Developing a Pay Adjustment Technique for Flexible Pavement Highways Projects

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***Abstract*—The influence of variations in asphalt concrete properties in flexible pavement performance during its design life is a critical factor in highways construction. Shortly after laying down the asphalt concrete, it is hardened; therefore, no adjustment can be applied. Quite often, materials quality does not meet specification requirements. The effect of this non-conformation on pavement serviceability has not been established; however, it results in reduced payments to contractors. The pay adjustment methods currently used in Egypt is based mainly on discounting the present cost from the contractor's payment. This method of penalizing contractors is not based on sound engineering principles. Thus, it is not always a reliable measure of pavement's reduced serviceability. The purpose of this study is to develop a pay adjustment method based on actual serviceability of the pavement. It is based on serviceability of the pavement defined in the ASSHTO method of thickness design. It assumes that the maximum penalty that a contractor can ever pay is equivalent to the adjusted cost of an overlay which upgrades the pavement to its design serviceability. The actual penalty is then, computed based on the actual loss of serviceability experienced over time.**

***Index Terms*—pay adjustment, HMA pavement, highways projects**

I. Introduction

Quality control evaluation during the construction process of flexible pavements is considered critical in determining the service life of a road. It normally happens that qualities of the materials used in construction are beyond the specification tolerance limits. In some cases, especially during the early stages of construction, the material that don't meet the specification requirements can rejected and contractor is responsible for replacement. However; in many cases, evaluation of finished pavement layer has proved deviation from design limits.

Worldwide, some agencies reject construction works that do not meet specification limits, and do not pay contractors. Others, however; accept these deviations in thickness, asphalt content and properties, compaction, and graduation but apply a pay adjustment factor that penalizes the contractor by reducing his balance.

The available methods for determining quality-related pay adjustment factors can be categorized based on the quality-adjustment factor relationship as follows [1]:

Empirical methods, which use empirical relationships derived from highway agency experience and not from engineering principles. Some of these methods conform to the definitions of PRS (*performance-related specifications*) provided in AASHTO R10. Such methods were developed for flexible and rigid pavements [2]. These methods are simpler and easier to implement, but they are likely to be less precise.

Experience-based methods*;* usually are not derived from either engineering or mathematical principles and do not consider predicting pavement performance. These methods compute pay factors based on an approach that reflects the perceived manner and extent to which the *AQCs* (*Acceptance Quality Characteristics*) influence pavement performance. These methods are generally compatible with AASHTO R9: Standard Practice for Acceptance Sampling Plans for Highway Construction (AASHTO R9) and AASHTO R42: Standard Practice for Developing a Quality Assurance Plan for Hot-Mix Asphalt (AASHTO R42).

In Egypt, deduction is based on the regulations stated in the Egyptian Code of Practice (*ECP*) for urban and rural roads (P-9). These rules reveal the following practices for flexible pavements:

- Percent Within Limits (*PWL*) is the single most often used quality measure except for evenness and consistency where quality is measured by the average value.
- Surface consistency (*as a measure of HMA visual quality*) is considered separately from materials / construction *AQC*s.
- Different triggers are used for applying a combination of a "maximum disincentive", "overlay", and/or a "remove-and-replace" clause.
- For surface consistency evaluation, the disincentive ranges from 0.5% to 5.0% based on discretional assumptions.
- For surface evenness evaluation, the disincentive ranges from 3.0% to 5.0% based on surface stratification.
- For HMA gradation evaluation, the disincentive ranges from 0.3% to 1.5% based on number of out- of-range sieve sizes.

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- For binder content evaluation, the disincentive ranges from 0.5% to 1.0% for each 0.1% deviation of design binder content range.
- For wearing layer compaction evaluation, the disincentive ranges from 1.0% to 5.0% for each 1% loss of required compaction.
- For wearing layer thickness evaluation, the disincentive is inapplicable if the lack is less than 6%. The deduction is becoming 1% for each 1% loss of design thickness while an overlay clause is applied in case of the shortage found to be greater than 10%.
- No deduction is applied upon any deviation of Air Voids Content (AVC) in wearing layers hot mix asphalt.

None of the previously mentioned approaches for pay adjustment have been based on sound engineering principles. Therefore, these factors are not considered measures of serviceability reduction of pavement. Hence, many problems between the highways agencies and contractors are presently experienced. In fact, the need for an actual engineering procedure for accepting and for rejecting non-compliance work is warranted.

