10/16/09

Concrete Pavement Analyst (CPA) - Setting the Record Straight

The National Ready Mix Concrete Association (NRMCA) has developed and is distributing parking lot design software titled Concrete Pavement Analyst (CPA). The CPA User's Manual states: "The Concrete Pavement Analyst (CPA) is a powerful tool that can be used to compare design and cost differences between concrete and asphalt parking areas. …. the comparative asphalt designs are inferred from information from the Asphalt Institute as well as other specifier provided information."

This document is intended to set the record straight by illustrating that CPA **does not** produce results similar to the Asphalt Institute (AI) thickness design methods. We will also illustrate where CPA has unreasonable biases to skew results in favor of concrete. In this document, we only address the inaccurate representation and manipulation of the asphalt pavement design and cost analysis within CPA, and do not comment on the concrete design and analysis.

The true AI design methods are available in our software *SW-1, Asphalt Pavement Thickness Design for Highways, Airports, Heavy Wheel Loads and Other Applications.* These methods and their underlying design principles are also covered in our publication *MS-1, Thickness Design– Asphalt Pavement for Highways & Streets.* In addition, *IS-91, Full-Depth Asphalt Pavement for Parking Lots, Service Stations and Driveways* provides an abbreviated approach to designing parking lots with Full-Depth asphalt (no granular base). These are the untainted tools that should be used when designing asphalt pavement parking areas with AI methods, and are referenced here in this paper.

Thickness Design and Subgrade CBR

While CPA refers to Asphalt Institute design methods for their asphalt pavement designs, CPA does not replicate them nor does CPA produce results that are comparable. AI's design methodology is based on layered elastic design using modulus values (or CBR values correlated to modulus), yet CPA's methodology is based on structural numbers using layer coefficients. Suggested (or default values within CPA) of layer coefficients skew the resulting structural numbers and thickness design towards a thicker and more expensive asphalt design. Rather than discussing differences in design methodologies, we will focus the discussion here on inputs and results to illustrate how CPA generated asphalt designs are not comparable to those performed using AI's methods.

Asphalt pavement thickness designs (referred to as flexible designs) are highly dependant on the input variable that defines the strength of the subgrade, and this dependency is generally greater in an asphalt design versus a concrete pavement design (called a rigid design). Thus, correctly characterizing the subgrade strength is very important in order that the designed asphalt cross section is sufficient to carry the loads with a reasonable factor of safety, yet without being excessively conservative. The CPA software assigns unreasonably low subgrade CBR values for given soil types, falling well below suggested ranges in published literature. This results in excessive asphalt thicknesses, driving the cost up for the "comparative" asphalt design. This is illustrated in detail below.

The CPA software offers three subgrade choices, with their descriptions and assigned CBR values listed as:

- Fine-grained soils in which silt and clay-sized particles are predominate (CBR 2)
- Sand and sand/gravel mixtures with moderate amounts of silt and clay (CBR 3)
- Sands and sand/gravel mixtures relatively free of plastic fines (CBR 10)

The AI's IS-91 also has three subgrade choices, with their descriptions and assigned CBR values listed as:

- Soils having appreciable amounts of clay and fine silt (CBR 3)
- Loams, silty sands and sand and gravel containing moderate amounts of clay and fine silt (CBR 8)
- Clean sands and sand and gravel free of detrimental amounts of plastic materials (CBR 17)

Note that CPA's subgrade descriptions are almost identical to those in AI's IS-91, yet the CPA's recommended CBR subgrade values for the same soil type are substantially less, which has a big effect on design thickness. Comparative examples between CPA and AI's IS-91 are shown below for each of the three subgrade categories. Besides a CBR value, other design inputs or assumptions used for these comparative designs were: no aggregate base (AI's Full-Depth Asphalt), 4000 psi concrete compressive strength (for the "comparative" concrete design), and up to 20 heavy trucks per day (CPA's Category "C" traffic and AI's Class III traffic).

