



August 20, 2018

Amy Miller, PE
National Director
Asphalt Pavement Alliance
2233 Park Avenue, Suite 200U
Orange Park, Florida 32073

Re: Verification of PaveXpress with 1993 and 1998 AASHTO Pavement Design Guide

Dear Ms. Miller:

Palmer Engineering was contracted by the Asphalt Pavement Alliance to complete a study comparing pavement designs within the *AASHTO Guide for Design of Pavement Structures* (AASHTO 1993) and *Supplement to the AASHTO Guide for Design of Pavement Structures, Part II – Rigid Pavement and Rigid Pavement Joint Design* (AASHTO 1998) to design procedures within the web-based program, PaveXpress, developed by the Asphalt Pavement Alliance. The attached memorandum report describes in detail the results of these analyses.

The testing matrix for comparison of asphalt pavement designs involved the following:

- Four CBRs (2, 5, 7, and 11) were evaluated. The conversion from CBR to resilient modulus was determined on the basis of the relationship – $M_R = 2555 * CBR^{.64}$.
- Five levels of Equivalent Single Axleloads were evaluated (1,000,000, 5,000,000, 10,000,000, 20,000,000, and 50,000,000 ESALs).
- Two levels of reliability were evaluated – 90% Reliability and 95% Reliability
- Initial Serviceability = 4.5
- Terminal Serviceability = 3.0
- Overall Standard Deviation = 0.45

The testing matrix for concrete pavements was predicated upon replicating selected concrete pavement designs presented in Tables 16 - 24 from the *1998 Supplement to the AASHTO Guide for Design of Pavement Structures, Part II – Rigid Pavement Design and Rigid Pavement Joint Design*. The following design parameters were considered for development of comparative concrete pavement designs using PaveXpress with the pavement designs presented in the 1998 Supplemental Guide.

- Modulus of Subgrade Reaction $k = 250$ pci. The relationship $k = \frac{M_R}{19.4}$ and $M_R = 2555 * CBR^{.64}$ were used to estimate a corresponding CBR for the comparative analysis – CBR = 2.73
- ESALs ranging from 1,000,000 to 100,000,000 were evaluated
- Elastic Modulus of the Base Modulus was varied:
- Joint Spacing was varied:



- 144 inches
- 192 inches
- 240 inches
- Flexural Strength of Concrete = 600 psi
- Elastic Modulus for Concrete = 4,200,000 psi
- Temperature Differential = 9 degrees
- Overall Standard Deviation = 0.39
- Initial Serviceability = 4.0
- Terminal Serviceability = 2.5
- 12 foot lanes
- Shoulders
 - Tables 16 - 24 were based on 12-foot lanes with AC Shoulders
 - PaveXpress provides for an Input Parameter for Edge Support. Two values for pavement edge support were evaluated:
 - E = 1.0 (more indicative of Asphalt Shoulders)
 - E=0.94 (more indicative of tied Concrete Shoulders)

The results of these analyses were summarized in both tabular format and graphical format. The analyses of the comparative analyses were highly consistent and typically within 5% for calculated Structural Numbers for AASHTO 1993 versus PaveXpress. The variations noted between the two methodologies are believed to be attributed to rounding and computational precision. When the results for PaveXpress were compared with the catalog of designs summarized in Tables 16 - 20 of the *1998 Supplement to the AASHTO Guide for Design of Pavement Structures*, resulting slab thicknesses were consistently within ½ inch and in many cases were within ¼ inch. Both results are well within the range of thickness for construction of Portland Cement Concrete Pavements.

In conclusion, our analysis confirmed that the calculations and results provided by PaveXpress are within acceptable tolerances of those results provided by both the *AASHTO Guide for Design of Pavement Structures* (AASHTO 1993) and *Supplement to the AASHTO Guide for Design of Pavement Structures, Part II – Rigid Pavement and Rigid Pavement Joint Design* (AASHTO 1998) and, in our professional opinion, PaveXpress calculates pavement designs consistent with the methodologies presented in AASHTO '93 and '98.

We appreciate the opportunity to provide these services for the Asphalt Pavement Alliance.

Sincerely,

A handwritten signature in black ink that reads 'Gary W. Sharpe'.


Gary W. Sharpe, P.E., PLS
Senior Project Manager

Enclosure



Verification of PaveXpress with 1993 and 1998 AASHTO Pavement Design Guide

TO: Amy Miller, PE
National Director
Asphalt Pavement Alliance
2233 Park Avenue, Suite 200U
Orange Park, Florida 32073

FROM: 
Gary W. Sharpe, P.E., PLS
Senior Project Manager
Palmer Engineering

DATE: August 3, 2018

SUBJECT: Verification of PaveXpress with 1993 and 1998 AASHTO
Pavement Design Guide

Scope of Project

As tasked by the Asphalt Pavement Alliance, Palmer Engineering has completed a study to compare pavement designs per the *AASHTO Guide for Design of Pavement Structures* (AASHTO 1993) and *Supplement to the AASHTO Guide for Design of Pavement Structures, Part II – Rigid Pavement and Rigid Pavement Joint Design* (AASHTO 1998) design procedures with the web based program, PaveXpress. The comparison includes both concrete and asphalt designs, and compares both pavement types at varied subgrade soil strengths ($M_R = 2555 * CBR^{.64}$), as well as the corresponding moduli of subgrade reaction ($k = M_R/19.4$) for concrete pavements, and varied equivalent single axle loads (ESALs). Palmer Engineering developed 80 designs, as follows: 20 concrete designs using both AASHTO 1993 and AASHTO 1998; 20 asphalt designs using AASHTO 1993; 20 asphalt designs and 20 concrete designs using PaveXpress.

For Portland Cement Concrete pavements, Tables 16 - 17 - Slab thickness computed for granular base and 95 percent Reliability, and Tables 19 - 20 - Slab thickness computed for granular base and 90 percent Reliability, in the AASHTO 1998 supplement, were used to establish the slab thickness based on AASHTO procedures. Palmer then compared the results of PaveXpress designs determined using the same parameters of the AASHTO 1998 design.

Testing Matrix

Asphalt Matrix

AASHTO 1993 Asphalt Evaluation

Palmer used Figure 3.1 “Design Chart for Flexible Pavements Based on Using Mean Values for Each Input” from AASHTO 1993 and solved the equation for the required structural number.

The input parameters used, evaluation criteria, and the results are summarized below, in Table 1.

Table 1: Flexible Pavement Designs based on AASHTO 1993 Guide

		Asphalt (SN)	
		90% Reliability	95% Reliability
		So = .45 & Δ PSI = 1.5	So = .45 & Δ PSI = 1.5
CBR	2.00		
	ESAL's		
	1 Million	4.54	4.81
	5 Million	5.74	6.04
	10 Million	6.30	6.62
	20 Million	6.90	7.23
	50 Million	7.73	8.10
CBR	5.00		
	ESAL's		
	1 Million	3.63	3.87
	5 Million	4.70	4.99
	10 Million	5.23	5.52
	20 Million	5.76	6.06
	50 Million	6.51	6.84
CBR	7.00		
	ESAL's		
	1 Million	3.33	3.56
	5 Million	4.37	4.63
	10 Million	4.86	5.14
	20 Million	5.38	5.67
	50 Million	6.10	6.41
CBR	11.00		
	ESAL's		
	1 Million	2.97	3.17
	5 Million	3.91	4.16
	10 Million	4.38	4.65
	20 Million	4.88	5.15
	50 Million	5.56	5.86

*So = Standard Deviation

* Δ PSI = Design Serviceability Loss

*SN = Structural Number

PaveXpress Asphalt Evaluation

The PaveXpress's design evaluation matrix was set up similarly to the AASHTO 1993 matrix shown in Table 1, the only difference being the additional inputs that were required in PaveXpress. In addition to the parameters entered into the AASHTO 1993 equation, PaveXpress required a design period to be entered, as well as the initial and terminal serviceability index. The testing criteria, input parameters, and the results generated by PaveXpress are summarized below in Table 2.

Table 2: Flexible Pavement Designs based on PaveXpress

Design Period = 20 Years $P_i = 4.5$ $P_t = 3$		Asphalt (SN)	
		90% Reliability	95% Reliability
		$S_o = .45$ & $\Delta PSI = 1.5$	$S_o = .45$ & $\Delta PSI = 1.5$
CBR	2.00		
	ESAL's		
	1 Million	4.50	4.75
	5 Million	5.80	6.10
	10 Million	6.30	6.55
	20 Million	6.80	7.15
	50 Million	7.65	8.05
CBR	5.00		
	ESAL's		
	1 Million	3.75	4.00
	5 Million	4.70	4.95
	10 Million	5.20	5.45
	20 Million	5.70	6.05
	50 Million	6.45	6.80
CBR	7.00		
	ESAL's		
	1 Million	3.45	3.65
	5 Million	4.30	4.60
	10 Million	4.85	5.10
	20 Million	5.35	5.60
	50 Million	6.05	6.40
CBR	11.00		
	ESAL's		
	1 Million	3.05	3.25
	5 Million	4.00	4.10
	10 Million	4.30	4.60
	20 Million	4.85	5.10
	50 Million	5.55	5.80

* S_o = Standard Deviation

* ΔPSI = Design Serviceability Loss

*SN = Structural Number

* P_i = Initial Serviceability Index

* P_t = Terminal Serviceability Index

Concrete Matrix

AASHTO 1993/1998 Concrete Evaluation

Palmer used the catalog of slab thicknesses shown in Tables 16 - 24 in the *Supplemental AASHTO Guide for Design of Pavement Structures, Part II – Rigid Pavement and Rigid Pavement Joint Design* (AASHTO 1998) for comparison with designs evolving from PaveXpress. While determining the values to use from Tables 16 - 24, Palmer considered the following input scenarios that were common in Kentucky: Temperature differential, base modulus, CBR (and the corresponding k-value), overall standard deviation, joint spacing, and poisson's ratio. The results of these analyses are summarized in Table 3.

