World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:7, No:10, 2013

Behavior of Concrete Slab Track on Asphalt Trackbed Subjected to Thermal Load

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Open Science Index, Civil and Environmental Engineering Vol:7, No:10, 2013 publications.waset.org/17310.pdf

Abstract**—**Concrete track slab and asphalt trackbed are being introduced in Korea for providing good bearing capacity, durability to the track and comfortable rideness to passengers. Such a railway system has been designed by the train load so as to ensure stability. But there is lack of research and design for temperature changes which influence the behavior characteristics of concrete and asphalt. Therefore, in this study, the behavior characteristics of concrete track slab subjected to varying temperatures were analyzed through structural analysis using the finite element analysis program. The structural analysis was performed by considering the friction condition on the boundary surfaces in order to analyze the interaction between concrete slab and asphalt trackbed. As a result, the design of the railway system should be designed by considering the interaction and temperature changes between concrete track slab and asphalt trackbed.

Keywords**—**Con'c Track Slab, Asphalt Trackbed, Thermal Load, Friction Condition.

I. INTRODUCTION

DUE to the recent increase of railway traffic and speedup of railroad operation, the structural design of new track is necessary to ensure stability and durability. Thus, introduction of asphalt trackbed for improving driving stability and supporting orbit is under review in Korea. Previous researches on the railway track system mainly focus on the mechanical behavior characteristics due to the train load [1], [2]. Subsequent development of design method, the railroad track system to sufficiently ensure the stability is being developed, even with the increase of load from the acceleration of the trains.

However, the research on the railway track system by temperature change, which has been regarded as the important factor for the behavior characteristics of concrete and asphalt, has not been conducted. In the railway track system research by temperature change, materials that were directly affected by temperature change such as slab behavior analysis by rail expansion and contraction, research on the joint in the continuous slab, bridge construction were mainly conducted. Limited research on temperature change of asphalt trackbed was conducted.

In this study, the railway track system focused on the asphalt trackbed and pre-cast concrete slab track were included. The behavior characteristics of concrete track slab in consideration of the train load as well as the load of the temperature change were analyzed. Previous work of the fillings, which determine the conditions of contact between the concrete track slab and subgradebottom layer, was only focused on the material itself. In order to understand the mechanical behavior of concrete track slab and asphalt trackbed and their interactions, the behavior characteristics of two materials according to contact conditions were analyzed. In order to analyze the behavior characteristics, the finite element analysis program, ABAQUS [3], were used for structural analysis. By the nature of construction, the temperature of asphalt elevates for a certain amount of time. The structural behavior characteristics of concrete track slab during this elevated temperature were analyzed. In addition, interaction analysis was also conducted in consideration of temperature change due to outside temperature. Further, a modeling of underground of the asphalt trackbed was also analyzed, in order to consider the interactions in the railway track system holistically.

II. CONFIGURATION OF ANALYSIS MODEL

A. Finite Element (FE) Model

Current study focused on the pre-built railway track system, a precast concrete slab track. Pre-cast concrete panels manufactured in the factory were placed on the asphalt trackbed. Then, filler materials were inserted underneath the slab to form a vertical and horizontal shear key support structure. The vertical directional structure of the current system was consist of concrete panel-mid packed bed – asphalt trackbed layer, as shown in Fig. 1. It is slightly different from the current factory-made concrete panels designed to use of reinforced concrete. The mid-packed filler between asphalt trackbed were constructed with non-shrink cement mortar; therefore it serves to maintain the lateral support and the substrate level. For a consideration of concrete track slab cross- section, design concepts proposed by Eisenmann, Leykauf in Munich University, and German railway standard (AKFF) were applied in current study [4]. The second level of the slab on top of Semi-infinite elastic foundation were included in the modeling, in that the RC panel design and the substrate and stress review panel design were used for the concrete slab, as shown in Fig. 2. The RC slab design was applied to both vertical and horizontal direction of slab, so that the amount of reinforcement steel to

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resist limit bending moment were determined according to the method for ultimate strength.

