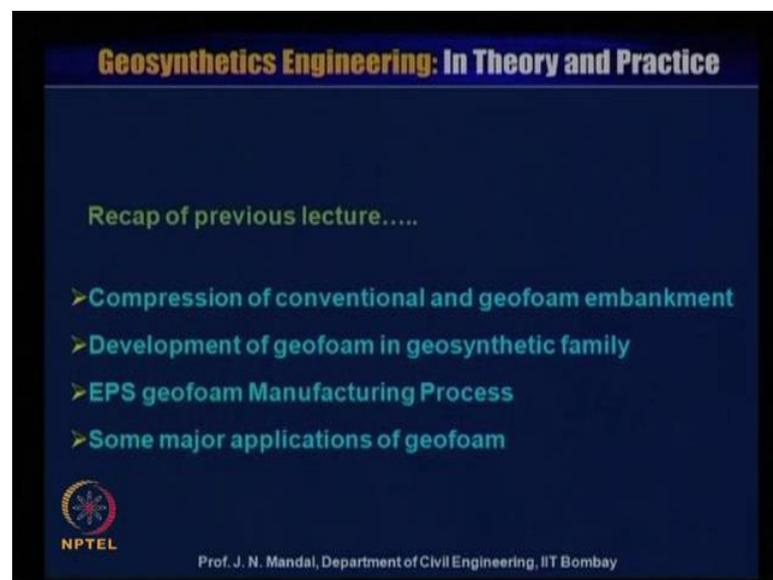


Geosynthetics Engineering: In Theory and Practices
Prof. J. N. Mandal
Department of Civil Engineering
Indian Institute of Technology, Bombay

Lecture - 59
Designing with Geofom

Dear students warm welcome to NPTEL phase two program, video course on geosynthetics engineering in theory and practice. My name is Professor J N Mandal department of civil engineering, Indian Institute of Technology, Bombay, Mumbai, India. This is module lecture number 59 designing with geofom.

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I will now focus the recap of the previous lecture, compression of conventional and the geofom embankment, development of geofom in geosynthetics family, EPS geofom manufacturing process and some major application of geofom.

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Geosynthetics Engineering: In Theory and Practice

Advantages: Geofoam offers the following benefits:

- Transport costs are very low,
- Higher, steeper embankment,
- Smaller excavations and Reduced structural support
- Faster Construction and ease of installation
- No mechanical fastening necessary
- Helps protect against frost
- Heave and stress from expansive soil movement

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Now, what are advantage using the geofoam. Geofoam offer the following benefits, transport cost are very low because it is a lighter material. Higher and steeper embankment can be constructed, smaller excavation and reduced structural support, faster construction and ease of installation, because it is a super lighter material I say that 1 mole is about 2 meter by 1 meter by 0.5 meter it weight about the 36 kg. So, it very easy to handle and install, no mechanical fastening necessary, help protect against the frost. Heave and stress from expansive soil movement, no special equipment for installation, saving for simplified design handle and install easily save time and labor.

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Geosynthetics Engineering: In Theory and Practice

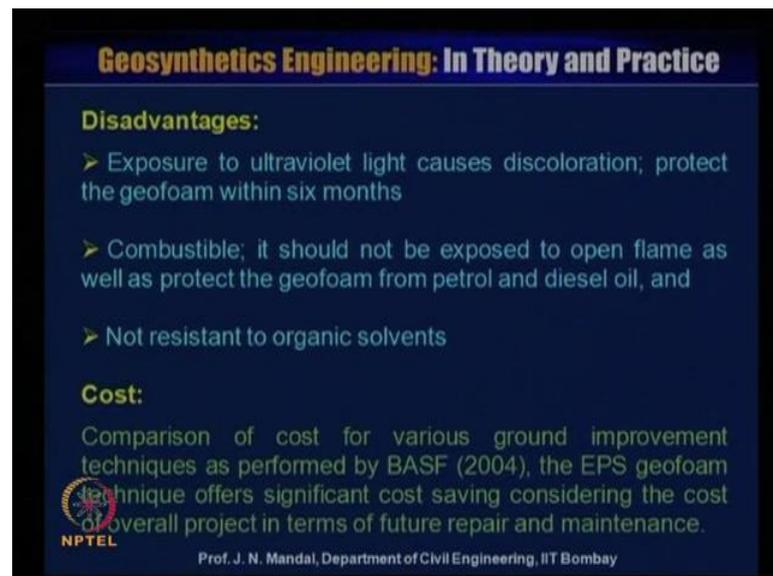
- No special equipment for installation
- Saving for simplified design
- Handled and install easily
- Save time and labor
- Relief of hydrostatic pressure
- Light weight, factory-fabricated panels
- Low material cost with respect to piling, foundations, and
- Insoluble in water

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So, you do not need skilled labor, unskilled labor can also install the geofoam material. Relief of hydrostatic pressure, it is a light weight and factory fabricated panel. So, as you like it you can have it. And also you can have it in different density low material cost with respect to piling foundation and insoluble in water. So, every material has an advantage as well as disadvantage.

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This geofoam material also have certain disadvantages, this exposure to ultraviolet light causes discoloration and protect the geofoam within the 6 month. And combustible it should not be exposed to open flame as well as protect the geofoam from petrol diesel oil and no resistant to organic solvent.

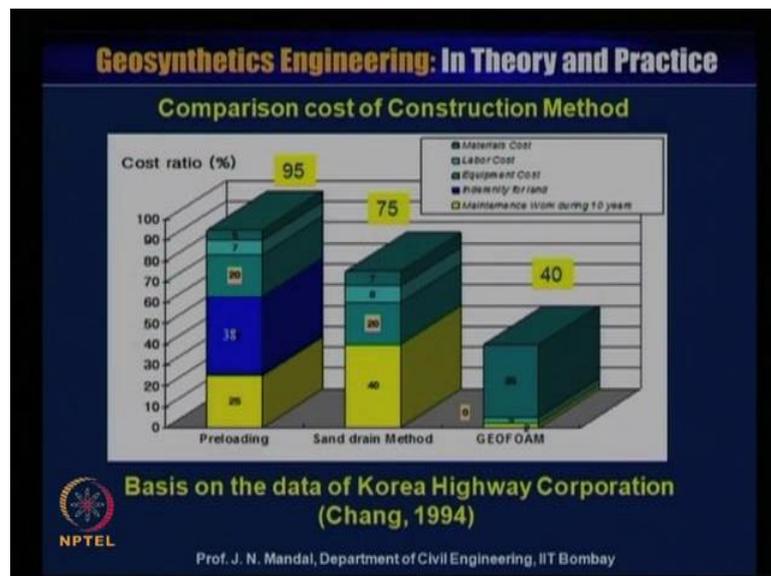
So, one has to be taken care for the use of the geofoam material. Sometimes it is also the use for any construction like that embankment. If there is a any fire then contactor will be the responsible for this. And he has to pay for that because one has to be very cautious about the use of the geofoam from firing. If there is any petrol, is passed through the road then it is necessary to protect the petrol or the diesel by providing some impermeable material. In order that petrol or diesel cannot be passed and should not be destroyed this geofoam material .

