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Effects of Materials Properties and Thickness Variations of a Multilayer Elastic System under Dual-Tandem Axle Load using KENLAYER Program

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Abstract

Flexible pavements can be modeled as multilayered elastic systems. Each of the pavement layers can have its own elasticity parameters such as the modulus of elasticity and poison's ratio. The objective of this study is to investigate the effects of variations of modulus of elasticity of each layer on pavement performance or response which reflected as displacement values, also thickness effect of each layer within the system was studied under the dual-tandem axles. KENLAYER program was used to conduct this objective. After running KENLAYER program for fifteen cases that simulates cases for study, it was found that displacement values were decreased when thickness increased, and increased when modulus of elasticity for each layer was decreased.

Key Wards: Flexible pavement, Displacement, layer system, , KENLAYER program

الخلاصة

يمكن تمثيل التبليط المرن بنظام متعدد الطبقات ولكل طبقة خصائصها المرنة مثل معامل المرونة ونسبة بوسون. الهدف من الدراسة هو بحث تأثيرات التغيرات في معامل المرونة لكل طبقة من طبقات التبليط الإسفلتي على أداء التبليط معبرا عنه بالتغير الحاصل في قيم الإزاحة , كما تمت دراسة تأثير التغير في عمق كل طبقة من الطبقات تحت تأثير حمل محوري مزدوج . تم استخدام برنامج KENLAYER للوصول لهدف الدراسة.تبين من خلال النتائج التي تم الحصول عليها من البرنامج وفي خمس عشرة حالة مثلت حالات التغير المفترضة إن قيم الإزاحة قلت في حالات زيادة العمق وازدادت في حالات نقصان قيم معاملات المرونة للطبقات المختلفة.

1. Introduction

Flexible pavements generally consist of a prepared subgrade layer which is the roadbed soil or borrow material compacted to a specified density. A subbase course is constructed on top of the prepared roadbed, and may be omitted if the subgrade soil is of a high quality. The base course is constructed on the subbase course, or if no subbase is used, directly on the roadbed soil. It usually consists of aggregates such as crushed stone, or crushed gravel and sand. On top of the base course is the surface course that typically consists of a mixture of mineral aggregates and bituminous materials.

A layered elastic model can compute stresses, strains and deflections at any point from the application of a surface load. Layered elastic models assume that each structural layer is homogeneous, isotropic, linearly and elastic. In other wards, it is the same everywhere and will rebound to its original form once the load is removed. The origin of layered elastic theory is credited to V.J.Boussinesq who published his classic work in 1885.Today, Boussinesq influence charts are still widely used in soil mechanics and foundation. design.*(Huang,1993)*

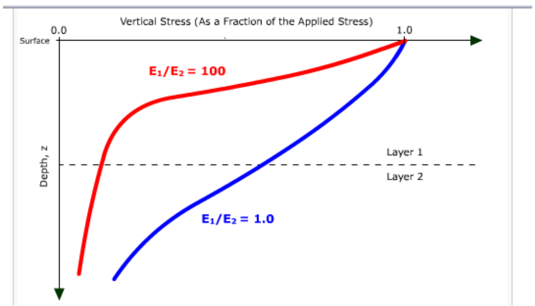
How a pavement responds to applied stresses determines how it will behave structurally. Stresses and the resultant pavement response are the combined result of loading, environment, subgrade and pavement material characteristics. The next articles of this paper present the typical stresses and stress characteristics experienced by a flexible pavement under load.*(Waelt.al2006)*

1.1 Stress

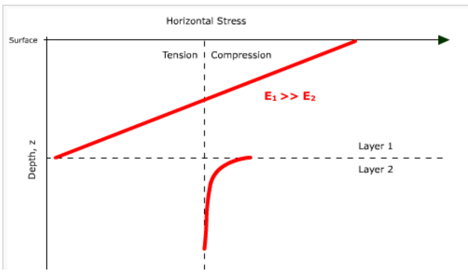
The stresses occurs in a flexible pavement under load are quite complex. Although rigid pavement stresses have been routinely calculated since the 1920s, routine calculation of flexible pavement stresses is more recent development. First, two dimensional layered elastic programs offered desktop computers the ability to calculate these stresses. More recently, three dimensional finite element programs have allowed more exact and detailed calculations.*{ Khabiri ,2008.)*

1.2Two- Dimensional Layered Elastic Model

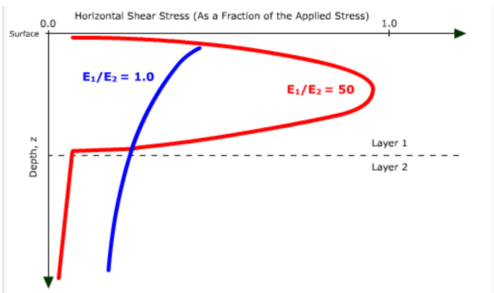
Using a two- dimensional layered elastic model, the basic relationships between layer stiffness and stress for a two- layer flexible pavement structure is show in Fig. (1). Fig. (a) shows vertical stress as a fraction of applied stress with depth, Fig. (b) shows relationship of horizontal stress with depth and Fig. (c) shows relationship of horizontal shear stress as a fraction of the applied stress) In reality, stress distributions are more complex, however the basic relationship hold true.



(a): Vertical stress as a fraction of applied stress with depth



(b) Relationship for horizontal stress with depth



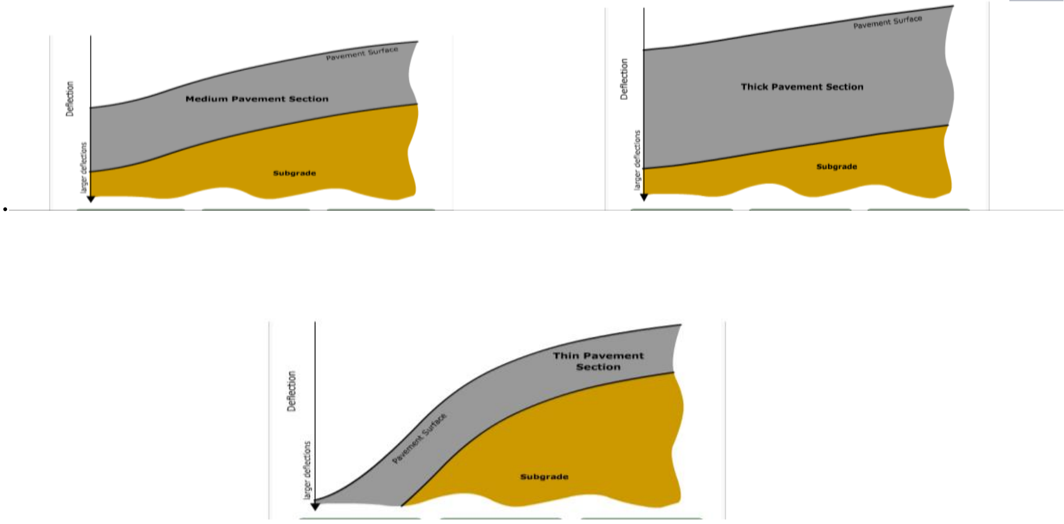
(c) (Relationship for horizontal shear stress as a fraction of the applied stress)

Fig. (1): the basic relationships between layer stiffness and stress for two layer flexible pavement

1.3 Surface Deflection

The pavement surface must be constructed to a higher standard than other layers in the pavement structure. It is subjected to both direct loadings from the applied traffic and greater wear from environmental factors. The surface layer is designed to provide a smooth riding surface while maintaining adequate friction. Because of its importance to the overall pavement structure, materials used in the construction of the surface are generally of higher quality. The materials most commonly used for pavement surfacing are aggregates, asphalt mixtures, and Portland cement concrete (PCC).

