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A Study on Long-term Pavement Performance by Changing Layer Stiffness of Composite Pavement using Finite Element Method

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ABSTRACT

Composite pavement combines layers of asphalt pavement on top of concrete pavement and has the advantages of both asphalt and concrete pavements. Composite pavement provides good ride comfort and long-term performance and the study and field application have been underway extensively. In this study, a long-term pavement performance of composite pavement depending on stiffness of asphalt, concrete and lean concrete layer was evaluated. Pavement simulation tool(Abaqus 6.10) was used in this study. Modeling pavement structure in abaqus consisted of asphalt, concrete, lean concrete and base. 125 variables were selected depending on Young's modulus (Stiffness) of Asphalt, concrete and lean concrete. Maximum asphalt horizontal tensile strain of the sub-base of asphalt concrete was obtained from structural analysis. And the result was applied to the equation suggested by American Asphalt Association to estimate the allowable repeated load frequency (life cycle) As a result of the study, regression equation between stiffness and life cycle, indicating the effect of asphalt layer was the greater.

Keywords: *Finite Element method, Composite Pavement, Modeling, Simulation, Abaqus 6.10, Layer Stiffness*

1. INTRODUCTION

1.1 Research Background and Objective

Road pavement consists of asphalt pavement and concrete pavement. Asphalt pavement is flexible pavement which disperses the load on surface to base and sub-base. The asphalt pavement generates low noise and good ride comfort and is easy to maintain with shorter curing period. Concrete pavement is rigid pavement, and most of loads are supported by bending resistance of slab. The concrete pavement can minimize suspension of traffic because of no need of maintenance. It is appropriate for heavy load by such as heavy vehicle. Composite pavement which provides the good durability and ride quality by combining the advantage of asphalt pavement and concrete pavement has been under development and applied to many sites.

This research is intended to evaluate the long-term performance of composite pavement using structural analysis. The variables for finite element method include the thickness of pavement layers, friction factor, young's modulus and Poisson ratio. This research is also intended to compare pavement life depending on stiffness of pavement layer focusing on young's modulus.

1.2 Research Scope

This research used Abaqus 6.10 for finite element method. The Young's modulus and material properties of modeling pavement layer were decided by literature review. Structural analysis of 5 different elastic coefficients of asphalt layer, concrete layer and lean concrete layer was implemented and total 125 numbers of cases were analyzed. Maximum tensile strain of asphalt layer in 125 different cases was obtained and applied to American Asphalt Association's equation to estimate the life cycle of pavement and multiple regression analysis was carried out for statistical verification.

2. LITERATURE REVIEW

2.1 System of Composite Pavement

The composite pavement is the system combining the advantage of asphalt pavement and concrete pavement. Laying asphalt pavement on concrete pavement has been also under development in foreign countries. Composite pavement can secure sufficient bearing force using concrete layer as base layer. Asphalt surface provide a good ride quality. Also, composite pavement can be used permanently through regular maintenance of asphalt surface. And composite pavement can prevent concrete failure from chloride deicing material or environmental factor because asphalt layer functions to protect concrete layer[1].

Flintsch and Diefenderfer (2008)[2] studied deflection of composite pavement. As shown in figure 1, deflection of composite pavement was smaller than normal asphalt pavement.

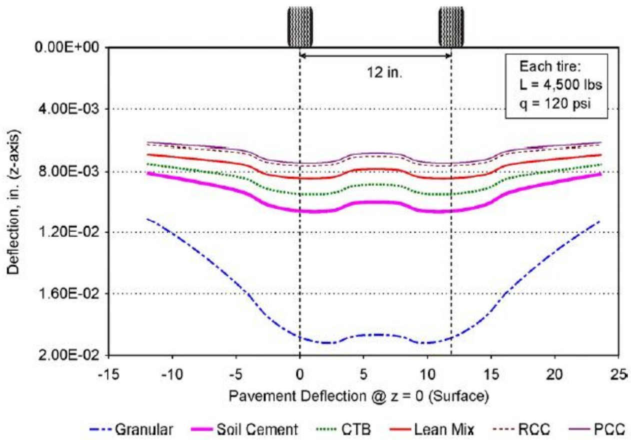

Fig 1: Surface Pavement Deflections of Various Structures(Flintsch and Diefendrfer, 2008)[2]