So, these are the some of the issue you have to keep it in mind, sometimes also it has been observed that some ends make a hole and build a room into the geofoam material. And if it happens also, some chemical treatment can be provided to protect the geofoam

material. Nowadays, also some alternative geofoam material is also coming up. So, in terms of the cost, most of the time it has been felt that geofoam material is costly, but I say this concept is totally wrongly. I will show you some slide where you can think about that what should be the overall cost of the project, if you adopt the different kind of the system.

And you ultimately prove that which will be the faster and which will be the more economical as well as the stable. So, comparison of cost for various ground improvement technique as performed by BASF 2004, the expanded polystyrene geofoam technique offer significant cost saving, considering the cost of overall project in terms of future repair and maintenance.

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So, you can see is this comparison cost of construction method. So, this is the basic on the data of the Korean highway corporation. And this reported by Chang 1994, you can see that this is the cost ratio in percentage. And this is the preloading system what we generally adopt for any ground improvement technique. So, here is 25 percentage is for maintenance work during the 10 years. This is 38 percentage and this is 20 percentage for the equipment cost. And then this 7 percentage is the is the labor cost 7 percent is the labor cost and this is 5 percentage is the alternate cost.

So, you can see that what are the cost for the preloading, but overall you can have this cost ratio about 95 percentage, but if you adopt the sand drain method whereas, 40

percentage is the maintenance work during the 10 years. And then this is the 20 percentage for the equipment cost. And this is the 43 percentage is the labor cost and this 7 percent is the material cost. Whereas, if you adopt the this is the geofoam system. So, here you require only the 40 percent that labor cost. So, you can see that with these three system, whether it is a preloading and the sand drain method and the geofoam method. So, geofoam method is cost ratio is 40 percent. So, it is drastically reduce the cost, for the ground improvement if you deploy this geofoam material which is a super light material.

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Geosynthetics Engineering: In Theory and Practice

Farnsworth et al. (2008) compared the construction time and performance of three types of techniques.

1. *MSE wall supported by lime cement column:* In this system, time for construction is about 12 months and settlement after ten years is 137 mm.
2. *MSE wall with prefabricated vertical drains installed and surcharging:* In this system, time for construction is about 14 months and settlement after ten years is 112 mm.
3. *Expanded polystyrene embankment:* In this system, time for construction is about 4 months and settlement after ten years is 76 mm.

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Farnsworth et al 2008, compare the construction time and performance of 3 type of the technique. One is MSE or mechanically stabilized earth wall, supported by lime cement column. In this system time for construction is about 12 month. And settlement after 10 years is 137 millimeter. Number 2 mechanically stabilized earth wall with prefabricated vertical drain or PVD or weak drain band drain, installed and surcharging. In this system time for construction is about 14 month and settlement after 10 years is 112 millimeter. And number 3 expanded polystyrene embankment or the geofoam, embankment is made with the geofoam. In this system time for construction is about 4 month and settlement after 10 year is 76 millimeter.

So, we can observe here with 3 different system and you look at the time. So, when you are adopting the mechanically stabilized earth wall your construction time is the 12

month. When you are using prefabricated vertical drain with the mechanically stabilized earth wall this time is about 14 month. On the other end you can see that when you will use only geofoam or the expanded polystyrene material the time is only 4 month. So, time can be drastically reduced. And you know that time is money and also is in terms of the settlement.

And in case of the mechanically stabilized earth wall, supported by the lime cement column, the settlement after ten year is 137 millimeter. Whereas, in case of MSE wall with prefabricated vertical drain, the settlement after 10 years is 112 millimeter, but if you simply use the expanded polystyrene material, the settlement after 10 year is 76 millimeter. You can see that how this dramatically reduced the settlement, by the inclusion of the geofoam material. Now, here it shows that technique what we use 1, 2, 3.

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Technique	Time for construction (months)	Cost	Settlement after 10 yrs
1	12	\$160,000	137mm
2	14	\$110,000	112mm
3	4	\$120,000	76mm

> The geofoam embankment had best performance in terms of settlement and rapid construction time consideration.

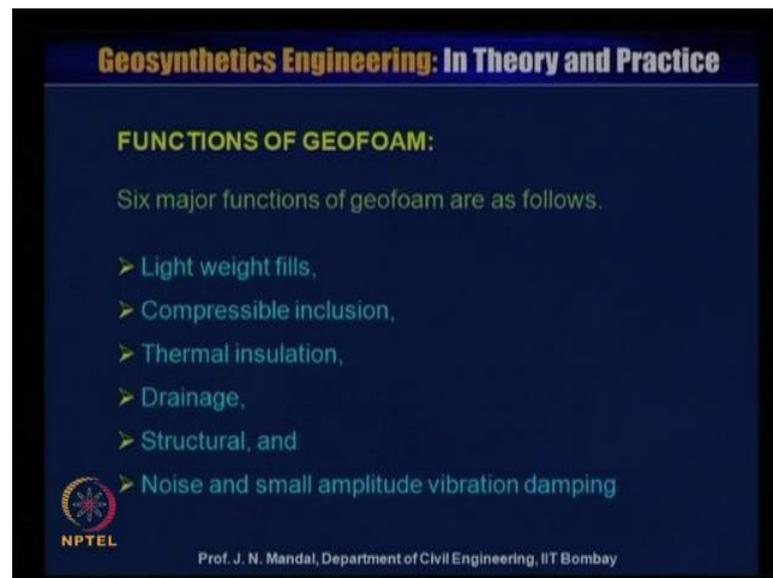
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Time for construction month 12 month for one technique, two techniques is say 14 month. And three it is 4 month and in cost for technique 160,000 dollar and for technique two 110,000 dollar and technique three 120,000 dollar, And settlement after 10 years technique one 137 seven millimeter and technique two is 112 millimeter and technique three is 76 millimeter.

So, look that geofoam embankment had best performance in terms of the settlement and rapid construction time consideration. Even then that it is little bit higher than the technique 2, but in terms of the settlement and the performance this geofoam material is

the best. Now, as you have known that when we use the geosynthetic material and that material also has a different function like a separation function, reinforcement function, filtration function, drainage function, sealing function, erosion control function etcetera. Similarly, the expanded polystyrene or the geofoam have a major 6 function. So, 6 major function of the geofoam are as follow.

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This is a light weight fill is a function, compressible inclusion, thermal insulation, drainage, structural and noise and small amplitude vibration damping. I have also shown you earlier that how this material has been used for the different function, where the construction for embankment, where it can use as a light weight fill material, where at the back of the retaining wall, where the geofoam material act as a compressible inclusion or where there is a storage or temperature control, how you can use that thermal insulation where geofoam is used. Also the geofoam material itself can act as a drainage material, also that any structural aspect also. And also noise I say that how you can use then as a noise and small amplitude of the vibration damping at the ground.

