Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 791 - 802, 2005

DETERMINATION OF THE LAYER THICKNESS FOR LONG-LIFE ASPHALT PAVEMENTS

Heemun Park
Senior Researcher
Korea Institute of Construction Technology
2311, Daehwa-Dong, ilsan-Gu, Goyang-Si, Gyeonggi-Do,
411-712 Republic of Korea
Fax: +82-31-9100-161
E-mail: hpark@kict.re.kr

Jewon Kim
Researcher
Korea Institute of Construction Technology
2311, Daehwa-Dong, ilsan-Gu, Goyang-Si, Gyeonggi-Do,
411-712 Republic of Korea
Fax: +82-31-9100-161
E-mail: jewonkim@kict.re.kr

Yeonbok Kim
Senior Research fellow
Korea Institute of Construction Technology
2311, Daehwa-Dong, ilsan-Gu, Goyang-Si, Gyeonggi-Do,
411-712 Republic of Korea
Fax: +82-31-9100-161
E-mail: hpark@kict.re.kr

Hyunjong Lee
Professor
Civil & Environmental Engineering
Sejong University
98 Gunja-Dong, Gwangjin-Gu, Seoul,
143-747 Republic of Korea
Fax: +82-2-3408-3332
E-mail: hlee@sejong.ac.kr

Abstract: This study is a part of research for developing the technologies of long life pavements having more than 40-year design life. The objective of this study is to develop the simplified design procedure for determining the layer thickness and modulus satisfying with long life pavements. A synthetic database was established using the finite element program of a pavement structure with various combinations of layer thickness and modulus. The synthetic database includes the structural and material information, surface deflection, and critical pavement responses. Using the developed synthetic database, this paper suggests the minimum layer thickness and modulus for long life pavements based on the limited strain level concept.

Results demonstrate that the pavement greater 410mm of total AC layer thickness is considered as the long life pavements regardless of the material characteristics and thickness in each layer. To become a long life pavement, a total thickness of AC layer should be greater than 250m. The design procedure for determining the thickness and modulus in each layer for pavement with AC layer thickness ranging from 250 to 410mm is also presented in this paper.

Key Words: Long Life Pavement, Limited Strain Level, Pavement Response Model

1. INTRODUCTION

Due to the high volume of traffic, increase of heavy vehicle, and environmental effects, the various types of distress such as fatigue cracking and rutting have been recently occurred in asphalt pavements. These distresses are associated with the structural deterioration causing the reduction of remaining life of pavements and increase of the rehabilitation and maintenance cost.

To overcome this situation, the long-life pavement has been introduced and studied by other researchers (Nunn *et al*., 1997, and Newcomb *et al*., 2001). By repairing and rehabilitating surface distresses periodically, the long-life pavement is capable of maintaining the pavement performance more than 40 years without any significant structural deficiencies or failures.

The objective of this study is to develop a simplified design procedure for determining the layer thickness and modulus to become long life pavements. The performance of a pavement structure is strongly dependent on the pavement responses and strength of the pavement layers. The critical pavement responses considered here include tensile strain at the bottom of asphalt concrete layer for fatigue cracking (ε_t) and compressive strain on top of the subgrade for rutting (ε_c). The thickness design procedure is based on limiting the critical pavement responses in pavement layers. A concept of endurance limit is used for developing the design procedure in this study.

2. SENSITIVITY ANALYSIS OF PAVEMENT RESPONSES

A typical structure of long life pavement is shown in Figure 1(Newcomb *et al.*, 2001). The asphalt layer is composed of three different layers including wearing course, intermediate layer, and base layer.

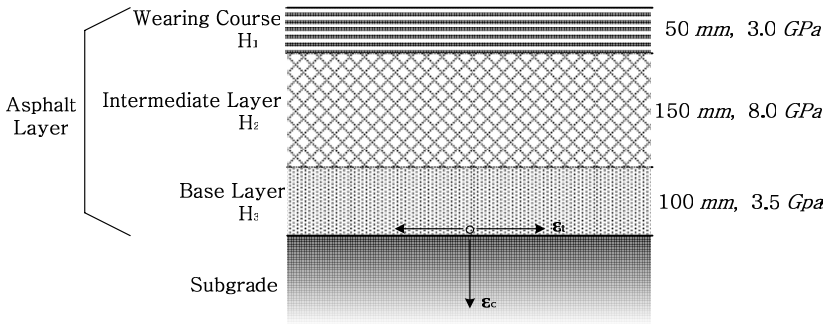

Figure 1. A Typical Structure of Long Life Pavement

Thorough the sensitivity analysis for pavement responses, the input variables mostly affecting the fatigue cracking and rutting were determined. In the sensitivity analysis, each of layer thickness and modulus in intermediate and base layer was varied one at a time from its assumed base value, while the other parameters were held at their corresponding base values. The change in the predicted critical pavement response due to a change in a given parameter was evaluated using the ILLIPAVE finite element program.
Because the mill and overlay process is applied to the wearing course at 5 to 10 year interval , this layer was excluded in this study and set to be 50mm of thickness and 3.0GPa of modulus.

