Effect of a Second Subbase Layer

The subgrade k value was originally developed for characterizing the support of natural soils with fairly low shear strength. Substantially higher k values were obtained based on plate tests on the top of granular and stabilized base layers. The FAA airfield pavement design approach as well as the current PCA design procedure and the 1986 AASHTO Guide for concrete highway pavements all adopt the concept of a composite "top-of-the-base" k-value for design, though many researchers have indicated the inadequacy of this concept. Through the review of results from several field studies and the examination of the k-value methods introduced in the 1986 AASHTO Guide, "it is recommended that k values be selected for natural soil materials, and that base layers be considered in concrete pavement design in terms of their effect on the slab response, rather than their supposed effect on k value" (Hall et al. 1995; Darter et al. 1995). Improved guidelines for k-value selection from a variety of methods are provided in the 1998 Supplement Guide for the design of concrete pavement structures accordingly.

Even though the concept of transformed section was frequently utilized to account for the stress reduction factor (R_5) due to a bonded or unbonded second layer, it was found sometimes misused in the literature (Salsilli-Murua 1991; Lee et al. 1997; Kuo 1994). Subsequently, a more complete treatment of this concept is presented as follows.

Stress Adjustment due to a Second Unbonded Subbase Layer

Following the formulation given by Tabatabai-Raissi (1977), a system of two unbonded layers is transformed into an equivalent single layer based on the assumption of same total bending moment as shown in Figure 3. The maximum bending moment per unit of width of a given single layer is equal to $\sigma h^2/6$. Assuming both layers have the same Poisson's ratio, the relationship of the top layer stress (σ_1) and the bottom layer stress (σ_2), the total bending moment per unit of width (M_T) and the effective thickness (h_{eff}) can be expressed by:

[10] $$\frac{\sigma_1}{\sigma_2} = \frac{E_1 h_1}{E_2 h_2}$$

[11] $$M_T = \frac{\sigma_1}{6}\left[h_1^2 + \left(\frac{E_2 h_2}{E_1 h_1}\right)h_2^2\right] = \frac{\sigma_1 h_{eff}^2}{6}$$

[12] $$h_{eff} = \sqrt{h_1^2 + \left(\frac{E_2 h_2}{E_1 h_1}\right)h_2^2}$$

In which, E_1, E_2= modulus of elasticity of the slab and subbase layers; and h_1, h_2= thickness of the slab and subbase layers, respectively.

Alternatively, using equivalent moment of inertia per unit of width (I_{eff}) for the transformed section with modulus E_1, the effective thickness (h_{eff}) and the slab bending stress (σ_{unbond}) of the two-layer unbonded system can be determined by:

[13] $$I_{eff} = I_1 + \left(\frac{E_2}{E_1}\right)I_2 = \frac{h_1^3}{12} + \left(\frac{E_2}{E_1}\right)\frac{h_2^3}{12} = \frac{h_{eff}^3}{12}$$

[14] $$h_{eff} = \sqrt[3]{h_1^3 + \left(\frac{E_2}{E_1}\right)h_2^3}$$

[15] $$\sigma_{unbond} = \sigma_{wc} \times \frac{h_1}{h_{eff}} \times \frac{\sigma'}{\sigma} = \sigma_{wc} \times R_5$$

In which, σ and σ' are the slab bending stress of a single layer and the equivalent single layer to be determined by equation (1), respectively. Also note that the multiplication factor of h_1/h_{eff} is necessary to adjust the stress proportionally according to Figure 3 (b) and (c).

Stress Adjustment due to a Second Bonded Subbase Layer

As for the case of two bonded layers, considering a cross section of the slab/subbase system as an equivalent single layer, its corresponding strain and stress relationships are shown in Figure 4. The location of the neutral axis is defined at a distance x' from the bottom of the second layer:

$$[16]\quad x' = \frac{E_1 h_1^2 + 2E_1 h_1 h_2 + E_2 h_2^2}{2(E_1 h_1 + E_2 h_2)}$$

In which, α' and β' are the distances of the neutral axis from the middle surfaces of the second layer and the top layer, respectively ($\alpha' = x' - h_2/2,\ \ \beta' = h_2 + h_1/2 - x'$).

By converting this system into an equivalent unbonded system as shown in Figure 5, the equivalent top layer thickness (h_{1f}) and bottom layer thickness (h_{2f}) become $h_{1f} = \sqrt[3]{h_1^3 + 12h_1\beta'^2}$ and $h_{2f} = \sqrt[3]{h_2^3 + 12h_2\alpha'^2}$. Similarly, using the equivalent moment of inertia per unit of width (I_{eff}) for the transformed section with modulus E_1, the effective thickness (h_{eff}) and the slab bending stress (σ_{bond}) of the two-layer bonded system can be determined by the following expression:

$$[17]\quad h_{eff} = \sqrt[3]{h_{1f}^3 + \left(\frac{E_2}{E_1}\right) h_{2f}^3}$$

$$[18]\quad \sigma_{bond} = \sigma_{wc} \times \frac{2(x' - h_2)}{h_{eff}} \times \frac{\sigma'}{\sigma} = \sigma_{wc} \times R_5$$

In which, σ and σ' are the slab bending stress of a single layer and the equivalent single layer to be determined by equation (1), respectively. Also note that the multiplication factor of $2(x'-h_2) / h_{eff}$ is necessary to adjust the stress proportionally according to Figure 5 (a) and (b).

