Geosynthetics Engineering: In Theory and Practices
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Module - 13
Lecture - 62
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, the name of the course geosynthetics engineering in theory and practice. This module 13, lecture number 62, designing with geofoam. I will now forecast the recap of the previous lecture, this design of embankment using geofoam overturning due to the seismic effect.

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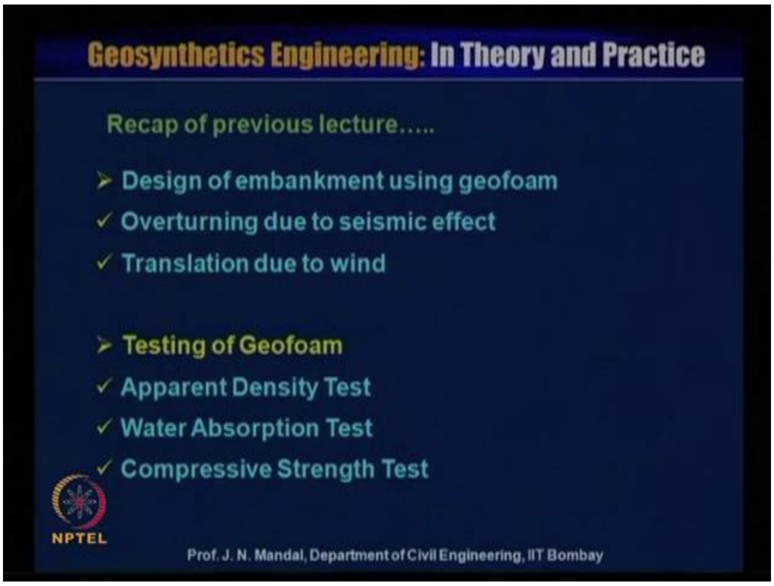

Translation due to wind, next we are continuing with the testing of the geofoam material, that is apparent density test, water absorption test and compressive strength test.

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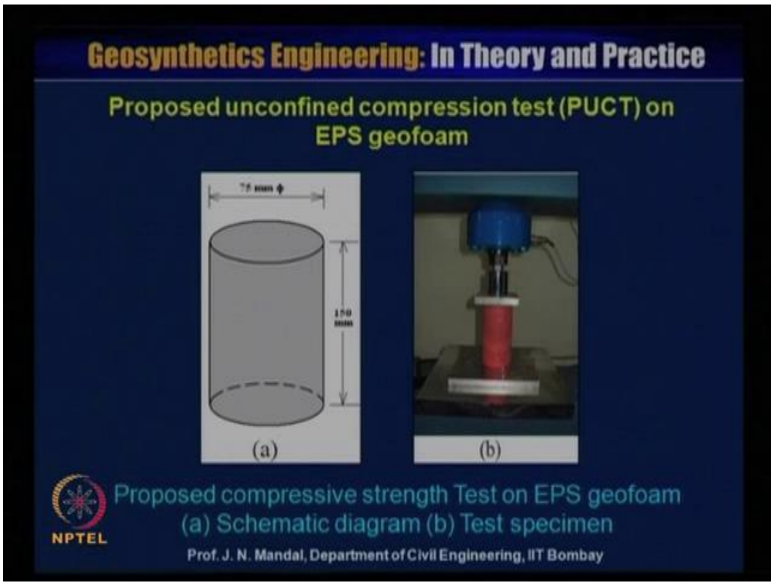

Now, I will address the proposed unconfined compression test PUCT unexpanded polystyrene geofoam. There is no proper compressive strength specification in India on expanded polystyrene geofoam. So, here we are just recommending this proposed compressive strength test on the expanded polystyrene geofoam. The specimen size is shown here, that is this schematic diagram of the expanded polystyrene geofoam. And it is a kind of cylindrical shape geofoam. Whose height is about 150 millimetre and diameter is 75 millimetre because you may be aware of the triaxial compression test of the soil.

So, that looks like a cylindrical in shape and the ratio through the diameter to height about two. So, here this diameter is considered about seventy 5 millimetre and height is this double that is 150 millimetre. So, this here a type of the unconfined compression test is proposing on the EPS geofoam. The right hand side that is b that is the test specimen and this is the red colour this is the expanded polystyrene geofoam, which is cylindrical in shape. And also this specimen is kept between the 2 plate at the top and the bottom. And then you are applying the load from the top here which is connected to the computer.

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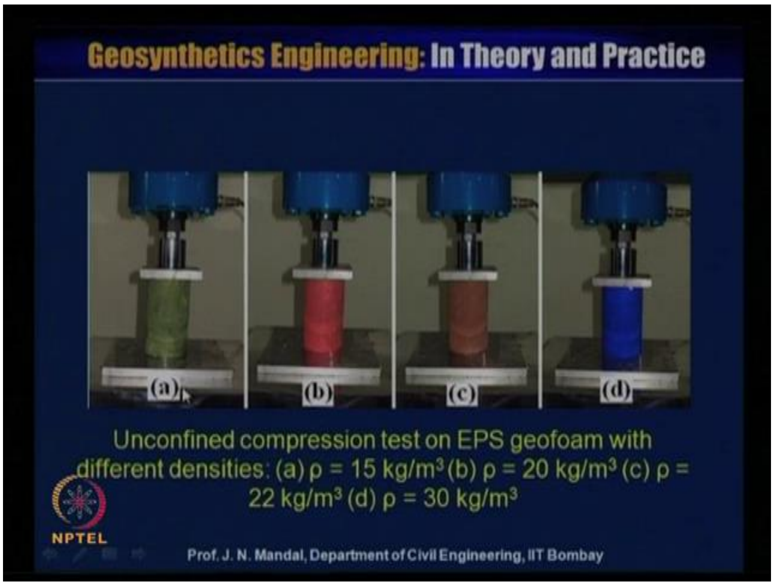

So, here is the unconfined compression test on EPS geofoam with different densities. So, we have given the different colour this is a, that in density of geofoam is 15 k g per metre cube. And this b that is density of EPS geofoam is 20 k g per metre cube and this is the c and whose density of EPS geofoam 22 kg per metre cube. And d, the density of the EPS geofoam whose density is 30 k g per metre cube. So, we have taken that 4 different density of the EPS geofoam and I have performed the compression test.

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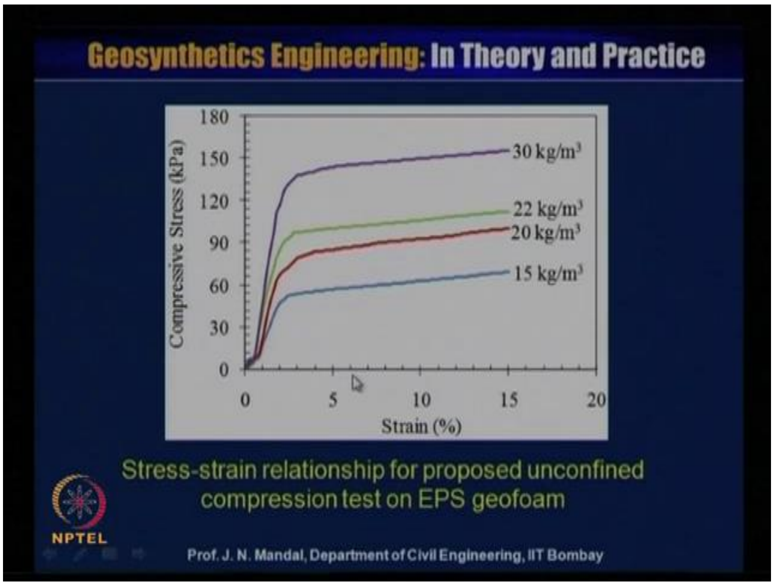

So, from the test result you can obtain the stress strain relationship for the proposed unconfined compression test on the expanded polystyrene geofoam. Here this x axis is the strain in percentage and y axis is the compressive stress in kilo Pascal. So, you can see that initially this is the compressive stress is increasing, with increasing the strain and then you can see that strain is increasing, but with respect to the compressive strength it is not so as it was in the beginning. So, even then it is it is increasing so there is no decreasing kind of the trend is available here when you went up to even then 15 percentage of strain.

So, from this figure you can we observe that compressive stress value is increasing with increasing the density of the expanded polystyrene geofoam. Even then at a particular strain minimum strain value, the compressive stress value is lying on the almost at the same line. So, this compressive stress is very important to us.

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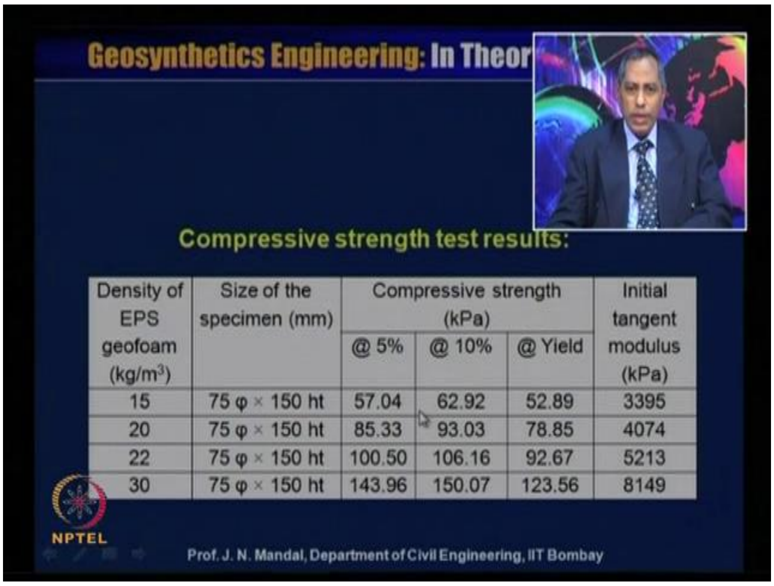

So, here we have performed the 4 different density of the sample. So, density of EPS geofoam is 15 k g per metre cube, 20 k g per metre cube, 22 k g per metre cube and 30 k g per metre cube. And size of the specimen is the same for all cases that is 75 millimetre in diameter and 150 millimetre in height. Now, most important that we have to determine what will be the compressive strength value in kilo Pascal at 5 percent strain and 10 percent strain. And also the yield value and the initial tangent modulus value in kilo

Pascal. So, this value is important because we wanted to adopt for the design of any structure.

So, for the 5 percent when the density of the EPS geofoam is 15 k g per metre cube at the 5 percent this is 57.04 kilo Pascal at the 10 percent compressive strength value is 62.92 kilo Pascal. And at the yield strength compressive strength value 52.89 kilo Pascal and initial tangent modulus is 3395 kilo Pascal. When the density of EPS geofoam is 20 k g per metre cube and size of the sample is same that is 75 millimetre diameter and 150 millimetre height compressive strength at 5 percent strength is 85.33 kilo Pascal, and 10 percent 93.03 kilo Pascal. And yield 78.8 kilo Pascal initial tangent modulus 4074 kilo Pascal.