HMA(hot mix asphalt) pavements are often described as "flexible" because they reflect under load. Fig. (2) shows deflections for different pavement thicknesses*(Yoder 1975)(www.wikipidia).*



Fig(2) Deflections for different pavement thicknesses

From the above three figures it can be noticed that deflection is clearer when layer thickness is less.

1.4 Multi-Layer System

Usually a base layer with an underlying subbase layer is placed between the asphalt concrete and subgrade. These layers may be either unbound or stabilized granular materials which have distinctly different properties from the surface and subgrade layers.*(Yoder,197)5*. For a three-layer pavement several charts and tables have been developed by Peattie Jones and Fox, to determine the stresses, strains and deflections. Peattie (1962) developed graphical solutions for vertical stress in three-layer systems. Jones (1962) presented solutions for horizontal stresses in a tabular form. The logical extension of these solutions was the development of computer programs in order to expedite analysis and allow greater flexibility in accommodating material properties and multiple loads. During the 1980s, as these mainframe computer programs were converted to run on microcomputers, a greater potential was developed to use elastic analysis tools in pavement design and rehabilitation decision-making.

Typical input required for using these computer programs include:

1. Material properties of each layer like:
   - Modulus of elasticity
   - Poisson ratio
2. Thickness of each pavement layer
3. Loading conditions including:
   - Magnitude of load
   - Radius of load
   - Contact pressure
   - Location of analysis points for output (x,y coordinates)

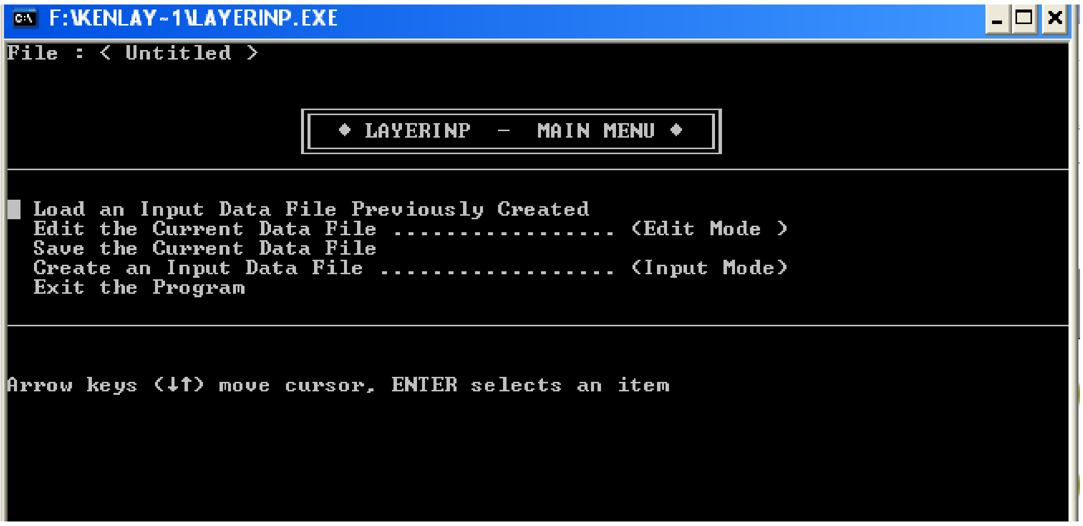
In this research, sensitivity analysis was carried out to illustrate the effect of various parameters pavement responses, variables to considered were: layer thicknesses (h1 & h2) and layer modulus of Elasticity (E1, E2 & E3) under dual axle load. KENLAYER computer program was used to compute strain values obtained due to application of the previous cases.

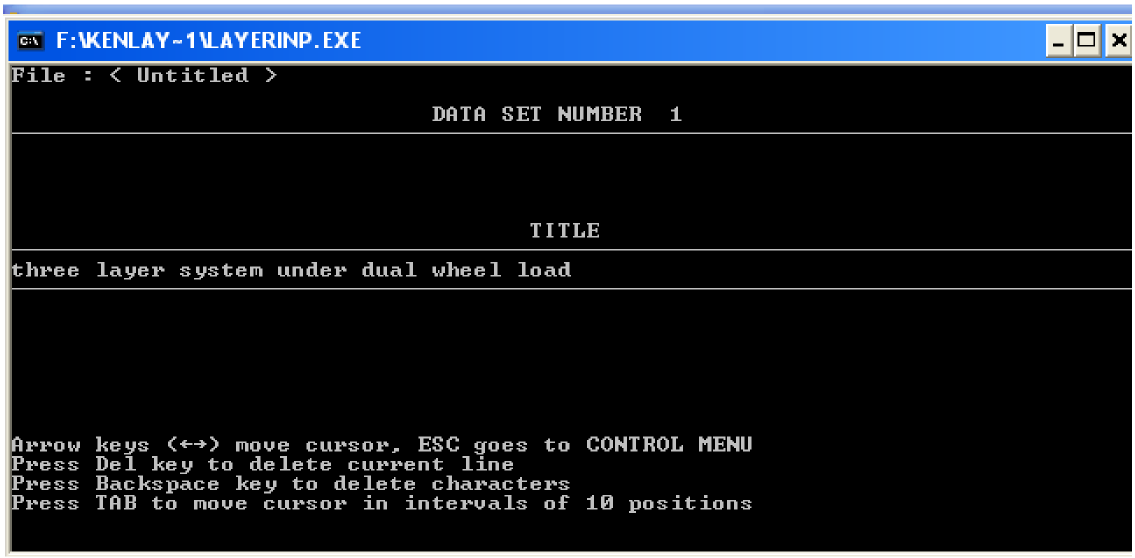
2. Application of KENLAYER computer program

