Optimizing Structural Design for Overlaying HMA Pavements with a Concrete Pavement Using Critical Stress/Strain Analysis

Richard Rogers[1], Michael Plei[2], Nancy Aguirre[3], Abbasali Taghavighalesari [3]

[1] Cement Council of Texas, [2] Consultant, [3] Department of Civil Engineering, The University of Texas at El Paso

Abstract

The critical design elements in each pavement layer were compared among traditional ***Elastic Layer Theory, 3-D Finite Element*** and ***Winkler*** modeling approaches. The weaknesses and strengths of each method were noted.

The continuously reinforced concrete pavement (CRCP) structure can be optimized for both stresses and strains using the Elastic Layer Theory Method and the 3-D Finite Element Method to maximize the performance and to minimize the cost. For jointed concrete pavement, only the 3-D Finite Element Method is currently considered.

Why is Optimizing Critical Load Analysis Important?

- Despite the fact that current concrete designs conservatively ensure that the critical concrete stress is below 20% of the design strength, failure of concrete pavements is not uncommon. The contributing factors:
  - Construction issues,
  - Lack of durable supporting layers,
  - Excessive critical stresses/strains in the supporting layers that exceed their elastic limits and that results in permanent deformation.
- While most concrete pavements are exceeding their design life expectancy, overlaying of existing pavements with concrete pavements are seldom considered because the current design methods are too conservative and hence result in higher construction costs.
- Ability to optimize the depth of reclaiming existing pavements that are no longer durable and provide a more efficient and effective method to preserve our nation's infrastructure.

Analysis Tools

FPS-21	NYSLAB
▪ Assumes a semi-infinite continuum medium ▪ Loading condition similar to load applied at the center of a single slab (interior loading) ▪ Limited to seven pavement layers	▪ Simulate an entire truck on a slab system ▪ No limit on the number of pavement and foundation layers ▪ Models PCC slabs as plate elements

Elastic Layer Theory	Winkler Model	3-D Foundation Model
▪ Considers thickness, elastic modulus and Poisson's ratio for each supporting layer ▪ Linear elastic response	▪ Considers supporting layers as a set of linear elastic vertical springs with a constant axial stiffness ▪ Contribution of all foundation layers (base, subbase and subgrade) is manifested as a single modulus of subgrade reaction or *k*-value	▪ All foundation layers (base, subbase and subgrade) are modeled using 3-D solid elements