Table 3: Rigid Pavement Designs based on the Supplement to the AASHTO Guide for Design of Pavement Structures, Part II – Rigid Pavement and Rigid Pavement Joint Design (AASHTO 1998)

	AASHTO 1998			k = 250 pci			TD = 9°			S'c = 600 psi			E _c = 4,200,000 psi		
P _i =4.5	Slab Thickness			E _b = 25 ksi			Slab Thickness			E _b = 500 ksi					
P _t =2.5	Table 19 (90% Reliability)			Table 16 (95% Reliability)			Table 20 (90% Reliability)			Table 17 (95% Reliability)					
ΔPSI=2	CBR = 2.73 (k=250 pci)			CBR = 2.73 (k=250 pci)			CBR = 2.73 (k=250 pci)			CBR = 2.73 (k=250 pci)					
μ = .2	S _o = 0.39			S _o = 0.39			S _o = 0.39			S _o = 0.39					
J = 3															
Joint Spacing (inches)	144	192	240	144	192	240	144	192	240	144	192	240	144	192	240
ESAL's															
1 Million															
1.5 Million	7.40	7.70	8.20				6.50	7.10	7.80						
2 Million	7.90	8.30	8.80				7.10	7.70	8.30						
2.5 Million	8.40	8.80	9.20				7.50	8.10	8.70						
3 Million	8.70	9.10	9.60				7.80	8.40	9.10						
4 Million	9.30	9.70	10.20				8.40	9.00	9.60						
5 Million	9.70	10.10	10.60	10.30	10.80	11.30	8.80	9.40	10.00	9.40	10.00	10.70			
7.5 Million	10.50	10.90	11.40				9.60	10.20	10.80						
10 Million	11.10	11.50	12.00	11.70	12.20	12.70	10.10	10.70	11.40	10.70	11.30	12.00			
20 Million				13.00	13.50	14.10				12.10	12.60	13.30			
30 Million				13.80	14.30	14.90				12.80	13.40	14.00			
40 Million				14.40	14.90					13.40	14.00	14.60			
50 Million				14.48						13.80	14.40	15.00			
75 Million										14.60	15.10				
100 Million															

*S_o = Standard Deviation

*ΔPSI = Design Serviceability Loss

*P_i = Initial Serviceability Index

*J = Load Transfer Coefficient

*TD = Temperature Differential

*k = Effective Modulus of Subgrade Reaction

*Pt = Terminal Serviceability Index

*E_b = Base Modulus

*μ = Poisson's ratio

*E_c = Elastic Modulus

*S'c = Modulus of Rupture

Concrete Matrix

PaveXpress Concrete Evaluation

To obtain a feature-by-feature comparison, Palmer used input parameters for PaveXpress that were the same as the inputs used for the AASHTO catalog of designs that Tables 16, 17, 19, and 20 references. While developing the pavement designs with PaveXpress, Palmer noted the AASHTO 1998 (Tables 16 - 24) catalog applied to a paved AC shoulder whereas PaveXpress requires a value to be entered for edge support. A 1.00 coefficient for edge support is used for a free edge, asphalt shoulder, and a value of 0.94 is used for a tied concrete shoulder. Both coefficients for edge support were evaluated using PaveXpress. However, Tables 16 - 24 in the 1998 AASHTO supplement were based only on asphalt shoulders.

As shown in Table 3, a Temperature Differential of 9 degrees was used for evaluation when selecting the appropriate AASHTO values from Tables 16 - 24. PaveXpress does not allow users to input specific Temperature Differentials but instead calculates the value based on the climate of the city that is selected by the user. PaveXpress predicted a Temperature Differential value for Lexington, KY, between 8.2 and 8.5 degrees, whereas Palmer used the catalog designs in Tables 16 - 20 on the basis of $TD = 9$ degrees. Palmer also used a concrete modulus of rupture of 600 psi for all analysis of PCC pavement.

The results and input parameters used for comparing rigid pavement designs, based on PaveXpress, are summarized below in Table 4.

Table 4: Rigid Pavement Designs based on PaveXpress

	PaveXpress																							
$P_i=4.5$ $P_t=2.5$ $\Delta PSI=2$ $\mu=.2$ $J=3$	Slab Thickness $E_b = 25$ ksi												Slab Thickness $E_b = 500$ ksi											
	CBR = 2.73 (k=250 pci)												CBR = 2.73 (k=250 pci)											
	$S_o = .39$ & E = 1.00						$S_o = .39$ & E = 0.94						$S_o = .39$ & E = 1.00						$S_o = .39$ & E = 0.94					
	90% Reliability			95% Reliability			90% Reliability			95% Reliability			90% Reliability			95% Reliability			90% Reliability			95% Reliability		
Joint Spacing (inches)	144	192	240	144	192	240	144	192	240	144	192	240	144	192	240	144	192	240	144	192	240	144	192	240
ESAL's																								
1 Million	7.4	7.7	8.1	7.9	8.2	8.6	6.9	7.2	7.5	7.4	7.7	8.1	6.7	7.2	7.8	7.3	7.8	8.4	6	6.4	7.1	6.7	7.2	7.8
1.5 Million																								
2 Million																								
2.5 Million	8.8	9.2	9.7	9.4	9.8	10.3	8.4	8.7	9.1	8.9	9.3	9.7	8.4	8.9	9.5	9	9.5	10.1	7.9	8.4	9	8.5	9	9.5
3 Million																								
4 Million																								
5 Million	10	10.5	11	10.6	11.1	11.6	9.5	9.9	10.4	10.1	10.5	11.1	9.6	10.1	10.7	10.2	10.7	11.3	9.1	9.6	10.2	9.7	10.2	10.8
7.5 Million																								
10 Million	11.3	11.8	12.4	12	12.5	13.1	10.7	11.2	11.8	11.4	11.9	12.5	10.8	11.4	12	11.4	12	12.6	10.3	10.8	11.5	10.9	11.4	12.1
20 Million	12.7	13.3	13.9	13.4	14	14.7	12.1	12.6	13.3	12.8	13.4	14	12.1	12.7	13.3	12.7	13.3	13.9	11.5	12.1	12.7	12.1	12.7	13.4
30 Million	13.6	14.2	14.9	14.4	15	15.1	13	13.5	14.2	13.7	14.3	15	12.9	13.4	14.1	13.5	14.1	14.7	12.3	12.9	13.5	12.9	13.5	14.1
40 Million	14.3	14.9	15.1	15.1	15.1	15.1	13.6	14.2	14.9	14.4	15	15.1	13.4	14	14.7	14.1	14.7	15.1	12.8	13.4	14.1	13.5	14.1	14.7
50 Million	14.8	15.1	15.1	15.1	15.1	15.1	14.1	14.7	15.1	14.9	15.1	15.1	13.8	14.4	15.1	14.5	15.1	15.1	13.3	13.9	14.5	13.9	14.5	15.1
75 Million	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	14.7	15.1	15.1	15.1	15.1	15.1	14.1	14.7	15.1	14.7	15.1	15.1
100 Million	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	14.6	15.1	15.1	15.1	15.1	15.1

$*S_o$ = Standard Deviation
 $*\Delta PSI$ = Design Serviceability Loss
 $*P_i$ = Initial Serviceability Index
 $*J$ = Load Transfer Coefficient
 $*E$ = Edge Support

$*\mu$ = Poisson's ratio
 $*k$ = Effective Modulus of Subgrade Reaction
 $*P_t$ = Terminal Serviceability Index
 $*E_b$ = Base Modulus

$*E_c$ = Elastic Modulus
 $*S'_c$ = Modulus of Rupture

Note: The analysis used Tables 16, 17, 19, and 20 from the 1998 AASHTO Supplemental Guide

Results

Asphalt Results

As shown in Figures 1 and 2, the PaveXpress accurately represents AASHTO's 1993 method for determining the required structural number. The graphs show a comparable trend for both 90 and 95 percent reliability, as the CBR and number of ESALs vary. The variations in estimated structure numbers shown are likely attributed to rounding and precision of computations.