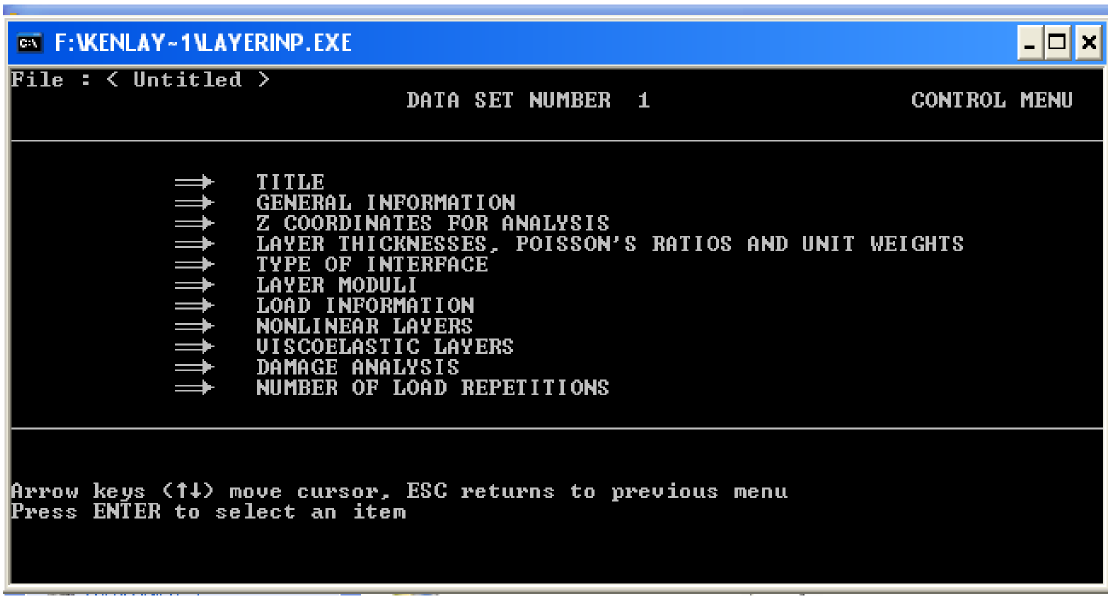
KENLAYER computer program applies only for flexible pavements with no joints. The backbone of KENLAYER is the solution for an elastic multilayer system under circular loaded are area.

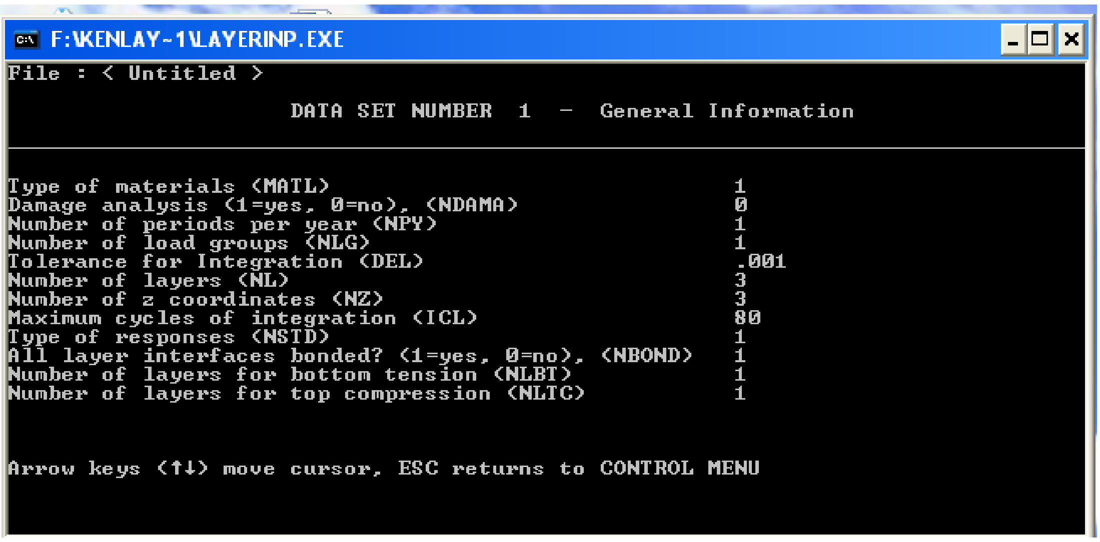
The solutions superimposed for multiple wheels, applied iteratively for non-linear layers, and collocated at various times for viscoelastic layers. As a result, KENLAYER can be applied to layered systems under single, dual- tandem or dual-tridem wheels with each layer behaving differently, linear elastic, nonlinear elastic, or viscoelastic.*(Daba.2007)*). In this study systems to be studied are linear elastic systems under a set of dual-tandem tires.

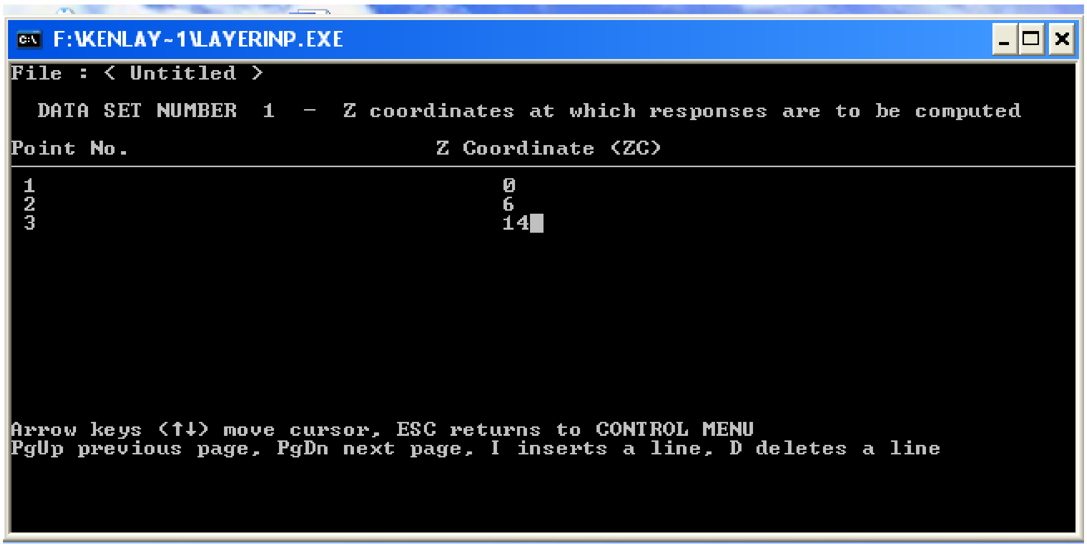
Main Input screens for KENLAYER program are shown below.