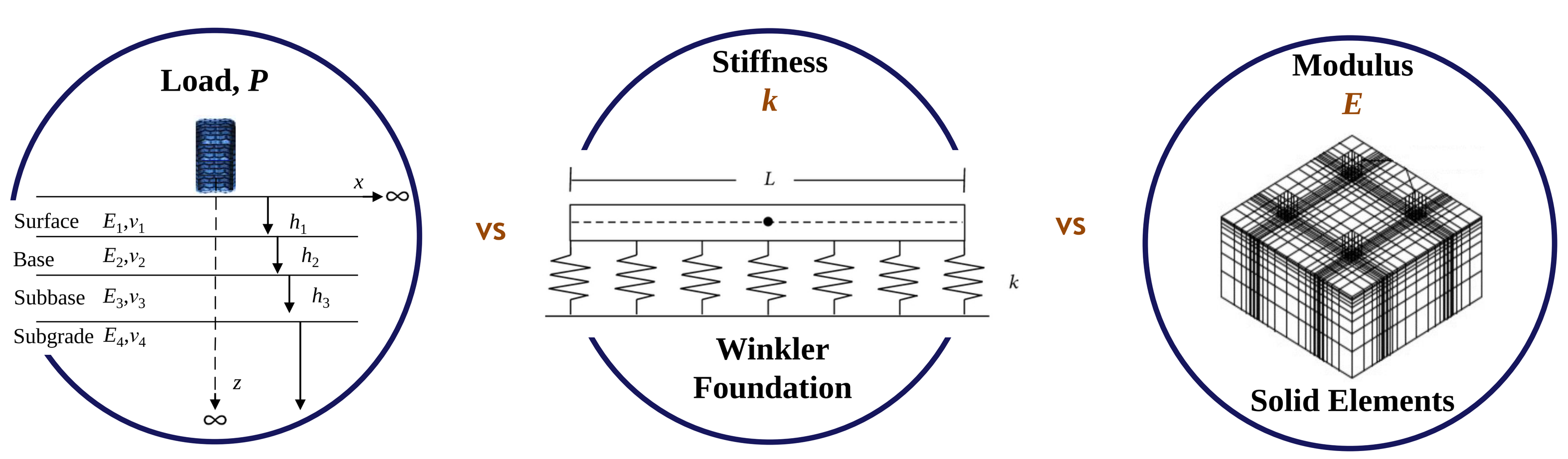

Figure 1. Comparison of Foundation Models

Has Elastic Layered Theory ever been used before for Design of Concrete Pavements?

- Based on the work of the late Dr. B. Frank McCullough, at The University of Texas, at Austin, in the early 1980's continuously reinforced concrete (CRCP) pavement overlay sections across Texas were designed and built.

Even though these pavements were designed for only a 20-year service life, many are still in service today, including the main lanes of IH 35, in San Antonio with a 7-inch CRCP over the existing pavement.

- Performance of relatively thin layers of roller compacted concrete (RCC) over thick stabilized layers in Louisiana can only be explained with 3-D Finite Element or Elastic Layered Theory.
- Both Elastic Layered Theory and 3-D Finite Element analysis can also be used to explain why new roads in the energy sector, designed using the K-value, have failed in less than one month.

Parametric Studies

Table 1. Case I. CRCP over Hot Mix Asphalt (HMA)

Pavement Layers	Thickness (in.)	Poisson Ratio	Modulus (ksi)
CRCP	6,7,8,9,10,11 &12	0.15	5000
Existing HMA	4	0.35	700
Existing Asphalt Base	8	0.40	350
Subgrade	144	0.35	5

Table 2. Case II. CRCP over Full Depth Reclamation (FDR)

Pavement Layers	Thickness (in.)	Poisson Ratio	Modulus (ksi)
CRCP	6,7,8,9,10,11 &12	0.15	5000
FDR	4,6,8 & 10	0.20	500
Distressed Asphalt Base	8,6,4 & 2	0.40	50
Subgrade	144	0.35	5

