다층 포장 구조체의 개선된 지반 모델
advanced model of subbases for the multi-layered pavement system.

조 병 완* 이 계 삼**

Jo, Byung Wan Lee, Kae Sam

ABSTRACT

Despite the recent development of structural analysis programs for the CRCP pavements over Westergaard's equations and finite element techniques, the Winkler foundations which are modelled by series of vertical springs at the nodes are generally used for the computer modelling of subbases under the concrete slab. Herewith, two parameter of soil foundation model is adopted as the most convenient mathematical model to enable deflections outside the loaded area to be effected and to upgrade the Winkler foundations.

This paper highlights the derivations of finite element method for the two-parameter soil foundation model in the concrete pavements.

1. introduction

The structural behavior of continuously reinforced concrete pavements (CRCP) can be characterized into two groups. One is the classical plate bending effects on the concrete pavements, mainly due to the gravity loads, traffic loads and temperature differentials between top and bottom slab, which cause the whole slab curling. The other is planar effects on the concrete pavements, due to the concrete shrinkage, subgrade friction and uniform temperature variations, which cause the whole slab contraction and expansion. Herewith, the finite element analysis for the concrete pavements to analyze above problems would be performed using 12-DOF plate bending elements and 8-DOF rectangular in-plane elements respectively for both problems.(Ref.1)

Despite the recent development of structural analysis programs for the CRCP pavements over Westergaard's equations and finite element techniques, the Winkler foundations which are modelled by series of vertical springs at the

* Prof. Dept. of Civil Eng., Hanyang University, Seoul, Korea

** Graduate Student of Civil Eng., Hanyang University, Seoul, Korea

nodes are generally used for the computer modelling of subbases under the concrete slab.

This model accounts for the deflections immediately under the loaded points or the nodes. The vertical springs does not account for the interactions of the soil. In a linearly elastic material or layer, when a load is applied, the surface deflects under the load. Besides, deflections also occur in the unloaded area adjacent to the load, with deflections diminishing with distance.

Consequently, the two-parameter soil foundation model is introduced as the most mathematically convenient model to enable deflections outside the loaded area to be considered.(Ref.2) This two-parameter soil foundation model is used to upgrade the existing Winkler foundation model in the current finite-element analysis program.

2. winkler foundation model

A jointed concrete pavement is usually modeled by a three continuous slab system with two intermediate joints as shown in Figure 2. Each concrete slab is modeled as an assemblage of rectangular plate bending elements. Load transfers across the transverse joints between two adjoining slabs are modeled by shear(or linear) and rotational(or torsional) springs connecting the slabs at the nodes of the elements along the joint.

Frictional effects of the tie bars at the longitudinal joints are modeled by shear springs at the nodes along the longitudinal edges. The subgrade is modeled as a Winkler foundation which is modeled by a series of vertical springs at the nodes. Subgrade voids are modeled as initial gaps between the slab and the springs at the nodes. A spring stiffness of zero is used when a gap exists.(Ref.1)

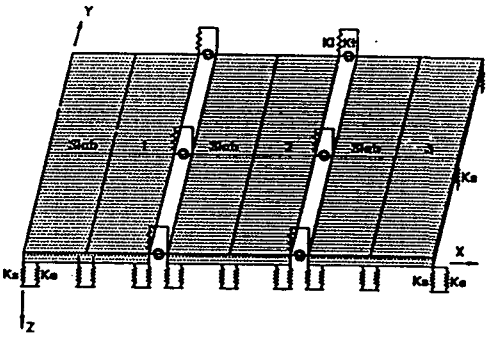

Fig.1 Finite element modeling of a three slab pavement system

Herewith, the basic governing equation for the Winkler foundation is given as (Ref.2)

$$P = KW$$

where, P = Applied loads

K = Subgrade stiffness
W = Vertical deflections

The stiffness for the KW term is the subgrade modulus times the effective area of the node.

