Comparison of Modern Concrete Pavement Performance Predictions, Thickness Requirements, and Sensitivity to Joint Spacing

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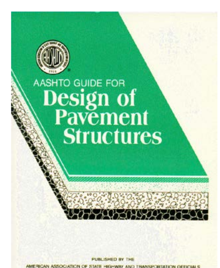
Introduction

- More than 25 design methods exist for jointed plain concrete pavements (JPCPs)
- Many are based on the 1950s AASHO Road Test, including AASHTO 93 and CHAUSEE2
  - The prominence of these methods created an expectation for JPCP thicknesses
- Modern JPCP design methods in North American are:
  1. Founded in mechanistic (M) principles such as finite element analyses and
  2. Supplemented with empirical (E) calibration to field performance to increase the accuracy of key performance predictions of importance to owners and users, such as:
     - Cracking in slabs,
     - Faulting in joints, and
     - International Roughness Index (IRI)

Empirical
1950s Era

Mechanistic and Empirical
Modern (2000s Era) JPCP Design Methods



AASHTO 93 | **ACPA's StreetPave** | **TCPavement's OptiPave** | **AASHTOWare Pavement ME**

Increasing number of inputs and model complexity

Design Method	Failure Mode(s) Predicted				Design Basis
	Cracking	Faulting	IRI	Other	
AASHTO 93				X	E
ACPA's StreetPave	X	X			M & E
TCPavement's OptiPave	X	X	X		M & E
AASHTOWare Pavement ME	X	X	X		M & E

Limitations of the Design Framework

AASHTO 93
- Based on empirical 1950s field testing
- 8 million ESAL limit in testing
- Non-measurable performance metric
- Less than 25% of concrete cells failed
- Limited and restrictive inputs
- Not calibrated to modern, local JPCP

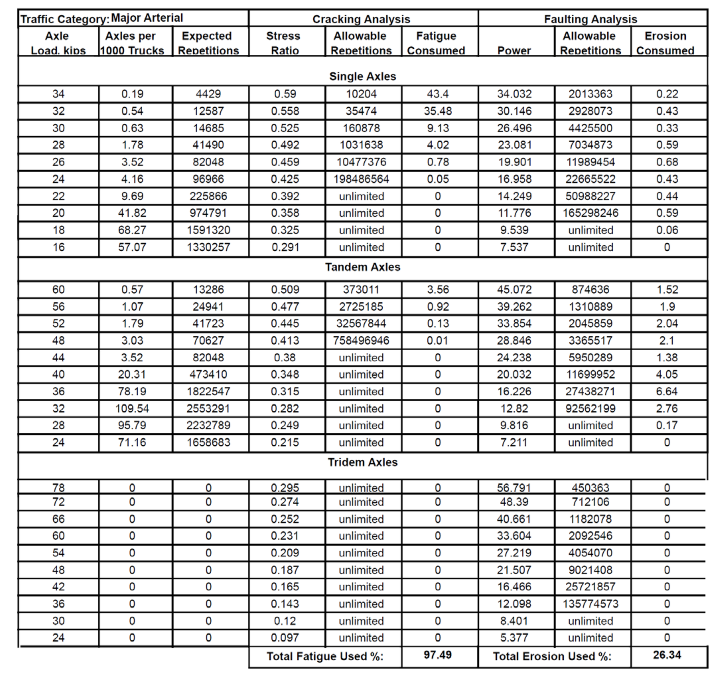
ACPA's StreetPave
- Cracking model only for bottom-up
- Incomplete consideration of k-value
- Beam-based fatigue model, underestimating slab capacity
- Overly simplistic faulting model
- No accounting for time of loading

AASHTOWare Pavement ME
- Complex inputs and interactions
- High access cost
- Requires panels > 10 ft (3 m)

