RELIABILITY OF FLEXIBLE HIGHWAY PAVEMENT SYSTEM IN SAUDI ARABIA

Abdulrahim M. Arafah

Civil Engineering Department, College of Engineering,
King Saud University, Riyadh, Saudia Arabia.

ABSTRACT

This paper presents an approach to evaluate the process standard deviation for the design of flexible pavements in Saudi Arabia as defined in AASHTO Guide 1986 and 1993 taking into consideration the local conditions of construction experience and traffic. This involves using a first order variance analysis as a procedure to determine the overall standard deviation. The study includes three major steps: (1) determination of the variability in pavement strength parameters, (2) determination of the variability in traffic load characteristics, and (3) determination of the process standard deviation. The process standard deviations are recommended to be 0.76, 0.63 for thin and thick pavements respectively. The AASHTO overall standard deviation is 0.49. Results indicate that due to the local construction experiences, materials and traffic in Saudi Arabia the process standard deviations for the design of flexible pavement systems are higher than the value proposed by the AASHTO Guide.

Keywords: Flexible Pavement, Pavement Design, Reliability, Safety Factors, Traffic loads, Pavement subgrade, Structural number.

1. BACKGROUND

1.1 Definitions

Reliability concepts were included in the 1986 and 1993 versions of the AASHTO Guide [1] for Design of Pavement Structures. Reliability of a pavement design during a performance period is the probability that a pavement section designed will perform satisfactorily under the prevailing traffic and structural conditions during the design period.

The performance of a pavement is measured by the present serviceability index, PSI. The value of PSI depends upon the extent of surface roughness and manifestation of distress and faulting (roughness, rutting, cracking and patching) over the length of the design section. The initial PSI is between 4.5 and 5.0 [1].

The failure of a pavement section occurs when PSI reaches a specified terminal serviceability index P_t(usually between 2.0 and 2.5). Fig. 1 shows a relationship between the actual PSI and time expressed in terms of the actual accumulated equivalent single axle load ESAL.

1.2 AASHTO Design Equation

The AASHTO design equation allows for the prevailing local conditions and parameters variability to be represented in the equation by the overall (process) standard deviation, S_o, as follows,

$\log w_T = Z_R S_o + 9.36 \log(STN+1) - 0.2 +$ خطأ! $+ 2.32 \log MR - 8.07$

where

$\log w_T$:	estimated total 18-kip equivalent single axle load (ESAL) application,
Z_R:	standard normal variate,
S_o:	the overall standard deviation,
STN:	the design structural number,
P_I:	the initial serviceability index,
P_t:	the terminal serviceability index,
MR:	the subgrade resilient modulus.

1.3 Prediction Errors

Fig. 2 shows the distributions of performance prediction error $\delta(N_t W_t)$ and the traffic prediction error $\delta(N_T w_T)$ where

$$\delta(N_t W_t) = \log N_t - \log W_t \quad \text{and}$$

$$\delta(N_T w_T) = \log w_T - \log N_T$$

where the parameters N_t, W_t , w_T and N_T are as defined in Fig. 2.

The variances of $\delta(N_t W_t)$ and $\delta(N_T w_T)$ are designated as $S^{2,N}$ and $S^{2,W}$ and known as the pavement performance prediction variance and the traffic prediction variance, respectively.

1.4 Process "Overall" Variance

The overall deviation, δ_o, is defined as,

$$\delta_o = \log N_t - \log N_T$$

The mean overall deviation of the actual section performance from the design period traffic is given by

$$\overline{\delta}_o = \log W_t - \log w_T$$

The overall variance of the pavement design performance, $S^{2,o}$, is the variance of the δ_o. It is the sum of the pavement performance prediction variance, $S^{2,N}$, and the traffic prediction variance in terms of equivalent single axle load (ESAL) application, $S^{2,W}$, such that:

$$S^{2,o} = S^{2,N} + S^{2,W}$$

The density function of the overall deviation, δ_o, is assumed as normal distribution as shown in Fig. 3.

1.5 Reliability Design Factor

The design reliability level of a pavement is the probability that δ_o equal or greater than zero, as shown in Fig. 2, i.e.

$$R(\text{percent}) = 100 * \Pr(\delta_o \geq 0)$$

The design safety factor, F_R , is the ratio of W_t to w_T . The safety factor depends on the target reliability level and the overall process standard deviation and is given as,

$$F_R = 10^{-Z_R * S_o}$$

AASHTO Guide suggests several levels of reliability for various highway classifications as shown in Table 1.

2. OBJECTIVES

The Guide recommends to estimate S_o value based on the local conditions and experiences. Conditions and experiences that were prevailing in the AASHTO road test suggest that S_o is about 0.49 for flexible pavements. These conditions may be completely different from those prevailing in the Saudi Arabia. A need existed to initiate a research study to thoroughly investigate and estimate the process standard deviation S_o for the local traffic, material and construction experience.

