Geosynthetics Engineering: In Theory and Practices
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Lecture - 63
Designing with Geofoam

Dear student, warm welcome to NPTEL phase 2, 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 module number 13 lecture 63, designing with geofoam.

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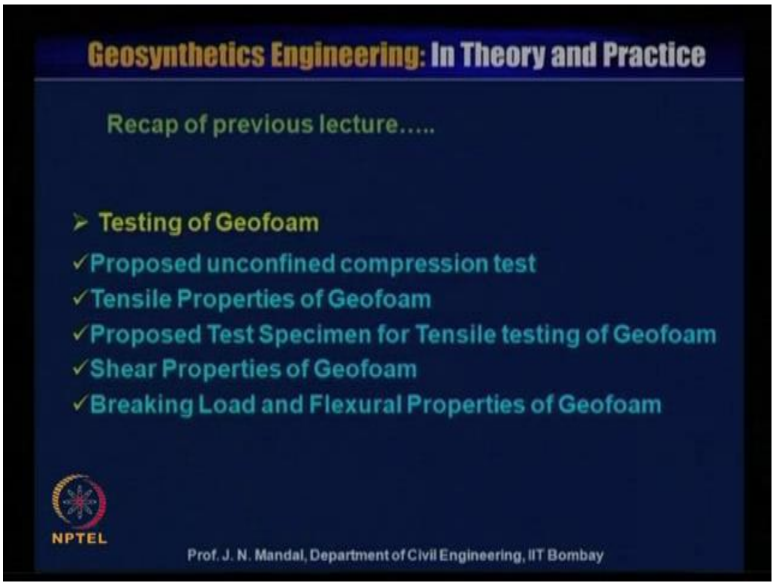

Now, I focus the recap of the previous lecture, testing of the geofoam, which we have covered proposed unconfined compression test, tensile properties of geofoam, proposed test specimen for tensile testing of geofoam, shear properties of geofoam and breaking load and flexural properties of geofoam.

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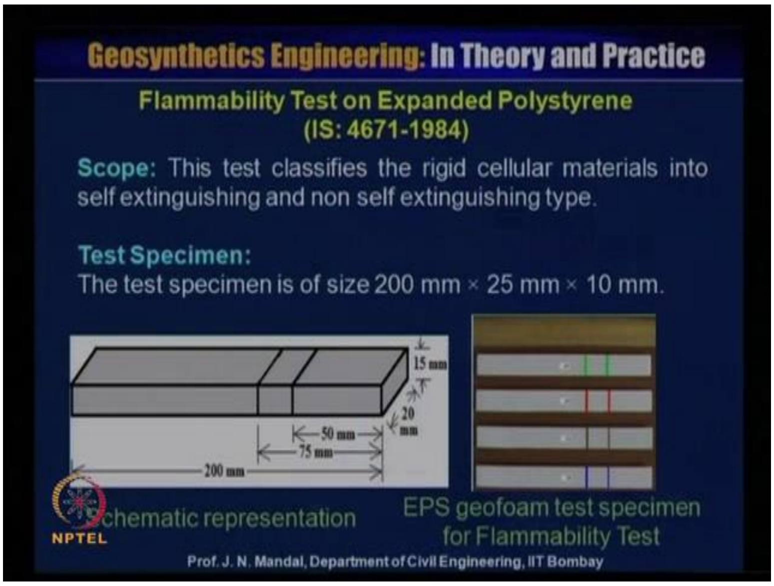

Now, I will address the flammability test on expanded polystyrene as per IS 4671-1984. So, scope of this test that, this test classifies the rigid cellular material into self extinguishing and non self extinguishing type. This material sometimes when, it come and across with the flame or the fire and there is no existing ship of the geofoam material. So, it is required, this kind of the flammability test on the expanded polystyrene material. So, test specimen is of size 200 millimeter and this is 15 millimeter and 25 millimeter and this is the EPS geofoam test specimen, for the flammability test. For different density may be, 15, 20, 22 and 30 and this, from here to here, this distance is 50 millimeter and this distance is 75 millimeter.

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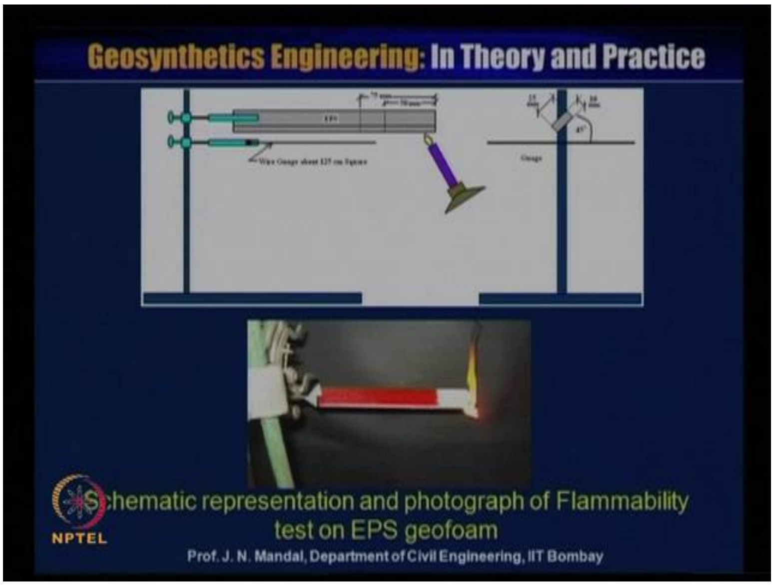

So, here is a schematic representation and the photograph of flammability test, on expanded polystyrene geofoam. I am just showing you, with these copies here is the EPS geofoam material, which is clamped and this is the stand and this is making at an angle of 45 degree, this is the 10 millimeter, this is 25 millimeter. And this from, here to here is the 50 millimeter, from here to here is 75 millimeter, this is wire gauge above the 125 centimeter of square. So, this act as an indicator and from here, that you are firing this geofoam material. So, you can see here this is the geofoam material and after the firing you see, but it should cover up to the certain distance not beyond that.

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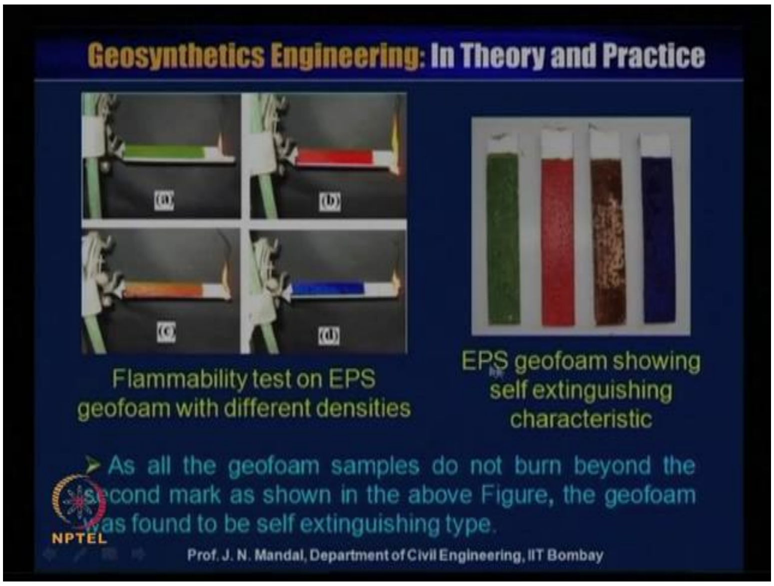

So, you can see that here the different density of flammability test on expanded polystyrene geofoam material. So, this may be 20, this is 15, 20, 22 and 30. So, this is EPS geofoam showing self-extinguish characteristic, you can see here is a burning and after that, you can see this end up of the burning here. So, as all the geofoam sample do not burn, beyond the second mark as shown here. Here is the second mark as shown here, it should not burn beyond this line.

So, this geofoam was found to be self extinguish type so in all cases you can see whatever this is burning, it is not going beyond this line. Here you can see it is not going beyond this line so if it does not go this, beyond this line then that geofoam was found to be self extinguishing type. So, here the if a geofoam showing self-extinguishing characteristic.

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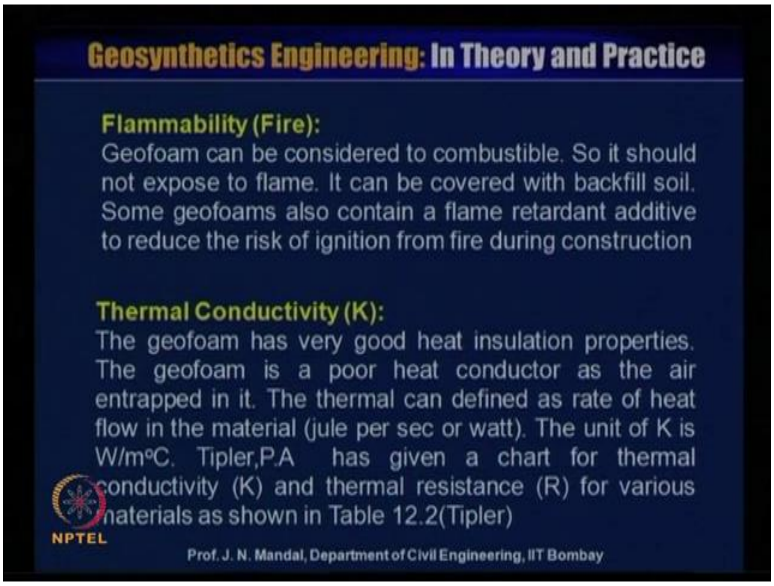

Now flammability or fire that, geofoam can be considered to combustible so it should not expose to flame. It can be covered with the backfill soil, some geofoam also contain a flame retardant, additive to reduce the risk of ignition from fire, during the construction. Because, when they will use for the geofoam for any construction then there is a possibility for any firing, that is due to various reason and then it will be the very great problem to all of us.

And now, in some cases the contact has been given that, contractor will be the responsible for that and he has to pay. So, one has to be very careful and from this test only, you will be able to tell that how far, that far will continue and after that, there should not be any fire. And how you can protect that, also geotextile geomembrane sometimes, that some kind of the additive also can be added, which can reduce the risk of ignition from the, during the construction.

There are other properties also, that is thermal conductivity, K. So, we use this geofoam material as a thermal conductivity, the geofoam has very good heat insulation properties. So, heat insulation is also as a function, the geofoam is a poor heat conductor, as the air entrapped in it. The thermal can define as rate of heat flow, in the material that is joule per second or watt, the unit of thermal conductivity, K is watt per meter degree centigrade. This is Tipler, PA has given a chart for thermal conductivity, K and thermal resistance, R for various material, as you can show next which is given by the thermal.

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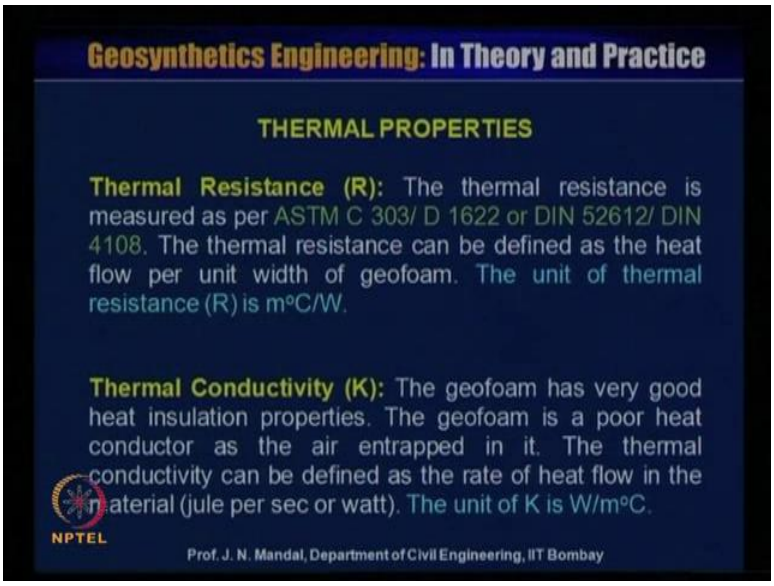

So, before that we discussed that what is thermal properties, that is thermal resistance, R the thermal resistance is measured as per ASTM C 303 by D 1622 or DIN 52612 by DIN 4108. The thermal resistance can be defined as the heat flow, per unit width of geofoam the unit of thermal resistance, R is meter degree centigrade per watt. And thermal conductivity, K that is geofoam has very good heat insulation properties. The geofoam is a poor heat conductor as the air entrapped in it, the thermal conductivity can be defined as the rate of heat flow, in the material that is joule per second or watt. The unit of K is watt per meter degree centigrade.