Example 1) Using CPA and their "Low" subgrade description (CBR 2), the resulting asphalt pavement design calls for 11.5-inches of hot-mix asphalt (HMA). Using CPA but with a CBR of 3 (from AI's "Poor" subgrade description), the design calls for 10-inches of HMA. Using AI's IS-91 and a CBR of 3, the design calls for 7.5-inches of HMA.

Example 2) Using CPA and their "Medium" subgrade description (CBR 3), the asphalt pavement design calls for 10-inches of HMA. Using CPA but with a CBR of 8 (from AI's "Medium" subgrade description), the design calls for 9-inches of HMA. AI's IS-91 with a CBR of 8 calls for 5.5-inches of HMA.

Example 3) Using CPA and their "High" subgrade description (CBR 10), the asphalt pavement design calls for 9-inches of HMA. Using CPA but with a CBR of 17 (from AI's "Good to Excellent" subgrade description), the design calls for 9-inches of HMA. (Note: the CPA asphalt design thickness with up to 20 trucks per day is the same for CBR values 8 - 26. It is not until you have a CBR of 27 that the asphalt section is reduced to 8.5-inches). AI's IS-91 with a CBR of 17 recommends 4-inches of HMA.

The results of these three examples are summarized in Figure 1.

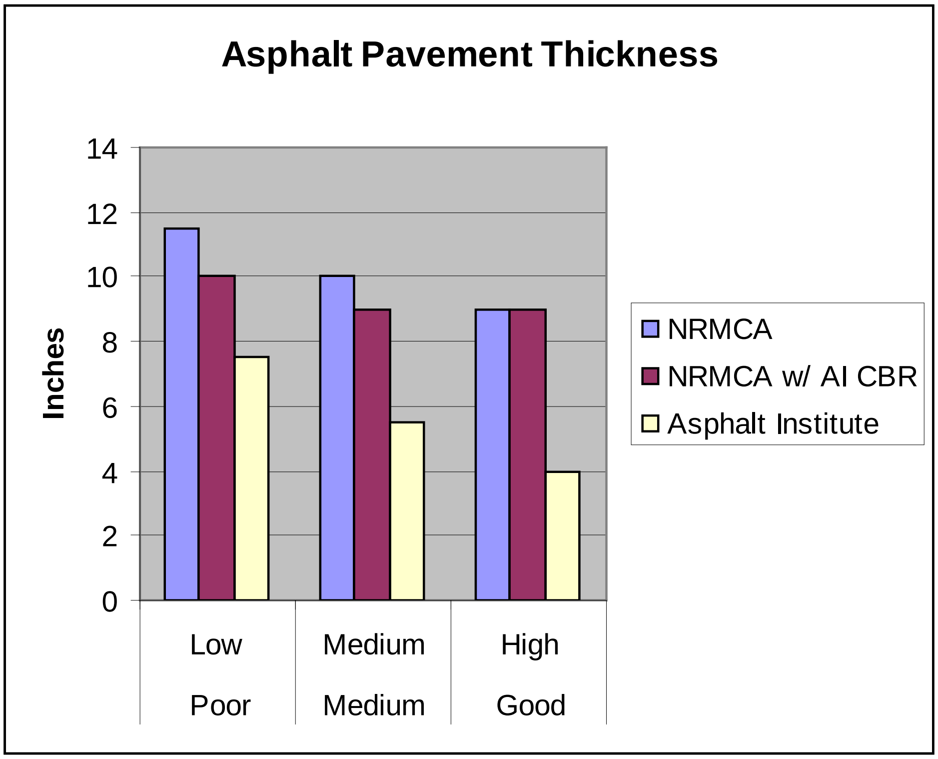


Figure 1 NRCMA's CPA Designs versus AI's IS-91 Designs (up to 20 trucks/day)

The CPA software overdesigns the asphalt pavement sections relative to AI's IS-91 methods by 4 to 5 inches of HMA, or up to 100% of total thickness. It is also apparent that even with using the same CBR value and other design parameters, CPA overdesigned the asphalt pavement section relative to AI's methods by 2.5 to 5 inches, or up to 100%.