B. Loading Conditions for the Railway Model

A Korea Train eXpress (KTX) load was used for the numerical analysis, as shown in Table I. For the FE analysis, train load was determined at the optimum location of the train using influence line (as seen in Fig. 3.), rail train loads were converted to uniformly distributed load and loaded on the slab.

As stated earlier, current study focused on the temperature-dependent constructability of concrete slab constructed on the asphalt trackbed, that this study was divided into two categories: Category 1. Pre-cast concrete slab mounted on the asphalt trackbed; Category 2. Structure behavior of concrete slab affected by temperature changes. For the first case, the initial temperature of the asphalt laying was set at 150 degree, because the slab contracture required to considering the cross-temperature between concrete-asphalt layers, unlike the asphalt substrate combination, which mixture reaches over 200 degrees for trackbed construction.

For behavior analysis considering interaction between asphalt trackbed and concrete slab [5], asphalt trackbed temperature were modified, as shown in Table II and Fig. 4. The contact condition of two materials was varied according to concrete slab exposed to outside air temperature, and its temperature distribution characteristics. For actual behavior of weight of concrete slab were considered in order to find the temperature dependent behavior. The temperature coefficients of concrete and asphalt were selected from previous study [6], and the other material properties applied in this study can be found in Tables III and IV.

For construction, it is important to consider the cross-temperature of concrete-asphalt layer; therefore the initial temperature was set at 150 (C^o) during asphalt laying process.

TABLE I
PARAMETERS OF TRACK LOADS (KTX)

Parameters	Moter	Passenger
Wheel load (KN)	2@170	2@170
Distance between constant loads (m)	3.0	3.0
Distance between center loads (m)	14.0	18.0

TABLE II
VARIABLES OF THE FE ANALYSIS

Variables	Case 1	Case 2	Case 3
Temperature of Con'c slab (Co)	15	T1 = 10 T2 = 0	T1 = 0 T2 = 10
Temperature of asphalt trackbed (Co)	0 ~ 150	-	-
Contact Friction	0.5 ~ 3.0	1.0 ~ 15.0	

TABLE III
MATERIAL PROPERTIES OF SUBGRADE

Parameters	Layer 1	Layer 2	Layer 3
Young's Modulus (MPa)	180	80	80
Poission's Ratio	0.2	0.2	0.2
Density (t/mm^3)	2.0e-09	1.60e-09	1.60e-09
Slope	1:1.8		
Thickness (m)	0.5	2.5	3.0

