump, and air content were not as strong as the four relations presented here and hence were not provided here. It is expected that f'_c is also impacted by aggregate gradation, angularity and admixtures.

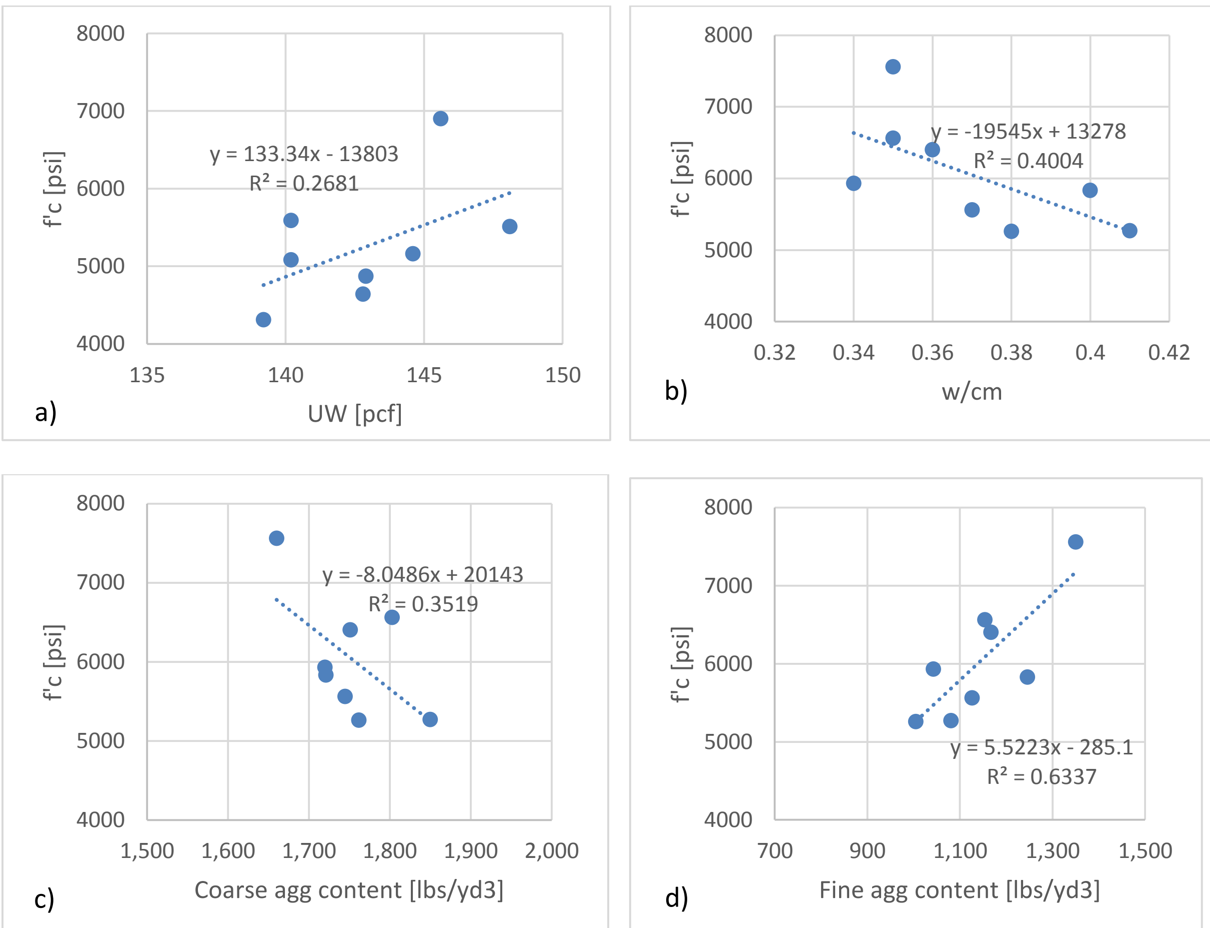


Figure 7. Correlations of f'_c with a) Unit Weight of Concrete, b) W/cm Ratio, c) Coarse Aggregate Content, and d) Fine Aggregate Content

Table 16 presents the district-based averages f'_c, while Table 17 shows average f'_c for paving, structural mixtures, as well as the state-wide averages. As seen in Table 16, paving mixture from District 3 exhibits the highest value of f'_c on 90-day test age, followed by paving mixtures from District 1, 2 and 5, respectively. In terms of structural mixtures, District 2 had the highest 90-day f'_c, followed by the corresponding mixtures from Districts 1 and 6.

Table 16. District-based Average Values of f'_c for Each Test Date

District	Mixture type	f'_c [psi]			
		7-day	14-day	28-day	90-day
1	Paving	4,170	4,920	5,080	6,060
	Structural	4,040	4,630	4,870	5,270
2	Paving	3,760	5,130	5,160	5,830
	Structural	5,340	5,610	6,900	7,560
3	Paving	3,890	4,510	5,590	6,400
5	Paving	4,540	4,850	5,080	5,930
6	Structural	2,800	3,400	4,310	5,260

Table 17. State-wide Average Values of f'_c for Paving and Structural Mixtures

Mixture Type	f'_c [psi]			
	7-day	14-day	28-day	90-day
Statewide Average- Paving Mixtures	4,100	4,860	5,200	6,060
Statewide Average- Structural Mixtures	4,060	4,540	5,360	6,030
All Mixtures Average	4,090	4,740	5,260	6,050

Modulus of Elasticity

Modulus of elasticity (E_c) is the ratio of stress to strain in the elastic range of the concrete's stress-strain curve. It is dependent on the mixture design parameters, primarily the w/cm ratio, aggregate type, and content. Modulus increases with the progress of hydration, which is associated with the formation of the hydration products, and decrease in porosity. In terms of pavement structural responses, E_c impacts the tensile stresses in the slab and influences distresses such as transverse fatigue cracking. At input Level 1, E_c should be experimentally determined for the concrete mixture at 7-, 14-, 28- and 90-day ages. Additionally, the ratio of the 20-year to 28-day E_c is another required Pavement ME input, with 1.2 as the maximum recommended value.

Experimental determination of E_c was conducted in RP-253 based on ASTM C469, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression". (11) The test procedure encompasses the determination of the chord modulus of elasticity and the Poisson's ratio (μ). Details of the test procedure were previously described in Deliverables 2 and 5.

Table 18 presents E_c for all tested mixtures, based on the test day.

Table 18. Modulus of Elasticity for All Mixtures on 7-, 14-, 28- and 90-day Ages

District	Mixture	E_c [x 10^6 psi] (Standard Deviation, psi)			
		7-day	14-day	28-day	90-day
1	SH-5 Bridge Crossing, Plummer	3.55 (100,000)	3.80 (150,000)	4.25 (150,000)	4.55 (200,000)
	I-90 Lookout Pass 2015, Mullan	3.85 (250,000)	3.90 (400,000)	4.15 (350,000)	5.15 (300,000)
	I-90 Lookout Pass 2016, Mullan	3.20 (100,000)	3.35 (100,000)	3.50 (50,000)	4.75 (250,000)
2	Thain Road Mixture, Lewiston	3.30 (100,000)	4.10 (200,000)	3.70 (200,000)	4.65 (150,000)
	US-95 Race Creek Mixture, Lewiston	4.65 (100,000)	4.35 (15,000)	4.90 (150,000)	5.50 (150,000)
3	I-84 Paving Mixture, Boise	2.75 (100,000)	3.20 (150,000)	3.60 (100,000)	3.80 (150,000)
5	US-91 Paving Mixture, Pocatello	4.05 (50,000)	3.75 (35,000)	4.30 (50,000)	4.30 (250,000)
6	Thornton Interchange, Idaho Falls	2.95 (100,000)	3.60 (250,000)	3.80 (350,000)	4.40 (180,000)

Note that when using the Pavement ME at input Level 1, the values of E_c need progressively increase with age. Slight decreases in E_c at later ages for some of the mixtures, if entered in the software will result in a user error. It is, therefore recommended that in those cases compressive strength test results at all four ages are used at input Level 2. Please refer to the companion database for the appropriate material inputs.

Correlations between 90-day E_c with mixture design and fresh concrete parameters were established and the most influential parameters were identified and are presented in Figure 8. As seen in Figure 8, higher values of unit weight are associated with higher $E_{c.}$ Mixtures with higher air percentage demonstrated lower $E_{c.}$, while increase in fine aggregate content was result in an increase in $E_{c.}$. Pronounced relationships of $E_{c.}$ with w/cm, cementitious materials content, coarse aggregate content and slump could not be established.

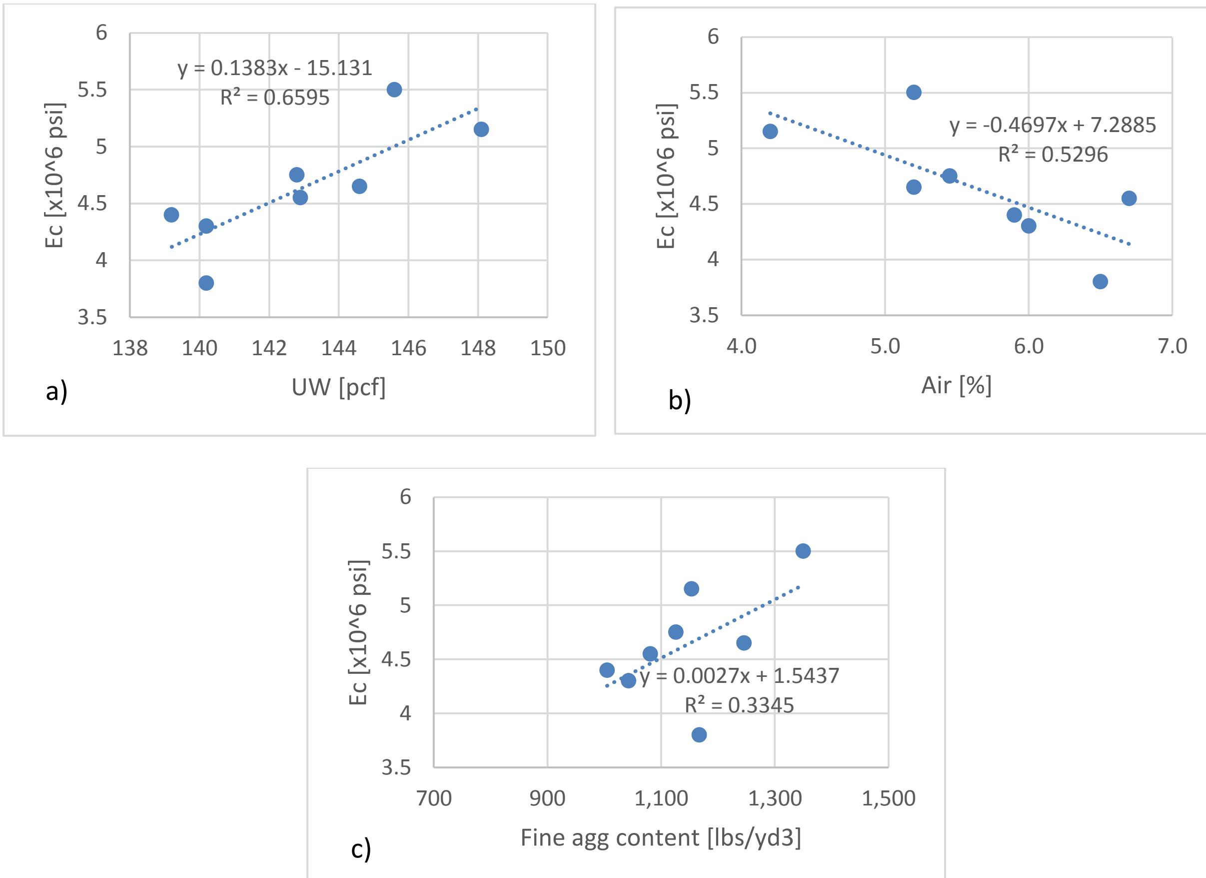


Figure 8. Correlations of E_c with a) Unit Weight, b) Air Content c) Fine Aggregate Content

Table 19 and Table 20 summarize district- and state-wide average E_c for paving and structural mixtures. As seen in Table 20, structural mixtures demonstrate higher values of E_c comparing to paving mixtures. The comparison of paving mixtures from different Districts reveals that mixtures from District 1 demonstrate the highest 90-day E_c at 4.95x10^6 psi, followed by mixtures from Districts 2 and 5. The paving mixture from District 3 exhibits the lowest E_c at 3.8 x 10^6 psi, however, it is noteworthy that this mixture also had the highest f'_c. In terms of structural mixtures, District 2 had the highest 90-day E_c, followed by Districts 1 and 6, which is also the trend observed for f'_c. of these mixtures.