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Geosynthetics Engineering: In Theory and Practice

Application of geofoam as light weight fills are as follows:

- Roads and embankments,
- Slope-sided fills and backfills,
- Vertical-faced fills and backfills (geofoam walls), and
- Railways

Applications of geofoam as a compressible inclusions are as follows:

- Behind retaining walls
- Beneath slabs or beams at foundation,
- Above the tunnels, pipes and culverts

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Now, application of geofoam as a light fill as follow, road and embankment, slope side fill and backfill vertical faced fill and backfill geofoam wall and railway, application of geofoam as a compressible inclusion are as follow. You can use behind the retaining wall beneath the slab or beam at foundation above the tunnel pipes and the culvert.

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Geosynthetics Engineering: In Theory and Practice

Applications of geofoam as thermal insulation are as follows:

- Below ground walls of structures
- Retaining structures
- Foundations (footing)
- Earth retaining structures
- Pavements and railways
- Under floor area of structures and
- Clay liners

Applications of geofoam as drainage are as follows:

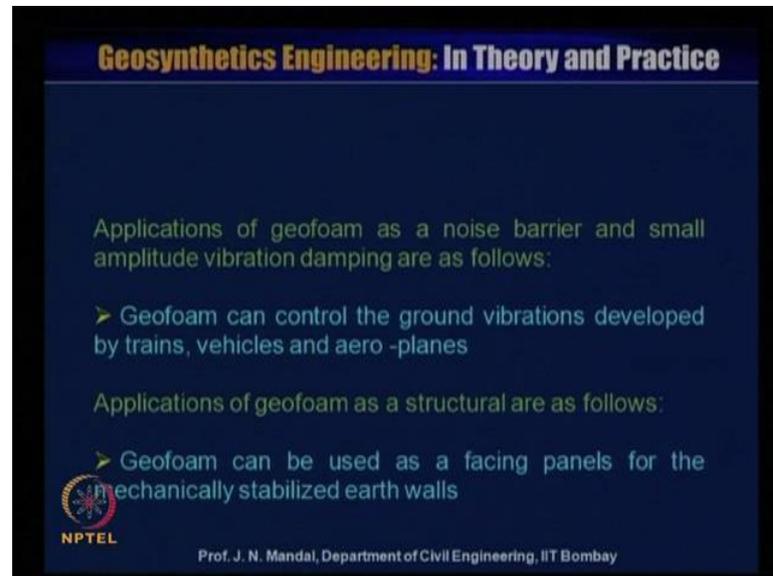
Geofoam can act as drainage to drain the water and gases in retaining walls and landfills respectively

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Applications of geofoam as a thermal insulation are as follow. Below ground wall of structure, retaining structure, foundation that is footing, earth retaining structure pavement and railways under floor area of structure and clay liner. Applications of

geofoam as drainage are as follows geofoam can act as drainage, to drain the water and the gases in retaining wall and landfill respectively.

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Geosynthetics Engineering: In Theory and Practice

Applications of geofoam as a noise barrier and small amplitude vibration damping are as follows:

- Geofoam can control the ground vibrations developed by trains, vehicles and aero -planes

Applications of geofoam as a structural are as follows:

- Geofoam can be used as a facing panels for the mechanically stabilized earth walls

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Application of geofoam as a noise barrier and small amplitude vibration damping are as follows. So, geofoam can control the ground vibration developed by the train vehicle and aero-plane. Now, applications of geofoam as a structural are as follow. So, geofoam can be used as a facing panel for the mechanically stabilized earth wall. That means geofoam can act as a facing element itself. So, you can construct the geofoam wall. And some also work is going on this related area too.

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Geosynthetics Engineering: In Theory and Practice

Example 1:
Characteristics of embankment and foundation:

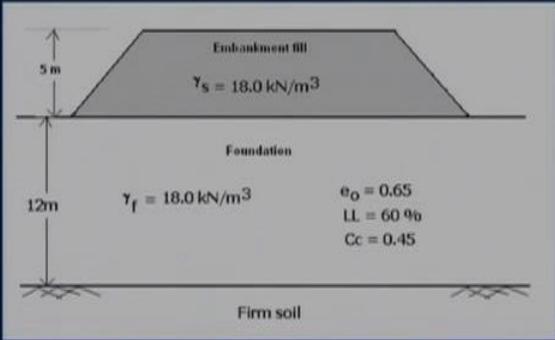
Without geofoam:-
Unit weight of embankment fill = 18 kN/m^3
Unit weight of foundation soil = 18 kN/m^3
Height of embankment including pavement covering (H_e) = 5 m
Thickness of pavement covering = 0.6 m
Liquid limit = 60%
Thickness of compressible layer (H_p) = 12 m
Unit weight of pavement layer = 19 kN/m^3

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So, this is example one characteristics of the embankment and foundation. Without geofoam unit weight of the embankment fill is equal to 18 kilo Newton per meter cube. Unit weight of foundation soil is 18 kilo Newton per meter cube. Height of the embankment including the pavement covering H_e is equal to 5 meter. Thickness of the pavement covering is equal to 0.6 meter. Liquid limit is equal to 60 percent, thickness of compressible layer that is H_p is equal to 12 meter. And unit weight of the pavement layer is equal to 19 kilo Newton per meter cube.

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Geosynthetics Engineering: In Theory and Practice

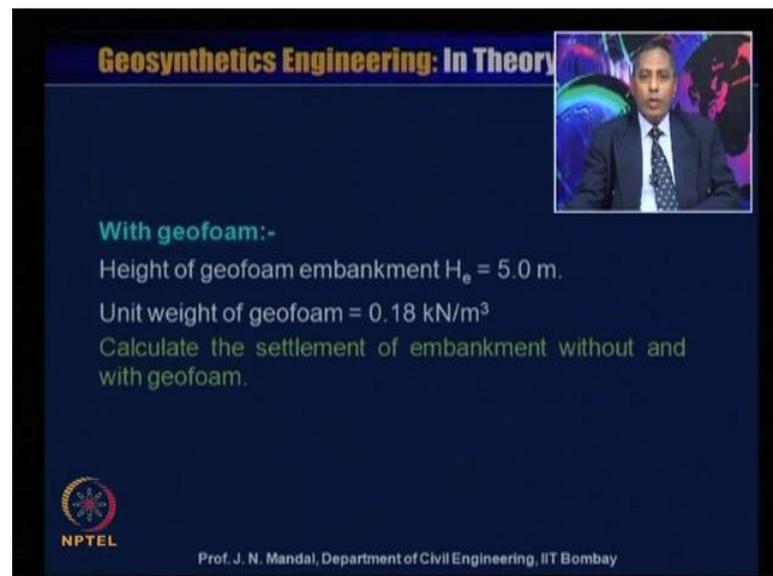


Embankment construction without geofoam

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So, this is the embankment construction without the geofilm. This is the embankment fill whose density is given 18 kilo Newton per meter cube. And this is the foundation soil and this unit weight of foundation 18 kilo Newton per meter cube. And void ratio is 0.65 liquid limit 60 percent and C c value is equal to 0.45. And depth of the foundation 12 meter and the height of the embankment is 5 meter.

