Geosynthetics and ReinForced Soil Structures
Prof. K Rajagopal
Department of Civil Engineering
Indian Institute of Technology, Madras

Lecture - 33
Geosynthetics in Flexible Pavements and Carbon Foot Print Analysis

A very good morning students, in the previous two classes we have seen how to design and construct flexible pavements by using geogrids and geotextiles.

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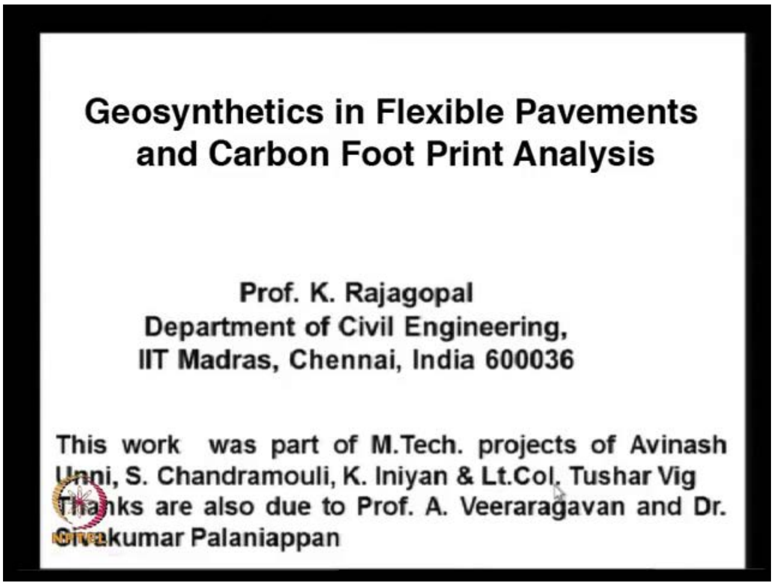

In today's lecture, let us look at how we can utilize the geocell materials for the same construction and also look at carbon footprint analysis and other aspects. I want to acknowledge the contribution made to this lecture as part of their M. Tech projects by several students starting form Avinash Unni, Chandramuoli, Iniyan and Lieutenant Colonel Tushar Vig. I also want to thank my faculty, colleagues Professor Veeraraghavan and Doctor Shivakumar Palaniappan for their contributions.

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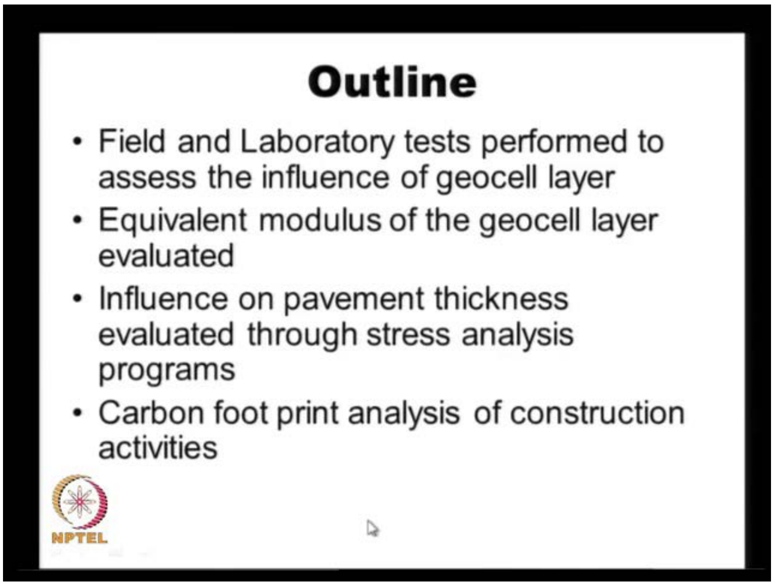

A brief outline, we will go through some field and laboratory tests performed to assess the influence of geocell layer and performance of the pavement. Then we will look at how to determine the equivalent modulus of the geocell reinforced layer. And then its influence on the pavement thickness, and then the carbon footprint analysis towards the end of the topic.

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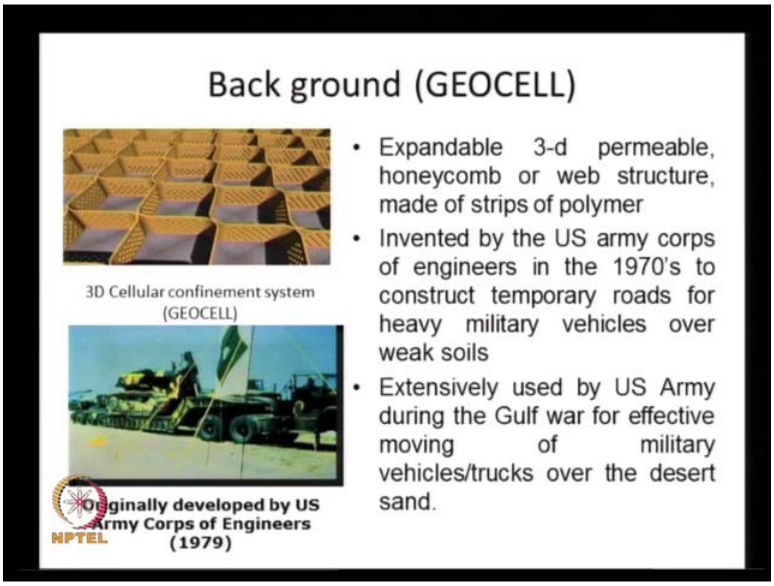