II. Study Purpose and Methodology

The main objective of this analysis is to develop a sound method for setting a pay adjustment method for flexible pavements in Egypt.

The conditions of constructed subgrade, subbase or base course layers can be adjusted to satisfy the specification requirements either by thickness increase, by additional compaction or by both of them.

The surface course is responsible for 40 percent or more of the total serviceability and cost of pavement. Therefore, the proposed method should concentrate of finding a rational relation between asphalt concrete quality and the total pavement serviceability, hence, it can be specified whether the work could be accepted or rejected and how much compensation the contractor would pay.

To satisfy this purpose, major elements that affect asphalt concrete properties are first determined. Then a predictive model which reflects these properties in one representative value is selected. The relation between pavement components and pavement serviceability over time is then based on the AASHTO method of design. The final step will, then, be responsible for determining the penalty or the pay adjustment factor.

III. Mix Properties Versus Serviceability

The pavement serviceability can be defined as "*its ability to serve the traffic* for *which it is d*esigned *for*" **[**3**]**. Pavement is designed to reach a Predefined Serviceability Index (*PSI*) under a predefined traffic flow which is expected to occur during a specified period of time. The number of repetitions of standard axle, 18 kips (80kn) single axle, has been related to the subgrade soil properties, environmental conditions and the pavement quality and structure in the AASHTO method of design [4].

In this study, since it is assumed that base and subbase courses are perfectly controlled, the surface course properties could have been directly related to the pavement serviceability index. Some major properties of the finished surface course are discussed in the following paragraphs

A. Air Voids

Percentage air voids (V_a) is the most principal factor that determines the asphalt mix quality. Fatigue life of a bituminous surface course is primarily affected by the level of compaction: a higher fatigue life of pavement is the result of decreased percentage of air voids. From a mix design points of view; the asphalt content, aggregate graduation, and percent filler are selected to obtain the smallest voids spaces possible so that bleeding do not occur. Research, elsewhere, has confirmed that fatigue life decreases sharply with increasing void content of the mix [5]. Low in-place air voids have been historically associated with distress types such as flushing/bleeding and rutting/shoving.

During the development of the Marshall design methodology [6], it was found that surface AC mixtures constructed to an in situ AVC of 2.5% or less shoved under traffic loads during hot weather conditions. In a study set out specifically to identify mix design parameters that may affect rutting **[**7**]**, 42 pavements were sampled from 14 different locations and based on coring, trenching and laboratory tests, it was concluded that; pavements that rutted had in-place AVCs below 3%; and most of the observed rutting was confined to the top 3-4 inches of the pavement. Other volumetric properties of the asphalt mixture may also affect rutting, such as Voids in the Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA). By providing appropriate VMA, it is believed that rutting may be minimized, and mixture durability will be enhanced [8].

B. Asphalt

When all other properties are fixed, the viscosity of asphalt cement affects the fatigue life of asphalt concrete. Low penetration asphalt cement imparts a lower fatigue life for the asphalt concrete than a higher penetration one [9].

The asphalt content is also a critical factor that rules all mix properties. The binder is the most expensive constituent of the mix; in addition, it controls the flexibility of surface course. The content of bitumen in mix is directly related to the percent air voids and affects aggregate antiparticle friction which in turn influences the stability, durability, strength, and fatigue life of mix.

Recent researches, aimed to developing a mathematical model for prediction of the modulus of elasticity of asphalt concrete, has proved that not only the percent asphalt content (P_{ac}) that affects the elastic modulus but also its deviation from the optimum value (P_{opt}) [10]. In the recent asphalt institute method of pavement design, the fatigue life of asphalt concrete has been found to be dependent on the modulus of elasticity and level of elastic strain [4]. As binder content increased, so did rut depth. This is expected because too much binder can actually lubricate the aggregate particles, allowing them to shift. Of course, as binder film thickness increases, rut depth also will increase, as too much film thickness causes the aggregate to be more likely to move, creating instability.

In general, percent bitumen content and properties is a factor that interacts with all other mix components to determine the quality of asphalt concrete.

C. Aggregate

The gradation of an aggregate usually determines the amount of voids present to be filled with asphalt cement. The degree to which the voids are filled with bitumen influences the elasticity and fatigue life of mix. Also, the amount of voids, provided by aggregate, controls and fatigue life of finished mix.