Now, density of the EPS geofoam is 22 k g per metre cube and size of the sample is the same 75 millimetre diameter and 1 hundred 50 millimetre in height and compressive strength at 5 percent is 150 kilo Pascal and compressive strength at 10 percent is 100 and 6.16 kilo Pascal and yield value is 96, 92.67 kilo Pascal. Initial tangent modulus 5213 kilo Pascal and at the end the density of EPS geofoam is 30 k g per metre cube size of the specimen 75 millimetre diameter into 155 millimetre height.

Compressive strength at 5 percent strength is 143.96 kilo Pascal at 10 percent strength compressive strength 150.07 kilo Pascal and at yield value is 123.56 kilo Pascal and initial tangent modulus 8149. You can observe that from this table that density is increasing, then compressive strength value also are increasing with increasing the strength. And also the yield values also are increasing and initial tangent modulus value also are increasing.

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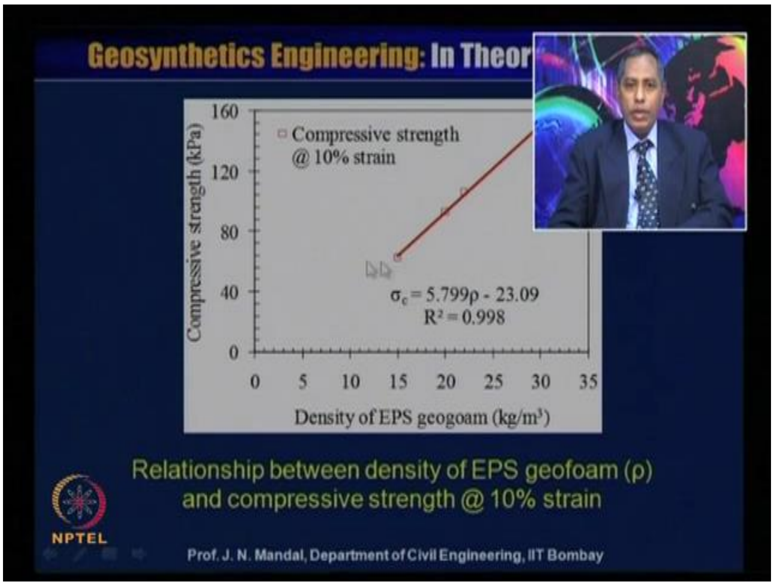

So, this value is important for the analysis. Now, here these figure show the relationship between the density of EPS geofoam rho and the compressive strength at 10 percent strength. So, this is the different density as we mentioned here 15, 20, 22 and 30. So, here for 15, 20, 22 and 30 this is density of the EPS geofoam in the x axis that is k g per metre cube and compressive strength is kilo Pascal.

So, we know that for this density 15 so what will be the compressive strength. So, we put this compressive strength value at 10 percent strength. So, 10 percent strength suppose when its 15 then 62.92. So, neither 15 then 62.92 like that for when there is a 20 then for at 10 percent strength 93.03. So, 93.03 now next when it is density is 22 at 10 percent strength 106.16. So, this is 106.16, when it is the density is 30 then at 10 percent strength that compressive value 150.07. So, this is 150.07.

So, if we see here you can draw a line which will give the straight line. So, from this relationship, you can develop tan equation for the compressive strength that is sigma c will be equal to 5.799 into rho, that is density of the geofoam minus 23.09, where r square is equal to 0.998, so this equation also very important, if you know that what will be the density of the geofoam. So, you can directly calculate that what will be the compressive strength of the EPS geofoam using this equation. This equation also can be used for any analysis.

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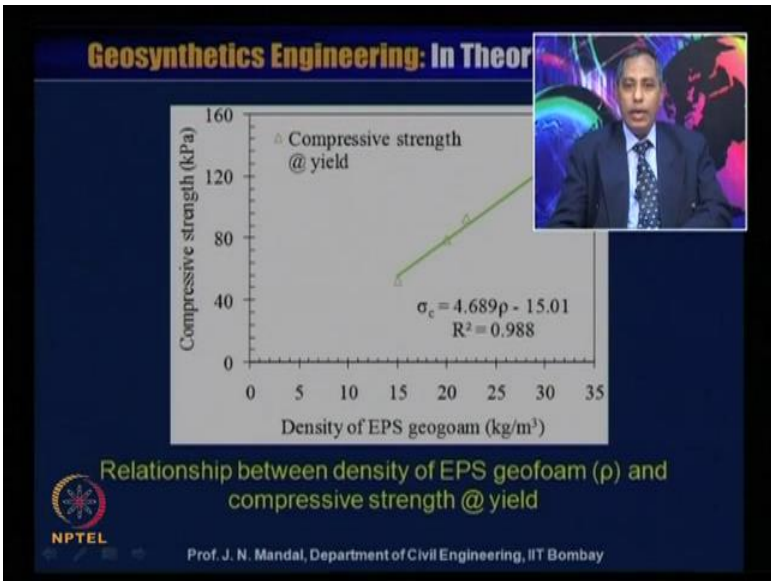

Here the relationship between the density of EPS geofoam rho and the compressive strength at yield. So, this is the compressive strength at yield. So, we know that this is the x axis this is the density of EPS geofoam k g per metre cube, y axis is the compressive strength in kilopascal. So, we know for the different density, either 15, 20, 22 and the 30 we know what is the compressive strength at yield, that means this value compressive strength at yield.

So, if you substitute this value so you can have a linear equation like this and then you can develop that what will be the compressive strength at yield, that even then if you say sigma c will be equal to 4.689 rho minus 15.01 r square is equal to 0.988. So, from this equation also we can calculate what will be the compressive strength at yield. So, if you know that what will be the density of the expanded polystyrene geofoam. So, you can calculate compressive strength at yield.

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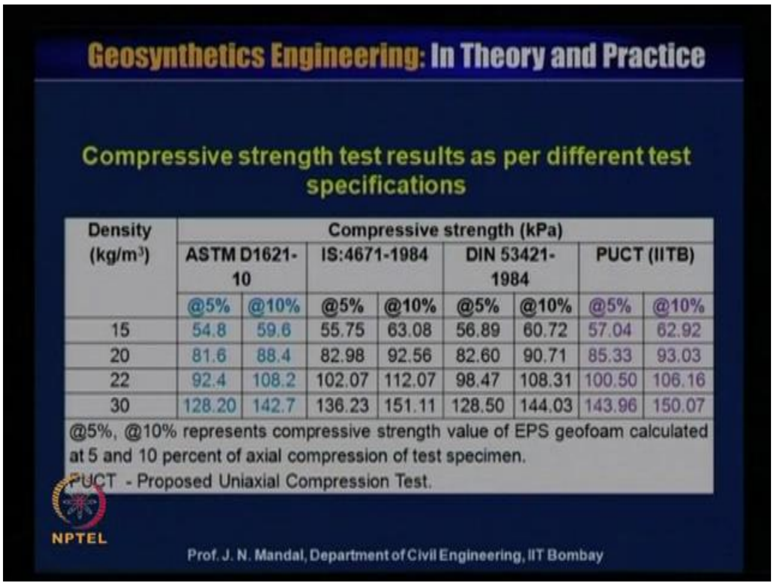

Now, this is compressive strength test result as per different test specification. We have performed in our geosynthetics testing research and testing laboratory. For all the different density of the EPS geofoam and the different method you can see as per ASTM D1621-10, IS 4671-1984, DIN 53421-1984 and PUCT IIT Bombay this is the proposed. So, you can see that for different density that what will be the compressive strength at 5 percent and 10 percent, for all specification.

You can see as per ASTM this is 54.8, then at when it is density is 20 it is 81.6, when density is 22 then compressive strength value is 92.4. And when density is 30 this is 128.20 at 10 percent, when the density is 15 this value compressive strength value 59.6, when density is 20 this compressive value strength value 88.4 and when it is 22 this is 108.2. When density is 30 this is 142.7 and this 5 percent and 10 percent represent the compressive strength value of EPS geofoam, which has been calculated at 5 and 10 percent of axial compression test of the specimen.

And this is the PUCT- IIT Bombay that is proposed uniaxial compression strength value, if you can see at the 5 percent strength it gives 57.04, when the density is 15 k g per metre cube when density is 20 k g per metre cube. Then compressive strength value at 5 percent is 85.33 and when it is 22 this is 100.50, when it is 30 k g per metre cube density then compressive strength value 143.96. Whereas, in case of the 10 percent when density is 15 k g per metre cube, compressive strength value is 62.92 and when it is density is 20 k g per metre cube this compressive strength value 93.03, when density is 22 k g per metre cube this at 10 percent compressive strength value 106.16 and when that density is 30 k g per metre cube at 10 percent 150.07.

Now, if you can compare with the ASTM and the proposed that uniaxial compressive strength, you can see that variation in the result this is 54.8 whereas, this is 57.04 this is 81.6 at 5 percent strength this is 85.33 this is 92.4 at 5 percent this is about 100.50 this is 1288.2 0 and this is 143.96. Similarly, at the 10 percentage this is 59.6 for 15 density whereas, this gives 62.92 compressive strength then this is 88.4 at 20 k g per metre cube density then this propose is given 93.03. So, at 22 density 108.2 at 10 percent and these are at 10 percent 106.16.

So at 30 density 142.7 and this proposed is giving 150.07 even then if you compare with the ASTM it is reasonably well match. So, we can recommended this kind of the testing for the compressive strength. Even then you can compare with the other method at 5 percent and the 10 percent you can have something variation not so variation where some variation in result, also in the DIN also you can see that there is some variation in result.

So, it is much more the appropriate this result which is matching with the ASTM and this proposed method. It is also that very easy to produce a geofoam material like cylindrical in shape, if you have any machine compressive strength in machine even then triaxial machine you can perform easily, you do not require any additional kind of the equipment to perform the compressive strength value. So it is easy to perform the test and it is easy to produce this cylindrical geofoam material. This will be the more appropriate method to calculate this compressive strength of the expanded polystyrene geofoam.

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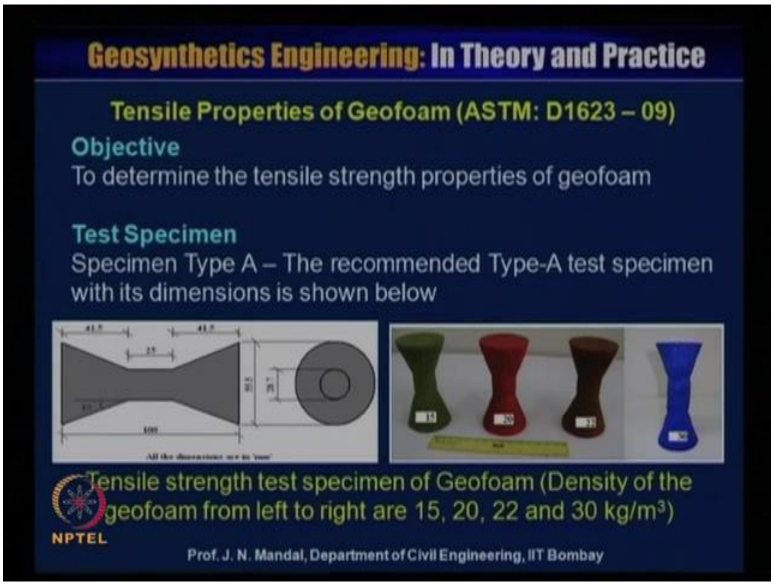

Now, we will discuss the tensile properties of geofoam as per ASTM D 162309, the objective of this test to determine the tensile strength properties of the geofoam. Here the test specimen type a, that is recommended type a test specimen with its dimension as shown here. You can see here very typical tensile strength test specimen of geofoam of density is 15 k g per metre cube, this is 20 k g per metre cube, this is 22 k g per metre cube and this is 30 k g per metre cube.