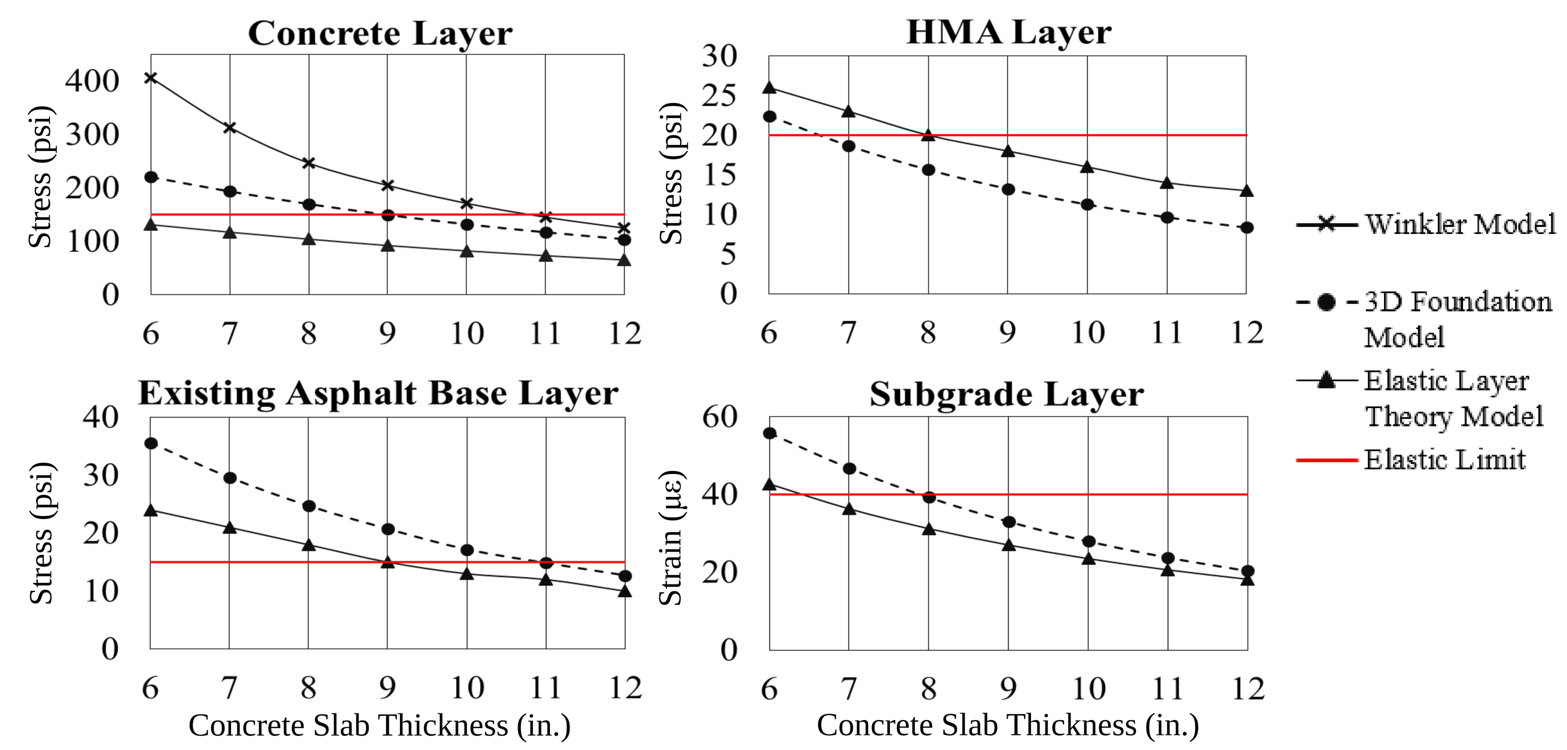

Figure 2. Comparison of Responses under a 10 kip Load from different Foundation Models (Case I)

