NEW GENERATION PAVEMENT DESIGN WITH NANOTECHNOLOGY

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ABSTRACT

We have come a long way since *experience based* road design of 1950s, to today's *Mechanistic Empirical Pavement Design Guideline (MEPDG)*. However, MEPDG being expensive and heavily dependent on software programs, *AASHTO 1993 Empirical Pavement Design* continues to form the basis for pavement design even today; in most parts of the world, including in India (IRC Design). There have been many technological improvements since the AASHO road test carried out in Ottawa, Illinois between 1958 & 1960, and there is a scope to take benefit of these improvements in optimizing the design.

The new design approach proposed in this paper, takes into account, the new technological improvements since 1960, enabling optimization of pavement design. The three major improvements, namely (i) Higher Layer Coefficients due to stronger materials, (ii) Higher Drainage Coefficients due to nanotechnology for waterproofed layers and (iii) Higher moduli of subgrade due to better soil stabilization technology; enable designing pavements that are 14 times better (in terms of ESAL value) at zero extra cost, as compared to conventional designs.

This paper puts forth, a new design approach, taking advantage of the opportunities presented to a pavement designer, by the new nanotechnology. The new optimized pavement design is green, sustainable & economical; while remaining within the AASHTO 1993 guidelines.

KEY WORDS
AASHTO 1993 Empirical Design, Nanotechnology, Waterproof, Layer Coefficient, Drainage Coefficient, Subgrade Modulus, Green, Sustainable.

AASHTO 1993 DESIGN GUIDELINE : A BRIEF BACKGROUND

The American Association of State Highway and Transportation Officials (AASHTO) pavement design guides published from 1962 through 1993 *(1,2)* were based primarily on the AASHO Road Test *(1)* conducted in Ottawa, Illinois from 1958 until 1960. Though updated and improved over time, the design guides still rely heavily upon observed pavement performance during the road test. The performance resulted from the cross-sections, climate, materials, construction practices and traffic applications representing late 1950's conditions and technology at this one test location. For example, the thickest asphalt section placed at the AASHO Road Test was 6 inches. Furthermore, the advances in pavement engineering, design, materials and construction fields over the past years has made the AASHTO Design Guide *(2)* more outdated with every passing year, forcing designers to extrapolate well beyond the original conditions of the road test. These advances include the development of the Superpave asphalt mix design procedures, the development of the performance graded (PG) asphalt binder specification, the use of polymers and other modifiers in asphalt, improved asphalt plant production controls, improved construction techniques and quality control procedures, advent of **nanotechnology for moisture resistance** and **waterproof subgrades** etc, to name just a few.

The National Cooperative Highway Research Program (NCHRP) recognized the need for an improved and updated pavement design system and began Project 1-37A in 1998 entitled, "Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase I." The project ran through 2004 and resulted in the Mechanistic Empirical Pavement Design Guide (MEPDG). In 2008, the MEPDG was transitioned to the AASHTOWare series of programs and was renamed DARWin-ME as the program developers continued to improve the program's capabilities.

In 2013, the software became commercially available under the name AASHTOWareTM Pavement ME Design. The software and accompanying documentation [4], represents a tremendous leap forward from the 1993 Design Guide *(2)* and software, DARWin.

Though the MEPDG is recognized as a technological advance in pavement design, there are costs associated with implementing the new procedure. The costs include software licensing and training, development of numerous data sets through laboratory and field testing required to run the software and validation/calibration studies that must be conducted before fully implementing the new procedure. These activities can also take significant amounts of time to accomplish. That is the reason why in most parts of the world including the USA, even today, the most popular approach is to use some edition (i.e., 1972, 1986 or 1993 Design Guide) of the older empirical AASHTO procedure *(3,5)*.

OVERVIEW OF AASHTO EMPIRICAL DESIGN PROCEDURE

Observations from the AASHO Road Test established correlations between the following four main factors for flexible pavements:

1. Soil condition as quantified by the subgrade resilient modulus (M_R)
2. Traffic as quantified by equivalent single axle loads (ESALs)
3. Change in pavement condition as quantified by the change in pavement serviceability index (ΔPSI)
4. Pavement structure as quantified by a structural number (SN)

This relationship is shown in the Equation below.

$$\log W_{18} = Z_R S_0 + 9.36\log(SN+1) - 0.20 + \frac{\log\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32\log M_R - 8.07$$

EQUATION 1 AASHTO Design Equation

Since flexible pavements are typically comprised of diverse layers with varying engineering properties, it was necessary for AASHTO to introduce the pavement structural number (SN) concept. Terms Z_R and S_0 are reliability and variability factors not originally part of the

AASHTO design procedure but added later to incorporate a safety factor into the design. The other quantities in the equation are regression coefficients that provided the best match between the independent variables (SN, ΔPSI, M_R) and the performance of the pavement section as quantified by ESALs.