So, just to give a brief outline the geocells, these are three dimensional permeable honeycomb structures made of strips of polymer something like this. These were originally invented by the US army core of engineers in the 1970s, mainly to construct temporary access roads in the forward areas like especially the desert areas, and then in soft clay areas and so on. Here, we see a picture of the US army mobilizing their equipment on geocell reinforced pavements and during the gulf war the US army extensively utilized the geocells for all their construction works. Not only for constructing pavements, we can also build temporary shelters or tank barriers or other structures using the geocells in very innovative manners.

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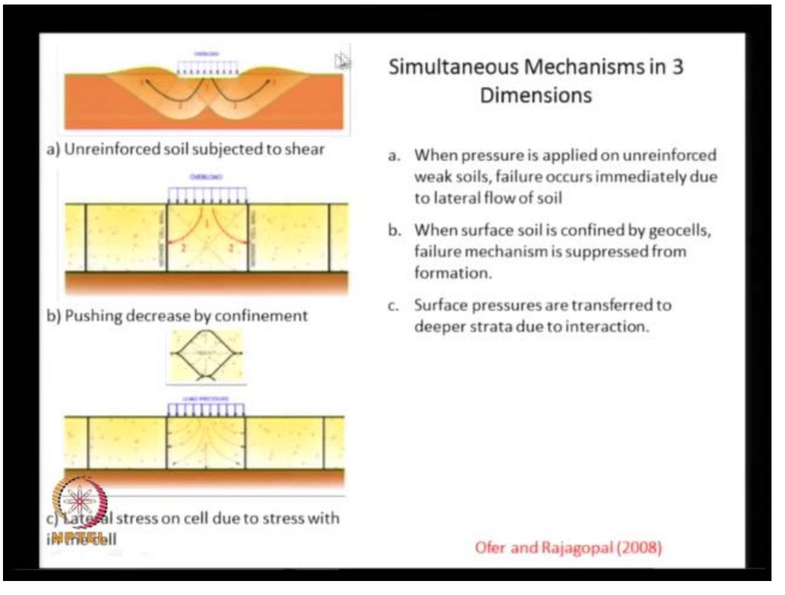

In one of the earlier lectures, we have seen that because of the lack of surface confinement whenever we deal with soft clay soils, loose sands we get immediate bearing capacity failure as illustrated in this in this picture. If we are able to confine the top soil by placing of layer of geocell this is what happens; the soil gets an abstraction from the pockets of the geocell. It will not undergo any failure and also because of the frictional force that is developed on the vertical surfaces of the geocell walls, the pressure that is transmitted into the sub grade soil reduces.

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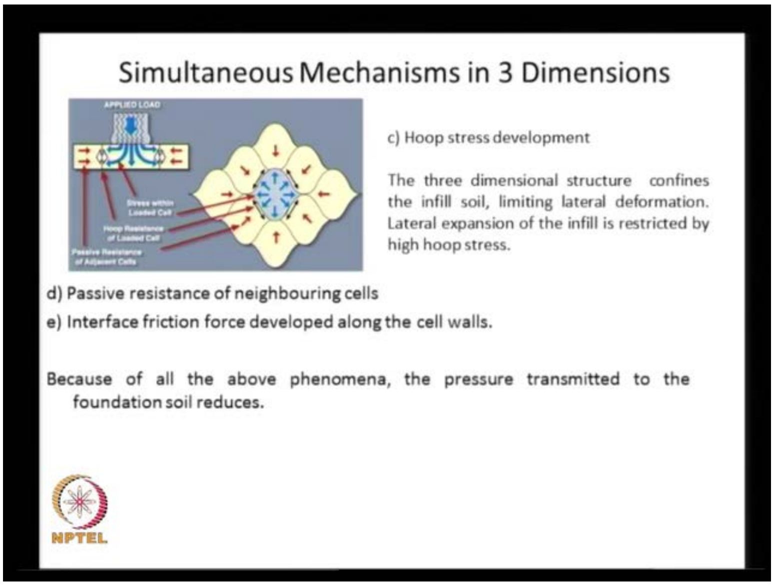

This is the mechanism on how the geocells contribute because of the vertical pressure that we apply, lateral pressure are setup in each of these cell pockets and because of that we induce some membrane stresses in the geocell walls. This in turn increases the confining pressure on the soil and once the confining pressure increases, the granular soils you know that they can their load carrying capacity increases tremendously.