2.1 Effect of Layer Thickness on the Pavement Response

The assumed base thicknesses in intermediate and base layer are 150mm and 100mm, respectively. Each layer thickness was varied ±30 percent from its base value. Figure 2 shows the percent change in the predicted strain due to a corresponding change in a given thickness

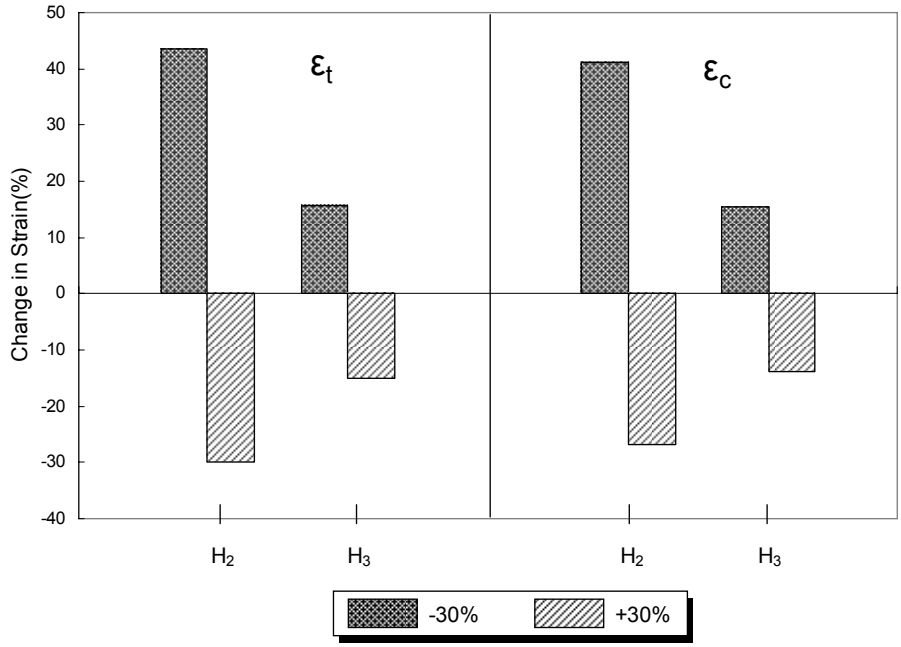

Figure 2. Sensitivity of the Strain to Changes in Thickness of Intermediate and Base Layer

The percent change in ε_t and ε_c of intermediate layer are 2.3 times greater than that in base layer. It is concluded from Figure 2 that the thickness change in intermediate layer is very sensitive to the ε_t and ε_c.

2.2 Effect of Layer Modulus on the Pavement Response

The base modulus in intermediate and base layer are assumed to be 8.0*GPa* and 3.5*GPa* in this analysis. Similar to the sensitivity analysis for layer thickness, the percent change of ε_t and ε_c varying with layer modulus by ±30% was analyzed. The result of the analysis is shown in Figure 3.

It can be observed from this figure that the percent change of ε_t in varying the modulus of intermediate layer is about 1.4 times greater than that of base layer. However, there is no difference in change of ε_c when varying the modulus in intermediate and base layer. As a result of the sensitivity analysis, the thickness in intermediate layer is most influential factor for controlling the critical pavement responses and should be considered in pavement layer thickness design.