Figure 1: Asphalt Designs at 90% Reliability

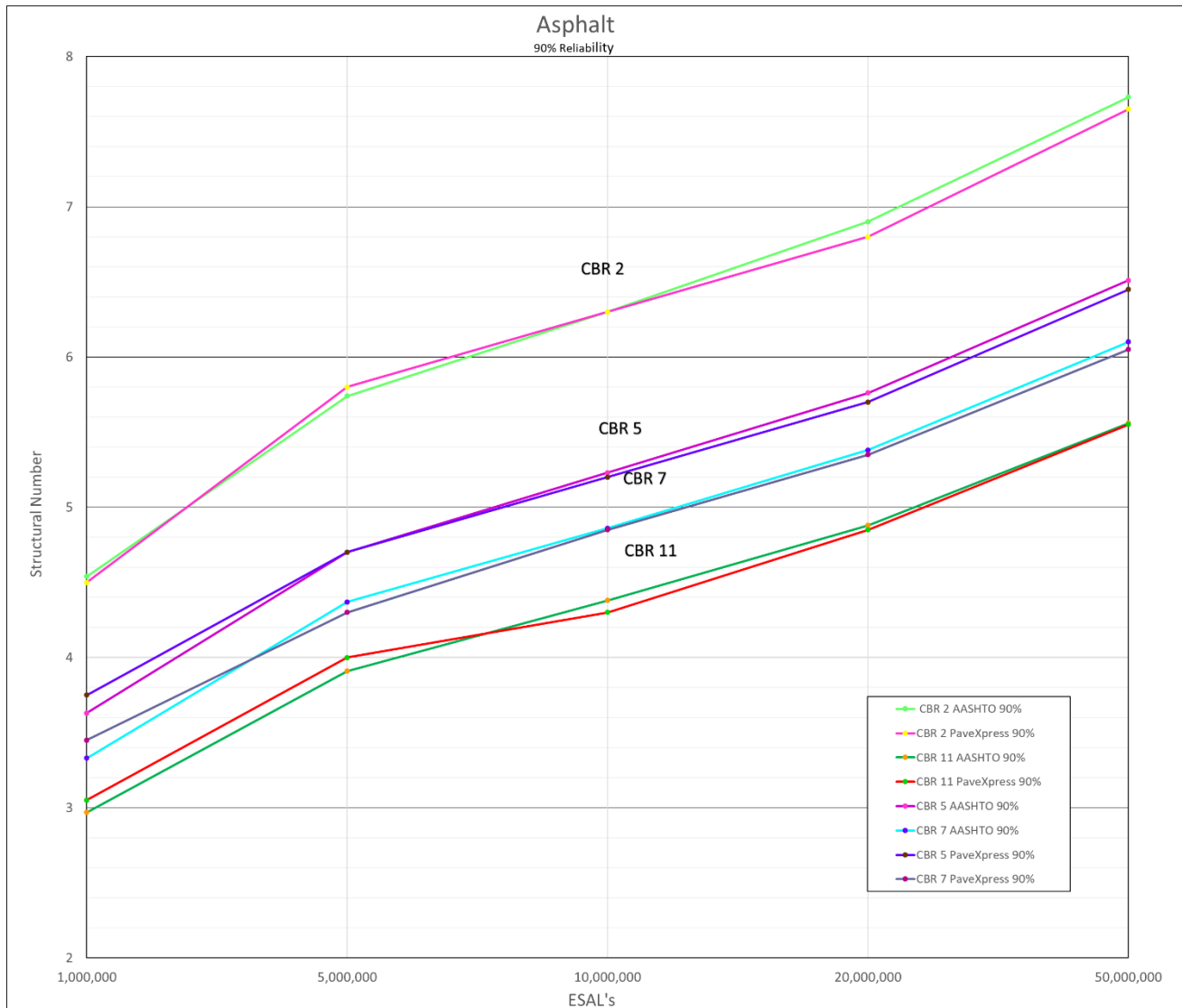
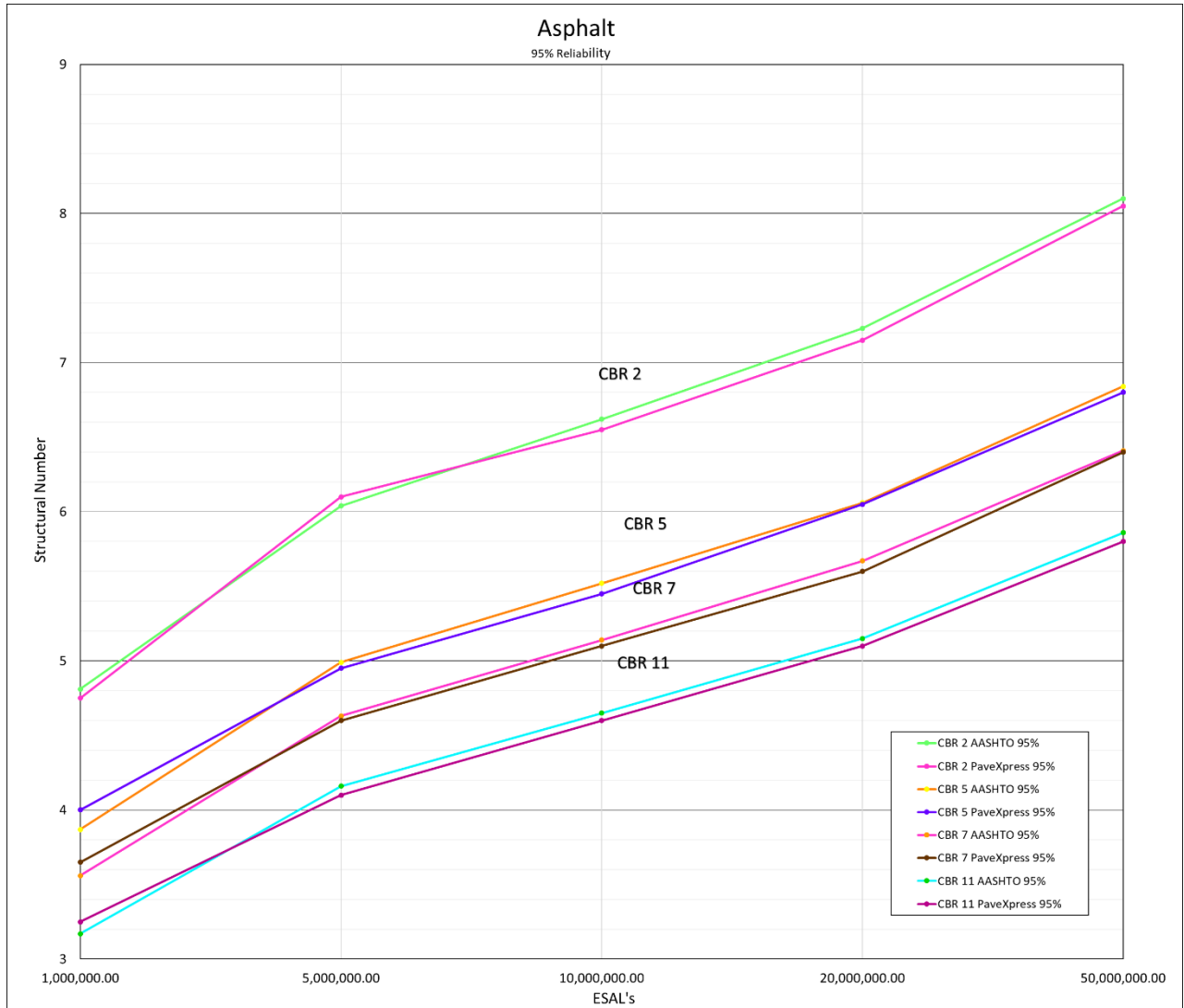


Figure 2: Asphalt Designs at 95% Reliability



Concrete Results

As shown in Figures 3a - 3l, PaveXpress adequately represents slab thickness determined from the AASHTO 1998 catalog of pavement designs. The graphs have been categorized by base modulus, percent reliability, and joint spacing. The PaveXpress pavement designs follow AASHTO 1998 closely, with typically only a quarter of an inch to a half inch separating the two results. Therefore, the pavement designs developed using PaveXpress are still within the range of constructability for concrete pavements.

Figure 3a: Concrete Designs for $E_b = 25$ ksi at 90% Reliability and Joint Spacing = 144"