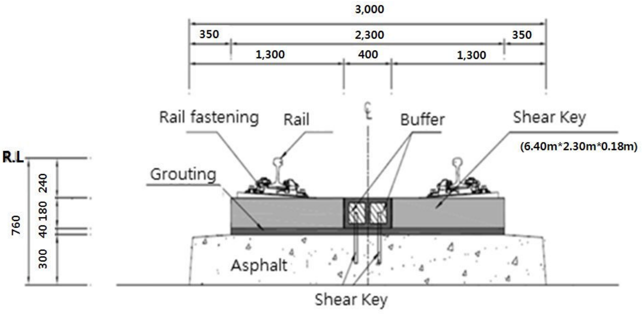


Fig. 1 Cross-section of the concrete slab track system

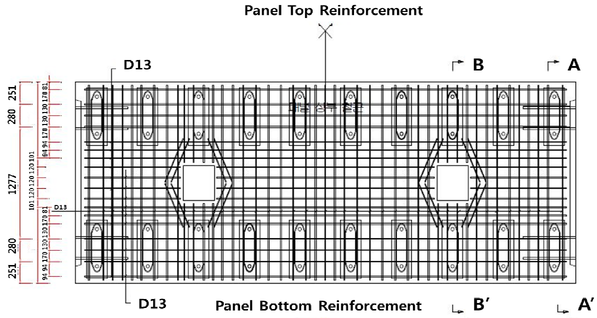


Fig. 2 Reinforcing bar details of the concrete slab track

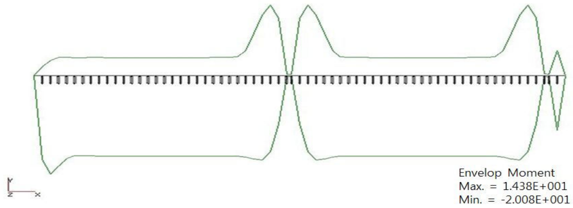


Fig. 3 Influence line based on the track loadingprotocol

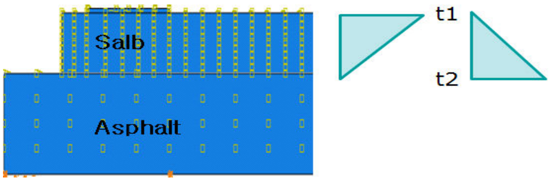


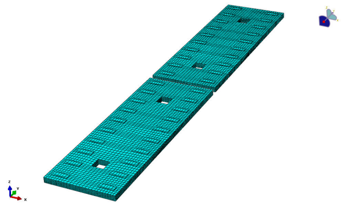
Fig. 4 Temperature distribution of the concrete slab system

TABLE IV
MATERIAL PROPERTIES OF RAIL SYSTEM

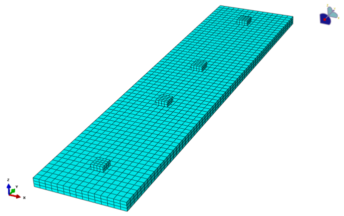
Parameters	Con'c Slab	Asphalt Trackbed
Young's Modulus (MPa)	31928	2000
Poission's Ratio	0.2	0.3
Density (t/mm^3)	2.45e-09	2.30e-09
Thermal Expansion Coefficient	1.00e-05	3.30e-05
Thickness (m)	9800	9800

C. Finite Element Modeling of Railway Track System

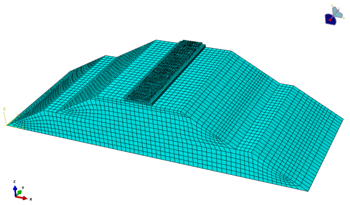
Three-dimensional finite element analysis was conducted using a Finite Element Package Program (ABAQUS). As can be seen in Fig. 5, each of concrete slab track, asphalt trackbed and subgrade were modeled respectively. Non-linear contact model was selected as part of tangential contact behavior characteristic conditions, in order to determine the behavior characteristics between concrete slab and asphalt trackbed with varied contact condition. For frictional modeling, different friction coefficients were set. Loaded rail train load was converted into a uniform load on the slab model. Therefore modeling for rail itself was excluded. Slab,asphalt, and subgrade were modeled with a 20-node solid element, and reinforcement elements near concrete slab were modeled with embedded element.