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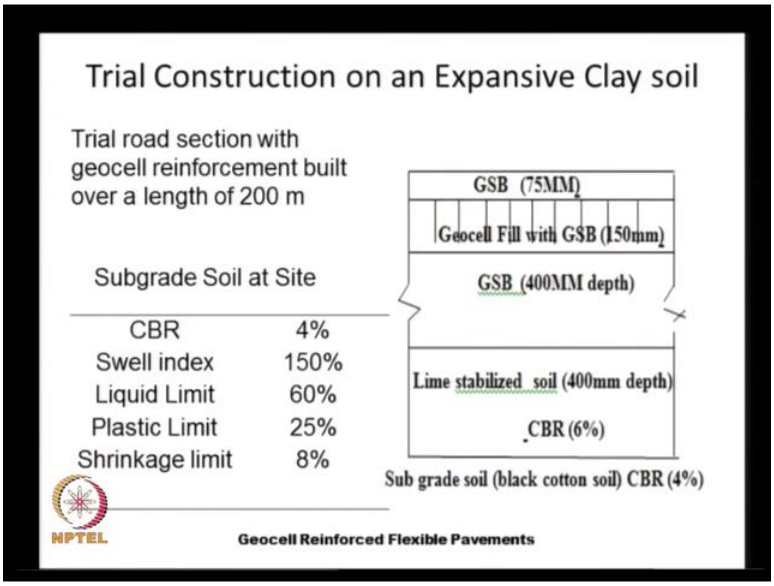

So, in several investigations, several researchers have seen the performance of the geocell layer for construction of flexible pavements, and I will illustrate the effectiveness of the using the geocell through some field work that we have done. This particular trail construction took place in a dairy farm factory very near to Pune and expansive clay, and the trail road section was built using geocell reinforcement, or a length of 200 meters and the sub grade soil.

The CBR value 4 percent and the free swell index is 150 percent, that means that this soil is highly plastic this the proposed cross section is something like this, 400 millimeters thick line stabilized soil that has a CBR value of 6 percent. Then GSB of 400 mm thickness and then finally the geocell layer of 150 millimeters site filled with granular sub base material then topped with 75 millimeters of cover soil, so that we do not directly load on the on the geocell walls.

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The construction procedure is like this: we need to prepare the ground by leveling it and by removing all the tree roots and other abstractions. Then we can stretch the geocell layer on the on the surface on the prepared surface, and then we use a pneumatic staple gun to staple the geocells because these geocells they come in length of about 4 meters wide by 6 meters long. So, our construction length is much longer we need to join the geocells together and then we dump the stone aggregate, and then we can spread them by using spreader like this to fill all the geocell pockets. It is very important that we do not directly run the construction vehicles on the geocell pockets, when they are empty because when they are empty or when there is no confinement they will just simply squished because of the loading that is applied. Then after we give the cover soil that is 75 millimeters thick GSB layer, we can do the normal compaction.

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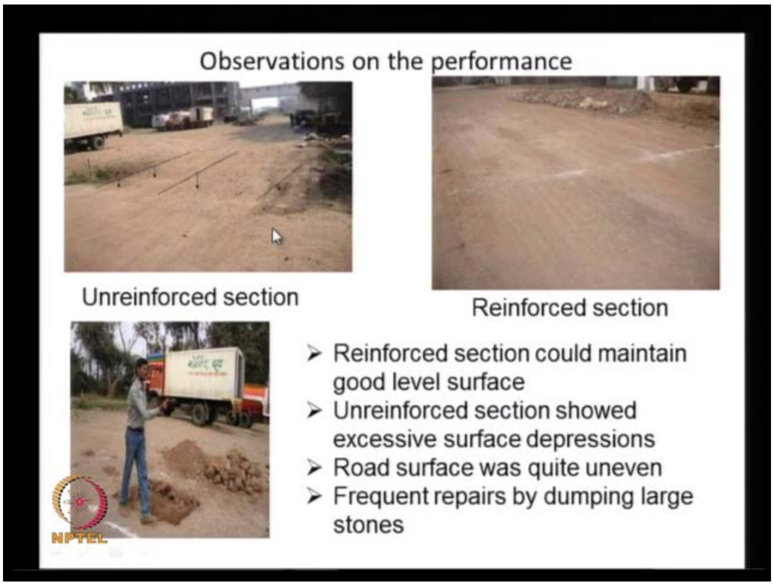

200 meters length of the stretch was reinforced with geocell and the other section it was only stabilized by using a line and it was not given the geocell reinforcement. The performance is quite obvious; see here on the left hand side we see the section without reinforcement. It has undergone lot of angulations and at one particular section, we can see the surface deformations, whereas the reinforced section, it had perfectly flat surface. The geocell is able to act as a semi rigid mat and suppress any swelling potential of the soil. In the unreinforced section, wherever there was a swelling there was just simply the heaving of the soil and some observations on the performance.