Since different aggregate types have different capabilities as load-carriers thus, it is expected that fatigue life of mix differs by aggregate type. Shape, surface texture, durability and others are factors defining aggregate type, a recent study relating the number of load repetitions to failure with mix properties has demonstrated that the type of the aggregate has important consequences on fatigue life of asphalt concrete [5].

They asserted that mixes composed of crushed stone have better fatigue life than those composed of crushed gravel. Also, the rutting resistance of a mix increases as the nominal maximum size of the aggregate increases. Larger stones can possess greater stability, and therefore may cause an asphalt mixture to be less susceptible to failure by rutting.

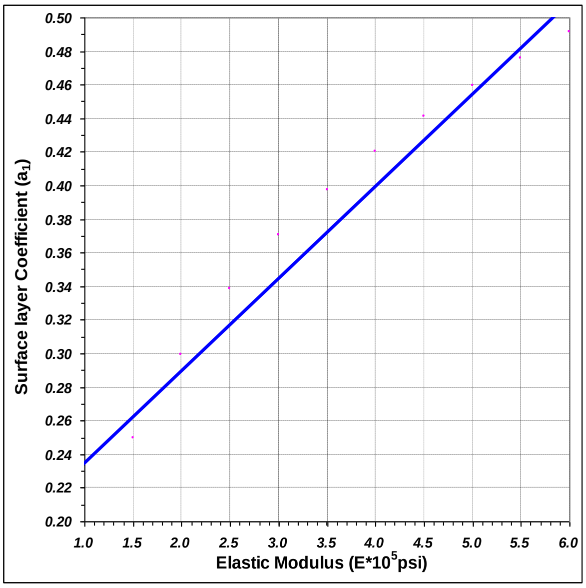

Figure 1. Correlation between mix modulus of elasticity and surface layer coefficient [3]

IV. The Predictive Model of Mix Properties

The properties of the surface course material are reflected in the AASHTO pavement design method through one variable called layer coefficient (a). This coefficient varies from 0.20 to 0.44 depending on quality and type of asphalt mix. Based upon the NCHRP (The National Cooperative Highway Research Program in USA) evaluation study of AASHTO design guide [11], a correlation between layer coefficient (a_1) and elastic modulus (E) has been proposed from a combined analysis of individual state highway results and theoretical analysis as illustrated in Fig. 1.

A mathematical model correlating the mix properties to its elastic modulus has been developed for use in the asphalt institute thickness design method [10]. The model was based on measuring the modulus of elasticity of 369 asphalt concrete specimens made from crushed stone aggregates mixed at optimum asphalt content. However, the model has recently been refined to include wider range of mix properties [9].

The latest model form was based on 1179 points and had coefficient of determination (R^2) of 0.891. This excellent result created a highly accurate predictive equation that can reflect the properties of asphalt mix with only one dependent value, the model can be reduced for a temperature of 20°C and a load frequency of 1.0 Hz to be:

$$\text{Log}(E) = 6.486 + 0.029(P_{200}) - 0.035(V_v) + 2077(\text{Pent})^{-2.19} - 0.457(P_{ac} - P_{opt.} + 4.0)^{0.5} \quad (1)$$

where:

E = Elastic modulus in psi,
P_{200} = Percent material passing #200 sieve,
V_v = Percent air voids in mix,
Pent = Penetration of asphalt cement in (1/100) units,
P_{ac}= Percent asphalt content by weight of mix and
$P_{opt.}$= Percent Opt. Asp. Cont. by Marshal test.

Hence; the major properties of the finishing mix can be reflected by one value, elastic modulus (E), which in turn, can be used to determine any change in the pavement serviceability.

V. Analysis Assumptions and Approaches

In this analysis, the following assumptions were made:

- Subgrade, subbase and base course are matching the design requirements, since any defect in any of these layers can be easily treated during construction.
- The pavement is designed to serve an initial annual number of 18-kips (80kn) single axle load with repetition of (N_o).
- The growth of the axle load over a time period of (T-years) is at a rate of (i) before it reaches the recommended minimum serviceability index (PSI=2.0).
- The pavement that has a minimum serviceability index (PSI=1.5, which is the least accepted by ECP) is not worth zero cost value.