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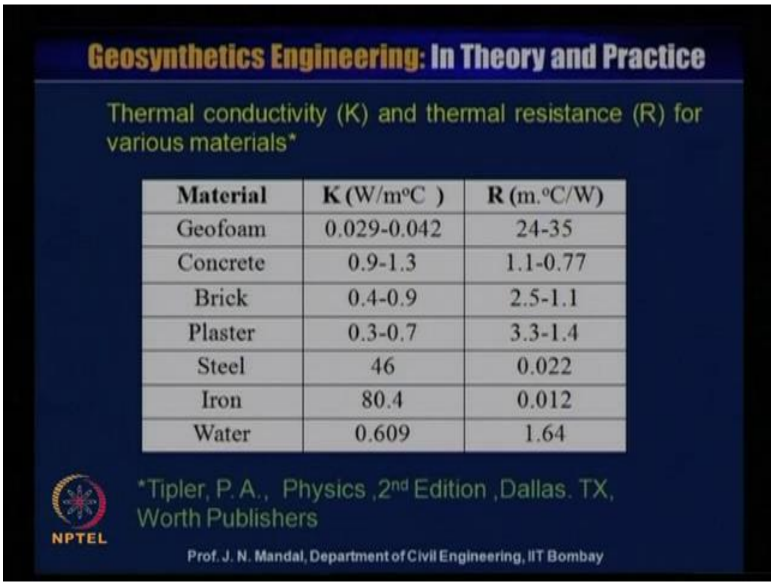

So, you can see here this table thermal conductivity K and thermal resistance R, for various materials. This material like geofoam and thermal conductivity K value lies between, 0.029 to 0.042 watt per meter degree centigrade. And thermal resistance R, that is vary from 24 to 35 meter degree centigrade per watt, if it is a concrete then thermal conductivity K lies between 0.9 to 1.3 watt per meter degree centigrade. And thermal resistance R, 1.1 to 0.77 meter degree centigrade per watt. If it is a brick, then thermal conductivity K lies between 0.4 to 0.9 and thermal resistance R, value lies between 2.5 to 1.1 meter degree centigrade per watt. If it is a plaster, the thermal conductivity value K lies between 0.3 to 0.7 watt per meter degree centigrade.

And thermal resistance R value lies between 3.3 to 1.4 meter degree centigrade per watt, if it is a steel thermal conductivity K value is 46 watt per meter degree centigrade and thermal resistance R, value is 0.022 meter degree centigrade per watt. If it is an iron, the thermal conductivity K value 80.4 watt per meter degree centigrade and thermal resistance R, value 0.012 meter degree centigrade per watt. If it is water, the thermal conductivity K, 0.609 watt per meter degree centigrade and thermal resistance R is 1.64 degree centigrade per watt. This table is given Tipler PA, physics 2nd edition Dallas, Texas worth publisher.

So, what you observed from this table you can see that, how the geofoam material can be used alternative to the concrete, brick and plaster most of the cases we use the concrete and the brick. So, alternatively you can use that geofoam material whose thermal conductivity and the thermal resistance, is thermal conductivity, is much more lower than the concrete and the brick. And also, the thermal resistance also, is relatively lower than the concrete and the other kind of the material. So, this kind of the problem also I have given earlier, that how you can make use of the geofoam material, as a thermal insulation and how you can save the money and also the energy.

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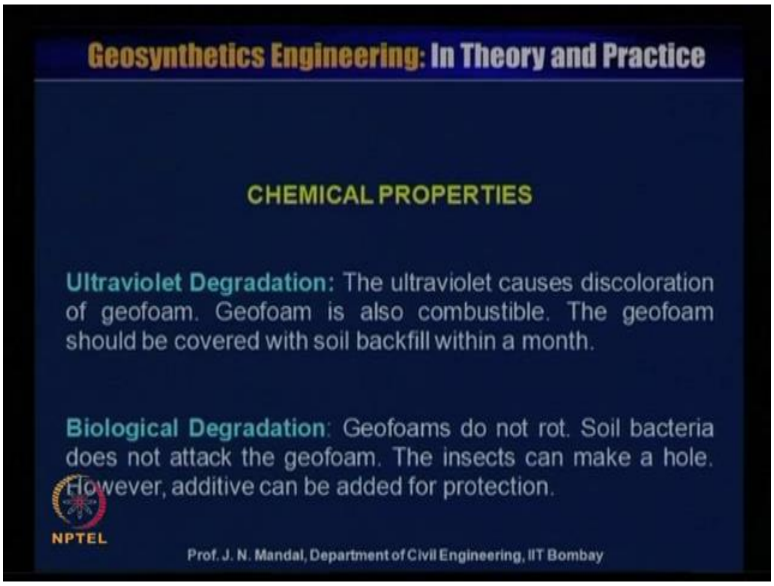

Next chemical properties, ultraviolet degradation, the ultraviolet causes the discoloration of the geofoam material. Geofoam is also combustible, the geofoam should be covered with soil backfill within a month. So, you cannot keep open the geofoam material in sunlight for longer time because there will be a problem for the UV light radiation or vandalism. So, one has to be taken care even then in case of geotextile material you know that, you cannot keep the open for many days. So, you are to be cover the geofoam material within a month, in order to protect from the sunlight. Otherwise, these all the properties of the geofoam material will deteriorate or reduced.

Biological degradation, geofoam do not rot, soil bacteria does not attack the geofoam, the insect can make a hole, however additive can be added for protection. Some also in the project in USA, it has been observed that some ants has make a hole for its nest. So, then in that case, there is a possibility for the failure or deteriorated of the geofoam material. But nowadays, some additive can be added to protect the geofoam material from the biological degradation.

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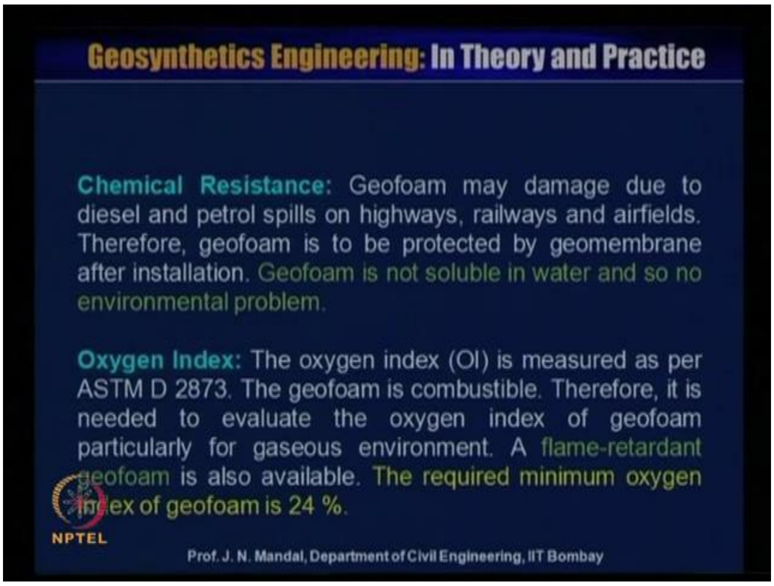

Chemical resistance geofoam may damage due to the diesel and petrol spill on highway, railway, airfield. Therefore, geofoam is to be protected by geomembrane after installation, geofoam is not soluble in water so no environmental problem. However, as we can observe that, when is come and contact with the petrol or the diesel so there will be no existence of the geofoam material.

So, it is always preferable that it should provide with the protection of a barrier or impermeable material like geomembrane, in order that petrol and diesel cannot directly percolated, through the geomembrane to the geofoam. So, that was the reason that you should provide with the geofoam material, geofoam material with the geomembrane as a protection.

So, every material has its own advantage and disadvantage, but we have to observe overall how we can make use of that material and safety. Oxygen index, the oxygen index, OI is measured as per ASTM D 2873, the geofoam is combustible. Therefore, it is needed to evaluate the oxygen index, of geofoam particularly, for gaseous environment. A flame retardant geofoam is also available, the required minimum oxygen index of geofoam is 24 percentage.

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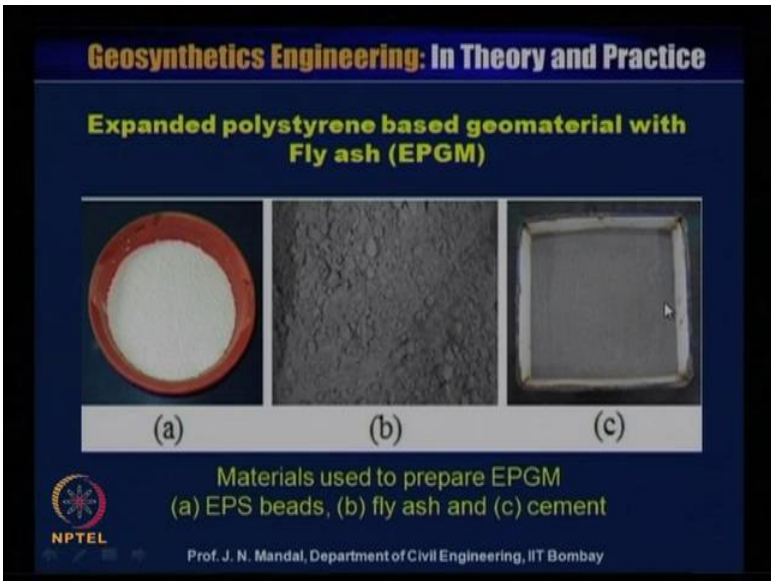

Now, we will discuss the another exciting new material, that is expanded polystyrene based geomaterial with fly ash, which you call the EPGM and this material also, newly developed in our geosynthetics research and testing laboratory. Now, this material is used to prepare the EPGM and here is the expanded polystyrene beads, this white in color. And this is the fly ash and this is the cement so we are using all these three material and are producing a new exciting material, which you call EPGM or which you newly material called the geomaterial.

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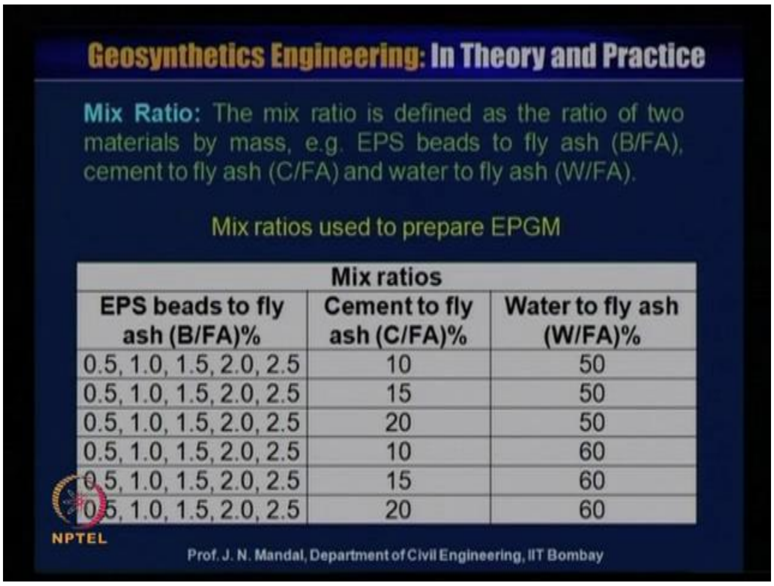

Now how to mix this, the mix ratio is defined either ratio of two material by mass, that is EPS beads to fly ash, that is B by FA, B is beads, FA is fly ash. Cement to fly ash, that is C by FA, C is cement, FA is fly ash and water to fly ash is, W is water and FA is fly ash. Here mix ratio used to prepare the EPGM, that is mix ratio EPS beads to fly ash, that is B by FA, you have taken the percentage 0.5, 1, 1.5, 2, 2.5.

That means, if you take the, this of about 5 gram and the fly ash is about 1000's gram. So, beads to fly ash ratio will be 5 by 1000 into 100 is 0.5 percentage. Similarly, you are taking the amount of beads is 5 gram, 10 gram, 15 gram, 20 gram and 25 gram and cement to fly ash ratio C by FA in percentage 10, we are keeping the amount of fly as constant that is 1000 gram.

So, you are taking that cement is about 100 gram or may be that 150 gram or 200 gram, if the cement is 100 gram and fly ash is 1000's gram. So, this ratio cement to fly ash will be equal to 100 by 1000 into 100, that will give the 10 percentage of cement to fly ash. So, like that you can take the cement amount 150 gram, that will give 15 percentage, you take 200 gram of the cement then it will give 20 percentage. And this is, water to fly ash, this percentage, so water is 500 ml and fly ash is 1000's so 500 by 1000's into hundred this will give the, 50 percentage. So, this all cases you have taken this up to 1 to 3, this is 50 percent and later on 60 percent water to fly ash ratio.

So, here EPS bead to fly ash is all cases is constant only, that mix ratio cement to fly ash because we have taken 10 percentage, 15 percentage and 20 percentage when, the water to fly ash ratio is 50 percentage. Then again, that EPS bead to fly ash B by FA is same only, that cement to fly ash ratio also kept same, that is 10, 15, 20, but water to fly ash ratio has changed to 60 percentage. So, this way this mix ratio used to prepare the EPGM.

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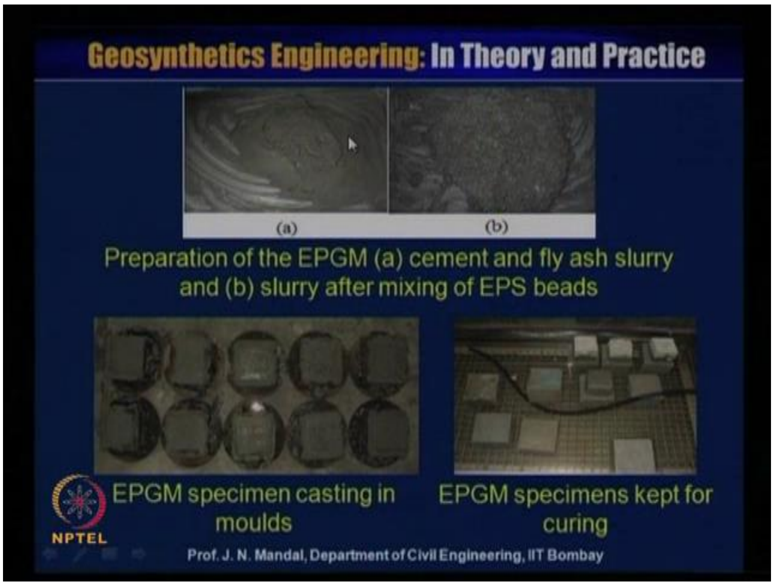

So, here is the preparation of EPGM a, this is the cement and the fly ash slurry and this is the bead, that this slurry is mixed with the EPS bead. So, this is cement and fly ash again cement and fly ash with the bead so this is the B slurry. Now, from this slurry it has produced the EPGS specimen casting in the mould so there is a mould. So, this has been cast, this specimen has been cast and then this material has been kept in water for curing. So, you can see this is the material has been kept under water for curing.