2.2 Analysis of Pavement Structures

The analysis methods of pavement structures include the method using precise solution and using numerical analysis. The typical methods of numerical analysis include multiple elastic theory based on continuum mechanics and finite element method. A multiple elastic theory consists of N number of layers that have different structures materials of pavement. This multiple elastic theory is simpler than other methods. Therefore, this method has been used widely. Finite element method is to calculate approximate solution by dividing continuum by finite element and dynamic characteristics and nonlinearity stress and strain could be considered. The multiple elastic theory has limit in reflecting actual condition. In order to deal with this limit, finite element method can be used. Finite element method has been used by many tools since developed in the 1960s by Texas University(Kim, 2002)[3].

3. FINITE ELEMENT METHOD

Abaqus6.10 was used in this study for finite element method. The variables for modeling composite pavement were set and modeling was implemented referring to actual road sizes at highway construction sites.

3.1 Variables Setting and Modeling

The variables were set by dividing them into fixing variables and variable variables. Fixing variables were used for structure modeling and variable variables were used to identify the effect depending on stiffness of elastic coefficient by layer, which is the objective of this study. Fixing variables include friction factor, load, layer, thickness and layer passion ratio while variable variables include young's modulus by layer. As shown in table 1, the friction factors of layer were set referring to Park et al.(2011)[4]. The load was set as 4.1ton, because in ESAL factor, 2 tires of one axis is considered 8.2ton. This research was based on a single tire.

Table 1: Adhesive condition of each floor (Parket al., 2011)[4]

Classification	Modeling Method	Friction Factor
Asphalt - Concrete	Tangential	0.6
Concrete - Lean Concrete	Tangential	0.1
Lean concrete - Sub grade	Tangential	0.45

As shown in table 2, the range of young's modulus of each layer was based on material properties of other researches. The representative values of young's modulus were chosen as shown in table 3, and 5 young's modulus were applied to each layer. In the case of sub grade, a single young's modulus was applied and as a result,125 number of case was obtained.

Table 2: Young's Modulus and Poisson's Ratio of Other Researches

Author	Asphalt		Concrete	
	Young's Modulus (Mpa)	**Poisson's Ratio**	**Young's Modulus (Mpa)**	**Poisson's Ratio**
Garzon et al. (2010)[5]	1400	0.35	28000	0.15
Park et al. (2011)[4]	-	-	**28000**	**0.18**
You et al. (2004)[6]	-	-	19400	0.15

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Parket al. (2009)[7]	**4000**	**0.39**	28000	0.18
Park et al. (2005)[8]	3000	-	-	-
Park et al. (2010)[9]	2918	0.4	-	-
Author	**Lean Concrete**		**Sub grade**	
	Young's Modulus (Mpa)	**Poisson's Ratio**	**Young's Modulus (Mpa)**	**Poisson's Ratio**
Garzon et al. (2010)[5]	-	-	-	-
Park et al. (2011)[4]	**15000**	**0.2**	70	0.3
You et al. (2004)[6]	12400	0.4	-	-
Parket al. (2009)[7]	-	-	**50**	**0.30**
Park et al. (2005)[8]	-	-	30 ~ 100	-
Park et al. (2010)[9]	-	-	186	0.4

Table 3: Young's Modulus of This Research

Classification	Young's Modulus(Unit: Mpa)
Asphalt	2000, 4000, 6000, 8000, 10000
Concrete	24000, 26000, 28000, 30000, 32000
Lean Concrete	11000, 13000, 15000, 17000, 19000
Sub grade	50

Modelling of pavement structure was performed referring to the design of Jung Expressway [10] as seen in Fig 2. And pavement structure was consisted of asphalt, concrete, lean concrete and sub grade. The road width was 3.6m and tire width was 0.2m. Tire load was 4.1ton based on road center Also, mesh size was 1cm to monitor the detail change of asphalt and concrete layer. And the size of lean concrete and sub grade layer was 5cm.