Table 19. District-based Average Values of E_c for Each Test Date

District #	Mixture type	E_c [x 10^6 psi]			
		7-day	14-day	28-day	90-day
1	Paving	3.55	3.65	3.85	4.95
1	Structural	3.55	3.80	4.25	4.55
2	Paving	3.30	4.10	4.60	4.65
2	Structural	4.65	4.50	4.90	5.50
3	Paving	2.75	3.20	3.60	3.80
5	Paving	4.05	3.75	4.30	4.03
6	Structural	2.95	3.60	3.80	4.40

Table 20. State-wide Average Values of E_c for Paving, Structural and All Tested Mixtures

Mixture type	E_c [x 10^6 psi]			
	7-day	14-day	28-day	90-day
Statewide Average-Paving Mixtures	3.45	3.75	4.05	4.55
Statewide Average- Structural Mixtures	3.70	3.90	4.30	4.80
All Mixtures Average	3.55	3.75	4.05	4.65

Flexural Strength

Modulus of rupture (*MR*) or flexural strength of PCC is the essential mechanical property of PCC, which substantially impacts the resistance of PCC pavement to fatigue cracking. Higher values of *MR* are associated with higher number of allowable load applications as this factor affects the applied stress ratio to the pavement. Fatigue damage (*FD*) is calculated in Pavement ME as follows:

$$FD = \sum \frac{n_{i,j,k,l,m,n}}{N_{i,j,k,l,m,n}}$$

Figure 9. Equation for Fatigue Damage used in Pavement ME

where $n_{i,j,k,l,m,n}$ stands for number of load applications at conditions i, j, k, l, m, n and $N_{i,j,k,l,m,n}$ for allowable number of load applications at same conditions. Conditions i, j, k, l, m and n account for impacts of pavement age, month of the year, axle type, load level, temperature difference and traffic path, respectively. $N_{i,j,k,l,m,n}$ is further calculated as:

$$\log(N_{i,j,k,l,m,n}) = C_1\left(\frac{MR_i}{\sigma_{i,j,k,l,m,n}}\right)^{C_2} + 0.4371$$

Figure 10. Equation for the Allowable Number of Loading Repetitions before Fatigue Failure

where MR_i stands for the modulus of rupture of concrete at age i, $\sigma_{i, j, k, l, m, n}$ for applied stress at conditions i, j, k, l, m, n and C1 and C2 represent calibration constants. It can be concluded from the equation in Figure 10 that MR exhibits a critical influence to $N_{i,j,k,l,m,n}$, with higher values of MR yielding higher allowable number of load applications and lower FD.

Pavement ME input Level 1 requires the experimentally determined values of *MR* on 7-, 14-, 28- and 90-day tests, as well as the ratio of 20-year to 28-day *MR*, with maximum recommended value at 1.2. Modulus of rupture was experimentally determined according to ASTM C293, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)". (22) Tests were performed on 6" by 6" by 20" beam specimens at 7-, 14-, 28- and 90-day ages. Three specimens were tested on each test day. Details of *MR* tests were specified in Deliverables 2 and 5.

Table 21 presents average values of experimentally determined *MR* based on mixture design and PCC age, with corresponding standard deviations.

Table 21. *MR* for All Tested Mixtures on 7-, 14-, 28- and 90-day Ages

District	Mixture	*MR* [psi] (Standard Deviation [psi])			
		7-day	14-day	28-day	90-day
1	SH-5 Bridge Crossing, Plummer	630 (35)	655 (30)	715 (15)	730 (20)
1	I-90 Lookout Pass Paving 2015, Mullan	750 (50)	755 (5)	895 (45)	890 (50)
1	I-90 Lookout Pass 2016, Mullan	620 (5)	665 (45)	810 (25)	995 (55)
2	Thain Road Mixture, Lewiston	595 (55)	660 (15)	785 (15)	865 (45)
2	US-95 Race Creek Mixture, Lewiston	795 (10)	785 (25)	810 (40)	895 (10)
3	I-84 Paving Mixture, Boise	650 (5)	755 (55)	745 (30)	880 (50)
5	US-91 Paving Mixture, Pocatello	655 (30)	730 (50)	775 (35)	790 (85)
6	Thornton Interchange, Idaho Falls	500 (55)	615 (40)	770 (65)	950 (105)

When using *MR* as an input in Pavement ME (Level 1), the software considers the progressive flexural strength growth with PCC age as a default and will report error, if any drop in *MR* value is present at a later age, which is the case with a few test results in Table 10. For those cases, it is recommended to switch to Level 2, which requires f'_c at four test dates as an input, which was previously provided in Table 15, as well as included in the database.

Ninety-day MR for different mixture designs was correlated to various mixture design and fresh concrete properties, and four selected scatter plots that showed the strongest relations are presented in Figure 11. Figure 11 shows that MR is inversely related to w/cm and air content. In terms of aggregate content, higher amounts of coarse aggregate resulted in lower MR, while increases in fine aggregate content yielded higher MR values. Note that these relationships are not statistically strong, which may due to the underlying simultaneous interactions of different factors on MR rather than a one-at-a-time effect.

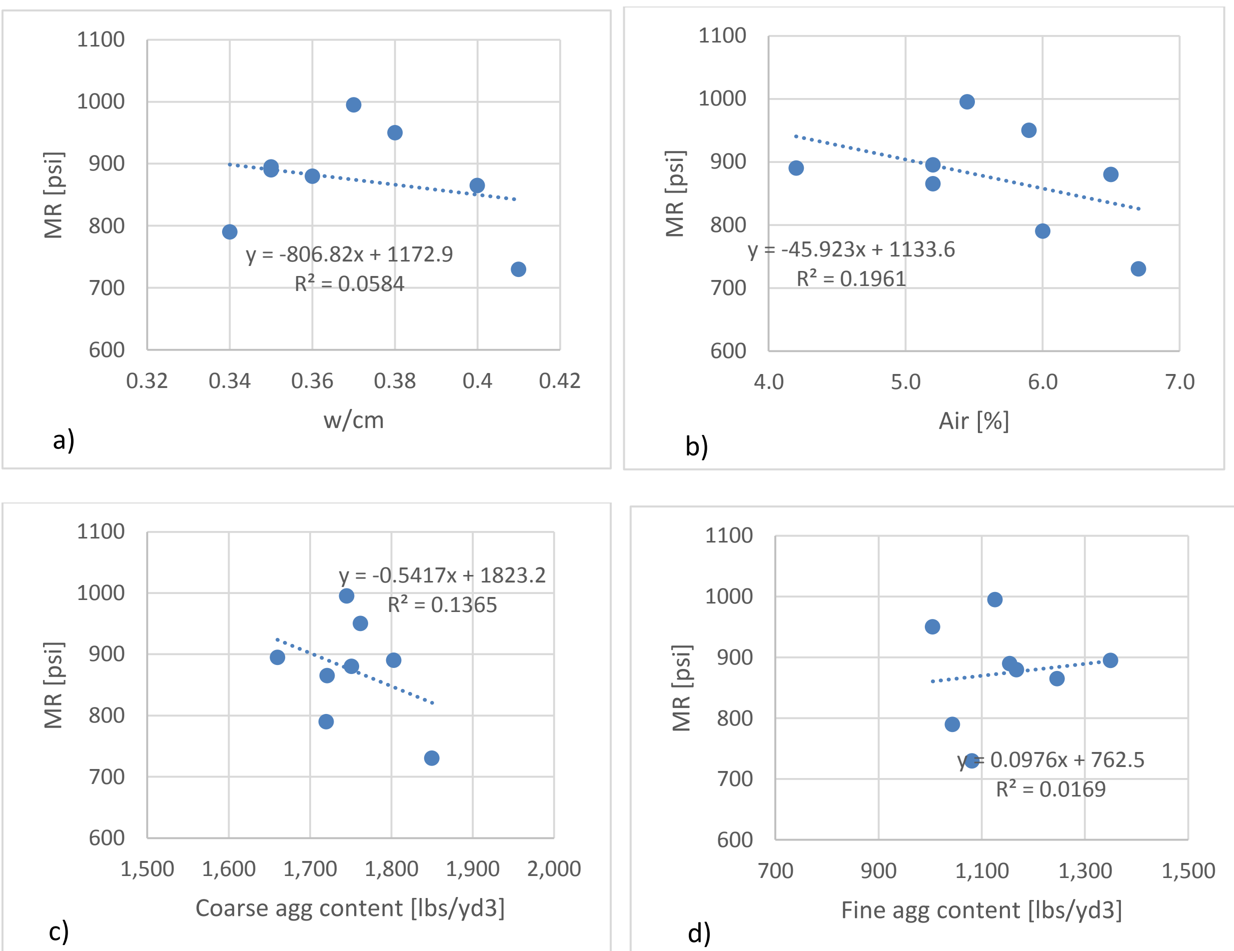


Figure 11. Correlations of *MR* with a) W/cm ratio, b) Air Content, c) Coarse Aggregate Content and d) Fine Aggregate Content

District-based average values of *MR* with analogous standard deviations, rounded to 5 psi, are listed in Table 22, while the average *MR* for paving, structural mixtures and the state are given in Table 23. Among the paving mixtures, District 1 mixtures exhibited the highest 90-day *MR* at 895 psi, closely followed by the mixtures from Districts 3 and 2, and finally the mixture from District 5 with 90-day *MR* at

790 psi. Mixture from District 6 demonstrated the highest 90-day *MR* among the structural mixtures, followed by the mixtures from Districts 2 and 1, respectively.

Table 22. District-based Average Values of *MR* for Each Test Date

District #	Mixture type	*MR* [psi]			
		7-day	14-day	28-day	90-day
1	Paving	685	710	855	895
1	Structural	630	655	715	730
2	Paving	595	660	785	865
2	Structural	795	785	810	895
3	Paving	650	755	745	880
5	Paving	655	730	775	790
6	Structural	500	615	770	950

Table 23. State-wide Average Values of *MR* for Paving, Structural and All Tested Mixtures

Mixture type	*MR* [psi]			
	7-day	14-day	28-day	90-day
Statewide average- Paving mixtures	655	715	800	885
Statewide average- Structural mixtures	640	685	765	860
All mixtures average	650	705	790	875

Strength Gain Curves and Comparison with Default Curves

Pavement ME Design Guide recommends the following equation for the estimation of E_c growth:

$$MODRATIO = \alpha_1 + \alpha_2 \log10(AGE) + \alpha_3 [\log10(AGE)]^2$$

Figure 12. Pavement ME Equation for E_c Growth with Pavement Age

where MODRATIO stands for the ratio of E_c at a given age to the 28-day E_c, AGE the age of specimen in years and α_1, α_2, α_3 regression coefficients. Based on the experimental data, strength growth curves for state-wide paving, structural mixtures and overall average were modeled and the regressions coefficients are provided in Table 24. Ratios of 20-year to 28-day E_c were calculated based on the strength growth curves for each mixture design (Figure 12) and reported in Table 24. For the mixtures with calculated ratio of 20-year to 28-day E_c beyond 1.20, the maximum recommended value of 1.20 was used. Similar procedure was followed for f'_c and *MR* and the corresponding regression coefficients and ratio of 20-year to 28-day f'_c and *MR* are given in Table 25 and Table 26. As seen in Table 24, Table 25 and Table 26, regression coefficients for all three mechanical properties differ markedly from Pavement ME defaults, which will cause difference in distress predictions between different input levels.

Table 24. Regression coefficients for E_c growth curve and 20-year to 28-day E_c ratio

Mixture type	α1	α2	α3	20-year E/28-day E
Statewide average- Paving mixtures	1.458	0.545	0.126	1.20
Statewide average- Structural mixtures	1.292	0.303	0.029	1.20
All mixtures average	1.388	0.445	0.085	1.20
Default Pavement ME	1.000	0.120	-0.0157	1.20

Table 25. Regression Coefficients for f'_c Growth Curves and 20-year to 28-day f'_c Ratio

Mixture type	α_1	α_2	α_3	20-year /28-day f'_c
Statewide average- Paving mixtures	1.285	0.161	-0.072	1.33
Statewide average- Structural mixtures	1.250	0.149	-0.083	1.29
All mixtures average	1.272	0.156	-0.076	1.31
Default Pavement ME values	1.000	0.120	-0.0157	1.35

Table 26. Regression Coefficients for *MR* Growth Curves and 20-year to 28-day *MR* Ratio

Mixture	α_1	α_2	α_3	20-year /28-day *MR*
Statewide average- Paving mixtures	1.208	0.129	-0.059	1.20
Statewide average- Structural mixtures	1.294	0.285	0.010	1.20
All mixtures average	1.234	0.185	-0.034	1.20
Default Pavement ME values	1.000	0.120	-0.0157	1.20

Pavement ME specifies the default equation for growth of flexural strength based on 28-day modulus of rupture ($MR_{28\text{-day}}$):

$$MR(t) = (1 + 0.12*\log_{10}(t/0.0767) - 0.01566*\log_{10}(t/0.0767)^2)*MR_{28\text{-day}}$$

Figure 13. Pavement ME Equation for *MR* Growth as a Function of Pavement Age and 28-day *MR*

where *MR*(t) stands for modulus of rupture at given age and t for time in years. The strength growth curve for MR can be further used to establish the development of f'_c, based on empirical equation:

$$f'_c = (MR/9.5)^2$$

Figure 14. Equation for the Estimation of *f'c* Based on the Corresponding *MR*

Further, E_c at various ages can be estimated based on f'_c and unit weight (γ) using the relation:

$$E_c = 33\gamma^{3/2}\sqrt{f'_c}$$

Figure 15. Equation for the Estimation of *Ec* Based on the Corresponding *f'c* and Unit Weight

Equations given in Figure 13, Figure 14, and Figure 15 with default values of 28-day *MR*=690 psi and γ equal to 150 pcf were used to establish Pavement ME default f'_c, E_c and *MR* growth with PCC age and these properties were plotted in Figure 16, 17 and 18, respectively. In addition, experimentally established values of f'_c, E_c and *MR* based on PCC age for paving, structural and all mixtures were added to Figure 16, Figure 17 and Figure 18.Error bars for the experimentally determined mechanical properties indicate standard deviation.