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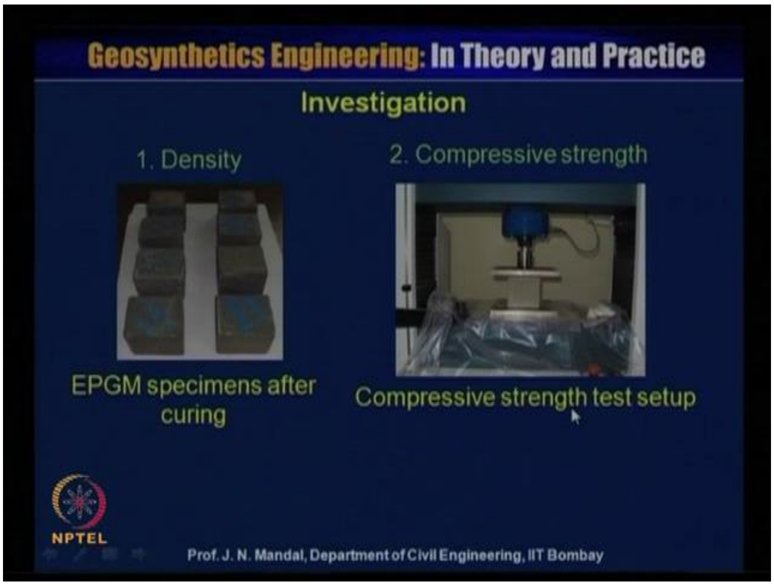

Now we have started this investigation, this is the density EPGM geofoam that, after the curing. So, various days it has been may be kept in, may be 7 days, 15 days, 28 days like this. And this is the, after this, this test has been performed in a ((Refer Time: 24:54)), this is the compressive strength and this is the compressive strength setup. This is the sample has been kept, between the two plate and then load is applied.

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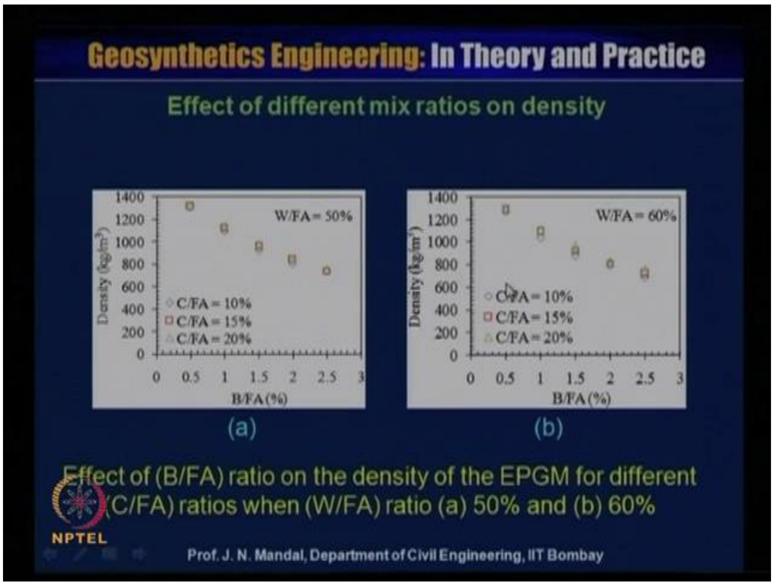

Now, from this experiment we obtained the what is effect of the bead fly ash ratio on the density of the EPGM, for different cement fly ash ratio when, water fly ash ratio a, case is 50 percentage. And when, the water fly ash ratio is 60 percentage so this figure a, show the x axis, that beads and fly ash difference ratio. So, 0.5, 1, 1.5, 2, 2.5 and this is the density that is kg per meter cube, this is the different cement by fly ash ratio that is 10 percent, 15 percent and 20 percentage. You can see, you can have those point for different value of beads and fly ash percentage and you can have the different density when, the water fly ash ratio is 50 percent.

So, this curve is shows that density is decreasing with the increasing, the beads and fly ash ratio, but when the water fly ash ratio is 60 percentage and cement fly ash ratio also keep 10, 15 and 20 percentage. This is x axis, that is beads and the fly ash percentage the same 0.5, 1, 1.5, or 2.5 and then this is the density. So, you can see the nature of the curve also is same, the density of the material, geomaterial is decreasing with the increasing the beads and fly ash ratio percentage. But here it has been observed that, in case of that water to fly ash ratio in 50 percent, the density is relatively, slightly more than the, when the, water fly ash ratio is 60 percentage under any density.

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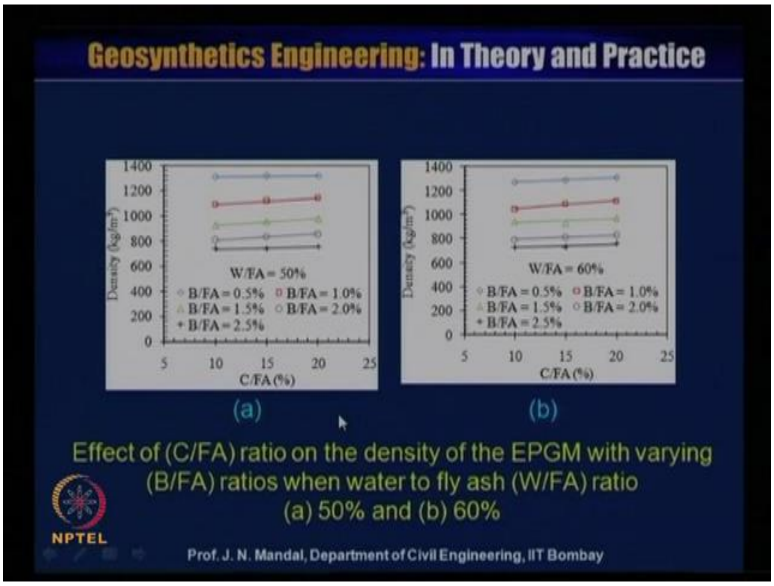

Now here, the effect of the cement fly ash ratio, on the density of the EPGM with varying the bead fly ash ratio when, the water to fly ash ratio here it is, here it is 50 percentage. And also, here it is 60 percentage so both the cases it has observed that cement and fly ash ratio with the beads and fly ash ratio. So, it is 0.5 percent then it is increasing the bead and fly ash ratio 0.5 percentage, 2 percentage and 2.5 percentage like this, it is increasing then density also it is increasing. Also similar nature of the curve, I have shown in case of that water fly ash ratio also 60 percentage.

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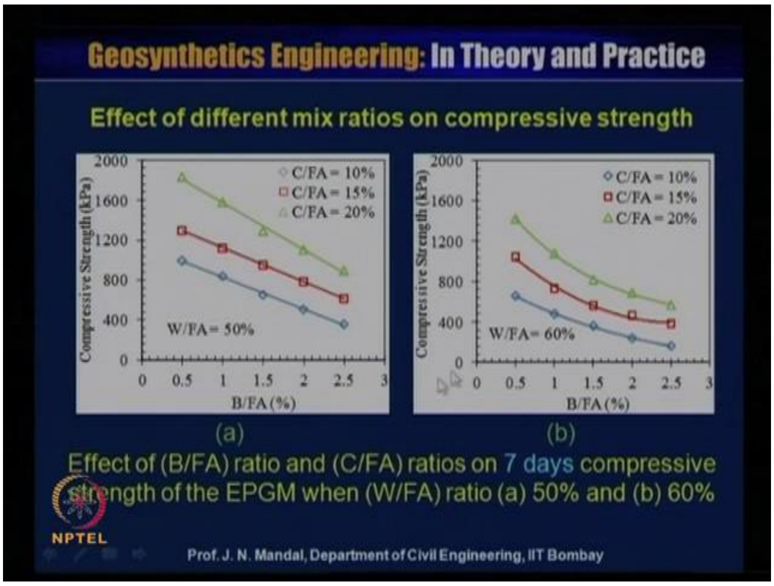

Now here, the effect of the beads and fly ash ratio and the cement and fly ash ratio that may be 10 percent, 15 percent, 20 percent and we were calculating what is the compressive strength Kpa. And here, water fly ash ratio 50 percentage so this may be 10 percent, 15 percent and 20 percentage of the cement and the fly ash ratio. So, this compressive strength value also, are decreasing with increasing the black and beads and the fly ash ratio.

But, in case of that water fly ash is 60 percent so you can see this curve is not linear, as in case of the water fly ash ratio is 50 percentage. So, this is little bit non-linear, but overall that improvement it has been observed when, the water fly ash ratio is taken 50 percentage. Because, compressive strength also has more than this case when, the water to fly ash ratio is 60 percentage. So, this test also has been performed for 7 days, compressive strength ratio of GPM geofoam, this is for the 7 days.

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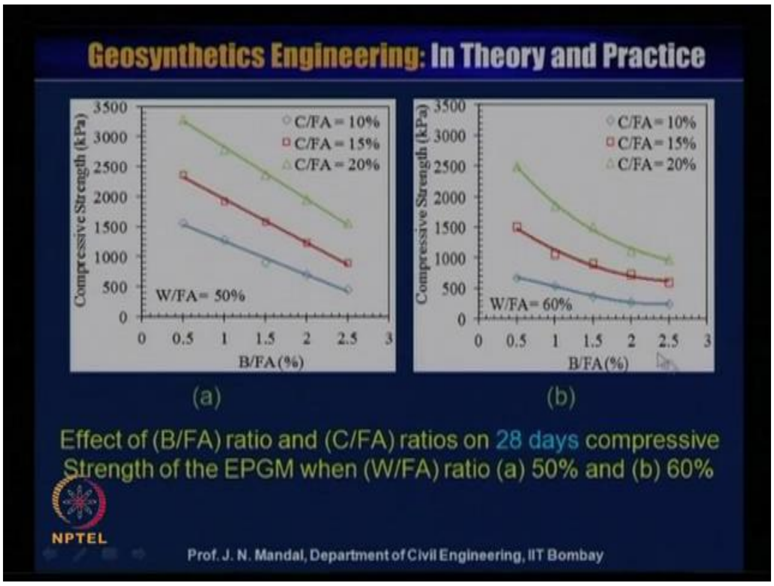

Similarly, it has been performed for 28 days and keeping all the same, water fly ash ratio here 50 percent, here it is 60 percent and you can see that, for different cement to fly ash ratio 10 percent, 15 percent and the 20 percentage. The compressive strength value is much much higher, in 28 days with respect to you can see this is for 7 days, a 7 days somewhere here, below 2000. Whereas, in case of the 28 days it is more than about 3000 nearer 500 so more days is curing you are having more compressive strength value, but here also, when the water then fly ash ratio is 60 percent, you can see this is also the not linear. And this value of the compressive strength is lower than, this case where the water fly ash ratio is 50 percentage.

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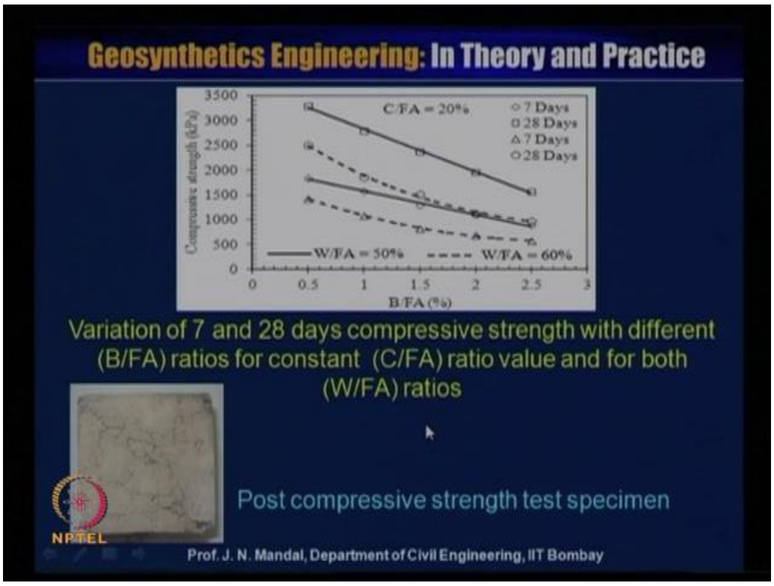

Now, this is variation of 7 and 28 days compressive strength with different beads and fly ash ratio, for constant cement and fly ash ratio value and for both water and fly ash ratio. Here it is mentioned for the 7 days, 28 days and 7 days and 28 days So, this is dotted which is 7 days this is the relationship between the beads and fly ash ratio here. And water to fly ash ratio is 60 percent is dotted line, this is the compressive strength so you can see it is a non-linear, this dotted line when the water fly ash ratio is 60 percentage. But when the water and fly ash ratio is the 50 percent, that mean this firm line, this is the firm line this also, for 7 days and this is for 28 days.