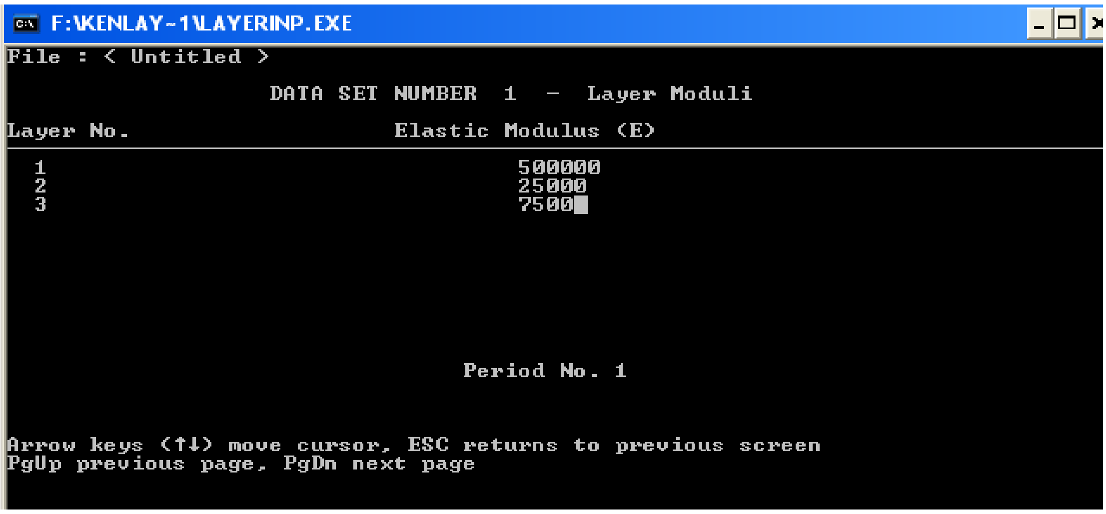


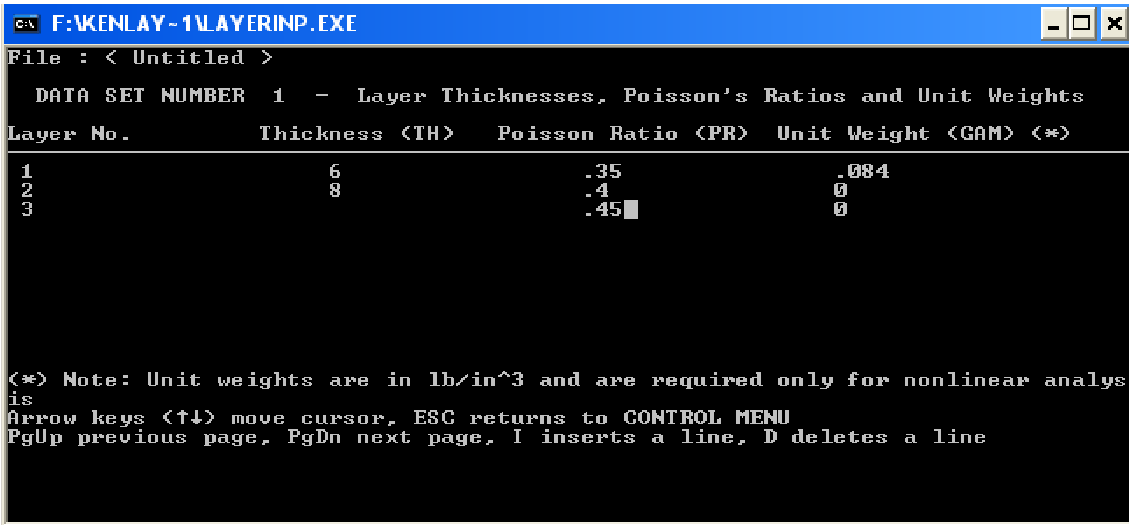

F:\KENLAY~1\LAYERINP.EXE
File : < Untitled >
DATA SET NUMBER 1
TITLE
three layer system under dual wheel load
Arrow keys (←→) move cursor, ESC goes to CONTROL MENU
Press Del key to delete current line
Press Backspace key to delete characters
Press TAB to move cursor in intervals of 10 positions

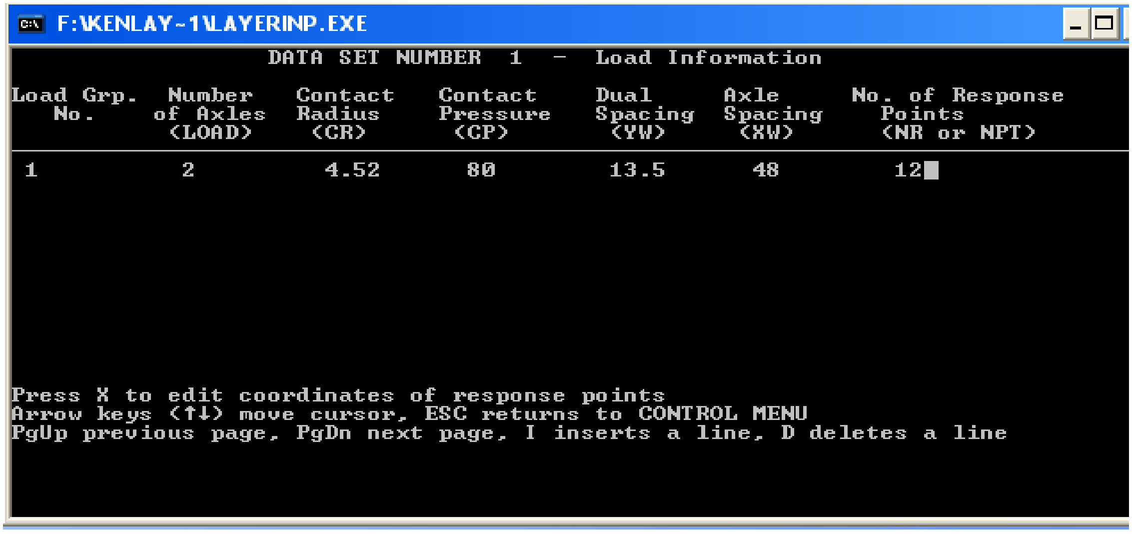

F:\KENLAY~1\LAYERINP.EXE
File : < Untitled >
DATA SET NUMBER 1
CONTROL MENU
TITLE
GENERAL INFORMATION
Z COORDINATES FOR ANALYSIS
LAYER THICKNESSES, POISSON'S RATIOS AND UNIT WEIGHTS
TYPE OF INTERFACE
LAYER MODULI
LOAD INFORMATION
NONLINEAR LAYERS
VISCOELASTIC LAYERS
DAMAGE ANALYSIS
NUMBER OF LOAD REPETITIONS
Arrow keys (↑↓) move cursor, ESC returns to previous menu
Press ENTER to select an item