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Geosynthetics Engineering: In Theory

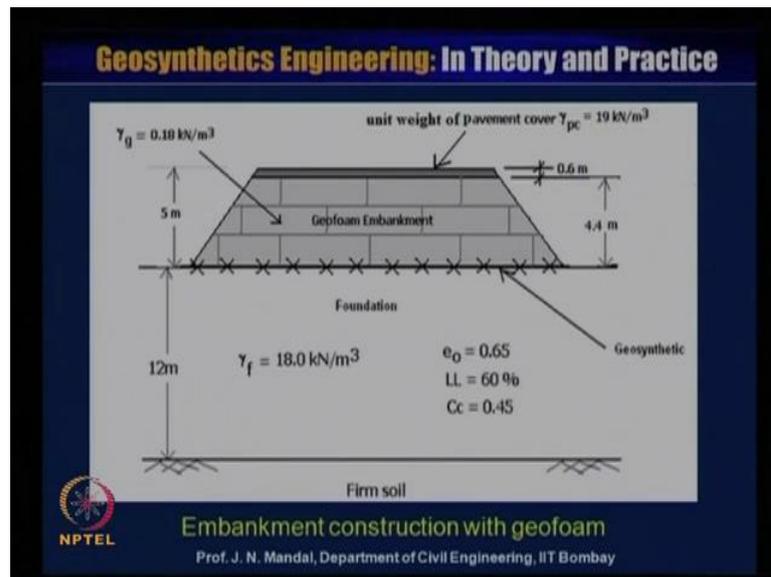
With geofilm:-
Height of geofilm embankment $H_e = 5.0$ m.
Unit weight of geofilm = 0.18 kN/m^3
Calculate the settlement of embankment without and with geofilm.

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So, with geofilm, so height of the embankment H_e is 5 meter. Unit weight of geofilm is 0.18 kilo Newton per meter cube. Here you can see that unit weight of geofilm is hundred times less than the unit weight of the soil. So, we have to calculate the settlement of the embankment without and with geofilm. So, we will observe that what will be the settlement, when there is no geofilm and what will be the settlement, when there is a geofilm.

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Now, here I just wanted to point out that, here is a unit weight of the pavement cover because its density is different. So, this is γ_{pc} is equal to 19 kilo Newton per meter cube. And this is thickness this pavement asphalt cover system is 0.6 meter. And this height is 4.4 meter. So, total will be equal to 5 meter.

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Geosynthetics Engineering: In Theory and Practice

Solution:

$C_c = 0.009 (L.L. - 10)$
 $= 0.009 (60 - 10) = 0.009 \times 50 = 0.45$

Holtz and Kovac (1981) reported the settlement as,

$$s = \frac{C_c \cdot H}{1 + e_0} \log \frac{P_0 + \Delta P}{P_0}$$

s = settlement, H = Thickness of compressible soil layer,
 e_0 = void ratio of compressible soil layer,
 P_0 = Existing pressure at the mean height of compressible soil layer, and
 ΔP = Embankment load due to settlement

Embankment construction with geofoam

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So, now the solution you know C_c is equal to 0.009 into liquid limit minus 1. So, is equal to 0.009 and liquid limit is 60 is given minus 10 is equal to 0.009 into 50, is equal to 0.45. Now, Holtz and Kovac 1981, reported the settlement as s is equal to C_c into H

divided by 1 plus e_0 into log of P_0 plus ΔP by P_0 , where s is equal to settlement H is equal to thickness of compressible soil layer, e_0 is void ratio of compressible soil layer. And P_0 is existing pressure at the mean height of the compressible soil layer. And ΔP is the embankment load due to the settlement.

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Geosynthetics Engineering: In Theory

Without Geofabric:

At mid height of compressible layer,

$$P_0 = \gamma_f \times H/2 = 18 \times 12/2 = 18 \times 6 = 108 \text{ kN/m}^2$$

H = Thickness of compressible layer

$$\Delta P = \gamma_e \cdot H_e = 18 \times 5.0 = 90.0 \text{ kN/m}^2$$

H_e = Height of embankment

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So, when you are not using the geofabric. So, without geofabric so at mid height of the compressible layer, what is P_0 ? So, P_0 is equal to the γ_f into H by 2 and γ_f is given 18 and height of the foundation is 12. So 18 into 12 divided by 2, that means 18 into 6 is equal to 108 kilo Newton per meter square. So, at the mid height of the compressible layer that is P_0 , is equal to 108 kilo Newton per meter square. Where you know the H is equal to thickness of compressible layer.

Now, what is ΔP . So, ΔP is equal to γ_e into H_e . You know the height of the embankment is 5 meter and unit weight of the embankment is 18 because it is a soil. So, its density is 18 kilo Newton per meter cube because there is no geofabric. So, it will be 18 into 5 is 90 kilo Newton per meter square. Here H_e is equal to height of embankment.

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Geosynthetics Engineering: In Theory

Settlement of embankment without geofabric (s)

$$\begin{aligned} &= [(0.45 \times 12) / (1 + 0.65)] \times \log [(108 + 90) / 108] \\ &= (5.4 / 1.65) \times \log (198 / 108) \\ &= 3.27 \times \log 1.833 \\ &= 3.27 \times 0.263 \\ &= 0.86 \text{ m.} \end{aligned}$$

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Now, settlement of embankment without geofabric that means this is C_c into you know this equation C_c into H by $1 + e_0$. So, it will be the C_c is 0.45, H is 12 meter this divided by $1 + e_0$ and e_0 value is given 0.65, so $1 + 0.65$ into log of $P_0 + \Delta P$ by P_0 . So, here this is the equation we are using $P_0 + \Delta P$ by P_0 . So, you know that what is that.

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Geosynthetics Engineering: In Theory

Without Geofabric:

At mid height of compressible layer,

$$P_0 = \gamma_r \times H/2 = 18 \times 12/2 = 18 \times 6 = 108 \text{ kN/m}^2$$

H = Thickness of compressible layer

$$\Delta P = \gamma_o \cdot H_o = 18 \times 5.0 = 90.0 \text{ kN/m}^2$$

H_o = Height of embankment

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P_0 is 108 and ΔP is 90. So, you are substituting this here, log of $P_0 + \Delta P$ is 108 plus ΔP is 90. This divided by P_0 108, where we have obtained from here P_0 and ΔP 90

kilo Newton per meter square. So, then you can have 5.4 divided by 1.65 into log of 198 by 108 that is equal to 3.27 into log of 1.833. So, is equal to 3.27 into 0.263 is equal to 0.86 meter. So, you see that settlement of the embankment without geof foam is equal to 0.86 meter. Now, we will calculate that what should be the settlement with the geof foam.

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Geosynthetics Engineering: In Theory and Practice

With geof foam:

$$\Delta P = \gamma_g \cdot H_e + \gamma_f \cdot H_p$$

$$= 0.18 \times 4.4 + 19 \times 0.6$$

$$= 0.792 + 11.4 = 12.192 \approx 12.2 \text{ kN/m}^2$$

H_e = Height of embankment,
 H_p = Height of pavement layer

$$S = \frac{C_c \cdot H}{1 + e_0} \log \frac{P_0 + \Delta P}{P_0} \quad S = \frac{0.45 \times 12}{1 + 0.65} \times \log \frac{108 + 12}{108} = 0.154 \text{ m}$$

The reduced settlement due to geof foam
 $= (0.86 - 0.154) \text{ m} = 0.706 \text{ m}$
 or, $0.706 / 0.86 = 82.09 \%$.