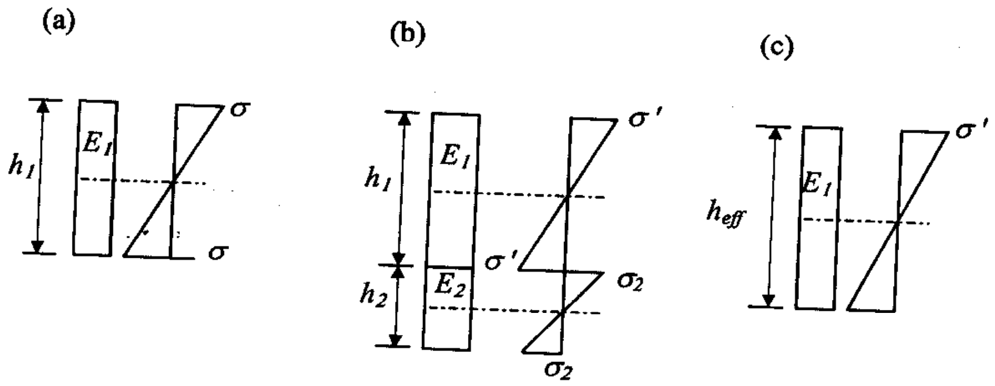

Figure 3 - Transforming two unbonded layers into an equivalent single layer: (a) single layer; (b) two unbonded layers; (c) equivalent single layer

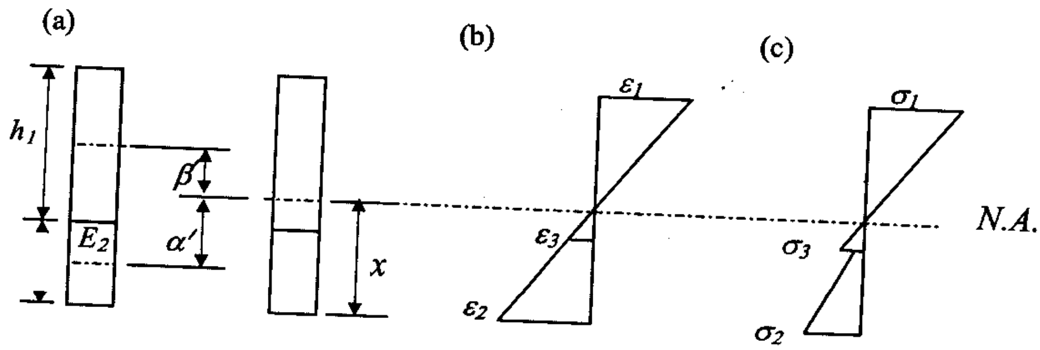

Figure 4 - Considering two bonded layers as an equivalent single layer: (a) two bonded layers; (b) strain; (c) stress

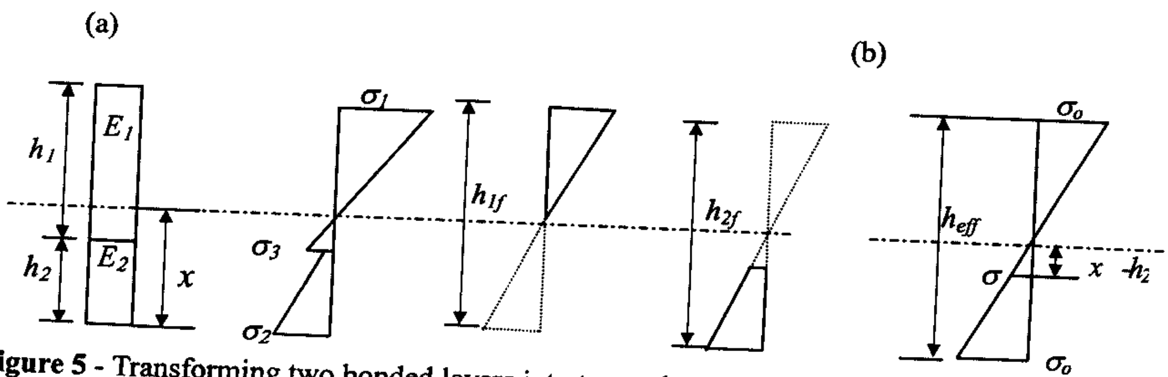

Figure 5 - Transforming two bonded layers into two unbonded layers: (a) converting into two unbonded layers; (b) stress