

# Analysis and Design of Bituminous Pavements

Dr. A Padma Rekha

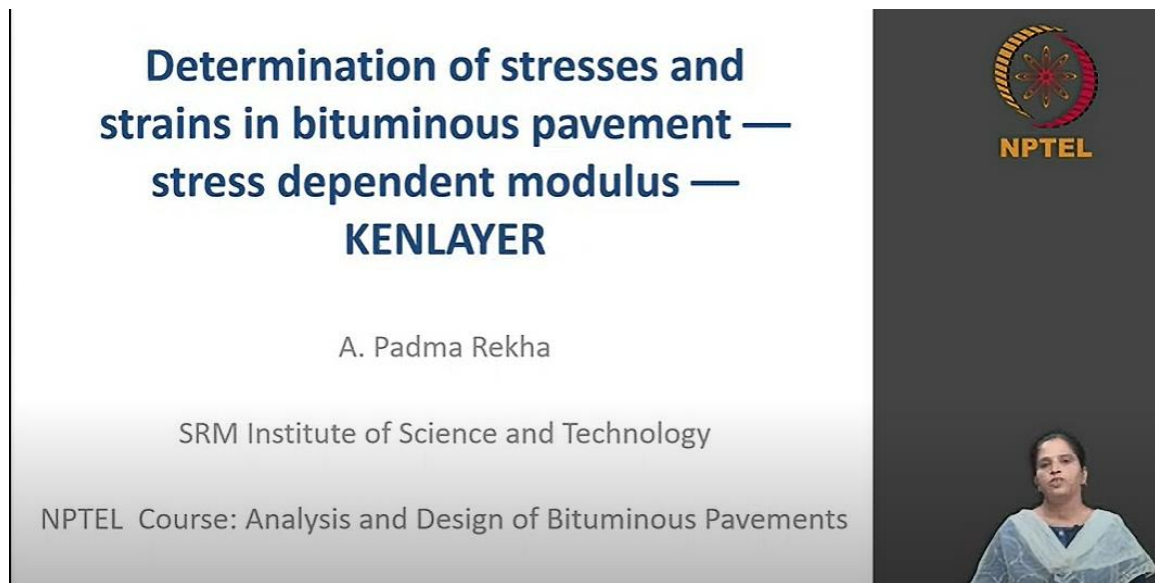
Department of Civil Engineering

Indian Institute of Technology, Madras

Lecture – 39

**KENLAYER - Nonlinear Analysis**

(Refer Slide Time: 00:22)



The slide thumbnail features a dark background with a white gradient at the bottom. The main title is in large, bold, blue font: "Determination of stresses and strains in bituminous pavement — stress dependent modulus — KENLAYER". Below the title, the presenter's name "A. Padma Rekha" and affiliation "SRM Institute of Science and Technology" are listed in a smaller white font. At the bottom left, the NPTEL course name "NPTEL Course: Analysis and Design of Bituminous Pavements" is displayed. On the right side, there is a vertical strip containing the NPTEL logo (a red and yellow circular emblem) and a small video inset of the presenter, Dr. A. Padma Rekha, wearing a light blue shawl.

Hello everybody, in this course we introduced you to the KENLAYER software that is used for determining stress and strain at different locations of the pavement. In the previous exercise that we solved using the KENLAYER software, we used elastic modulus to determine stresses and strains at different locations in the pavement. Now, you know that we use a resilient modulus in place of elastic modulus in the pavement analysis. In such case, resilient modulus of a granular material or soil material is stress dependent. Now the question is, how to account for this stress dependent material property in the analysis of pavement. So, we will solve this exercise using the KENLAYER software.

You have been already introduced to a stress dependent resilient modulus value of the granular layer and soil layer by Professor Nivitha. Now, we will have a glance into these equations and we will focus on the material properties so that we can use these material properties in our analysis. So, you know that the granular layer and this soil layer exhibit a stress dependent modulus and modulus of the granular layer can be given by this expression.

$$E = k_1 \theta^{k_2}$$

Here, E is the resilient modulus. So, when you measure the resilient modulus of a granular layer for different stress invariant, you can see that the resilient modulus exhibits a straight-line function when you plot it in a logarithmic scale. So, the constant, the intercept here is called as  $k_1$  and the slope of this line is  $k_2$ . So, this value of  $k_1$  and  $k_2$  depend on the type of the granular layer. So, you can see that for different types of granular layer, the  $k_1$  value varies from 1620 psi to 7210 psi and  $k_2$  value is somewhere nearing 0.5. So, you can determine this value of  $k_1$  and  $k_2$  by conducting a resilient modulus test in the laboratory but, if you do not have such kind of a facility you can infer to the values of  $k_1$  and  $k_2$  from this reference table.

(Refer Slide Time: 02:25)

### Stress dependent Modulus

- Granular layer and subgrade layer modulus is stress dependent

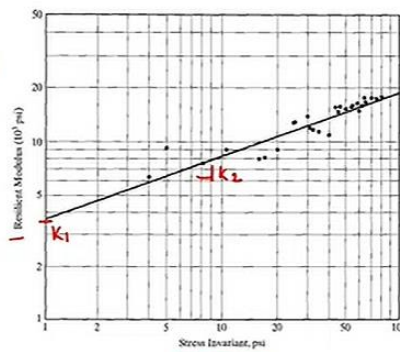
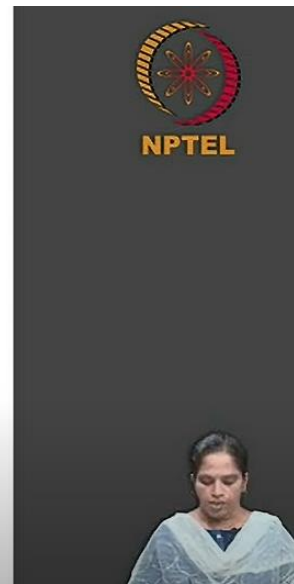


TABLE 3.1 Nonlinear Constants  $K_1$  and  $K_2$  for Granular Materials

| Material type        | No. of data points | $K_1$ (psi) |                    | $K_2$ |                    |
|----------------------|--------------------|-------------|--------------------|-------|--------------------|
|                      |                    | Mean        | Standard deviation | Mean  | Standard deviation |
| Silty sand           | 8                  | 1620        | 78                 | 0.62  | 0.13               |
| Sand-gravel          | 37                 | 4480        | 4300               | 0.53  | 0.17               |
| Sand-aggregate blend | 78                 | 4350        | 2630               | 0.59  | 0.13               |
| Crushed stone        | 115                | 7210        | 7490               | 0.45  | 0.23               |

$$E = K_1 \theta^{K_2}$$

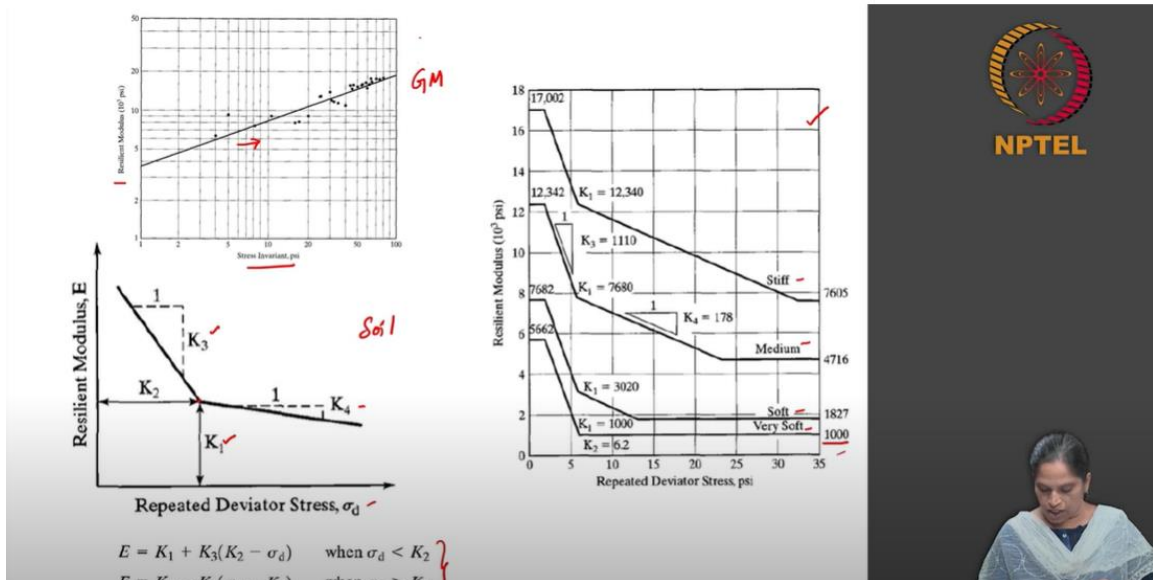
Note: 1 psi = 6.9 kPa.  
Source: AASHTO Road Test and Wisconsin (1981)



You can also see that the resilient modulus of a granular material increases when the stress invariant increases. This is the resilient modulus of a granular material. But if you see a resilient modulus of a fine-grained material or a soil value, it decreases with the increase in deviatoric stress and you can also see that there is a two-stage slope curve for resilient modulus of a soil layer. So, to define this resilient modulus of a soil layer as a function of deviatoric stress, you need 4 constants  $k_1$ ,  $k_2$ ,  $k_3$  and  $k_4$ . The  $k_1$  here, is the resilient modulus value at a point of slope change,  $k_2$  is the deviatoric stress value at a point of slope change,  $k_3$  and  $k_4$  are the two different slopes.