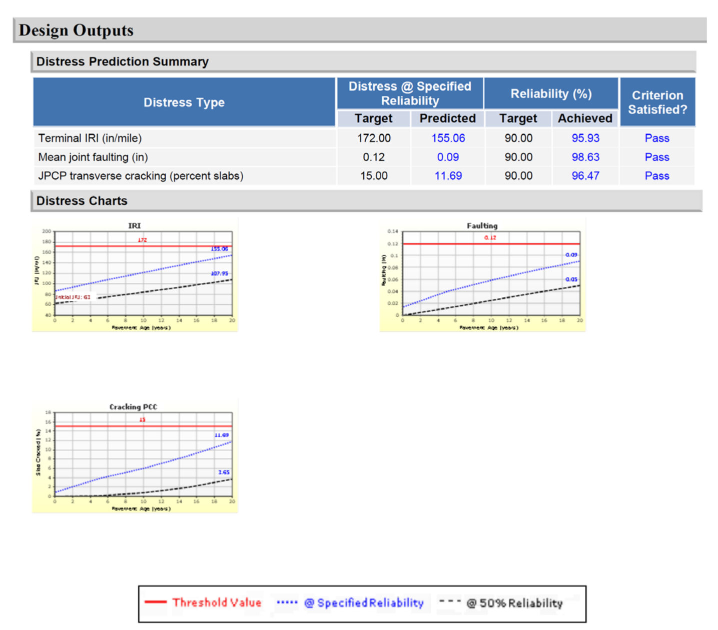
TCPavement's OptiPave
- Less design variables than Pavement ME
- Requires panels < 8 ft (2.4 m)
- Shorter performance history

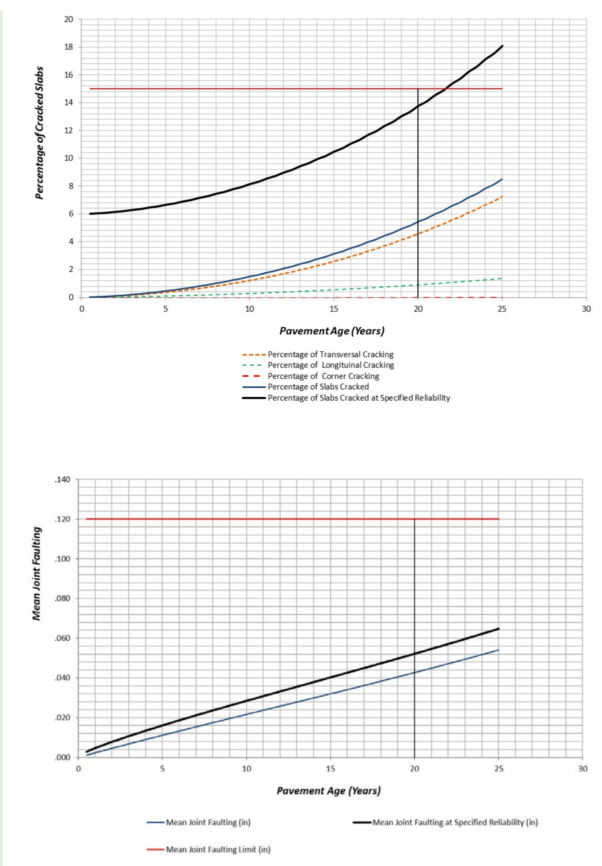
Performance Predictions Comparison

- This study extends prior work that compared AASHTO 93, Pavement ME, and StreetPave to illustrate the breadth of design variables considered and the sensitivity of required JPCP thickness to traffic magnitude, the use of dowels, concrete flexural strength, concrete modulus of elasticity, edge support, design reliability, and k-value
- As with the previous comparison, "default" input values are used as much as possible across all of the software to best represent the actions of a novice pavement designer
- Modelling began with Pavement ME, where a 6 in. (150 mm) thick non-stabilized stone base was added atop an A-7-6 soil and the surface course is a doweled JPCP for Chicago O'Hare International Airport (ORD) to model a freeze-thaw location
- Comparable AASHTO 93, StreetPave, and OptiPave designs were then developed using identical values from Pavement ME for common inputs or assuming the software's default value if the input is unique to the design framework

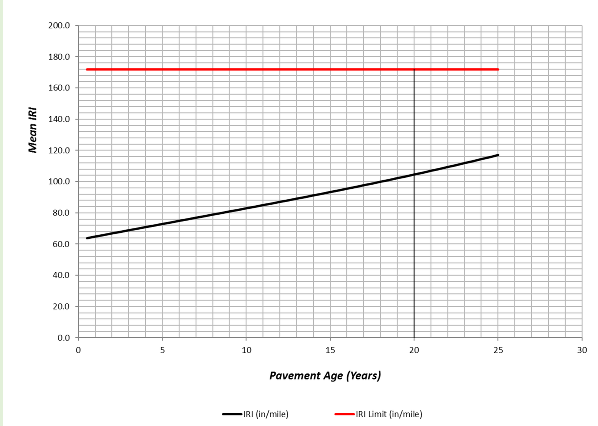


StreetPave's performance predictions at 5,000 trucks per day for a 9.5 in, (241 mm) thick JPCP





