R&T UPDATE
Concrete Pavement Research & Technology

StreetPave's Equivalent Design of Asphalt

Proof of the Accuracy of StreetPave's Asphalt Module

Background

This issue of R&T Update is written to address the Asphalt Institute's (AI's) recent assertions in a memo titled, "Debunking StreetPave's Claim of an "Equivalent" Asphalt Design," that the American Concrete Pavement Association's (ACPA's) StreetPave design software does not fairly compare asphalt and concrete pavements.[1] The Asphalt Institute's claims are unfounded, inaccurate, and without merit.

StreetPave calculates asphalt thicknesses using the design methodologies presented in the AI's own document, *MS-1, Thickness Design-Highways & Streets*. It then compares those asphalt pavement designs to concrete pavement designs based on ACPA's mechanistic design process, which is well-recognized for its use in designing a wide range of pavement facilities for streets and roadways. AI's claim is based on the manner in which StreetPave handles concrete and asphalt pavement reliability.

This R&T Update explains and demonstrates how StreetPave incorporates reliability into asphalt designs by adjusting the resilient modulus to produce a design resilient modulus (Design M_r). The formula used by StreetPave to calculate Design M_r is the same as the AI's *SW-1, Asphalt Pavement Thickness Design Software* uses and, thus, StreetPave will yield the same asphalt thicknesses as both *MS-1* and *SW-1*.

The StreetPave design software is intended primarily for designing concrete pavements for municipal pavements for residential, collector, and arterial roadways. The software addresses the common practice of over-designing concrete pavements and under-designing asphalt pavements. By simultaneously calculating comparable designs, StreetPave gives an engineer or specifier two design options to choose from when designing a roadway for total load carrying capacity. During the design process, the designer is presented with the option to select a level of reliability for their design, improving on the single level of reliability built into the concrete industry's previous design software.

Reliability is a statistical factor, but it is easiest to understand as a factor of safety for the design. Increasing reliability enables an engineer to reduce the risk associated with premature failure. Simply stated, the higher the reliability (or factor of safety), the less likely a pavement will fail prematurely for the given design inputs.

Reliability in StreetPave

For concrete pavement design, StreetPave applies reliability to the flexural fatigue equations within the software (because applying reliability to this critical input parameter in a mechanistic design is logical). This provides a good means of selecting a factor of safety for pavement performance, ensuring that StreetPave's concrete pavement thickness results will provide serviceable pavement solutions to the end of the desired design life, typically 30 to 40 years.

For an asphalt pavement design, StreetPave applies reliability to the resilient modulus of the subgrade. Applying reliability to the subgrade and base support in an asphalt pavement design is most appropriate because of the high degree of sensitivity that these factors have on asphalt pavement performance. This is exactly the same manner of applying reliability that is recommended by the AI, which is evident in both *MS-1* and *SW-1*. AI's design recommendations suggest that a user characterize the soil for asphalt design by taking multiple (six to eight) soil strength tests and applying a statistical representation of these results in the design as the subgrade strength input value. StreetPave uses the same formulation as the AI's design methodologies but only requires the mean (average) resilient modulus and coefficient of variation to be defined by the user in order to characterize the expected statistical spread of the resilient modulus.

Design M_r Formulation

The User's Guide for the AI's *SW-1* states that "…a normal distribution can be assumed for computing M_r using the following relationship:

$$Design\ M_r = x - Z * S$$

where:

M_r = resilient modulus
x = average of all data
Z = Z statistic based on the design percentile value
S = sample standard deviation"

This formula from the AI is the basis of the StreetPave Design M_r formulation. But, rather than requiring the designer to enter in six or more data points to obtain the average and standard deviation, ACPA utilized a statistical property to simplify the inputs; namely, standard deviation is equal to the mean times the coefficient of variation, or:

$$S = x * COV$$

where:

COV = coefficient of variation

This allows the AI's equation to be rewritten as:

$$Design\ Mr = x - Z * x * COV = x*(1 - Z * COV)$$

When it is assumed that the user will enter the average resilient modulus value (i.e., $x = User\text{-}Entered\ M_r$), the Design M_r equation becomes:

$$Design\ M_r = User\text{-}Entered\ M_r * (1 - Z * COV)$$

This equation (which is improperly quoted in the AI memo) is what StreetPave uses and is clearly displayed on the resilient modulus help screen. As shown, this is mathematically the exact same formula that the AI uses in their design software *SW-1.* Due to this equivalency, AI's claim that "ACPA's StreetPave software deliberately reduces the user's design input for subgrade strength prior to running the asphalt pavement design calculation" is false.