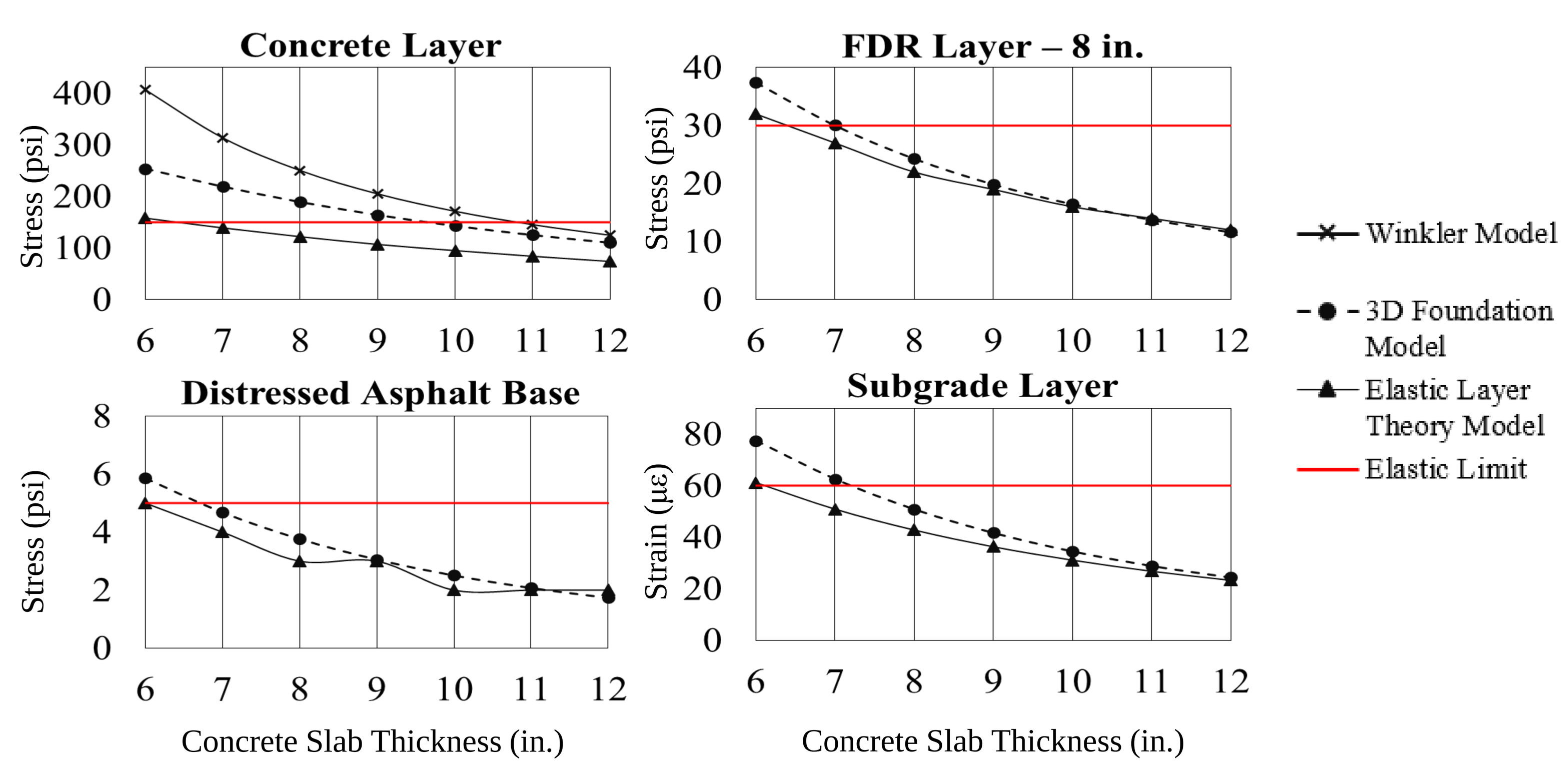

Figure 3. Comparison of Responses under a 10 kip Load from different Foundation Models (Case II)