Figure 16 demonstrates that Pavement ME default f'_c is higher than that of the mixtures tested in this project at early ages (7- and 14-days). However, beyond 28-day age both paving and structural mixtures surpass Pavement ME default.

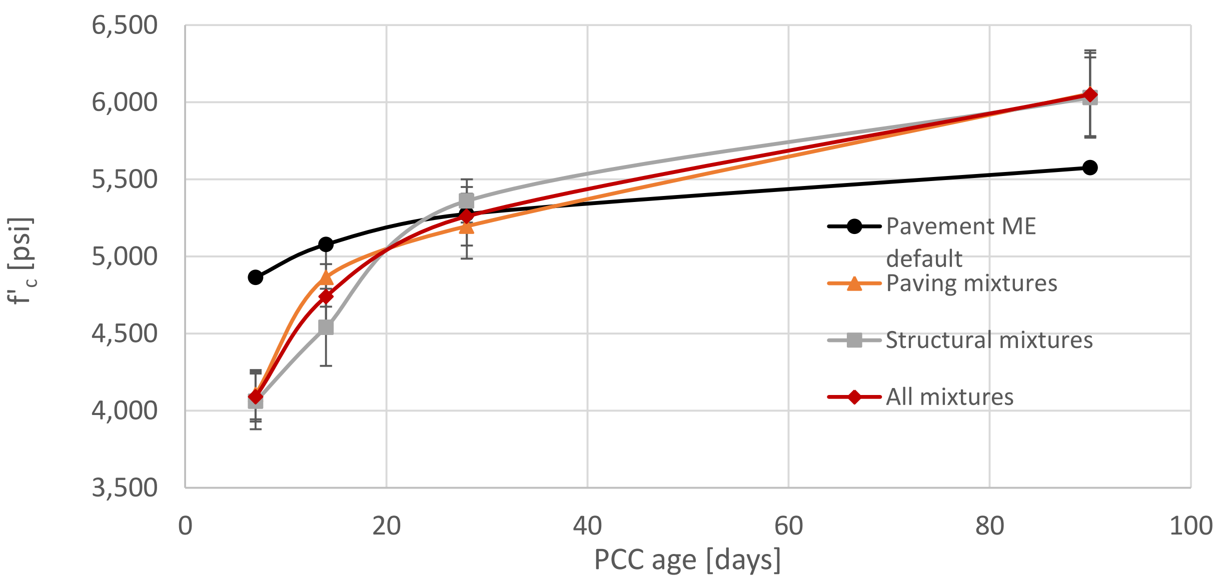


Figure 16. Compressive Strength Growth Curve: Comparison of Pavement ME Default and Idaho State-Wide Averages for Paving, Structural and All Tested Mixtures

As seen in Figure 17, Pavement ME default E_c at 7-day age is higher than that of the paving and structural mixtures. At 90-day, the default E_c agrees well to the state-wide average for all mixtures. Structural mixtures are showing higher E_c compared to the default Pavement ME curve; conversely, E_c of paving mixtures is lower than Pavement ME default on all test ages. It is noteworthy that the default E_c is significantly influenced by *γ* (see Equation 10).

In terms of *MR*, Pavement ME default values are clearly lower than that of the structural and paving mixtures from the state of Idaho on all test ages (Figure 18). Overall, based on the three figures discussed, the experimental results suggest higher growth for all mechanical properties comparing to the default growth curve in Pavement ME.

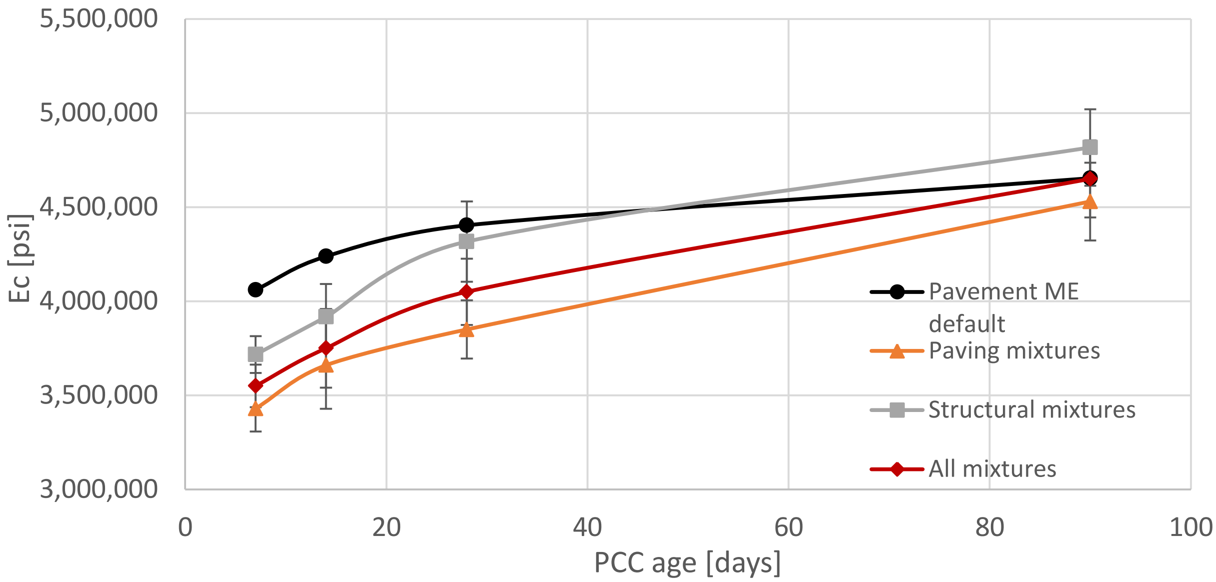


Figure 17. Modulus of Elasticity Growth Curve: Comparison of Pavement ME Default and E_c for Idaho State-wide Averages for Paving, Structural and All Tested Mixtures

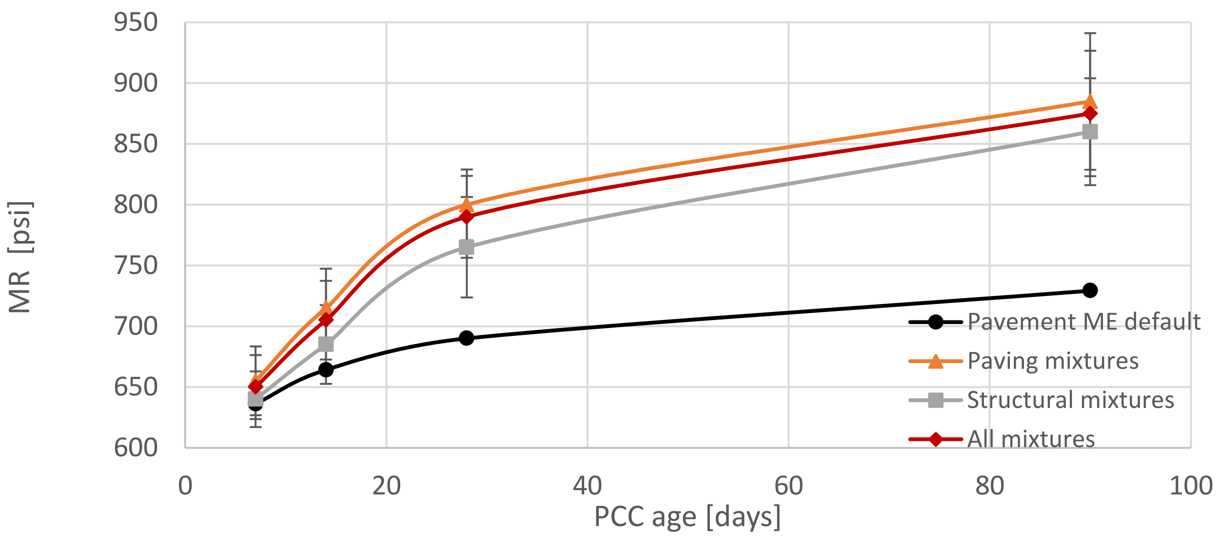


Figure 18. Modulus of Rupture Growth Curve: Comparison of Pavement ME Default and *MR* for Idaho State-wide Averages for Paving, Structural and All Tested Mixtures

Relationship between Different Mechanical Properties

Since the 28-day f'_c is the most typically determined mechanical property of PCC, it is commonly used to estimate other mechanical properties. The correlation of 28-day *MR* and E_c with the square root of f'_c were given in equations in Figure 14 and Figure 15.

Relationship between *MR* and f'_c (Figure 14) can be expressed in the following form:

$$MR = 9.5\sqrt{f'_c}$$

Figure 19. Equation for the Estimation of *MR* Based on the Corresponding f'_c

When the default unit weight of PCC γ equal to 150 pcf is used in equation in Figure 15, a value of correlation coefficient between E_c and square root of f'_c is equal to 60,625. In order to evaluate this coefficient, as well as the equation in Figure 19, the values of correlation coefficient (factor in front of square root of f'_c) were calculated based on the experimental data. Obtained correlation coefficients for E_c and *MR* are listed in Table 27 and Table 28, respectively. Coefficients were calculated based on Idaho state-wide average results for paving, structural and all mixtures and as the function of test date. As seen in Table 27, values of the correlation coefficients are generally lower than the default at 60,625. Conversely, correlation coefficients that describe the relationship between *MR* and square root of f'_c are higher than the default 9.5 for all mixture types and all test dates.

Table 27. Factors to Estimate E_c Based on f'_c for Paving, Structural and All Tested Mixtures

Mixture type	Correlation Coefficient (Equation in Figure 15)
Statewide average- Paving mixtures	53,450
Statewide average- Structural mixtures	59,250
All mixtures average	55,650

Table 28. Factors to Estimate *MR* Based on f'_c for Paving, Structural, and All Tested Mixtures

Mixture type	Correlation Coefficient (Equation in Figure 19)
Statewide average- Paving mixtures	11.1
Statewide average- Structural mixtures	10.6
All mixtures average	10.9

Mechanical properties of all mixtures necessary for the design using Pavement ME were organized and listed in PCC ME Database, given in Appendix D.

Chapter 6
Design Case Studies

To assess the impact of laboratory-established design inputs versus the national default values in the Pavement ME on JPCP pavement design, two JPCP sections in the state of Idaho that are part of the LTPP database were designed using the Pavement ME at two hierarchal input levels of 1 and 3. Information about the sections' structure and their average annual daily truck traffic (AADTT) is provided in Table 29.

Table 29. Pavement Structure and Traffic Data for the Two JPCP Sections in Idaho from LTPP Database

SHRP ID	ITD District	Location	PCC Slab Thickness [in]	Base Type, Depth [in]	Subbase Type, Depth [in]	Subgrade Type	AADTT	Road Class
16-3017	5	Pocatello Area, Highway I-86	10.5	Asphalt Treated, 5.4	Crushed Gravel (A-1-b), 11.6	Silty Sand (A-4)	924	Interstate
16-3023	3	Boise Area, Highway I-84	9	Crushed Gravel (A-1-a), 4.4	Soil-aggregate mixture (A-1-b and A-2-6)*, 14.3	Silty Sand (A-4)	1,425	Interstate

*Subbase layer of Section 16-3023 consisted of two layers of soil aggregate mixture, 5.3-inch A-1-6 and 9-inch thick A-2-6 type layer. Subbase was modeled in Pavement ME with two layers, but presented in table as a single layer.

Both sections were first analyzed at input Level 3, using the default values for PCC parameters for a 40-year design life. Subsequently, the PCC material inputs were defined as obtained in RP-253 and the analysis was repeated at input Levels 1 and 2.

Section 16-3017

Input parameters used to design Section 16-3017 that remain the same in all three design scenarios are the pavement structure, traffic inputs and JPCP design features. The values for these inputs were defined based on Table 29 and are presented in the following three figures.