F:\KENLAY~1\LAYERINP.EXE
File : < Untitled >
DATA SET NUMBER 1 – General Information
Type of materials (MATL) 1
Damage analysis (1=yes, 0=no), (NDAMA) 0
Number of periods per year (NPY) 1
Number of load groups (NLG) 1
Tolerance for Integration (DEL) .001
Number of layers (NL) 3
Number of z coordinates (NZ) 3
Maximum cycles of integration (ICL) 80
Type of responses (NSTD) 1
All layer interfaces bonded? (1=yes, 0=no), (NBOND) 1
Number of layers for bottom tension (NLBT) 1
Number of layers for top compression (NLTC) 1
Arrow keys (↑↓) move cursor, ESC returns to CONTROL MENU


F:\KENLAY~1\LAYERINP.EXE
File : < Untitled >
DATA SET NUMBER 1 – Z coordinates at which responses are to be computed
Point No. Z Coordinate (ZC)
1 0
2 6
3 14
Arrow keys (↑↓) move cursor, ESC returns to CONTROL MENU
PgUp previous page, PgDn next page, I inserts a line, D deletes a line


F:\KENLAY~1\LAYERINP.EXE
File : < Untitled >
DATA SET NUMBER 1 – Layer Moduli
Layer No. Elastic Modulus (E)
1 500000
2 25000
3 7500
Period No. 1
Arrow keys (↑↓) move cursor, ESC returns to previous screen
PgUp previous page, PgDn next page



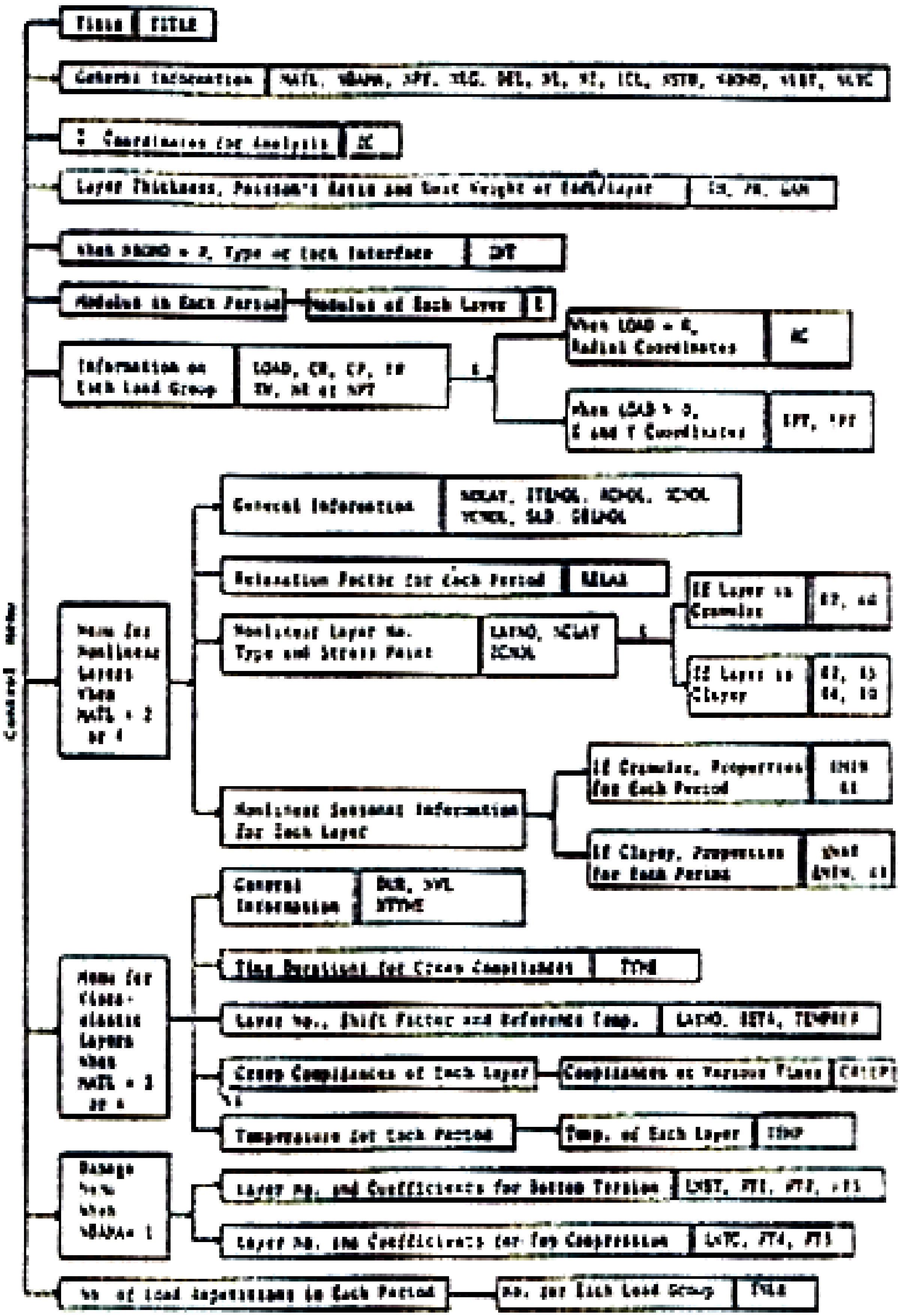


Screens of input of KENLAYER program

2.1 Input parameters in KENLAYER program

There are so many input parameters in this program. The parameters can be inputted both in British and U.S. customary units. Some of them for linear elastic analysis are traffic load, material properties, thickness of each layer, number of periods, number of load groups etc.

In flow chart shown below, all details of input parameters are illustrated.



Location of input parameters on various screens in LAYERINP

2.2Output parameters of KENLAYER

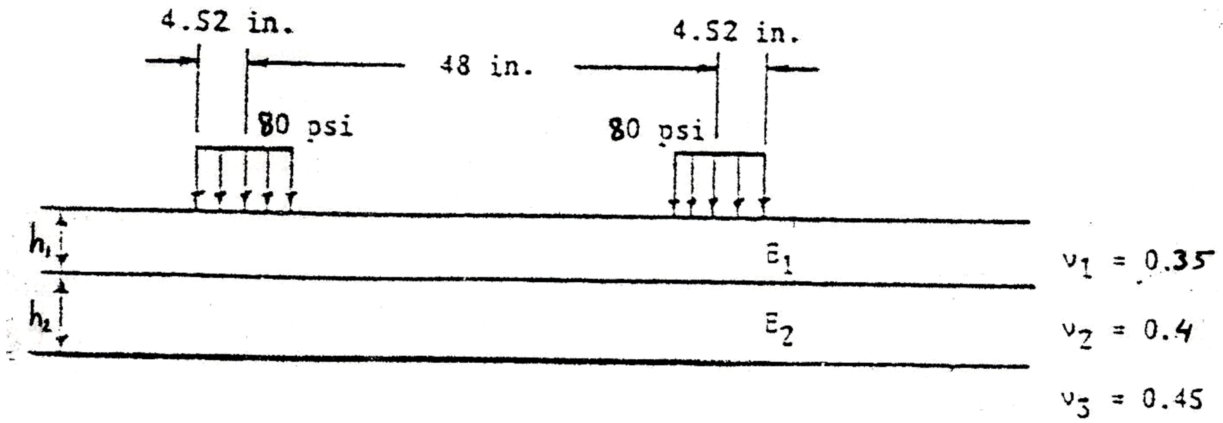
For a single and multiple load groups, a maximum of nine and ten responses can be obtained. The use of a layered elastic analysis computer program would allow to calculate the theoretical stresses, strains, and deflections anywhere in a pavement structure. However, there are a few critical locations that are often used in pavement analysis Table (1), contains the most important locations and reasons to use them.