Pavement ME's performance predictions at 5,000 trucks per day for a 8.5 in. (216 mm) thick JPCP with 15 ft (4.6 m) joint spacing



OptiPave's performance predictions at 5,000 trucks per day for a 6.9 in. (175 mm) thick JPCP with 6 ft (1.8 m) joint spacing

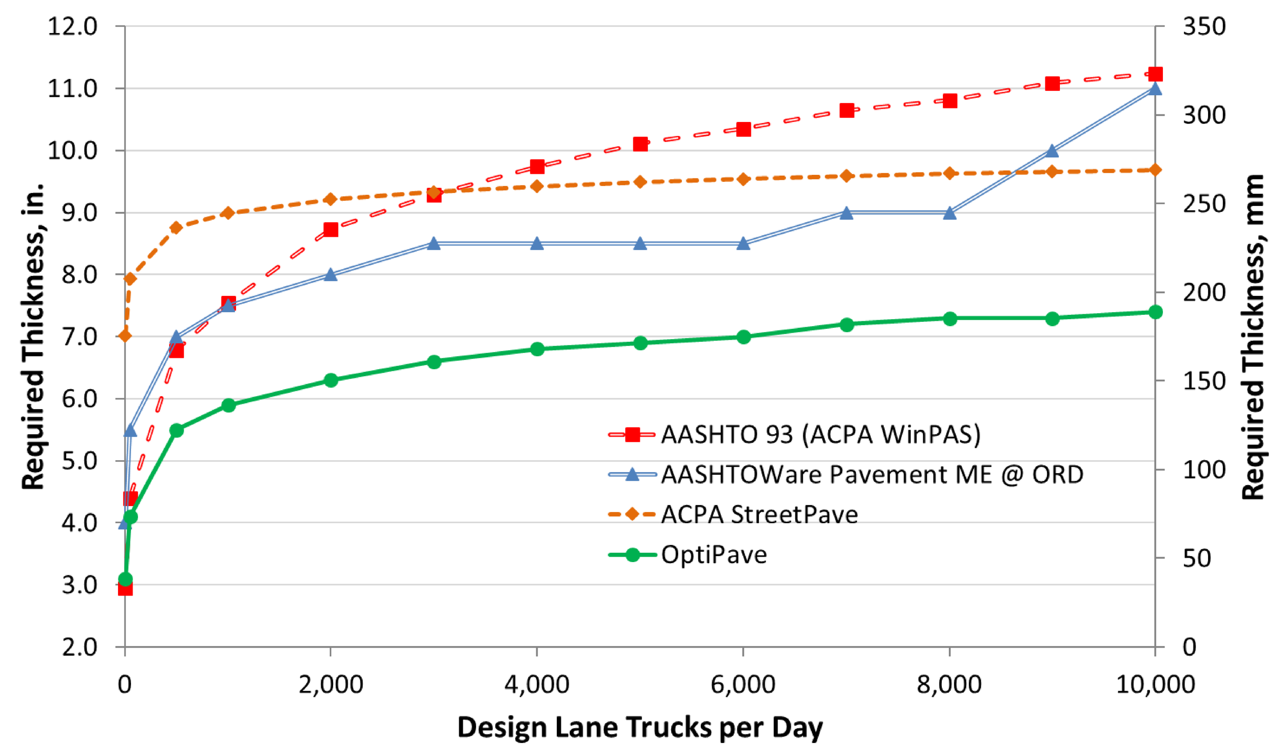
- AASHTO 93 does not predict a measurable performance metric, so it is not plotted
- StreetPave begins with a very thin JPCP and incrementally increases the thickness until the total fatigue consumed and total erosion consumed are both less than 100%; thus, rather than being a performance prediction design tool, thickness is adjusted to manage performance expectation below the acceptable level for the duration of the design life
- Pavement ME and OptiPave both compute and report accumulated percent slabs cracked, magnitude of faulting, and IRI over the design life

As shown, all three modern JPCP design approaches compute responses and failure modes of interest to owners and users whereas AASHTO 93 cannot