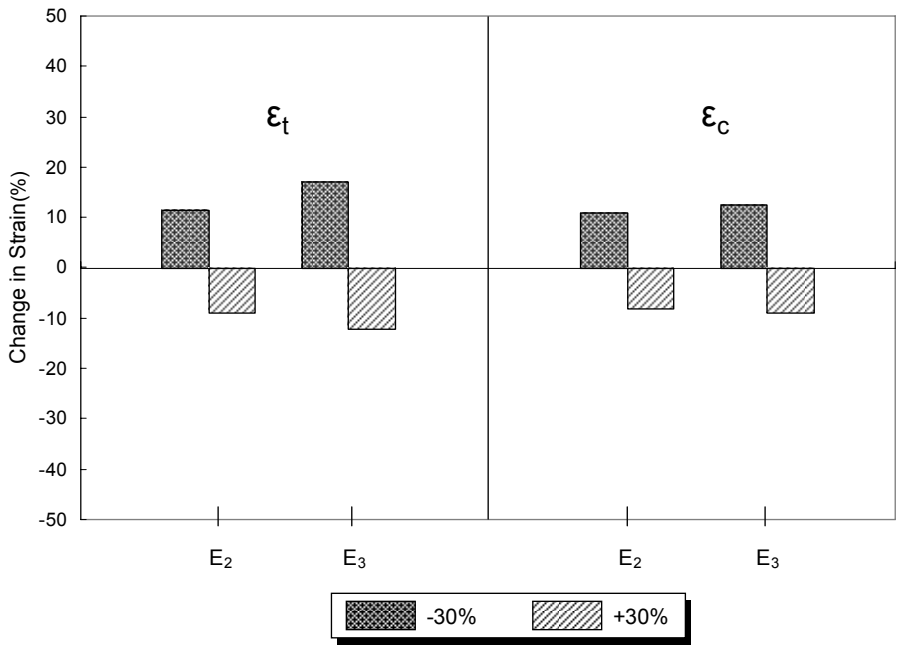

Figure 3. Sensitivity of the Strain to Changes in Modulus of Intermediate and Base Layer

3. SYNTHETIC DATABASE GENERATION

The pavement structure for synthetic database generation, typically used in Korea, is composed of a total of six layers including wearing, intermediate, base course, subbase, anti-frost layer, and subgrade layer. Layer thickness and modulus selected from the random number generation method are inputted to the ILLIPAVE finite element program to calculate the critical pavement response. A contact pressure for loading is 689kPa and radius of contact are is 152.4mm in the forward calculation. The critical pavement responses considered here are the tensile strain at the bottom of AC layer and the compressive strain on top of the subgrade. Figure 4 presents the standard pavement structure for synthetic database generation and Table 1 shows the range of input parameters for the analysis. A total of 1,000 data are generated to establish the synthetic database.

The thickness of wearing course is set to be 5cm because the milling and overlay is usually performed at 5 to 10 year interval in long life pavements. Since the high stiffness asphalt concrete is used for durability improvement purpose, the modulus of intermediate layer is 4 times greater than that of typical asphalt materials. To reduce the tensile strain at the bottom of AC layer, the asphalt materials in base layer has the minimum 2GPa of modulus. The subbase and anti-freezing layer are included in this analysis because they are used in the Korean Pavement Design Guide. The modulus of subbase and anti-freeze layer are assumed to be 0.17GPa and 0.1GPa, respectively. The modulus of subgrade ranges from 0.03 to 0.1GPa.

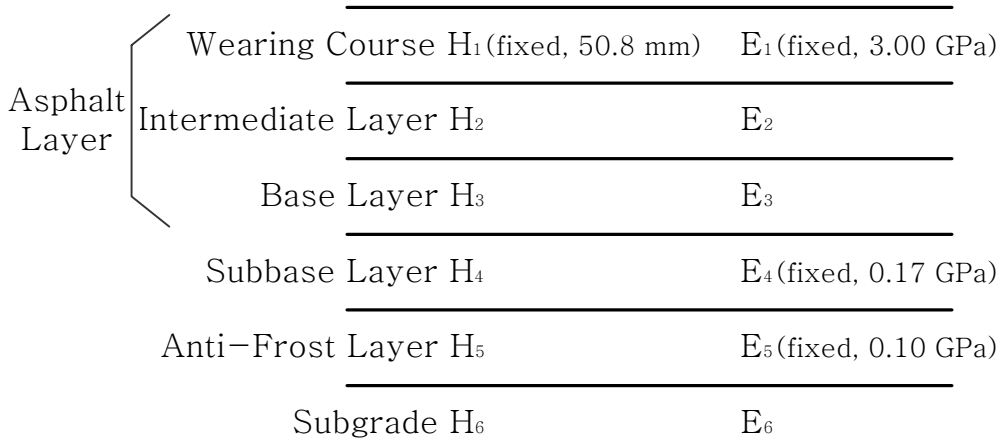

Figure 4. Standard Pavement Structure for Synthetic Database Generation

Table 1. Range of Input Parameters

Input Parameter	MIN(*mm*, *GPa*)	MAX(*mm*, *GPa*)
H_1	50.8	50.8
H_2	101.6	304.8
H_3	0	152.4
H_4	203.2	406.4
H_5	0	203.2
E_1	3.00	3.00
E_2	4.00	12.06
E_3	2.07	5.00
E_4	0.17	0.17
E_5	0.10	0.10
E_6	0.03	0.10