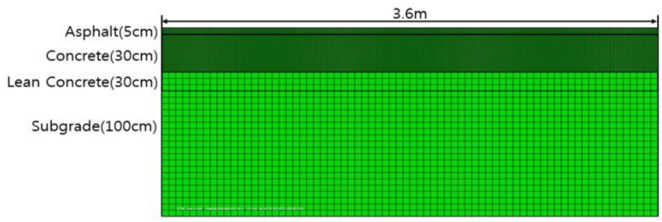

Fig 2: Pavement Structure

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3.2 Result of Structural analysis

Total 125 cases were implemented for simulation. Stress and strain of each mesh were obtained by modeling. This research was intended to estimate the life cycle of the pavement based on maximum tension strain of asphalt layer. As shown in Fig3 ~ 7, maximum asphalt horizontal tensile strain was significantly dependent on young's modulus of asphalt. But the difference in maximum asphalt horizontal tensile strain by concrete and by lean concrete was insignificant.

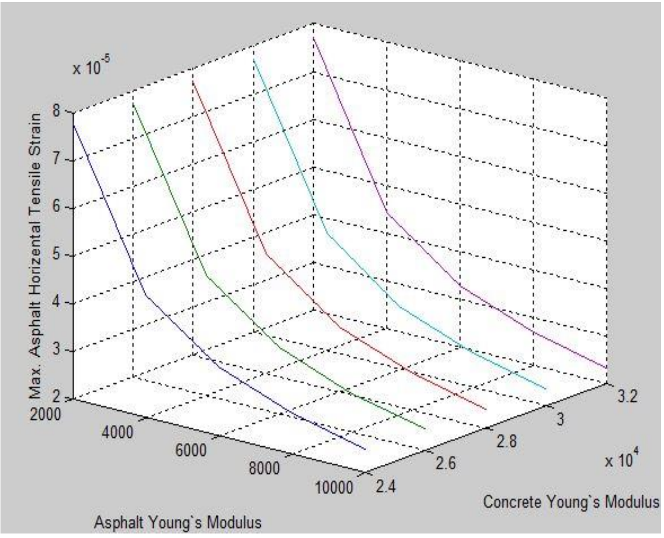

Fig 3: Max. Asphalt Horizontal Tensile Strain(Lean Concrete Young's Modulus: 11000)

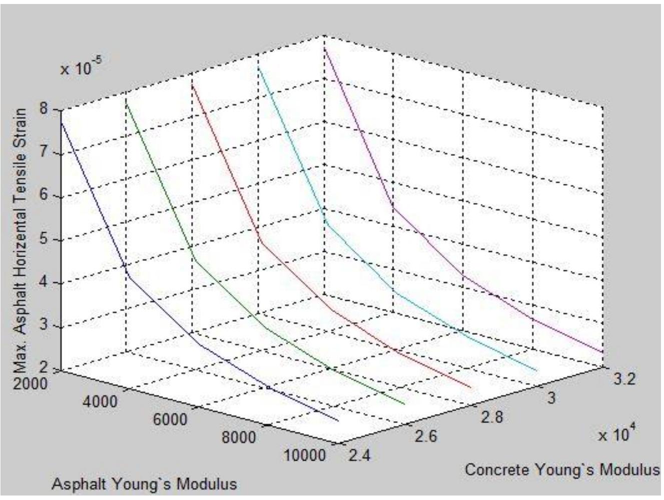

Fig 4: Max. Asphalt Horizontal Tensile Strain(Lean Concrete Young's Modulus: 13000)