All the parameters other than SN are either known or are design decisions. Putting in all these parameters into the equation and then solving it for SN gives the designer a target structural number, for those design parameters.

The designer now has to design the cross-section of the pavement with depth of each layer, as illustrated below; such that the sum of structural numbers of all layers is greater than or equal to the target structural number derived from the AASHTO equation.

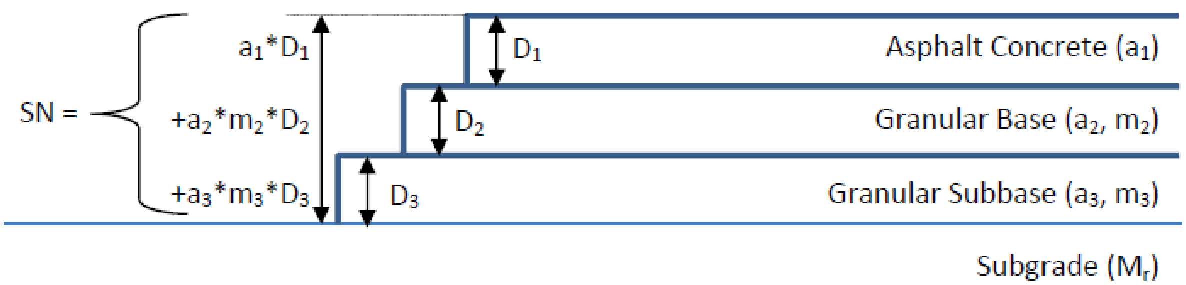

FIGURE 1 Concept of Structural Number

SN represents the cumulative pavement structure above subgrade expressed as a product of individual layer thicknesses (Di), their respective structural coefficients (ai) and drainage coefficients (mi) as illustrated. The structural coefficients are empirical values meant to relate the relative load-carrying capacity of different materials. The drainage coefficients are meant to empirically adjust the design according to site-specific rainfall expectations and quality of drainage provided by the material itself *(1)*. Drainage coefficients range from 0.4 to 1.4, represented as 1.0 in the original AASHO Road Test conditions.

This in a nutshell, is the AASHTO 1993, flexible pavement design procedure.

THE TECHNOLOGICAL IMPROVEMENTS SINCE 1960

As we know, a lot of water has flown after the AASHO road test that concluded in 1960. The technological improvements since then, potentially may allow us to optimize the pavement design under 1993 empirical procedure.

The three major improvements since 1960 are as follows.