Here I am showing that what should be the sample, this is the one dimension is given in millimetre this to this is about 108 millimetre, and from here to here is about 505.5 millimetre and this here to here is 41.5 millimetre. This is also 41.5 millimetre and this to this is about 25 millimetre and this angle is 18 degree. So, it is like a dumbbell shape this also is 28.7, this is the diameter here 28.7 and this also 55.3. So, it is a like a dumbbell shape and sometimes also is very difficult to manufacture or to produce a, this kind of dumbbell shape, for the determination of the tensile strength of the expanded polystyrene geofoam. So, we have also fabricated the gripping assembly for this.

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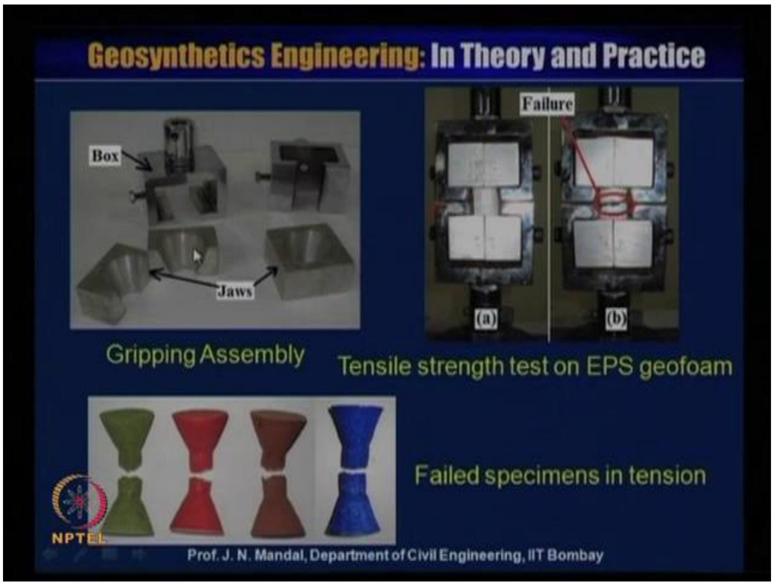

It is also very complex you can see this is the jaw, you have we have also fabricated and developed and this is the box. Here is the tensile strength test set up on the expanded polystyrene geofoam material, this is a kind of I say that like this dumbbell kind of the shape and which you have to be grip at the top and the bottom. And this is the what we call the gauge length and this is the test before the test and you can see that after the test, and this is very typical failure. You can see here is the typical failure almost at the middle of this portion. So, the failure pattern is here. So, this is tensile strength before the test and after the test. So, for all densities we have performed and this is the failed specimen in tension you can see very typical failure.

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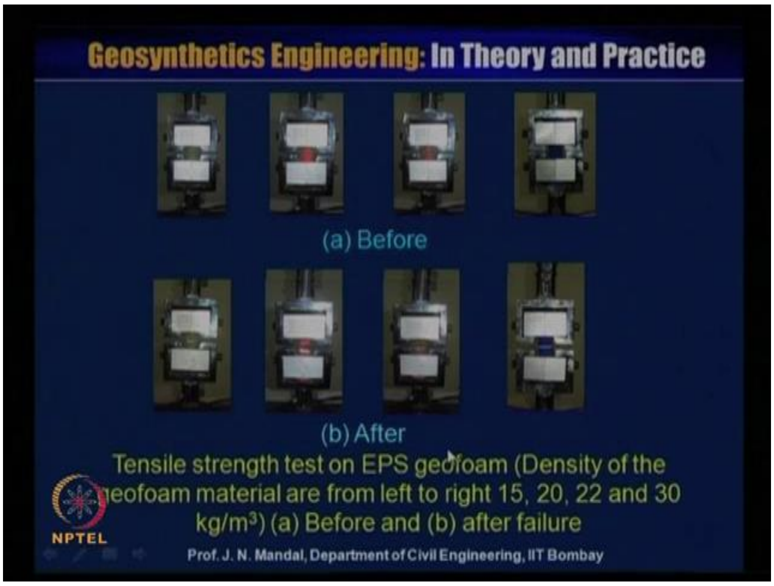

So, this is very important also parameter, this is here is showing that 4 density that is 15 20 22 and 30 k g per metre cube. This is the before the test and you can see this is the after the test, that how the sample fail.

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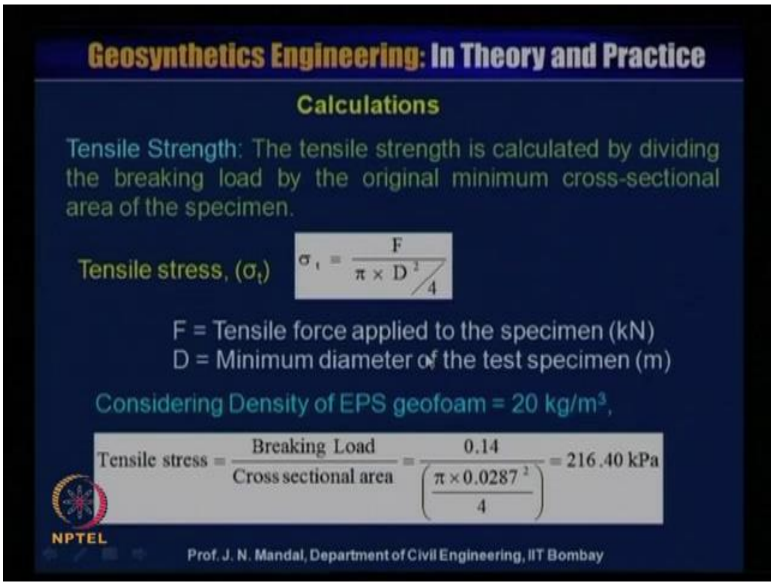

So, you have to calculate from this tensile strength, that what will be the tensile strength is calculated by dividing the breaking load by the original minimum cross sectional area of the specimen. So, tensile strength sigma t is equal to F divided by pi into D square by

4. So, that means F is the tensile force applied to the specimen is kilonewton and D is the minimum diameter of the test specimen in metre.

So, considering the density of the expanded polystyrene geofoam is 20 k g per metre cube. Let us consider that we are calculating only for the density of 20 k g per metre cube. So, tensile stress will be equal to breaking load by cross sectional area and breaking load is 0.14, this divided by cross sectional area pi into 0.0287 square divided by 4. That will give the tensile stress value 216.40 kilo Pascal.

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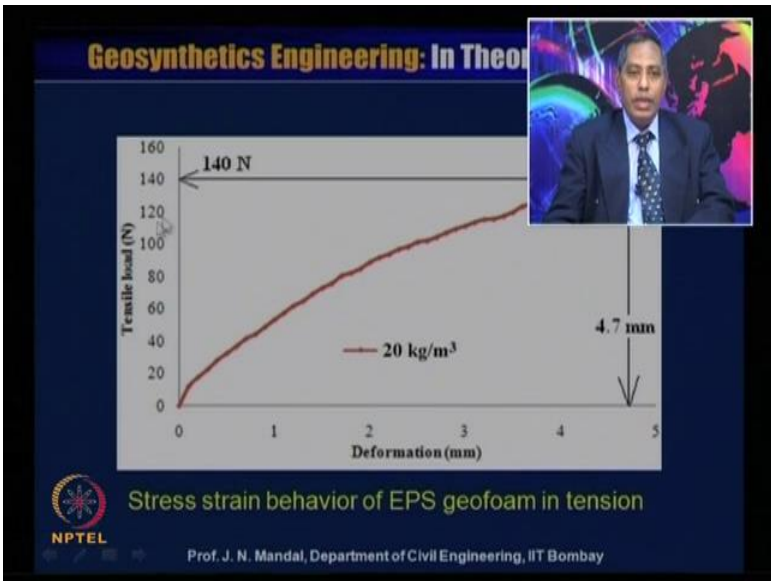

Now, this is the stress strain behaviour of the expanded polystyrene geofoam in tension. So, this is x axis is give the deformation in millimetre and this is the tensile load in kilo Newton you can see the nature of the curve is like this that means the tensile load is increasing with increasing the deformation. This is shown only for the density of expanded geofoam is 20 k g per metre cube. So, when the deformation is about 4.7 millimetre then the tensile load is 140 Newton.

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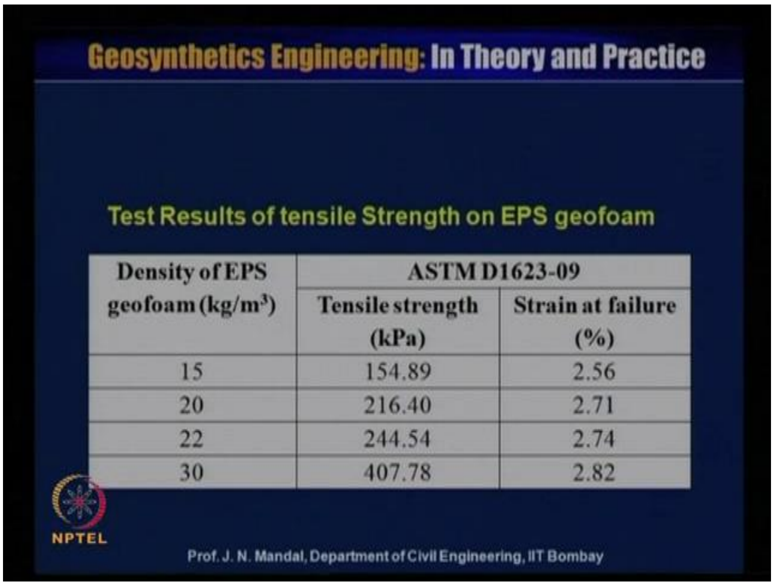

Density of EPS geofoam (kg/m^3)	ASTM D1623-09	
	Tensile strength (kPa)	Strain at failure (%)
15	154.89	2.56
20	216.40	2.71
22	244.54	2.74
30	407.78	2.82

Now, this is the test result for the tensile strength of expanded polystyrene geofoam for various density when the density of EPS geofoam is 15 k g per metre cube. This is as per ASTM D1623-09, the tensile strength value is 154.89 kilo Pascal and strain at failure is 2.56 percentage. When the density of EPS geofoam is 20 k g per metre cube the tensile strength value is 216.40 kilo Pascal and strain at failure 2.71 percentage. When the density of EPS geofoam is 22 k g per metre cube the tensile strength is 244.54 kilo Pascal and strain at failure 2.74 percentage.