So, you can mathematically represent this line using these two equations given here. So, again, you can determine the resilient modulus value in a laboratory for different deviatoric stress and measure this constant  $k_1$ ,  $k_2$ ,  $k_3$  and  $k_4$  for the analysis purpose. If you do not have laboratory values, you can infer to this chart for different  $k_1$ ,  $k_2$ ,  $k_3$  and  $k_4$  values. So, you can see that the  $k_1$ ,  $k_2$ ,  $k_3$  and  $k_4$  values vary depending on the type of clayey soil. So, you have for 4 different clayey soils - very soft, soft, medium and a stiff clay, you have the material parameters listed here. You can also see that there is a minimum value of  $k_1$  and minimum value of resilient modulus is defined for different materials here. So, we will see how to use these parameters in the analysis.

(Refer Slide Time: 04:00)



So, KENLAYER uses this pressure dependent material property in the analysis and it is called as nonlinear analysis. So, what exactly the nonlinear analysis in the KENLAYER means is, we use this stress dependent material property in determination of stresses and strains. So, this nonlinear analysis is carried out only for a granular layer and a subgrade layer. So, when we determine stresses and strains at different locations, we get 3 normal stresses and these 3 normal stresses are going to depend on depth. So, if the depth varies, the modulus at the depth is going to vary. So, in such case, the stresses and modulus are interdependent parameters. So, what KENLAYER does is, it assumes the initial seed modulus value and determines the stresses and back calculates the modulus value using the equations that we have seen previously and so this process is iterated many times till the solution converges. So, for this purpose, KENLAYER uses 3 different approaches.

(Refer Slide Time: 05:17)

## KENLAYER - Nonlinear analysis

- What exactly the nonlinear analysis in KENLAYER means?
- Nonlinear analysis – only for granular layer and subgrade layer
- The Normal stresses depends on the depth and hence the modulus varies with the depth
- Three approaches used

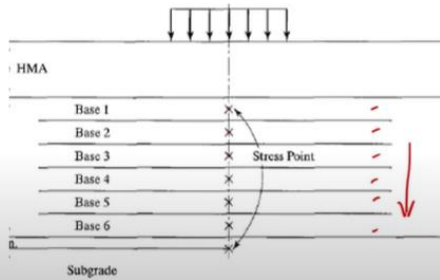


So, in the first approach, what it does is, the entire base layer is divided into small sub layers. So, after dividing into small sub layers, the center point of each layer is defined as a stress point. Now, knowing the seed modulus value, the normal stress value that is  $\sigma_1, \sigma_2, \sigma_3$  or you can call it as  $\sigma_x, \sigma_y, \sigma_z$  that is, normal stress at x, y and z direction can be obtained. So, you get the normal stress value from this and you can compute the modulus value here and this process, you can iterate till the solution converges. So, in some cases, for determining the stress invariant, you can also include the dead weight of the material above where  $\gamma$  which is the unit weight of the material at a depth at which we are interested in (z) and  $k_0$  is a passive earth pressure constant. So, you can see that the stress invariant depends on the normal stress. Sometimes, these normal stresses can also be a negative value. So, this negative normal stress occurs when you go deep below away from the loading conditions. In such cases if you get a negative normal stress, that negative normal stress value is adjusted to 0 value for determining the stress invariant in these conditions. So, this is a first method.

(Refer Slide Time: 06:48)

# KENLAYER – Nonlinear Analysis

- Method 1



$$E = K_1 \theta^{K_2}$$

$$\theta = \sigma_1 + \sigma_2 + \sigma_3 = \sigma_x + \sigma_y + \sigma_z$$

$$\theta = \sigma_x + \sigma_y + \sigma_z + \underline{\gamma z(1 + 2K_0)}$$

- Stress invariant is computed from three normal stresses
- If any of the normal stress is negative, it is



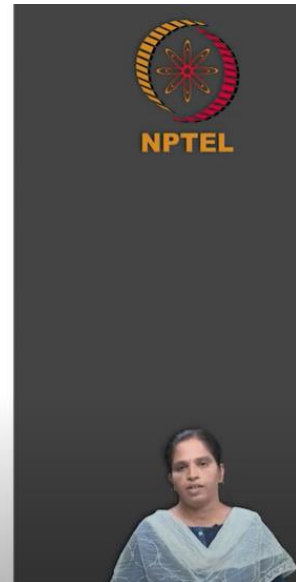
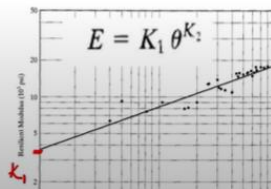
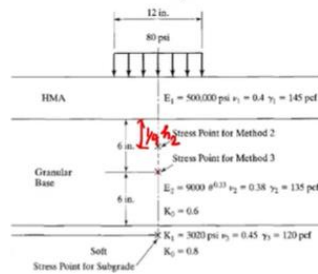
In the second approach, it is not divided into sub layer, the entire base layer is considered as a single layer. So, now when you consider entire base layer as a single layer, the next question is, at which point we are going to determine the stress and then the modulus value. So, the second method uses a stress point as one fourth of the height of the base layer. So, if  $h_2$  is the height of the base layer, one fourth of the height of the base layer is considered as a stress point for determining the modulus value. So, you assume a seed modulus value, determine stress at these locations and then compute back the modulus value and iterate this process. So, while doing this process here, since this point is very near to the loading conditions, there may not be any chance for the negative normal stresses. So, you do not need any kind of adjustment here. So, you can consider a normal stress, even if it is a negative value, it may be a very small value. So, you can consider a negative normal stress as such. So, since you have a negative normal stress compensating on the vertical normal stress, we define a minimum modulus here. So, the minimum modulus here, is defined as the  $K_1$  parameter that we have seen for the granular layer. So, the minimum modulus value is considered as  $K_1$ . So, the modulus will never go less than  $K_1$ . So, this is the method 2 approach.

(Refer Slide Time: 08:29)

# KENLAYER – Nonlinear Analysis

- Method 2
  - Normal stresses are used in the computation of stress invariant
  - Negative normal stress is also considered ✓
  - Minimum Modulus is defined

$$\text{PHI} = K_1$$



In the method 3 approach, the stress point is considered as the midpoint of the granular layer. In such conditions, the midpoint is away from the loading condition and so, there can be a chance for a negative normal stress. So, you need to adjust the principal stress values or normal stress value so as to avoid this negative value in the stress invariant. So, this adjustment is carried out using a Mohr-Coulomb theory. So, you have a relation here,

$$\sigma_h = \sigma_v \tan^2 \left( 45 - \frac{\varphi}{2} \right),$$

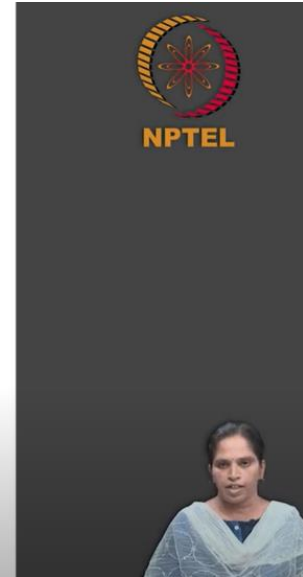
where,  $\sigma_h$  is the horizontal stress,  $\sigma_v$  is the vertical stress and  $\varphi$  is defined as the cohesion of the soil or cohesion of the granular material. So, when the  $\varphi$  is 0, you will get  $\sigma_h = \sigma_v$ . So,  $\sigma_h$  is adjusted and then modulus is recalculated. So, this is the third approach which the KENLAYER uses.

(Refer Slide Time: 09:14)

## KENLAYER – Nonlinear Analysis

- Method 3
  - At the mid point of layer
  - Principle stresses are used
  - Adjustment made for horizontal principle stress
  - Mohr – Coulomb theory

$$\sigma_h = \sigma_v \tan^2\left(45^\circ - \frac{\phi}{2}\right)$$



Now, we will solve this numerical using the KENLAYER software. So, you have a 3 layered structure as shown in the figure and it is subjected to a single wheel load and with a pressure intensity of 75 psi and the diameter of the load application is 9 inch. So, we will use inches and psi for the solution here. So, now we need to determine what is the maximum tensile strain at the bottom of layer 1 - HMA layer and maximum compressive strain at the top of layer 3 that is the subgrade layer. So, we will use method 1. So, method 1 is dividing the base course into multiple layers and determine stresses and strains at critical locations. And method 2 is, we consider the second layer as 1 layer and determine stresses and strains for the modulus determination is considered at upper quarter point of layer 2.