So, you can see from here also that, how there is a improvement of the compressive strength, if you keep that water fly ash ratio is 50 percent, 7 days also it is increasing also 28 days also it is increasing. So, after the test you can see when is the sample that post compressive strength test specimen, that what type of the failure as observed in the sample, after the test.

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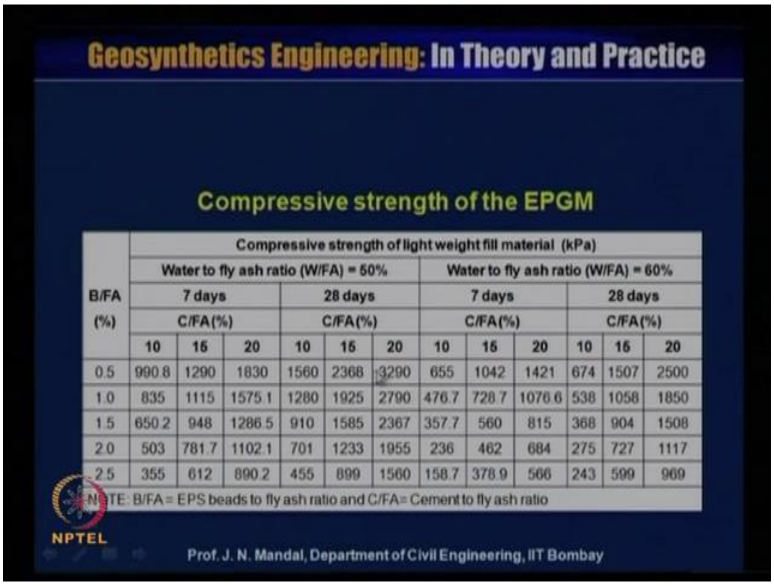

B/FA (%)	Compressive strength of light weight fill material (kPa)											
	Water to fly ash ratio (W/FA) = 50%						Water to fly ash ratio (W/FA) = 60%					
	7 days			28 days			7 days			28 days		
	C/FA(%)			C/FA(%)			C/FA(%)			C/FA(%)		
	10	15	20	10	15	20	10	15	20	10	15	20
0.5	990.8	1290	1830	1560	2368	3290	655	1042	1421	674	1507	2500
1.0	835	1115	1575.1	1280	1925	2790	476.7	728.7	1076.6	538	1058	1850
1.5	650.2	948	1286.5	910	1585	2367	357.7	560	815	368	904	1508
2.0	503	781.7	1102.1	701	1233	1955	236	462	684	275	727	1117
2.5	355	612	890.2	455	899	1560	158.7	378.9	566	243	599	969

So, this is compressive strength of EPGM, this is compressive strength of, the light weight fill material in kilopascal, this is beads to fly ash ratio 0.5, 1, 1.5, 2, 2.5 percentage. This is the water to fly ash ratio is 50 percentage, for 7 days cement to fly ash ratio is 10, you can see this compressive strength value of EPGM 990.8, when it is a B by FA 1 percentage. Compressive strength value 835 then when the B by FA, 1.5 this is 50.2 when, B by FA ratio is 2.0 then C by FA is 503 kilopascal. And when it is the B by F is 2.5 percentage, this is 355 kilopascal.

And when the cement to fly ash ratio is 15 percentage and beads to fly ash ratio is 0.5 percentage, compressive strength value 1290 then for beads and fly ratio 1. And for 15 percent, C by FA 1115 kilopascal then for 1.5 percentage B by F then it is 948 then 2 percentage, it is 781.7 and 2.5 percent this is 612.

So, you can see here that when the beads and fly ash ratio with the 7 days and the cement and fly ash ratio increasing 10, 15 let us say 20 you can see, this compressive strength value is increasing ,with increasing the cement and fly ash ratio value. It comes from 990 to 1830 for 7 days curing. Like that, you can see in all cases it is this increasing value when, this is for 28 days cement to fly ash ratio percentage, let us say 10 percent and this beads and fly ash ratio is 0.5 percentage.

And this compressive strength value 1560 for 28 days then when, it is the cement to fly ash ratio value than 2368, then when it is the cement to fly ash ratio 20 percentage then compressive strength value 3290. For the 28 days curing, you can see that compressive strength of the light weight fill material is dramatically increasing from 1560 to 3290. And this is the water to fly ash ratio for 50 percentage.

So like that, you can observe in all cases this, there is a, this improvement of the compressive strength with increasing the cement to fly ash ratio or the beads to fly ash ratio. Similarly, when the water to fly ash ratio is 60 percentage, for 7 days for the beads to fly ash is 0.5 and cement to fly ash ratio is 10, percentage it give 655 kilopascal. Then when the cement to fly ash ratio is 15 percentage then this gives 1042 kilopascal then when, cement to fly ash ratio 20 percent it gives 1421 kilopascal. You can see that, when the water to fly ash ratio is 60 percent, for the 7 days it also is increasing, this value is increasing.

Even then 28 days for the 10 percent cement to fly ash ratio, the compressive strength value 674 kilopascal, for 15 percentage 1507 kilopascal, for 20 percentage this is 2500. So, for the 28 days under the 60 percentage this value also is increasing with respect to 7 days. But overall if you can look here that, when the water and the fly ash ratio 50 percentage for the 28 days is give much, much higher value than this water fly ash ratio, with 60 percentage. Here it is giving, let us say 2500 for 20 percentage, here it is giving 3290 kilopascal for 20 percentage.

Similarly, if you can see that for the 7 days it gives when, it is the water fly ash ratio 50 percentage then the compressive strength value for 20, it gives 1830. Whereas, for water fly ash ratio is 60 percentage and this value for this 7 days, these 20 percentage give value 1.21 kilopascal. So, in all other cases you can have similar value so overall it can be convey that water to fly ash ratio of 50 percent is superior than, the water to fly ash ratio of 60 percent in terms of the compressive strength of the EPGM.

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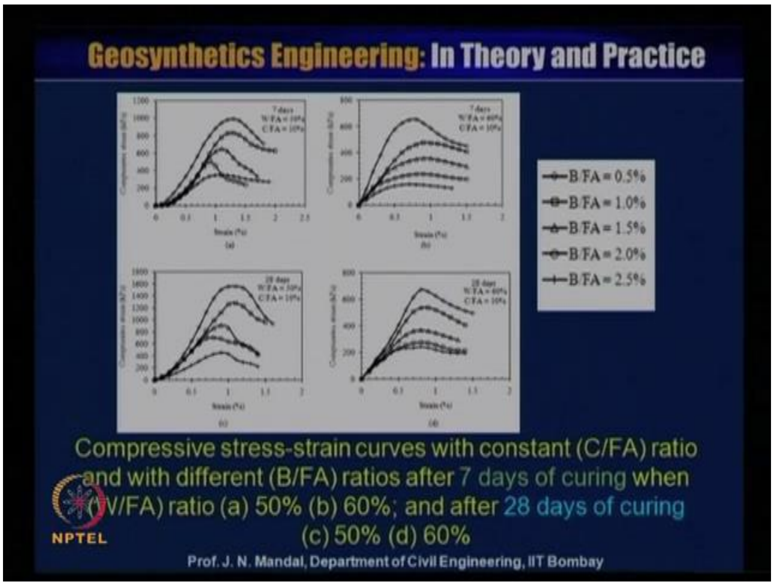

Now this is the compressive stress strain curve, with different cement to fly ash ratio and with the constant beads and fly ash ratio the after 7 days of the curing, when water to fly ash ratio a, is 60 percentage, 50 percentage. And this is b, is for 60 percentage and after 28 days of curing that is, c, this is 50 percentage and this is d, is 60 percentage. So, here you can see, here this is the strain and the compressive stress value so this is for 7 day and water fly ash ratio is 50 percentage. And the beads and fly ash ratio is 2 percentage, this is cement fly ash ratio 10, 15 and 20 percent, 10, 15 and 20 percent, you can see that compressive strength value is higher. And within a very strain, which may not be less than 1, which will give the compressive strength value on the higher side.

Similarly, for the 7 days, but water fly ash ratio is 60 percentage, you can see the nature of the curve is increasing and then reach to the maximum value and then it is this decreasing. But strain is almost less than 1 percentage, but compressive strength value is lower than, the compressive strength value for the 7 days where, the water fly ash ratio is 50 percentage. Similarly, this figure also shown water fly ash ratio is 50 percentage for 28 days, this is water fly ash ratio 60 percentage with 28 days. So, you can see this value is quite higher than, with respect to this value and here is the compressive stress strain curve, with constant the cement and fly ash ratio.

And with different beads and fly ash ratio after 7 days of curing when, water fly ash ratio this a, case is 50 percent b, case is 60 percent and after 28 days curing the c, is 50 percent and d, is 60 percent. You can see here also, this is the strain and compressive strength curve for 7 days, the water fly ash ratio 50 percentage and this is the, beads and fly ash ratio this is 0.5 then beads and fly ash ratio 1 percent beads and fly ratio 1.5 percent then beads and fly ratio is 2 percent like this.

Beads and fly ash ratio is 2.5 percentage so like this for 7 days if you can compare with the water fly ash ratio is 60 percentage, you can see this value is much higher than this value. Similarly, for the 28 days that water fly ash ratio is 50 percentage, you can see this value is higher than with respect to the 28 days. When water fly ash ratio is 60 percentage also, the strain value which is lying below the 1 percentage.

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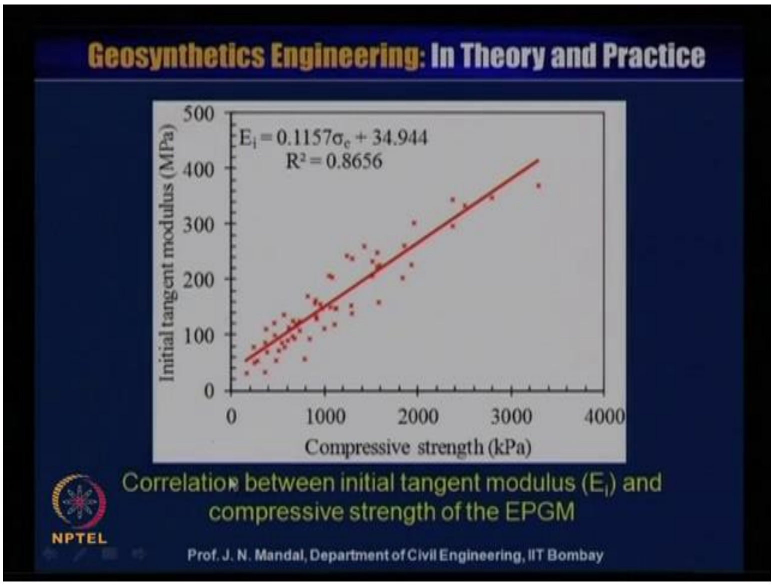

So, this is correlation between the initial tangent modulus and the compressive strength value, that is tangent module Ei. And this is the compressive strength initial tangent, you can correlate and Ei is equal to 0.1157 sigma c plus, 34.944 where R square is equal to 0.856. So, you can directly also calculate for this material, what will be the initial tangent modulus. If you know what will be the compressive strength of the material so with this equation you can use for analysis, if you know, what is the compressive strength of the EPGM material? So, you can directly calculate the, what will be initial tangent modulus.

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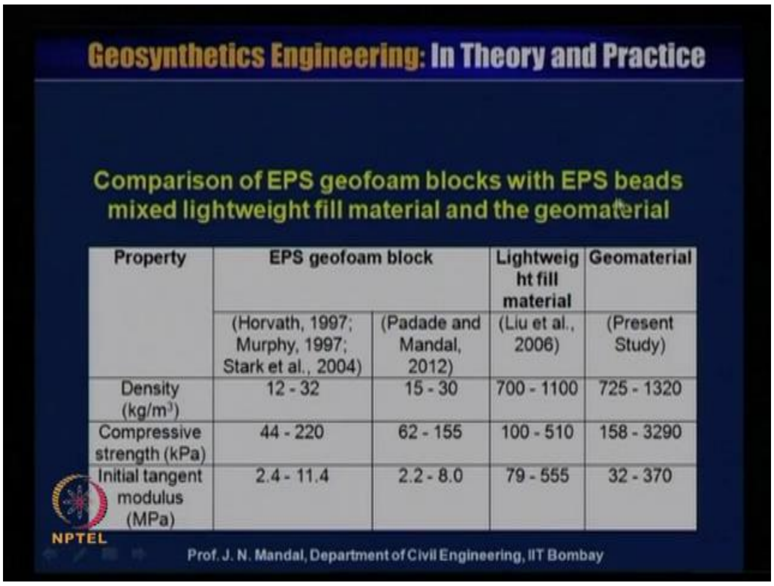

So, this is the comparison of EPS geofoam block, with the EPS beads mixed lightweight fill material and the geomaterial. This property density that EPS geofoam block the Horvath 1997, Murphy 1997 and Stark et al 2004 and this is Padade and Mandal 2012. So, this EPS density is 12 to 32 and Padade Mandal 2012, 15 to 30 apart from all the test and this compressive strength in case of this author, it comes about 44 to 220 kilopascal. And here the Padade Mandal got 62 to 155 kilopascal, initial tangent modulus in mega pascal, for these authors is come 2.4 to 11.4 mega pascal and this is for Padade and Mandal this 2.2 to 8.0 mega pascal.

Whereas, this is for the EPS geofoam block whereas, in case of the light weight geomaterial, fill material this is the new material, what has been developed. Here Liu et al 2006, this density is 700 to 1100 kg per meter cube and this our study which give 725 to 1320 kg per meter cube. And compressive strength value is, case of Liu et al this 100 to 510 kilopascal whereas, in our study 158 to 3290 kilopascal.