When the density of EPS geofoam is 30 k g per metre cube, then tensile strength is 407.78 kilo Pascal and strain at failure 2.82 percentage. So, you observe that the density is increasing, then the tensile strength value also is increasing and the strain value also is increasing. So, if the tensile strength value is from about 154.89 to 407.78 kilo Pascal depending on the density of the expanded polystyrene geofoam. Also the strain value which is lying between 2.56 percentage to 2.82 percentage.

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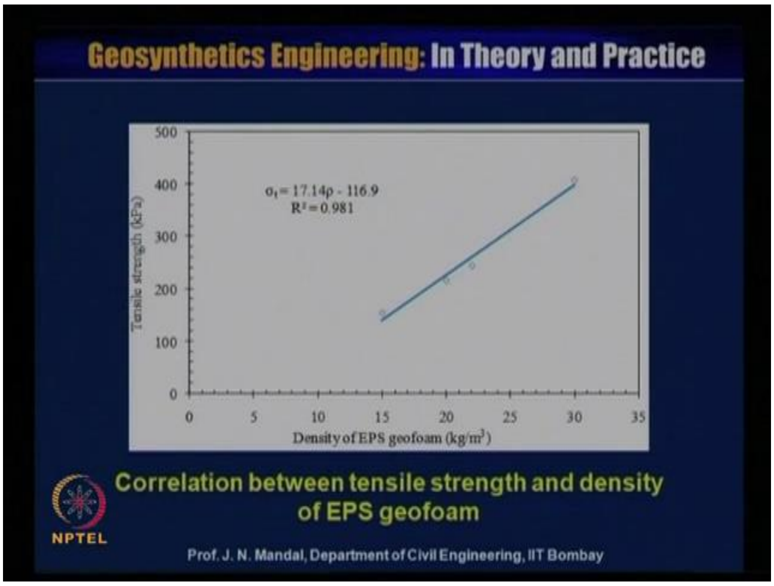

Now, correlation between the tensile strength and the density of the expanded polystyrene geofoam. So, here is the x axis is density of the EPS geofoam is k g per metre cube and y axis is the tensile strength in kilo Pascal. For the different density you know what will be the tensile strength value so for 15 you know what will be the tensile load similarly, for 20 22 and then 30. So, then you can have a linear line like this. You can establish a equation which is sigma t is equal to 17.14 rho minus 116.9 or R square is 0.981.

So, from this equation also you can directly determine what will be the tensile strength of the geofoam. If you know that what will be the density of the geofoam, if the rho is known, then you can calculate what will be the tensile strength of the geofoam from this equation.

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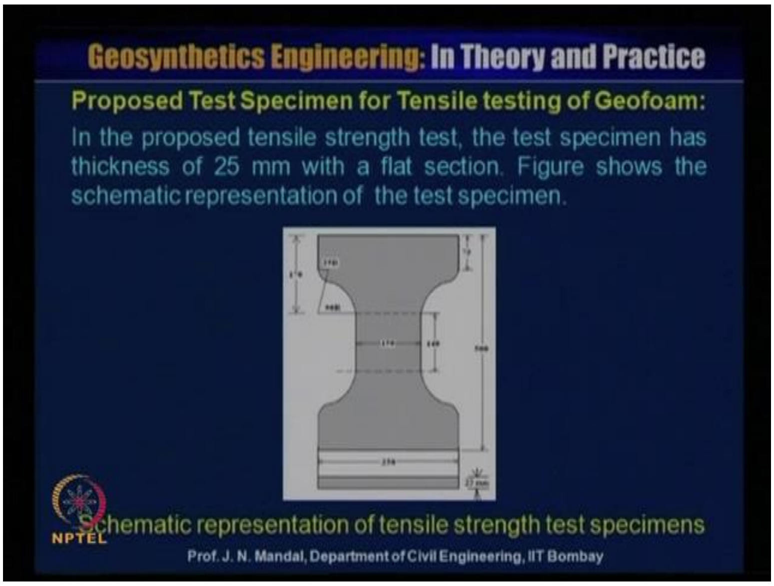

Now, as you have observed that, tensile strength of the expanded polystyrene geofoam by the ASTM method is quite complex because it is sometimes very difficult to produce the dumbbell shape of the specimen. As well as you also require typical clamping arrangement or jaw arrangement for this to hold this specimen into this machine. So, we have recommended and proposed the test specimen for the tensile strength of the geofoam.

So, in this proposed tensile strength test this test specimen has thickness of 25 millimetre, with a flat section. This figure show that schematic representation of the test specimen. You can see that here, we have performed with the different density and also different shape and size and the different thickness. Then we have come to a conclusion that this kind of the thickness will be the much more appropriate. Here I am showing you that detail dimension of this I shaped this expanded polystyrene geofoam specimen.

Here this is 250 millimetre and this is 170 millimetre and this one is 140 millimetre, this is 150 millimetre, this is 75 millimetre and this is about your 90 R this is 25 R here. This to this is about 500 millimetre and this to this here is 25 millimetre. So, if you have because you can very easy to make this sample because you can have the different thickness of the expanded polystyrene geofoam, then you can simply can cut with this dimension.

So, it is very easy to prepare this kind of the geofoam sample. So, it is easy to cut and easy to prepare, it is not a dumbbell shape or where there is a complex. And also it is very easy to clamp at the both end of this sample. So, we have developed this kind of the gripping assemble.

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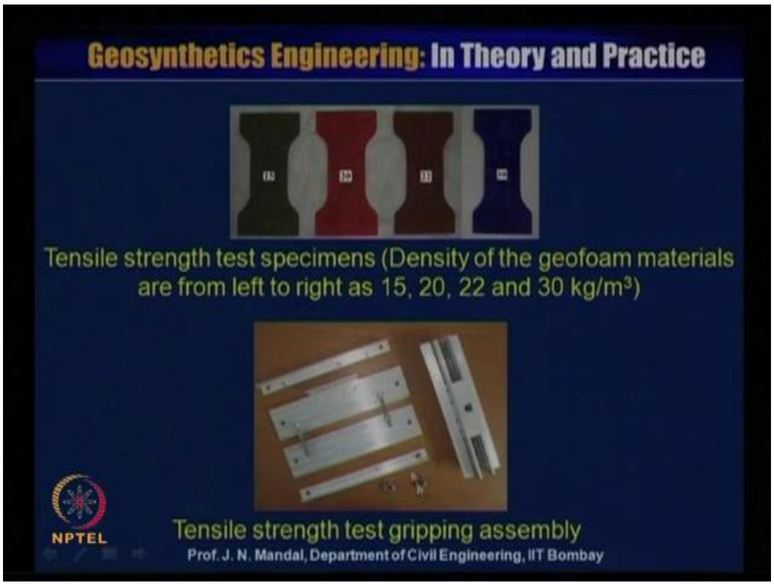

You can see this is the gripping, this assemble for the tensile strength of the expanded polystyrene geofoam. This is the different tensile strength test specimen whose density of the geofoam material, are from this is 15 k g per metre cube, this is 20 k g per metre cube, this is 22 k g per metre cube and this is 30 k g per metre cube. So, this is the testing sample with different density and this is the gripping assembly.

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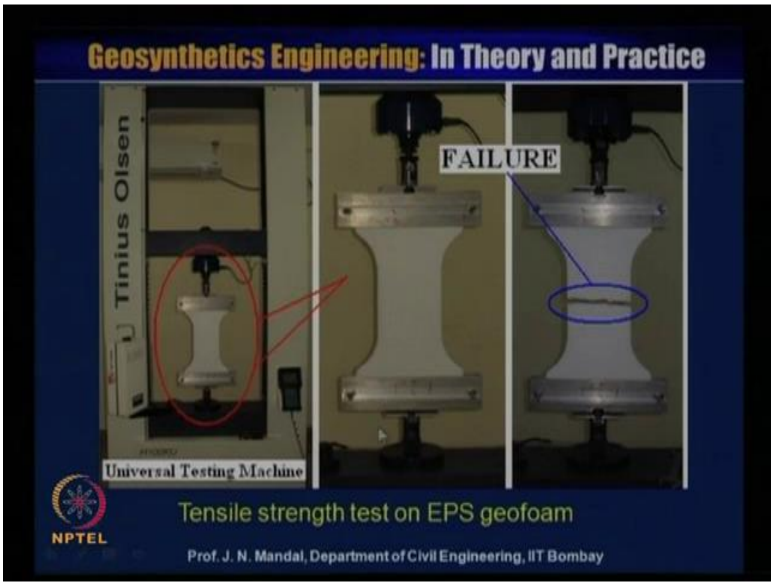

So, here we are performing that tensile test on the expanded polystyrene geofoam. So, here it is a clamping, you can see clamping is very easy with this kind of the specimen. This is you can see this extension form, here it is this is the sample of geofoam white in colour and before the test and after test you can see this is a kind of the failure. This is a kind of very typical failure of the geofoam in a for the tensile test. So, here is the different sample different density before the test and here you can see after the test from the different density.

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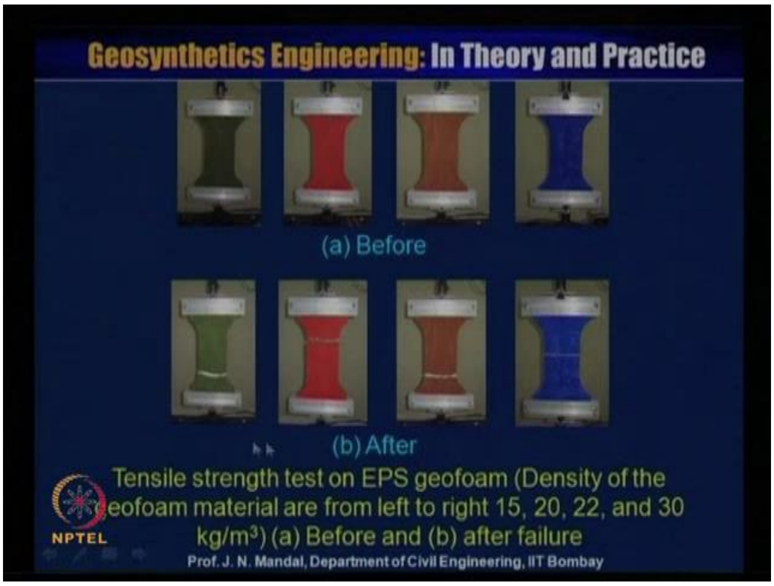