4. DATA ANALYSIS

Endurance limits for critical pavement response to satisfy with the long life pavements were determined according to the TRL Report 250 and other studies (Monismith, et al.). For endurance limit for fatigue cracking, the tensile strain at the bottom of AC layer is equal to or less than 65 μstrain. The compressive strain on top of the subgrade equal to or less than 200 μstrain is the endurance limit for permanent deformation. Once the actual strain value is below the endurance limit, the pavement has more than 40 years of remaining life and is considered to be long life pavement.

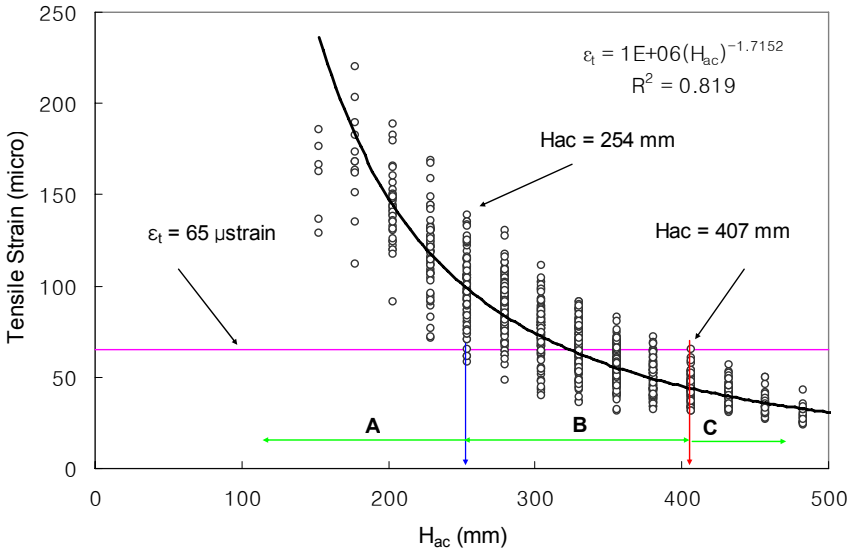

Figure 5. Relationship between Total AC Layer Thickness and ε_t

Figures 5 and 6 show the relationship between total AC layer thickness and ε_t and ε_c using the synthetic database. As shown in these figures, if the pavement has less than 65 μstrain of ε_t, it always has less than 200 μstrain of ε_c indicating ε_t is the controlling factor for this relationship. Therefore, the relationship between ε_t and AC layer thickness is analyzed in this study.

When a total AC thickness is less than 250mm (Region A), the calculated strain in most cases is greater than the endurance limit regardless of the modulus and other layer thickness. These pavements cannot be considered as a long life pavement. The pavements with equal to or greater than 410mm of AC layer thickness (Region C) are considered to be a long life pavement. In case of Region B, the long life pavement is determined based on the modulus of material and other layer thickness.