Thickness Requirements Comparison

- Although there are many variables with which a pavement engineer can optimize a JPCP with regards to cost, sustainability, etc., the JPCP thickness required for the same set of conditions is of particular interest to practicing pavement engineers
- The table and image at the top of the next column show the required thickness of the "defaults" case example previously presented for varying levels of trucks per day
- AASHTO 93 thickness requirements have a trendline with a slope that is significantly different than the modern design approaches across the entire traffic range considered
  - The maximum calibration point from the AASHO Road Test occurs at 8 million ESALs, corresponding to a traffic level of approximately 3,000 trucks per day in this example
  - All values to the right of 3,000 trucks per day, where AASHTO 93 is increasingly thicker than all modern design approaches, are beyond the design calibrated inference space
  - For traffic levels less than 3,000 trucks per day, AASHTO 93 still shows much disagreement with the modern design approaches, underpredicting thickness
- StreetPave appears conservative to the other modern design approaches
- Pavement ME allows for a more localized answer of the required thickness with local environmental conditions and responses considered
- OptiPave allows for additional thickness reductions beyond Pavement ME because the reduction of maximum joint spacing from 15 ft (4.6 m) to 6 ft (1.8 m)

Trucks per Day	AASHTO 93	ACPA StreetPave		AASHTOWare Pavement ME		OptiPave	
	Thickness, in. (mm)	*Thickness, in. (mm)*	*Controlling Failure Mode(s)*	*Thickness, in. (mm)*	*Controlling Failure Mode(s)*	*Thickness, in. (mm)*	*Controlling Failure Mode(s)*
5	3 (75)	7 (176)	Cracking	4 (102)	Cracking	3.1 (79)	Cracking
50	4.4 (112)	7.9 (199)	Cracking	5.5 (140)	Cracking	4.1 (104)	Cracking
500	6.8 (172)	8.8 (220)	Cracking	7 (178)	Cracking	5.5 (140)	Cracking
1,000	7.5 (192)	9 (226)	Cracking	7.5 (191)	Cracking	5.9 (150)	Cracking
2,000	8.7 (222)	9.2 (231)	Cracking	8 (203)	Cracking	6.3 (160)	Cracking
3,000	9.3 (236)	9.3 (234)	Cracking	8.5 (216)	IRI	6.6 (168)	Cracking
4,000	9.7 (247)	9.4 (236)	Cracking	8.5 (216)	IRI	6.8 (173)	Cracking
5,000	10.1 (257)	9.5 (238)	Cracking	8.5 (216)	IRI	6.9 (175)	Cracking
6,000	10.4 (263)	9.5 (239)	Cracking	8.5 (216)	Cracking	7 (178)	Cracking
7,000	10.7 (271)	9.6 (241)	Cracking	9 (229)	IRI	7.2 (183)	Cracking
8,000	10.8 (275)	9.6 (242)	Cracking	9 (229)	IRI	7.3 (185)	Faulting
9,000	11.1 (282)	9.7 (242)	Cracking	10 (254)	Faulting	7.3 (185)	Faulting
10,000	11.2 (285)	9.7 (243)	Cracking	11 (279)	Faulting	7.4 (188)	Faulting