While one may question or debate how much conservatism is appropriate for designing a parking lot, there is no questioning that CPA does not produce an asphalt design that is "comparative" to the AI's methods. In addition, it should be noted that AI's design methods have been used for decades and have a long track-record of success.

A logical follow-up question that might be asked is which side is right relative to assigning a CBR value to a general soil description. To answer this, the Unified Soil Classification System (USCS) chart is shown in Appendix A. A table from the new Mechanistic-Empirical Pavement Design Guide is shown in Appendix B and a table from the textbook *Principles of Pavement Design* by Yoder and Witzak is shown in Appendix C. Both of these tables, from well-respected and recognized sources in the pavement design industry, show a suggested CBR range for each USCS type. The best fit USCS type for both the AI's and the CPA's "Medium" and "High" subgrade descriptions are within the USCS Gravels and Sands (Appendix A). The CBRs for those descriptions range from 10 - 70 (Appendix B) or 10 - 80 (Appendix C). Clearly, CPA assigning a CBR of 3 for a "Medium" subgrade and a CBR of 10 for a "High" subgrade is excessively conservative in an attempt to over-design the asphalt section. The AI's assigned CBR values of 8 for their "Medium" subgrade, and 17 for their "Good", is still conservative, yet more in-line with published guidelines. For silt and clay USCS soil types, Appendix C shows CBR ranges from 3 - 5 up to 5 - 15, with no range falling below a 3. AI uses a conservative CBR value of 3 for silts and clays, while CPA uses a CBR of 2.

Assigning a CBR value based on only three soil descriptions is certainly a simplified approach. When possible, designers should base the CBR value on testing from the actual subgrade. If test data is not available, then assigning a CBR value based on an accurate USCS or AASHTO soil classification type (such as Appendices B or C) is desirable.

CPA states, "Asphalt Institute's recommendations do not give value to aggregate bases in excess of 4-inches thick…" This is not a correct statement. AI's IS-91 does not address aggregate base because it refers only to Full-Depth asphalt pavements. However, the AI's MS-1 publication and SW-1 software give credit for aggregate bases in excess of 4-inches. Figure 2 is a screen from SW-1. Note that it allows the designer to choose six types of cross-sections, with Types 2, 3 and 4 using untreated aggregate bases. Type 4 allows the user to choose aggregate base thicknesses ranging from 4 to 18-inches. As examples, AI's MS-1 or SW-1 provides the following thickness design options for 20 trucks on a poor subgrade:

- 6.2-inches HMA over 4-inches aggregate base
- 5.3-inches HMA over 8-inches aggregate base
- 4.5-inches HMA over 12-inches aggregate base
- 4.2-inches HMA over 16-inches aggregate base