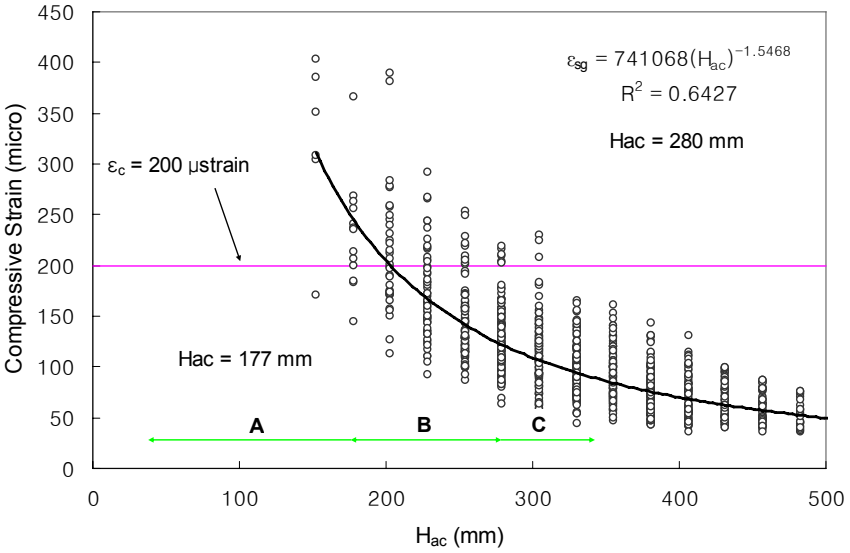

Figure 6. Relationship between Total AC Layer Thickness and ε_c

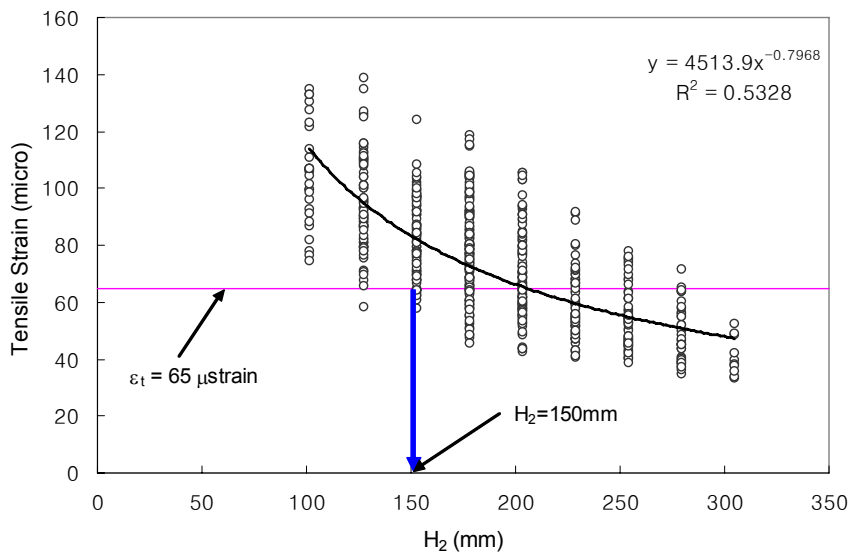

Figure 7. Effect of Thickness of Intermediate Layer on the Tensile Strain at the bottom of AC Layer.

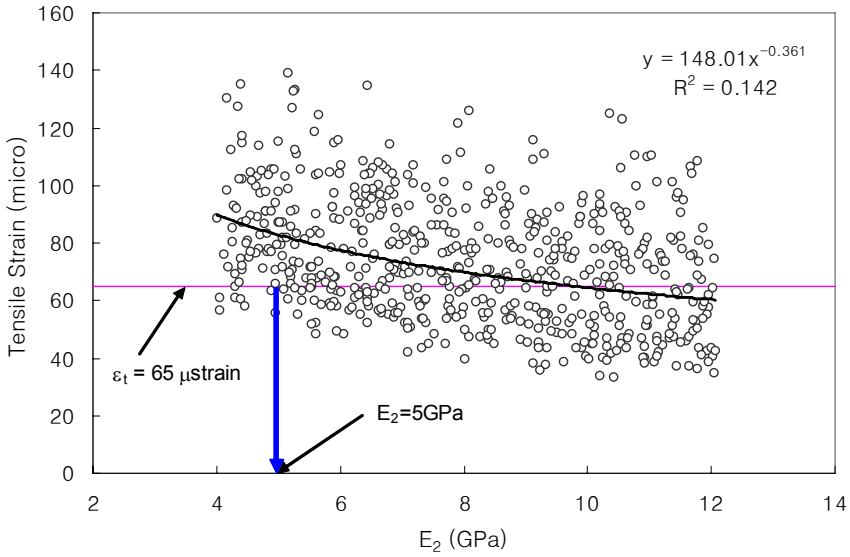

Figure 8. Effect of Modulus of Intermediate Layer on the Tensile Strain at the bottom of AC Layer

Figures 7 and 8 show the effect of thickness and modulus of intermediate layer on the tensile strain at the bottom of AC layer. It can be observed from these figures that the tensile strain tend to decrease as the thickness and modulus increases. A 95% of pavements greater than 150mm of thickness of intermediate layer or 5GPa of modulus show the less than 65μstrain of ε_t. To become a long life pavement, the thickness of intermediate layer should be greater than 150mm and the asphalt material with more than 5GPa of modulus should be used. It is found that there no clear relationship between ε_t and, layer thickness and modulus in the base, subbase, subgrade.