(a) Concrete slab system



(b) Asphalt trackbed



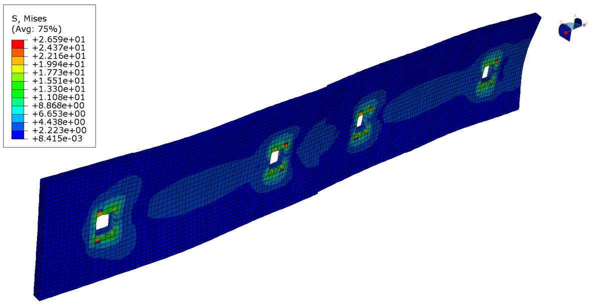
(c) Railway track system with subgrade

Fig. 5 Finite element model of railway track system

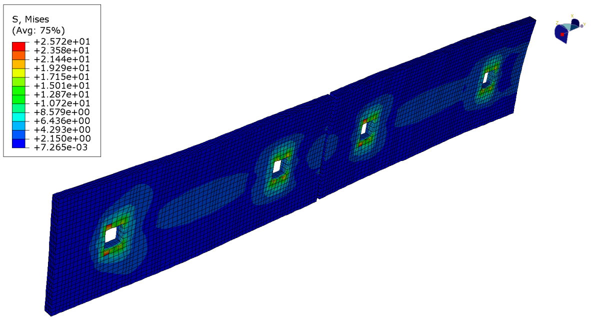
III. RESULTS OF FINITE ELEMENT ANALYSIS

A. Effect of Asphalt Temperature

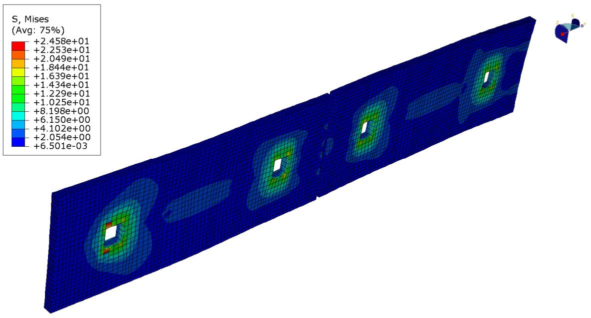
The analysis was mainly focused on the behavior characterization of concrete track slab because it plays an important role in the stability of railway track system. In the case of analysis result of asphalt substrate temperature, the maximum stress of concrete slab track occurred at the bottom of the slab, where the joint shear key located. As shown in Fig. 6, with constant asphalt trackbed temperature, the shape and stress distribution according to the friction caused by asphalt trackbed and concrete slab appears to be same. However, with constant friction coefficient, as temperature of asphalt trackbed increases, the slab track stress concentration was found to be prominent, as seen in Fig. 7.It appears that the deformation of asphalt concrete track slab was sensitive to the temperature of the asphalt trackbed temperature.



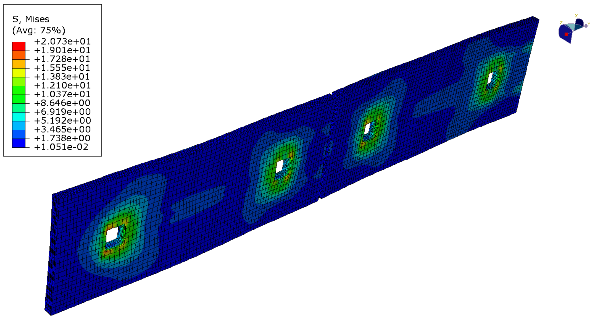
(a) Friction coefficient: 0.5



(b) Friction coefficient: 1.0

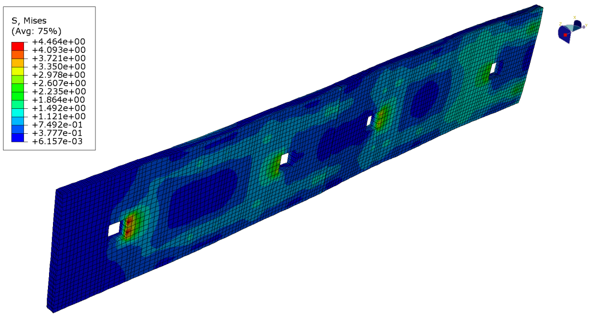


(c) Friction coefficient: 2.0

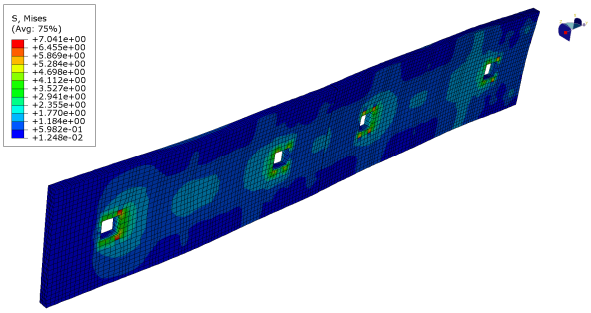


(d) Friction coefficient: 3.0

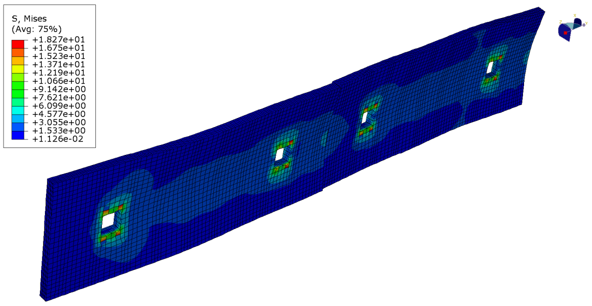
Fig. 6 Stress distribution of the concrete slab track with various friction coefficients