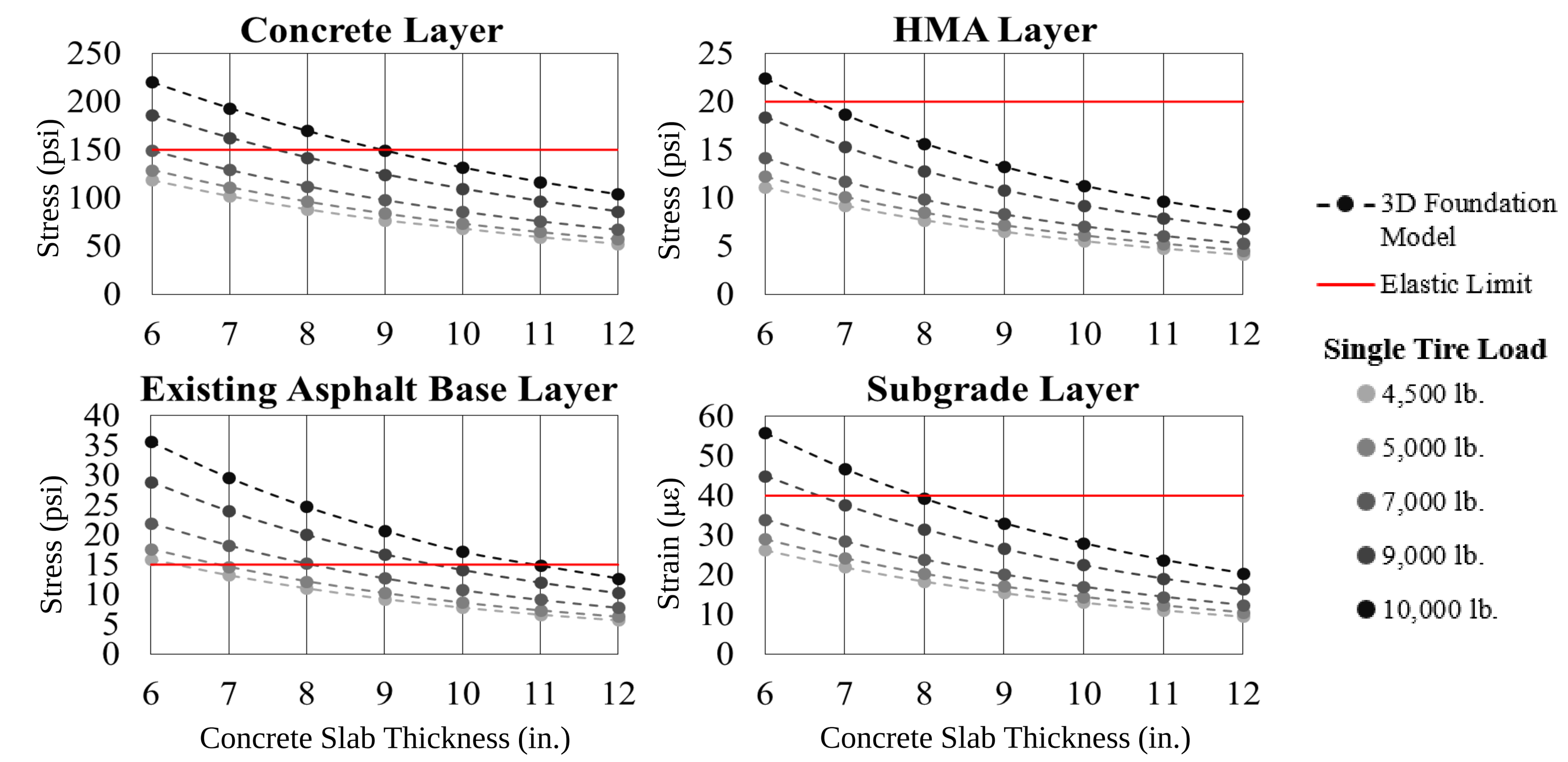

Figure 4. Effects of Varied Loading Using 3D Foundation Model (Case I)