3. two-parameter soil foundation model

Despite the fact that the concrete pavements bend up and down as a whole unit according to the point of load applications, thermal and moisture gradients. The Winkler foundation model makes use of simple assumptions that deflections occur immediately under the loaded points only. The vertical springs does not account for the interactions of the soil. However, deflections also occur in the unloaded area adjacent to the load, with deflections diminishing with distance.

Accordingly, the two-parameter soil foundation model in Ref.2 is adopted to enable deflections outside the loaded area to be effected. This model can be considered as the tops of the Winkler springs forming the ground surface being tied together by a stretched elastic spring, membrane or shear beam. The effect of the stretched string on the mathematics is to modify the surface reactions of the foundation soil from the simple P=KW of the Winkler spring to following derivations.

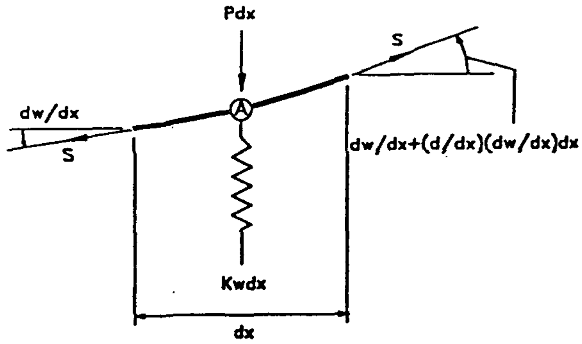

Fig.2 Free body diagram of the forces on a two-parameter soil foundation model

By applying for the equilibrium of forces, summation of forces in the vertical direction gives

$$KW\cdot dx + S\left\{\frac{dW}{dx} + \left(\frac{d^2W}{dx^2}\right)\cdot dx\right\} - S\cdot\frac{dW}{dx} - P\cdot dx = 0$$

Since the two $S\cdot\frac{dW}{dx}$ terms cancel each other,

Above equation becomes

$$P\cdot dx = KW\cdot dx + S\cdot\left\{\frac{d^2W}{dx^2}\right\}dx$$

By dividing each terms by dx,

$$P = KW + S\cdot\left\{\frac{d^2W}{dx^2}\right\}$$

In Figure 2, the string are connected to point A in the X direction. The

pavement structures require a two dimensional foundations. Therefore, there must also be strings connected to point A in the Y-direction in order to account for a two dimensional foundation.
Similarly, above equation extended for the X and Y directions is

$$P = KW + S \cdot \left\{ \frac{d^2 W}{dx^2} \right\} + S \cdot \left\{ \frac{d^2 W}{dy^2} \right\}$$

Therefore, the governing equation for the two-parameter soil foundation model for the concrete pavements is finally given as

$$P = KW + S \cdot W_{x,x} + S \cdot W_{y,y}$$

where, the subscripts X and Y denotes the partial derivatives of W with respect to X and Y.

4. conclusion

The Winkler foundation which was used to model the subgrade in the pavement structures has been upgraded to a two-parameter soil foundation model, which accounts for deflections outside the loaded area. This mathematically upgraded model effects the overall slope of the deflection curves.

Tension forces in the horizontal strings, S1, S2 in the X, Y directions, turns out to be similar values. Field test shows that S1 and S2 values which range from 35% to 55% of the estimated subgrade modulus describes deflection profiles that are close to the measured deflections. S1 and S2 values can be used to change the slope of the deflection curves and shift the curves up or down.

This two-parameter soil foundation model is turned out to be effective in the pavement structures. Accordingly, the finite element derivations for the upgraded subgrade stiffness should be performed and implemented in the program in the near future.

5. reference

1. Byung-Wan Jo
"A Finite Element Parametric Study for the Response of Concrete Highway Pavement with Skewed Joints", Ph D Dissertation

2. Ronald F. Scott
"Foundation Analysis", Prentice-Hall, Inc.,Englewood Cliffs

3. William Weaver Jr., Paul R. Johnson
"Finite Elements for structural Analysis", Prentice-Hall, Inc., Englewood Cliffs