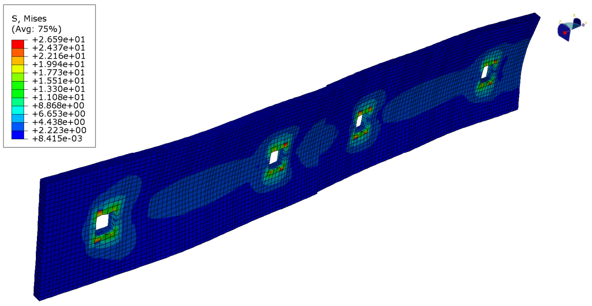
(a) Asphalt trackbed temperature: 0 C^o



(b) Asphalt trackbed temperature: 60 C^o



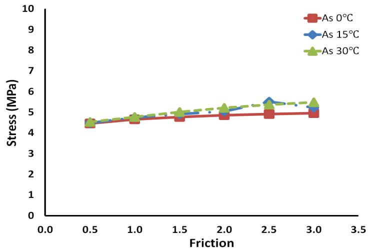
(c) Asphalt trackbed temperature: 120 C^o



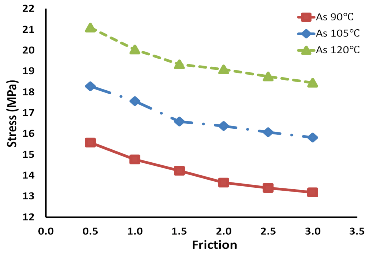
(d) Asphalt trackbed temperature: 150 C^o

Fig. 7 Stress distribution of the concrete slab track with various asphalt trackbed temperatures

When the temperature of asphalt were low (i.e. 0°C~30°C), the concrete track slab affected by friction coefficient was not large. However, when the asphalt temperature was above 90°C, the concrete track slab was greatly affected (Fig. 8). In addition, as the friction coefficient increased, the stress greatly decreased. In other words, the change of friction coefficient was influenced greatly by the stress of concrete track slab at the high temperature. When the temperature deviation of concrete track slab and asphalt interlayer was not large, the connection stiffness by friction coefficient was relatively less influenced. The decrease of stress as the friction increase at the elevated temperature could be due to the behavioral effect by strength changes at the concrete-asphalt interface. Also, the stress increased as the asphalt trackbed temperature increase regardless of friction coefficient, (Fig. 9 (a)). In contrary, if the asphalt temperature is within 30C, the stress change of concrete track slab was minimally affected.

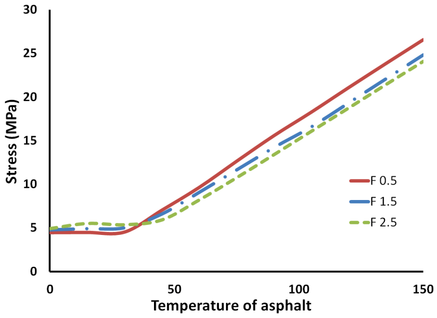


(a) Low temperature

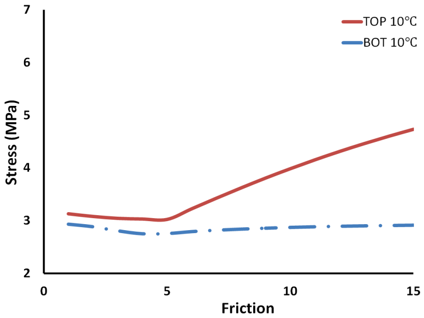


(b) High temperature

Fig. 8 Effect of the stress of concrete slab track with asphalt temperatures



(a) Stress due to asphalt temperatures



(b) Stress due to the friction coefficients

Fig. 9 Effect of the Stress of concrete slab track with the friction coefficients