5. DEVELOPMENT OF PAVEMENT RESPONSE MODEL

A regression approach is adopted to develop the pavement response model using input variables and critical responses in pavement layers. Because the layer thickness and modulus in subbase, anti-frost layer, and subgrade layer did not affect the tensile strain at the bottom of AC layer, they are excluded from the regression equation.

A total of 500 data are used to develop the regression equation for determining the ε_t.
The layer thickness and modulus in intermediate and base layer are inputted to the regression equation to calculate the ε_t.

$$\log(\varepsilon_t)=5.545-1.191\log(H_2)-0.2731\log(H_3)-0.397\log(E_2)-.288\log(E_3) \quad (1)$$

[R^2 = 0.9579 , SEE = 0.0375]

where,

ε_t = tensile strain at the bottom of AC layer(μstrain)
H_2 = thickness of intermediate layer (mm)
H_3 = thickness of base layer (mm)
E_2 = modulus of intermediate layer (GPa)
E_3 = modulus of base layer (GPa)

Similar to the tensile strain, the regression equation for calculating the ε_c was developed using synthetic database.

$$\log(\varepsilon_c) = 5.868-1.032\log(H_2)-0.255\log(H_3)-0.386\log(H_4)-0.142\log(H_5) -0.312\log(E_2)-0.126\log(E_3)-0.442\log(E_6) \quad (2)$$

[R^2 = 0.9720 , SEE = 0.0306]

where,

ε_c = compressive strain on top of the subgrade (μstrain)
H_2 = thickness of intermediate layer (mm)
H_3 = thickness of intermediate layer (mm)
H_4 = thickness of intermediate layer (mm)
H_5 = thickness of intermediate layer (mm)
E_2 = modulus of intermediate layer (GPa)
E_3 = modulus of intermediate layer (GPa)
E_6 = modulus of intermediate layer (GPa)

A 500 of database not used in model development was used to verify the developed regression equation. Figures 9 and 10 present the comparison of measured and predicted tensile strain values and indicate a good agreement with two values.

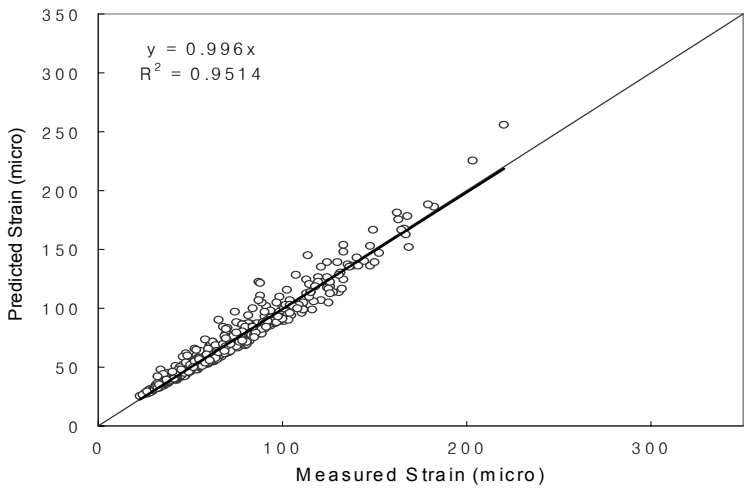

Figure 9. Comparison of Measured and Predicted Tensile Strain

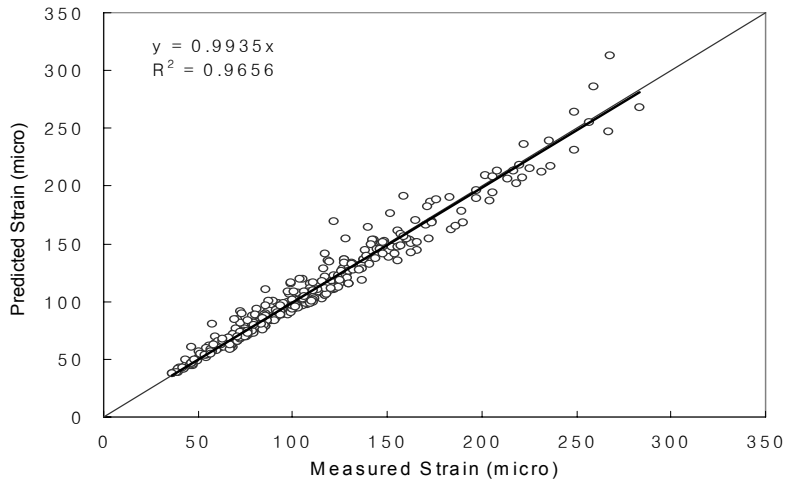

Figure 10. Comparison of Measured and Predicted Compressive Strain

6. DETERMINATION OF LAYER THICKNESS IN LONG-LIFE PAVEMENTS

As a result of the analysis, the flowchart for procedure of determination of the layer thicknesses in a long life pavement is presented in Figure 11. The optimum layer thicknesses will be determined by changing the layer thickness and modulus to satisfy with the requirements for long-life pavements.