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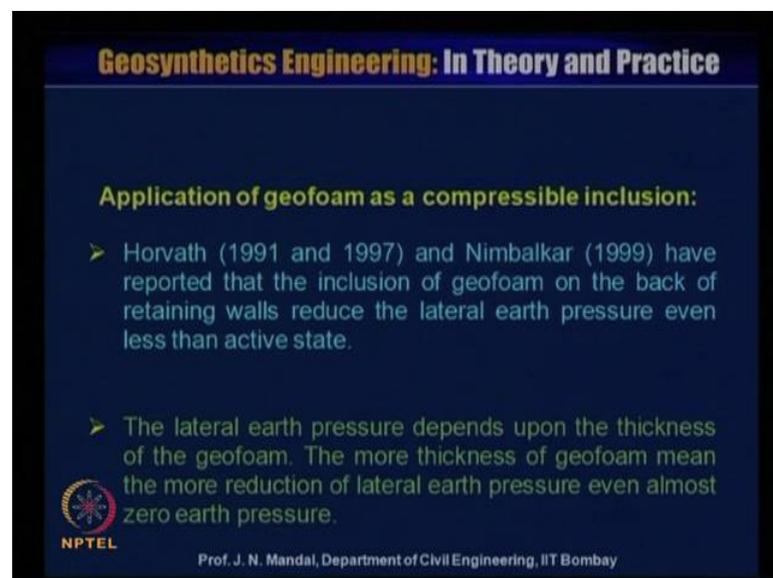
Now, with geof foam you have to calculate what is delta of P. So, delta of P is equal to gamma of g into H e plus gamma of f into H p. So, here the density, a unit weight of the geof foam is 0.18 and H e is 4.4. I showed you that what is H e is 4.4 plus that because on the top here that asphalt overlay is there, the density is nineteen and H p is 0.6. So, I am just showing you here again here you can see this is the 4.4 and density is 0.1 8 kilo Newton per meter cube. So, 4.4 into 0.1 8 kilo Newton per meter cube for this part. And this part unit weight of the pavement cover for gamma P c is 19 kilo Newton per meter cube and this thickness is 0.6.

So, 0.6 into 19 kilo Newton per meter cube. So, that is why it has written that 0.18 into 4.4 plus this is gamma is 19 into H p is 0.6. So, you can obtain is equal to 0.792 plus 11.4 is equal to 12.192 and let us say approximately 12.2 kilo Newton per meter square. So, here I say that H is the height of the embankment and H p is the height is the height of the pavement layer on the top. Now, we know this equation that is H is equal to C c into H by 1 plus C 0 into log of P 0 plus delta P by P 0. So, s is equal to 0.45 into 12 divided

by $1 + C_0$ is 0.65 into log of that $P_0 + \Delta P$. That means $108 + \Delta P$ here is 12 divided by 108. So, this will give approximately the settlement is 0.154 meter.

So, you can see when the, you are using the geof foam settlement is 0.154 meter when the only soil without geof foam this settlement is 0.86 meter. So, reduced settlement due to the application of geof foam will be equal to 0.86 minus 0.154 meter that means 0.706 meter, or you can say that reduced in settlement due to the geof foam is 0.706 divided by 0.86 is equal to 82.09 percentage. So, you can see that how the drastically, the settlement has been reduced due to the application of the geof foam material.

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Geosynthetics Engineering: In Theory and Practice

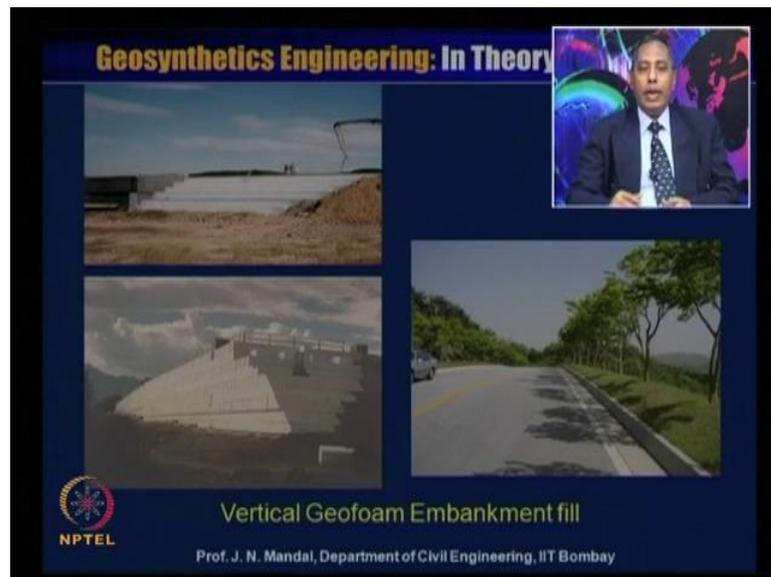
Application of geof foam as a compressible inclusion:

- Horvath (1991 and 1997) and Nimbalkar (1999) have reported that the inclusion of geof foam on the back of retaining walls reduce the lateral earth pressure even less than active state.
- The lateral earth pressure depends upon the thickness of the geof foam. The more thickness of geof foam mean the more reduction of lateral earth pressure even almost zero earth pressure.

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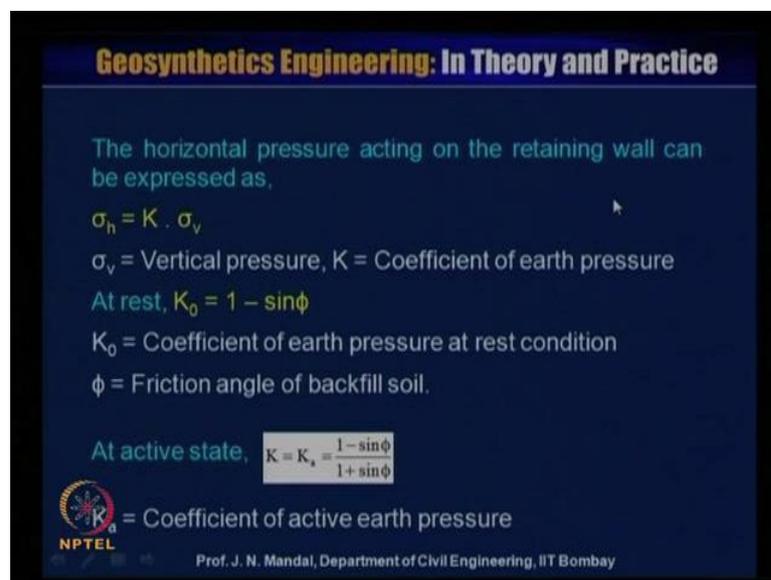
So, now we will discuss the application of the geof foam as a compressible inclusion. Horvath 1991, 1997 and Nimbalkar 1999, have reported that the inclusion of the geof foam on the back of retaining wall reduce the lateral earth pressure, even less than the active state. So, we have also performed number of test on the centrifuge using the geof foam, for the retaining wall where geof foam has been used as a compressible inclusion. Lateral earth pressure depend upon the thickness of the geof foam. The more the thickness of the geof foam mean the more the reduction of the lateral earth pressure, even almost 0 earth pressure.