The objectives of this study are to establish the variability in pavement and traffic characteristics for flexible pavements and to determine the overall standard deviation, S_o , for various regions in Saudi Arabia.

3. PAVEMENT DATA AND ESTIMATION OF $S^{2,N}$

3.1 Pavement Data

The approach for the investigation of material parameters (MR and STN) was based on the in-situ material characterization approach using nondestructive deflection testing, employing the Falling Weight Deflectometer [2,3,4].

The thirteen highway districts in Saudi Arabia were grouped into four major regions. Independent roadway sections that have 10 km of length were selected from main roadways which provide a comprehensive coverage for the 13 Kingdom's district. The number of selected sections was 390 from which 21 falling weight deflectometer measurements, every 500 meter, were taken within each section. More than 8000 data locations were obtained . These sections were then classified into groups of similar structural levels (Structural Number, STN). In order to ensure obtaining independent sections, sections within the same structural group (in the same range of structural number) were selected such that they are not adjacent. For each pavement section, site tests of the pavement material parameters (subgrade resilient modulus, MR, and structural number ,STN) were conducted [5].

3.2 Analysis of Pavement Data

For each pavement section, the statistics (mean, standard deviation and coefficient of variation) of the pavement parameters (subgrade resilient modulus, MR, and structural number, STN) were computed.

The C.O.V. of MR ranges between 9.7% to 51.3% compared to a typical value of 15% at the Road Test. Results suggest that the computed MR are higher than the MR at the AASHTO Road Test, however, the computed variability in MR is larger than in the AASHTO Road Test.

The C.O.V. of STN ranges between 5.5% to 22.9% compared to a typical value of 10.4% at the AASHTO Road Test. Results suggest that thick pavement (STN equal or greater than 4) have relatively lower variability compared to the variability reported at the AASHTO road test whereas thin pavements (STN lower than 4) exhibit relatively larger variability as compared with that reported in the AASHTO Road Test.

3.3 Estimation of $S^{2,N}$

The statistics of pavement parameters were then used to estimate the standard deviation of predicted pavement material performance, S_N, according to the following steps:

1. determine the pavements sections having an average structural number STN in the ranges of 2 - 4, 4 - 6 and 6 - 8 and assign these sections as STN = 3, 5, and 7,
2. compute the variance of predicted pavement performance $S^{2,Nrf}$ using the first order analysis of variances, and
3. compute the variance of predicted pavement performance $S^{2,N}$ by adding the unexplained and lack-of-fit material variances of the AASHTO model as follows:

$$S^{2,N} = S^{2,Nrf} + S^{2,Nru} + S^{2,NL}$$

where $S^{2,Nru} = 0.0113$ and $S^{2,NL} = 0.0763$ according to AASHTO Guide.

Table 2 presents a summary of the regional variation of S_N values for various STN levels together with the value recommended by the AASHTO Design Guide.

3.4 Pavement Variances Equality Tests

The equality of variances was then test to investigate the possibility of pooling these values. The Bartlett Test [6] was employed for the variances equality tests which can be employed for three or more populations with equal or unequal sample sizes. For two populations "F" Test is the standard test for checking the variances equality. Results indicated that :

1. there were no significant regional differences among the variances of the same STN, at 5 percent significance level, therefore S_N values were pooled to 0.69, 0.57 and 0.53 for STN levels of 3, 5 and 7 respectively,

2. the variances at the three levels of STN are not equal at 5 percent significance level.
3. the variances at the STN=5 and 7 are equal and can be pooled to $S_N = 0.55$.

The recommended values of S_N for Saudi Arabia were reduced to 0.69 and 0.55 for thin and thick pavements respectively indicating that thin pavements exhibit larger variability than thicker pavements. AASHTO Guide recommends 0.44 for both thick and thin pavements.

4. TRAFFIC DATA AND ESTIMATION OF $S^{2,W}$

4.1 Traffic Data

The general equation used to calculate the accumulated 18-kip ESAL is given as,

$$w_T\,(ESAL) = 365 * n * ADT * D_d * GF * \text{خطأ!}$$

where

n: number of years of the design period

m: number of truck types considered in the design

ADT: Average Daily Traffic using the facility and is typically calculated by dividing the total number of all vehicles using the facility in one year by 365.

D_d: directional distribution and is equal to the percent of the ADT in the heavier direction

GF: growth factor and is used to convert the current EAL to the accumulated EAL during the design period. GF depends on the design period and the growth rate.

P_i: percent of i^{th} truck type in the traffic mix.

L_i: lane distribution factor of the i^{th} truck type and is equal to the percent of i^{th} truck type in the design lane. Design lane is the lane with highest percent of trucks, typically the right lane.