Table (1) Critical analysis locations in a pavement structure *(www.pavementinteractive.org)*

location	Response	Reason for use
Pavement surface	deflection	Used for imposing load restrictions during spring thaw and overlay design(for example)
Bottom of HMA layer(Ist.layer)	Horizontal tensile strain	Used to predict fatigue Failure in HMA
Top of intermediate layer base or subbase(2nd.layer)	Vertical compressive stra	Used to predict rutting Failure in the base or subbase

3. Case study

Fig. (3a) shows the elastic three layer system under a set of dual-tandem tires. Each tire has a contact radius of 4.52 in. and contact pressure of 80 psi.. Displacement values were determined for twelve points shown in the figure Fig. (3b) below.



(a) System under study

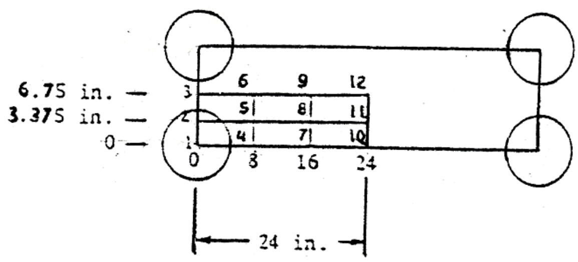


Fig.(3): Coordinates of the points under study *(Huang 1993)*

Two types of factors that would affect displacement were studied including layer thickness and modulus of elasticity. Thickness variation was studied through six cases (three cases for h1 and htree cases for h2) shown in table (2) below.

X	Y	case 1	case 2	case3	case 4	case 5	case 6
0	0	h1=2	h1=4	h1=6,	h1=2,	h1=2	h1=2
8	0	h2=8	h2=8	h2=8	h2= 6	h2= 8	h2= 10
16	0	E1=constant	E1=constant	E1=constant	E1=constant	E1=constant	E1=constant
24	0	E2=constant	E2=constant	E2=constant	E2=constant	E2=constant	E2=constant
		E3=constant	E3=constant	E3=constant	E3=constant	E3=constant	E3=constant
		E1=500000	E1=500000	E1=500000	E1=500000	E1=500000	E1=500000
		E2=25000	E2=25000	E2=25000	E2=25000	E2=25000	E2=25000
		E3=7500	E3=7500	E3=7500	E3=7500	E3=7500	E3=7500

Table (2) h1&h2 variations

3.1The effect of h1

In the first three cases the effect of changes in h1 (2, 4, and 6) in. was considered With constant h2 (8) in., trough multiple runs of KENLAYER program, it was found that displacements values would decrease with the increase of h1 as shown in Figs. (4a,b,c).

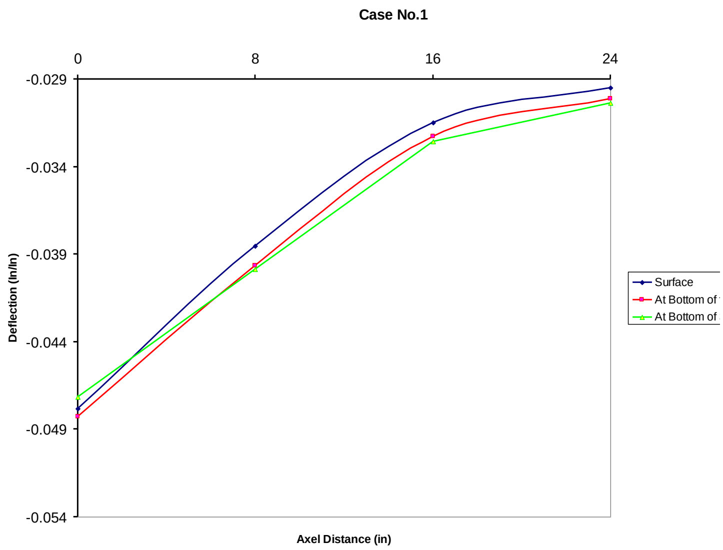


Fig (a): (for h1=2)

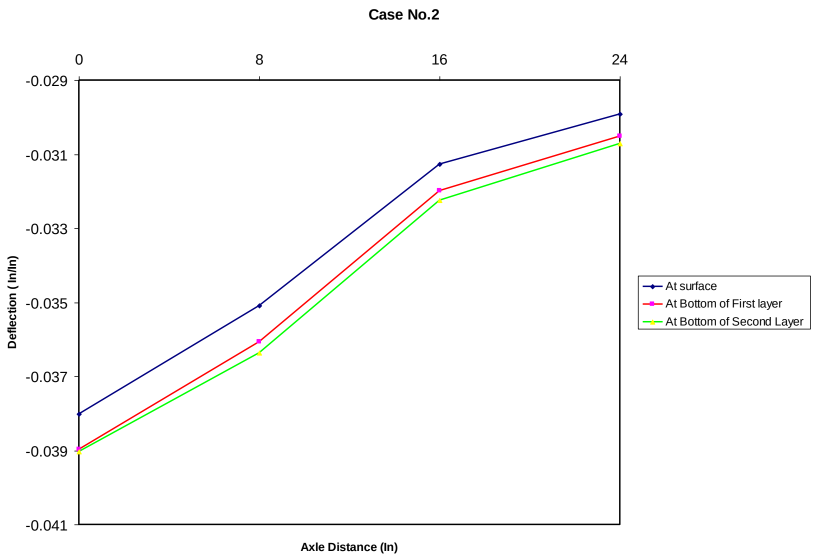


Fig (b): (for h1=4)