Thus, for a given pavement and based on the AASHTO method of design, a correlation between the total number of repetitions (N) and pavement variables (AASHTO typical design equation)can be reduced to the following equation: [4]

$$\text{Log}(N) = -0.43 + 9.36 \log(SN+1) + \{[\log(4.2-PSI)/2.7] / [0.4+(1094/SN+1)^{5.2}]\} \quad (2)$$

where:

N = Total number of repetitions,

SN = Structure number of pavement,

$= a_1 d_1 + a_2 d_2 + a_3 d_3,$

PSI= Present serviceability index

In equation (2), a reliability level (R) is selected depending on the functional classification of the road and was given a value of 75% and relevant standard normal deviation (Z_R) of -0.674 which were believed to reflect the environmental conditions in Egyptian Delta region. Also a soil CBR value of 5.0 was considered reasonable for non-stabilized clay present in Delta region.

Therefore; for a given pavement structure that is designed to carry a limited number of equivalent load repetitions (N) during a time (T), the relation between the serviceability index (PSI) and time (T) in years can be drawn as shown in Fig. 2 -curve-I . The pavement under evaluation will reach the minimum value of serviceability, (PSI=2.0), after a time (t) less than the design time (T) as shown in the same Figure-curve–II. The dashed area shown in the figure represents the lost serviceability over time which will be experienced by road users. If this imaginary area can be represented by cost units, a reasonable and rational pay adjustment or penalty factors can then be developed.

VI. Proposed Maximum Penalty (Pmax)

Assuming we have two pavements, both hold exactly the same structural components; however, one of them is new, i.e., it has serviceability index (PSI=4.2) and the second is old and has already reached the minimum serviceability (PSI=2.0). To upgrade the old pavement to its initial serviceability (PSI=4.2), overlay is needed to be added so that structure number (SN) is shifted back to its original value. The cost of upgrading the old pavement is equal to the maximum penalty (P_{max}) that a contractor should be charged for. A proposed method for computing maximum penalty is summarized herein.

For perfectly constructed pavement that was designed to have structure number (SN_p), then:

$$SN_P = a_1 d_1 + a_2 d_2 + a_3 d_3 \quad (3)$$

If this pavement has been used until serviceability of (PSI=2.0) is reached, before being overlaid to gain a structure number (SN_o) therefore;

$$SN_o = a_1 d_o + a_2 (d_1 + d_2) + a_3 d_3 \quad (4)$$

where:

d_o = thickness of overlay

Equating SN_P to SN_o or equation 3 to equation 4, then,

$$d_o = d_1 [1-(a_2/a_1)] \quad (5)$$

In developing equation: (4), (5), it was assumed that the old surface course layer would be considered as an additional base course with a layer coefficient of a_2.

The total cost of overlay (C_o), allowing 20 percent extra cost for batching and preparing old surface will therefore be:

$$C_o = 1.2\, C_s\, d_1 [1-(a_2/a_1)] \quad (6)$$

where:

C_s = unit thickness cost of surface layer.

Hence, the cost of overlay that the contractor will be obliged to pay under the assumption of this analysis (C_o) is equal to the maximum penalty (P_{max}).

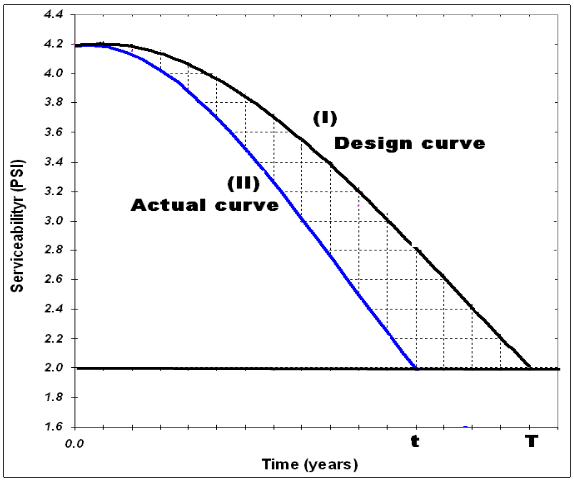

Figure 2. Change in Serviceability (PSI) over Time in years using AASHTO procedures

