Development of a Permanent Deformation Model of Asphalt Mixtures for Korean Pavement Design Guide (KPDG)

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1. INTRODUCTION

Korea has been developing a new Korean Pavement Design Guide (KPDG) (1) as a part of Korean Pavement Research Program (KPRP). The basic design approach of the KPDG is based on the mechanistic-empirical approach with a cumulative damage concept. The overall design approach of the KPDG is quite similar with AASHTO 2002 design guide. More detailed information about the KPDG program can be found elsewhere (1).

Since the accurate prediction of permanent deformation for asphalt mixtures is one of the key elements for the development of the KPDG, a permanent deformation model of asphalt mixtures was developed in this study. The material, traffic, and environmental conditions are the most important design parameters. Thus, three important model parameters, such as air voids of asphalt mixtures, temperatures, and number of load repetitions, were selected and how these parameters affect to the permanent deformation of AC was studied based on the laboratory tests. The basic form of the permanent deformation model was then established. The form of the model is the same as the classical power law model which is based on resilient strain. The triaxial repeated loading tests for various types of asphalt mixtures were conducted under different temperature and loading conditions to determine the model coefficients.

The permanent deformation model coefficients were first calibrated using an Accelerated Pavement Test (APT) data and then re-calibrated using a Long Term Pavement Performance (LTPP) database. Two different APTs were used in the calibration. Since the only temperature and loading conditions were controlled in the APTs, the measured data from the APTs were utilized to calibrate the relationship among the number of load repetitions, temperature and plastic strain.

During the calibration process of the model coefficients using the LTPP database, it was found that there was a need to employ a correction factor in the model. This correction factor is to take care of the effects of different AC layer thicknesses on the permanent deformation.

2. PERMANENT DEFORMATION MODEL FOR KPDG

Various types of model to predict the permanent deformation of asphalt mixtures have been developed. Among those models, the power law model is one of the most popular models as shown in Equation 1. This model assumes

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that the resilient strain is constant and independent of the number of load repetitions. The term “a” in Equation 1 can be described as a function of load level, mixture properties and other factors that may affect the permanent deformation characteristics of asphalt mixtures. This model was adopted in the MEPDG as a permanent deformation model of asphalt mixtures (2).

$$\frac{\varepsilon_p}{\varepsilon_r} = a * N^b * T^c \qquad (1)$$

where ε_p = accumulated plastic strain at N repetitions of load,
ε_r = resilient strain of the asphalt mixture,
T = temperature (℃),
N = number of load repetitions, and
a, b, c = model coefficients determined from laboratory tests.

Based on the triaxial repeated loading test results for various asphalt mixtures with different loading and temperature conditions, Park et al. (3) proposed Equation 2 for a permanent deformation model of asphalt mixtures in KPDG.

$$\frac{\varepsilon_p}{\varepsilon_r} = a * N^b * T^c * AV^d \qquad (2)$$

where AV = initial air void (%).

To apply the rutting model with coefficients determined from laboratory tests to the pavement in-service, it is necessary to calibrate the laboratory-based model. The calibration factors and correction factors are added to Equation 2 to establish the permanent deformation model of asphalt mixture as follows:

$$\frac{\varepsilon_p}{\varepsilon_r} = k_{sf} k_{AC} \beta_1 a N^{\beta_2 b} T^{\beta_3 c} AV^{\beta_4 d} \qquad (3)$$

where $\beta_1, \beta_2, \beta_3, \beta_4$ = calibration factors,
k_{AC} = correction factor, and
k_{sf} = shift factor.

The proposed permanent deformation model was calibrated and corrected through following steps:

1. Calibration: determine calibration factors β_i in order to minimize discrepancy between prediction from the permanent deformation model and measurement from APTs.

2. Correction:

- Determination of correction factor for total AC layer thickness (k_{AC})
- Determination of shift factor k_{sf} to minimize discrepancy between predicted and measured values.