And initial tangent modulus value in case of Liu 79 to 555 and in case of initial tangent modulus, in the present study 32 to 370 mega pascal. So, it is quite good value what we can obtain with this material, but you are using the all kind of the waste material, like a fly ash with an alternative material, which we can produce this kind of the new geomaterial and which will be very useful in Indian condition.

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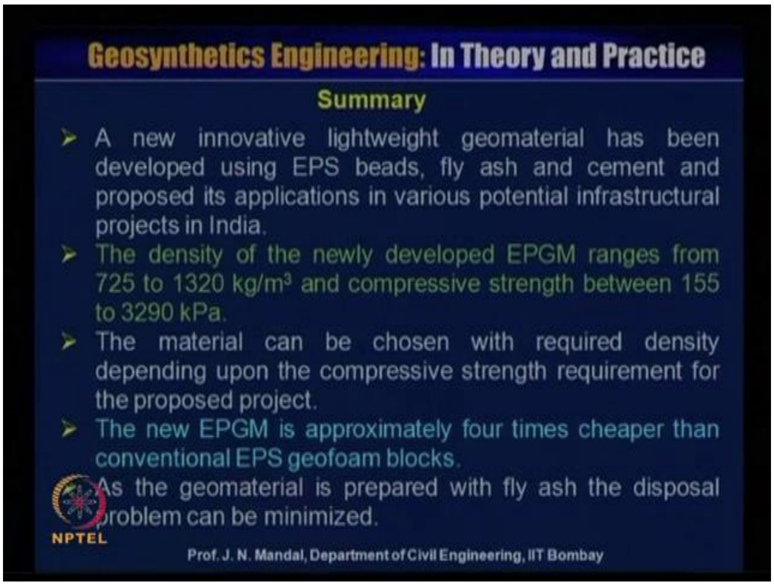

A new innovative light weight geomaterial has been developed using the EPS beads fly ash and cement and proposed its application, in various potential infrastructural project in India. The density of the newly developed EPGM ranges from 725 to 1320 kg per meter cube and compressive strength between 155 to 3290 kilopascal. The material can be chosen with the required density, depending upon the compressive strength requirement for the proposed project. The new EPGM is approximately 4 time cheaper than, the conventional EPS geofoam block material, as the geomaterial is prepared with fly ash the disposal problem can be minimized.

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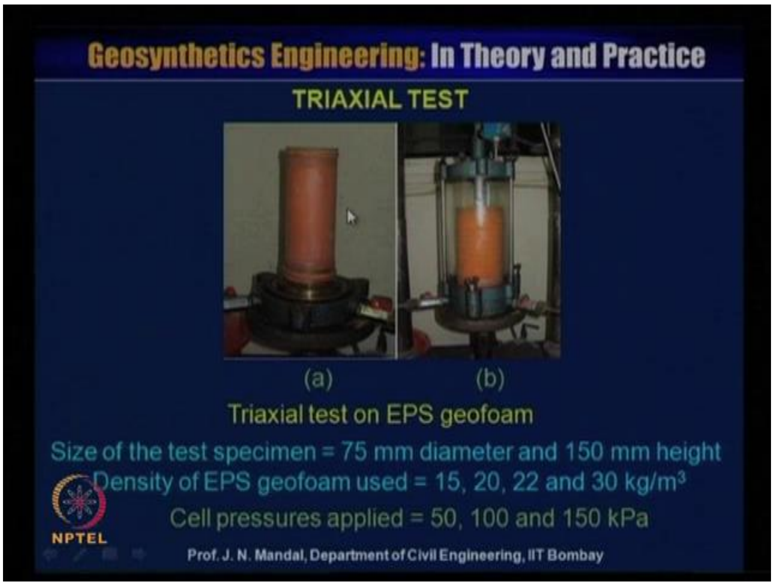

So, because for EPS geofoam material sometimes is very costly so alternative to the EPS geofoam material, you can use the new geomaterial which is developed by us. Now, Triaxial test on EPS geofoam, this is size of the test specimen is 750 millimeter diameter, 150 millimeter in height so density of the EPS geofoam used is 15, 20, 22 and 30 kg per meter cube. The cell pressure applied is about 50, 100 and 150 kilopascal.

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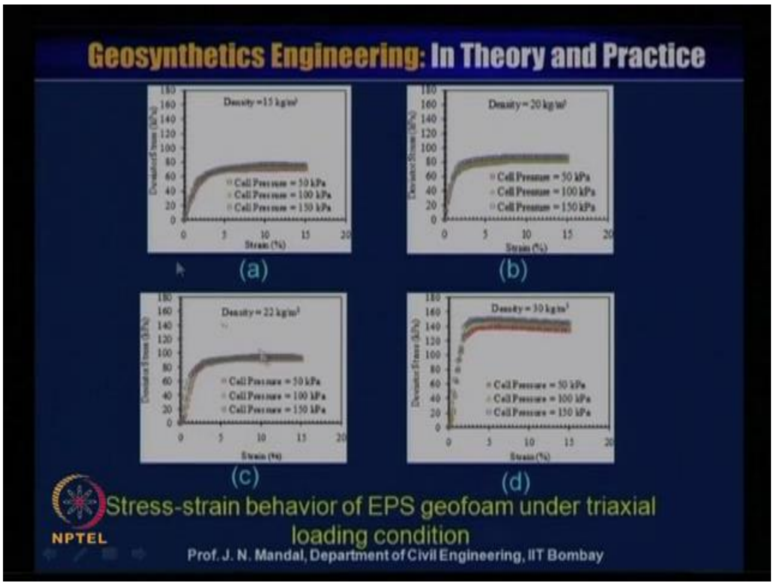

So, here is the stress strain behavior of EPS geofoam under triaxial loading condition, this is density is 50, you can see under the different these confining pressure or cell pressure. The nature of the curve within the deviator strain and the strain is the same, after a certain strain value it is almost constant. There is not so development of the deviator stress, due to the increase of the confining pressure or cell pressure.

This is very typical type of the geofoam material, but most of the cases the other material soil like this, these confining pressure increasing deviator stress is increasing. But, in this kind of the material, there is no development also the, deviator stage under the different confining pressure. You can see when you have used this density of 15 kg per meter cube or 20 k g per meter cube nature is the same, but only when it is density is increasing, the deviator stress only it is increasing. But strain value also is lies minimum strain value, 2 to 3 percentage of the strain value.

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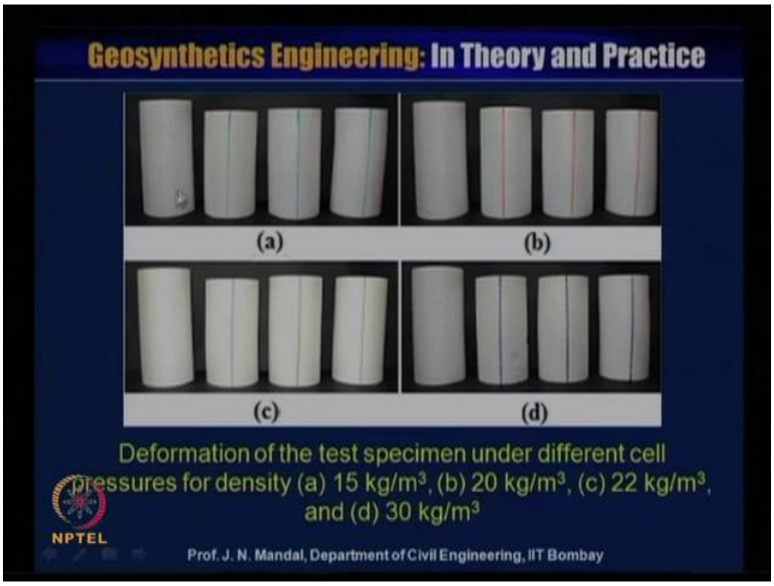

Now, here is the deformation of the test specimen, under different cell pressure for density of 15 kg per meter cube, 20 kg per meter cube b and c is 22 kg per meter cube and d is 30 kg per meter cube. This is ((Refer time: 48:48)) see before the test, this was the sample after the test, how it deform for 15 kg, this is the initial sample before the test. And you can say after the test, in case of 20 kg per cube density, this is for the 22 kg, this is the before the test and they can see how it deform after the test. This is 30 kg per meter cube, this is the before the test and this is after the test.

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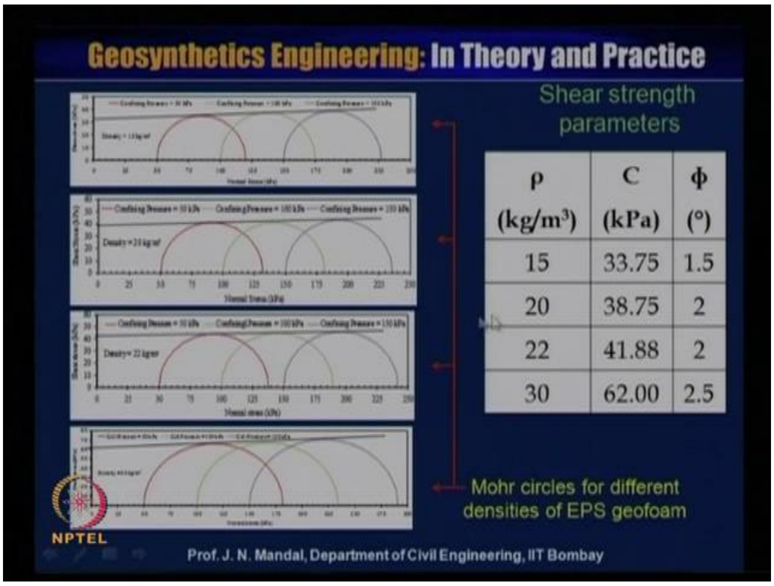

So, also you have performed more circle for different density of the EPS geofoam and from this, under the shear strength parameter also, is determined under different density. When density is, rho is 50 the c value is 33.75 kilopascal, phi value 150 degree, when density is 20, c value is 38.75, phi value is 2 degree, when density 22 kg per meter cube c value is 41.88 and phi value is 2 degree. When density is 30 kg per meter cube and c value is 62wo kilopascal and phi value is 2.5, you can see there is a improvement of the c value with increasing, the density of the geofoam material. But phi value is not so much significantly improving, that is angle of shearing resistance is not so much improving.

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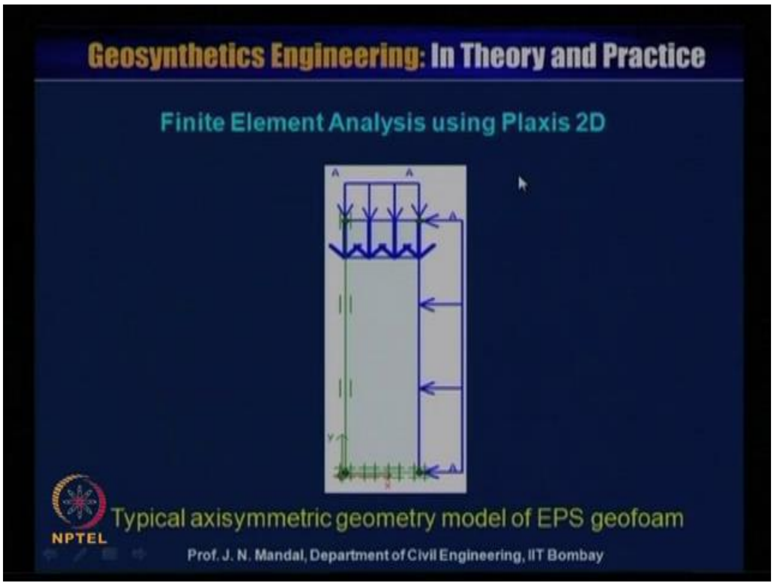

This is some finite element analysis, using triaxial, this is geofoam material triaxial, axisymmetric geometry model of EPS geofoam has been studied.

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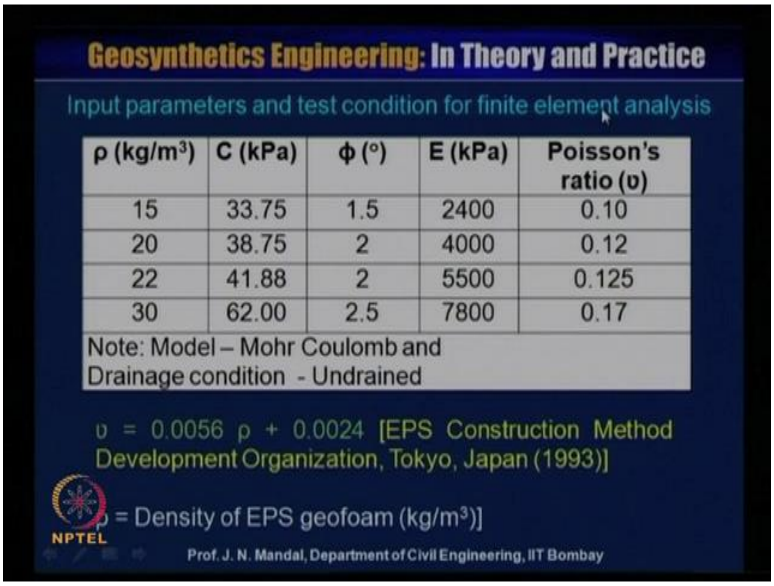

And this is the input parameter, of test condition of finite element analysis where, density 15, 20, 22 and 30. This is the model, this is the Mohr coulomb and drainage condition is the undrained and these are the c value and this is the phi value, what you have obtained, what you have obtained from here. So, this value also is incorporated into the FEM analysis and we also calculated the, what is the E value of the material and then Poisson's ratio is taken mu is 0.1 in this case.