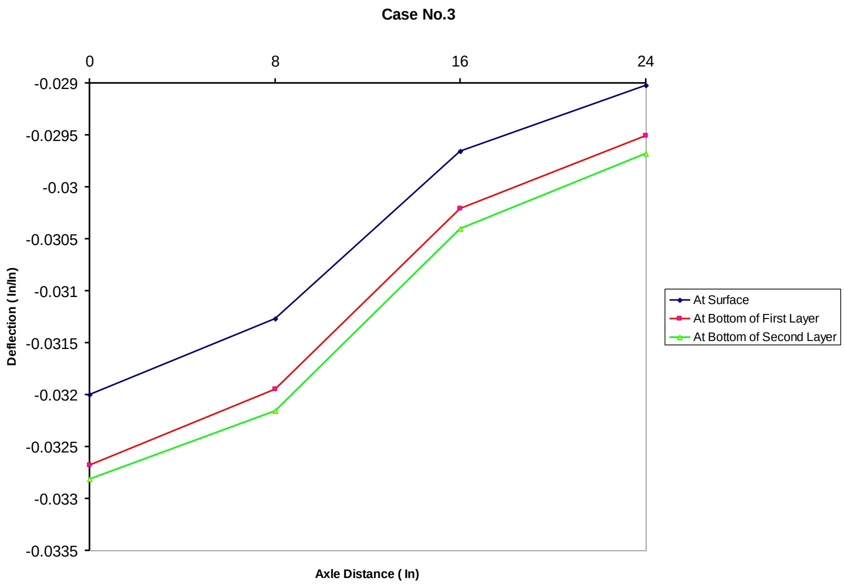
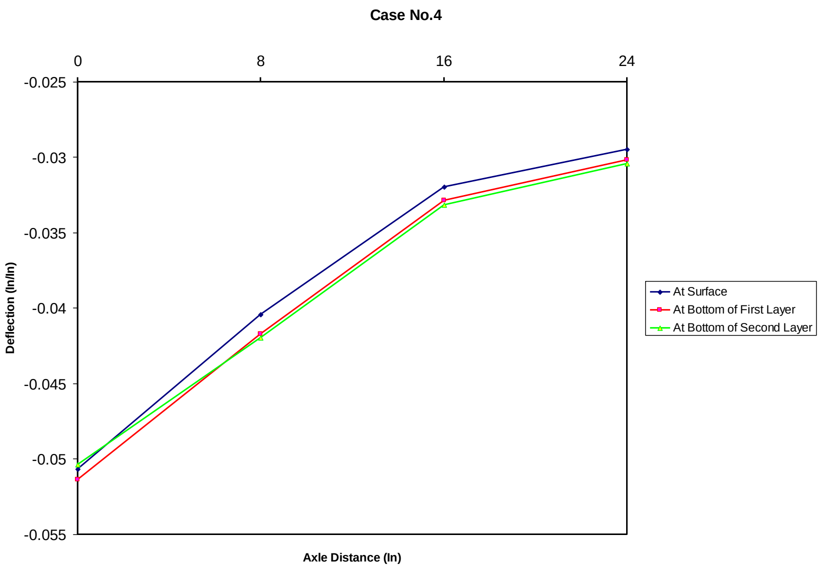


Fig.(c): (for h1=6)

Fig.(4): relationships between displacement variation with Ist. layer thickness

3.2The effect of h2

In the second three cases the effect of changes in h2 (6,8,10)in. was considered with constant h1(2)in., through multiple runs of KENLAYER program , results showed that displacements values would decrease with the increase of h2 as shown in Figs.(5a,b,c).



Fig(a): (for h2=6)

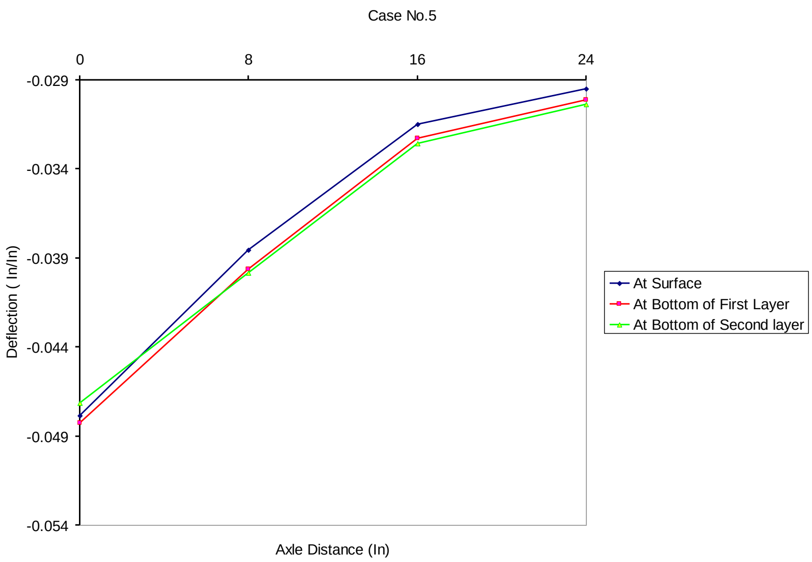


Fig (b) (for h2=8)

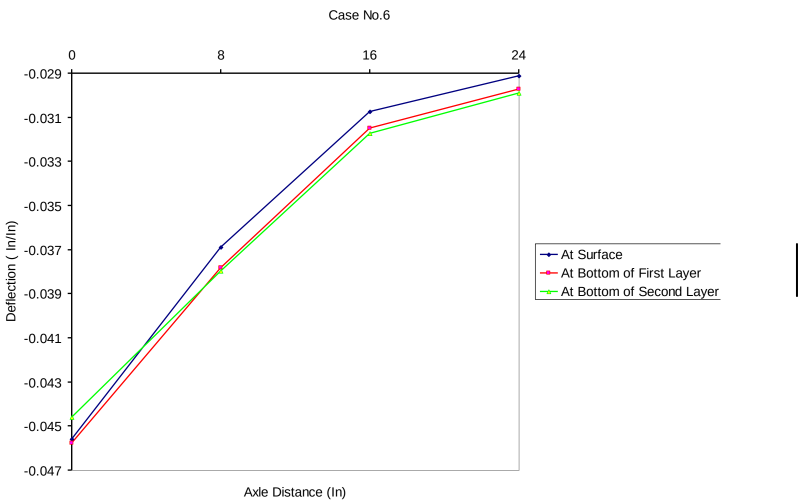


Fig (c): (for h2=10)

Fig (5): Relationships between displacement variations with 2nd. layer thickness

3.3The effect of E1

When Modulus of elasticity of the first layer was changed from 500000 to 300000 and 200000,
displacement values were increased as shown in Figs. (6a, b, c).Table (3) below shows cases for
variation of E1 .