(Refer Slide Time: 10:29)



3.5 Figure P3.5 shows a three-layer system under a single-wheel load. Layer 1 is linear elastic, layers 2 and 3 nonlinear elastic. The loading, thicknesses, and material properties are shown in the figure. With the use of KENLAYER, determine the maximum tensile strain at the bottom of layer 1 and the maximum compressive strain at the top of layer 3 by (a) method 1 in which layer 2 is subdivided into two layers, each 2 in. thick, and (b) method 2 in which layer 2 is considered as one layer and the stress at the upper quarter point of layer 2 is used to determine  $E_2$ . [Answer: (a)  $1.02 \times 10^{-4}$ ,  $2.85 \times 10^{-4}$ ; (b)  $1.04 \times 10^{-4}$ ,  $2.85 \times 10^{-4}$ ]

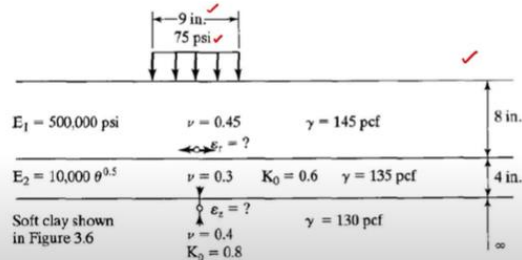
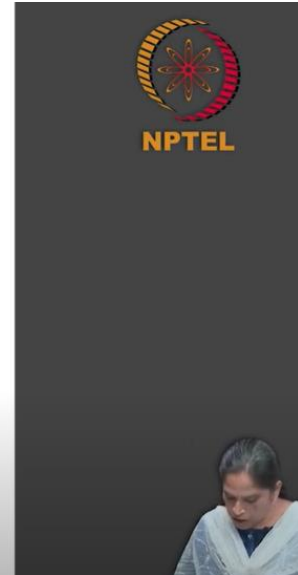


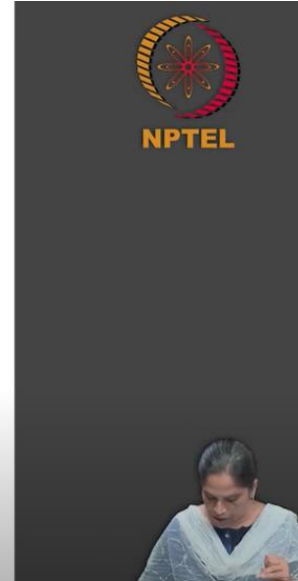
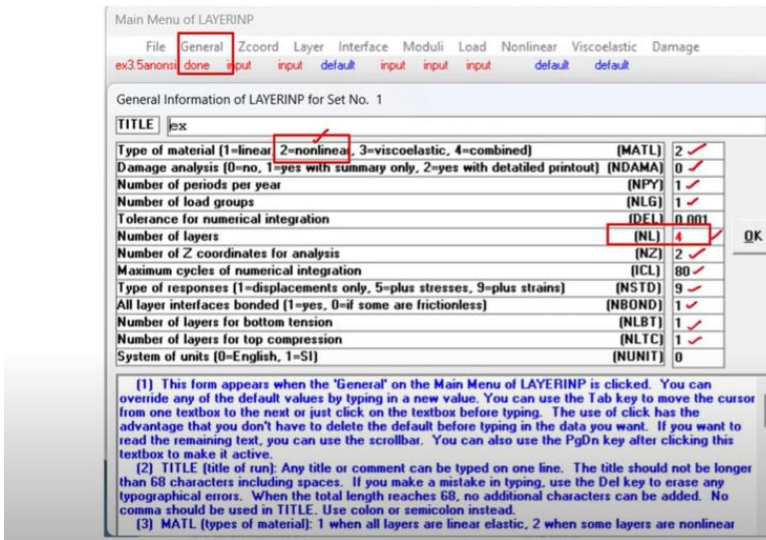
FIGURE P3.5



And so, when we go for this non-linear analysis, when you open a new file in the KENLAYER software, you will have the general menu option. When you click on this general menu options, this is what the information we have to give. So, type of material here is non-linear. This is called as non-linear analysis because we use the modulus as a stress dependent modulus. And so, we select 2 here and we do not perform any damage analysis here, so, we will keep this as 0, number of periods per year is 1, number of load group is also 1, we are not doing a multi group and a multi load analysis here. So, we will keep it as 1. Number of layers here, it is a 3 layered structure. But we divide the base layer into small layer. Let us divide the base layer with each layer of 2-inch thickness. So, the total thickness of the layer is 4 inch, we will divide into 2 layers each of 2-inch thickness. So, you will have 2 base layers, 1 HMA layer and 1 sub-grade layer, so total layers will be 4 layers here. Number of z coordinate for analysis, one is for fatigue strain corresponding to the fatigue damage, another is strain corresponding to rutting on the subgrade layer. So, you have 2 z coordinate for the analysis. So, these iterations, numerical integration, type of response, interface bounded and number of layers at the bottom tension and top compression this you are already aware of it.

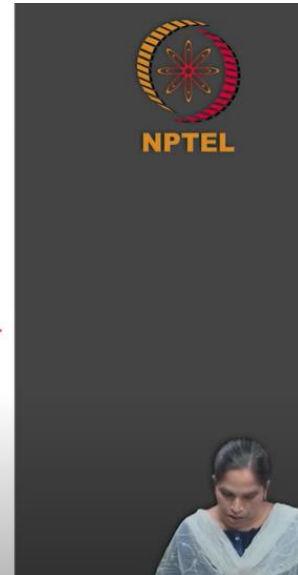
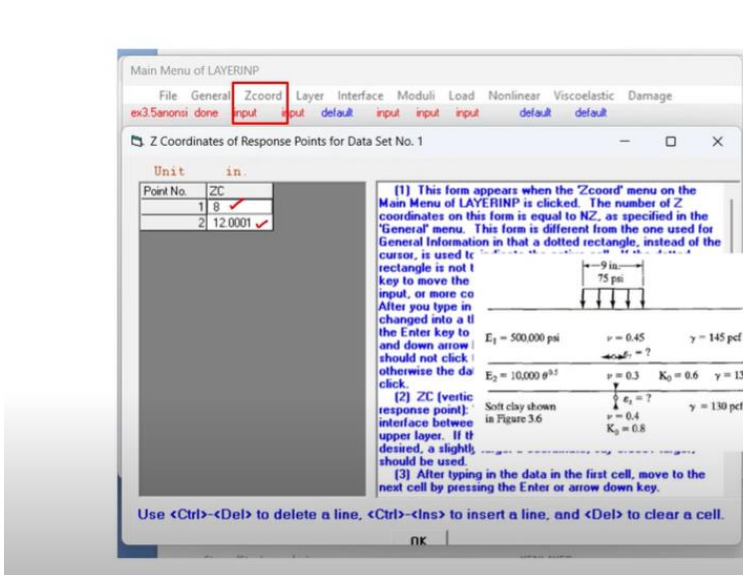
(Refer Slide Time: 12:07)





So, we will move to the next input - z coordinate. So, we are given 2 z-coordinates, one is at the top of subgrade layer. So, top of a subgrade layer which is nothing but 12 inches, so I have just given 12.0001, so that, the point exactly lies on the subgrade layer not at the interface and the other one is z is 8 inches which is at the bottom of the asphalt layer.

(Refer Slide Time: 12:44)



Now, the next input is the layer input which is the thickness of different layers. So, 8 inch first layer and the second and third layer are base layers. So, we divided into 2 inch, 2 inch each. So, the 4 inch base layer is divided into 2 layers and the third layer is of infinite thickness. So, you have an infinite thickness here already defined. Poisson's ratio

of the first layer is 0.45. Second layer and third layers are base layer and its Poisson's ratio is 0.3 and the fourth layer is a subgrade soil layer that has a Poisson's ratio of 0.4. So,  $\gamma$  here is defined as the density which is  $\text{lb}/\text{ft}^3$  values. So, the gamma value which is given in the numerical are given as input here for determining the self-weight of the material. And this self-weight of the material will be used in the computation of the stress invariant.

(Refer Slide Time: 13:23)

The screenshot shows the 'Main Menu of LAYERINP' with a 'Layer' menu highlighted. Below it is a window titled 'Layer Thickness, Poisson's Ratio and Unit Weight for Data Set No. 1'. A red box highlights the 'Layer' menu. The window contains a table with the following data:

| Layer No. | TH (in.) | PR  | GAM (pcf) |
|-----------|----------|-----|-----------|
| 1         | 8        | .45 | 145       |
| 2         | 2        | .3  | 135       |
| 3         | 2        | .3  | 135       |
| 4         | 4        | .4  | 130       |

To the right of the table is a cross-section diagram of a pavement structure. It shows a top layer of 8 inches thickness, followed by two 2-inch layers, and a bottom 4-inch layer. Material properties are listed:  $E_1 = 500,000 \text{ psi}$ ,  $\nu = 0.45$ ,  $\gamma = 145 \text{ pcf}$ ;  $E_2 = 10,000 \text{ psi}$ ,  $\nu = 0.3$ ,  $K_0 = 0.6$ ,  $\gamma = 135 \text{ pcf}$ ; and 'Soft clay shown in Figure 3.6' with  $\nu = 0.4$ ,  $K_0 = 0.8$ ,  $\gamma = 130 \text{ pcf}$ . A red circle highlights the 4-inch thickness of the bottom layer.