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I will give later one example on it, you can see here that vertical geofoam embankment fill and this is the road which is made of the geofoam. So, horizontal pressure acting on the retaining wall can be expressed as σ_H is equal to K into σ_v .

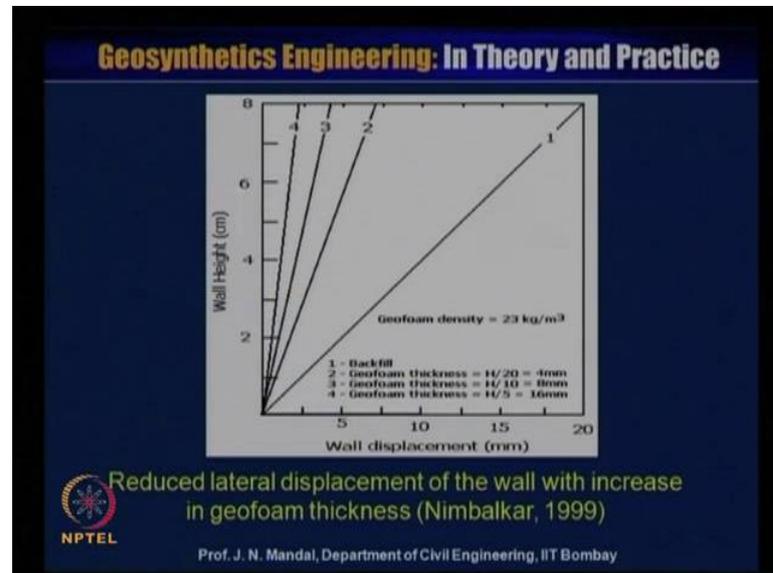
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Where σ_v is equal to vertical pressure K is equal to where σ_v is equal to vertical pressure K is equal to coefficient of earth pressure. As we know at rest K_0 is equal to $1 - \sin\phi$ as for K_0 is equal to coefficient of earth pressure at rest condition. And ϕ is friction angle of backfill soil. At active state K is equal to K_a

is equal to $1 - \sin \phi$ divided by $1 + \sin \phi$, where K_a is coefficient of active earth pressure.

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Now, this is some work in our geosynthetic testing laboratory. And we have used the centrifuge and have performed the test. This is the reduced lateral displacement of the wall, with increase in geofoam thickness this Nimbalkar 1999. So, this is the wall displacement versus, the wall height. The height of the wall is about 8 and this is the centimeter and this is the wall displacement is about 20 millimeter. And here the geofoam we have used that 23 k g per meter cube. And when you used only as a backfill material, this is the nature of the curve. You can have it this wall height with respect to the displacement, but in case 2 when you are using the geofoam thickness is H by 20 that is 4 millimeter that means H is the height of the wall.

So, that means if the height of the wall is eight. So, 8 by 20 will be equal to 4 millimeter. So, next is the 3 when the geofoam thickness is equal to h by ten that means h is equal to 8 by ten is equal to 8 millimeter then in number 4 . So, this is geofoam thickness H by 5 that means 8 by 5 will be 16 millimeter. So, you can see that how it is increasing the thickness and displacement is reducing gradually, so more the thickness and less the wall displacement by the inclusion of the geofoam material.

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Geosynthetics Engineering: In Theory and Practice

Example 2:

Height of retaining wall (H) = 8 m
Unit weight of backfill soil = 18 kN/m³
Angle of friction of backfill soil (ϕ) = 32°

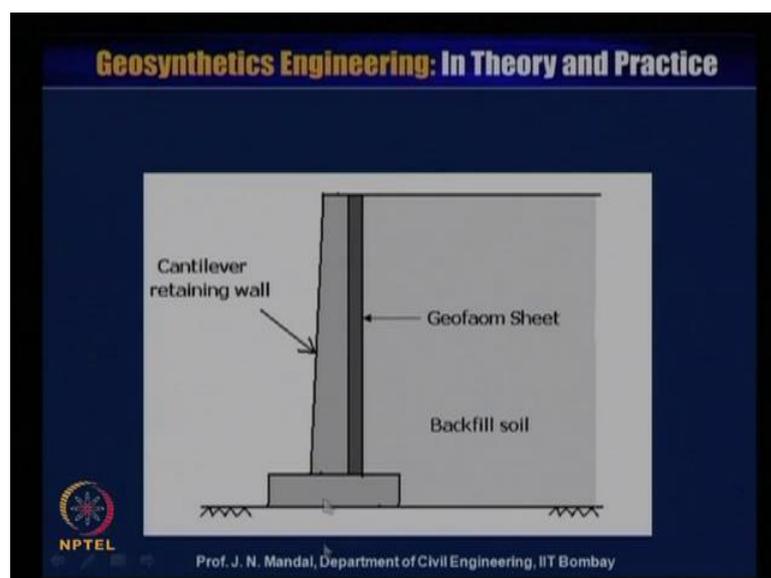
Determine the lateral earth pressure at the following conditions,

(a) Active condition without geofabric
(b) Using geofabric of thickness 4mm, 8mm and 16mm

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Now, I will explain one example, let us say height of the retaining wall H is equal to 8 meter, unit weight of backfill soil is equal to 18 kilo Newton per meter cube. Angle of friction of backfill soil phi is equal to 32 degree. Now, determine the lateral earth pressure at the following condition a active condition without geofabric, b using the geofabric of thickness 4 millimeter, 8 millimeter and 16 millimeter.

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So, let us say this is the wall cantilever retaining wall, here is a geofabric and this is the backfill material will change thickness of the geofabric material. And will observe that

how the lateral pressure either it is increasing or the decreasing by the inclusion of the different thickness of the geofom material.