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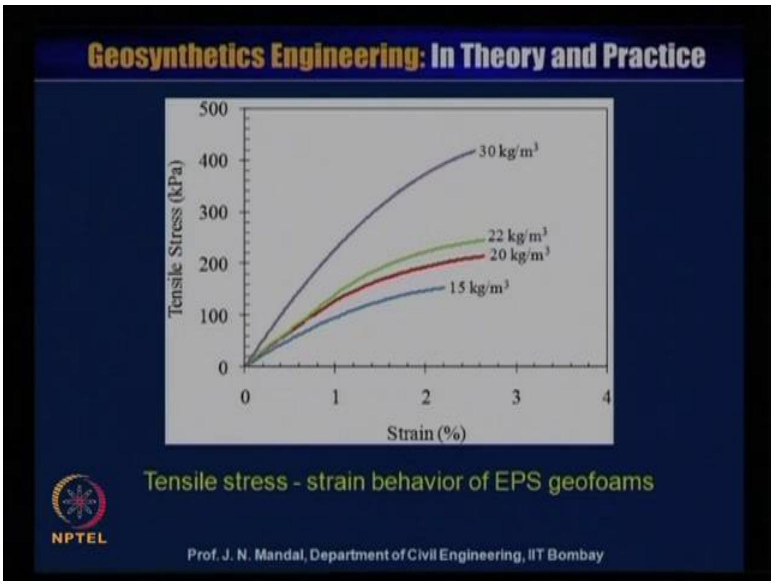

So, now we have obtained the tensile stress strain behaviour of expanded geofoam material. This is x axis is the strain value and y the tensile stress in kilo Pascal. This is for 15 k g per metre cube the density of the EPS geofoam. And next red one is that 20 k g per metre cube. Then green again the 22 k g per metre cube and then this is 30 k g per metre cube. You can see here that the strain increasing tensile stress value also are increasing, in all cases and in all cases this density of the EPS geofoam is increasing, with increase in the tensile stress of the EPS geofoam. This all case almost this strain value is lying the below the even then 3 percentage of strain.

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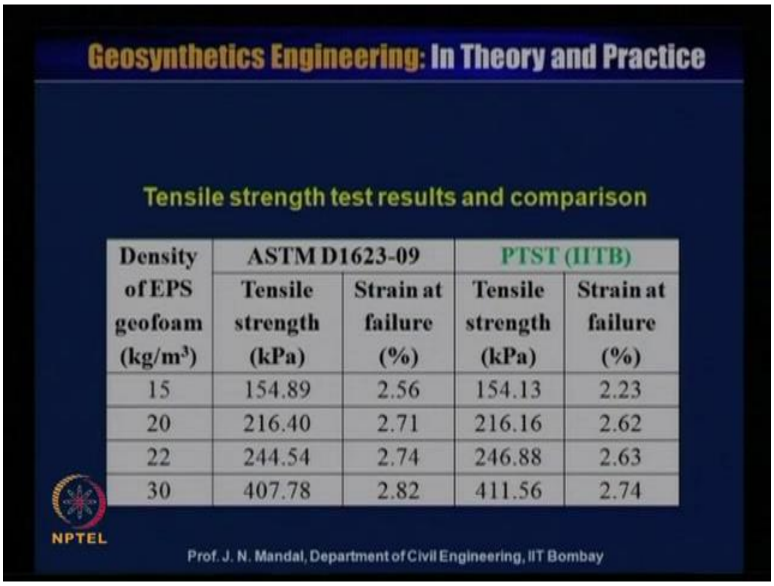

Density of EPS geofoam (kg/m³)	ASTM D1623-09		PTST (IITB)	
	Tensile strength (kPa)	Strain at failure (%)	Tensile strength (kPa)	Strain at failure (%)
15	154.89	2.56	154.13	2.23
20	216.40	2.71	216.16	2.62
22	244.54	2.74	246.88	2.63
30	407.78	2.82	411.56	2.74

So, here is the table which shows the tensile strength test result and then comparison with the ASTM D1623-09, because these we are proposing because it is very easy to produce this kind of the product, very easy for the gripping arrangement, very easy to perform the test. So, here density of EPS geofoam is 15 k g metre cube as per ATM D1623-09 tensile strength is 150.9 kilo Pascal and strain at failure is 2.56 percentage.

Whereas in the proposed tensile strength at IIT Bombay, that tensile strength is 154.13 and strain at failure 2.23. You can see that lot of similarity is there with the ASTM and the proposed tensile strength method and this test is recommended for use in India. So, density of the EPS geofoam is 20 k g per metre cube, the tensile strength is 216.40 kilo Pascal, the strain at failure is 2.71 percentage. This proposed tensile strength in IIT B is 216.16 and strain at failure 2.62 percentage.

So density of EPS geofoam is 22 k g per metre cube the tensile strength value 244.54 kilo Pascal, strain at failure 2.74 percentage, the proposed method tensile strength value is 246.88 kilo Pascal and strain at failure 2.63 percentage. When the density of the EPS geofoam is 30 k g per metre cube as per ATM tensile strength is 407.78 and the strain at failure is 2.82 percentage, whereas the proposed method tensile strength is 411.56 kilo Pascal and strain at failure 2.74. So, you can see that lot of similarity of the value of the tensile strength and the corresponding the strain value has been obtained.

So, tensile strength value for the ASTM lies between 154.8924 107.78 kilo Pascal. Whereas, this proposed method this tensile strength value lies between 154.1324 11.56 kilo Pascal, so depending upon the density of the EPS geofoam. So, there is a quite good agreement between the tensile strength and also the corresponding the strain value. So, strain at failure as per ATM is 2.56 percentage to 2.82 percentage whereas, this proposed method this 2.23 percentage to 2.74 percentage.

So, it is well examined with the ASTM method and proposed method. So, we recommend that proposed method is much more the simpler and easy to manufacture. And easy to test because different types of the thickness of the expanded polystyrene geofoam is available, so you can cut the proper size and the shape which we have optimized and we come up with the proper specification, and which is matching as per the ASTM test specification is concerned. So, this will be very useful and recommended for the tensile strength of the EPS geofoam.

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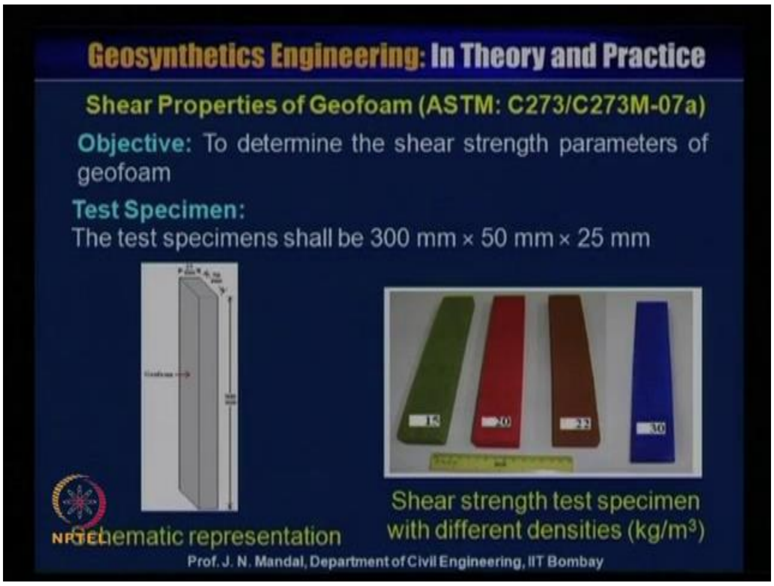

So, next we will talk the shear properties of the geofoam is ASTM: C273/ C273M dash 07 a. Now, objective of this test to determine the shear strength parameter of the geofoam, this is also very important because the geofoam material has to placed with the other kind of the material, and we have to you should know that what will be the shear strength properties of the geofoam material. So, test specimen all shall be the 300 millimetre into 50 millimetre into 25 millimetre.

So, here is the schematic representation of the sample of geofoam, this is at 300 millimetre, this is 50 millimetre, this is 25 millimetre. You can see right hand side this is the shear strength test specimen with the different density, this is 15 k g per metre cube and this is 20 k g per metre cube, this is 22 k g per metre cube and this is 30 k g per metre cube. With different colour has been given because to identify this what density you are using in the geofoam because this all the geofoam is white in colour. Sometimes it is difficult to identify that what will be the density.

So, that is why when we are performing the test and we have been provided with the different colour to identify. Like that geogrid has a different strength. So, some I did for identification some of the manufacturer had provide with some kind of the colour yellow, colour green, like a thread to identify for the worker that, what is the strength of the geogrid material. Similarly, here this colour has been given to identify that what will be the density of the EPS geofoam material.

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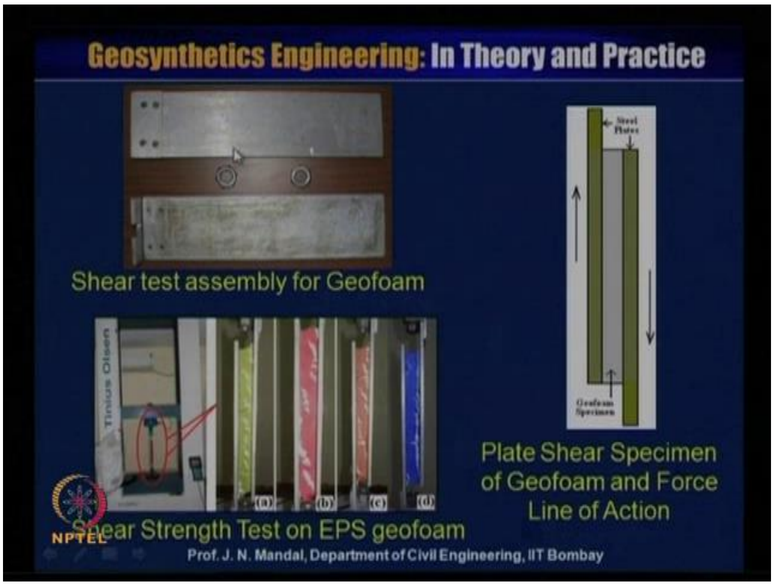

So, this is the shear stress assembly for the expanded geofoam material. This is the shear strength test of the EPS geofoam, you can see here this is the this way also this we have been fabricated, in our geosynthetics testing and research laboratory. This is the plate shear this specimen, this is the plate shear and this is the geofoam material geofoam material specimen is here. This is the steel plate this is the steel plate and this is moving this direction this is moving this direction.

So, there is a development of the shear between the geofoam and the steel, so which we can see here. So, here it is for different density this a for 15 k g per metre cube, this is for b 20 k g per metre cube, this is c 22 k g per metre cube and d 30 k g per metre cube. So, this has been test has been performed.