This is 0.12 for 22 and for 22 it is 0.125 and for 30 density is 0.17 and mu, that Poisson ratio is calculated using this equation, 0.0056 rho plus 0.0024 where rho is the density of EPS geofoam. It is kg per meter cube, this equation is taken from EPS construction method development organization, Tokyo, Japan 1993, these are the input data into this program.

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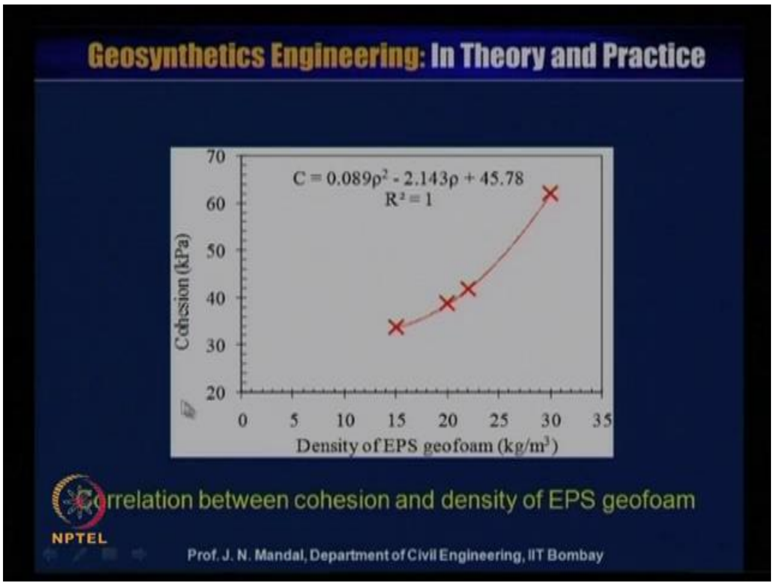

And this, the figure show the correlation between the cohesion and the density of the EPS geofoam. And you have, you can see that this density of the geofoam is increasing and this cohesion value is also increasing. And you can developed a correlation, that is equation that is c is equal to 0.089 rho square minus 2.143 rho plus 45.78, when R square is equal to 1. So, if you know that what will be the density of the geofoam material, you can directly also calculate what will be the cohesion value in terms of kilopascal.

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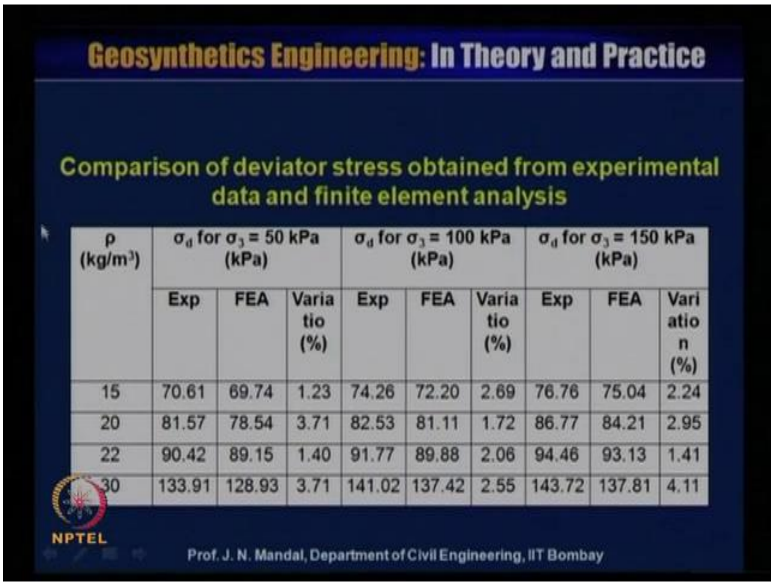

ρ (kg/m³)	σ_d for σ_3 = 50 kPa (kPa)			σ_d for σ_3 = 100 kPa (kPa)			σ_d for σ_3 = 150 kPa (kPa)		
	Exp	FEA	Variatio (%)	Exp	FEA	Variatio (%)	Exp	FEA	Variation (%)
15	70.61	69.74	1.23	74.26	72.20	2.69	76.76	75.04	2.24
20	81.57	78.54	3.71	82.53	81.11	1.72	86.77	84.21	2.95
22	90.42	89.15	1.40	91.77	89.88	2.06	94.46	93.13	1.41
30	133.91	128.93	3.71	141.02	137.42	2.55	143.72	137.81	4.11

This is the comparison deviator stress, obtained from the experimental data and finite element analysis. This here is the different density 15, 20, 22 and 30 and this is sigma of d, the sigma that is deviator stress, for when sigma 3 is 50 kilopascal. So, this is experimentally you are having 70.61, finite element analysis gives 69.74. So, variation is 1.23 so all cases you can see this is the experimental and finite element method. This is variation so it is well matched.

So, when the deviator stress is also 100 kilopascal, you can see that experimental 74.26, this is 72.20 by finite element method analysis. So, variation is 2.69 so not so much variations here, when the deviator stress is 150 kilopascal, that confining pressure 150 kilopascal. And then this deviator stress 76.76 and this for the finite element analysis, 75.04. So, variation is 2.24 percentage.

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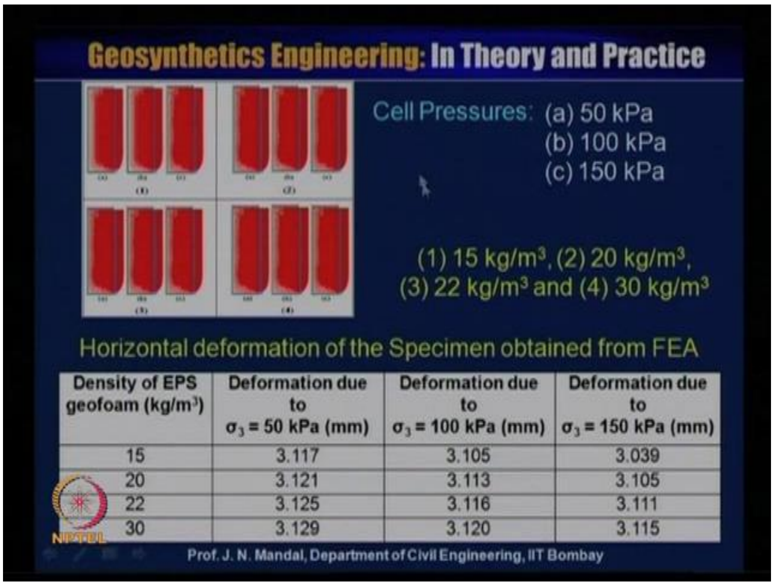

So, it is well matching with the experimental and finite element method when, all cases of density what we have been observed. Now, this is the cell pressure for 50 kilopascal, 100 kilopascal and 150 kilopascal this one, this is for 15 kg per meter cube, this is 20 k g per meter cube, this is 22 kg per meter cube and this is 30 kg per meter cube. This what will be the horizontal deformation of the specimen, obtained from finite element method, this is the different density 15, 20, 22 and 30.

And this is, deformation when sigma 3 is 50 kilopascal and this deformation is 3.117 when, the deformation when the sigma 3 is 100 kilopascal, deformation is 3.105. When the sigma 3 is 150 kilopascal then deformation is 3.039. So, there is no significant that any improvement of the deformation or horizontal deformation of the specimen, which is obtained from the finite element method. In all cases when the density is 20, 22 t and 30, we can see there is not so significant difference, with increasing this, increasing this sigma three value or confining pressure.

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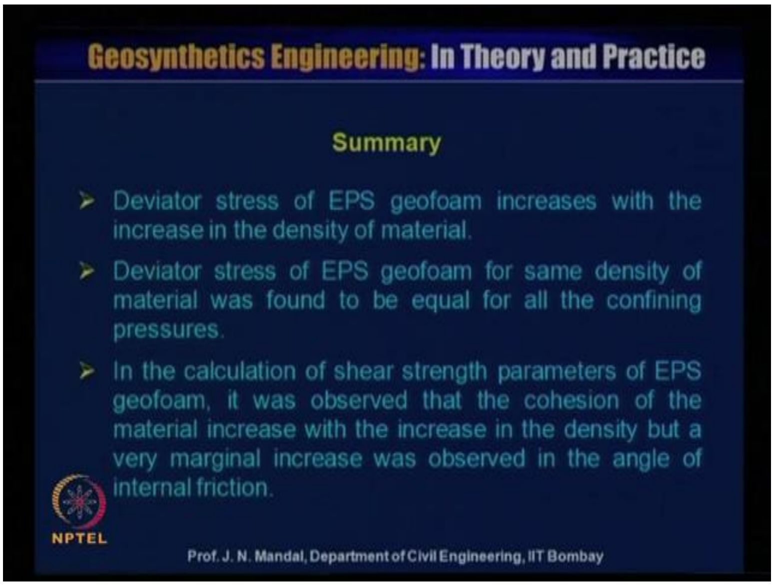

So, summary the deviator stress of the EPS geofoam increases, with the increase in the density of the material. Deviator stress of EPS geofoam for same density of the material was found to be equal, for all confining pressure. In the calculation of the shear strength parameter of EPS geofoam, it was observed that the cohesion of the material increase with the increase in the density. But a very marginal increase was observed in the angle of internal friction.

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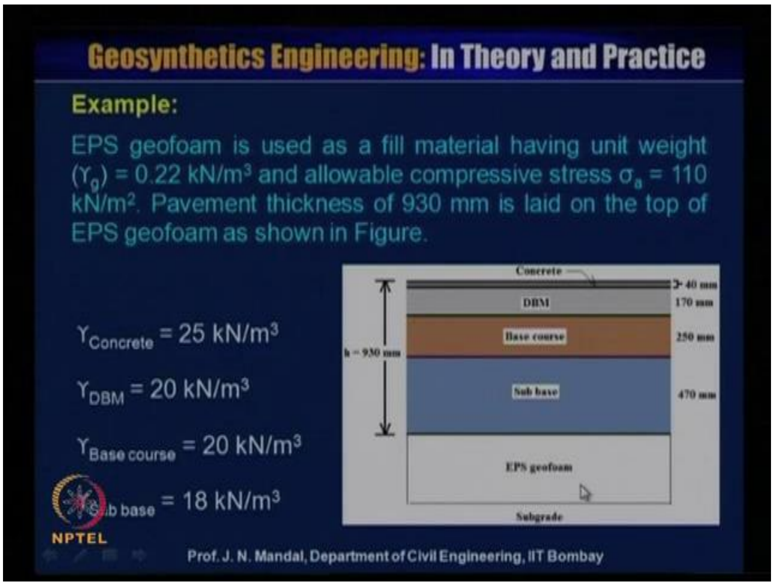

Now here is one example, EPS geofoam is used as a fill material having unit weight gamma g is 0.22 kilo Newton per meter cube. And allowable compressive stress sigma a is, 110 kilo Newton per meter, square pavement thickness is 930, this is pavement thickness 930 millimeter is laid on the top of the geofoam. This is the geofoam material so EPS geofoam as shown here.

So, here is the concrete that density of the concrete is 25 kilo Newton per meter cube and this is the DBM, that is dense bitumen macadam, whose density is 20 kilo Newton per meter cube. And this is the base course, that gamma base courses is 20 kilo Newton per meter cube and this is the sub base so gamma sub base 18 kilo Newton per meter cube. And this distance is 470 millimeter, that is sub base and the base course thickness is 250 millimeter and this is DBM, that is dense bitumen macadam is 170 millimeter and this is the concrete, is 40 millimeter in thickness. So, you have to calculate the stress due to the dead load, on the top of the EPS geofoam. So, here is the EPS geofoam so you have to calculate what will be the stress on the top.

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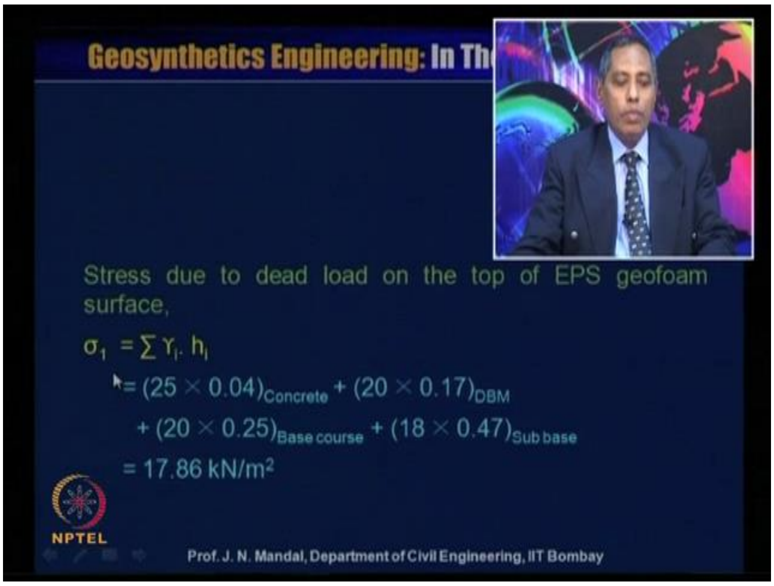

That is sigma 1 is equal to summation of gamma i into h i so here the top one the density is 24 concrete, 25 and this thickness is 40 millimeter. So, 25 into 0.04 that is in case of concrete, plus this is for DBM the density of, this is gamma DBM is 20 kilo Newton per meter cube. And this thickness is 170 millimeter so here it is 20 into 0.17 for DBM now, next is that base course, base course is 20 kilo Newton per meter cube. And this is 250 millimeter so 20 into 0.25 for the base course similarly, for the sub base course, this is 470 millimeter and gamma of sub base 18 kilo Newton per meter cube. So, 18 into 0.47 for sub base so if you add you can have 17.86 kilo Newton per meter square.