(i) Better Materials / HMA Mixing Methodology

CHART 1.0 Structural Coefficient Vs. HMA Elastic Modulus

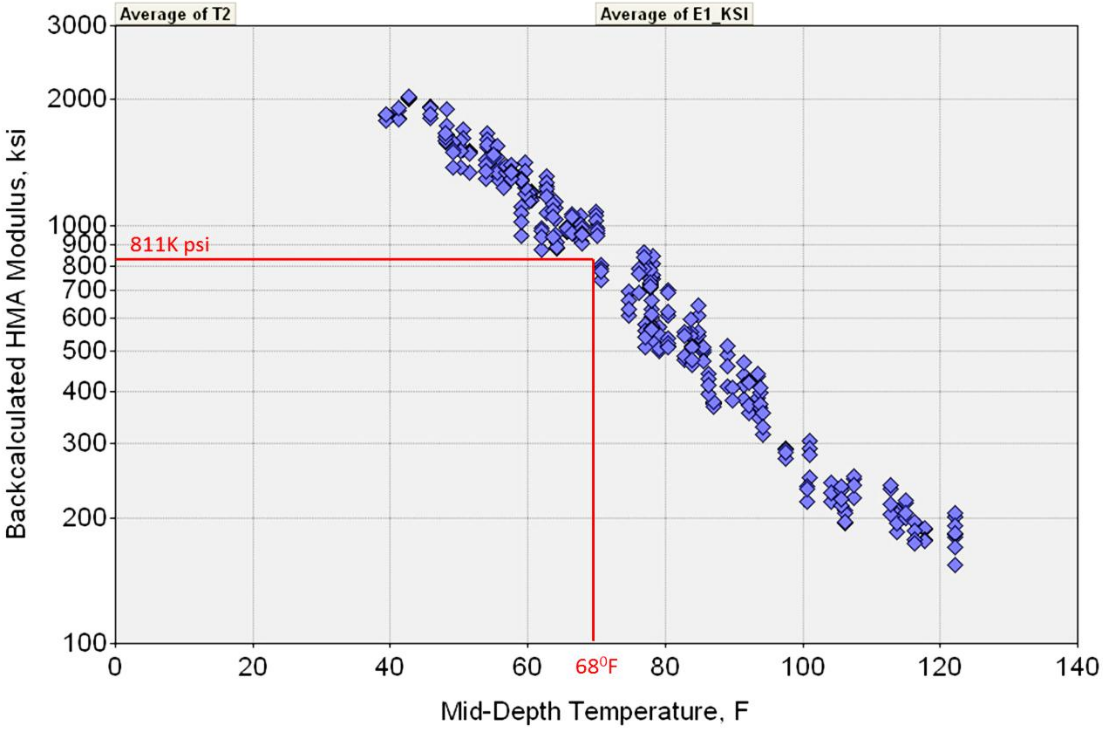

CHART 2.0 HMA Moduli at different temperatures

Although the AASHO test recommended a value of 0.44 as the layer coefficient for asphaltic layers, as illustrated in Chart 1.0 above, the quality of Hot Mix Asphalt (HMA) has substantially improved since then. Laboratory tests conducted by NCAT in 2012 indicate that the Elastic Modulus of HMA at 68^0F normalized, is 811K psi, as shown in the Chart 2.0 above. Referring back to the Chart 1.0, extrapolated corresponding value of structural coefficient would be approximately 0.54, which is indicative of a much stronger structural layer.

In practice, Alabama Department of Transport (ALDOT), takes Layer Coefficient for asphaltic layers as 0.54 and Washington State DoT assumes 0.50 as Layer Coefficient value. According to ALDOT, with LC of 0.54, they save about 18% on road construction cost.

(ii) New Technologies for Water-Resistant Structural Layers

As per the AASHTO 1993 guidelines, the Drainage Coefficient to be taken for design purpose is given by the table below.

Quality	95% Water Removed	% Time Saturated			
		<1%	1 - 5%	5 – 25%	>25%
Excellent	2 hours	1.40 – 1.35	1.35 – 1.30	1.30 – 1.20	1.20
Good	1 day	1.35 – 1.25	1.25 – 1.15	1.15 – 1.00	1.00
Fair	1 week	1.25 – 1.15	1.15 – 1.05	1.05 – 0.80	0.80
Poor	1 month	1.15 – 1.05	1.05 – 0.80	0.80 – 0.60	0.60
Very Poor	Never Drain	1.05 – 0.95	0.95 – 0.75	0.75 – 0.40	0.40

TABLE 1 AASHTO Guideline on Drainage Coefficient

The value of Drainage Coefficient can be anywhere between 0.4 and 1.4. One should take into consideration the % time saturation of the respective pavement layer, and consider the drainage efficiency (95% water removed), to arrive at the appropriate value of Drainage Coefficient.

However, the new nanotechnology makes this rather irrelevant as it ensures waterproofing of all layers. Hence, Time Saturation is always < 1% and 95% water is always removed within 2 Hours or less. Referring to the table above, the corresponding value of Drainage Coefficient for such a situation is 1.35 to 1.40.

(iii) Technologies for Water-Resistant Subgrade with Higher Moduli

The resilient modulus of the subgrade varies from season to season. AASHTO 1993 gives detailed guideline on how to arrive at the value of M_R, for the design purpose.
A new concept of 'Relative Damage' has been introduced here. The relative damage μ_f for different values of M_R in different seasons is given by the following equation.

$$\mu_f = 1.8 \times 10^8 \times M_R^{-2.32}$$

Having determined μ_f for different seasons with the help of this equation, a weighted average value of μ_f is to be determined over the whole year and the corresponding value of M_{REff} is to be found out. This is the value of M_R to be used for design purpose.

Again, since the new technology ensures dry subgrade M_R through all seasons, this exercise becomes redundant. If subgrade M_R worked out with above method is say - 10000 psi (based on weighted average μ_f), it is now possible to assume a value of dry M_R of say - 20K psi, with new technology.

Let us now see, how the conventional design can be optimized, taking into consideration these three improvements.

EXAMPLE OF NEW DESIGN FOR A 40 MSA ROAD

Let us now consider a 40 MSA road designed conventionally. Let the standard deviation of the traffic data be 0.45, let us assume that we are looking for a design Reliability of 95% and the Pavement Serviceability Index will drop from 4.2 (initial value at the time of construction), to 2.0 at the end of design period. Subgrade resilient modulus is assumed to be 10000 psi.

When all these values are inserted into the Equation 1, and it is solved for SN, it gives us the target structural number as 5.19. Designing layer thicknesses, as per standard practice, the thickness of asphaltic layers comes to DBM: 100 mm and WC: 60 mm.