The reinforced section could maintain very good level surface, and the unreinforced section showed excessive surface angulations because of the heaving and shrinkage behavior of the clay soil. It required the unreinforced section, it required frequent repairs by dumping of large stones like you surface here, in fact when we did the plate load test we were not able to expose the soil. We had to do the plate load test on the stones because they were dumped so much in such large quantities.

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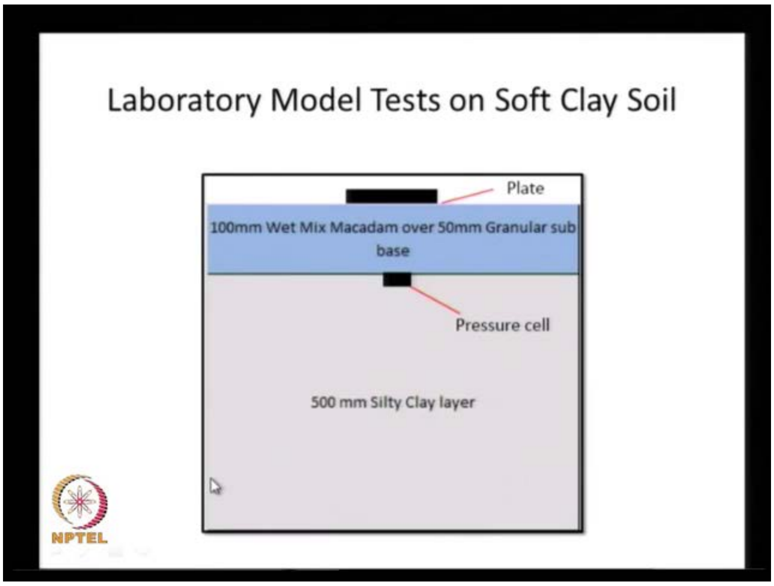

So, this the as part of this investigation work a series of laboratory test were performed to assess the influence of the geocell layer on the load spreading ability, and also how much this geocell layer activation reduce the pressures. Here, we surface the cross section of this schematic of the laboratory setup; there is 500 mm thick silty clay layer, very soft silty clay layer. Then on top of this there was a pressure cell to measure the pressures transmitted through the geocell layer and there is 100 mm thick wet mix macadam. Then we have a 50 mm granular sub base material GSB material on top of the geocell and then loading plate was put in.

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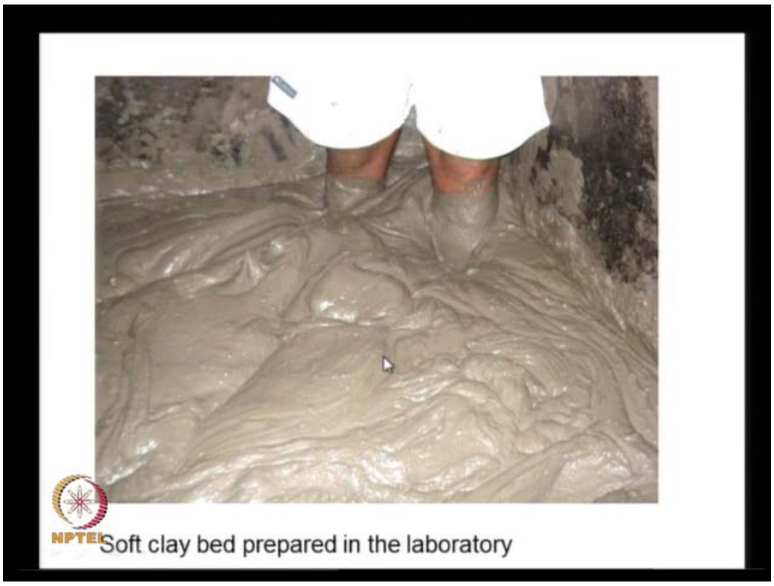

And here, you can see how soft the clay bed was if anybody stands on it just simply sink up to their knees because that is how soft it was. Then on top of this one geotextile separator layer was given and then we constructed the geocell filled with GSB, and then we did the load test.

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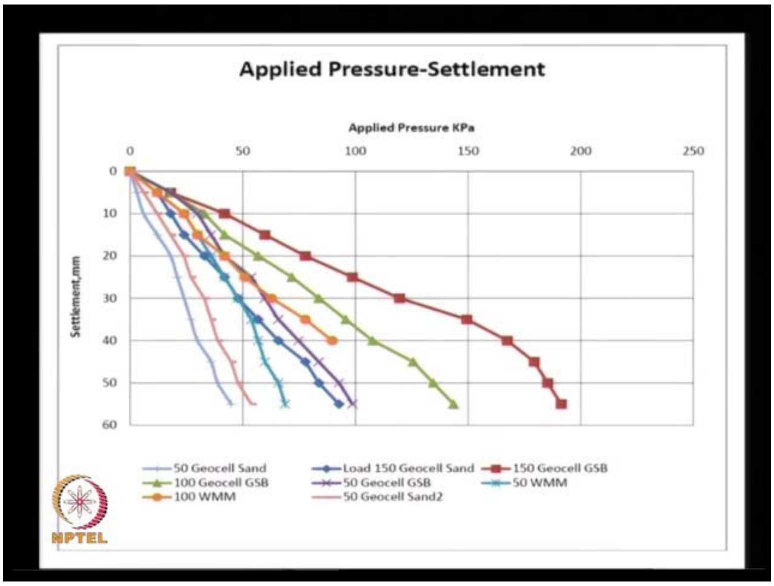