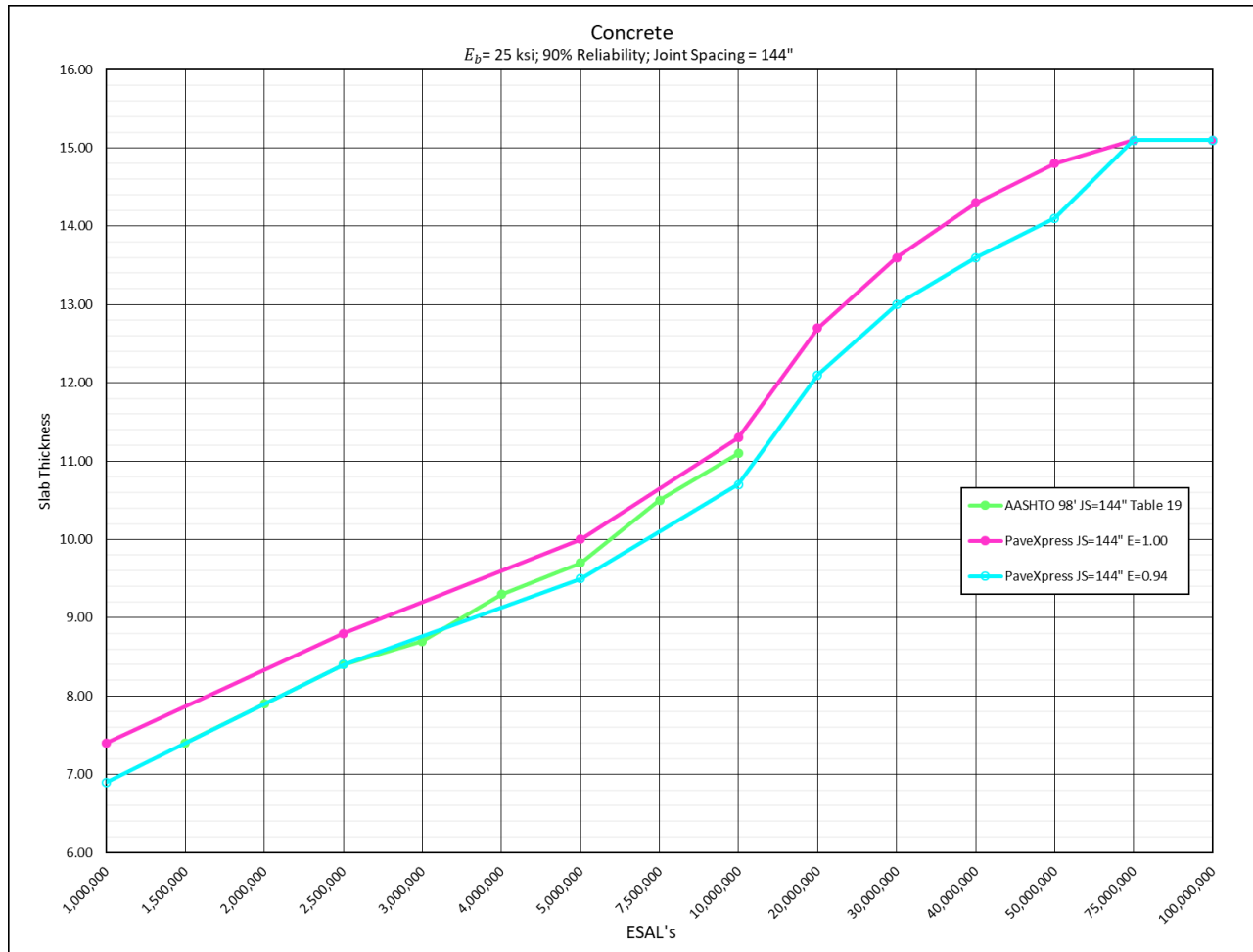


Figure 3b: Concrete Designs for $E_b = 25 \text{ ksi}$ at 95% Reliability and Joint Spacing = 144"

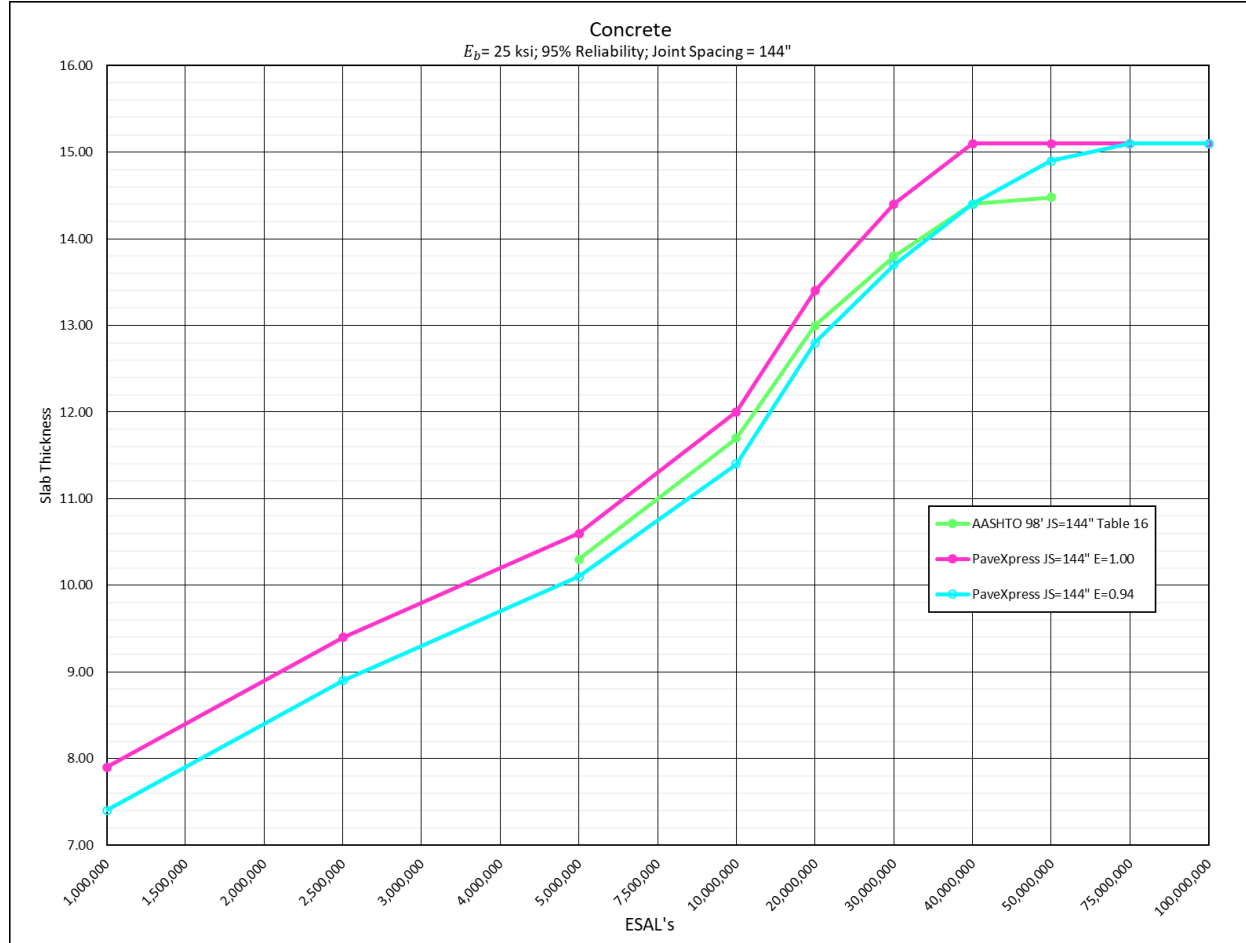


Figure 3c: Concrete Designs for $E_b = 25 \text{ ksi}$ at 90% Reliability and Joint Spacing = 192"

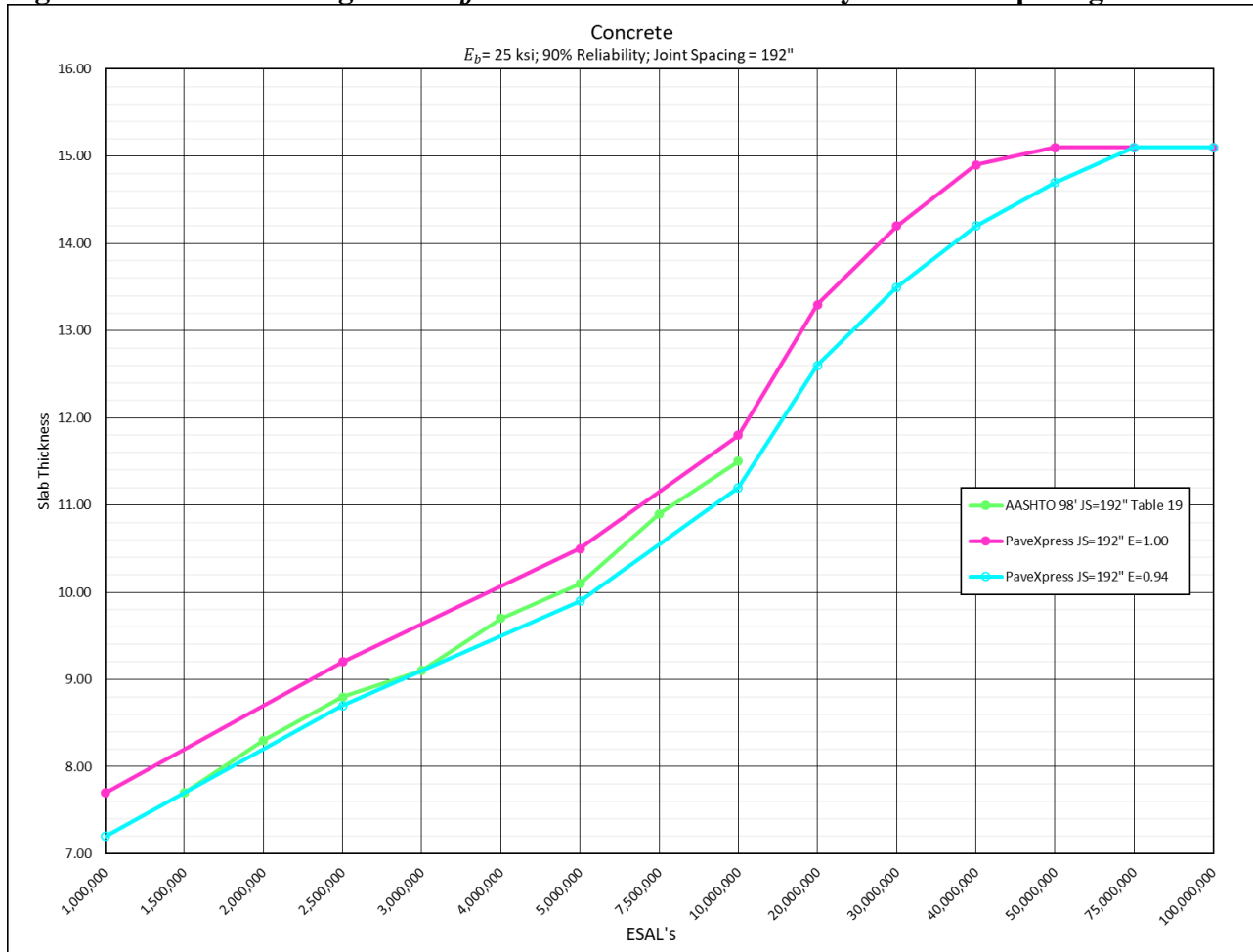


Figure 3d: Concrete Designs for $E_b = 25 \text{ ksi}$ at 95% Reliability and Joint Spacing = 192"