It is noted that APT and LTPP data obtained from the field are limited to the dense graded asphalt mixtures with maximum aggregate sizes of 19 and 25mm and PG 64-22 asphalt binder that are the most typical mixture types in Korea for AC surface and base layers, respectively. Therefore, the model coefficients for only those two mixtures as in Table 1 are calibrated and corrected.

3. CALIBRATION OF THE MODEL USING APT DATA

To calibrate the permanent deformation model in Equation 2, two different APTs were performed by Hanyang University and Korea Expressway Corporation (EX) (4). The predicted permanent deformation and measured values were compared and total error was calculated. Using an error minimization technique, the calibration factors β_i were determined and provide in Table 1. As can be seen in this table, model coefficients for temperature and air void (i.e., c and d in Table 1, respectively) obtained from the laboratory tests may not need any calibration for fitting APTs data. However, the model coefficient for number of load repetition, b, should be increased by 3.4 times. This might be mainly due to the fact that the loading conditions between laboratory and APT are not the same. In addition to the coefficient b, the coefficient a also need to be calibrated.

TABLE 1 Calibration Factors and Coefficients of Model

Layer	Mixture Type	β_1	β_2	β_3	β_4	a	b	c	d
AC Surface	19mm +PG 64-22	0.00026	3.4	1	1	12.794	0.185	0.708	0.688
AC Binder and Base	25mm +PG 64-22	0.00174	3.4	1	1	30.479	0.159	0.603	0.116

4. CALIBRATION OF THE MODEL USING LTPP DATA

4.1 Information of LTPP Data

Table 2 presents the general information of LTPP data that was used in the calibration of the permanent deformation model proposed in this study. The LTPP data was obtained from General Pavement Study (GPS) sections operated by Korean Institute of Construction Technology (KICT). Total 10 different sections were selected from the GPS sections considering weather and traffic conditions, and pavement thicknesses. Any major rehabilitation has not been performed to all the LTPP sections. Pavement condition evaluation has been conducted two times in the year of 2006 and 2007, respectively, using an automated condition survey vehicle, ARAN. In 2006, field cores were taken from every section to measure physical properties.

Some of the important physical properties are provided in Table 2. In this table, the asphalt contents are assumed values because it was found from laboratory tests that the measured asphalt contents of the field cores based on ASTM D6307 – 05 were not accurate enough to be used (5). In addition, the grade of asphalt binder was assumed PG 64-22 because this binder grade is the most popular one in South Korea. Using the physical properties obtained from the field cores, dynamic modulus values were predicted from a prediction model proposed by the KPDG (6). This dynamic modulus prediction model is almost the same as Witczak’s model (7) except that it is calibrated with Korean asphalt mixtures. It should be reminded here that the air void in Equation 3 is an initial air void. Thus, 4% of air void was added to the air void values in Table 2 to simulate the initial air void conditions in the field.

The LTPP data described above was used in the prediction of rut depth for the LTPP sections. The rut depth prediction was conducted using the KPDG program (1) with the permanent deformation model proposed in this study. In the rut depth prediction, elastic modulus and Poisson’s ratio values for subbase and subgrade were assumed for typical values used in Korea. They were 92MPa and 0.35 for subbase and 120MPa and 0.4 for subgrade. Since the permanent deformation models for the subbase and subgrade have not been developed yet for the KPDG, those models proposed by the MEPDG (2) were employed in the analysis.