Design Inputs

Design Life:	40 years	Existing construction:	-	Climate Data Sources (Lat/Lon)	42.92, -112.571
Design Type:	Jointed Plain Concrete Pavement (JPCP)	Pavement construction:	September, 1986		42.543, -113.772
		Traffic opening:	November, 1986		42.727, -114.456
					53.317, -113.583

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	10.5
Cement_Base	Cement stabilized	5.4
NonStabilized	A-1-b	11.6
Subgrade	A-4	Semi-infinite

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

Traffic

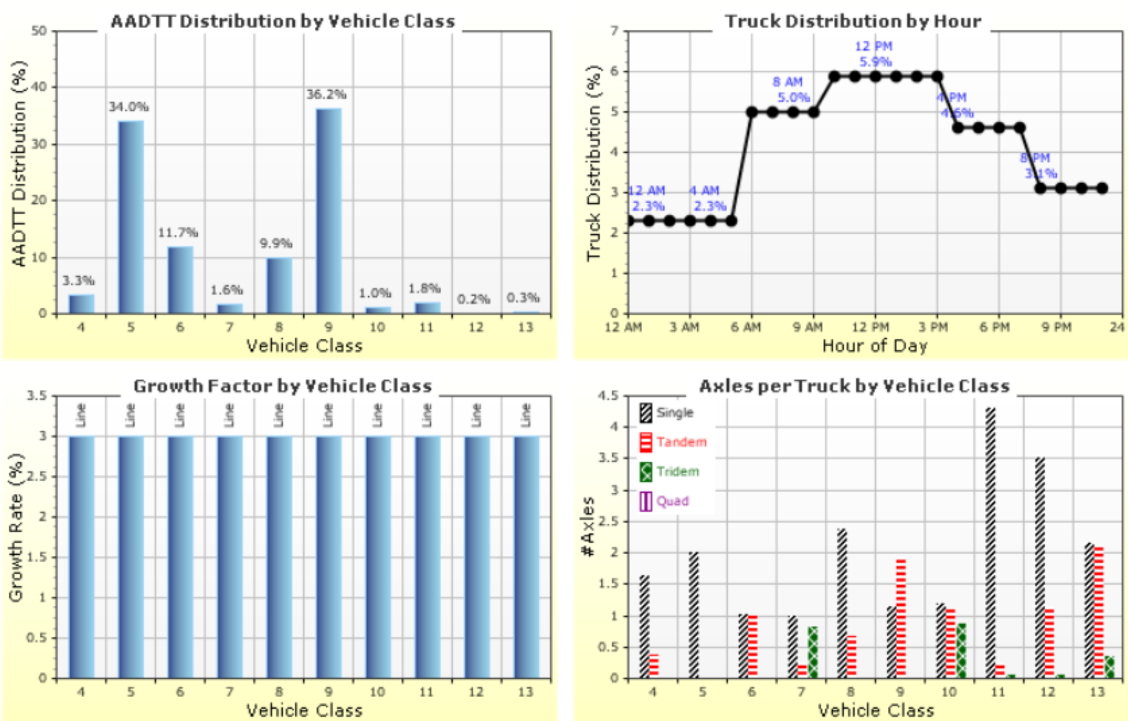
Age (year)	Heavy Trucks (cumulative)
1986 (initial)	923
2006 (20 years)	4,118,140
2026 (40 years)	10,159,100

Figure 20. Pavement Structure and Traffic Volume Inputs

Traffic Inputs

Graphical Representation of Traffic Inputs

Initial two-way AADTT:	924	Percent of trucks in design direction (%):	50.0
Number of lanes in design direction:	2	Percent of trucks in design lane (%):	95.0
		Operational speed (mph)	60.0



Volume Monthly Adjustment Factors

Level 3: Default MAF

Figure 21. Values of Traffic Inputs Used for Section 16-3017

Design Properties

JPCP Design Properties

Structure - ICM Properties	
PCC surface shortwave absorptivity	0.85

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

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

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

Sealant type	Preformed

Tied Shoulders	
Tied shoulders	False
Load transfer efficiency (%)	-

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

Erodibility index	5

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

Figure 22. JPCP Design Features Mainly Defined at Level 3

Figure 23 presents the values of PCC input parameters at three input levels. At input Level 3, all Pavement ME default values were used, while at input Levels 1 and 2 experimentally determined PCC properties were used. Since drying shrinkage tests are still in progress at the time of the analysis, the latest recorded results were utilized.

(a) Level 3 (default values)

PCC		
Thickness (in.)		10.5
Unit weight (pcf)		150.0
Poisson's ratio		0.2

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	5.5
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		600
Water to cement ratio		0.42
Aggregate type		Quartzite (0)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	87.6
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	632.3
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 modulus of rupture (psi)	690.0
28-Day PCC elastic modulus (psi)	4200000.0

(b) Level 2

PCC	
Thickness (in.)	10.5
Unit weight (pcf)	140.2
Poisson's ratio	0.2

Thermal	
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)	3.08
PCC thermal conductivity (BTU/hr-ft-ºF)	1.25
PCC heat capacity (BTU/lb-ºF)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		729
Water to cement ratio		0.34
Aggregate type		Quartzite (0)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	93.7
Ultimate shrinkage (microstrain)	Calculated Internally?	False
	User Value	520.8
	Calculated Value	-
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Curing Compound

PCC strength and modulus (Input Level: 2)

Time	Compressive strength (psi)
7-day	4540.0
14-day	4850.0
28-day	5080.0
90-day	5930.0
20-year/28-day	1.4

(c) Level 1

PCC strength and modulus (Input Level: 1)

Time	Modulus of rupture (psi)	Elastic modulus (psi)
7-day	655	3750000
14-day	730	4200000
28-day	775	4300000
90-day	790	4300000
20-year/28-day	1.2	1.2

Figure 23. PCC Material Inputs for Section 16-3017 at Three Levels Input Levels

Figure 24 shows Pavement ME-predicted joint faulting over the 40-year design life at input levels 1, 2 and 3 at 90 percent reliability. Lower CTE and PCC unit weight at Levels 1 and 2 comparing to defaults used at Level 3 may have induced the difference in the predicted joint faulting. As seen in Figure 24, the 40-year joint faulting is half at Levels 1 and 2 compared to the Level 3 defaults. However, joint faulting calculated for all three input levels is substantially below the threshold value at 0.12 inches.

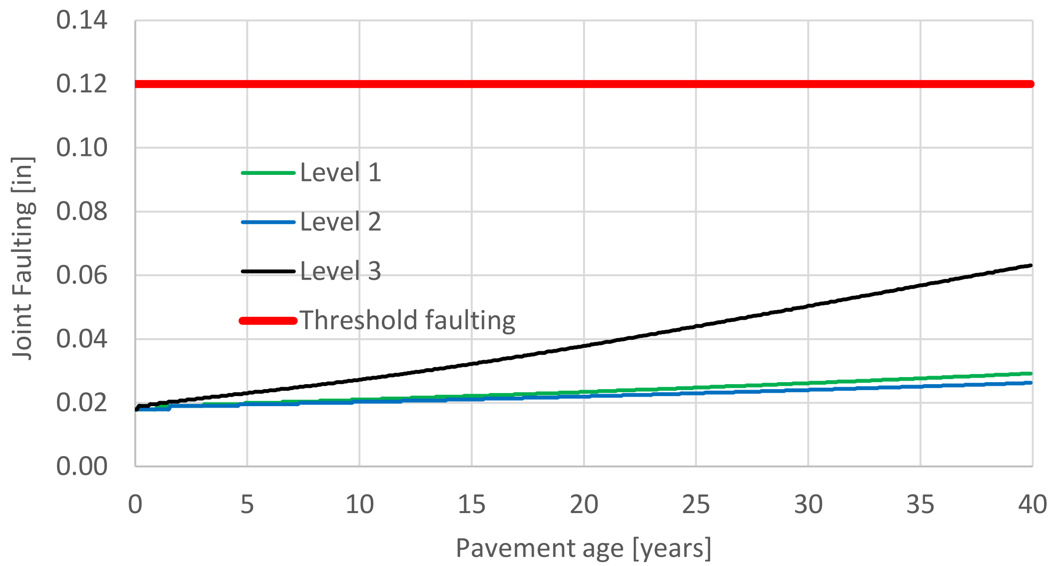


Figure 24. Joint Faulting for 16-3017 over 40-Year Design Period at Input Levels 1, 2 and 3

Figure 25 presents the predicted transverse fatigue cracking at all three input levels. All three runs generate comparable and minor cracking percentage, as seen in Figure 25. Levels 1 and 2 use higher *MR* (28-day value at 775 psi, as opposed to 690 psi as a defaults), which may have resulted in difference in calculated cracking percentage. The low predicted cracking percentage at all three input levels is most likely due to the overestimated slab thickness per AASHTO 1993 design guide, which is overshadowing the impact of the material inputs on the predicted cracking.

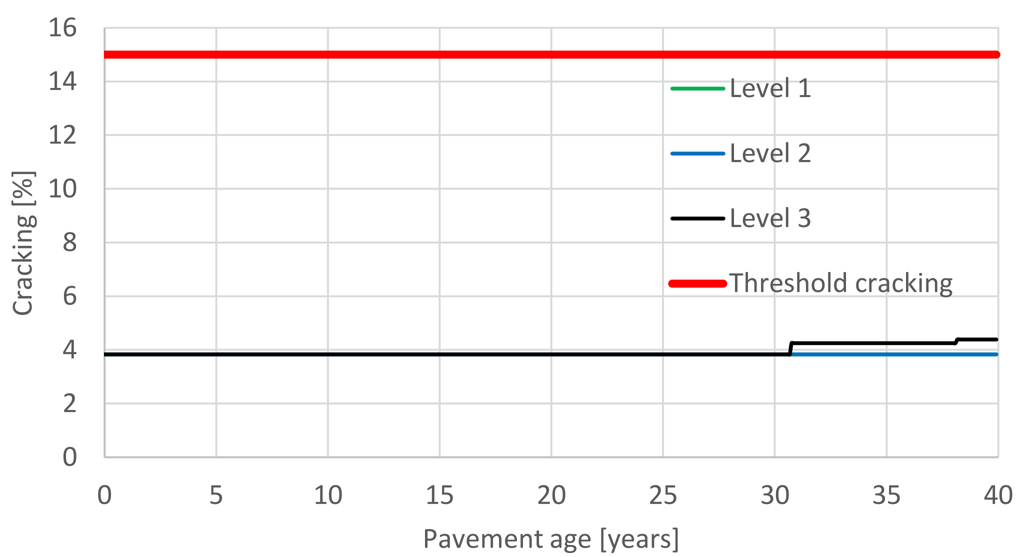


Figure 25. Cracking for 16-3017 over the 40-Year Design Period at Input Levels 1, 2, and 3

Based on Figure 26 design scenarios using Levels 1 and 2 result in lower values of 40-year IRI comparing to Level 3 by 30 to 37 percent, respectively. At all three levels, the pavement fails the criterion at about

25 years. Depending on the required design life, provisions need to be made to lower the joint faulting to maintain the IRI at lower levels.

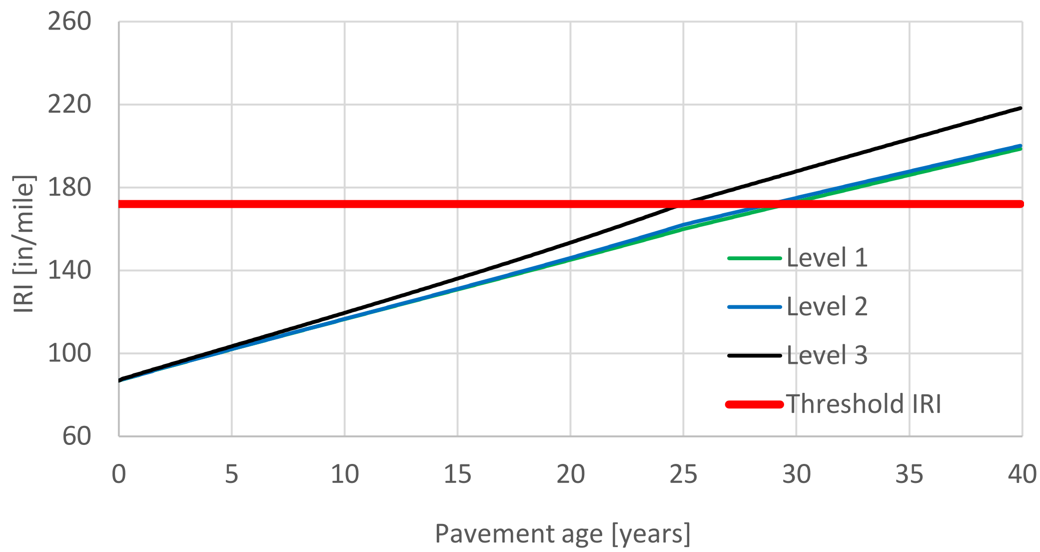
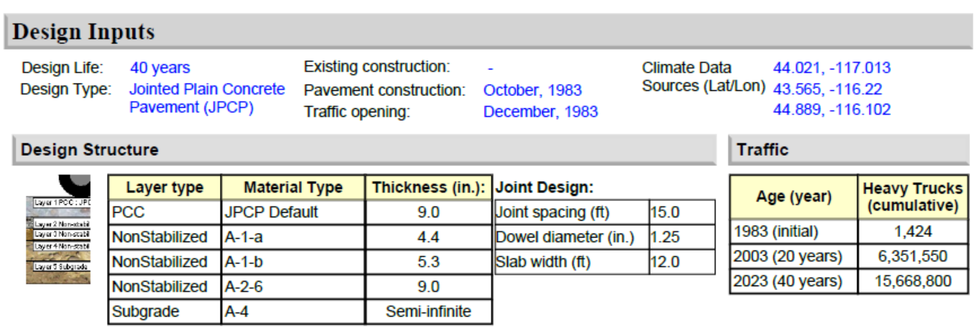


Figure 26. IRI for Section 16-3017 over the 40-year Design Period at Input Levels 1, 2 and 3

Section 16-3023

Input parameters used to design Section 16-3023 that remain the same in all three design scenarios are the pavement structure, traffic inputs and JPCP design features. The values for these inputs were defined based on Table 29 and are presented in the following two figures. In terms of JPCP design features, the same default values used for section 16-3017 given in Figure 22 were used for this section. All traffic inputs were defined the same as in Section 16-3017, except for the ADTT, which was slightly higher at 1,425.