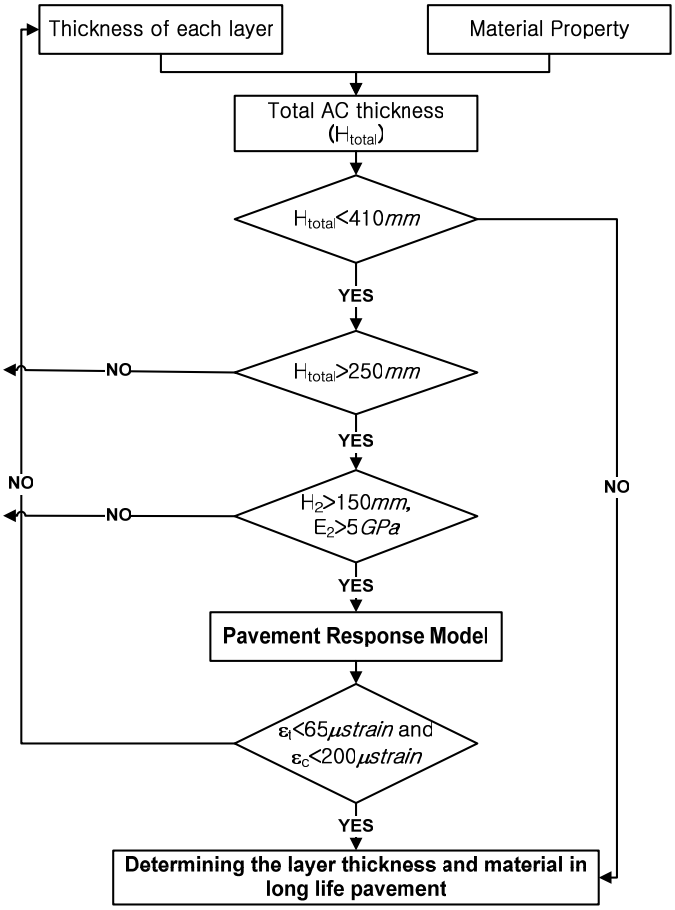

Figure 11. Flowchart for Determining the Layer Thicknesses in Long Life Pavement

A simplified procedure for determination of layer thickness is proposed in this study. Figures 12 to 14 show the relationship between the layer thickness and modulus in intermediate layer at different thickness and modulus of base layer. The area with gray color in these plots represents the possible candidate of layer thickness and modulus to become a long-life pavement. Once the stiffness of materials used are known, the appropriate layer thickness in both intermediate and base layer can be determined using the plots in Figures 12 to 14.

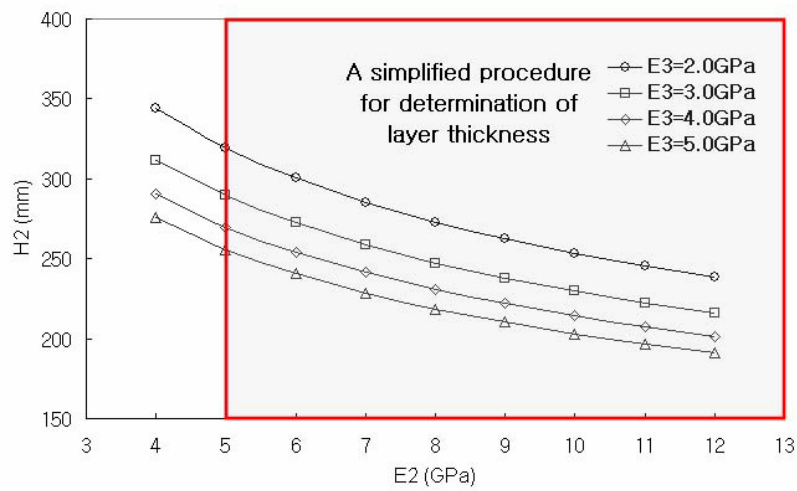

Figure 12. Relationship between E_2 and H_2 (H_3=25.4mm)