TABLE 2 Information of LTPP Sections

Section ID	Layer	Thick. (cm)	Max Agg. Size (mm)	Air Void (%)	Asphalt Content (%)	Weather Station	Initial AADT	Growth Rate (%)	Analysis Period (Year)
G1121	Surface	13	19	4.0	5.2	Haenam Mokpo Gwangju	10433	1.3	10
	Base	20	25	6.0	4.5				
	Subbase	40	–	–	–				
G1122	Surface	10	19	2.0	5.2	Haenam Mokpo Gwangju	13518	0	7
	Base	20	25	6.0	4.5				
	Subbase	20	–	–	–				
G1211	Surface	5	19	4.0	5.2	Haenam Mokpo Gwangju	5912	0	9
	Base	15	25	6.0	4.5				
	Subbase	40	–	–	–				
G1212	Surface	10	19	2.0	5.2	Wonju Chongju Chungju	15450	0	10
	Base	20	25	2.0	4.5				
	Subbase	30	–	–	–				
G1221	Surface	10	19	2.0	5.2	Jeonju Jeongeup Kunsan	10326	0	8
	Base	20	25	4.0	4.5				
	Subbase	35	–	–	–				
G1222	Surface	10	19	2.0	5.2	Chuncheon Echeon Chungju	10756	0	10
	Base	15	25	6.0	4.5				
	Subbase	25	–	–	–				
G2111	Surface	5	19	4.0	5.2	Haenam Gwangju Wando	5233	10.4	10
	Base	15	25	6.0	4.5				
	Subbase	40	–	–	–				
G2112	Surface	10	19	6.0	5.2	Chuncheon Wonju Gangneung	10050	7.1	7
	Base	19	25	6.0	4.5				
	Subbase	45	–	–	–				
G2212	Surface	10	19	2.0	5.2	Chungju Jecheon Yeongju	4425	0	10
	Base	15	25	4.0	4.5				
	Subbase	20	–	–	–				
G2222	Surface	10	19	4.0	5.2	Seoul Incheon Seowon	8790	4.0	10
	Base	25	25	4.0	4.5				
	Subbase	25	–	–	–				

4.2 Correction for Vertical Strain Distribution

The authors believe that we do not need the correction for vertical strain distribution when the AC layer is treated as separate layers (i.e., surface and base).

A case study has been made to verify those mentioned above. The case study using KPDG model was performed with the same input data for various AC layer thicknesses. AC surface layer thickness of 5cm was kept constant for all the cases. Only the thickness of AC base layer was adjusted. The permanent deformation model in Equation 3 with calibration factors and model coefficients in Table 1 were used in this case study.

Figure 1 shows distribution of vertical permanent strain accumulated in a period of 20-years. Since the distribution of vertical permanent strain along depth seemed be similar with the correction factor k_z as the MEPDG has done, the current model doesn' t need a correction factor that stipulates distribution of vertical permanent strain. However, from Figure 1, AC thickness of 10cm shows accumulated permanent strain less than the other cases such as 20 and 35cm. This result is completely inversed with typical analysis results observed from the MEPDG. It is expected that the thinner AC layer may produce more permanent deformation than the thicker one in case of the same traffic, material and environmental conditions. The correction factor for total AC thickness is necessary for the proposed permanent deformation model. The correction for total AC thickness will be discussed in following section.

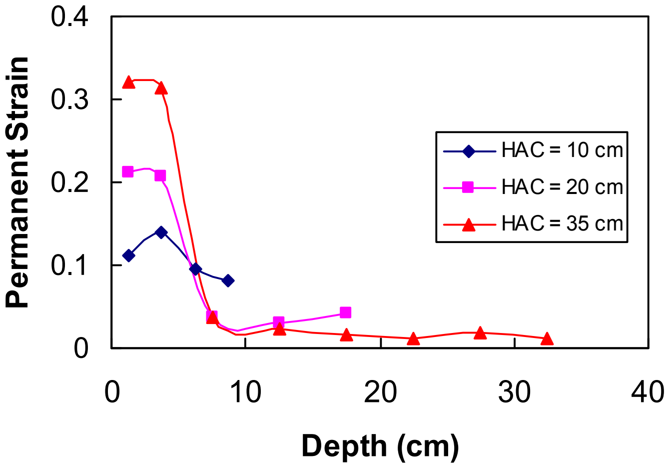

FIGURE 1 Distribution of vertical permanent strain obtained from the KPDG model.

4.3 Correction for Total AC Thickness

In this study, the correction for AC layer thicknesses has been performed. Because of the lack of measured field data, the correction values for the total AC thickness used in the MEPDG were adopted in this study with a slight modification. The modification was made by a comparison between the measured rut depths from the LTPP and predicted values. The rut depth prediction was conducted using the KPDG program (1) with the information provided in the previous section "Information of LTPP Data."