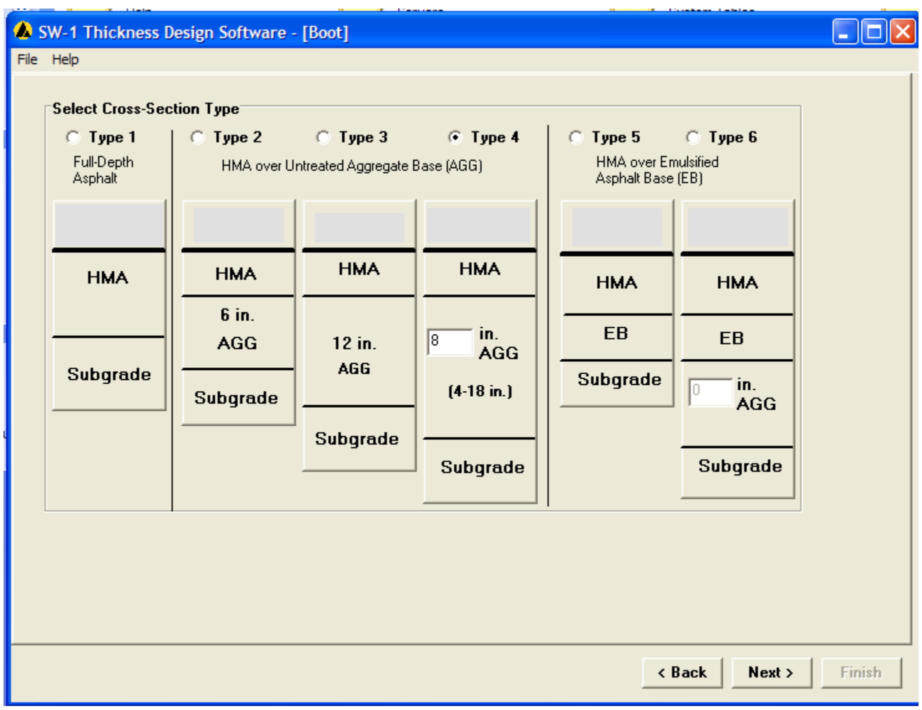


Figure 2 AI's SW-1 Screenshot Showing Aggregate Base Design Options

While AI's methods are based on mechanistic-empirical analysis and do not use structural coefficients, the CPA software uses structural coefficients to provide so-called "comparable" or 'equivalent" asphalt sections. CPA's default structural coefficient values for HMA are low relative to what is normally used by agencies. CPA uses 0.38 for a HMA surface mix and 0.32 for a bituminous base. For comparison, state agencies typically use coefficient values of 0.40 for an HMA base mix to 0.44 for a HMA surface mix. A CPA example using these more realistic structural coefficients (.40 for base and .44 for surface mixes) dropped the asphalt thickness from 10.5 inches to 8.5 inches. CPA's lower coefficients for HMA skew the results toward a thicker and more expensive asphalt section.

Life Cycle Cost

After CPA computes asphalt and concrete designed sections that are deemed "comparable," the program then performs a Life Cycle Cost Analysis (LCCA) on both. The outcome of the LCCA greatly depends on the input variables assigned and assumptions made for the analysis. CPA uses inappropriate default values and assumptions that are not very clear to the software user to skew the LCCA results towards the concrete design. A few of these biases are explained below.

Life cycle cost is the total cost of a roadway or parking lot over the life of the facility. It includes: initial construction, future rehabilitation / maintenance, and user delay over the analysis period. Initial construction costs may represent 80 to 90-percent of an agency's life cycle cost. Accurate pricing of both alternatives (asphalt and concrete) over the entire analysis period is critical for a valid life cycle cost analysis (LCCA). While covering all the pricing biases built into the CPA default values for the asphalt alternative would take too long, a few of them include: extraordinarily high seal coat costs ($2.50 per sq yd), drastically higher curb and gutter costs for the asphalt design versus concrete design, assuming all asphalt parking lots are "cut" jobs, additional lighting requirements and costs for asphalt compared to concrete, etc.

Besides pricing, another critical factor in LCCA for asphalt pavement is the initial and overlay performance periods. Performance periods are important because the preferred method of LCCA is using present worth. Present worth discounts future rehabilitation / maintenance dollars back to current dollars based on the real discount rate (discussed later). Resurfacing intervals too early or too late have a significant impact on the LCCA. A 2008 survey of state highway agencies (49 of 50 reporting) found that the average initial performance period (time to first overlay) used in their LCCA for an asphalt pavement is 15 years, and the average performance period (life) of that first overlay is 12 years. Comparatively, the default performance period by CPA for Full-Depth asphalt is 10 years, and is 8 years for locally designed asphalt sections. In addition, CPA assumes a seal coat and restriping at the midway point (4 or 5 years) during these overlay performance periods. The resulting CPA activity timeline calls for either an overlay or seal coat every 4 or 5 years for the entire analysis period. Clearly the CPA default performance periods for asphalt are significantly shorter than the average values highway agencies use in their LCCA (15 years initial asphalt life and 12 years for overlays, without any seal coats). Highway agencies typically base these assumed performance periods on actual historical data from their own detailed pavement management systems. On the other hand, CPA has selected asphalt performance periods and treatment schedules that are way out of line with what's reasonable.