Proof in the Numbers

Consider having seven field M_r values at 6,587 psi, 3,706 psi, 3,360 psi, 6,971 psi, 4,598 psi, 5,234 psi, and 6,780 psi. The average, standard deviation, and coefficient of variation of this set are 5,319 psi, 1,497 psi, and 28.13%, respectively. Assuming a reliability of 87.5%, the value of *Z* is 1.150.

Using the AI's formula:

$$\begin{aligned} Design\ M_r &= x - Z * S \\ &= 5{,}319\ psi - 1.150 * 1{,}497\ psi \\ &= 3{,}597\ psi \end{aligned}$$

(SW-1 output: Design M_r = 3,598 psi)

Using the StreetPave formula:

$$\begin{aligned} Design\ M_r &= User\text{-}Entered\ M_r * (1 - Z*COV) \\ &= 5{,}319\ psi * (1 - 1.150 * 0.2813) \\ &= 3{,}597\ psi \end{aligned}$$

(StreetPave output: Design M_r = 3,597 psi)

Understanding the Design M_r Equations

The assertion by the AI that StreetPave's calculation for Design M_r is occurring "automatically" is true, but this step is necessary to account for the statistical spread that occurs in any field data. This "automatic" calculation is intended to safeguard users from unintentionally characterizing soil strength to be uniform throughout the project length. With that said, several design inputs can be changed to negate the statistical significance of the spread of the field-measured resilient modulus data, although such alternations are ill advised.

If reliability is set to 50%, the value of *Z* becomes zero, causing the Design M_r to equal the average resilient modulus for both the AI and StreetPave equations. This concept alludes to a major downfall of the AI's methodology: if only one resilient modulus field data point is entered then the standard deviation (*S*) is zero and the Design M_r is always equal to the resilient modulus value entered by the user. The reason for this is that if *S* becomes zero then the *Z * S* portion of the AI's equation is zero regardless of what the reliability is set to. Thus, entering a single resilient modulus into the AI's *SW-1* negates the contribution of reliability in the asphalt design altogether. This will cause the Design M_r to likely be significantly higher than the actual strength of the soil in the field. The higher Design M_r will result in an asphalt design thickness that is too thin for field conditions.

Alternatively, if the COV is set to StreetPave's minimum of one percent then the Design M_r will approach the average resilient modulus for the StreetPave equation. Because the average resilient modulus value can never be zero, setting the COV to zero percent causes the standard deviation to be zero percent (i.e., in $S = x * COV$ the value of *x* can not be zero, so for *COV* to equal zero, *S* must equal zero). Having a standard deviation of zero would indicate that there is no spread in the data (i.e., every field sample test provided the same resilient modulus value as the average), again undermining the statistical significance of the inherent variability of field conditions. Ultimately, this would result in a Design M_r value that is significantly higher than what should be used, and the calculation of a thinner required asphalt thickness.

Thus, entering the average resilient modulus value rather than each individual field data point for resilient modulus in the *SW-1* design software will always result in falsely thin asphalt pavement results due to the method with which the AI calculates Design M_r. StreetPave safeguards the user from unintentionally misrepresenting the variability of the resilient modulus by instead requiring a COV, which is easily changed by the user. This makes StreetPave more accurate and reliable than *SW-1* at calculating the Design M_r if only the average resilient modulus value is entered.

StreetPave's Equivalence with SW-1

To illustrate some of the user-available means of manipulating the Design M_r in StreetPave and to show that StreetPave provides a design asphalt thickness equivalent to the output of *SW-1*, many design runs of each program were conducted with equivalent design inputs. With most design inputs being fairly straight-forward, the primary exception was flexible ESALs, which was recorded as an output from StreetPave and that value used as an input in *SW-1*. Also, the Design M_r was made the same in both programs by setting the value of COV to 1 percent in StreetPave and inputting the StreetPave Design M_r into *SW-1*. The results of this investigation show that required asphalt thicknesses are essentially equivalent in StreetPave and *SW-1* (Figure 1). The primary exception occurred on the lower boundary, where SW-1 has a minimum asphalt thickness of 4 in., a boundary that is not included in the current version of StreetPave.