The correction factor k_{AC} for total AC layer(s) thickness proposed in this study is as follows:

$$k_{AC} = 0.167 \ln\left(\frac{39.2 - H_{AC}}{H_{AC} - 8.7}\right) + 0.483 \quad (10\,\mathrm{cm} \le \mathrm{H}_{AC} \le 35\mathrm{cm}) \tag{4}$$

where H_{AC} = the total thickness of the AC layer(s), and
k_{AC} = correction factor.

4.4 Shift Factor k_{sf}

Finally, the shift factor k_{sf} was determined by directly comparing the measured and predicted rut depth values. Several different values of the shift factor were assumed and, then, rut depth values were predicted. The shift factor of 0.2 was selected that produces the smallest error between the measured and predicted rut depths.

Figure 2 presents the comparison results between the measured and predicted rut depths. The prediction of rut depth was performed using the KPDG program with the fully calibrated and corrected permanent deformation model. As can be seen in Figure 2, the prediction result is pretty reasonable. Since the amount of field measured data is limited, a further study is required to validate the permanent deformation model proposed in this study.

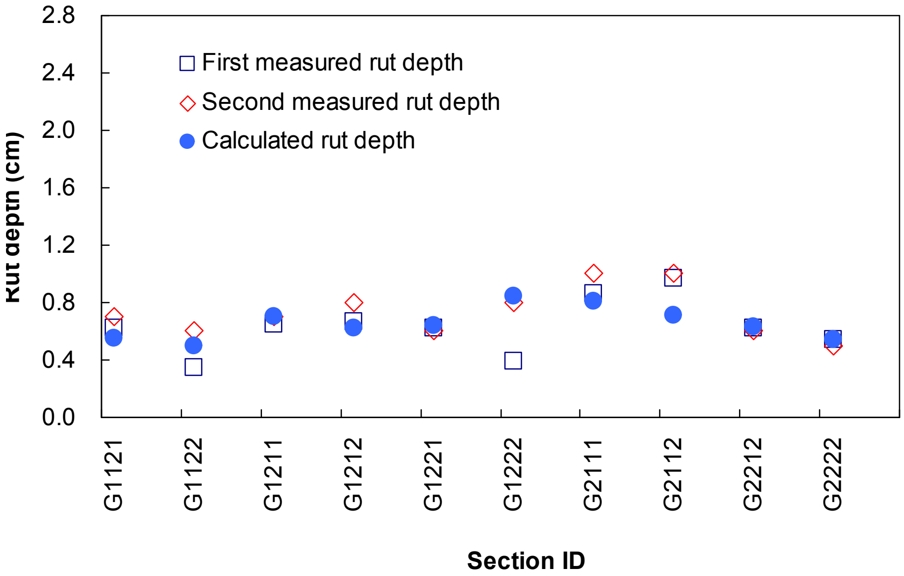

FIGURE 2 Comparison of rut depth obtained from LTPP measured data and estimation of KPDG permanent deformation model.

5. CONCLUSIONS

In this study, a permanent deformation model of asphalt mixtures has been developed through triaxial repeated loading tests to address the effect of temperature and air voids for various asphalt mixtures. The suggested model was first calibrated by comparison between measured APT data and the predicted values for the same APT pavement sections. It was observed from the calibration that the model coefficients for the temperature and air void obtained from the triaxial tests did not need to be calibrated. However, the model coefficients for the shift factor and number of load repetition should be calibrated.

The proposed model was further corrected using the LTPP data to consider the effect of AC layer thickness. Unlike the AASHTO MEPDG, the correction for the AC thickness was only required. By comparing the measured rut depth from the LTPP sections and predicted values from the KPDG program, the value of 0.2 was selected as a shift factor.

The finally calibrated and corrected model was able to predict field rut depth reasonably. However, a further calibration is required for the different asphalt binder types and aggregate gradations. Since the amount of field measured data is limited, a further study is required to validate the permanent deformation model proposed in this study.

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