This is the pressure settlement data that we have obtained for different configurations and the x axis we have the up pressure applied. The y axis settlement and this red line shows 150 millimeter thick geocell filled geocell material. It showed very good pressure settlement diagram, whereas at the least side 50 mm thick geocell filled with sand this is the one.

If we had done the testing on the soft clay itself, it would have gone something like this it just cannot be represented to the same scale because the pressure were very small and for different heights of the geocell, we got different response. For example, this this line represents the response that was obtained with 150 millimeters heighted geocell filled with a GSB, and this green line shows the 100 millimeters height geocell filled with GSB. This line shows 100 mm height geocell filled with a WMM and so on.

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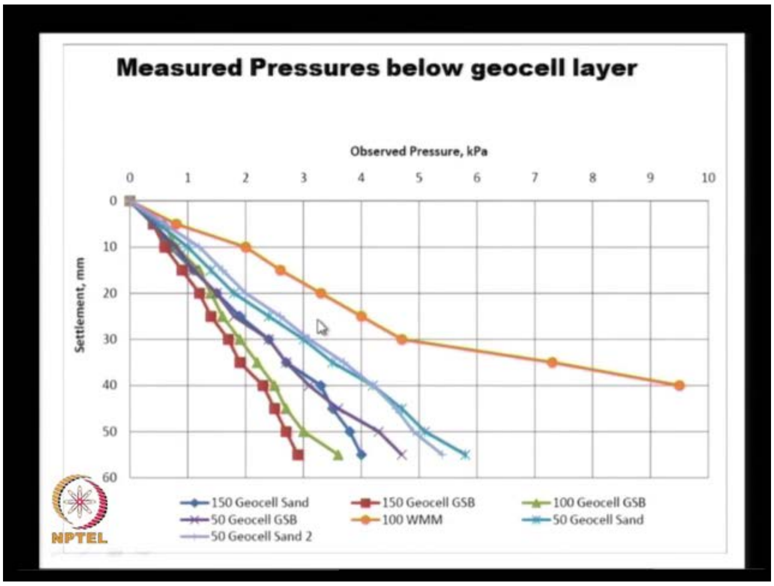

A very interesting data on the on the pressure that were transmitted through the geocell. If we plot these observed or measured pressures at settle at different settlement levels, these are the pressure that was developed below 150 millimeters thick geocell filled with GSB very small pressures. The 100 millimeters thick WMM layer it has shown this type of pressure distribution, whatever pressure is applied on the top surface it was directly transferred into the geocell, and this is this green line is with 100 mm thick geocell filled with GSB.

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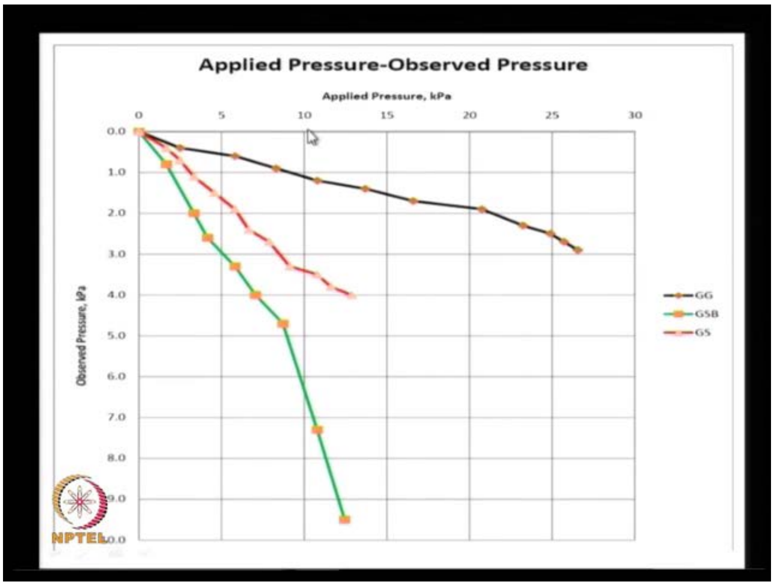

This graph summarizes the relation between the applied pressure and then the measured pressure. This black is for the geocell layer 150 millimeters thick geocell layer filled with GSB is actually even at an applied pressure of 25 kilo Pascals, the measured pressure was about 3 kilo Pascals. The 150 millimeters thick GSB layer alone the pressure applied and the pressure measured were almost similar. For example, at this at this location, the applied pressure is about 13 kilo Pascals whereas; the measured pressure is about 9.5 kilo Pascals. This is the same geocell filled with sand, it had given lower response because the response of this geocell also depends on the infill material that we have. If we have a stronger material, it can give much stronger response.