B. Effect of Concrete Slab Temperature

For analysis of concrete slab temperature, the temperature difference in upper and lower side of surface was considered. The result revealed that the stress of the upper surface of slab was greater than the stress of lower surface at higher temperature. The stress value was at the lowest when friction coefficient was between 4 and 5 (Fig. 9 (b)), and the stress increased with increase of friction coefficient. This can be the behavior effect caused by stiffness change, occurring at the interface surface. Another word, this can be the change caused by the separation and/or integrally behavior of two structure with the change of friction purely by the temperature changes Stress increment with increase of friction coefficient were found to be greater when the upper surface of the slab was at high temperature. The change of stress increment was small when the lower surface of slab was at high temperature. As Fig. 10 demonstrated, the stress of concrete track slab was evenly distributed, and found to be greatest at the end slabs. The reason(s) why the interpreted behavior was not symmetrical, was found to be due to the load conditions.

IV. CONCLUSIONS

The behavior characteristics of two substrates were analyzed according to the asphalt trackbed and concrete track slab temperatures, and following conclusions were derived.

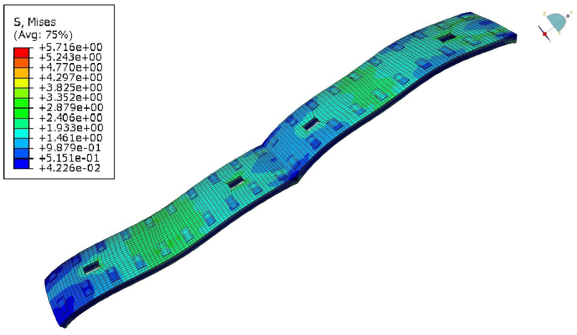
(1) Regardless of friction coefficient, the stress of concrete track slab increased, as the asphalt trackbed temperature increased. The slab change caused by friction coefficient was influenced sensitively at the higher temperature.

(2) The behavior, stress distribution and maximum stress of concrete track slab remained same (not affected), when the concrete trackbed temperature was within 30°C, which is twice higher than the fixed temperature of 15°C for concrete track slab. Therefore, it can be concluded that the effect of friction coefficient is minimal at the temperature within 0~30°C. However, the impact of friction coefficient was greater when the expected temperature is above 50°C. Therefore, determining the appropriate friction coefficient for design and analysis is extremely important.

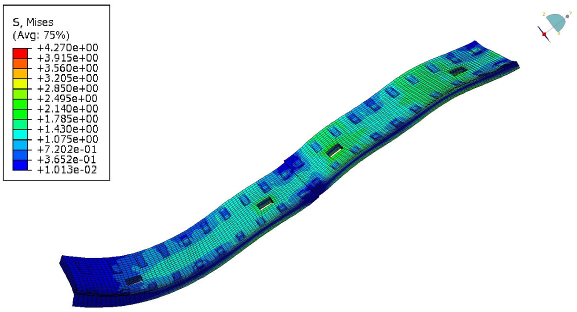
(3) When the temperature of upper part of concrete track slab was higher, as it exposed to outside temperature, the stress was at greatest, due to the combination of upward-bent slab load and the downward train load. However the stress seemed evenly distributed, therefore the risk from local damage would be minimal

(4) If the temperature difference between asphalt trackbed and concrete track slab was greater than 10°C, the direct tensile strength would be greater than 2.5MPa (slab tensile stress could cause the concrete tensile cracks, under all possible conditions). It showed that the concrete track slab in the railway track system is considerably vulnerable to the temperature change. In other words, temperature difference could cause the tensile cracks. Therefore, the temperature load must be considered in the design of concrete track slab, and development of the alternative design and construction method for preventing the concentrated tensile stress is necessary.

Furthermore, the nonlinear performance of the complex trackbed interaction among concrete, asphalt and soil subgrade must be evaluated and the inelastic behavior of the asphalt trackbed system must be achieved.



(a) Stress distribution at the top: 10 C^o



(b) Stress distribution at the bottom: 10 C^o

Fig. 10 Concrete track slab stress distributions

ACKNOWLEDGMENT

This research was also funded by Korea Railroad Research Institute, commissioned as part of asphalt trackbed technology and development project in 2013 and this work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST) (No. 2012-0008762).

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