Table (3) : cases for variation of E1

X	Y	case 7	case 8	Case9
0	0	h1=2	h1=2	h1=2
8	0	h2=6	h2=6	h2=6
16	0	E1=	E1=	E1=
24	0	E2=constant	E2=constant	E2=constant
		E3=constant	E3=constant	E3=constant
		E1=300000	E1=200000	E1=125000
		E2=25000	E2=25000	E2=25000
		E3=7500	E3=7500	E3=7500

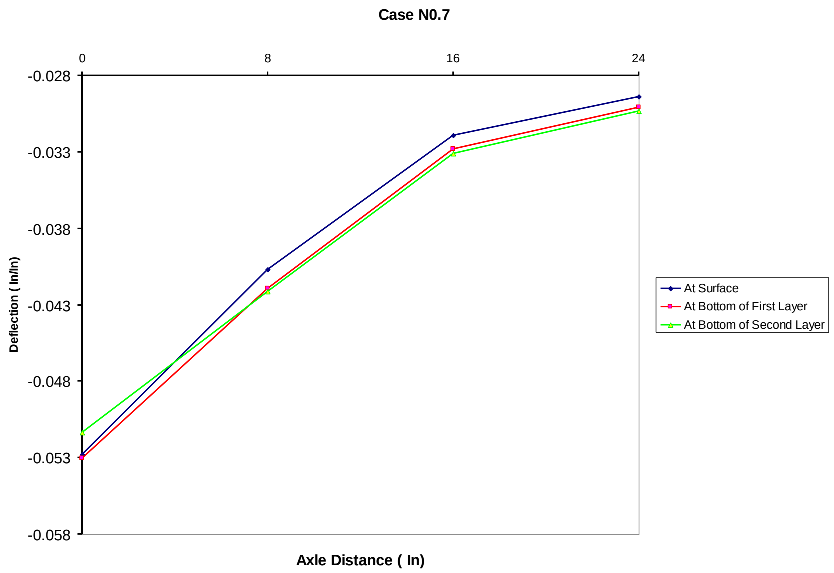


Fig.(a) : (for E1=500000)

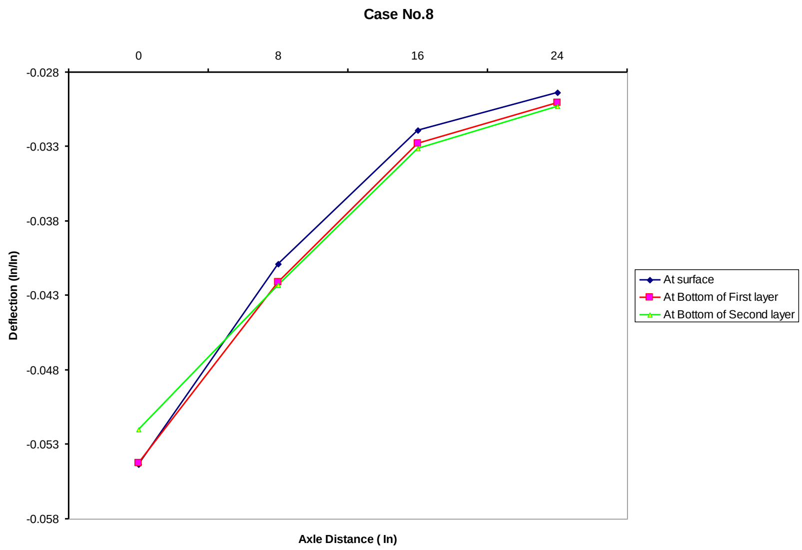
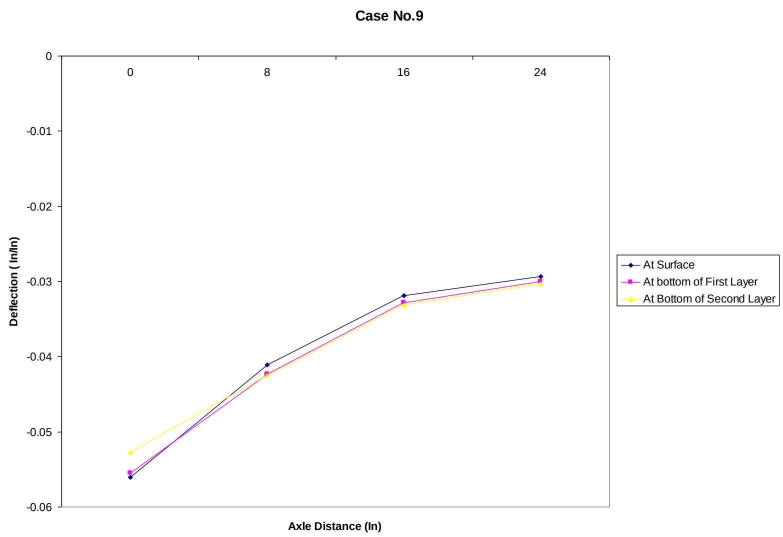


Fig.(b) : (for E1=300000)



Fig(c): (for E1=200000)

Fig (6) Relationships between displacement values and axle distance

3.4The effect of E2 and E3

As it was noticed from results obtained from kenlayer runs after using values of E2 (25000, 20000, 15000) and E3 (7500, 6500, 4500), displacement values were increased with the decrease of E2 and E3.These results are summarized in table (6) & (7).Table (4) & (5) contain cases
For variation of E2&E3.

Table (4): cases for variation of E2

case 10	case 11	case 12
h1=2	h1=2	h1=2
h2= 6	h2= 6	h2= 6
E1=constant	E1=constant	E1=constant

E2=	E2=	E2=
E3=constant	E3=constant	E3=constant
E1=500000	E1=500000	E1=500000
E2=20000	E2=17000	E2=15000
E3=7500	E3=7500	E3=7500

Table (5): cases for variation of E3

X	Y	case 13	case 14	Case15
0	0	h1=2	h1=2	h1=2
8	0	h2=6	h2=6	h2=6
16	0	E1=constant	E1=constant	E1=constant
24	0	E2=constant	E2=constant	E2=constant
		E3=	E3=	E3=
		E1=500000	E1=500000	E1=500000
		E2=25000	E2=25000	E2=25000
		E3=6500	E3=5500	E3=4500

Table (6): Changes in displacement values with different E2 values at the centre of the applied load

E2	Displacement at the centre of the applied load.(0,0)point
25000	.04784
20000	.05283
15000	1.12511

Table (7): Changes in displacement values with different E3 values at the centre of the applied load

E3	Displacement at the centre of the applied load.(0,0)point
7500	.04784
6500	.05625
4500	0.06857

Conclusions

In this study the effects of several factors on pavement response were investigated ,these factors were thickness of each layer(h1& h2) with in the multi layer system , and modulus of elasticity ,in the first three cases h1 was assumed to be (2,4,6)in. ,while h2 remains constant equals 8 in. ,results obtained from kenlayer program showed that displacement values decreased with the increase of h1.In the second three cases ,h1 remained constant while h2 changed (6,8,10)in., also displacement values decreased due to this change .In the other hand ,the effect of changes in E1,E2,E3 values was studied through multiple runs using kenlayer program, it was found that when E1decreased displacement would increase ,this is also right for E2 and E3.

Most of researches of pavement would focus on multilayer system under single axle load but in this

Research displacement values were studied under dual axle.

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