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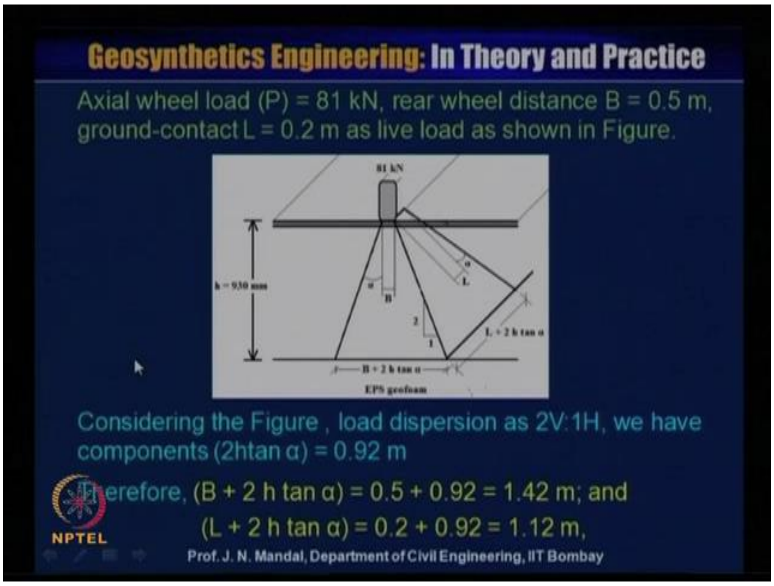

Now axial wheel load P, here 80 kilo Newton and rear wheel distance this is the, B is 0.5 meter and ground contact this is L, which will be the 0.2, meter as the live load as shown in this figure. This is the thickness that, what we consider h is equal to 930, this is millimeter, 930 millimeter and this angle is the alpha. So, this you know, that B plus twice h tan alpha because this is the h and this will be B plus twice h tan alpha and this is the L plus twice h tan alpha. So, this is making at an angle of alpha and here is a load, axial load that is 81 kilo Newton.

Now considering this figure that, load dispersion as the two vertical and one horizontal, we have a component of twice h tan alpha, this is twice h tan alpha. So, you know the two and h is equal to 9.30 and alpha value is about 2604 so if you consider then you can have twice h tan alpha value, h you know 9.30, 2 into 9.30 into tan of alpha is about 26 degree. So, this will give you that this value 0.92 meter therefore, B plus twice h tan alpha B, you know is given 0.5 here, 0.5 plus 2 h tan alpha is 0.92 so it will give 1.42 meter. And L plus twice h tan alpha that is, L is equal to 0.2 this as L, is 0.2 plus this twice h tan alpha is 0.92, it will give 1.12 meter. So, you know this and this 1.42 and 1.12.

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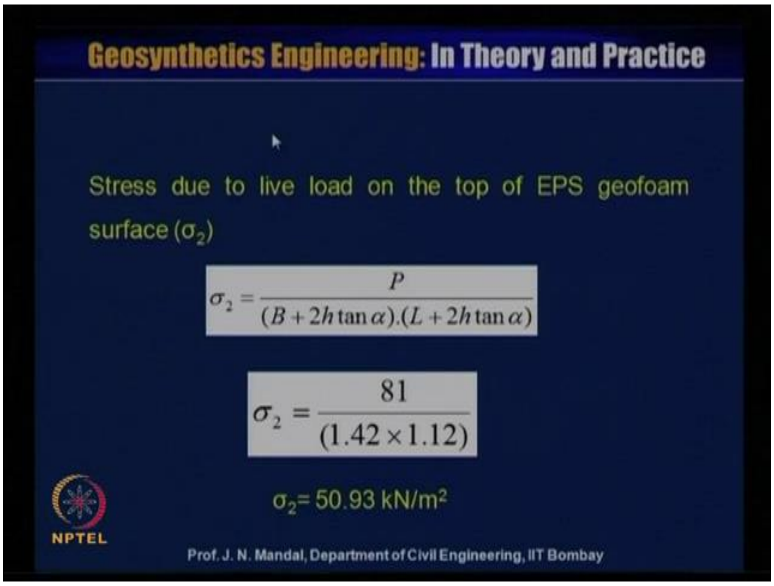

Now stress due to the live load on the top of the EPS geofoam, EPS geofoam on the bottom. So, this EPS geofoam surface sigma 2 so sigma 2 will be equal to at this level, this sigma 2 will be equal to P divided by B plus 2 h tan alpha into L plus 2 h tan alpha.

So, sigma 2 is equal to P axial whose 81 is given and this is 1.42 this is 1.12, this is 1.42, 1.12, this value. So, we are subsisting these value here this is 1.42 this is, 1.12 so this will give sigma 2 value is 50.93 kilo Newton per meter square.

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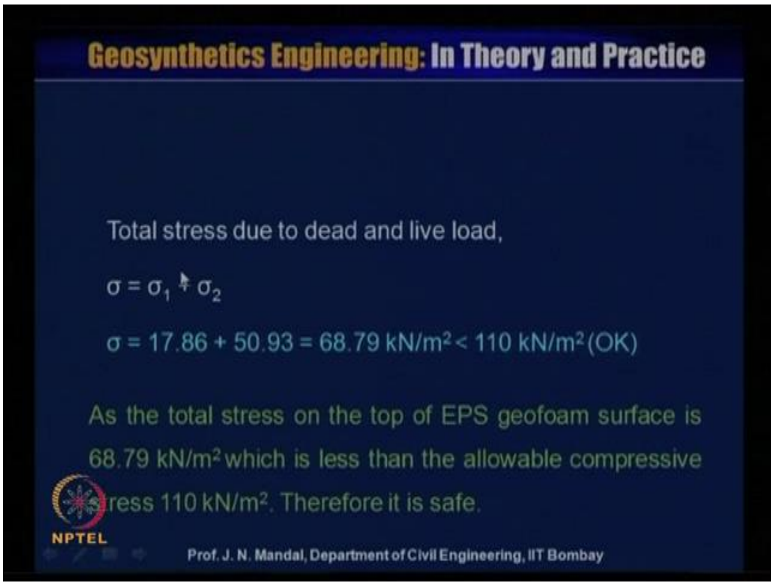

Now total stress due to the dead and the live load sigma is equal to sigma 1 plus sigma 2 that is, sigma is equal to 17.86 plus 50.93, that will give 68.79 kilo Newton per meter square, which is less than 110 kilo Newton per meter square that means, it is okay, it is given that what is allowable compressive stress. So, as the total stress on the top of the EPS geofoam surface, is 68.79 kilo Newton per meter square, which is less than the allowable compressive stress of 110 kilo Newton per meter square therefore, it is safe.

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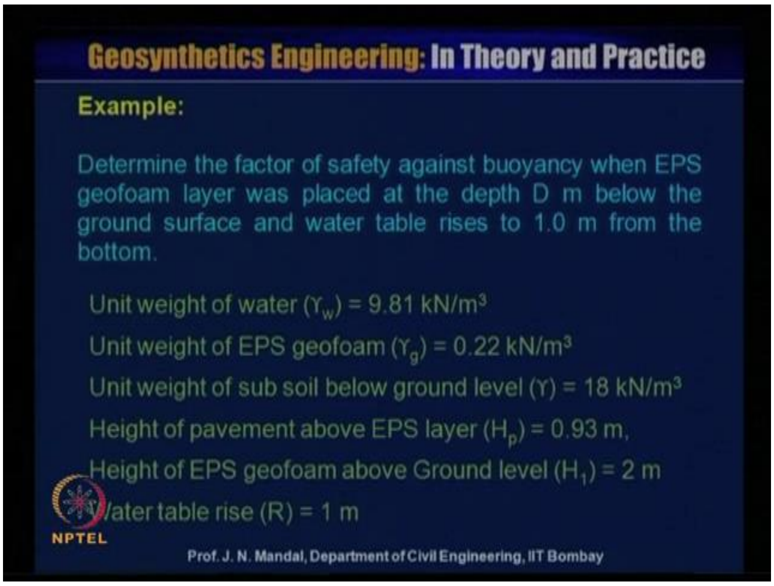

Now this, another this example that determination, the factor of safety against the buoyancy when the EPS geofoam layer was placed at depth of D meter, below the ground surface and water table rises to 1 meter, from the bottom. So, unit weight of water gamma w is equal to 9.8 kilo Newton per meter cube, unit weight of EPS geofoam gamma g is 0.22 kilo Newton per meter cube, unit weight of subsoil below the ground level gamma is equal to 18 kilo Newton per meter cube. Height of the pavement above the EPS layer Hp is 0.93 meter and height of EPS geofoam above ground level Ht is equal to 2 meter and water table rise R is equal to 1 meter.

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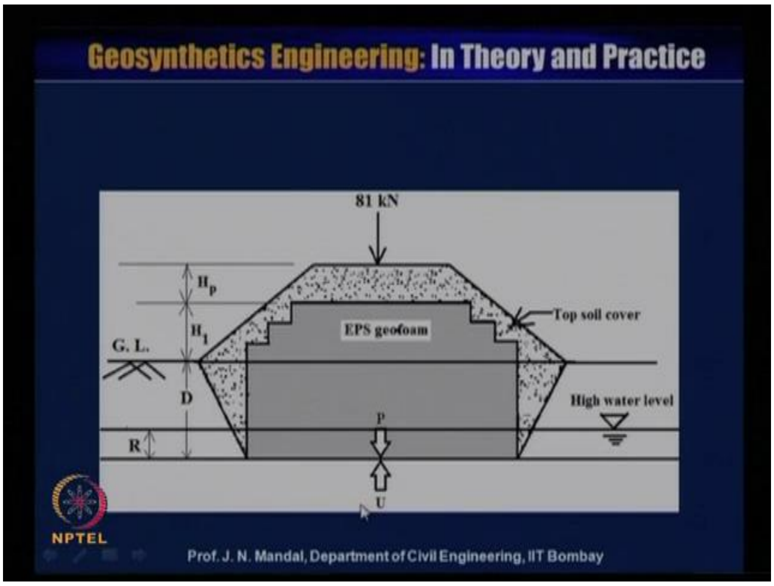

So, here is you can see this is the geofoam, this material and these are all I talked, this is the ground level and this is the water level, this is R, this is 1 meter, this is D, this is H1 and this is Hp. And here is the load, is the 81 kilo Newton so here pressure P and this is upward pressure is U, this is the high water level here and this is ground water level.

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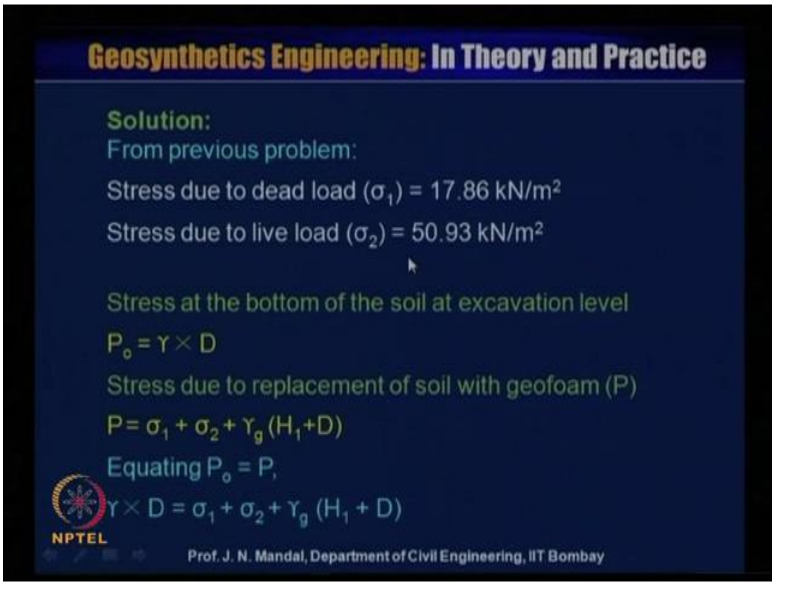

So, this is the solution, from the previous problem we know the stress due to the dead load, which is sigma 1 is 17.86 kilo Newton per meter square. Stress due to the live load sigma 2 is 50.93 kilo Newton per meter square, stress at the bottom of the soil at excavation level, that is P0 will be equal to gamma into D. So, stress due to the replacement of the soil with the geofoam, when you are using this geofoam material here, instead of soil, you are putting the geofoam material.

Then, stress P will be equal to sigma 1 plus sigma 2, which we have earlier calculated plus gamma g into H1 into D. This is H1 and this is D so this is gamma 1 into H1 plus D because this is up to the geofoam, geofoam height. So, gamma g into H1 into D so this is unit weight of the EPS geofoam. Now, if you can equate P0 is equal to P, P0 is equal to P, so gamma D is equal to sigma 1 plus sigma 2 plus gamma g into H1 plus D.