Description	Conventional Design DBM 100 mm WC 60 mm	New Tech Design-1 DBM 60 mm WC 50 mm (Zero Extra Cost)			New Tech Design-2 DBM 80 mm WC 50 mm (5.50% extra cost)		
Drainage Coefficient	1	1.2	1.3	1.4	1.2	1.3	1.4
Structural Number	5.19	5.27	5.62	5.92	5.78	6.17	6.56
Subgrade Modulus (psi)	10K	20K	20K	20K	20K	20K	20K
Equivalent MSA	40	230	380	574	475	790	1296
Times Improvement		6	10	14	12	20	32

TABLE 2 Conventional Design Vs. New Design

While designing a road with new technology, two options are considered. Option 1 assumes a condition of ‘Zero Extra Cost’ over conventional design, whereas in case of Option 2, a 5.50% extra cost is allowed. 3 different values of Drainage Coefficient are considered under each of these options.

As can be observed from Table 2.0 above, under both these new design options, the Equivalent MSA values are several times that of 40 MSA. The same findings are represented a bit differently in Figure 2.0 below.

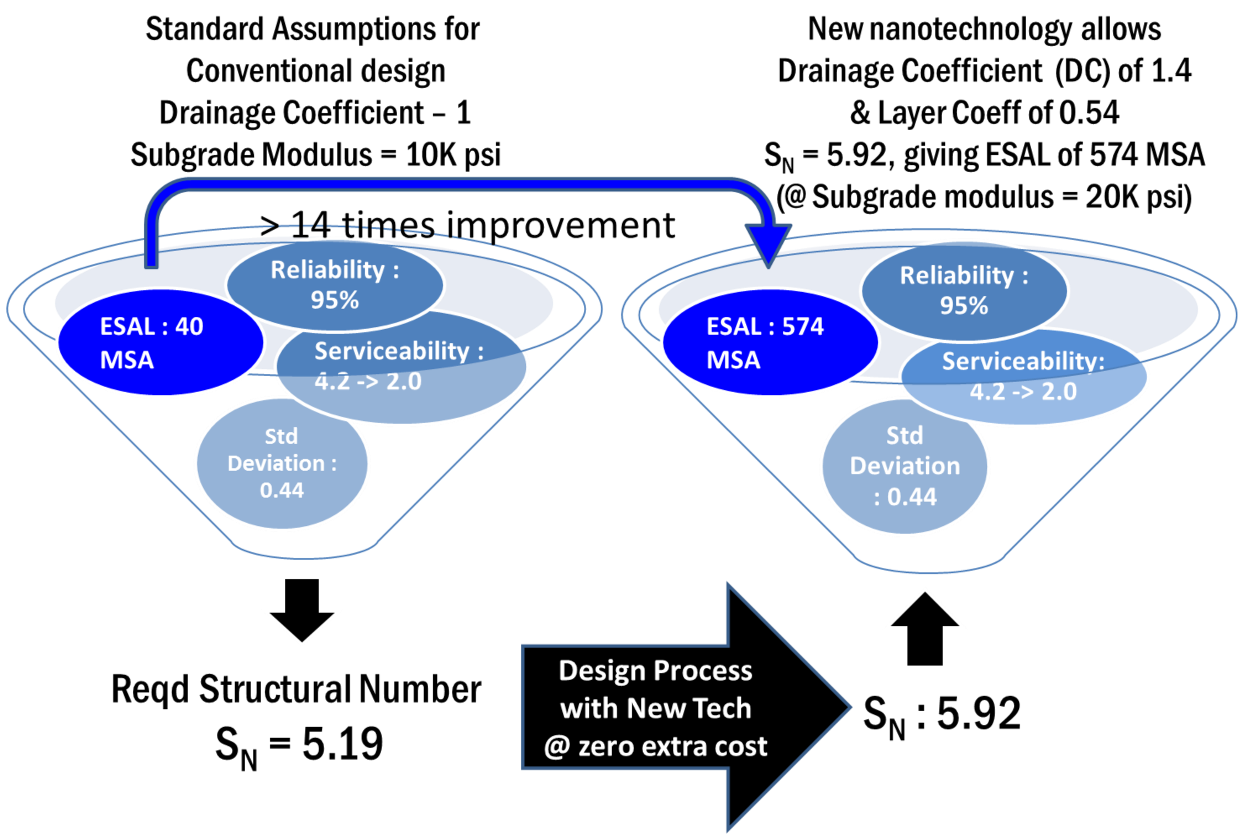

FIGURE 2 New Design is 14 times better than Conventional Design @ zero extra cost

CONCLUSION

There are many technological advancements since the AASHO road test, and taking into consideration these advancements, gives us an opportunity to optimize the conventional design.

As demonstrated in the example, the conventional 40 MSA road design can be improved 14 times (in terms of ESAL value), at zero extra cost, with the new design approach.

Moreover, the new technology enables reduction in thicknesses of layers, resulting in saving of limiting resources like bitumen, aggregates and fuel, thereby, contributing to building green sustainable roads of tomorrow.

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