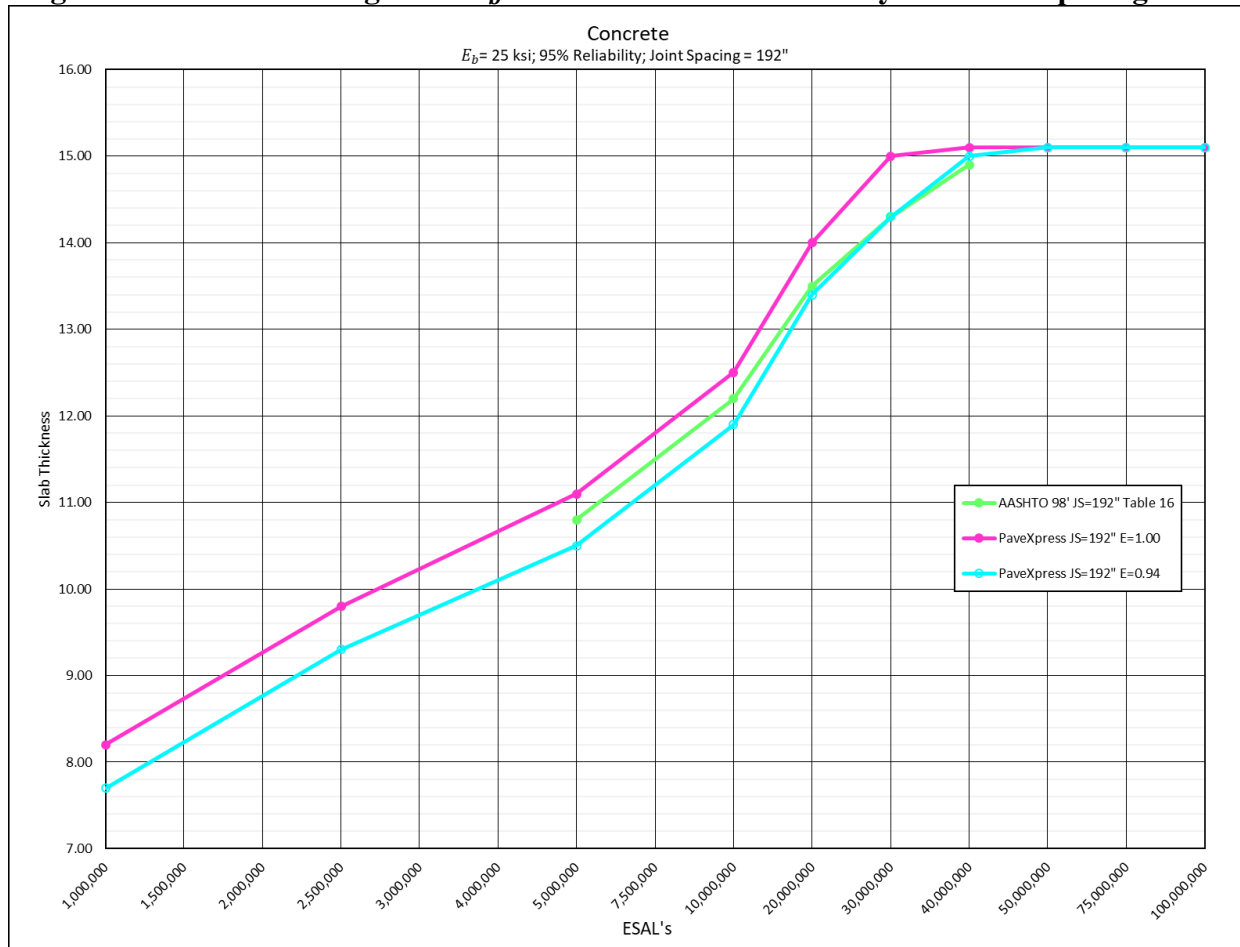


Figure 3e: Concrete Designs for $E_b = 25 \text{ ksi}$ at 90% Reliability and Joint Spacing = 240"

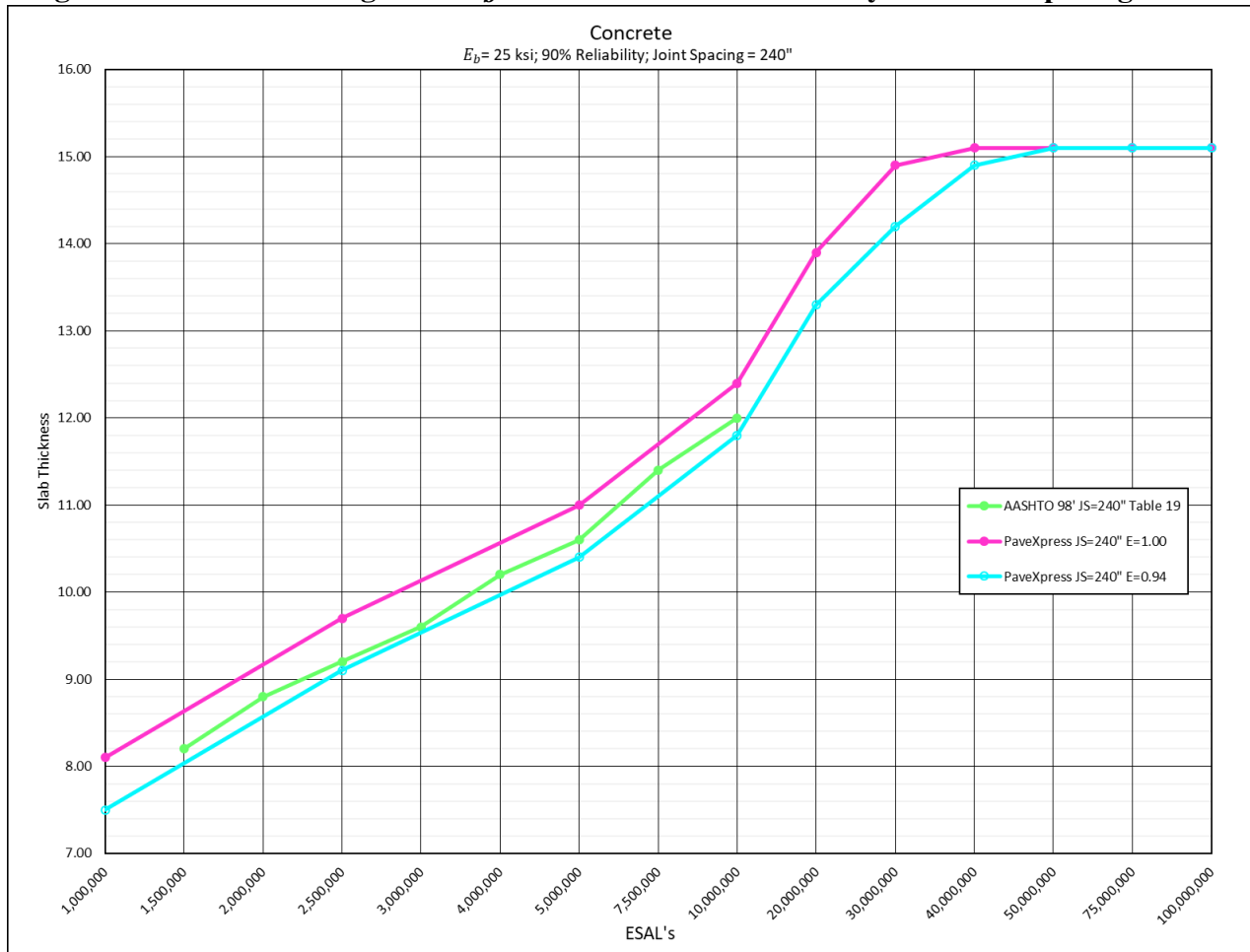


Figure 3f: Concrete Designs for $E_b = 25 \text{ ksi}$ at 95% Reliability and Joint Spacing = 240"