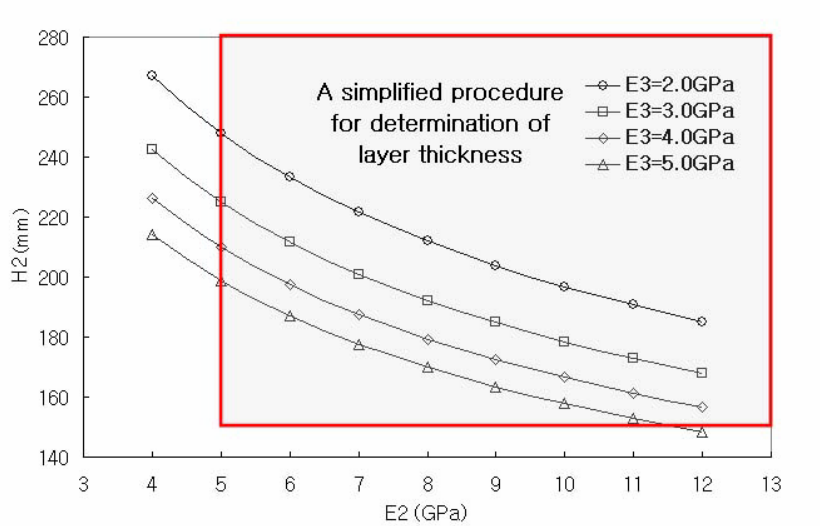

Figure 13. Relationship between E_2 and H_2 (H_3=76.2mm)

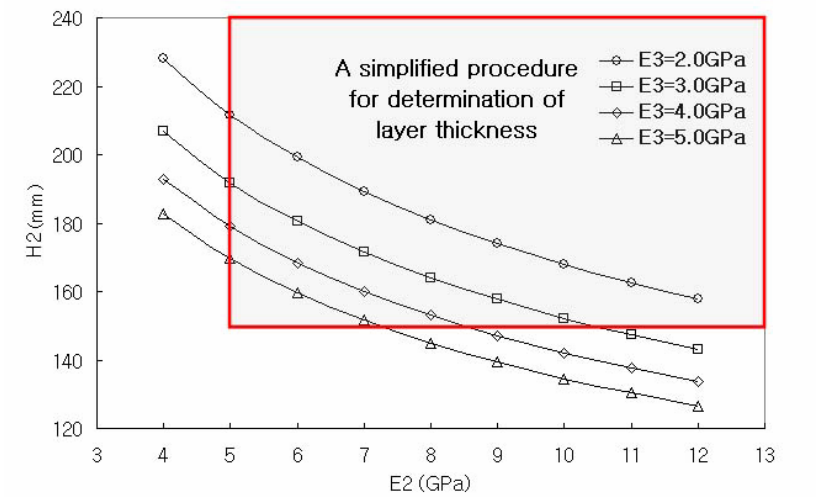

Figure 14. Relationship between E_2 and H_2 (H_3=152.4mm)

7. CONCLUSIONS

This research effort focused on the development of design procedure for determining the layer thickness in a long-life pavement. The conclusions drawn during this study are as follows:

1. The pavement greater 410mm of total AC layer thickness is considered as the long life pavements regardless of the material characteristics and thickness in each layer.
2. The design procedure for determining the thickness and modulus in each layer for pavement with AC layer thickness ranging from 250 to 410mm is also presented in this paper.
3. The pavement response model for long-life pavement was developed and the design procedure for determining the layer thickness also proposed in this paper.

REFERENCES

Newcomb, E. D, Buncher, M., and Huddleston, I. J. (2001) **Concepts of Perpetual Pavements**, *Transportation Research Circular* No. 503, pp. 4-11.

Nunn, M. E., A. Brown, D. Weston, and J. C. Nicholls. (1997) **Design of Long-Life Flexible Pavements** *for Heavy Traffic*. TRL Report 250, Transport Research Labortory, Crowthorne, U.K.

Von Quintus, H. L. (2001) **Hot-Mix Asphalt Layer Thickness Design for Longer-Life Bituminous Pavements**, *Transportation Research Circular* No. 503, pp. 66-78.

Asphalt Pavement Alliance (2001) **Perpetual Pavement: Structured for the future**.

Monismith, C. L., and F. Long. (1999) **Overlay Design for Cracked and Seated Portland Cement (PCC) Pavement** - Interstate Route 710. *Technical Memorandum TM UCB PRC 99-3*, Pavement Research Center, Institute for Transportation Studies, University of California, Berkeley.