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Geosynthetics Engineering: In Theory and Practice

Solution:

➤ **Active condition (only backfill)**

The lateral pressure at active condition,

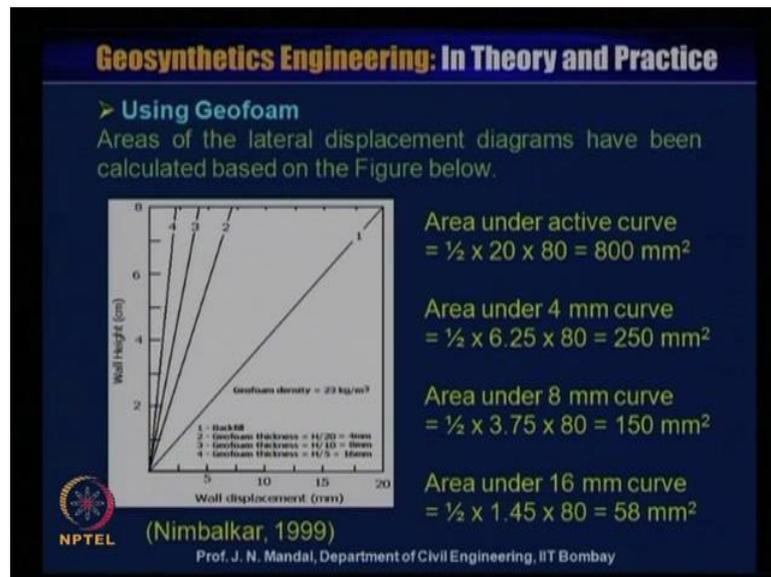
$$P_a = \frac{1}{2} \cdot K_a \cdot \gamma \cdot H^2$$
$$K_a = \tan^2(45^\circ - \phi/2)$$
$$= \tan^2(45^\circ - 32^\circ/2) = \tan^2(29^\circ) = 0.307$$

Therefore, $P_a = \frac{1}{2} \times 0.307 \times 18 \times (8)^2 = 176.832 \text{ kN/m}$

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So, here is the solution the active condition only backfill. So, the lateral pressure at active condition that is P_a is equal to half into K_a into γH^2 , where K_a is coefficient of active earth pressure is equal to $\tan^2(45^\circ - \phi/2)$. So, ϕ value is equal to 32° . So, $\tan^2(45^\circ - 32^\circ/2)$ is equal to $\tan^2(29^\circ)$ is equal to 0.307. So, K_a is 0.307 therefore, P_a that is lateral pressure at active condition is equal to half into K_a value is 0.307 into γ value is 18 and H is the height of the wall is 8, so this is 8 square. So, this P_a value will be 176.832 kilo Newton per meter.

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So, now we will use the geofoil. So, you have to calculate the area of the lateral displacement diagram I have been calculated based on this following figure now area under the active curve show here this is 8. So, from here to here is 20 and this is 8 centimeter and this is 20 millimeter. So, in case of figure one area under the active curve that means half into this is 20 into 80.

So, this will give 800 millimeter square. So, this is area under active curve, now the area under 4 millimeter curve. So, when you are considering 4 millimeter curve that means the thickness of the geofoil is 4 millimeter, so for the 4 millimeter your wall displacement somewhere here 6.25. So, this area will be equal to half into 6.25 into 80. So, this will give 250 millimeter square.

Now, if you use the 8 millimeter thickness of the geofoil. So, that mean we will take this area 3. So, here this will give you about 3.75. So, area will be half into 3.75 into 80 so this will give 150 millimeter square. Now, if we use 16 millimeter thickness of geofoil that mean this 4. So, this length will be equal to 1.45. So, this is 1.45 that means half into 1.45 into 80 is equal to 58 millimeter square.

So, you can see here that inclusion of the geofoil, this area is reducing, increasing the thickness of the geofoil, the area is gradually it is reducing from when there is no geofoil this is 800 millimeter square, and when you are providing 4 millimeter thickness of geofoil. Then it is 250 millimeter square area when it is 8 millimeter

thickness of geofoam the area is 150 millimeter square, and again when you are providing 16 millimeter thickness of geofoam, this area is coming 58 millimeter square.

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Case 1: Geofoam of 4mm thickness

Pressure for 4 mm thick geofoam,
 $P_4 = (\text{Area of 4mm curve} / \text{Area of active curve}) \times 176.832$
 $= 250/800 \times 176.832 = 55.26 \text{ kN/m}$
 $(= 55.26 / 176.832 = 31 \% \text{ of active})$

Case 2: 8mm thickness of geofoam

Pressure for 8mm thick geofoam,
 $P_8 = (\text{Area of 8mm curve} / \text{Area of active curve}) \times 176.832$
 $= 150/800 \times 176.832 = 33.156 \text{ kN/m}$
 $(= 33.156 / 176.832 = 19 \% \text{ of active})$

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Now, case one geofoam of 4 millimeter thickness. So, what is the pressure for 4 millimeter thick geofoam. Let us say P_4 is equal to area of 4 millimeter curve divided by area of active curve into 176.832. That means area of 4 millimeter curve you have calculated that, what is area of 4 millimeter curve that is 250 here. So, this is 250 this divided by area of active curve area of active curve this is 800 millimeter square. So, 258 by 800 millimeter curve into 176.832 which we have calculated earlier. Here this is the lateral pressure at the active condition 176.832. So, that is why here 176.832, so for the pressure for 4 millimeter thick geofoam.

So, you can write that 55.26 divided by 176.832 is equal to 31 percentage of active. Now, we consider case two, where 8 millimeter thick of geofoam have been used. So, what will be the pressure for 8 millimeter thick geofoam? So, that we expressed as P of 8 is equal to area of 8 millimeter curve divided by area of active curve into 176.832. So, you know for the area of 8 millimeter that is 150 millimeter square, and area under active 800 millimeter square. So, we can write 150 divided by 800 into this you know 176.832. So, this will give 33.156 kilo Newton per meter.

So, here you can see that 33.156 divided by 176.832 that means nineteen percentage of the active. So, here you see when 4 millimeter thickness of geofoam used that is 31

percentage of the active, but when you will use the 8 millimeter thickness this is 19 percent of the active. It is gradually this decreasing with the increase of the thickness of the geofoam material.

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Case 3: 16mm thickness of geofoam

Pressure for 16mm thick geofoam,

$$P_{16} = (\text{Area of 16mm curve} / \text{Area of active curve}) \times 176.832$$
$$= 58/800 \times 176.832 = 12.82 \text{ kN/m}$$
$$(\text{= } 12.82/176.832 = 7 \% \text{ of active})$$

➤ Evidently, it can be observed that lateral earth pressure reduced significantly with the increase in the thickness of geofoam.

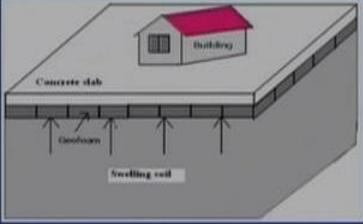
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Now, case 3, 16 millimeter thickness of geofoam. So, pressure for 16 millimeter thick geofoam that is P 16 is equal to area of 16 millimeter curve divided by area of active curve into 176.832. Here area of 16 millimeter you can see that area of under 16 millimeter 58 millimeter square. So, that is why 58 and you know area of active curve is 800 into 176.832. So, this will give P 16 is equal to 12.82 kilo Newton per meter. Now, 12.82 divided by 176.832 is equal to 7 percent of the active. So, evidently it can be observed that lateral earth pressure reduced significantly with the increase in the thickness of geofoam.

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□ As Geofoam is a compressible inclusion, it can be placed over **expansive soil** beneath the concrete slab of the footing of a building.



The diagram illustrates a cross-section of a building's footing. A concrete slab is shown above a layer of swelling soil. Geofoam is placed between the concrete slab and the expansive soil to reduce lateral pressure. The diagram is labeled with 'Concrete slab', 'Building', 'Geofoam', and 'swelling soil'.