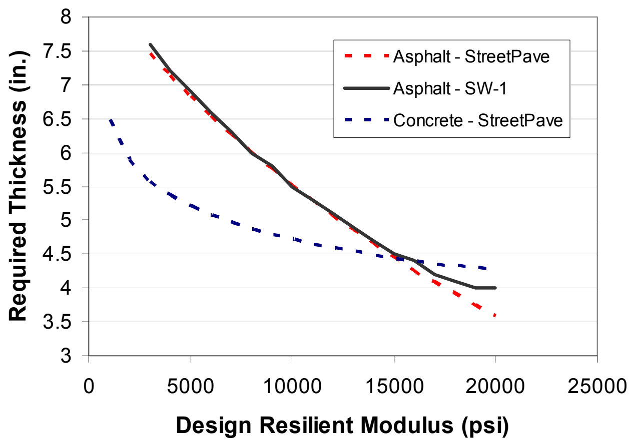

Figure 1. *Required concrete thickness from StreetPave and required asphalt thickness from StreetPave and SW-1 versus design resilient modulus.*

The effects of the reliability input also were investigated (with the COV still set to 1 percent on the asphalt portion of StreetPave) by changing the reliability input from the default of 85% to 50%. As expected, the required asphalt thickness was not changed (Figure 2) because *Z* was equal to zero in the asphalt module but the required concrete thickness decreased. This illustrates that the asphalt Design M_r equations are not equipped to account for reliability if only one resilient modulus (the average) is used as a design input (i.e., COV is approximately 0).

The reason that the required asphalt thickness from the AI design is equivalent to that of StreetPave is because both StreetPave and *SW-1* use the design charts from *MS-1* to calculate asphalt thickness. Thus, the output from each program is identical assuming equivalent inputs (including Design M_r) are used in each design procedure.

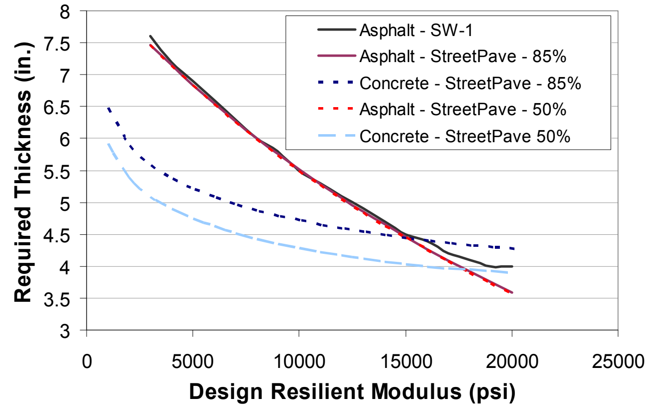

Figure 2. *Thickness versus resilient modulus for concrete and asphalt reliabilities of 50% and 85% using StreetPave and asphalt using SW-1.*

The AI's Mistreatment of the 3,000 psi Boundary Presented in MS-1 and SW-1

Most of the claims by the AI, though possibly fueled by a misunderstanding of the statistical equivalence of the StreetPave and AI Design M_r equations, reveal some confusion amongst some asphalt professionals as to the implications of the Design M_r.

As mentioned, if only one resilient modulus is used as an input in *SW-1*, then the Design M_r will equal that resilient modulus. This was the case for every example presented in the AI's memo. Thus, the statistical significance in the inherent variation of field subgrade support was negated.

When using StreetPave, the AI did not change the reliability and/or COV from default values. Thus, the Design M_r was automatically reduced by a value equal to *User-Entered M_r * Z * COV* to account for the variation in field data. (If the AI had used several data points with the average of 3,000 psi and the same COV as what was set in StreetPave then *SW-1* would have outputted the same thickness as StreetPave). The decreased Design M_r, which is clearly seen on each screenshot of StreetPave provided in the AI memo, results in an increase in asphalt thickness.

Further to this, both the AI's *MS-1* and *SW-1* limit the Design M_r to a minimum value of 3,000 psi, a peculiarity of the asphalt pavement design theories. The manner in which the asphalt thickness design plots are presented in *MS-1* (e.g., Subgrade Resilient Modulus versus Equivalent 80 kN Single Axle Load and full-depth on different plots than sections with 6 or 12 inches of aggregate base) can make it difficult to visualize the effects of resilient modulus on asphalt thickness. Thus, Figure 3 presents a simple investigation into this matter by keeping all things constant (including ESALs at 250,000) except asphalt cross section type and Design M_r. As shown, one possible reason for the AI to terminate their design charts at a minimum resilient modulus value of 3,000 psi is because, at this point, the required thickness would be less for a full depth asphalt pavement than for an asphalt pavement with either a 6 in. or a 12 in. base course, an illogical result. StreetPave extends these design lines beyond their 3,000 psi terminus to allow for a fair comparison of asphalt and concrete at very low support values.