Design Inputs

Design Life: 40 years
Design Type: Jointed Plain Concrete Pavement (JPCP)
Existing construction: -
Pavement construction: October, 1983
Traffic opening: December, 1983
Climate Data Sources (Lat/Lon): 44.021, -117.013; 43.565, -116.22; 44.889, -116.102

Design Structure

Layer type	Material Type	Thickness (in.):
PCC	JPCP Default	9.0
NonStabilized	A-1-a	4.4
NonStabilized	A-1-b	5.3
NonStabilized	A-2-6	9.0
Subgrade	A-4	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)
1983 (initial)	1,424
2003 (20 years)	6,351,550
2023 (40 years)	15,668,800

Figure 27. General Pavement Structure and Design Inputs for Section 16-3023

(a) Level 3 (Default values)

PCC		
Thickness (in.)		9.0
Unit weight (pcf)		150.0
Poisson's ratio		0.2
Thermal		
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)		5.5
PCC thermal conductivity (BTU/hr-ft-ºF)		1.25
PCC heat capacity (BTU/lb-ºF)		0.28
Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		600
Water to cement ratio		0.42
Aggregate type		Quartzite (0)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	75.3
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	632.3
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 modulus of rupture (psi)	690.0
28-Day PCC elastic modulus (psi)	4200000.0

(b) Level 2

PCC		
Thickness (in.)		9.0
Unit weight (pcf)		140.2
Poisson's ratio		0.2
Thermal		
PCC coefficient of thermal expansion (in./in./ºF x 10^-6)		5.08
PCC thermal conductivity (BTU/hr-ft-ºF)		1.25
PCC heat capacity (BTU/lb-ºF)		0.28
Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		625
Water to cement ratio		0.36
Aggregate type		Quartzite (0)
PCC zero-stress temperature (ºF)	Calculated Internally?	True
	User Value	-
	Calculated Value	76.3
Ultimate shrinkage (microstrain)	Calculated Internally?	False
	User Value	347.0
	Calculated Value	-
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Curing Compound

PCC strength and modulus (Input Level: 2)

Time	Compressive strength (psi)
7-day	3890.0
14-day	4510.0
28-day	5590.0
90-day	6400.0
20-year/28-day	1.4

(c) Level 1

PCC strength and modulus (Input Level: 1)

Time	Modulus of rupture (psi)	Elastic modul
7-day	650	2750000
14-day	745	3200000
28-day	828	3600000
90-day	880	3800000
20-year/28-day	1.2	1.2

Figure 28. PCC Material Inputs for 16-3017 at Three Input Levels

Distress prediction summaries for joint faulting, transverse cracking and IRI from the Pavement ME are presented in Figure 29 through Figure 31. Comparable distress predictions for Level 1 and 2, observed in previous section, can also be seen in distress predictions for section 16-3023, however using Level 3 values results in an overestimation of the distresses for this section. As seen in Figure 29, input data at

Level 1 and 2 resulted in 24 and 31 percent lower 40-year faulting comparing to Level 3, which can be attributed to lower CTE and unit weight used at Levels 1 and 2 in comparison to the default values.

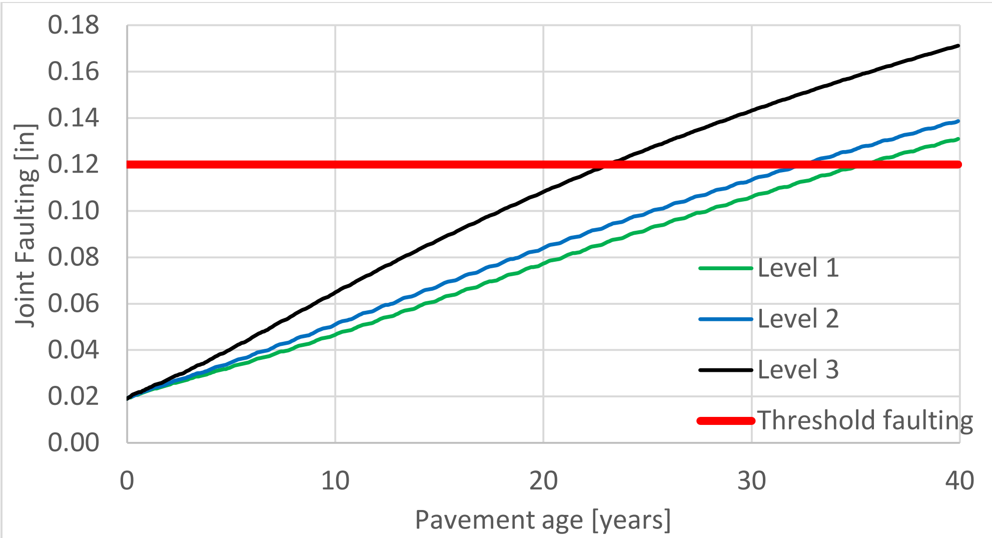


Figure 29. Joint Faulting for 16-3023 over the 40-Year Design at Input Levels 1, 2 and 3

Figure 29 indicates substantially higher percentage cracking when the default inputs are used in comparison to Level 1 and 2, which is due to the difference in *MR* of 828 psi at Level 1, compared to 690 psi for the default 28-day *MR*.

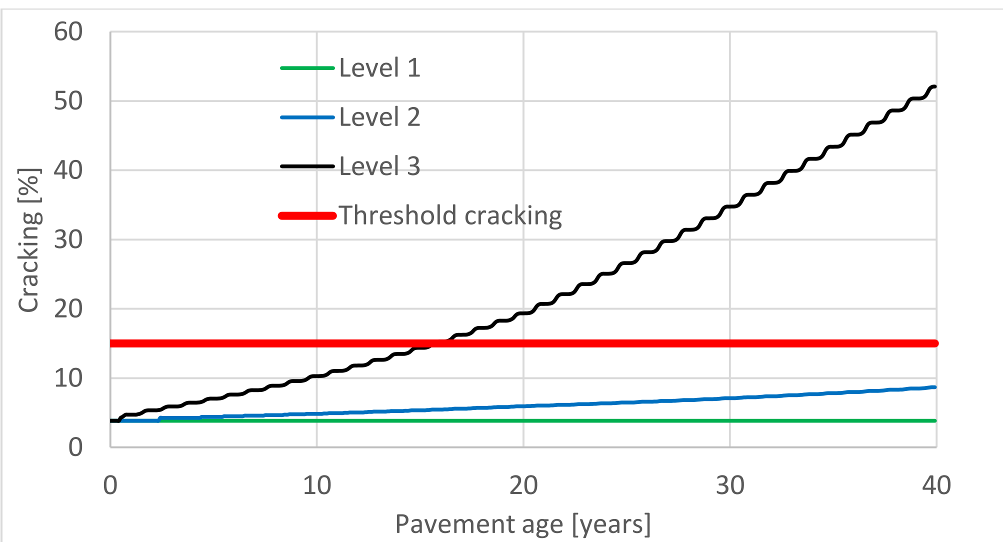


Figure 30. Cracking for 16-3023 over 40-Year Design Period at Input Levels 1, 2 and 3

As expected, Level 1 and 2 data generate approximately 50 percent lower 40-year IRI compared to the default run. It is noteworthy that IRI is computed internally based on the other distress predictions (faulting, transverse cracking and spalling in the case of JPCP), age, patching, as well as the miscellaneous site factors (freezing index, percentage of fines in the subgrade). It is thus expected that altering the structural design to make other distresses pass the criteria will also result in satisfactory IRI.

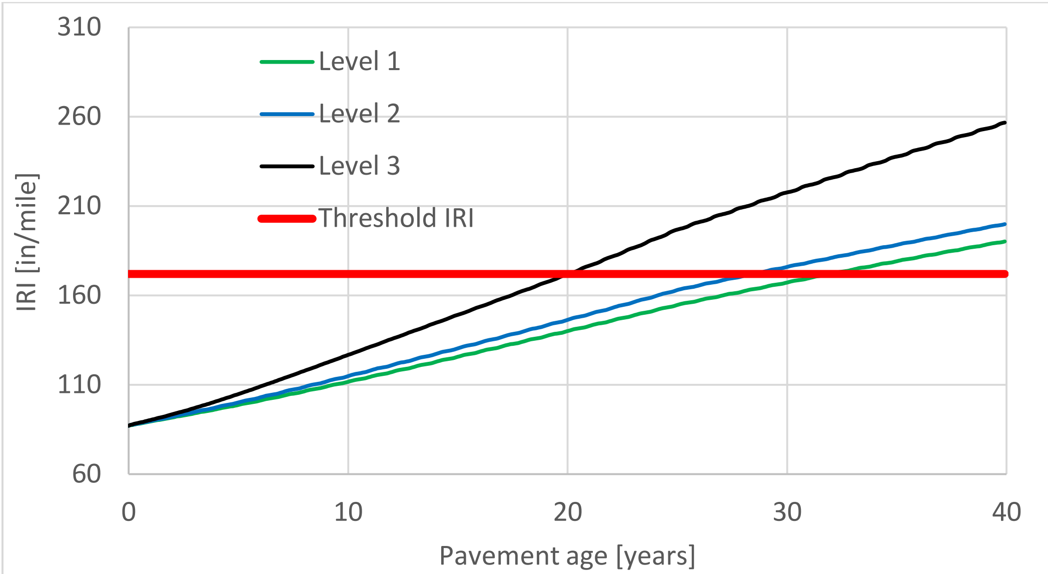


Figure 31. IRI for Section 16-3023 over the 40-Year Design Period at Input Levels 1, 2 and 3

The results of the two case studies presented here suggest the significance of material design inputs in distress predictions. Pavement ME overestimates the distresses for both pavement sections, especially for Section 16-3023. For this section, using the default values the slab thickness needs to be increased to meet the transverse cracking criteria, while using the inputs at Level 1 and 2, the criteria is satisfied for 40 years and beyond. The utilization of experimentally established material inputs results in more accurate distress predictions, as well as savings to agencies due to optimized pavement design.

Chapter 7
Conclusions and Future Research

Research Project 253 was an initial step in preparation for Pavement ME implementation for rigid pavement design in the state of Idaho. This experimental study aimed to establish a PCC material database for Idaho Transportation Department (ITD) concrete mixtures. Eight mixtures (five paving and three structural mixtures) from five districts in Idaho were tested in the study.

The material parameters selected for the experimental determination were the ones identified as influential in terms of distress predictions in the earlier studies of the MEPDG and Pavement ME. The project included laboratory characterization of PCC mechanical properties such as compressive strength (f'_c), modulus of elasticity (E_c), Poisson's ratio (μ), modulus of rupture (*MR)* and splitting tensile strength (f'_t). In terms of thermal properties, the coefficient of thermal expansion (CTE) was characterized experimentally. Ultimate drying shrinkage (ε_∞) was determined for specimens exposed up to 51 weeks of air drying. This test is still in progress for a few of the mixtures and the most recent values will be provided in the final version of the report. Values of unit weight, water-to-cementitious materials ratio, and cementitious material content were reported based on the mixture design and/or laboratory values. All the material parameters necessary for pavement design in Pavement ME were organized and provided in the PCC ME Material Database in Appendix D.

Pavement ME requires the continuous increase of all the mechanical parameters with time. For a handful of cases where a minor decline in E_c or *MR* with age was observed (necessary parameters at input Level 1), use of Level 2 which relies on f'_c at all ages was recommended. As seen later in the design case studies, input Levels 1 and 2 generate comparable distress predictions. Strength growth curves for f'_c, E_c and *MR* based on the experimental results were developed and compared to Pavement ME defaults. While experimentally determined *MR* and f'_c on later test ages surpass Pavement ME default values, experimentally established E_c is lower than Pavement ME default. The only exception for this trend can be seen for structural mixtures beyond 14-day age. The strength growth for all three of these mechanical properties is at a higher rate based on the experimental data than with the default Pavement ME strength growth curve model. The correlations between 28-day E_c and *MR* with f'_c were also compared to Pavement ME defaults. It was concluded that the correlation coefficients for experimentally determined *MR* were higher than the default coefficient specified by Pavement ME. Conversely, the correlation factors for E_c are lower than the default value utilized in Pavement ME.

Two case studies were designed in Pavement ME based on Long Term Pavement Performance (LTPP) rigid pavement sections in Districts 3 and 5 in Idaho. Pavement structure, coordinates and traffic data were obtained from the LTPP database, while the material inputs were classified in three distinct cases correspondent to three input Levels. Level 3 included all Pavement ME default inputs, while Level 1 and Level 2 used experimentally-established PCC properties. For both sections, the use of input data at Levels 1 and 2 resulted in substantially lower distress predictions in terms of joint faulting, transverse cracking and international roughness index (IRI). The input levels were found insignificant for Section 16-3017 in terms of fatigue cracking, however the influence of the input levels seem to be masked by the initially overdesigned slab thickness following AASHTO 93 Design Guide. Therefore, it is recommended to utilize the experimentally-established input data when available to obtain the most realistic distress predictions and an optimized design. For additional mixtures beyond those tested in this project, determination of f'_c on the four test dates, characterization of CTE and ε_∞ are recommended at minimum. It is expected that this experimental scheme can provide a satisfactory accuracy for pavement design and distress predictions.