Another area where the CPA has biased the LCCA is in the asphalt's annual maintenance cost, which is defaulted to be two times more than the concrete maintenance cost. The asphalt maintenance cost in CPA is in addition to the cost of the overlays and seal coats every 5 years. The Federal Highway Administration's published guidance for LCCA in pavement design is Pub. No. FHWA-SA-98-079, which states:

> "…annual maintenance costs have only marginal effect on Net Present Value. They are hard to obtain, generally very small in comparison to initial construction and rehabilitations costs, and differentials between competing pavement strategies are usually very small, particularly when discounted over 30 to 40-year analysis periods."

Besides pricing, performance periods and maintenance costs, another parameter used in LCCA is discount rate. Discount rate reflects the difference between interest earned and inflation. As an example, if you purchased a 3-year CD offering 4% interest, at the end of that 3-year period your real gain in value would be 4% less inflation over that 3-year period. If inflation averaged 1.5%, then your real increase is 2.5%. It is important to select a discount rate for LCCA that reflects the true forecasted discount rate over the analysis period. The best method to do this is to consult the U.S. Office of Management and Budget (OMB). The OMB periodically publishes the real discount rate to be used for government LCCA. This guidance published in December 2008 is shown in Appendix D. Pavement LCCA analysis periods typically range between 30 and 50 years. The current recommended real discount rate for a 30-year or more analysis is 2.7-percent (Appendix D). The survey mentioned in the above paragraph showed that the average discount rate used by the various state highway agencies was 3.8%, with the lowest being 2.3% and the highest being 7.1%. Conversely, CPA's default discount rate is 1.5-percent (5.5% interest – 4.0% inflation). Selecting a low discount rate in LCCA favors the alternative that has less future maintenance and rehabilitation. Along with CPA's skewed assumptions of short asphalt performance periods and high maintenance costs, selecting a discount rate that is lower than published recommendations slants the LCCA results towards the concrete alternative.

The CPA Users Manual, under the heading "Asphalt Costs", states: "Typically, Bituminous Base is less expensive and of lower quality than the surface course material". The less expensive statement is correct, the lower quality is not. Base mixes are less expensive because they use larger aggregate which have less surface area to coat with asphalt cement. Quality is the result of a proper mix design and construction practices, rather than cost.

Conclusions

The CPA software and user's manual is a concrete industry marketing tool to promote the increased use of concrete parking lots. The software is biased against asphalt by calculating an asphalt section that is overdesigned relative to Asphalt Institute methods. It performs a life cycle cost analysis that is full of biases against asphalt through its assumptions and default values. Some of the biases include:

- providing subgrade CBR values which are not in line with nationally accepted values

- providing structural coefficients for asphalt mixes that are too low
- inaccurately representing Asphalt Institute design methods
- overly aggressive rehabilitation and maintenance schedules for asphalt pavements
- Low discount rates

Each of the above bullets increases the thickness and economics of an asphalt pavement.

Takeway

It is not wise to use a concrete association's software to design an asphalt pavement or calculate asphalt pavement life-cycle costs. The results will be skewed in the concrete industry's favor.

Asphalt Institute Thickness Design References

Full-Depth Asphalt Pavement for Parking Lots, Service Stations, and Driveways (IS-91)

Points out the advantages of Full-Depth asphalt and gives design and construction information and model specifications

Thickness Design – Highways & Streets (MS-1)

The Ninth Edition presents a multi layered elastic design approach to pavement thickness design , rather than empirical

Asphalt Pavement Thickness Design Software (SW-1)

A mechanistic / empirical pavement thickness design program based on familiar Asphalt Institute methods.