Below the table and diagram, there is a text box with instructions: 'Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to [1] This form appears when the 'Layer' menu on the Main Menu of LAYERINP is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu. This form is different from the one used for General Information in that a dotted rectangle, instead of the cursor, is used to indicate the active cell. If the dotted rectangle is not the location for input, you can use the arrow key to move the dotted rectangle to the cell you want to input, or more conveniently by clicking the cell you want. After you type in the data, the dotted rectangle will be changed into a three dimensional box and you must press the Enter key to make it effective. You can also use the up and down arrow keys to make the entry effective. Note that the dotted rectangle is now in the upper left cell, so you can type in the data right away. If you want to read the remaining text and use the PgDn key, instead of the scrollbar, you

So, now, next input is the modulus value. So, now when you see the modulus value, we have used only one period here. When you click on this, you will get the modulus value. Now, if you see the modulus value, we used the modulus  $E_1$  as the modulus of the asphalt layer. This asphalt layer is going to be an elastic layer with the same elastic modulus and it is only one value. Now if you consider the base course, now this is the resilient modulus value and it is a stress dependent resilient modulus and it is defined by this equation here. So, this equation says  $k_1$  value is equal to 10,000 psi and  $k_2$  value is equal to 0.5. Now, we need a seed modulus value, you can assume any seed modulus value for base layer. So, you have two base layers of 2 inch thickness. So, I have just given two different modulus values as seed modulus values. So, likewise you can take some other seed modulus value for the soil layer also. So, the soil is also considered to have a stress dependent modulus value. So, here it is given that we use a soft clay, I just assume some seed value modulus here to be 5000 psi for determination of stresses and strains.

(Refer Slide Time: 15:03)

Main Menu of LAYERINP

File General Zcoord Layer Interface Moduli Load Nonlinear Viscoelastic Damage

ex35anonsi done done done default input input input default default

Layer Modulus of each period for Data Set No. 1

Period1 input

Layer Moduli for Period No. 1 and Data Set No. 1

| Unit      | psi      |
|-----------|----------|
| Layer No. | E        |
| 1         | 500000 ✓ |
| 2         | 30000 ✓  |
| 3         | 15000 ✓  |
| 4         | 5000 ✓   |

(1) This form appears when the period button on the Layer Modulus of Each Period is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu.

(2) E [elastic modulus of each layer]: Use as the assumed modulus for the first iteration when the layer is more conversent, you can enter the modulus i form such as 1.234E5. Assign 0 or any value viscoelastic layer.

(3) After typing the data in the first cell, a cell by pressing the Enter or arrow down key, be sure to click the Enter key.

(4) You can delete a line, or one layer, by anywhere on the line to make it active and th <Ctrl>-<Del> keys. The NL in the 'general' as reduced automatically by 1.

(5) You can add a new line, or one more la given line by first clicking the cell in the gives appear for you to enter the necessary data. } 'General' menu will increase automatically by to add a line after the last line, you can chan 'General' menu by adding 1 and a blank line will appear as the last line. Remember that always use the <Ctrl>-<Ins> ]

Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.

Handwritten notes:  $K_1 = 10,000$ ,  $K_2 = 0.5$

Diagram: 9 in. contact radius, 75 psi load, 8 in. total thickness, 4 in. sub-base course, 4 in. base course. Material properties:  $E_1 = 500,000$  psi,  $\nu = 0.45$ ,  $\gamma = 145$  pcf;  $E_2 = 10,000$  psi,  $\nu = 0.3$ ,  $K_0 = 0.6$ ,  $\gamma = 135$  pcf; Soft clay shown in Figure 3.6,  $\nu = 0.4$ ,  $K_0 = 0.8$ ,  $\gamma = 130$  pcf.

So, once you give the modulus value, the next input is the load parameter. So now, we have a single wheel load. So, single wheel single axle is defined by load group 0, contact pressure is 75 psi and contact radius is 9 by 2 which is 4.5 inches. Since it is a single axle single wheel, there is YW to be 0 as there is only one wheel. So, centre to centre distance between two wheels is 0, centre to centre distance between two axles is 0. So, we are interested in determining stresses and strain exactly at the centre of loading. So, you just click on this NR and give this input RC to be 0 which defines the centre of the pointer.

So, we define a stress value, we need to find out the critical stress values at the interface of two layers. But to compute this stress value, you need a modulus value. These modulus values are computed using the first method that is by dividing this sub base course into two layers each of 2 inch thickness and the mid of each layer is defined as a stress point and the modulus value are determined in the mid of this layer. So, now the next input is the nonlinear input which is something very new to you.

(Refer Slide Time: 16:20)

Main Menu of LAYERINP

File General Zcoord Layer Interface Moduli Load Nonlinear Viscroelastic Damage

Load Information for Data Set No. 1

Double click anywhere on a line to get auxiliary form for NR or NPT.

| Unit           | in.  | psi | in. | in. | NR or NPT |           |
|----------------|------|-----|-----|-----|-----------|-----------|
| Load Group No. | LOAD | CR  | CP  | YW  | XW        | NR or NPT |
| 1              | 0    | 4.5 | 75  | 0   | 0         | 1         |

Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.

(1) This form appears when the 'Load' menu on the Main Menu of LAYERINP is clicked. The number of lines, or load groups, is equal to NLG, as specified in the 'General' menu. Please refer to Figure 3.8 for wheel and axle arrangements.

(2) LOAD [type of loading]: Assign 0 for single axle with single tire, 1 ft for tandem axles, and 3 for tridem axles.

(3) CR [contact radius of circular loaded area].

(4) CP [contact pressure on circular loaded area].

(5) YW [center to center spacing between two dual wheels along the y one wheel or LOAD = 0].

(6) XW [center to center spacing between two axles along the x axis]: exists, i.e. LOAD = 0 or 1.

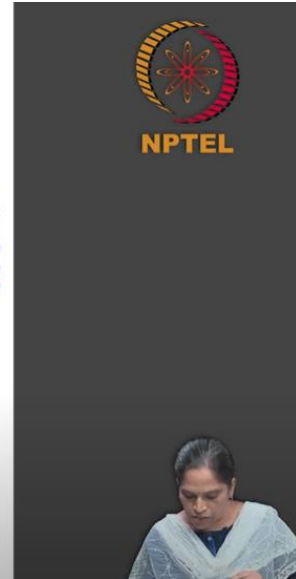
(7) NR [number of radial coordinates to be analyzed under a single wheel]

Radial Coordinates of Response Points for Load Group No. 1 of Data Set No. 1

| Unit | RC |
|------|----|
| 1    | 0  |

Soft clay shown in Figure 3.6

Diagram parameters:  
 $E_1 = 500,000 \text{ psi}$   
 $E_2 = 10,000 \text{ psi}$   
 $r = 0.45$   
 $\gamma = 145 \text{ pcf}$   
 $\gamma = 135 \text{ pcf}$   
 $\gamma = 130 \text{ pcf}$



So, in the nonlinear input if you click, you will get these options, general relaxation, non seasonal input, seasonal input and Mohr-Coulomb theory input. So, when you click on this general input, this is the information you have to give in for the analysis. One is number of nonlinear layers. So, how many number of nonlinear layers we have? We have two base course and one subgrade layer. So, you have number of layers to be 3, maximum number of iterations as this modulus is computed based on the iterations. So, maximum number is restricted to 15 and tolerance for numerical analysis is 0.01.

So, now these radial coordinates, x coordinate and y coordinate values and slope of load distribution is defined in this figure. So, now assume like this is the radius of the load, as of now, this is 4.5 inch. So, now, the point at the top surface will get transferred at any depth z depending on the slope of load distributions. So, if you define the slope of load distributions, you can find out what exactly is the radius, x and y coordinate at any depth using these equations for r, x and y. So, you need the parameter to be defined here, what is ZCNOL or what is the slope value, what is the radius value, what is the x and y value, x and y is applicable in case if you have a 2-wheel loads. So, for this input, we assume that the slope here is 0 and we will give all these inputs to be 0. Since slope is 0 the capital R will match with the small r value here. We do not have x and y here because it is only a single axle single wheel.

(Refer Slide Time: 18:30)



Main Menu of LAYERINP

File General Zcoord Layer Interface Moduli Load Nonlinear Viscroelastic Damage

ex3Sanonsi done done done default done done done default default

Data Set 1 Data Set 2 Data Set 3 Data Set 4 Data Set 5 Save Save As Exit

Nonlinear Layers Menu for Data Set No. 1

General done Relaxation default Nonseasonal input Seasonal input Mehr-Coulomb Theory Use default input for clay Do not use default input for c

Nonlinear General Information for Data Set No. 1

Number of nonlinear layers [NOLAY] 3 ✓

Maximum number of iterations [ITENL] 15 ✓

Radial coordinate for nonlinear analysis in in. [RCNOL] 0 ✓

X coordinate for nonlinear analysis in in. [XPTNOL] 0 ✓

Y coordinate for nonlinear analysis in in. [YPTNOL] 0 ✓

Slope of load distribution [SLD] 0 ✓

Tolerance for nonlinear analysis [DELNOL] 0.01 ✓

Unit in. pcf

| Layer No. | TH         | PR  | GAM |
|-----------|------------|-----|-----|
| 1         | 8          | .45 | 145 |
| 2         | 2          | .3  | 135 |
| 3         | 2          | .3  | 135 |
| 4         | XXXXXXXXXX | .4  | 130 |

Diagram showing a nonlinear layer with parameters: RCNOL, XPTNOL, YPTNOL, SLD, ZCNOL, and r, x or y.