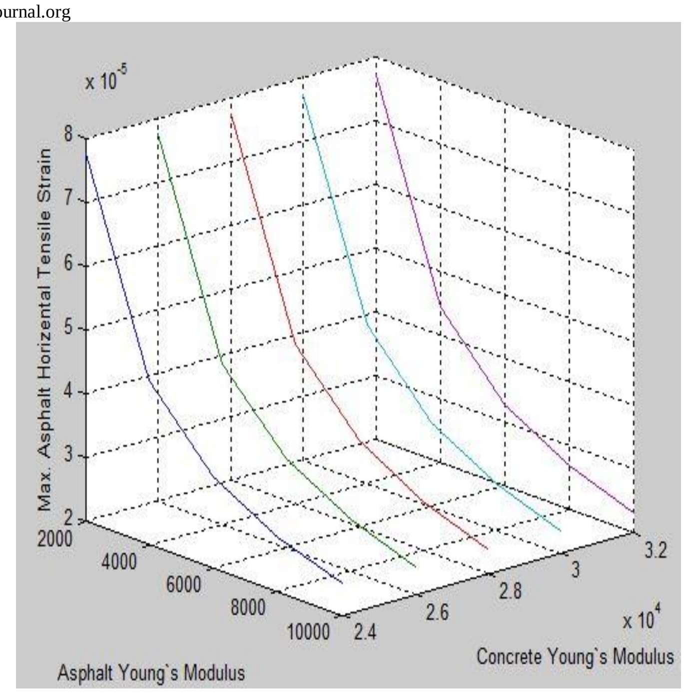

Fig 5: Max. Asphalt Horizontal Tensile Strain(Lean Concrete Young's Modulus: 15000)

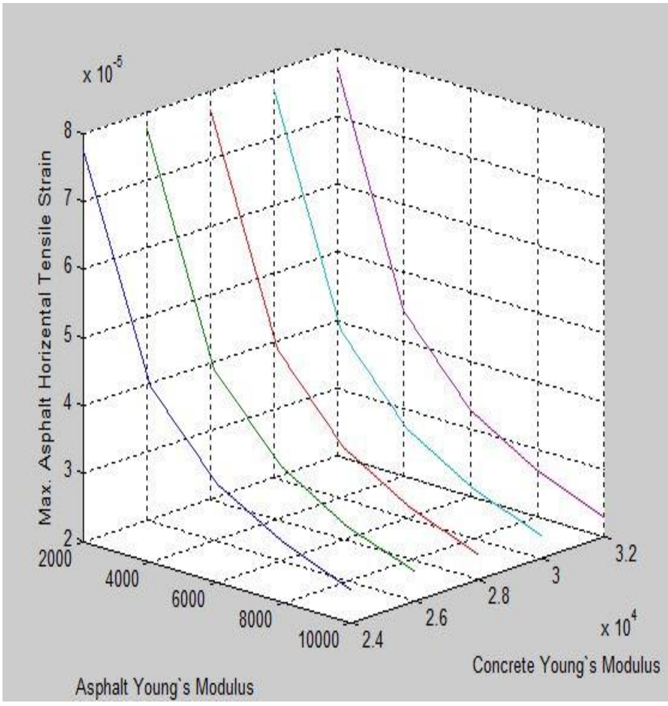

Fig 6: Max. Asphalt Horizontal Tensile Strain(Lean Concrete Young's Modulus: 17000)

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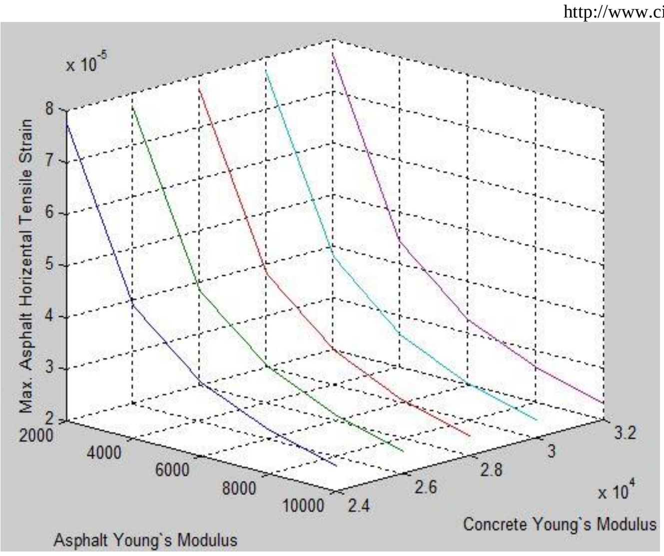