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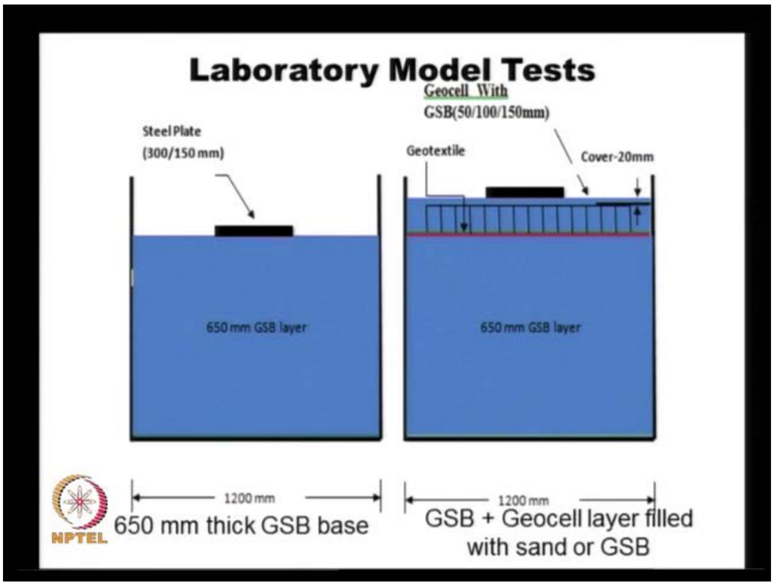

These same tests were continued for a stiffer sub grade material and here another series of test were done with 650 millimeters height GSB layer. This GSB soil or the GSB aggregate was hand packed to give a sub grade CBR of about 6 percent. On top of that the geocell layers were constructed filled with different type of soils either GSB, or sand and then the test were performed.

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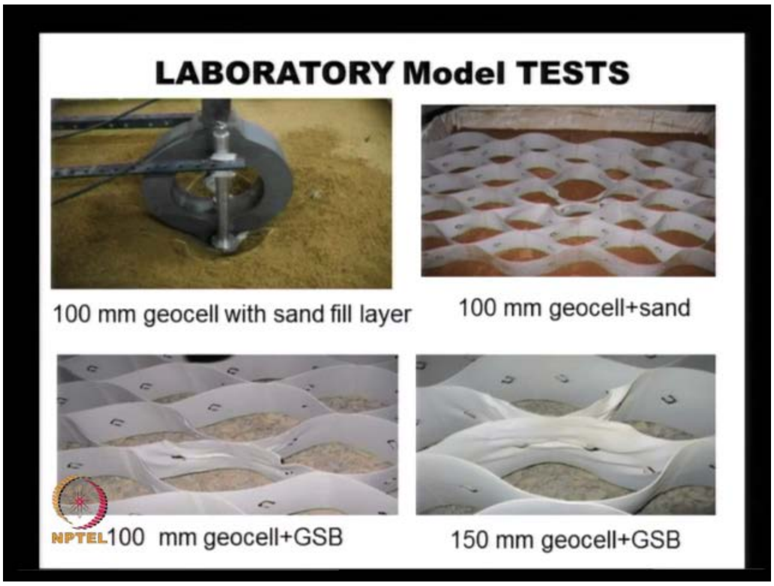

This particular picture shows how the test were performed, this is the proving ring attached to a load cell. These are the damaged geocell layers after the test this is with 100 mm height geocell filled with sand 100 mm GSB with, sorry hundred mm geocell filled with GSB and 150 mm height geocell filled with GSB.

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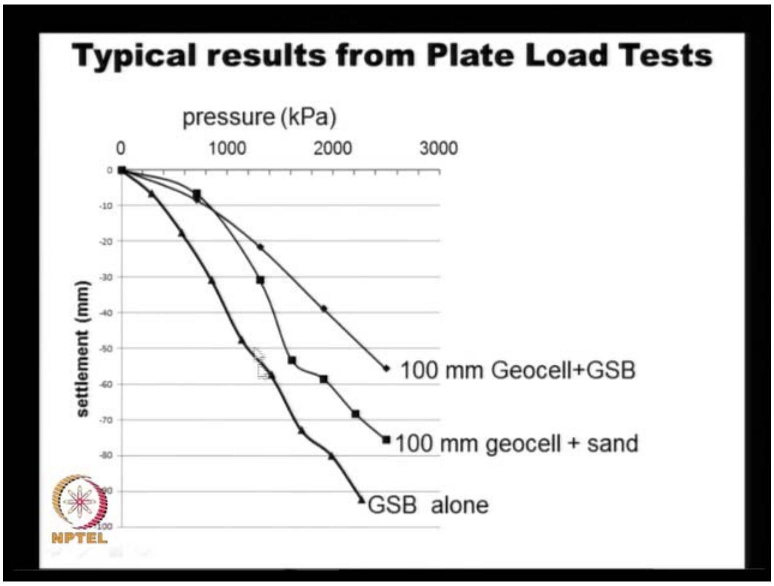