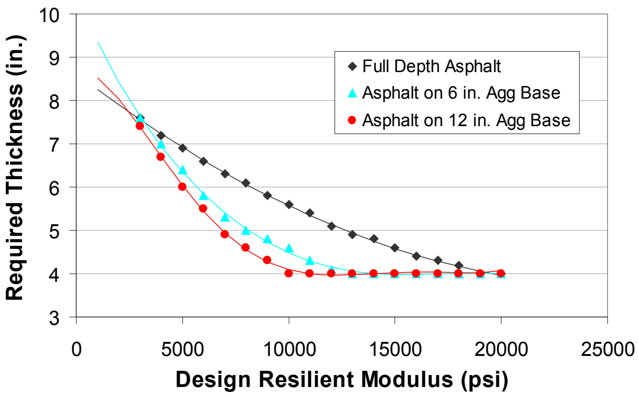

Figure 3. *Required asphalt thickness versus design resilient modulus per the Asphalt Institute's SW-1. Note that the data points stop at a resilient modulus of 3,000 psi, but the "fit" lines extend past to illustrate the trend at the lower boundary.*

Because this minimum bound of 3,000 psi is a key to any asphalt design procedure/software and because StreetPave extrapolates the asphalt design curves beyond this boundary, it becomes impossible to compare the output of StreetPave and *SW-1* at **Design M_r** values of less than 3,000 psi, as was done in the AI memo. Because every design example presented in the AI's memo included a Design M_r of 3,000 psi for design using *SW-1* and less than 3,000 psi for design using StreetPave, all examples presented in the AI memo are not comparing "apples-to-apples"; if the Design M_r input is not the same on each program, it's no surprise that the outputs are different, especially at a range of Design M_r less than 3,000 psi.

AI certainly must be aware of this restriction of their design charts. The fact that they manipulated StreetPave to use Design M_r values of less than 3,000 psi goes against their own design philosophies. Using these miscalculated and incorrect comparisons of asphalt and concrete design to affect the opinions of pavement design engineers should be considered questionable engineering practice.

Acknowledgement of Design M_r

The AI's assertion that the calculation for Design M_r is occurring in StreetPave "behind-the-scenes", "covertly", and "unbeknownst to the user" are false. The Design M_r has been displayed on the analysis output screen for all versions of StreetPave. However, to provide additional clarity to the user, StreetPave 1.2 incorporates Design M_r directly into the "Pavement Properties" screen. Free updates to version 1.2 are available on ACPA's website and have been since its release in May of 2007. It's important to note that the AI was using StreetPave version 1.0 to perform their August 22, 2007 analysis even though StreetPave version 1.2 had been released three months prior.

Conclusions

StreetPave is a useful pavement design comparison tool that provides flexibility to the user. It uses a logical, engineering-based means to provide a factor of safety or reliability to concrete and asphalt pavement designs. If a user wishes to minimize the impact of reliability in a design comparison, they may simply input a reliability of 50 percent or a coefficient of variation of subgrade resilient modulus of 1 percent.

The benefit of the StreetPave method of calculating the design resilient modulus is that only one modulus value (the average) is needed, along with a coefficient of variation value, in order to properly calculate a Design M_r that accounts for the variability of soil strength in the field. If only the average resilient modulus is inputted into *SW-1*, the Design M_r is always equal to the user-entered resilient modulus value. The resulting consequence is to negate variability and effectively exclude reliability from design consideration.

Because the reliability factor is automatically applied to the concrete strength, it should also always be applied to the resilient modulus for the asphalt portion of the design. By negating the effects of reliability on asphalt pavement design when only one resilient modulus is entered, *SW-1* allows pavement engineers to justify thinner asphalt pavements than might be necessary to survive the specified design life.

Such was the case when the AI incorrectly applied the statistical significance of the inherent spread in data for the sample StreetPave runs they presented in their August 22, 2007 memo but did not include equivalent statistical adjustments in their designs using *SW-1*.

References

1. Duval, J., "Debunking StreetPave's Claim of an "Equivalent" Asphalt Design," Asphalt Institute, August 22, 2007, http://www.asphaltinstitute.org/ai_pages/Temp_Pages/Debunking_Streetpave.pdf.

5420 Old Orchard Road, Suite A100, Skokie, IL 60077
Tel.: 847.966.2272; Fax: 847.966.9970; www.pavement.com