Fig 7: Max. Asphalt Horizontal Tensile Strain(Lean Concrete Young's Modulus: 19000)

4. STATISTICAL ANALYSIS

In this research, maximum tensile strain of asphalt was applied to the equation (1) suggested by American Asphalt Association described below and the life cycle of pavement was estimated.

$$N_f = 0.0796(\epsilon_t)^{-3.291}(E)^{-0.854} \quad (1)$$

Where,

N_f:Pavement service life
ϵ_t: Maximum asphalt horizontal tensile strain
E: Young's Modulus of Asphalt Layer

A multiple regression analysis of elastic modulus of each layer and pavement life cycle was implemented to identify the relations between stiffness of each layer of composite pavement and life cycle and then regression equation was estimated and statistical effectiveness was determined.

In this research, multiple regression analysis was implemented using SPSS. Young's modulus of asphalt, concrete and lean concrete were used as independent variables. And life cycle of pavement was used as dependent variable. As a result, coefficients in Table 4 were obtained and then regression equation (2) was obtained accordingly. In model equation, VIF(Variance Influence Factor) was 1.00 which was smaller than reference value 10.Therefore, this equation did not have multi-collinearity problem.

Table 4: The result of a Coefficient

Model	Non-Standardized Path Coefficients		Standardized Path Coefficients	
	B	Standard Error	Beta	
a constant	-2.598×10^{10}	-1.607×10^{9}		
Asphalt	5679649.343	55851.128	0.988	
Concrete	632525.869	55851.128	0.110	
Model	t	Significance Probability	Multi-collinearity Statistics	
			A tolerance	VIF
a constant	-16.168	0.000		
Asphalt	101.693	0.000	1.000	1.000
Concrete	11.325	0.000	1.000	1.000

$$N_f = -2.598 \times 10^{10} + 5679649.343A_y + 632525.869C_y \quad (2)$$

Where,

N_f: Pavement Life
A_y: Young's modulus of Asphalt Layer
C_y: Young's modulus of Concrete Layer

The result of variance analysis is as shown in table 5. Significance probability was 0.000. Because significance probability was lower than 0.05, a linear regressing model proved to have existed.

Table 5: The Result of Variance Analysis

Model	Sum of Squares	The Degree of Freedom	Mean Square
Regression Model	3.266×10^{22}	2	1.633×10^{22}
Residual	3.806×10^{20}	122	3.119×10^{18}
Sum	3.304×10^{22}	124	
F			Significance Probability
5234.828			0.000

As shown in table 6, stiffness of lean concrete had insignificant effect on pavement life cycle. Significance probability of lean concrete was 0.426 which was considered higher. Therefore, lean concrete was excluded from final variable. The R square of this model was 0.988, showing high explanation power about pavement life.

Table 6: Model Summary and Excepted Variable

The Model Summary			
R	**R Square**	**Modified R Square**	**Standard Error of Estimated Value**
0.994	0.988	0.988	1.76617×10^{9}
The Excluded Variable			
Model	**Beta Input**	**t**	**Significance Probability**
Lean Concrete	0.008	0.799	0.426

5. CONCLUSION

A long-term pavement performance of composite pavement depending on stiffness of asphalt, concrete and lean concrete was carried out in this study. This research used pavement simulation tool (Abaqus 6.10). Variables used for structural analysis were abstracted based on reviewing the documents. 5 young's moduli were applied to each layer. Total 125 cases were selected depending on young's modulus (Stiffness) of Asphalt, concrete and lean concrete. Maximum asphalt horizontal tensile strain was obtained by simulation. Pavement life cycle was obtained in a way of applying to the equation proposed by American Asphalt Association Regression equation between stiffness and pavement lifecycle was obtained through multiple regression analysis. The result showed that asphalt's stiffness had the greatest influence on pavement life.

In the future, we will calculate model equation using other algorithm and will conduct comparing research.

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