In terms of input characterization, it is recommended that proper values are developed for the permanent curl/warp temperature difference for the rigid pavements in the state of Idaho.

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Appendix A
Mixture Designs for the Tested Mixtures in the Project

District 1

I-90 Lookout Pass 2015 Paving Mixture Design

CONCRETE MIX CALCULATION

DATE: 24-Jul-15

FOR: ACME

PROJECT: i-90 Paving

MIX: Centralia Mix - Adj #1

W/C RATIO 0.38

WT.CU.FT. 144.55

	SSD WT.	VOLUME	BATCH WT.	Revised Mix for Moisture (CUBIC FEET 2.00)			MATERIAL SOURCE	S.S.D. SP.G
Type I	550	2.80	550	40.74	pounds		Type I	3.15
Fly Ash	138	0.85	138	10.22		20%	Fly Ash	2.59
Silca Fume	0	0.00	0	0.00	pounds	0%	Silica Fume	2.20
Slag	0	0.00	0	0.00	pounds	0%	Slag	2.87
Coarse SAND	808	4.85	823	60.96	pounds	27%	C Sand	2.67
1 1/2	541	3.28	539	39.91	pounds	18%	1 1/2	2.64
3/4	1262	7.66	1250	92.57		43%	3/4	2.64
Fine Sand	346	2.06	345	25.54	pounds	12%	3/8	2.69
WATER	31.0	4.14	31.1	19.21	pounds		WATER	1.00
AIR%	5.0%	1.35	5.0%				AIR ENTRAINED	
AIROZ/100	1.00		6.9	15.02	mL			AE-90
WROZ/100	5.00	---	34	75.08	mL		WATER REDUCER	POZZ 80
SWR/100	0.00	---	0	0.00	mL		SUPER PLASTICIZER	
TOTAL WT	3903	VOLUME 27.00						

c/a ratio	60.98%		
% MORTAR	50%	PASS #8	90.0%

TARGET VOLUME	27.00
Total Moisture - Sand	5.25%
Total Moisture - 1 3/8"	1.00%
Total Moisture - 3/4"	0.50%
	0.50%

SH-5 Bridge Crossing Mixture

INTERSTATE
CONCRETE & ASPHALT

CONCRETE MIX DESIGN

PROJECT:	SH-5 RAILROAD BR, PLUMMER	DATE:	03/24/15
CONTRACTOR:	RALPH L. WADSWORTH CONSTRUCTION	SLUMP:	3.5"
MIX DESIGN:	320006 ITD CLASS 40 A	w/ Super P:	8.5" MAX
PLANT LOCATION:	INTERSTATE	W/C:	.44 MAX
CEMENT TYPE:	LAFARGE I-II	AIR:	5.0%-8.0%
PRODUCT USE:	CLASS 40 A		

DISPATCH:
208-712-2030

AGGREGATE	SPECIFIC GRAVITY
3/4" ROCK	2.62
ITD FINE AGG	2.59

DESCRIPTION	VOLUME	WEIGHTS
CEMENT	3.11	611
FLYASH	0.00	0
OTHER	0.00	0
WATER	4.13	258
3/4" ROCK	11.32	1850
ITD FINE AGGREGATE	6.69	1081
AIR PERCENT	1.76	6.5%
TOTAL	27.00	3800

ADMIXTURES: AIR ENTRAINMENT ADMIXTURE, WATER REDUCING ADMIXTURE.

REMARKS: MAY BE PLACED BY CHUTE OR PUMP.

Edward Benson
QUALITY CONTROL

I-90 Lookout Pass 2016 Paving Mixture Design

CONCRETE MIX CALCULATION

DATE: 5-Jul-16

FOR: ACME
Look Out Pass

PROJECT:

MIX: Ritchey Sand
4000psi 5" Max Slump

W/C RATIO 0.40
WT.CU.FT. 142.01

	SSD WT.	VOLUME	BATCH WT.	Revised Mix for Moisture (CUBIC FEET 1.00)	
MaxCem	550	2.80	550	20.37	pounds
Fly Ash	138	0.97	138	5.11	
Silca Fume	0	0.00	0	0.00	pounds
Slag	0	0.00	0	0.00	pounds
Coarse SAND***	619	3.72	639	23.66	pounds
Fine Sand	507	3.02	499	18.50	pounds
1 1/2	615	3.73	612	22.66	
3/4	1130	6.86	1124	41.62	pounds
WATER	33.0	4.41	32.6	10.13	pounds
AIR%	5.5%	1.49	5.5%		
AIROZ/100	1.00		6.9	7.51	mL
WROZ/100	5.00	---	34	37.54	mL
SWR/100	4.00	---	26	30.03	mL
	----	VOLUME			
TOTAL WT	3834	27.00			
c/a ratio	61%				
% MORTAR	48%	PASS #8	90.0%		

	MATERIAL SOURCE	S.S.D. SP.G	Absorption
	Type ISM	3.15	
20%	Fly Ash	2.27	
0%	Silica Fume	2.20	
0%	Slag	2.87	
22%	C Sand	2.67	2.21%
18%	F Sand	2.69	2.52%
21%	1.5	2.64	1.00%
39%	3/4	2.64	1.05%
	WATER	1.00	
	AIR ENTRAINED	AE-90	
	WATER REDUCER	pozz 80	
	SUPER PLASTICIZER	matrix 33	
			-0.566

TARGET VOLUME	27.00
Total Moisture - Sand	5.25%
Total Moisture - 1 3/8"	1.00%
Total Moisture - 3/4"	0.50%
Total Moisture - 3/8"	0.50%

This concrete mix design is only a suggested starting point, based upon materials meeting ASTM requirements. LAFARGE NORTH AMERICA MAKES NO WARRANTY OR REPRESENTATION WITH RESPECT TO THIS MIX DESIGN AND WILL ACCEPT NO LIABILITY FOR ITS USE.

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SUBMITTED BY: ______________________

____

DATE: ______________

District 2

Thain Road Paving Mixture

Atlas Concrete
4341 Snake River Ave.
Lewiston , Idaho , 83501
208-746-9985

Concrete Mix Design
Mix 8
Strength Compressive: 4,000 psi

Contractor : Stillwater Electric
Project : Thain And Grelle Intersection
Source of Concrete : Atlas Concrete
Construction Type : Class 40
Placement : Tailgate/Pump

Weights per Cubic Yard (Saturated, Surface-Dry)	Quantity	Density	Yield, ft^3
ASTM C-150 Type I/II Cement, lb	489	3.150	2.49
ASTM C-618 Class F Fly Ash, lb	122	2.600	0.75
Well Water , lb	265	1.000	4.25
ASTM C-33 Coarse Aggregate , lb	1,721	2.720	10.14
ASTM C-33 Fine Aggregate , lb	1,246	2.640	7.57
ASTM C-494 Type A Water Reducer , oz (US)	45.0	1.000	0.05
ASTM C-260 Air Entrainment , oz (US)	5.0	1.000	0.01
Total Air, %	6.5 ± 1.5		1.76
		TOTAL	27.00

Water/Cement Ratio, lbs/lb	0.43
Slump, High, in	5.00
Low, in	3.00
Super Plasticizer High, in	8.00
Super Plasticizer Low, in	5.00
Concrete Unit Weight, pcf	142.47
Yield, %	100.0

Exposure Condition : Moderate exposure

ACTUAL BATCH WEIGHTS WILL VARY DEPENDING ON THE MOISTURE CONTENT OF THE CONCRETE AGGREGATES. ACCEPTANCE OF THIS MIX CARRIES WITH IT THE INCLUSION OF ATLAS CONCRETE ON THE DISTRIBUTION LIST OF ALL TEST REPORTS PLASTISIZER, STABILIZER ON REQUEST

Prepared by :

Dennis Anderson

US95 Race Creek Bridge Mixture

Accumix

CONCRETE MIX DESIGN

Mix ID Number:	40 Class A	Date:	26-Aug-15
Design Strength:	4000 psi 28 MPa	Plant:	Grangeville
		Designed By:	Accumix

MIX DESIGN QUANTITIES:

Material	Product/Source	Spec Grav	Weight (English Units)	Volume (ft3) (English Units)	Mass (Metric Units)	Volume (m3) (Metric Units)
Cement	Ash Grove Durkee, Type I-II	3.15	500 lb	2.54	297 kg	0.094
Fly Ash	ENX Genesee Class F	2.03	125 lb	0.99	74 kg	0.036
Silica Fume	Basf	2.20	0 lb	0.00	0 kg	0.000
Water (Total)	City Source	1.00	250 lb	4.01	148 kg	0.148
3/4-#4	Salmon River Pit	2.76 *	1660 lb*	9.64	985 kg*	0.357
Ground Limestone	John Day Cr. Pit	2.68 *	0 lb*	0.00	0 kg*	0.000
		2.60 *	0 lb*	0.00	0 kg*	0.000
Fine Aggregate	Salmon River Pit	2.68 *	1350 lb*	8.07	804 kg*	0.300
			lb			
	Total Mix Weight:		3885 lb		2308 kg	
	Air (Entrap/Entrain)	6.5 %		1.76		0.065
	Total Mix Volume:			27.01		1.000

ADMIXTURES:

Product	Product Name/Type	Dosage Rate	Dosage (English)	Dosage (Metric)
Air Entrainment	Basf AE-90	0.28 oz/cwt**	1.8 oz/cy**	70 mL/m3**
Water Reducer	322N	4.0 oz/cwt**	25.0 oz/cy**	968 mL/m3**
Superplasticizer	Basf Z60	4.0 oz/cwt**	25.0 oz/cy**	968 mL/m3**
Superplasticizer	Basf Glenium 3030	2.0 oz/cwt**	13.0 oz/cy**	503 mL/m3**
Hydration Stabilizer	Basf Delvo	0.0 oz/cwt**	0.0 oz/cy**	0 mL/m3**
Accelerator	Basf NC534	0.0 oz/cwt**	0.0 oz/cy**	0 mL/m3**
Fibers		0.0 lb/cy**	0.0 lb/cy**	0.0 kg/m3**

MIX DESIGN PROPERTIES:

Aggregate Properties:

	SG	Abs	FM	Dry Rodded Unit Wt	
3/4-#4	2.76	1.3%	n/a	101.0 pcf	1618 kg/m3
Ground Limestone	2.68	0.2%	n/a	pcf	kg/m3
	2.60	3.1%	n/a	pcf	kg/m3
Fine Aggregate	2.68	1.6%	2.90	n/a	n/a

Plastic Properties:

	English	Metric
Slump:	6.0 ± 2.0 inch	150 ± 50 mm
Air Content:	6.5 ± 1.5 %	
Unit Weight:	143.8 pcf	2308 kg/m3

Design Properties:

Total Cementitious:	625 lb		371 kg
Fly Ash Replacement:	20.0 %	W/C Ratio:	0.40 (incl Admix)

Project:

Contractor:

Comments: W/C ratio can be increased to but not exceed .42

Usage:

Footnotes: * SSD Weights and Spec Gravities. **Admixture dosage rates will be adjusted according to manufacturer's recommendations to accommodate varying field conditions.

This mix design is predicated on the specific information and/or materials provided by the customer and therefore. Change in design components or proportions, materials gradations and/or field placement and curing practices will all strongly affect the ultimate quality of concrete. User should confirm each laboratory design with concrete batched on site and then routinely run quality control checks to verify yield, air content and compressive strength because the physical and chemical characteristics of materials may vary.

District 3

I-84 Paving Mixture

Concrete Placing Company
6451 West Gowen Road
Boise, Idaho 83709
Phone: 208.362.2100 Fax: 208.362.2220

CONCRETE MIX DESIGN REPORT BIC/MIC_500_125 Mix#2014_001
Compressive Strength: 5600

Contractor:	Concrete Placing Company
Project:	Broadway IC A009(081), A012(029) & A012(379)
Source of Concrete:	Portable Wet Batch
Project Type:	4500 PSI Paving
Placement Type:	Slipform

Material / Source or Designation / Blend[1]	Quantity (SSD)	S.G.	Yield, ft^3
Type I/II Cement / Ash Grove Cement / 80%	500 lb	3.15	2.54
Type F Ash (Bridger) / Head Waters / 20%	125 lb	2.36	0.85
Water / Boise City Water	248 lb	1.00	3.97
1 1/2" / 1.5" / 17.96%	524 lb	2.61	3.22
3/4" / .75" / 42.05%	1227 lb	2.61	7.54
Sand / Sand / 39.99%	1167 lb	2.59	7.23
Total Air, percent	6%		1.62
AE 90 / BASF	5 fl oz (US)	1.01	0.00
Pozz 80 / BASF	30 fl oz (US)	1.20	0.03
			27.00

[1] The blend percentage indicated (by weight) is listed separately for cementitious materials and aggregates.