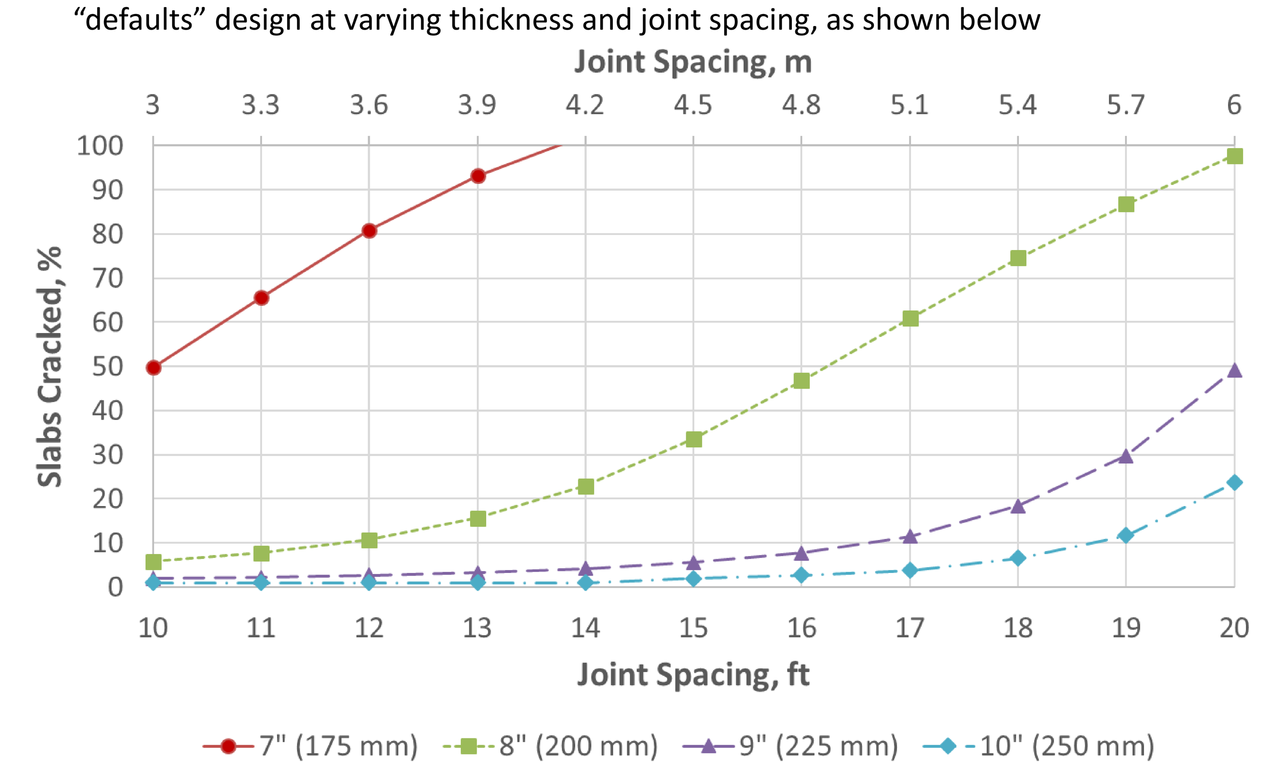


Comparison of Thickness Requirements and Controlling Failure Mode(s) for the Modern JPCP Design Methods and AASHTO 93 at Varying Traffic Levels

As shown above, StreetPave provides a reasonably accurate solution, and via a relatively simple design framework. Also shown, Pavement ME's consideration of local conditions and more complex models can reduce thickness by approximately 1 in. (25 mm) versus StreetPave in this case and OptiPave's consideration of shorter joint spacing can produce approximately 2 – 2.5 in. (50 – 64 mm) of thickness reduction versus StreetPave.

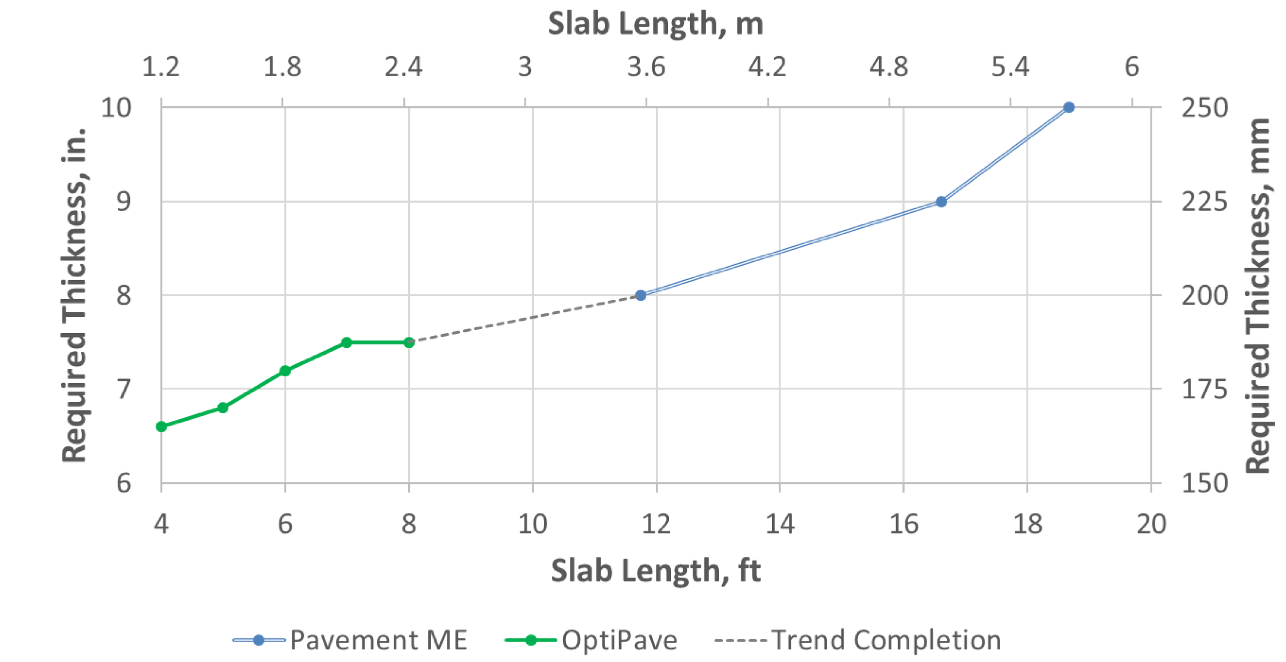
Sensitivity of Cracking Response to Joint Spacing