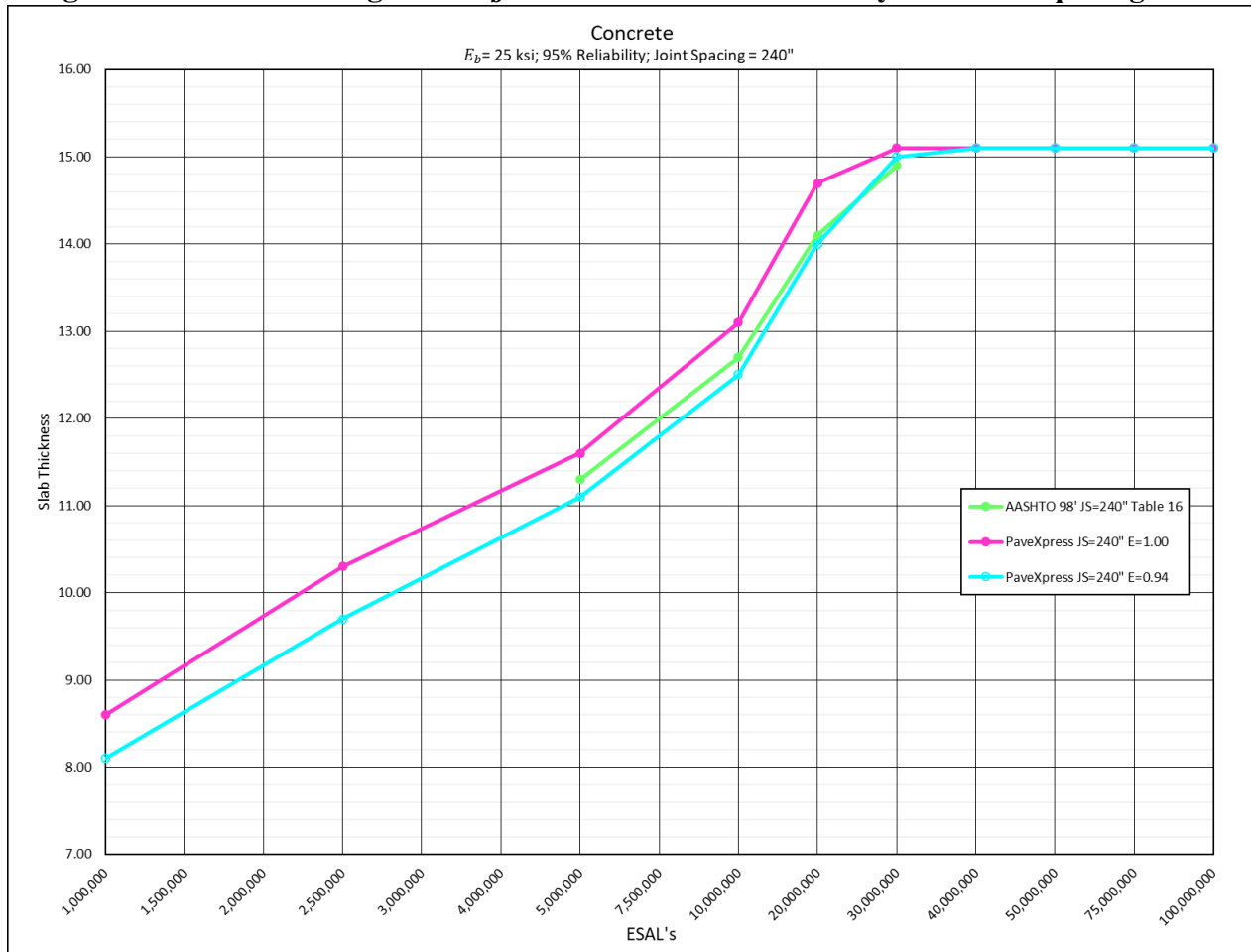


Figure 3g: Concrete Designs for $E_b = 500 \text{ ksi}$ at 90% Reliability and Joint Spacing = 144"

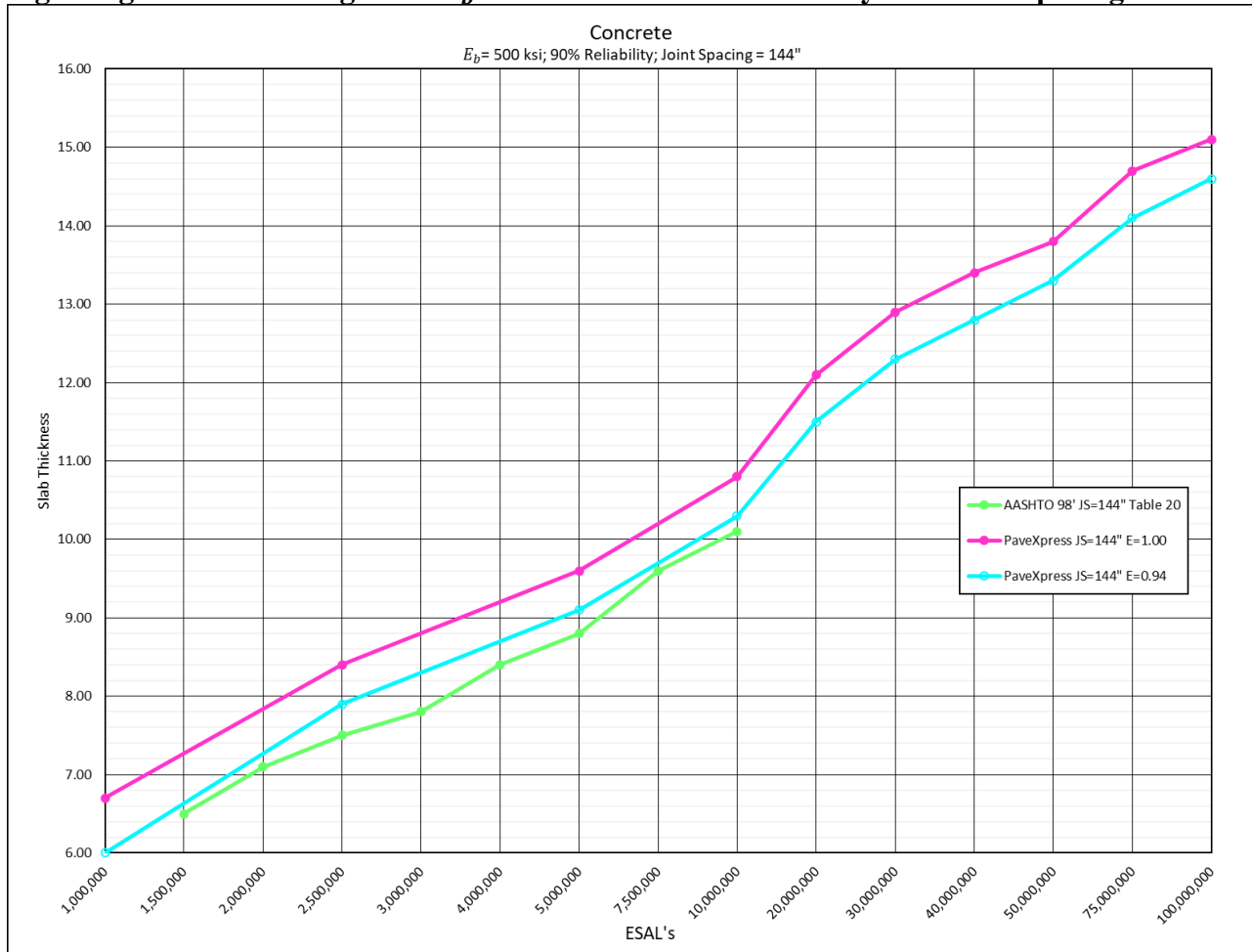


Figure 3h: Concrete Designs for $E_b = 500 \text{ ksi}$ at 95% Reliability and Joint Spacing = 144"