TF_i: Truck factor of the i^{th} truck type and is defined as the number of ESAL applied by each truck.

Traffic parameters were obtained out of the traffic count and classification and weigh stations. The main purpose of collecting data on traffic is to investigate the variability of the 18-kip Equivalent Single Axle Load (ESAL) applications. To do so, detailed traffic data were gathered and analyzed to identify the types of vehicles using the road network [5]. Data from twenty four traffic count stations and eighteen weigh stations was employed in the study.

4.2 Analysis of Traffic Data

The traffic counts and classifications from count stations were used to estimate the variability in ADT, P_i, L_{di} whereas records of axle weight stations were used estimate the variability in TF_i.

Only four truck classes were selected to be used in the analyses. The four truck classes are shown in Figure 3. It was found that these four classes represent more than 95% of the total truck traffic, and the equivalent single axle load (ESAL) repetitions produced by these types constitute more than 97% of the total ESAL.

The analysis of traffic data includes the following steps,

1. determine the statistics of the traffic parameters (ADT * D_d, P, and L_d) at each traffic classification location,
2. determine trucks factors TF at each truck weigh Station,
3. determine the weighted values of traffic parameters for each traffic classification and truck weight location, and
4. determine the weighted values of traffic parameters for each region using all the traffic classification and truck weight locations within that region.

4.3 Estimation of Traffic Variance, $S^{2,w}$

The standard deviation of traffic prediction, S_W , can be estimated in accordance to the following steps:

1. compute $S^{2,wrf}$ which is the variance of log ($\sum$ESAL) using the first order analysis of variances [1],
2. compute the standard deviation of traffic prediction $S^{2,w}$ by adding the unexplained and lack of fit variances of the AASHTO design equation as follows,

$$S^{2,w} = S^{2,wrf} + S^{2,wru} + S^{2,wL}$$

where $S^{2,wru}$ = 0.0025 and $S^{2,wL}$ = 0.0066 according to AASHTO Guide [1].

The variability analyses of different traffic parameters were used to determine the total traffic variability and estimate S_W. The recommended values for the four regions are 0.30, 0.29, 0.34 and 0.32, respectively.

4.4 Traffic Variances Equality Tests

Bartlett Test was conducted to check the equality of these variances at 5% significance level. The pooled value is 0.31 whereas the recommended values by AASHTO is 0.21.

5. Estimation of the Overall Standard Deviation, S_o

The computed S_o values are 0.76 and 0.63 for thin and thick pavements respectively. High S_N values obtained for thin pavements resulted in higher S_o values compared to thick pavements. These values are higher than 0.49 the AASHTO suggested value.

In order to show the significance of these values in pavement design in saudi Arabia, let us design a thin pavement for a mean service lifetime of 20 years and a reliability level of 80%. Employing the recommended and AASHTO values of S_o=0.49, the mean life time will be 11.8 years which is much lower that the target value. The design value can be considered to be 20 years with reliability level of 70%.

Employing the same conditions for a thick pavement the actual design period is 15.22 years instead of 20 years. The design value can be considered to be 20 years with reliability level of 75%.

6. CONCLUSIONS

The following conclusions can be drawn from the study for Saudi Arabia,

1. Mean values of subgrade resilient modulus are higher than those obtained from AASHTO Road Test . However, the computed variability in subgrade resilient modulus is larger than that obtained from the AASHTO Road Test.
2. Thick pavements (structural number equal to or greater than 4.0) have relatively lower variability compared to the variability reported at the AASHTO Road Test. This is not true for thin pavement (structural number lower than 4.0).
3. The computed values of standard deviation of pavement performance, S_N, are 0.69 and 0.55 for thin and thick pavements, receptively, which are larger than 0.44 the value recommended by AASHTO.
4. The computed value of standard deviation of traffic prediction is 0.31 whereas the recommended value by the AASHTO Guide is 0.21.
5. The recommended values of S_o are 0.76 and 0.63 for thin and thick pavements respectively. These values are higher than 0.49 the AASHTO suggested value.
6. Low reliability levels of flexible highway pavement are expected in Saudi Arabia by employing the AASHTO process standard deviation.

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Table 1 Reliability Levels Suggested in AASHTO Pavement Design Guide

Functional Classification	Recommended Level of Reliability	
	Urban	Rural
Interstate and other freeways	85 - 99.9	80 - 99.9
Other Principal Arterials	80 - 99	75 - 99
Collectors	90 - 95	75 - 95
Local	50 - 80	50 - 80

Table 2 Computed S_N Values versus AASHTO Recommended Value

STN	Region I	Region II	Region III	Region IV	AASHTO
3	0.74	0.69	0.66	0.74	0.44

5	0.64	0.56	0.55	*	0.44
7	0.53	0.56	0.63	*	0.44