Equations for coordinates:

$$r = RCNOL + (SLD)(ZCNOL)$$

$$x = XPTNOL + (SLD)(ZCNOL)$$

$$y = YPTNOL + (SLD)(ZCNOL)$$

So, once the general input is done, the next one is the relaxation input. This relaxation input is a factor used for the convergence of the modulus value and the default value is given as 0.5. You can use the same default value.

(Refer Slide Time: 18:47)

Main Menu of LAYERINP

File General Zcoord Layer Interface Moduli Load Nonlinear Viscroelastic Damage

ex3Sanonsi done done done default done done done default default

Data Set 1 Data Set 2 Data Set 3 Data Set 4 Data Set 5 Save Save As Exit

Nonlinear Layers Menu for Data Set No. 1

General done Relaxation default Nonseasonal input Seasonal input Mehr-Coulomb Theory Use default input for clay Do not use default input for c

Relaxation factor of Each Period for Data Set No. 1

| Period No. | RELAX |
|------------|-------|
| 1          | 5     |

Help text:

(1) This form appears when the 'Relaxation' menu on the Nonlinear Layers Menu is clicked. The number of periods on this form is equal to NPY, as specified in the 'General' menu on the Main Menu of LAYERINP.

(2) RELAX (relaxation factor for nonlinear analysis): The use of relaxation factor is to ensure the convergence of elastic modulus. A default of 0.5 is suggested. However, if the results for a given period diverge, a smaller relaxation factor, usually one half of the initial value, say 0.25, should be used for that period. Usually a weak foundation will cause the moduli to diverge.

(3) After typing in the data in the first cell, move to the next cell by pressing the Enter or arrow down key. After the last cell is filled, be sure to click the Enter key.

(4) You can delete a line, or one period, by first clicking anywhere on the line to make it active and then press the <Ctrl>-<Del>. The NPY in the 'General' menu will be reduced automatically by 1.

(5) You can add a new line, or one more period, above any given line by first clicking the cell in the given line to make it active and then press the <Ctrl>-<Ins>. A blank line will appear for you to enter the necessary data. The NPY in the 'General' menu will increase automatically by 1. If you want to add a line after the last line, you can change NPY in

Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.

The next input from the modulus is the non-seasonal input in which we define the constants here. In the non-seasonal input, so you have parameters here, we define the layer number. So, second layer, third layer and fourth layer are non-linear layers. So, for second layer, now the value at which we need to find out stress is exactly 8+1 inch which is 9 inch. So, second layer is 8+2+1 which is 11 inches. So, the value where the modulus to be determined is the for the first layer, it is 9 inch, for the second layer it is 11 inch and for

the subgrade layer, it is 1 inch below the interface. So, it is 4+8+1, so it is 13 inch. So, now, whether to define whether it is a fine grained soil or a granular layer, we use this NCLAY. So, if you give NCLAY to be 0, it represents the granular material. If you give NCLAY to be 1, it represents the clayey soil or a fine grained soil. So, now, when you click on this NCLAY value, you will get these parameters that is non-seasonal input parameter, that is the value of  $k_2$  which is nothing but the slope of a resilient modulus value and we have seen that this value was close to 0.5. So, by default, this value will be taken as 0.5. If you have any other number other than this 0.5, based on the experimental results, you can use those numbers here and  $k_0$  is the earth pressure constant and in the numerical values it is given as 0.6. So, we use the same number over here, 0.6. Now, for NCLAY which is a fine grained soil, you will have 4 constants that is excluding  $k_1$ , you will have  $k_2$ ,  $k_3$ ,  $k_4$ . So, for all these 4 constants values, these are the default values which is used here and the earth pressure constant for the clay soil is taken as 0.8. So, these are the non-seasonal input which is going to be same for any number of periods. So, the value of  $k_1$  is dependent on the period.

(Refer Slide Time: 21:10)

The screenshot displays the 'Main Menu of LAYERINP' software. The 'Nonlinear' menu is active, showing 'Nonseasonal input' selected. Below, the 'Nonseasonal Information for Data Set No. 1' is shown. A table lists three nonlinear layers:

| Sequence | LAYNO | ZCNOL | NCLAY |
|----------|-------|-------|-------|
| 1        | 2     | 9     | 0     |
| 2        | 3     | 11    | 1     |
| 3        | 4     | 13    | 1     |

The auxiliary form for Layer No. 2 (Granular) shows parameters: Nonlinear exponent for granular materials (K2) 0.5 and Coefficient of earth pressure at rest (K0) 0.6. The auxiliary form for Layer No. 4 (Clay) shows parameters: Deviator stress at break point for clay in psi (K2) 6.2, Slope when deviator stress smaller than K2 (K3) 1118, Slope when deviator stress greater than K2 (K4) 178, and Coefficient of earth pressure at rest (K0) 0.8. A graph of Resilient Modulus (R) vs. Deviator Stress (S) is also visible, showing a peak at  $S = K_2$  and a slope of  $K_3$  for  $S < K_2$  and  $K_4$  for  $S > K_2$ .

So, we have defined here only 1 period. So, we will give the seasonal input here for only 1 period and we have 3 layers. So, you can give the input for all 3 layers. So, when you click layer 2, second layer, so you have to give the value of  $k_1$ . So, the  $k_1$  value as per numerical, it is 10000 psi and you also define a minimum value of  $k_1$ . So, minimum value of  $\phi$  represents the minimum value of  $k_1$  which is taken as 0 here. So, this is for the granular layer. Now, for a fine-grained soil or a clayey soil, now that is a layer four subgrade soil, you give what type of clay it is. So, for very soft from very soft medium and stiff clay, the number here defines what type of clay ranging from very soft, medium

and stiff clay. So, you go from 1, 2, 3 and 4 here. So, you give it is a soft clay. So, when you click on the soft clay, these are the minimum parameters used. So, you already saw that you have a minimum value defined for a soft clay, maximum value defined for the soft clay and  $k_1$  value used for the soft clay, we give that as input parameters, you can also get these parameters value from the experimental results. So, once you give this parameter, your non-linear input is done.

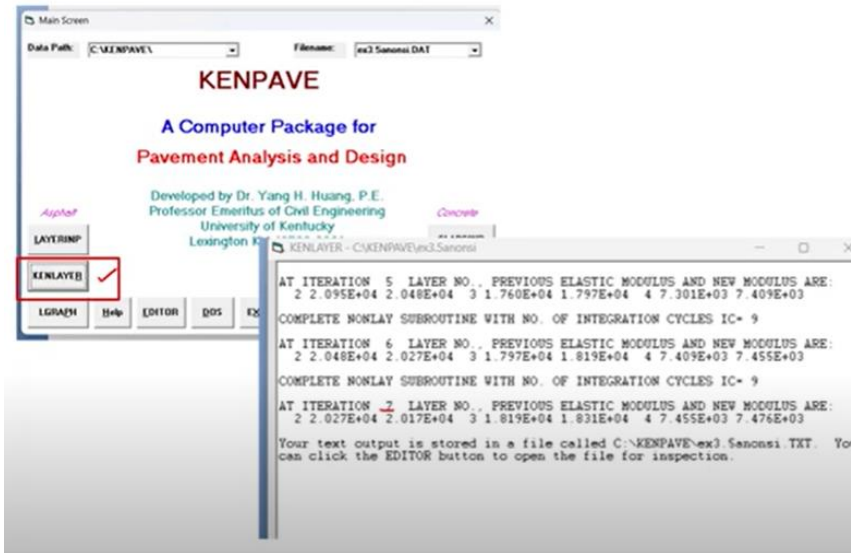
(Refer Slide Time: 22:38)

The screenshot displays the 'Main Menu of LAYERNP' with various options like 'File', 'General', 'Zcoord', etc. Below, there are several windows for defining seasonal input parameters for different layers (Layer 2, Layer 3, Layer 4) and Data Set No. 1. A table shows parameters for Layer No. 2 (Granular) and Layer No. 4 (Clay). A graph plots Resilient Modulus (MPa) against Vertical Stress (kPa) for different soil types: Stiff, Medium, and Soft. The graph shows curves for different soil types with associated  $K_1$  values:  $K_1 = 12,340$  for Stiff,  $K_1 = 1,110$  for Medium, and  $K_1 = 178$  for Soft. A legend indicates  $K_1 = 3020$  for Soft. A person is visible in the bottom right corner of the slide.

So, after giving this, just save and exit out of this main menu options and you run this program using the KENLAYER. When you compile it, so, you will get the screen something like this once the compilation is completed. So, this is the number of iterations which was taken to compute the modulus value at subgrade layer and the base layer.