This is the summary plot of typical results, the pressure verses settlement when there is only GSB alone this is the pressure settlement data, and with geocell reinforcement the both the ultimate pressure and also the initial slope they have increased. This particular response is with 100 mm heighted geocell filled with sand, whereas this response is with 100 mm geocell filled with the GSB. In fact there were large series of tests that were performed and I am not showing all the data here, but a summary data shown here.

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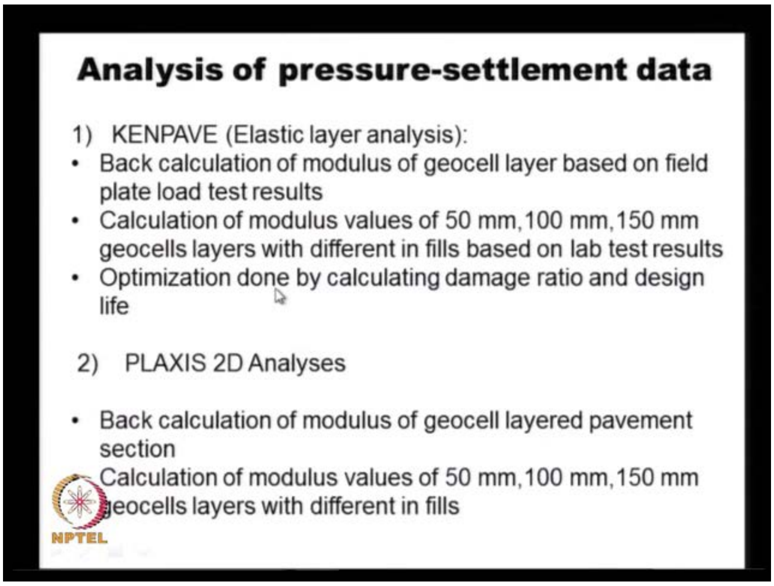

Our interest in all this test is to somehow characterize the equivalent modulus of the geocell reinforced layer that we can use in our design software. The back calculation of the modulus was done through stress analysis. Two different approaches were used one is by using Kenave program, that is the elastic layer analysis, and the other is finite elemental analysis program PLAXIS 2D. The modulus of the geocell layer was back predicted by continuously varying the modulus, and seeing are trying to match the pressure settle settlement diagram.

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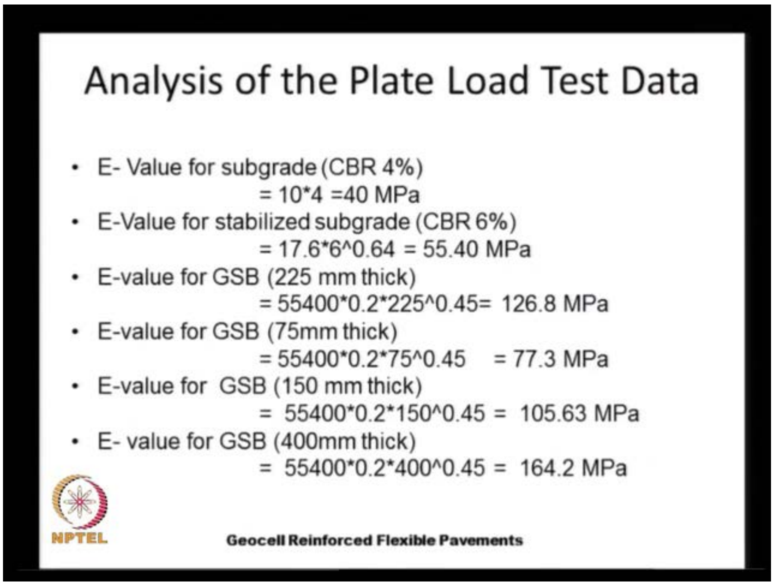

In the IRC code, they give the approximate E values that we can used based on the CBR of different materials, the sub grade CBR and then the stabilized sub grade and GSB and so on. When it comes to the granular base, the modulus is also a function of thickness because if usually the compaction is done in small layers. If you have a thicker layer, it undergoes more number of compactions and because of that the modulus is also a function of the thickness here. For example, the for the GSB, the young’s modulus is given as 55,400 times 0.2 times the height to the power of 0.45, this height is in millimeters.