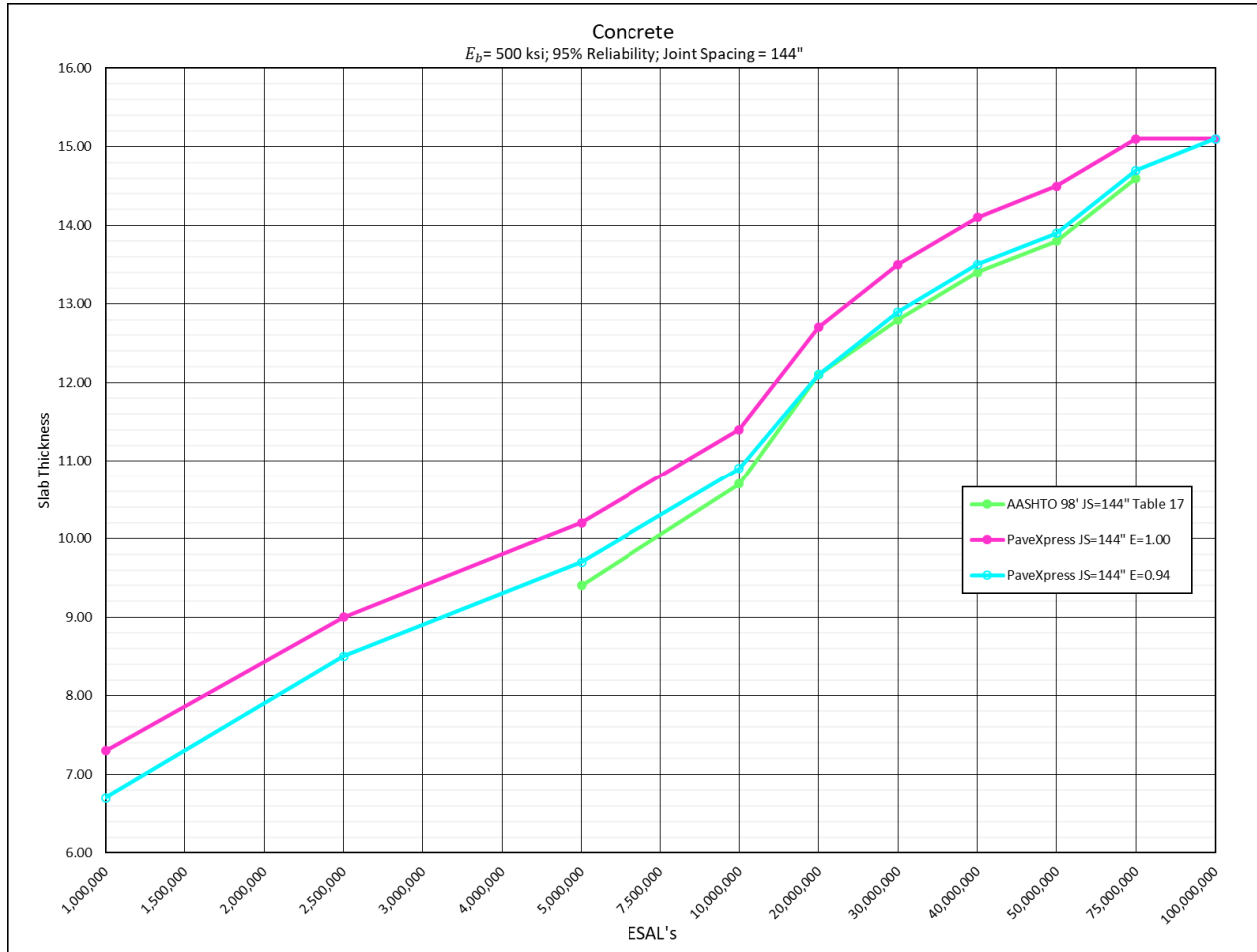


Figure 3i: Concrete Designs for $E_b = 500 \text{ ksi}$ at 90% Reliability and Joint Spacing = 192"

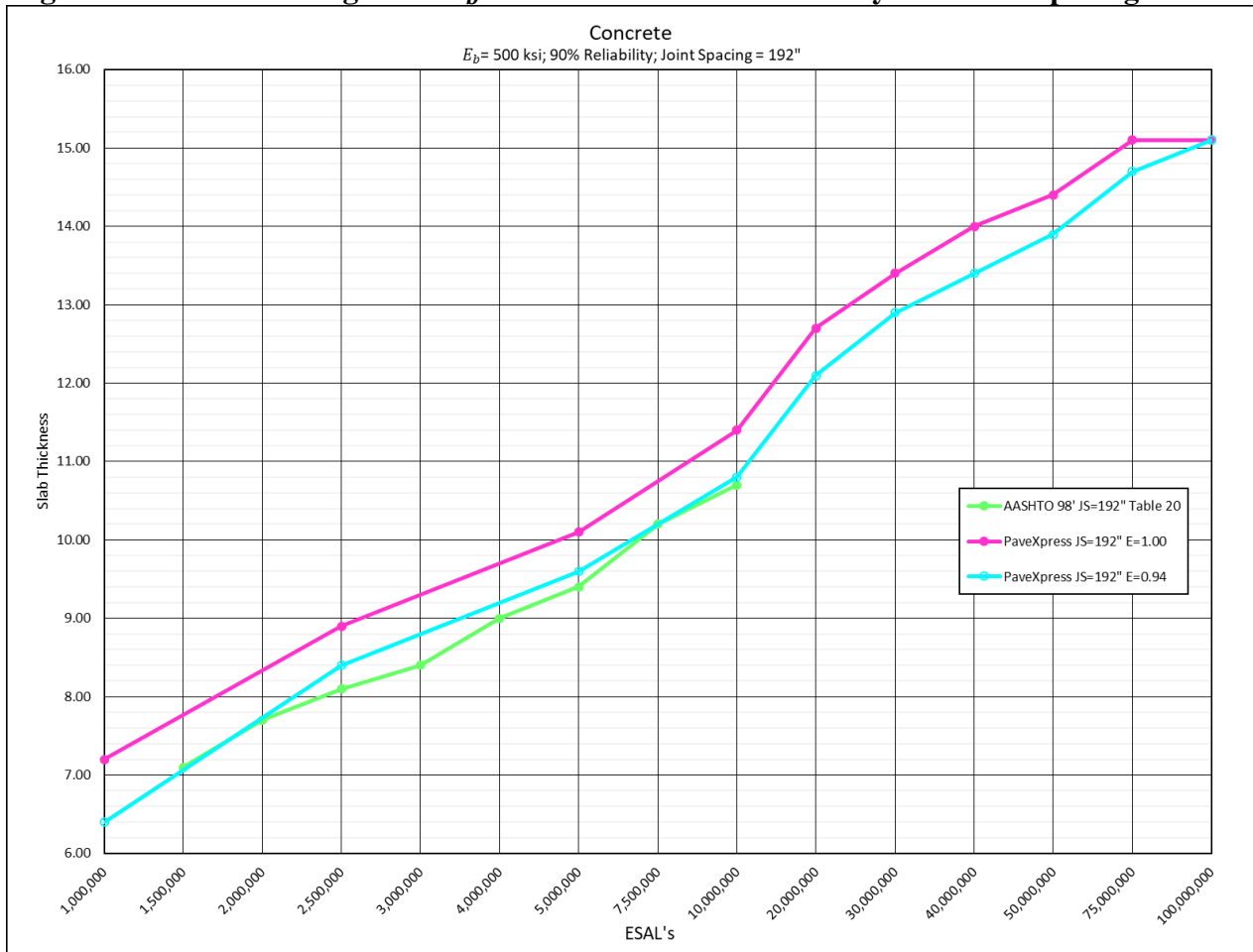


Figure 3j: Concrete Designs for $E_b = 500 \text{ ksi}$ at 95% Reliability and Joint Spacing = 192"

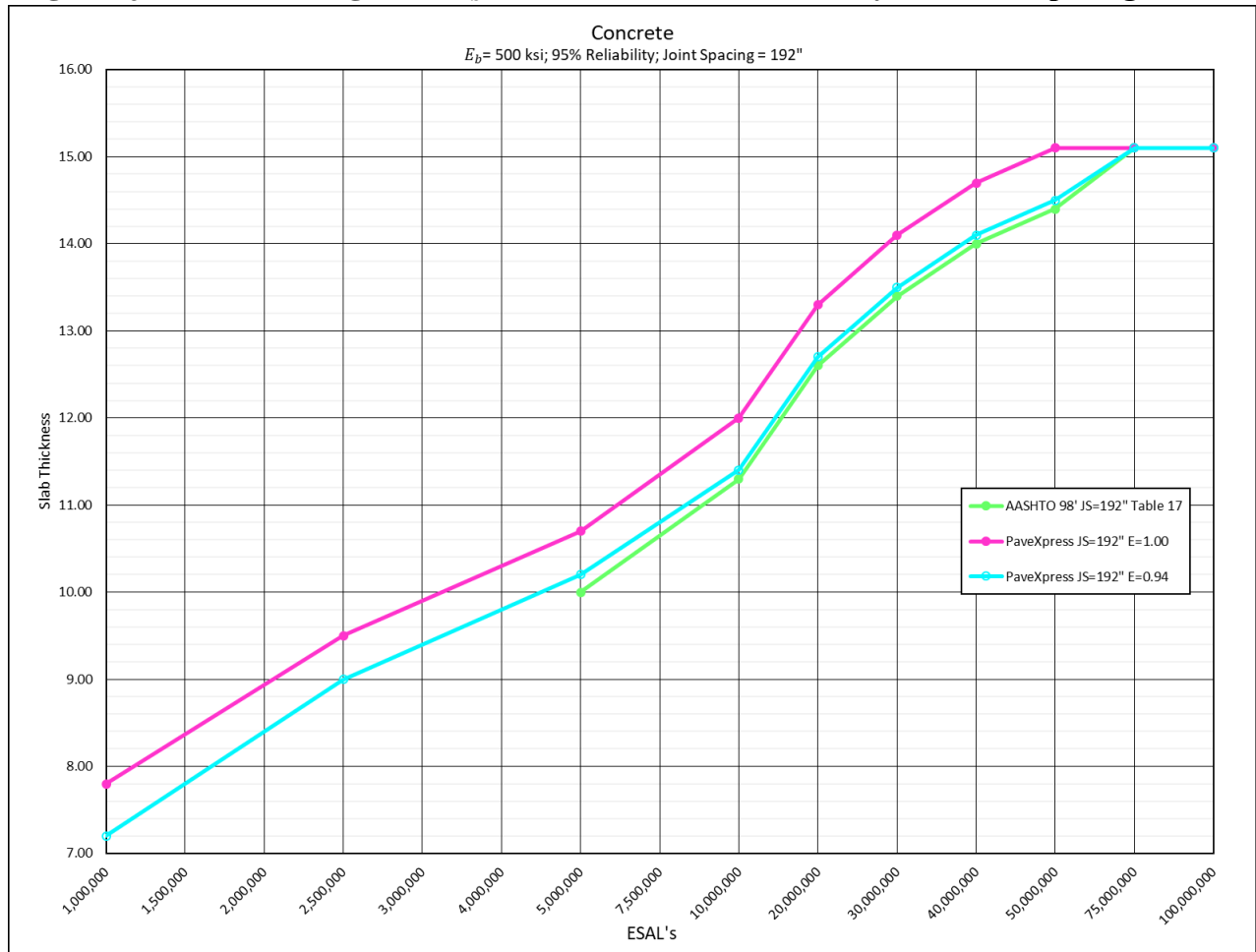


Figure 3k: Concrete Designs for $E_b = 500 \text{ ksi}$ at 90% Reliability and Joint Spacing = 240"