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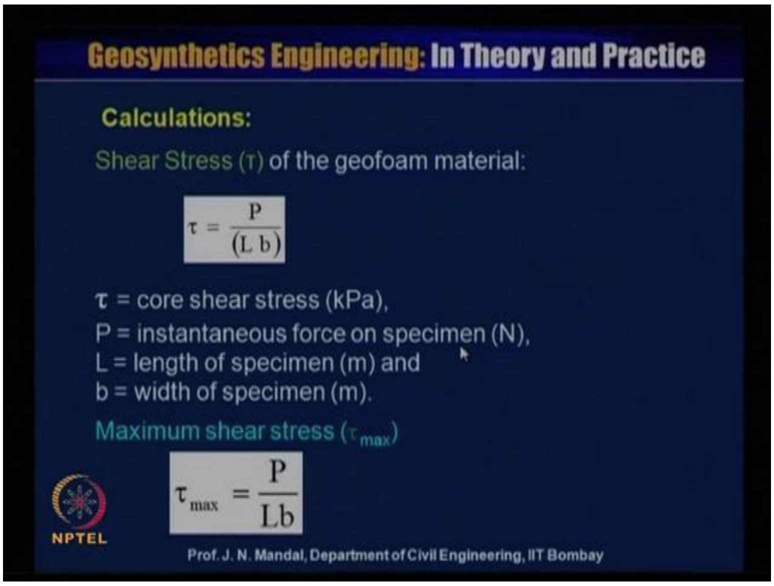

So, from this test you have to calculate what will be the shear stress, that means tau of the geofoam material. So, tau is equal to P divided by L into b, where tau is equal to core shear stress in kilo Pascal and P is instantaneous force on specimen that is in newton. L is equal to length of the specimen in metre and b is width of the specimen in metre. So, maximum shear stress tau max can be defined tau max is equal to P divided by L into b.

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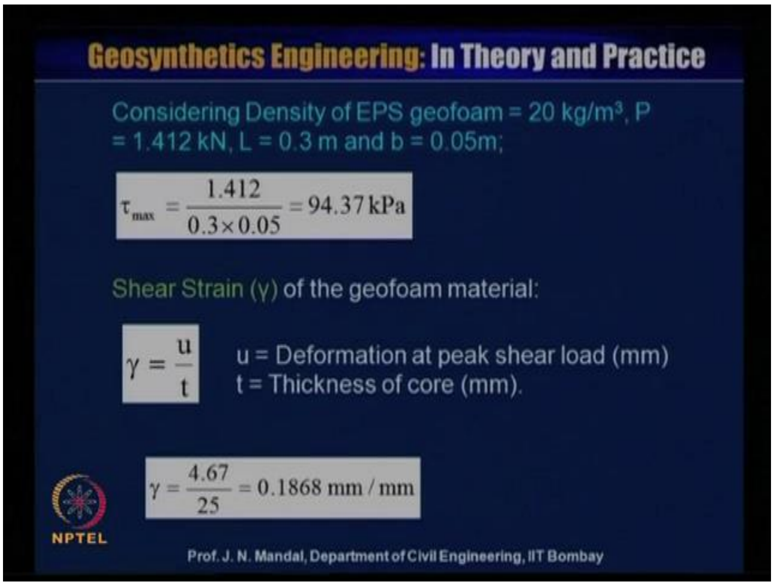

So, now considering the density of the EPS geofoam 20 k g per metre cube. So, we have only shown for the one density similarly, we can calculate for the other densities also, for

20 k g per metre cube of density P value is giving 1.412 kilo Newton and L length is 0.3 metre and b is 0.05 metre. So, tau max will be equal to 1.412 divided by 0.3 into 0.05, will give 94.37 kilo Pascal.

So, shear stress strain gamma of the geofoam material also can be determined that gamma is equal to u by t, where u is equal to deformation at peak shear load, that is in millimetre, t is the thickness of the core that is in millimetre. So, this gamma value here having that 4.67 millimetre, this divided by thickness of the core in millimetre is this is 2.5. So, this will give 25 so this will give you 0.1868 millimetre per millimetre. So, this is the shear strength of the geofoam material. Now, core shear modulus that is capital G of the geofoam material.

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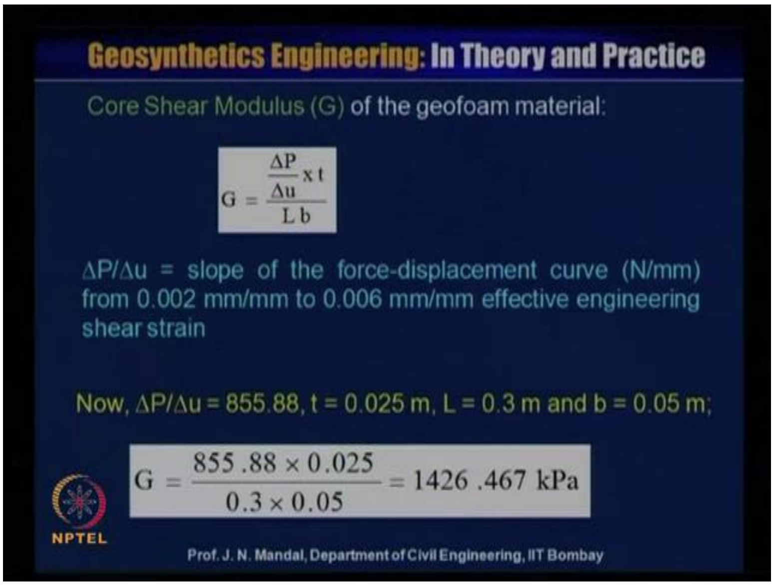

So, G is equal to delta P by delta u into t divided by L into b, where delta P by delta u is equal to slope of the force displacement curve. That is newton per millimetre, from 0.002 millimetre per millimetre to 0.006 millimetre per millimetre effective engineering shear strain. Now, delta P by delta u, you can obtain 855.88 and t is equal to 0.025 metre, L is 0.3 metre and b is 0.05 metre. You know the size of the sample length width and breadth.

So, from this you can calculate what will be the shear modulus G. So, G will be equal to delta P b delta u is 855.88 into the t is 0.025, this divided by L is equal to 0.3 metre into that b, b is equal to 0.05 metre. So, this will give G value; that means shear modulus value of geofoam is 1426.46 kilo Pascal. So, here is the shear strength test result for density of the EPS geofoam.

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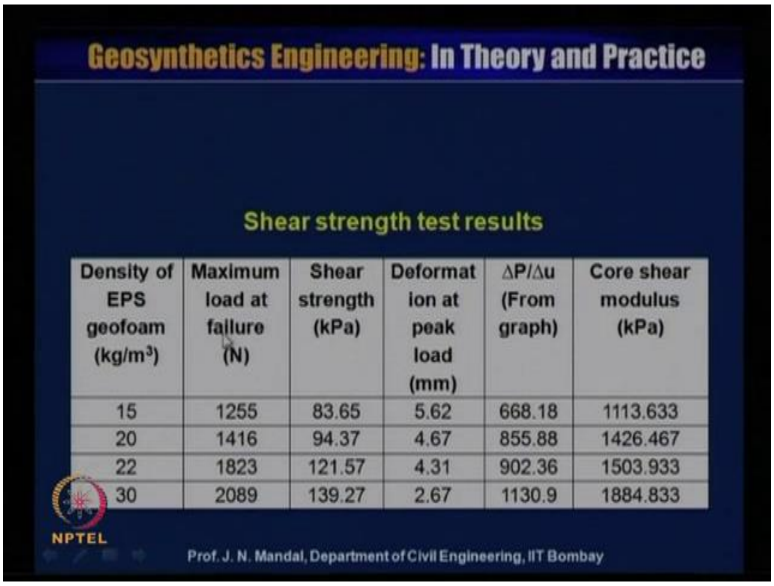

Density of EPS geofoam (kg/m³)	Maximum load at failure (N)	Shear strength (kPa)	Deformation at peak load (mm)	ΔP/Δu (From graph)	Core shear modulus (kPa)
15	1255	83.65	5.62	668.18	1113.633
20	1416	94.37	4.67	855.88	1426.467
22	1823	121.57	4.31	902.36	1503.933
30	2089	139.27	2.67	1130.9	1884.833

Then the maximum load at failure, what is the shear strength in kilo Pascal, deformation at peak load is millimetre delta P by delta u, which you can obtain from the graph. Core shear modulus in kilo Pascal, when density of EPS geofoam is 15 k g per metre cube. Maximum load at failure 1255 Newton, shear strength 83.65 kilo Pascal, deformation at peak load is 5.62 millimetre. Delta P by delta u is 668.18, which you can obtain from the graph and the core shear modulus is 1113.633 kilo Pascal.

When the density of the EPS geofoam is 20 k g per metre cube, maximum load at failure 1416 Newton, shear strength is 94.37 kilo Pascal, deformation at peak load is 4.67 millimetre and delta P by delta u is equal to 855.88. Core shear modulus value 1426.467 kilo Pascal, when density of the EPS geofoam 22 k g per metre cube, the maximum load at failure 1823 Newton, shear strength value is 121.57 kilo Pascal. And deformation on peak load 4.31 millimetre and delta P by delta u is 92.36 and core shear modulus 153.933 kilo Pascal.

When the density of the EPS geofoam is 30 k g per metre cube, the maximum load at failure 2089 Newton, the shear strength value 139.27 kilo Pascal, deformation at peak load 2.67 and delta P by delta u 1130.9 and core shear modulus 1884.833 kilo Pascal.

You can see from this table that shear strength value is lying between 83.65 to 139.27 that means density is increasing, this shear strength value also are increasing.

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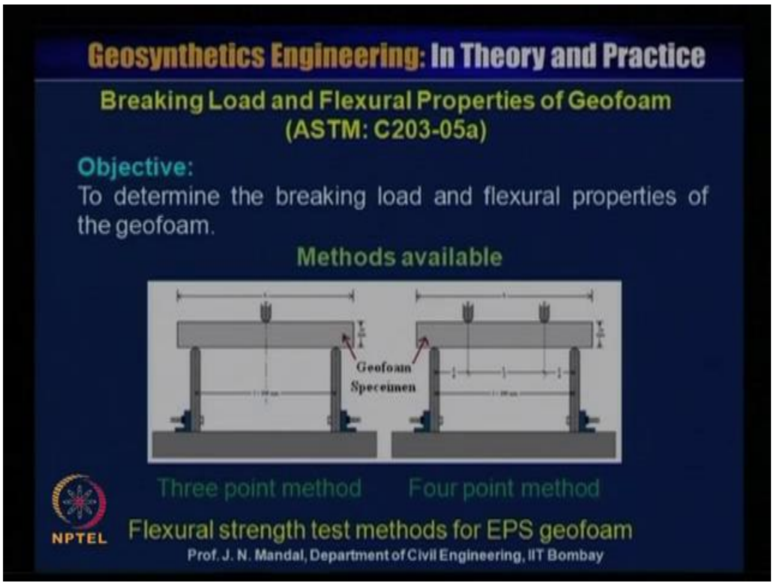

Now, breaking load and flexural properties of the geofoam as per ASTM C203-05a. Now, objective of this test to determine the breaking load and the flexural properties of the geofoam, this is also very important parameter. So, this method available is the 3 point method and the 4 point method. Here you can see this is the 3 point method and this is the 4 point method here. So, this is the beam and whose dimension also is given, you can perform the test that flexural strength test. Then you can calculate what will be the flexural strength of the geofoam material.