VII. Pay Adjustment Procedures

It is proposed that the pay adjustment can be applied as a penalty that a contractor has to pay to compensate the user for the loss of serviceability experienced during the pavement design life. The concept is that the pavement constructed within design thickness and mix specifications are accepted with full payment. A deviation, from mix specifications and/or design thickness may reduce the level of service offered to user overtime, as illustrated in Fig. 2. Therefore; a new term is introduced in this study called the "integrated time service (ITS)". The (ITS) is defined as "the area under the service-time curve between PSI=4.2 and PSI=2.0". In a mathematical form, the integrated time-service (ITS) can be represented by;

$$ITS = \int_{t=0}^{t=T} \int_{PSI=2}^{PSI=4.2} d(psi)\,.\,dt \quad (7)$$

For design period (t) an initial annual number of load repetitions (N_o), a traffic growth rate (i) and design structure number $(SN)_d$, the integrated time service (ITS) will have its design value. When the ITS equal to its design value the pay adjustment factor will be equal to unity, or the penalty is zero. However; the ITS will be zero if the constructed pavement has deviation from the design specifications so that its serviceability is minimum, i.e.; PSI=2.0.

Therefore, any pavement with an Integrated Time Service of $(ITS)_{act}$, has a penalty (P) that can be computed as follows:

$$P = K.\ P_{max} \quad (8)$$

where:

K = penalty coefficient

$$= [(ITS)_{des} - (ITS)_{act}] / (ITS)_{des} \quad (9)$$

Application Example: Fig. 3 shows the service time curves for a pavement which was assumed to have a design structure number (SN=3.6) as well for the same pavement when its structure number was reduced. Detailed data for each one curve are also given in Table I for comparison.

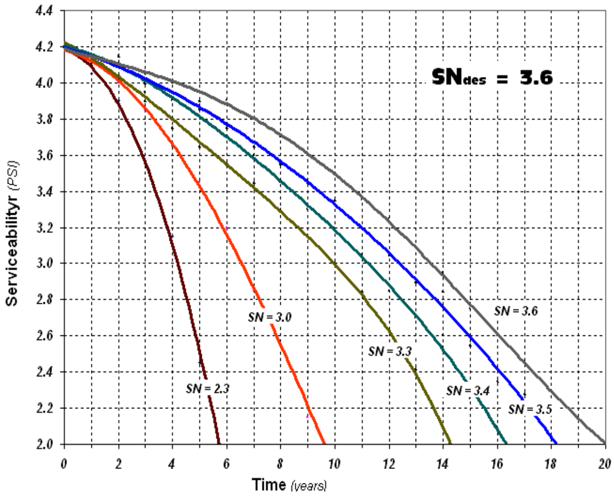

Figure 3. Effect of pavement structure number (SN) on Serviceability (PSI) over Time (T)

TABLE I. SUMMARY OF THE EXAMPLE DATA

Present (SN)	Life time (t-years)	ITS	K	Serviceability model (PSI)
3.6	20.0	24.48	0.000	$4.2-0.78(1.08^t-1)^{0.80}$
3.5	18.1	22.67	0.088	$4.2-0.86(1.08^t-1)^{0.85}$
3.4	16.2	20.50	0.175	$4.2-0.97(1.08^t-1)^{0.90}$
3.3	14.5	18.47	0.256	$4.2-1.11(1.08^t-1)^{0.96}$
3.0	9.5	12.80	0.483	$4.2-2.00(1.08^t-1)^{1.22}$
2.3	5.6	8.14	0.670	$4.2-5.94(1.08^t-1)^{1.63}$

The example assumes growth rate of 8.0 percent
ITS=Area under time serviceability curve (2 PSI 4.2)
K=Penalty Coefficient

It can be noticed that a reduction in the pavement structure number from SN=3.6 to SN=3.5 results in reducing its design life from 20 to about 18 years. In addition, the serviceability, as measured by PSI, is less than expected during all reduced time of 18 years using proposed method, it was found that contractor should pay a penalty of ***9%*** of the maximum penalty (P_{max}) as compensation.

Assuming a 10cm thickness surface course of a design layer coefficient a_1=0.440 then; a reduction of 0.10 in SN will happen when a_1 is reduced to a value of 0.415. This reduction can be the result of an *increase* of percent air voids of 1.0 percent, *decrease* in the percent filler of 1.35 percent, or any other equivalencies of combined deviations.

As shown in Fig. 4 the correlation between the penalty coefficients (K) and the structure number of pavement is a linear correlation. The slope of this line is equal to difference between the minimum and design structure number, i.e. [slope = $(SN_{min} - (SN)_{des}]$, this finding will facilitate the use of the proposed method.