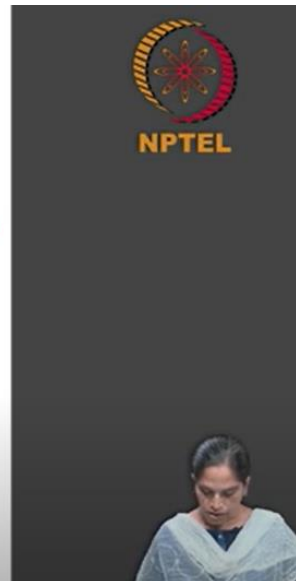
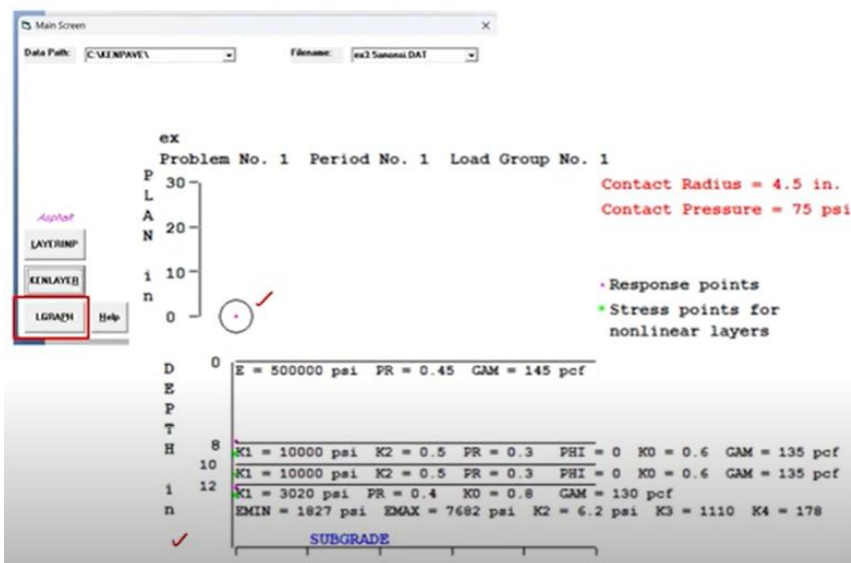
(Refer Slide Time: 23:07)





So, once the compilation is over, you will get the graphical representation of the results. So, this you can see that in plan and in elevations. The elevation of the section looks like this. So, you have different modulus, what you have assumed, different depth what you have assumed and the modulus value computed and also the input parameters are given here.



(Refer Slide Time: 23:38)



The results can be viewed as a text file and you can see that the modulus value of the second layer was computed to be 2.017E4 psi and the third layer it is 1.831E4. So, you know that second layer and third layer, both layers are the base layer. So, depending on the stress point you consider, the modulus values here are different. Fourth layer is a subgrade

layer and the modulus of the subgrade layer after iterations was found out to be this. So, this modulus was computed at the locations of 9 inch, 11 inch and 13 inch and the normal stress computed at these locations is given here. So, at the second layer exactly which is at the 9 inch, this is the modulus value computed, you can see 3 normal stresses. So, you can see that these normal stresses value have a negative value. So, we said that negative value will be adjusted to 0 in computation of the modulus value. So, the negative values were adjusted to 0 for the computation of the modulus value. So, this is how the iteration goes on. And finally, once the result converges for the tolerance value, we mentioned, you will get the results of modulus at different locations. So, for this computed modulus, we have given two critical locations one is at the interface of asphalt layer and the base layer and second one is at the interface of base layer and subgrade layer. So, you will get the critical stresses. So, you can see that at the interface, a tensile stress is going to control the fatigue damage which is this  $\epsilon_t$  value  $-1.024E-4$ , this is your critical stress which is going to control the fatigue damage at the asphalt layer. Now, rutting on the subgrade layer is controlled by  $\epsilon_c$  which is vertical compressive strain at the top of the subgrade layer. So, these are the critical strains for this computed modulus. So, it is clear that these values depend on the modulus value. So, this process is iterated to compute the modulus value. So, we have to keep in mind that the modulus is determined at different locations. So, you get the stress at those points first and then modulus is computed from the determined stress. So, till this process is iterated till the solution converges.

(Refer Slide Time: 26:06)

```

PERIOD NO. 1  LOAD GROUP NO. 1
AT ITERATION 1 LAYER NO. AND MODULUS ARE : 2 3.000E+04 3 1.500E+04
4 5.000E+03
AT ITERATION 2 LAYER NO. AND MODULUS ARE : 2 2.643E+04 3 1.402E+04
4 6.457E+03
AT ITERATION 3 LAYER NO. AND MODULUS ARE : 2 2.202E+04 3 1.497E+04
4 7.051E+03
AT ITERATION 4 LAYER NO. AND MODULUS ARE : 2 2.095E+04 3 1.740E+04
4 7.301E+03
AT ITERATION 5 LAYER NO. AND MODULUS ARE : 2 2.048E+04 3 1.797E+04
4 7.405E+03
AT ITERATION 6 LAYER NO. AND MODULUS ARE : 2 2.027E+04 3 1.815E+04
4 7.455E+03
AT ITERATION 7 LAYER NO. AND MODULUS ARE : 2 2.017E+04 3 1.831E+04
4 7.474E+03
LAYER NUMBER AND THREE NORMAL STRESSES INCLUDING GEOSTATIC STRESSES
2 4.032 -0.596 -0.996 3 3.396 -1.051 -1.051
4 3.155 0.957 0.957
LAYER NUMBER AND ADJUSTED THREE NORMAL STRESSES INCLUDING GEOSTATIC
STRESSES FOR COMPUTING ELASTIC MODULUS ARE:
2 4.032 0.000 0.000 3 3.396 0.000 0.000
4 3.155 0.957 0.957
RADIAL VERTICAL VERTICAL VERTICAL RADIAL TANGENTIAL SHEAR
COORDINATE COORDINATE DISPLACEMENT STRESS STRESS STRESS STRESS
(STRAIN) (STRAIN) (STRAIN) (STRAIN) (STRAIN) (STRAIN) (STRAIN)
0.00000 0.00000 0.01059 3.826 -19.824 -59.884 0.000
(STRAIN) (STRAIN) 1.496E-04 2.742 -1.024E-04 .000E+00
0.00000 12.00010 0.00980 2.742 0.137 0.137 0.000
(STRAIN) (STRAIN) 2.879E-04 -2.100E-04 -1.100E-04 .000E+00

```

So, now, second part of the problem is by using a method 2 that is considering the base course as a single layer and considering the stress point to be at the upper quarter of the base layer. So, you have total 4 inch thickness. Now, from the base layer, you take 1 inch thickness and determine the modulus value at this point and further determine  $\sigma$ ,  $\epsilon_r$  and  $\epsilon_z$  at two different locations. So, for these conditions, these are going to be your input.

(Refer Slide Time: 26:28)

3.5 Figure P3.5 shows a three-layer system under a single-wheel load. Layer 1 is linear elastic, layers 2 and 3 nonlinear elastic. The loading, thicknesses, and material properties are shown in the figure. With the use of KENLAYER, determine the maximum tensile strain at the bottom of layer 1 and the maximum compressive strain at the top of layer 3 by (a) method 1 in which layer 2 is subdivided into two layers, each 2 in. thick, and (b) method 2 in which layer 2 is considered as one layer and the stress at the upper quarter point of layer 2 is used to determine  $E_2$ . [Answer: (a)  $1.02 \times 10^{-4}$ ,  $2.85 \times 10^{-4}$ ; (b)  $1.04 \times 10^{-4}$ ,  $2.85 \times 10^{-4}$ ]

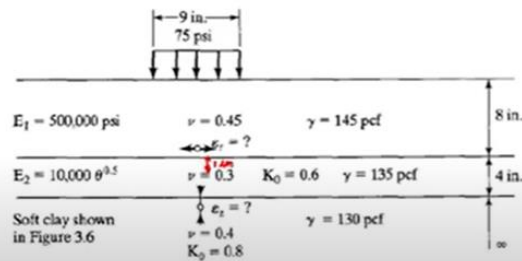


FIGURE P3.5



So, for the general information, we take the type of material to be non-linear. Damage analysis as of now we are not doing, so 0. Number of period and number of load group each is 1, tolerance of numerical integration, we keep it as the same as a default value. Now, number of layers is 3. In the previous case, we took it as 4 because we divided the base course into two sub layers. Here, base course is considered as a single layer. So, we take the number of layers to be 3 alone and number of z coordinates for the analysis is 2, 1 at the first interface and the second at the second interface. So, maximum number of integration - default value. So, this is the general information.

(Refer Slide Time: 27:31)

General Information of LAYERINP for Set No. 1

TITLE Ex3 5b

|   |         |         |
|---|---------|---------|
| Type of material (1=linear, 2=nonlinear, 3=viscoelastic, 4=combined)          | (MATL)  | 2 ✓     |
| Damage analysis (0=no, 1=yes with summary only, 2=yes with detailed printout) | (NDAMA) | 0 ✓     |
| Number of periods per year  | (NPY)   | 1 ✓     |
| Number of load groups   | (NLG)   | 1 ✓     |
| Tolerance for numerical integration   | (DEL)   | 0.001 ✓ |
| Number of layers  | (NL)    | 3 ✓     |
| Number of Z coordinates for analysis  | (NZ)    | 2 ✓     |
| Maximum cycles of numerical integration                                       | (ICL)   | 80 ✓    |
| Type of responses (1=displacements only, 5=plus stresses, 9=plus strains)     | (NSTD)  | 9 ✓     |
| All layer interfaces bonded (1=yes, 0-if some are frictionless)               | (NBOND) | 1 ✓     |
| Number of layers for bottom tension   | (NLBT)  | 1 ✓     |
| Number of layers for top compression  | (NLTC)  | 1 ✓     |
| System of units (0=English, 1=SI)   | (NUNIT) | 0 ✓     |

OK

(1) This form appears when the "General" on the Main Menu of LAYERINP is clicked. You can override any of the default values by typing in a new value. You can use the Tab key to move the cursor from one textbox to the next or just click on the textbox before typing. The use of click has the advantage that you don't have to delete the default before typing in the data you want. If you want to read the remaining text, you can use the scrollbar. You can also use the PgDn key after clicking this textbox to make it active.