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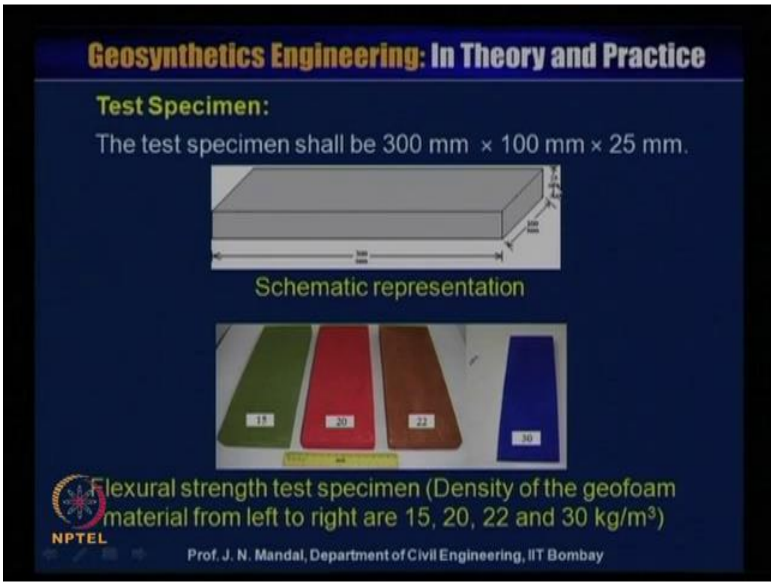

So, here is the test specimen, this test specimen that size is about 300 millimetre. This is the 100 millimetre and this is the 25 millimetre. This is the flexural strength test specimen of density of the geofoam material, this is 15 k g per metre cube, this is 20 k g per metre cube, this is 22 k g per metre cube and this is 30 k g per metre cube. So, these are the different densities of the expanded polystyrene geofoam material. Now, this is the flexural test assembly has been developed and fabricated in our laboratory.

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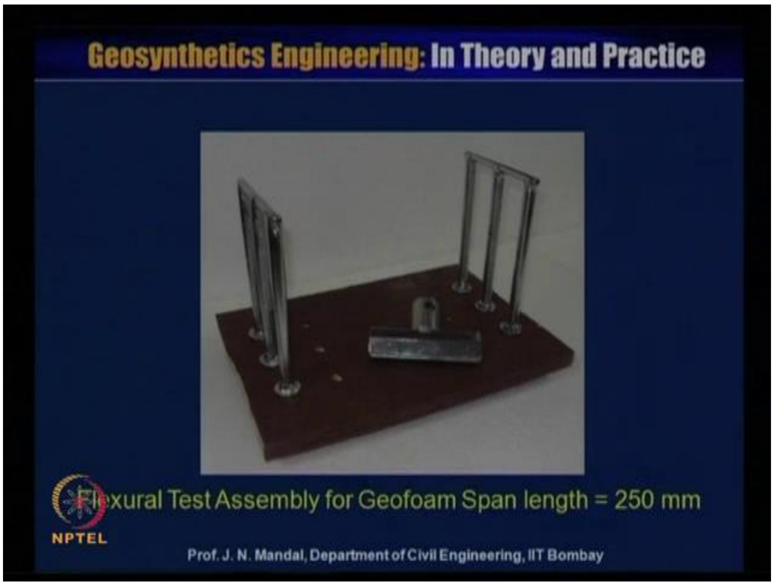

So, this is the flexural test assembly of geofoam span length is 250 whereas, there you can see that geofoam specimen sample is 300 millimetre. So, that 300 millimetre also can be rest on this assembly.

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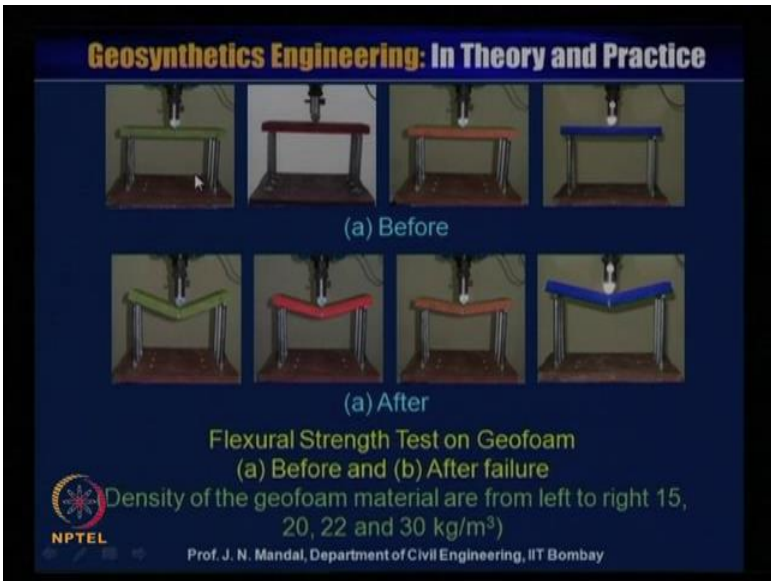

You can see that different type of densities of the material before the test. So, this is flexural strength test on the geofoam, this is the before the test. Then you can look that after the test, this is for density is 15 k g per metre cube, this is 20 k g per metre cube and this is 22 k g per metre cube and this is 32 k g per metre cube. This is like a bending you can see and this all are typical nature of the failure of expanded polystyrene geofoam material, during the flexural test.

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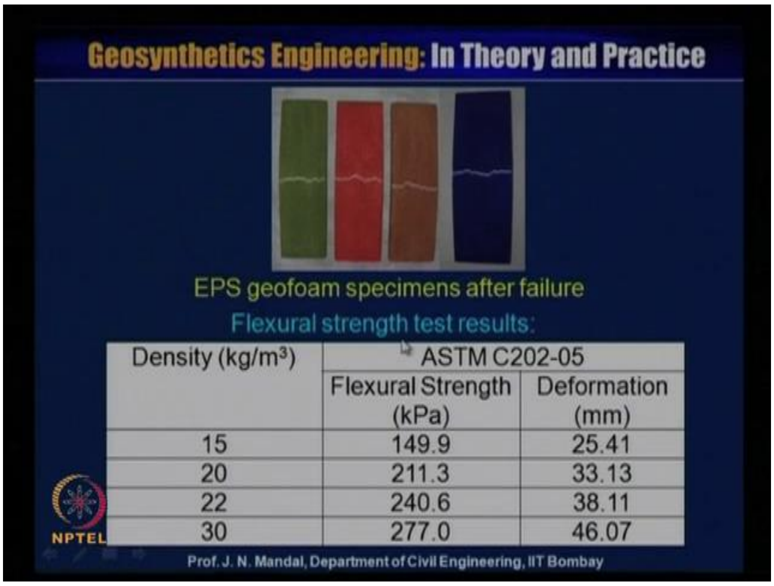

So, here we can also observe the EPS geofoam specimen after failure. Very typical failure of the expanded polystyrene geofoam for different density. Now, here is the flexural strength test result, when the density of the EPS geofoam with 15 k g per metre cube this is as per ASTM C202-05. So, flexural strength value 149.9 kilo Pascal and deformation is 25.41 millimetre, when the density is 20 k g per metre cube, the flexural strength 211.3 kilo Pascal and deformation is 303.13 millimetre. When density is 22 k g per metre cube the flexural strength 240.6 kilo Pascal and deformation is 38.11 millimetre. When the density is 30 k g per metre cube, flexural strength 277 kilo Pascal and deformation 46.07.

So, from this table also it has been observed that the flexural strength also are increasing with increasing the density. So, it lies between 149.9 to 277 kilo Pascal, also deformation also equally are increasing, with increasing the density of the expanded polystyrene geofoam that lies between 25.41 millimetre to 46.07 millimetre.

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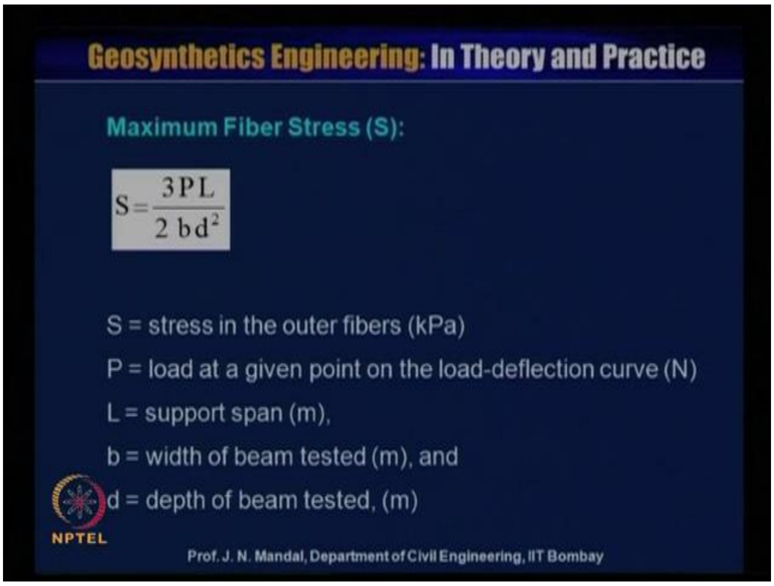

So, maximum fiber stress S can be determined using this equation, S is equal to 3 into P L by 2 b d square. S is equal to stress in the outer fibre that is in kilo Pascal, P is equal to load at given on the load deflection curve in Newton. L is equal to support span in metre and b is equal to width of the beam tested in metre and d is equal to depth of the beam tested in metre.

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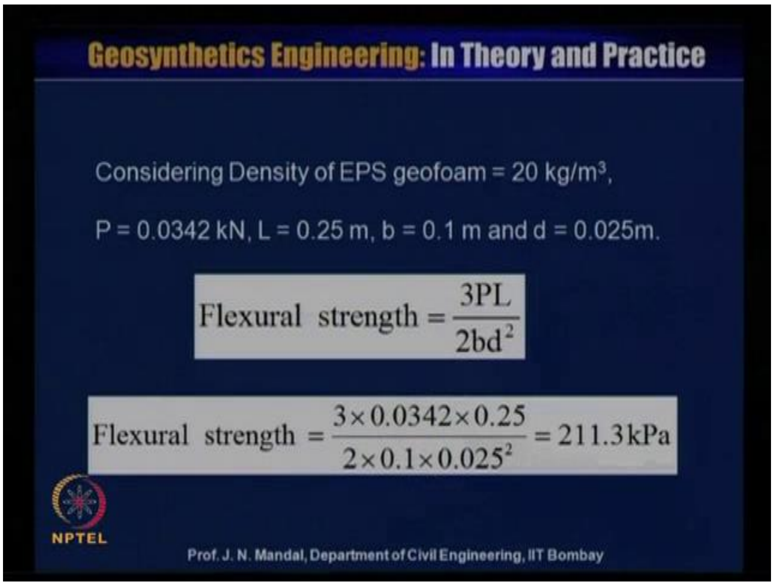

Now, considering the density of the EPS geofoam, 20 k g per metre cube where P is equal to 0.0342 kilo Newton, L is equal to 0.25 metre and b is equal to 0.1 metre and d is equal to 0.025 metre. So, flexural strength can be defined 3 P L divided by 2 b d square. So, flexural strength is equal to 3 into P is 0.0342 this into L, L value is 0.25 this divided by 2 into b value is 0.1 and d value is 0.025 square. So, this will give the flexural strength value 211.3 kilo Pascal, which I have shown you earlier.