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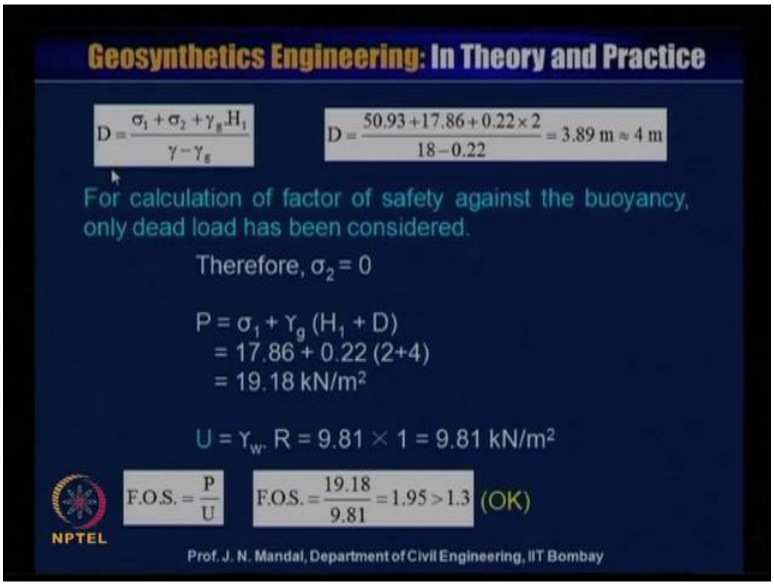

So, from this equation you can calculate D is equal to sigma 1 plus sigma 2 plus gamma g into H1 divided by gamma minus gamma g. So, D is equal to sigma 1 we know 50.93, sigma 2 17.86, plus gamma g is 22 into H1 is given 2 and this gamma is 18 and this is gamma g is 0.22, this will give 3.89 meter, this is approximately 4 meter. Now for calculation of the factor of safety, against the buoyancy only dead load has been considered. Therefore, sigma 2 will be equal to the 0 so P will be equal to sigma 1 plus gamma g into H1 plus D because we have considered sigma 2, 0.

So, this is sigma 1 is 17.86 plus gamma g is 0.22, H1 is 2 and D value which we calculated here, D is 4. This is 4 so this will give P value 19.18 kilo Newton per meter square. Now, we know U is equal to gamma w into R so this gamma w is 9.81, this water density, this is R is equal to 1 is given so this will give 9.81 kilo Newton per meter square. So, factor of safety against P by U will be 19.18 by 981, which will give the 1.95, that is greater than the 1.3 that means, it is ok.

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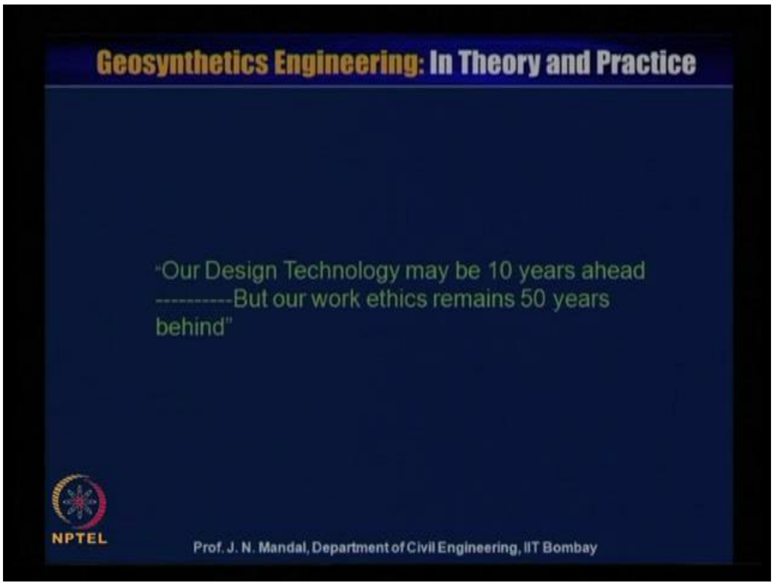

Our design technology may be 10 years ahead, but our work ethics remains 50 years behind.

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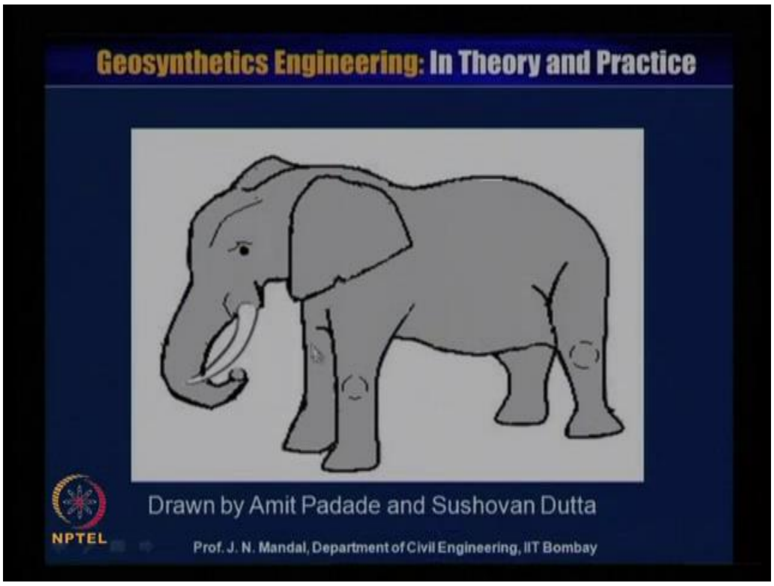

So, we are like the 6 blind man who try to define and elephant, one touch the ear and said this is not a gigantic piece, but ((Refer Time: 01:05:28)) leaf. Another felt the trunk and said this is a snake, the other touched the leg and say it is a big thumb and so on, but we do not know what is that exactly, this beast or the animal. So, this subject is like that one touch and can be able to say this is all the geosynthetic system material, it is not. So, one has to know all aspect of the geosynthetics material then only will be know what it is, for this kind of example.

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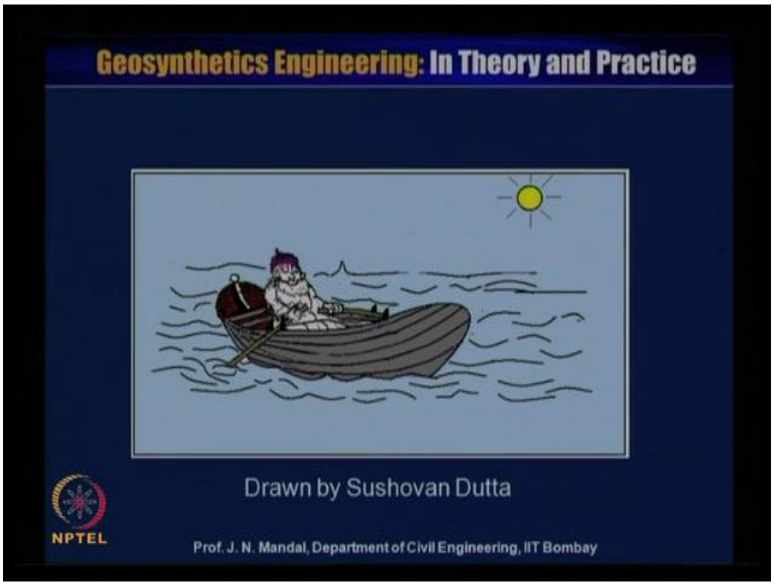

Now, here you can this person is moving along the shore where, there is a wave and sometimes he has to face a difficult any kind of the rock. But he has to tackle and has to pass so this is unprecedented global challenges and the opportunity. So, we need that economic, social and the environmental challenges for the coming century and require that innovative technology and the infrastructure. We need that, proper kind of the product development at the same times, it is very much essential the country like us, that manufacturing equipment of geosynthetics material. Use of these geosynthetics is various infrastructure projects in India also, we require working with the real people and making India a hub and the knowledge and the innovation.

There is also one term, that is forensic engineering when geosynthetic material is fail so you require proper rules and regulation and law there is a law, but there is no law of law. There should be a proper justice so we, that is the, why that this forensic engineering has come up and how this forensic engineering can be used, in the failure of geosynthetic infrastructure. In the centrifuge as you know there is a model and model of model similarly, it is required law of law. And this is the opportunity and the, this is the opportunity and the challenges in the design and construction of geosynthetics reinforced system. So, use this geosynthetics material with confidence.

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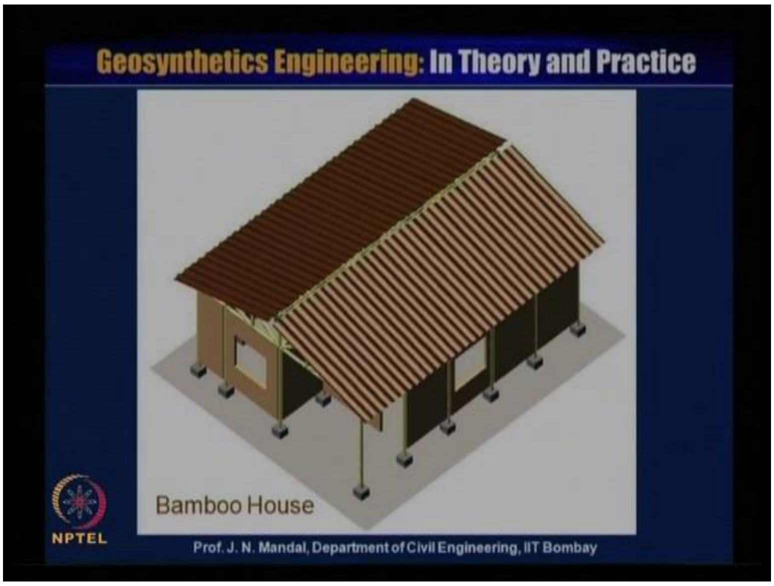

We have also developed a kind of the reinforced earth house, which is bamboo house and this is 1 BHK house, we have to go back to the rural area than, the development in the urban area. So, this is kind of the more economical design and structure also have been, have been proposes this 1 BHK estimation, cost is about coming about 50 to 60 100's, last I go for the acknowledgement.

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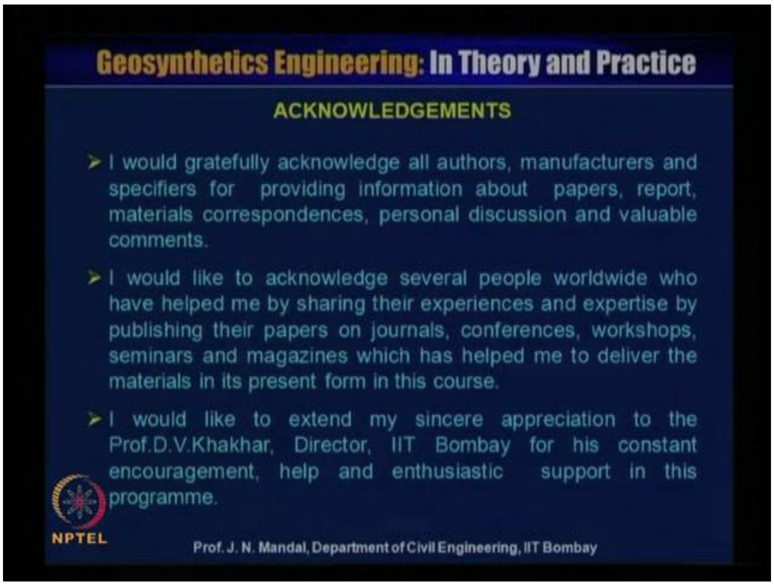

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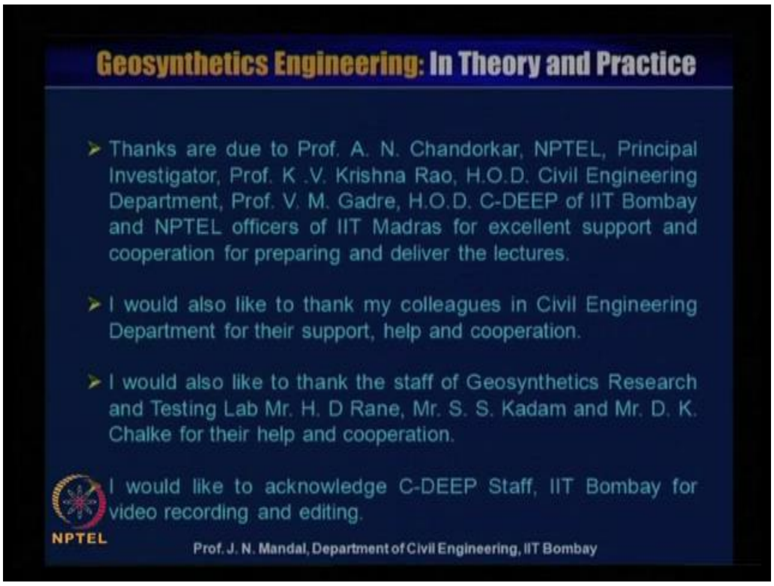

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I do hope that this video course will prove with student design engineer manufacturer and specifier, engaged in this discipline of work. This course could not be complete with this research scholar of civil engineering department Dr. Asha B S, Ram Rathan Lal, Amit Padade, Sushovan Dutta, Maheboob Nadaf and Sariput Navghare and Usha Kadam. This is not at all possible without the help and support from the C-DEEP side Mr. Arun Kalwankar, Ms. M Sangeeta Shrivastava, Mr. Tushar Deshpande, Mr. Devendra Parab, Mr. Vijay Kedare, Mr. Amit B Shaikh, Mr. Ravi Paswan and Mr. Vinayak Raut. Please let us hear from you, any question.

Thanks for listening.