Total Water Content (including water in admixtures), lb			250		
Water / Cementitious Material Ratio:			0.4		
Concrete Unit Weight, pcf			140.5		
Target Slump, in.			1.5 ± 0.5		
Paste Content, percent			27.39%		
Workability Factor (WF)	Target:	35.0		Actual:	36.8
Coarseness Factor (CF)	Target:	60.2		Actual:	58.5
Prepared On:			7/10/14 3:17 PM		

Prepared By:

District 5

US-91 Paving Mixture

4500 ITD Paving

	#	Material	Description	Amount		Based On
1 >>	0	~~BRIG-SND~~ Polley Sand	FINE AGG	1,043.000	lb	0.000
2	1	POC-#57	COARSE AGG	1,260.000	lb	0.000
3	2	BRIG-#4 1.5 Rock	BRIG-#4	460.000	lb	0.000
4	3	DUR-I/II	CEMENT	584.000	lb	0.000
5	4	NAVAJO	FLYASH	145.000	lb	0.000
6	5	WATER	COLD WATER	34.000	gl	0.000
7	6	MICRO-AE	AIR	20.000	oz	0.000
8	7	P-200N	MR-WATER REDUCER	22.000	oz	0.000
9	8	DELVO	HYDRATION STABILIZER	25.000	oz	0.000
*						

District 6

Thornton Interchange Mixture

WALTERS Ready Mix, Inc.

342 West 4th North • P.O. Box 390 • Rexburg, Idaho 83440
PHONE (208) 356-5491 • FAX (208) 356-5553 • EMAIL: wrm@ida.net

Mix# 500F- Class 40F
Project: ITD-NH-6470(129)Thornton Interchange
Slump-4" Date: 1/29/16
Slump-With HRWR-8"

Contractor: Cannon Bldrs.

MATERIALS		*VOL.*		*WEIGHT*
% Air:	6.5	1.76		
Gal water:	31.0	4.14		258.54
Lbs Cement:	494	2.51	Holcim I-II	494.00
LbsFly Ash:	164	1.14	Navajo class F	164.00
Silica Fume:			S.F. 100	
Sub Total:	9.55	17.45		

		Source		SPEC.GRAV.			
S/A Ratio:	38.00						
Sand:	6.63	MA-22	6.63	2.43	62.40	151.63	1005.32
% Split:		MA-68		2.51	62.40	156.62	
3/4" Rock:	10.82	MA-68	10.82	2.61	62.40	162.86	1762.18
3/8"% Split:		MA-22		2.47	62.40	154.12	
W/C Ratio:	0.393		27.00			*lbs/cuyc*	3684.04
						lbs/c.f.:	136.45

Moisture	*Wet*	*Dry*	*Total*	*Moisture %*	*Absorption*	Total Moisture
Sand				0	3.15	
3/4 "Rock		Dry	0	0.00	0.8	
				0.00	0.8	
					0.8	

Free Water

Sand		Per Yard
3/4" Rock		Per Yard
		Per Yard

		Admixtures:	Product:	Dose:
		Air Entrainme	MA-AE90	To meet spec
POZ	AIR	Water Reducer	MP-322N	5 oz./cwt
		Set Control	MS-Delvo	To meet spec
		HRWR	PS-1466	To meet spec
		Accelerator	MS-AC534	To meet spec

Quality Assurance Record
Walters Ready Mix Inc.

Appendix B
CTE Data from LTPP Database for Rigid Pavement Sections in Idaho and Washington

SHRP ID	District	Aggregate type	CTE [x 10^{-6} in/in/˚F]
16-3017	5	Gravel, Igneous Sedimentary, Limestone	5.06 4.89 5.06 4.72 5.22 4.94 5.06 5.28 5.00 4.89 4.56 4.72 4.61
			Average 4.92
			St. dev. 0.22
16-3023	3	Gravel, Igneous Sedimentary, Chert or Diabase	5.00 4.44 4.28 4.33 3.83 4.11 3.94 4.67 4.61
			Average 4.36
			St. dev. 0.37
16-5025	5	Gravel, Igneous Sedimentary, Quartzite	5.67 5.67 5.61 5.50 5.28 5.61 5.56 5.61 5.39 5.56
			Average 5.56
			St. dev. 0.13

SHRP ID	District	Aggregate type	CTE [x 10^{-6} in/in˚F]
53-3011	Not applicable	Gravel, Igneous plutonic, Granite or basalt	4.56 5.50 5.89 5.50 4.56 4.83 4.72 5.17
			Average 5.09
			St. dev. 0.50
53-3013	Not applicable	Gravel, Igneous extrusive or plutonic, andesite or granite	5.28 4.89 4.83 6.11
			Average 5.28
			St. dev. 0.59
53-3014	Not applicable	Gravel, igneous extrusive, basalt or andesite	3.89 4.78 4.56 4.11 4.56 3.94 4.33 4.11
			Average 4.29
			St. dev. 0.32
53-3019	Not applicable	Gravel, igneous extrusive, basalt	4.56 4.50 4.33 4.50 4.56 4.72 4.61 4.39 4.44 4.11 4.33 4.50
			Average 4.46
			St. dev. 0.16

SHRP ID	District	Aggregate type	CTE [x 10^{-6} in/in/˚F]
53-3812	Not applicable	Gravel, igneous plutonic, basalt or andesite	4.89 4.94 4.67 4.89 4.89 4.83 8.89 5.17 4.28 4.39 4.44 4.67 5.17 4.28
			Average 5.03
			St. dev. 0.12
53-3813	Not applicable	Gravel, igneous extrusive, basalt	3.44 3.94 3.44 4.17 4.06 4.28 4.28 4.22 4.39 3.72 3.89 4.06 4.06 3.56 4.67 3.72 3.78 4.22 4.22 4.00
			Average 4.00
			St. dev. 0.32
53-7409	Not applicable	Gravel, igneous extrusive, basalt	4.17 3.83 4.22 3.89 4.06 4.22
			Average 4.03
			St. dev. 1.70
53-A800	Not applicable	Gravel, igneous extrusive, basalt	3.94

Appendix C
Mill Certificates for Cementitious Materials

LAFARGE CEMENT

Cement Mill Test Report

Month of Issue: MARCH 2016

Plant:	Richmond, British Columbia
Product:	Portland Cement Type I/II
Mill Test Report #	R-TI-16-03
Manufactured:	FEBRUARY 2016

ASTM C 150-12 and AASHTO M 85-12 Standard Requirements

CHEMICAL ANALYSIS

Item	Spec limit	Test Result
Rapid Method, X-Ray (C 114)		
SiO2 (%)	---	20.2
Al2O3 (%)	6.0 max	4.7
Fe2O3 (%)	6.0 max	3.3
CaO (%)	---	63.6
MgO (%)	6.0 max	0.8
SO3 (%)	3.0 max*	3.1
Loss on ignition (%)	3.0 max	2.7
Insoluble residue (%)	0.75 max	0.2
CO2 (%)	---	1.7
Limestone (%)	5.0 max	4.1
CaCO3 in Limestone (%)	70 min	98
Adjusted Potential Phase Composition (C 150)		
C3S (%)	---	52
C2S (%)	---	19
C3A (%)	8 max	7
C4AF (%)	---	10
C3S+4.75*C3A (%)	100 max	84

PHYSICAL ANALYSIS

Item	Spec limit	Test Result (Mpa)	Test Result (PSI)
Air content of mortar (%) (C 185)	12 max	4.9	
Blaine Fineness (m2/kg) (C 204)	260 - 430	395	
Passing 45 um (%) (C 430)	72 min	96.7	
Autoclave expansion (%) (C 151)	0.80 max	-0.02	
Compressive strength (MPa, [PSI]) (C 109)		Mpa	PSI
3 days	12.0 [1740] min	28.2	4080
7 days	19.0 [2760] min	34.5	5000
28 days (Reflects previous month's data)	28.0 [4060] min	44.4	6440
Time of setting (minutes)			
Vicat initial (C 191)	45 - 375	94	
False Set (%)	50 min	88	
Heat of Hydration (C186)** - 28 day (KJ/Kg)		399	
Colour (Lafarge Index)	---	30	
Mortar Bar Expansion (%) (C 1038)**	0.020 max	0.007	

ASTM C 150-09 and AASHTO M 85-09 Optional Chemical Requirements:

Item	Spec limit	Test Result
NaEq (%)	0.60 max	0.55

* May exceed 3.0% SO3 maximum based on our C 1038 results of <0.02% expansion at 14 days. C1038 tested Q4-15

** Current Production run not available - most recent provided

Note: Specific gravity for Portland cement is considered to be 3.15

We certify that the above described cement, at the time of shipment, meets the chemical and physical requirements of applicable DOT Specifications for Type I and Type II;
ASTM C 150-12 & AASHTO M 85-12 STANDARD SPECIFICATIONS FOR TYPE I AND TYPE II CEMENT;
ASTM C 150-12 & AASHTO M 85-12 OPTIONAL CHEMICAL REQUIREMENTS FOR TYPES I & II LOW ALKALI CEMENT.

Western BU - Richmond
7611 No 9 Rd Richmond, BC
604 244 4300

Questions or enquiries can be directed to Rob Shogren
Rob Shogren, PhD
Lafarge - Technical Director
5400 W Marginal Way SW, Seattle WA
P +1 206 923 9953
E Rob.Shogren@lafargeholcim.com

Certified By:

Harold Ptachyk B.Sc., PChem
Quality Manager
3/14/2016

ASH GROVE

ASH GROVE CEMENT COMPANY
WESTERN REGION
33060 SHIRTTAIL CREEK ROAD
P.O. BOX 287
DURKEE, OREGON 97905
(541) 877-2411

Durkee Plant
Mill Test Report

Mill Analysis No. 16-10   Cement Type I-II L.A.   Date 05-10-2016
Bin No. 2,3,4,D   Production Period April 1 thru April 30, 2016

STANDARD REQUIREMENTS
ASTM C150

CHEMICAL

Item (C114)	Spec. Limit	Test Result
SiO2 (%)	A	21.3
Al2O3(%)	6.0 max.	3.5
Fe2O3(%)	6.0 max.	3.3
CaO (%)	A	64.1
MgO (%)	6.0 max.	2.1
SO3 (%)	D	2.8
Loss On Ignition (%)	3.0 max.	1.44
Na2O (%)	A	0.22
K2O (%)	A	0.46
TiO2 (%)	A	0.27
P2O5 (%)	A	0.16
Mn2O3 (%)	A	0.07
Insoluble Residue (%)	0.75 max.	0.43
CO2 (%)	A	0.94
Limestone %	5.0 max.	2.33
CaCO3 in Limestone	70 min.	99.35
C3S + 4.75C3A	100 max.	78
Potential Compounds (%)	C	
C3S	A	59
C2S	A	16
C3A	8.0 max.	4
C4AF	A	10
C4AF+2(C3A)	A	18

PHYSICAL

Item		Spec. Limit	Test Result
Air Content of Mortar (volume %)			
C185		12 max.	6.1
Fineness (m²/kg)			
C204 (Air permeability)		260 min.	393
Autoclave Expansion (%)		0.80 max.	0.021
C151			
Compressive Strength Psi (Mpa)		Min.:	
C109	1 Day	A	2100 (14.5)
	3 Days	1740 (12.0)	4170 (28.8)
	7 Days	2760 (19.0)	5350 (36.9)
Time of Setting (minutes)			
C191 (Vicat)			
	Initial	not less than 45	124
	Final	not more than 375	230

OPTIONAL REQUIREMENTS
ASTM C150, (other)

CHEMICAL

Item	Spec. Limit	Test Result
Equivalent Alkalies (%)	0.60 max.	0.52
Chloride (%)	B	0.002

PHYSICAL

Item		Spec. Limit	Test Result
False Set (%) C451		50 min.	89
Heat of Hydration (cal /g)	C186		
	7 days	B	80
Compressive Strength (Mpa)			
	28 Days	4060 (28.0)	F
Sulfate Resistance (%)	C452	0.040	0.032
Water Expansion (%)	C1038	0.020	0.006
% retain on 45µm sieve		B	0.62

A = not applicable
B = Test results represents most recent value and is provided for informational purposes only.
C = Adjusted per A 1.6.
D = C1038 expansion in water does not exceed 0.02 at 14 days.
F = Test results for this production period not yet available.

We certify that the above described cement, at the time of shipment, meets the chemical and physical requirement of the ASTM C150-16 or AASHTO M-85 -12 Type I-II specification also will meet CSA A3000-13 Type GU, MS and HS.

NSF
Certified to NSF/ANSI 61

Signature: [signature]   Title: Chief Chemist

LAFARGE
NORTH AMERICA

Cement

FLY ASH TEST REPORT

Analysis by:	Lafarge Seattle Concrete Lab
Sample from :	Centralia Power Plant
Average Analysis:	December 1 - 31, 2015
Test Report Number	1-16 Class F

Chemical Analysis

	Results	Limits
Silicon Dioxide (SiO_2)	48.6 %	
Aluminum Oxide (Al_2O_3)	16.7 %	
Iron Oxide (Fe_2O_3)	6.3 %	
Total (SiO_2) + (Al_2O_3) + (Fe_2O_3)	72 %	70% Min - ASTM
Sulphur Trioxide (SO_3)	0.9 %	5% Max - ASTM
Calcium Oxide (CaO)	13 %	
Magnesium Oxide	5.6 %	
Moisture Content	0.13 %	3% Max - ASTM
Loss on Ignition	0.34 %	6% Max - ASTM
Available Alkali as Equiv. Na_20 *(previous month's result)*	0.95 %	

Physical Analysis

Fineness Retained on 45 um (No. 325 Sieve)	15.0 %	34% Max - ASTM
Strength Activity Index with Portland Cement		
% of Control at 7 Days	90 %	75% Min - ASTM
% of Control at 28 Days *(previous month's result)*	106 %	75% Min - ASTM
Water Requirement, Percent of Control	95 %	105% Max- ASTM
Autoclave Expansion	0.03 %	0.8% Max - ASTM
Density	2.68 Mg/m^3	

Uniformity Requirements

Density, Variation from Average	0.00 %	5% Max - ASTM
Fineness 45um Sieve, Variation from Average	2.40 %	5% Max - ASTM

We hereby certify that the composite fly ash sample above meets the chemical and physical requirements of ASTM C618 and AASHTO M295 for class F and C fly ash.