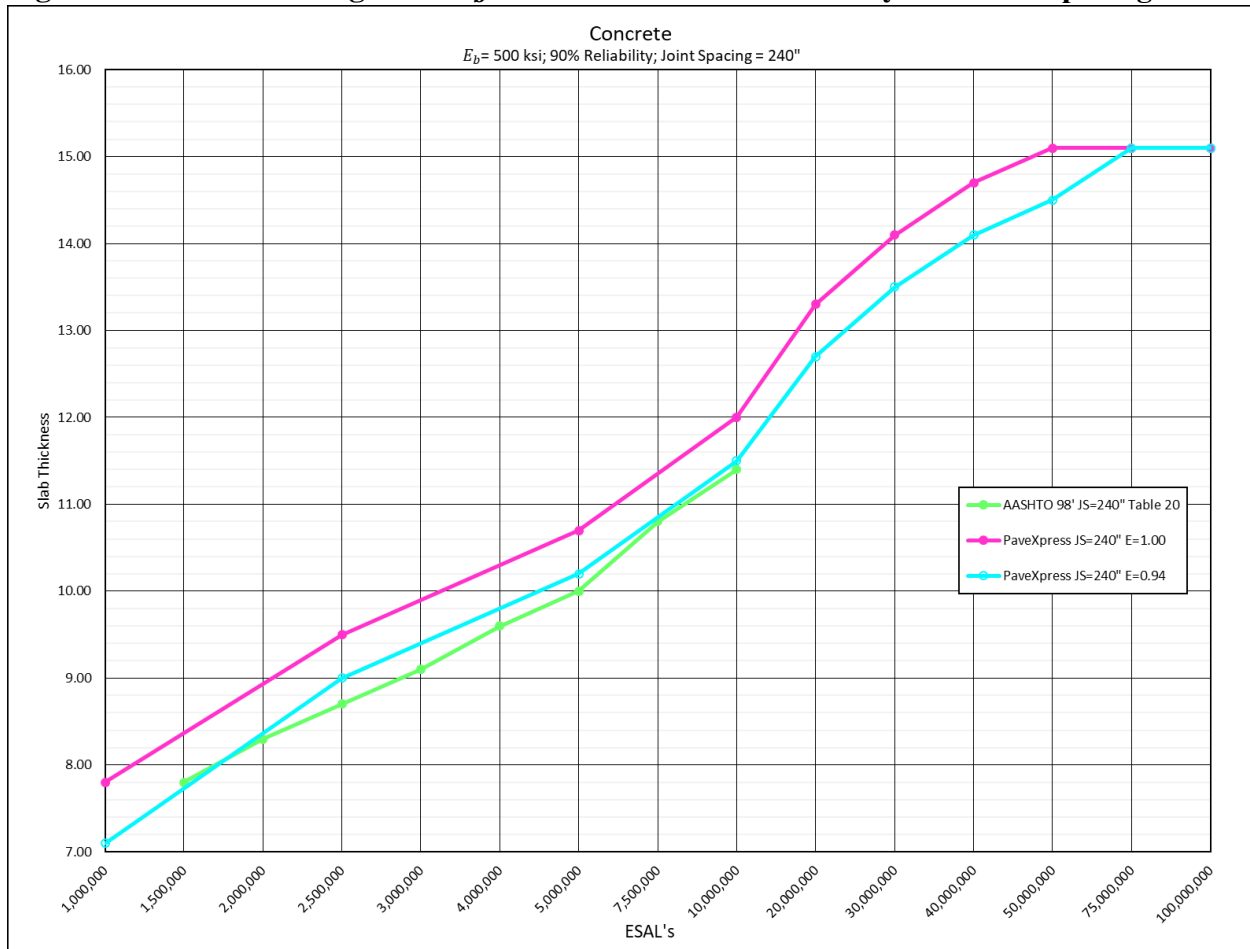
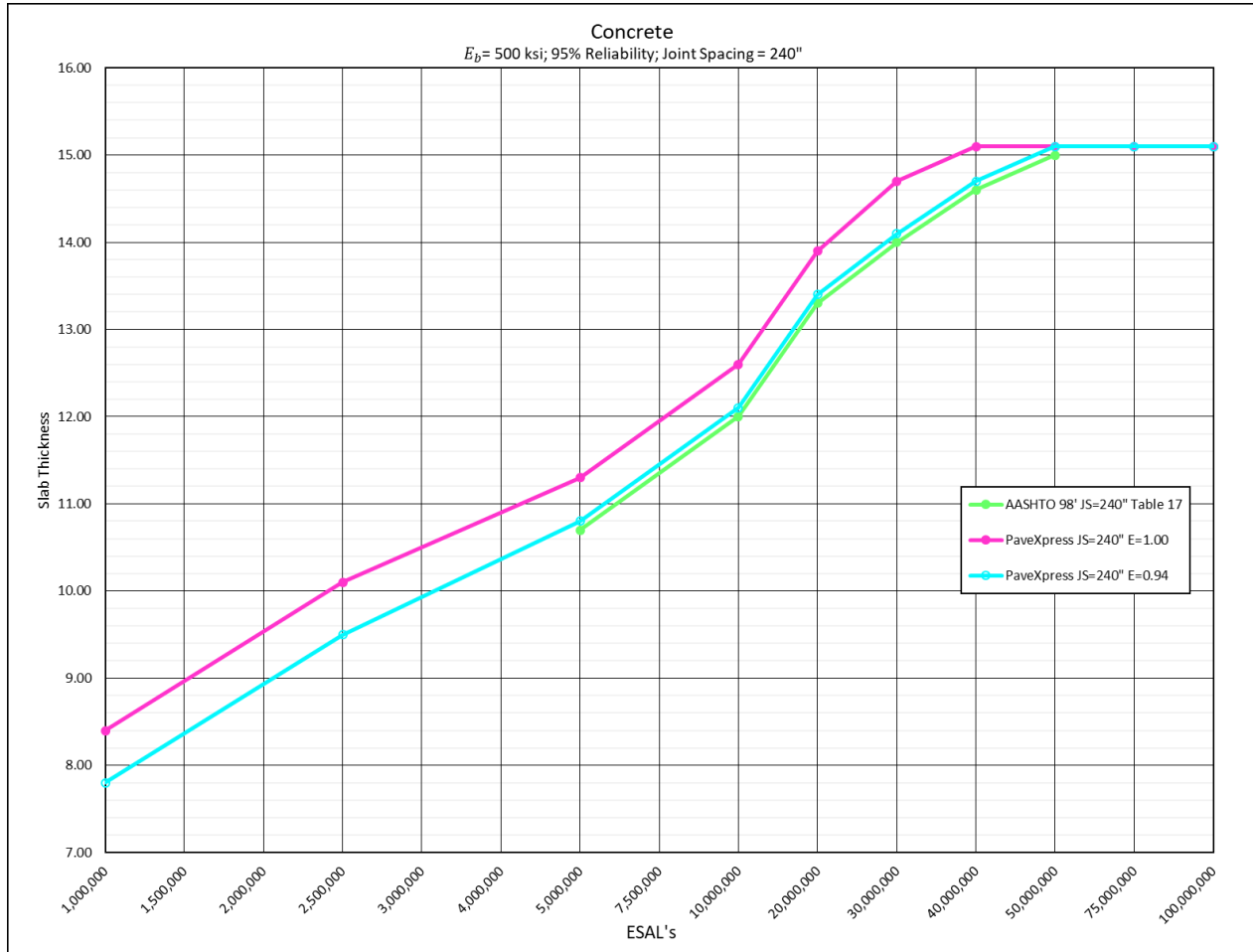


Figure 3l: Concrete Designs for $E_b = 500$ ksi at 95% Reliability and Joint Spacing = 240"



Conclusion

In conclusion, our analysis confirmed that the calculations and results provided by Pavexpress are within acceptable tolerances of those results provided by both the *AASHTO Guide for Design of Pavement Structures* (AASHTO 1993) and *Supplement to the AASHTO Guide for Design of Pavement Structures, Part II – Rigid Pavement and Rigid Pavement Joint Design* (AASHTO 1998) and, in our professional opinion, Pavexpress calculates pavement designs consistent with the methodologies presented in AASHTO '93 and '98.