Geofoam in between the expansive soil and concrete slab of the footing of a building

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So, overall you can have some idea that how the inclusion of the geofoam can reduce the lateral pressure drastically. Now, here the geofoam in between the expansive soil and this is concrete, this is the swelling soil and this is the concrete slab of the footing of a building. This is the building this the concrete slab and below the concrete slab you can provide with the geofoam material.

So, there will be no crack of the building, there is a upward thrust from the swelling soil. And how you can reduce how it can be prevented by the placement of the geofoam material below the concrete slab. So, here as the geofoam is a compressible inclusion. So, it can be placed over the expansive soil beneath the concrete slab of the footing of a building.

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Example 3:

The maximum allowable stress developed below the concrete slab of a building foundation from swelling is 40 kPa causing deformation of 12 mm.

Determine the required thickness of the geofoam to prevent it.

Solution:

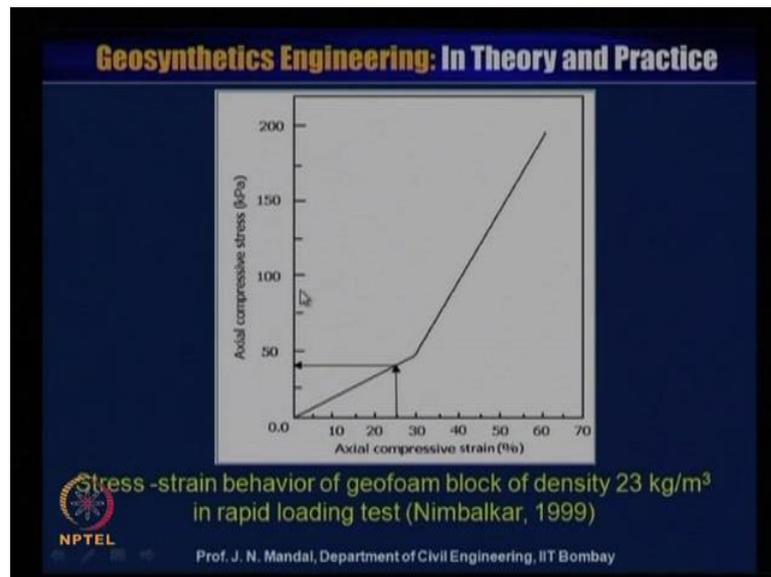
For the swelling pressure or compressive stress of 40 kPa, the compressive strain of geofoam is 25% as obtained from the rapid loading test as shown in figure below.

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So, example three the maximum allowable stress developed below the concrete slab of a building foundation from swelling is 40 kilo Pascal, causing the deformation of 12 millimeter. So, you have to determine what should be the required thickness of the geofoam to prevent it. So, here in this problem we will calculate the wall thickness is required due to that swelling and the deformation. So, there is solution for the swelling pressure or the compressive stress of 40 kilo Pascal. The compressive strain of geofoam is 25 percent as obtained from the rapid loading test as shown here. So, this is the curve the stress strain behavior of the geofoam block of density of 23 k g per meter cube in rapid loading test the Nimbalkar 1999.

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So, here you can see that, what will be the axial compressive stress in kilo Pascal and here is the axial compressive strain in terms of the percentage. So, this is the rapid loading test. So, you know that in your problem that 40 kilo Pascal. So, you check from this curve for the 40 kilo Pascal what will be the axial compressive stress. So, here is the axial compression strain which lies between 20 and 30. So, it will be 25 percentage.

So, that is why 40 kilo Pascal the compressive strain of geofoam is 25 percent. So, you can obtain from this rapid loading testing that what should be the strain for that compressive strain. In our problem we have a that compressive stress is 40 kilo Pascal. So, corresponding stress is 25. So, for any other problem also you can calculate that what will be the strain and corresponding to the compressive stress.

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Required thickness of geofabric

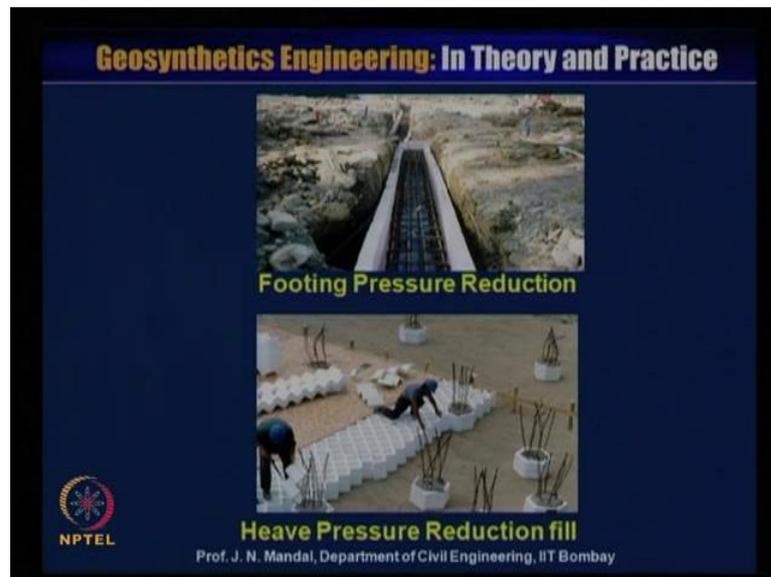
$$= \left[\frac{\text{Design magnitude of surface deformation}}{\text{geofabric strain (\%)}} \right] \times 100$$
$$= \frac{12}{25} \times 100$$
$$= 48 \text{ mm}$$

 The design of geofabric is cost effective for expansive soil.

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So, required thickness of the geofabric that is design magnitude of surface deformation, divided by geofabric strain in percentage into 100. So, you know that design magnitude of surface deformation is 12. So, which you have obtained and this divided by geofabric strain is this 25, which you find out and this deformation is given the 12 in the problem, here is the deformation is given that for this swelling pressure of 40 kilo Pascal the deformation is 12 millimeter. So, you know this is 12 millimeter and you calculate that for this 40 kilo Pascal this compressive strain is 25 percentage. So, 12 divided by 25 into 100 is equal to 48 millimeter. So, this design of geofabric is cost effective for expansive soil.

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So, you know that how you can use the geofabric for below the building or the foundation. And here we can see that some of the application that is footing pressure how it is reducing. Here is the geofabric has been introduced and here you can see that how the heave pressure also reduction the fill, how the geofabric has been used. So, different type of the geofabric and it depend upon the density also, it depend upon that what will be the density of the geofabric and as well as the thickness of the geofabric. And you should know for a particular the density what should be the thickness.

And how to calculate the thickness of the geofabric this is very important, either you use or the back of the retaining wall or you use at the base of the foundation soil, where there is a swelling soil and you can see that how pressure can be reduced drastically. So, you have an overall some idea that how geofabric inclusion can reduce the lateral pressure, where the geofabric material act as a inclusion. And on the other hand how we can reduce the also the settlement and as well as the swelling pressure can be reduced. How we can determine the thickness of the geofabric material. With this I finish my lecture today, let us hear from you any question.

Thanks for listening.