Appendix A USCS Chart

UNIFIED SOIL CLASSIFICATION SYSTEM

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	Clean Gravels (Less than 5% fines)	
	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	Clean Sands (Less than 5% fines)	
	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

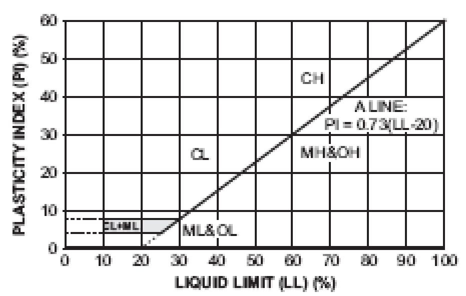
LABORATORY CLASSIFICATION CRITERIA

GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .... GW, GP, SW, SP
More than 12 percent .... GM, GC, SM, SC
5 to 12 percent .... Borderline cases requiring dual symbols

PLASTICITY CHART



Appendix B Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures (NCHRP Project 1-37A, Appendix CC-1)

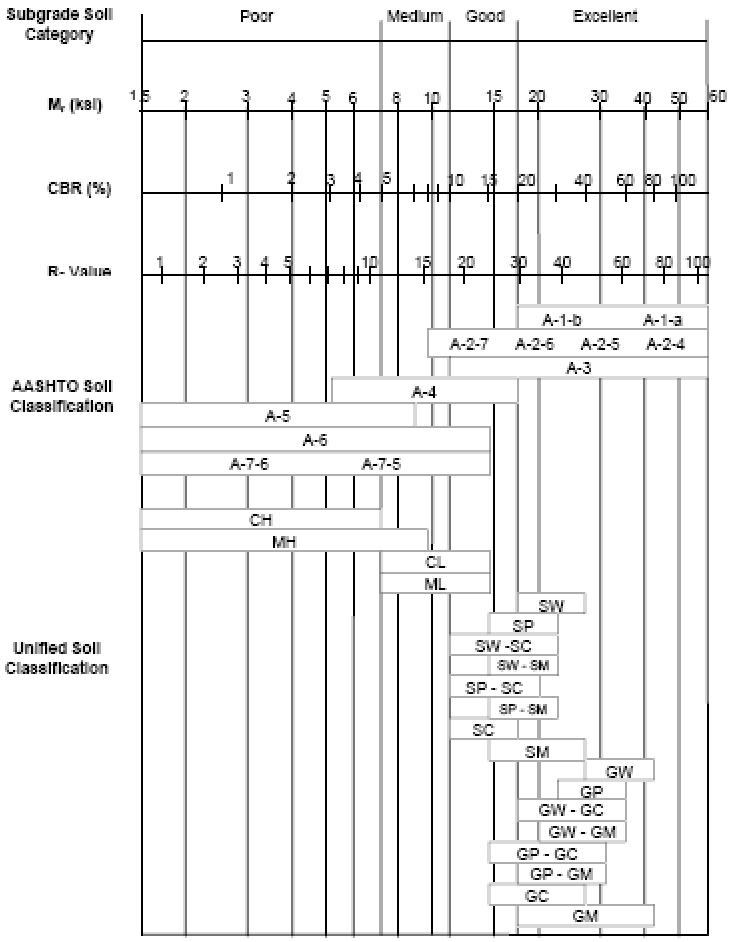


Figure 1. Typical Resilient Modulus Correlations to Empirical Soil Properties and Classification Categories.
(Modified from NAPA Information Series 117, "Guidelines for Use of HMA Overlays to Rehabilitate PCC Pavements", 1994)