(2) TITLE (title of run): Any title or comment can be typed on one line. The title should not be longer than 68 characters including spaces. If you make a mistake in typing, use the Del key to erase any typographical errors. When the total length reaches 68, no additional characters can be added. No comma should be used in TITLE. Use colon or semicolon instead.

(3) MATL (types of material): 1 when all layers are linear elastic, 2 when some layers are nonlinear



Followed by the general information, we give z coordinate that is the point where we need a critical stress and strain, one is at 8 inch from the top, another is second interface which is 12 inch from the top. So, it is 12.001 inch.

(Refer Slide Time: 27:48)

Main Menu of LAYERINP

File General **Zcoord** Layer Interface Moduli Load Nonlinear Viscoelastic Damage

Untitled done input input default input input input default default

☐ Data Set 1 ☐ Data Set 2 ☐ Data Set 3 ☐ Data Set 4 ☐ Data Set 5 Save Save As Exit

Yes No No No No

Z Coordinates of Response Points for Data Set No. 1

| Point No. | ZC       |
|-----------|----------|
| 1         | 8 ✓      |
| 2         | 12.001 ✓ |

(1) This form appears when the "Zcoord" menu on the Main Menu of LAYERINP is clicked. The number of Z coordinates on this form is equal to NZ, as specified in the "General" menu. This form is different from the one used for General Information in that a dotted rectangle, instead of the cursor, is used to indicate the active cell. If the dotted rectangle is not the location for input, you can use the arrow key to move the dotted rectangle to the cell you want to input, or more conveniently by clicking the cell you want. After you type in the data, the dotted rectangle will be changed into a three dimensional box and you must press the Enter key to make it effective. You can also use the up and down arrow keys to make the entry effective. You should not click the other cell before pressing the Enter key, otherwise the data you have typed will move to the cell you click.

(2) ZC (vertical distance, or z coordinate, of each response point): When the point is located exactly at the interface between two layers, the results are at the bottom of upper layer. If the results at the top of lower layer are desired, a slightly larger z coordinate, say 0.0001 larger, should be used.

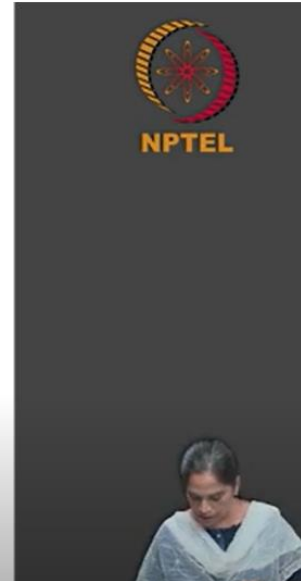
(3) After typing in the data in the first cell, move to the next cell by pressing the Enter or arrow down key.

Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.



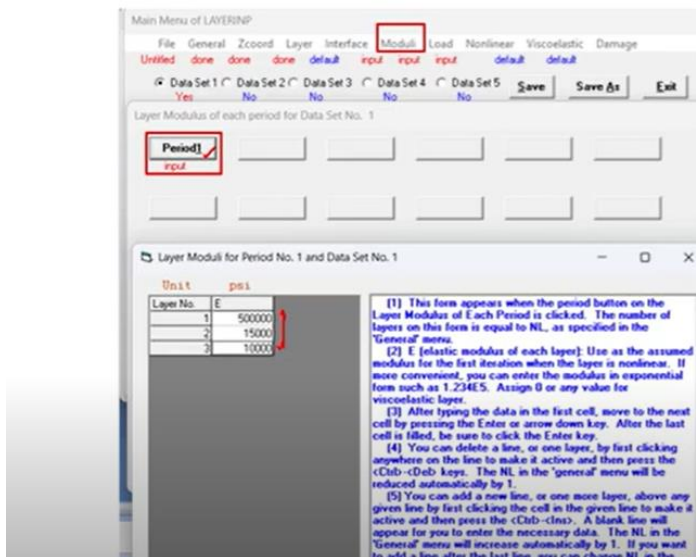
So, layer input, same as the previous case, you have thickness of different layer but the second layer, base course is not split into two it is considered as a one single layer. So, you have 4 inch thickness. So, otherwise the Poisson's ratio and the  $\gamma$  values are same as the previous condition.

(Refer Slide Time: 28:08)



So, when you go to the moduli value, we define only one period and you can assume the modulus value again except first layer, the second and the third layer are a seed modulus which is assumed. You can assume to any nearest number.

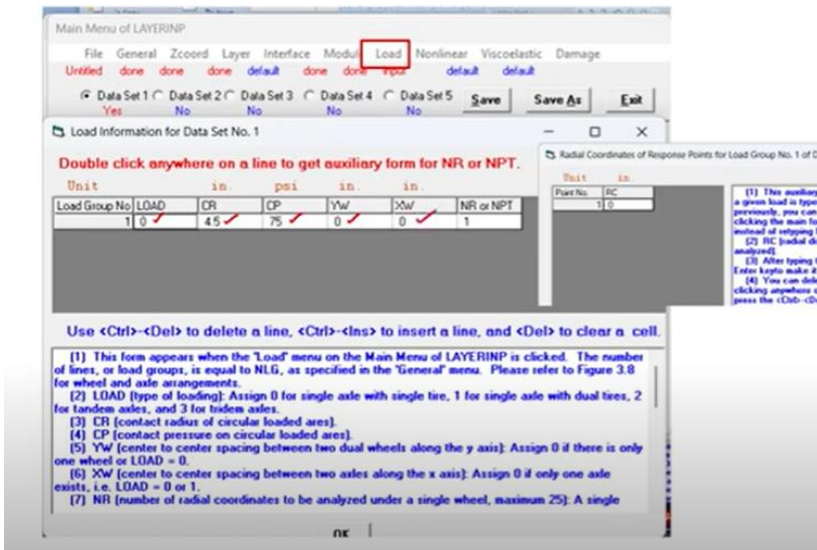
(Refer Slide Time: 28:26)



So, once the modulus input is done, the load input is same as the previous type, we give 0 load category as it is a single axle single wheel, contact radius is 4.5 inch, contact pressure is 75 psi and YW is 0 because there is only one axle and one wheel XW is also 0, NR is given as 1 and it is exactly at the center of loading. So, RC value is 0.

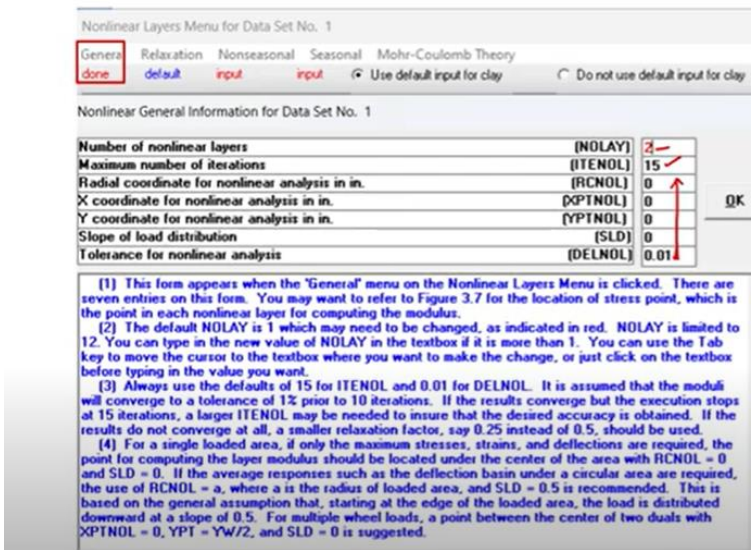
(Refer Slide Time: 28:48)





So, once the load input is given, next input is the non-linear input. In the non-linear general input, the number of non-linear layers is only 2. In a previous case we kept the number of non-linear layers to be 3 because we divided the base layer into 2. So, here, number of non-linear layers is only 2. Maximum number of iterations we will keep it as a default value and other parameters are same as that was explained previously.

(Refer Slide Time: 29:28)



So, in the non-seasonal input, you have layer number 2 and layer number 3. Layer number 2, the depth at which we determine the modulus value is at the upper quarter. So, it is 8 inch and upper quarter is 2 inch. So, it is 8+2, 10 inch and at the subgrade layer, 1 inch below the interface, it is 13 inch. So, this is a value here is 13 inch. So, granular layer

NCLAY, you give it as 0 and soil subgrade layer you give it as 1 and the corresponding input for granular layer, that is constant  $k_2$  and earth pressure constant are given as defined in the previous cases. So, you keep in mind you have only 2 layers here. So, for the seasonal input, that is for defining a  $k_1$  value and for the minimum  $k_1$  value, it is same as defined earlier, but the thing is you have only 2 layers here and in the previous case, we had 3 layers.