- Joint spacing is the 4th most sensitive input in Pavement ME, only trumped by concrete flexural strength at 28 days, thickness, and surface shortwave absorptivity (SSA)
- Consider percent slabs cracked results for Pavement ME for 5,000 trucks per day and our "defaults" design at varying thickness and joint spacing, as shown below



Pavement ME predictions of percent slabs cracked for 5,000 trucks per day varying slab thickness and joint spacing

- The traditional mindset is to manage percent slabs cracked after determining the required thickness; if the allowance is for 10% slabs cracked, slab thicknesses of 8 in. (200 mm), 9 in. (225 mm), and 10 in. (250 mm) can have maximum joint spacings of 11.75 ft (3.5 m), 16.6 ft (5.0 m), and 18.7 ft (5.6 m), respectively
  - Consider, instead, the same set of solutions from an alternative perspective where maximum joint spacings of 18.7 ft (5.6 m), 16.6 ft (5.0 m), 11.75 ft (3.5 m) require slab thicknesses of 10 in. (250 mm), 9 in. (225 mm), and 8 in. (200 mm), respectively, to achieve just 10% slabs cracked; shorter panels can become thinner and still achieve the same performance requirements
- Now consider the same inputs modelled in OptiPave at a joint spacing of 8 ft (2.4 m) and less, as shown below and with a single line between 8 ft (2.4 m) and 11.75 ft (3.5 m) to complete the trend in sensitivity to joint spacing for this example



Required Thickness versus slab length at 5,000 trucks per day

As shown, while a 1.5 – 2 in. (28 – 50 mm) reduction in thickness due to a reduction in joint spacing from 15 ft (4.6 m) to 6 ft (1.8 m) might appear excessive at first glance in the figure to the left, the sensitivity of required thickness to joint spacing as shown above when considering both OptiPave and Pavement ME solutions across varying joint spacing presents a rational transition in sensitivity to this key input variable

Summary and Conclusions

- Project-level pavement management and network-level asset management are increasingly tracked as owners aim to maximize the effectiveness of their limited resources
- Key to that is accurate pavement performance predictions and an understanding of how the various modern JPCP methods can facilitate optimization by means such as inclusion of fibers, consideration of joint spacing, or adjustment of any other inputs allowed in the design framework
- While AASHTO 93 is historically the most common JPCP design method in the world, its limitation prompted development of modern mechanistic-empirical frameworks, such as ACPA's StreetPave, AASHTOWare Pavement ME, and TCPavement's OptiPave
- The modern software are increasingly adopted in N.A. and abroad because of their more accurate and reliable performance predictions of the key indicators that owners and users observe and feel as they drive across a pavement
- With adoption of such modern JPCP design methods, pavement engineers have an opportunity to optimize JPCP design while minimizing their risk and liability
- Comparison of the modern JPCP designs to AASHTO 93 illustrate that AASHTO 93 is the outlier, with a distinctly different slope of its sensitivity of thickness to traffic
- Among the modern JPCP designs, thickness may be reduced through consideration of more complex models and key inputs such as joint spacing
- Continuous sensitivity of required thickness to joint spacing is presented through modelling comparable inputs in both Pavement ME and OptiPave; the trend illustrates that while the thickness reductions suggested by OptiPave seem optimistic if approached with an AASHTO 93 seeded bias in thickness expectations, the results are consistent with the thickness reduction trendline realized in Pavement ME