Appendix C Characteristics of USCS Soil Types (from Table 7.4 in Yoder and Witzak, Principles of Pavement Design)

TABLE 7.4. Characteristics Pertinent to Road and Runway Foundation[a]

Major Divisions (1)	(2)	Letter (3)	Name (4)	Value as Foundation When Not Subject to Frost Action (5)	Value as Base Directly under Wearing Surface (6)	Potential Frost Action (7)	Compressibility and Expansion (8)	Drainage Characteristics (9)	Compaction Equipment (10)	Unit Dry Weight (pcf) (11)	Field CBR (12)	Subgrade Modulus k (pci) (13)
Coarse-grained soils	Gravel and gravelly soils	GW	Gravel or sandy gravel, well graded	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	125–140	60–80	300 or more
		GP	Gravel or sandy gravel, poorly graded	Good to excellent	Poor to fair	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	120–130	35–60	300 or more
		GU	Gravel or sandy gravel, uniformly graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	115–125	25–50	300 or more
		GM	Silty gravel or silty sandy gravel	Good to excellent	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	130–145	40–80	300 or more
		GC	Clayey gravel or clayey sandy gravel	Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120–140	20–40	200–300
	Sand and sandy soils	SW	Sand or gravelly sand, well graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	110–130	20–40	200–300
		SP	Sand or gravelly sand, poorly graded	Fair to good	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	105–120	15–25	200–300
		SU	Sand or gravelly sand, uniformly graded	Fair to good	Not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100–115	10–20	200–300
		SM	Silty sand or silty gravelly sand	Good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	120–135	20–40	200–300
		SC	Clayey sand or clayey gravelly sand	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105–130	10–20	200–300
Fine-grained soils	Low compressibility LL < 50	ML	Silts, sandy silts, gravelly silts, or diatomaceous soils	Fair to poor	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	100–125	5–15	100–200
		CL	Lean clays, sandy clays, or gravelly clays	Fair to poor	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100–125	5–15	100–200
		OL	Organic silts or lean organic clays	Poor	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired equipment, sheepsfoot roller	90–105	4–8	100–200
	High compressibility LL > 50	MH	Micaceous clays or diatomaceous soils	Poor	Not suitable	Medium to very high	High	Fair to poor	Rubber-tired equipment, sheepsfoot roller	80–100	4–8	100–200
		CH	Fat clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	90–110	3–5	50–100
		OH	Fat organic clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	80–105	3–5	50–100
Peat and other fibrous organic soils		Pt	Peat, humus, and other	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical			

[a] From Corps of Engineers.

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Yoder + Witczak, Principles of Pavement Design

Appendix D OMB Recommendations for Real discount Rates, December 2008

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APPENDIX C
Revised December 2008

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DISCOUNT RATES FOR COST-EFFECTIVENESS, LEASE PURCHASE,
AND RELATED ANALYSES

Effective Dates. This appendix is updated annually. This version of the appendix is valid for calendar year 2009. A copy of the updated appendix can be obtained in electronic form through the OMB home page at http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html, the text of the main body of the Circular is found at http://www.whitehouse.gov/omb/circulars/a094/a094.html, and a table of past years' rates is located at http://www.whitehouse.gov/omb/circulars/a094/dischist-2009.pdf. Updates of the appendix are also available upon request from OMB's Office of Economic Policy (202-395-3381).

Real Discount Rates. A forecast of real interest rates from which the inflation premium has been removed and based on the economic assumptions from the 2010 December Budget Baseline is presented below. These real rates are to be used for discounting constant-dollar flows, as is often required in cost-effectiveness analysis.

Real Interest Rates on Treasury Notes and Bonds
of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
0.9	1.6	1.9	2.4	2.9	2.7

Analyses of programs with terms different from those presented above may use a linear interpolation. For example, a four-year project can be evaluated with a rate equal to the average of the three-year and five-year rates. Programs with durations longer than 30 years may use the 30-year interest rate.