(Refer Slide Time: 30:21)

The screenshot shows the 'Main Menu of LAYNONP' with the 'Nonseasonal Layers Menu for Data Set No. 1' active. The 'Nonseasonal' tab is selected, and the 'NCLAY' column in the table below is highlighted. The 'Nonseasonal Input Parameters for Layer No. 2 (Granular) and Data Set No. 1' dialog box is open, showing parameters for granular materials. The 'Nonseasonal Input Parameters for Layer No. 3 (Clay) and Data Set No. 1' dialog box is also open, showing parameters for clay. The NPTEL logo is visible in the top right corner of the software window.

| Sequence | LAYNO | ZCNOL | NCLAY |
|----------|-------|-------|-------|
| 1        | 2     | 10    | 0     |
| 2        | 3     | 11.0  | 1     |

Nonseasonal Input Parameters for Layer No. 2 (Granular) and Data Set No. 1

Nonlinear exponent for granular materials (K2) 0.5

Coefficient of earth pressure at rest (K0) 0.6

Nonseasonal Input Parameters for Layer No. 3 (Clay) and Data Set No. 1

Deviator stress at break point for clay in psi (K2) 6.2

Slope when deviator stress smaller than K2 (K3) 1116

Slope when deviator stress greater than K2 (K4) 178

Coefficient of earth pressure at rest (K0) 0.8

So, now, once you complete this input and compile the program this is the result you will get. So, a total of 6 number of iterations were made to compute the modulus value. So, these are the modulus values of the base layer and sub base layer at a computed depth and you can see that these are the values of normal stress you get. These normal stress value if you have a negative number are adjusted to 0 and the modulus values are computed at these specific locations. So, for these modulus values we determine critical stresses and strains. So,  $\epsilon_t$  which is critical is this value  $-1.025E-4$  which is same as your previous case and here vertical stress at the top of a sub grade is  $2.861E-4$  which is also nearing to the previous case that we determined. So, in a non-linear analysis to account for the stress dependent modulus value, we use the iteration process, we first give a seed value of a modulus, use the iteration process until the result converges and finally, we get the modulus at different depths and that modulus is further used in determining stresses and strain at critical locations.

(Refer Slide Time: 31:56)



```

ex15.out
File Edit Input parameters Output parameters Data File Examples Help

Z COORDINATE (ZCNL) FOR COMPUTING ELASTIC MODULUS ARE: 10 13
W COORDINATE (WCNL) FOR COMPUTING ELASTIC MODULUS ----- = 0
X COORDINATE (XCNTNL) FOR COMPUTING ELASTIC MODULUS ----- = 0
Y COORDINATE (YFTNL) FOR COMPUTING ELASTIC MODULUS ----- = 0
SLOPE OF LOAD DISTRIBUTION (SLD) ----- = 0
TOLERANCE (TOL) FOR NONLINEAR ANALYSIS ----- = 0.01
RELAXATION FACTORS (RELAX) FOR NONLINEAR ANALYSIS OF EACH PERIOD ARE: 0.5

UNIT WEIGHT OF LAYERS (GAM) ARE: 145 135 130

LAYER NO. = 2 HCLAY = 0 E2 = 0.5 ED = 0.4
LAYER NO. = 3 HCLAY = 1 E2 = 4.2 E3 = 1110 EA = 170 ED = 0.8

LAYER NUMBER AND GEOSTATIC STRESS (GEO) ARE:
2 0.52755 3 1.05903

FOR PERIOD 1 LAYER NO. = 2 HCLAY = 0 PHI = 0 E1 = 10000
FOR PERIOD 1 LAYER NO. = 3 HCLAY = 1 EDIM = 1527 EDAX = 7482
E1 = 3020

FOR LOAD GROUP 1 LAYER NO. AND R COORDINATE FOR COMPUTING MODULUS ARE:
1 2 0 3 0

PERIOD NO. 1 LOAD GROUP NO. 1

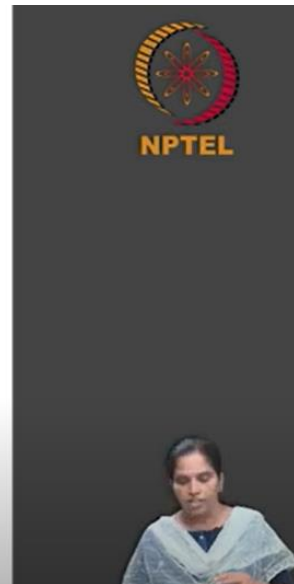
AT ITERATION 1 LAYER NO. AND MODULUS ARE: 2 1.500E+04 3 1.000E+04
AT ITERATION 2 LAYER NO. AND MODULUS ARE: 2 1.748E+04 3 7.482E+03
AT ITERATION 3 LAYER NO. AND MODULUS ARE: 2 1.930E+04 3 7.558E+03
AT ITERATION 4 LAYER NO. AND MODULUS ARE: 2 1.972E+04 3 7.538E+03
AT ITERATION 5 LAYER NO. AND MODULUS ARE: 2 1.993E+04 3 7.516E+03
AT ITERATION 6 LAYER NO. AND MODULUS ARE: 2 1.994E+04 3 7.506E+03

LAYER NUMBER AND THREE NORMAL STRESSES INCLUDING GEOSTATIC STRESSES
2 3.665 -0.904 -0.904 3 3.165 0.990 0.990

LAYER NUMBER AND ADJUSTED THREE NORMAL STRESSES INCLUDING GEOSTATIC
STRESSES FOR COMPUTING ELASTIC MODULUS ARE:
2 3.665 0.000 0.000 3 3.165 0.990 0.990

RADIAL VERTICAL VERTICAL VERTICAL RADIAL TANGENTIAL SHEAR
COORDINATE COORDINATE DISPLACEMENT STRESS STRESS STRESS STRESS
0.00000 0.00000 0.01057 3.748 -0.904 -90.035 0.990
(STRAIN) (STRAIN) (STRAIN) (STRAIN) (STRAIN) (STRAIN) (STRAIN)

```



. This figure shows the influence of the stress dependent material on the critical stresses, that is the tensile strain at the bottom of the HMA layer and the compressive strain at the top of the subgrade layer. So, this computation is made for the pavement thickness as shown here. So,  $h_1$  is considered as two different values, one is 2 inch thickness, another is 8 inch thickness,  $h_2$  is considered as 12 inch thickness. So, the value of  $h_2$  is considered to be stress dependent and the equation is given here,  $8000\theta^{0.5}$ ,  $E_3$  value is also considered as an elastic material. So,  $E_1$  is elastic,  $E_3$  is elastic and  $E_2$  is considered to be a stress dependent material. In such case, when you vary the pressure intensity, you can see that the tensile strain and the vertical compressive strain increasing with the load value.

And you can also see that when the thickness of the HMA layer is thin that is for a 2 inch thickness, you can see that the influence of non-linearity of this case and this case is more pronounced compared to the thick asphalt layer. So, this is the same case even here when the layer thickness is small, the non-linearity influence is more pronounced when compared to the thick asphalt layer here. So, we can see that the stress dependent modulus value is more influential in case if you provide a thin asphalt pavement compared to the thick asphalt pavement and this value increases when the load value increases. So, that is what we see here the difference is more for a higher load category compared to the lower value.

(Refer Slide Time: 34:15)

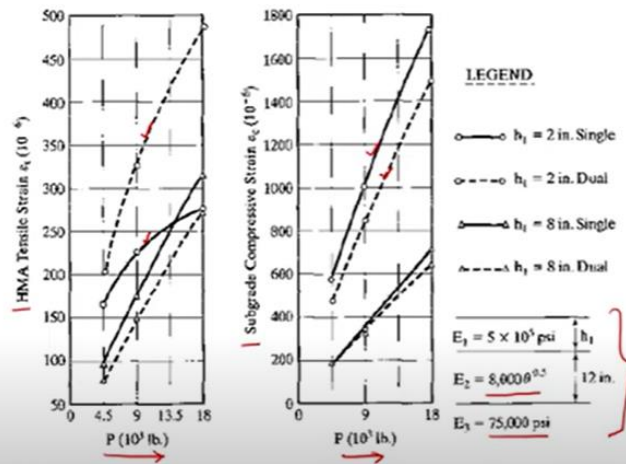
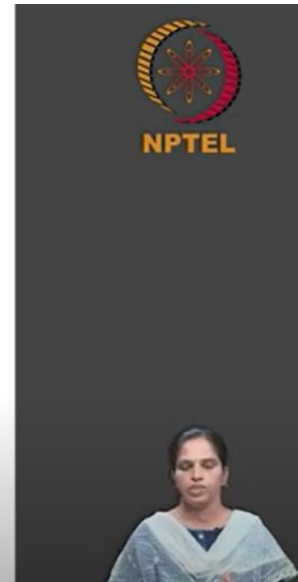


FIGURE 3.30  
Effect of wheel loads on nonlinear responses (1 in. = 25.4 mm, 1 psi = 6.9 kPa)



So, we have seen how the stress dependent modulus value influences the critical stresses and strains. In the next lecture, we will see damage analysis and how to do damage analysis using the KENLAYER software. Thank you so much.