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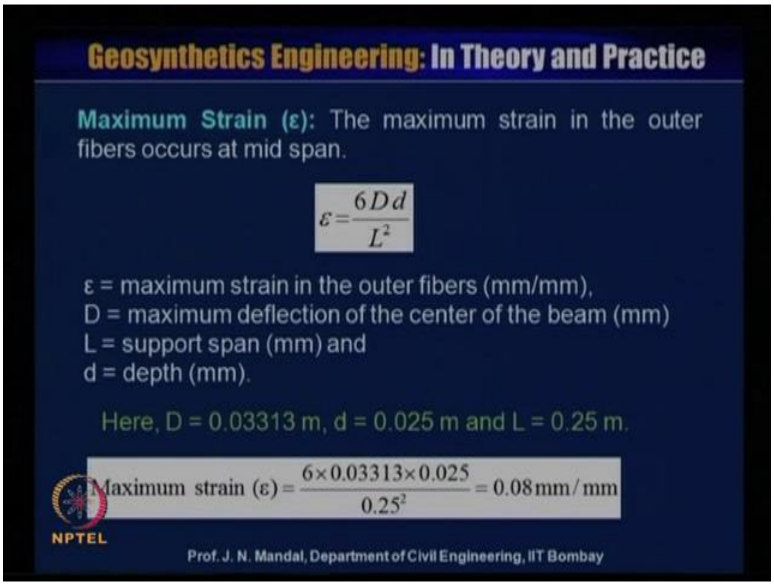

Maximum strain value epsilon, the maximum strain in the outer fiber occur at this mid span. So, epsilon is equal to 6 capital D into small d by L square, where epsilon is equal to maximum strain in the outer fiber, that is millimetre by millimetre and capital D is equal to maximum deflection of the centre of the beam, that is in millimetre and L is support span is millimetre and d is depth is millimetre.

Here D, capital D is equal to 0.03313 metre and small d is equal to 0.025 metre and L is equal to 0.25 metre. Now, maximum strain epsilon can be we can substituted value that 6 into D is 0.03313 into small d. So, this is small d 0.025 this divided by L square 0.25 square. So, this will give the maximum strain value 0.08 millimetre per millimetre.

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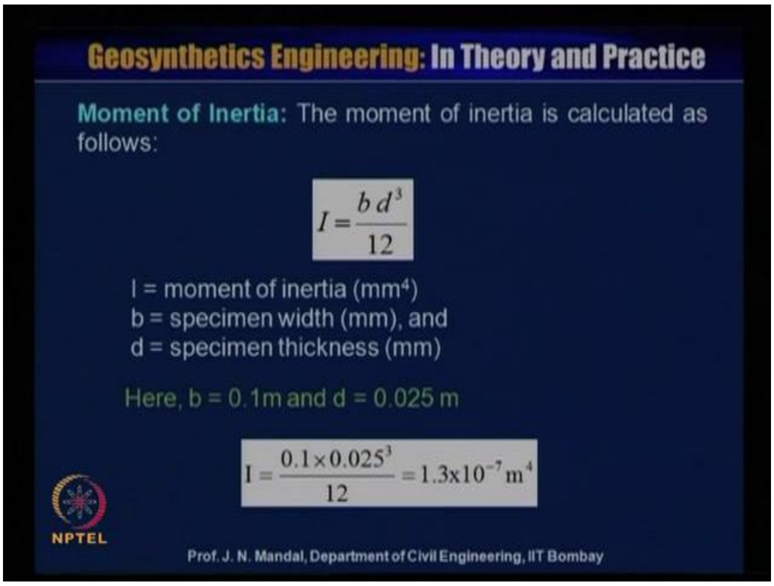

So, you can calculate that what will be the maximum strain, also you can calculate that moment of inertia. The moment of inertia is calculated as follow I is equal to b d to the power cube by 12, where I is equal to moment of inertia that is millimetre to the power 4 and b is equal to specimen width is millimetre and small d is specimen thickness is millimetre.

Here b is given 0.1 metre and d is equal to 0.025 metre. So, I that is moment of inertia will be equal to this is b, b value is 0.1 and this is d, d value is 0.025 to the power cube, this divided by 12 which give the moment of inertia value 1.3 into 10 to the power minus 7 metre to the power 4. So, you can calculate that what will be the moment of inertia of the expanded polystyrene geofoam.

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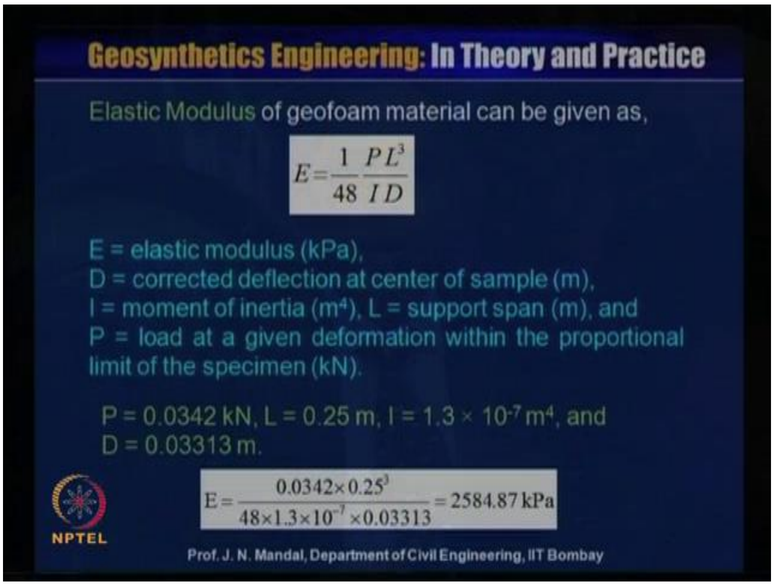

Elastic modulus of the geofoam material can be given as E is equal to 1 by 48 P L to the power cube divided by I into d where e is equal to elastic modulus in kilo Pascal. Capital D is the corrected deflection at centre of the sample is metre, I is equal to moment of inertia metre to the power 4, capital L is equal to support span that is in metre. And P is load at a given deformation within the proportional limit of the specimen that is kilo Newton. Here P is equal to 0.0342 kilo Newton, capital L is equal to 0.25 metre, I is equal to 1.3 into 10 to the power minus 7 metre to the power 4 and capital D is 0.03313 metre.

Now, you substitute this value into this equation E is equal to I, I is equal to 1.3, this is 1 by 48, P is equal to 0.0342 into L, L is 0.25 to the power cube. This divided by 48 into I, this is I, I is equal to 1.3 into 10 to the power minus 7 into D, that is D is equal to 0.03313. So, this will give you that what will be the elastic modulus of the geofoam this is 2584.87 kilo Pascal.

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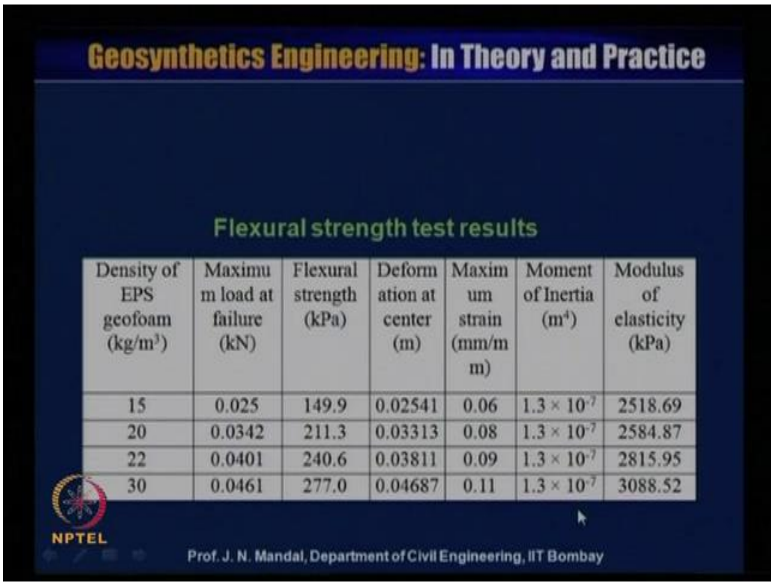

Now, this is the flexural strength test result, that is density of the EPS geofoam. Then maximum load at the failure flexural strength in kilo Pascal, deformation at the centre in metre and maximum strain as millimetre per metre and moment of inertia m to the power 4 and modulus of elasticity in kilo Pascal. When the density of EPS geofoam is 15 k g per metre cube maximum load at failure is 0.025 kilo Newton, flexural strength 149.9 kilo Pascal and the deformation 0.02541 metre. The maximum strain at millimetre per millimetre 0.06 and moment of inertia 1.3 into 10 to the power minus 7 m to the power 4.

Modulus of elasticity 2518.69 kilo Pascal, when density of EPS geofoam 20 k g per metre cube, the maximum load at failure 0.0342 kilo Newton and flexural strength 211.3 kilo Pascal. The deformation at the centre is 0.03313 metre, the maximum strain millimetre per millimetre is 0.08 and the moment of inertia 1.3 into 10 to the power minus 7 m to the power 4 and the modulus of elasticity 2584.87 kilo Pascal, when the density of the EPS geofoam is 22 k g per metre cube, maximum load at failure 0.0401 kilo Newton.

The flexural strength is 240.6 kilo Pascal, deformation at centre is 0.03811 metre and the maximum strain 0.09, the moment of inertia 1.3 into 10 to the power minus 7 metre 4 and modulus of elasticity 2815.95 kilo Pascal. When density of the EPS geofoam is 30 k g per metre cube the maximum load at failure 0.0461 kilo Newton, flexural strength 277.0 kilo Pascal, deformation at centre 0.04687 metre and the maximum strain is 0.11, the moment of inertia 1.3 into 10 to the power minus 7 and modulus of elasticity 3088.52 kilo Pascal.

So, you can have that different values of the maximum load at failure what will be flexural strength, deformation and the strain. Also you can calculate the moment of inertia and modulus of elasticity of expanded polystyrene geofoam material. So, these are the properties these are the data. All these data in the flexural strength is very important to our various problem in geotechnical or civil engineering. So, these are the mainly there are some of the test we have covered in this courses. With this I just finish my lecture today. Please let us hear from you, any question?

Thanks for hearing.