Knowing $(SN)_{des}$, it needs only to compute the $(SN)_{act}$ using equation (1) and Fig. 1 as well $(SN)_{min}$; or structural number of the pavement when the surface layer has a coefficient equivalent to base course layer coefficient (a_2), a relation similar to that shown in figure (4) is drawn and penalty coefficient can be found. Knowing the penalty coefficient, the total penalty can be calculated as given in previous section.

Computing the penalty using the above discussed method is considered a rational way of compensating the users for serviceability they are going to lose over time.

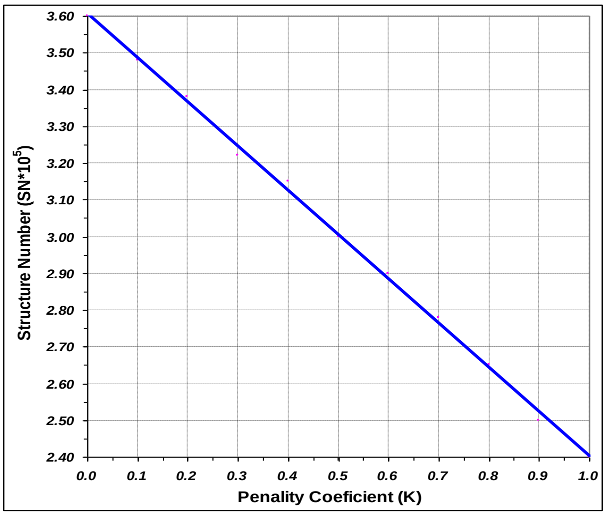

Figure 4. Structure number (SN) versus penalty coefficient (K)

VIII. CONCLUSIONS

1) Initial deviation of surface mix properties from specification can cause a high reduction in the pavement's serviceability over time.

2) Deviation of percent of air voids in HMA should be incorporated in evaluation of the flexible pavement wearing surface beside the other factors that currently considered.

3) Pay adjustment using the maximum penalty value as a reference is based on a sound engineering principles and penalty computed using the proposed method represents the actual compensation for a lower service during pavement's life time.

4) Although applying this technique may result in higher or lower penalty values than the methods currently used, it is offering a fair compromise for both government agencies and contractors.

5) A more practical pay adjustment method can be settled if a relation between serviceability index (PSI) and the present worth of pavement's rehabilitation cost is developed.

REFERENCES

[1] National Cooperative Highway Research Program, Research Results Digest 371, 2013.

[2] R. M. Weed, "Practical framework for performance related specifications," *Transportation Research Record: Journal of the Transportation Research Board*, no. 1654, pp. 81–87, 1999.

[3] W. N. Carey and P. E. Irick, "The pavement serviceability performance concept," *Highway Research Bulletin 250*, 1960.

[4] AASHTO, "Guide for design of pavement structures," Washington D.C, Association of State Highways and Transportation Officials 1986, pp. 157, 1993.

[5] P. Paungchit, R. G. Hicks, J. E. Wilson, and C. A. Bell, "Development of rational pay adjustment factors for asphalt concrete," *Transportation Research Record 911*, pp. 70-79,1983.

[6] C. R. Foster, "Development of marshall procedures for designing asphalt paving mixtures," NAPA Report IS-84. National Asphalt Pavement Association, Landham, Maryland, 1982.

[7] National Study of Rutting in Hot Mix Asphalt Pavements, NCAT Report 92-5, National Center for Asphalt Technology, Auburn, Alabama, 1992.

[8] R. M. Anderson and R. A. Bentsen, "Voids in the mineral aggregate (VMA) on the mechanical properties of coarse and fine asphalt mixtures," *Journal of the Association of Asphalt Paving Technologists*, vol. 70, 2001.

[9] J. S. Miller, J. U. Uzan, and M. W. Witczak, "Modification of asphalt institute bituminous mix modulus predictive equation," *Transportation Research Record 911*, pp.27-36, 1983.

[10] *Research and Development of Asphalt Institute's Thickness Design Manual*, The Asphalt Institute College Park, MD, Research Series 2, 1982.

[11] C. J. van Til, B. F. McCullough, B. A. Vallerga, and R. G. Hicks, "Evaluation of AASHTO interim guide for design of pavement structure," NCHRP, Rept.128, 1972.

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