Certified : Robert D. Shogren

Rob Shogren
Technical Director

WESTERN REGION
5400 West Marginal Way SW, Seattle, Washington 98106-1517
Office: 206.923.0098 or 800.477.0100 Fax: 206.923.0388

LAFARGE
NORTH AMERICA

Cement

FLY ASH TEST REPORT

Analysis by:	Edmonton Mortar Lab
Sample from :	Sundance Power Plant
Average Analysis:	May 2016
Test Report Number	6-16 Class F

Chemical Analysis

	Results	Limits
Silicon Dioxide (SiO_2)	56.9 %	
Aluminum Oxide (Al_2O_3)	23.3 %	
Iron Oxide (Fe_2O_3)	3.5 %	
Total (SiO_2) + (Al_2O_3) + (Fe_2O_3)	83.7 %	70% Min - ASTM
Sulphur Trioxide (SO_3)	0.2 %	5% Max - ASTM
Calcium Oxide (CaO)	9.6 %	
Magnesium Oxide	1.0 %	
Moisture Content	0.06 %	3% Max - ASTM
Loss on Ignition	0.61 %	6% Max - ASTM
Available Alkali as Equiv. Na_2O *(previous month's result)*	0.41 %	

Physical Analysis

Fineness Retained on 45 um (No. 325 Sieve)	24.6 %	34% Max - ASTM
Strength Activity Index with Portland Cement		
% of Control at 7 Days	78 %	75% Min - ASTM
% of Control at 28 Days *(previous month's result)*	89 %	75% Min - ASTM
Water Requirement, Percent of Control	97 %	105% Max- ASTM
Autoclave Expansion	0.07 %	0.8% Max - ASTM
Density	2.03 Mg/m^3	

Uniformity Requirements

Density, Variation from Average	0.05 %	5% Max - ASTM
Fineness 45um Sieve, Variation from Average	0.00 %	5% Max - ASTM

We hereby certify that the composite fly ash sample above meets the chemical and physical requirements of ASTM C618 and AASHTO M295 for class F and C fly ash.

Certified : Robert G. Shogren

WESTERN REGION
5400 West Marginal Way SW, Seattle, Washington 98106-1517
Office: 206.923.0098 or 800.477.0100 Fax: 206.923.0388

TECHNICAL REPORT

CCIL CERTIFIED CONCRETE TESTING LABORATORY
IN ACCORDANCE WITH CSA A283-06

amec foster wheeler

Chemical and Physical Analysis of Fly Ash

Developed For: ENX Incorporated
P.O. Box 67025
Meadowlark Postal Outlet
Edmonton, AB T5R 5Y3

Project: CA18390	**Plant of Origin:** Genesee	**Sample Date:**	March 1-31, 2016
Report Date: 17-May-16	**Sample ID:** 16ENX-3	**Date Received**	26-Feb-16

Chemical Composition (%)			ASTM C 618-12a Specifications Class F	ASTM C 618-12a Specifications Class C
Total Silica, Aluminum, Iron:	80.5		70.0 Min	50.0 Min
Silicon Dioxide		55.5		
Aluminum Oxide:		20.5		
Iron Oxide:		4.5		
Sulfur Trioxide:	0.20			5.0 Max
Calcium Oxide:	8.9			
Moisture Content:	0.0		3.0 Max	3.0 Max
Loss on Ignition:	0.6		6.0 Max	6.0 Max
			AASHTO M295-11 Specifications	
Available Alkalies (as Na_2O):	1.3		1.5 Max	1.5 Max
Sodium Oxide:		0.93		
Potassium Oxide:		0.48		

Physical Test Results		ASTM C 618-12a Specifications Class F	ASTM C 618-12a Specifications Class C
Fineness, Retained on #325 Sieve (%):	24.4	34 Max	34 Max
Strength Activity Index (%)			
Ratio to Control @ 7 Days:	77.0		
Ratio to Control @ 28 Days:	79.7	75 Min	75 Min
Water Requirement, % of Control	94.7	105 Max	105 Max
Soundness, Autoclave Expansion (%):	0.1	0.8 Max	0.8 Max
Drying Shrinkage, Increase @ 28 Days (%):		0.03 Max	0.03 Max
Density Mg/m^3:	2.02		

COMMENTS:
- Meets Class F, ASTM C 618-12a Specification

(Final Report)

Amec Foster Wheeler
Environment & Infrastructure

Justin Han, E.I.T.
Materials Engineer-in-Training

Reviewed By:

Tony Lai, P.Eng.
Senior Project Manager

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written request.

ISG RESOURCES

A HEADWATERS Company

Material Safety Data Sheet

CLASS F FLY ASH

SUBBITUMINOUS COAL FLY ASH
Jim Bridger Power Plant, Rock Springs, WY U.S.A.

(801) 984-9400
Information Phone Number

(800) 241-7799
Emergency Phone Number

Prepared: October 25, 2001 (reviewed June 2004)

SECTION 1 – MATERIAL IDENTIFICATION AND INFORMATION

INGREDIENT		FORMULA	%[1]	OSHA PEL[2]	ACGIH TLV[2]
Aluminosilicate Glass		Contains Al, Ca, Si, Fe, Mg, Ti	85-90	Not Listed[3]	Not Listed[3]
Crystalline Silica	Total	SiO_2	5-10	30/% SiO_2+2[4]	0.3
	Respirable	SiO_2	See Note (5)	10/% SiO_2+2[4]	0.1
Iron Minerals		Fe_2O_3, Fe_3O_4	2-6	10	5
Lime		CaO	5-9	5	2
Magnesia		MgO	< 6	15	10
Titania		TiO_2	< 5	15	10
Sodium Oxide		Na_2O	< 4	Not Established	Not Established

Notes:

(1) Values approximate. This fly ash is the product of combustion of subbituminous coal. It is a complex inorganic substance composed, primarily, of compounds of the elements silicon, aluminum, iron, and calcium, with smaller amounts of magnesium, titanium, sodium, and potassium. This fly ash has not been classified by particle size.
(2) Airborne exposure limits in mg/m^3.
(3) Not listed specifically by substance name. Exposure to aluminosilicate glass dust may be covered by inert or nuisance dust limits of 15 mg/m^3 for total dust and 5 mg/m^3 for respirable portion.
(4) The percentage of crystalline silica in the formula is the amount determined from airborne samples.
(5) Presence of respirable crystalline silica has not been established.

SECTION 2 – PHYSICAL / CHEMICAL CHARACTERISTICS

Boiling Point: N/A
Vapor Pressure (mmHg and Temperature): N/A
Vapor Density (Air = 1): N/A
Solubility in Water: Slight
Appearance and Odor: Fine Brownish-Grey, Odorless Powder

Specific Gravity (H_2O = 1): 2.2-2.5
Melting Point: >1990° F
Evaporation Rate: N/A
Water Reactive: Not Reactive

SECTION 3 – FIRE AND EXPLOSION HAZARD DATA

Extinguisher Media: Use extinguishing matter suitable for surrounding fire.
Flammability Limits in Air (% by Volume): N/A
Special Fire Fighting Procedures: N/A
Unusual Fire and Explosion Hazards: None. This mineral matter is considered non-flammable and non-combustible. Use fire extinguishing agent suitable for surrounding media.

Auto Ignition Temperature: N/A
LEL: N/A **UEL:** N/A
Flash Point and Method Used: N/A

SECTION 4 – REACTIVITY HAZARD DATA

Stability: Considered to be stable.
Hazardous Decomposition Products: Decomposition products are unknown and not suspected.
Hazardous Polymerization: Hazardous polymerization not known to occur.
Reactivity: Material is considered inert.
Conditions to Avoid: None.

N/A = Not Applicable

Appendix D
ITD PCC-ME Database

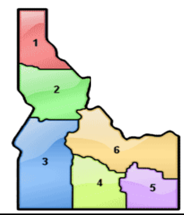
Note: This Database is provided in an Excel Book for all mixes. This appendix includes summary tables for all results. The raw data for all tests are provided, as a backup, only in the Excel book due to its size.

Main Screen

AASHTOWare Pavement ME Design

Idaho PCC Mixes

ITD Research Project RP253



District Number with Mixture Description (Please click on the Mix for Details)	Cement Type Specified by Mixture Design	Fly Ash Type Specified by Mixture Design	PCC RAW Data
District 1, Structural Mixture	Lafarge Type I/II	No Fly Ash	RAW DATA
District 1, I-90 Lookout Pass Paving Mixture, 2015	Lafarge Type I	Centralia	RAW DATA
District 1, I-90 Lookout Pass Paving Mixture, 2016	Lafarge Type I	Sundance	RAW DATA
District 2, Thain Road Paving Mixture	Ash Grove Type I/II	Sundance	RAW DATA
District 2, US-95 Race Creek Bridge	Ash Grove Type I/II	ENX Genesee Class F	RAW DATA
District 3, I-84 Paving Mixture	Ash Grove Type I	Type F, Headwaters	RAW DATA
District 5, US-90 Paving Mixture	Ash Grove Type I /II	Naavajo	RAW DATA
District 6, Thornton Interchange Mixture	Lafarge Type I/II	Naavajo	RAW DATA

District 1, SH-5 Bridge Crossing

PCC

Unit weight (pcf)	142.9
Poisson's ratio	0.16

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	4.83
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	611
Water to cement ratio	0.41
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-295.000
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	33
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	630	3.55E+06	410
14-day	655	3.80E+06	465
28-day	715	4.25E+06	490
90-day	730	4.55E+06	510
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	4040
14-day	4630
28-day	4870
90-day	5270
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	4870

OR

Time	Modulus of rupture (psi)
28-day	715

District 1, I-90 Lookout Pass Paving Mixture, 2015

PCC

Unit weight (pcf)	148.1
Poisson's ratio	0.14

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	3.75
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	688
Water to cement ratio	0.35
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-315.000
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	33
Curing method	Wet Curing

Strength

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	4830
14-day	5470
28-day	5510
90-day	6560
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	5510

OR

Time	Modulus of rupture (psi)
28-day	895

District 1, I-90 Lookout Pass Paving Mixture, 2016

PCC

Unit weight (pcf)	142.8
Poisson's ratio	0.16

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	3.78
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	688
Water to cement ratio	0.37
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-540.833
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	35
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	620	3.20E+06	375
14-day	665	3.35E+06	440
28-day	810	3.50E+06	520
90-day	995	4.75E+06	615
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	3500
14-day	4360
28-day	4640
90-day	5560
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	4640

OR

Time	Modulus of rupture (psi)
28-day	810

District 2, Thain Road Paving Mixture

PCC

Unit weight (pcf)	144.7
Poisson's ratio	0.19

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	4.51
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	611
Water to cement ratio	0.40
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-565.667
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	31
Curing method	Wet Curing

Strength

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	3760
14-day	5130
28-day	5160
90-day	5830
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	5160

OR

Time	Modulus of rupture (psi)
28-day	785

District 2, US-95 Race Creek Bridge

PCC

Unit weight (pcf)	145.6
Poisson's ratio	0.20

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	5.38
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	625
Water to cement ratio	0.35
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-481.667
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	31
Curing method	Wet Curing

Strength

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	5340
14-day	5610
28-day	6900
90-day	7560
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	6900

OR

Time	Modulus of rupture (psi)
28-day	810

District 3 - I-84 Paving Mixture

PCC

Unit weight (pcf)	140.2
Poisson's ratio	0.15

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	5.08
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	625
Water to cement ratio	0.36
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-352.000
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	37
Curing method	Wet Curing

Strength

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	3890
14-day	4510
28-day	5590
90-day	6400
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	5590

OR

Time	Modulus of rupture (psi)
28-day	745

District 5 - US-90 Paving Mixture

PCC

Unit weight (pcf)	140.2
Poisson's ratio	0.16

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	3.79
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	729
Water to cement ratio	0.34
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-545.833
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	36
Curing method	Wet Curing

Strength

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	4540
14-day	4850
28-day	5080
90-day	5930
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	5080

OR

Time	Modulus of rupture (psi)
28-day	775

District 6 - Thornton Interchange Mixture

PCC

Unit weight (pcf)	139.1
Poisson's ratio	0.16

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	3.83
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	658
Water to cement ratio	0.38
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	-
Ultimate shrinkage (microstrain)	-366.667
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	31
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	500	2.95E+06	350
14-day	615	3.60E+06	385
28-day	770	3.80E+06	455
90-day	955	4.40E+06	525
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	2800
14-day	3390
28-day	4310
90-day	5260
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)
28-day	4310

OR

Time	Modulus of rupture (psi)
28-day	770