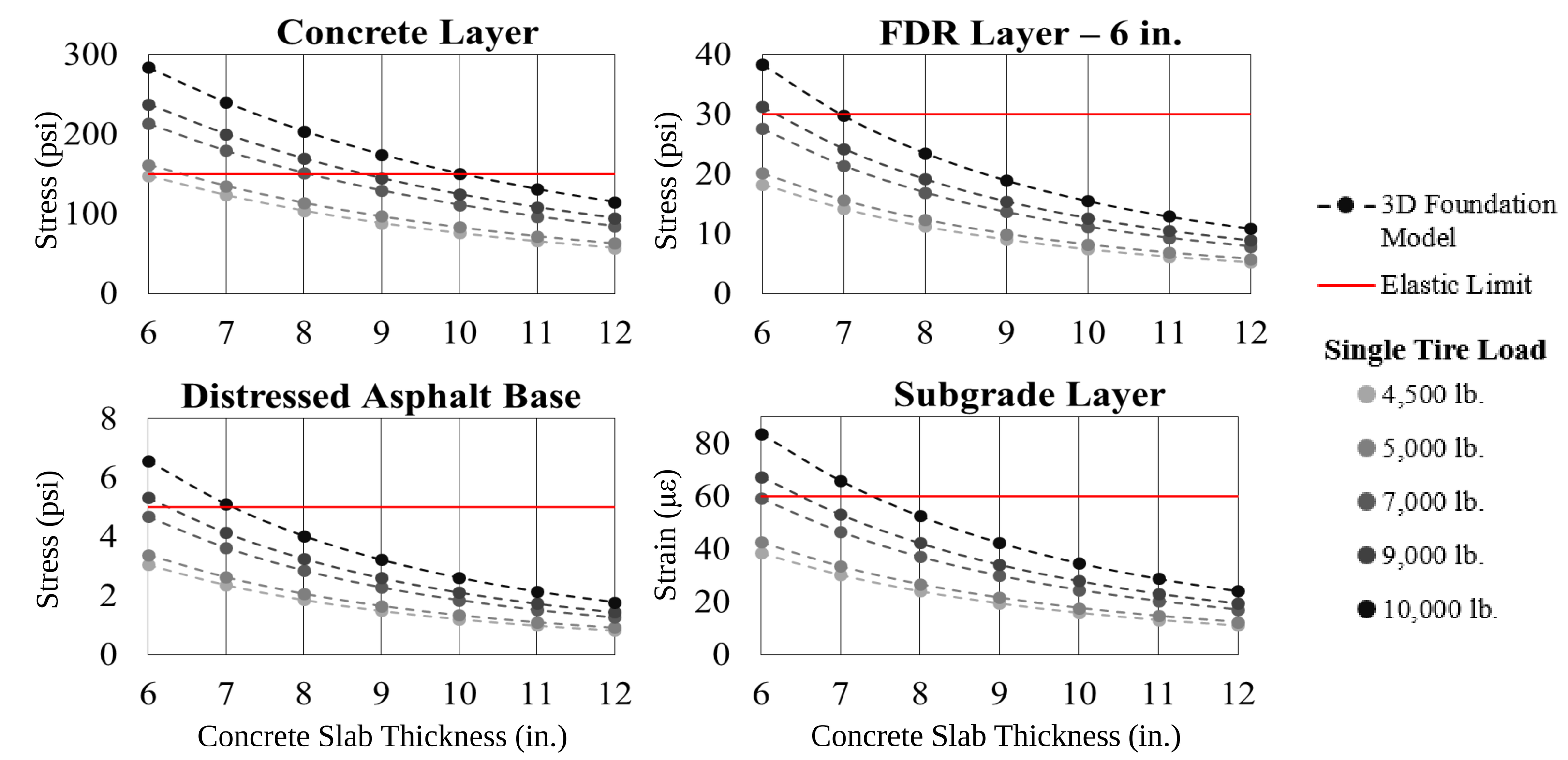

Figure 5. Effects of Varied Loading Using 3D Foundation Model (Case II)

Summary and Conclusions

- While none of the methods presented took into account the environmental effects or the durability of the pavement layers, both the Elastic Layered Theory and the 3-D Finite Element models did provide an assessment of the critical stresses and strains for the pavement structure.
  - The Elastic Layered Theory model and the 3-D Foundation model provided an assessment of the critical responses for all pavement layers.
  - The Winkler model is limited to the assessment for the concrete layer only.
  - The Winkler model demonstrated higher concrete stresses compared with the Elastic Layered Theory model and 3-D Foundation model.
  - The critical stresses and strains for all foundation layers (base, subbase and subgrade) obtained from the 3-D Foundation model provided similar results to the corresponding stresses obtained from the Elastic Layered Theory model.
- The Elastic Layered Theory and the 3-D Finite Element models allow the structural modeling of concrete overlays and provide an assessment for the depth of full depth reclamation.
  - Increasing the depth of the FDR layer provided lower concrete stresses and lower subgrade strains.
- The linear response models already evaluate the benefits and limitations of the supporting layers. Moreover, the use of Finite Element method allows the implementation of algorithms that can account for the nonlinear response to the load of the soil.