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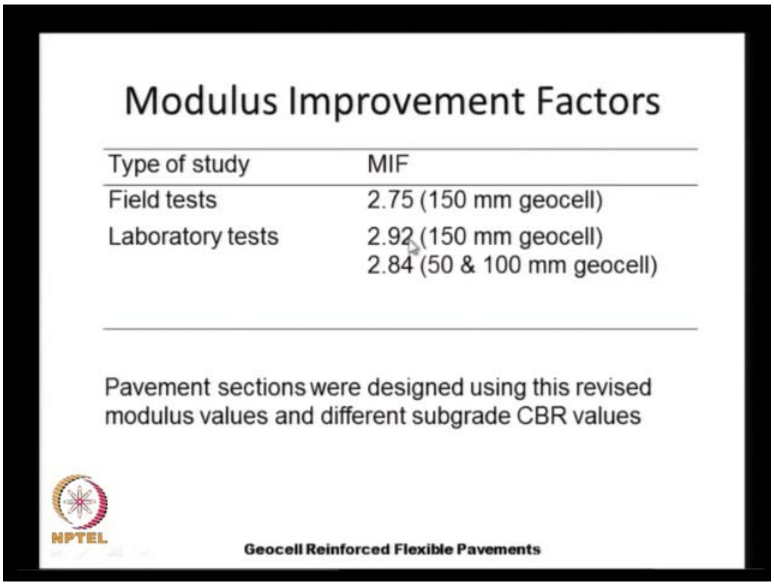

The typical modulus improvement factors that were obtained from the field test data is 2.75 for 150 millimeters geocell filled with GSB material. The laboratory test is in the same range 2.92 for 150 millimeter geocell and 2.84 for lower height geocells 50 and 100 mm geocells. We can utilize this data in our design software that is by using Circley and come out with some pavement sections.

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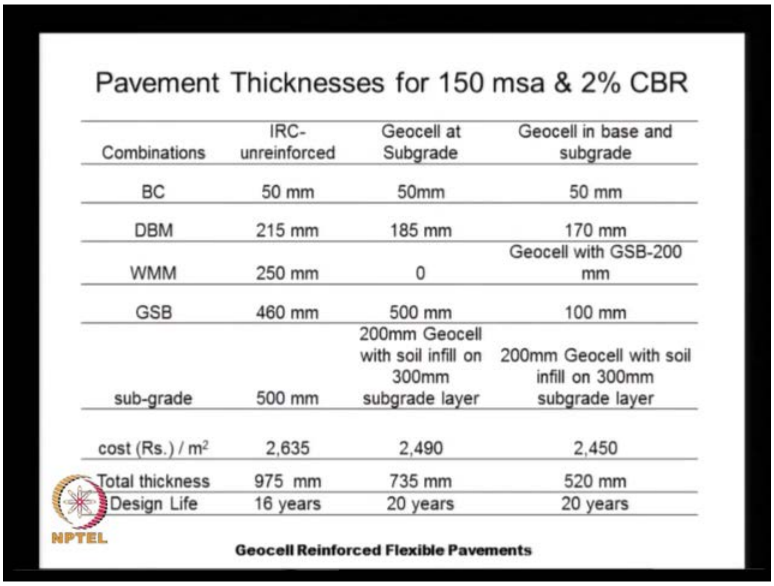
Pavement Thicknesses for 150 msa & 2% CBR

Combinations	IRC-unreinforced	Geocell at Subgrade	Geocell in base and subgrade
BC	50 mm	50mm	50 mm
DBM	215 mm	185 mm	170 mm
WMM	250 mm	0	Geocell with GSB-200 mm
GSB	460 mm	500 mm	100 mm
sub-grade	500 mm	200mm Geocell with soil infill on 300mm subgrade layer	200mm Geocell with soil infill on 300mm subgrade layer
cost (Rs.) / m^2	2,635	2,490	2,450
Total thickness	975 mm	735 mm	520 mm
Design Life	16 years	20 years	20 years

Here, you see a typical design for 150 million standard axes and 2 percent sub grade CBR. In the first column, we have the standard section, that is as per the IRC 37 code book. It says that bitumen concrete BC or the varying course 50 mm thick and the dense bitumen macadam 215 millimeters and wet mix macadam 250 mm GSB 460 and then sub grade 500. The approximate cost of this based on the prevailing rates is 2635 and the total thickness of this pavement is 975 millimeters. It has a design life of 16 years is actually all these programs, the design software.

They look at the repeated load applications say for example, we design the pavement for one fifty million standard axel passes, and we measure the tensile strength that are developed in the pavement section. Once the tensile strain exceeds the certain limits, we say that the pavement has failed and if we do that analysis, the reinforced section has a design life of 16 years and the geocell provided at sub grade level gives some other design.

Once again, the BC layer is 50 mm thick and the dense bitumen macadam 185 millimeters thick. We can get rid of the WMM layer and the GSB 500 mm and the sub grade two 200 mm geocell with soil infill and 300 mm sub grade layer and the total cost comes to 2490 and the total thickness, so is only 735 millimeters and the design life is 20 years. If we use two layers of geocell one at the sub grade one at a higher elevation the section looks something like this the BC layer 50 mm and the DBM 170 millimeters, and the WMM layer. In place of WMM, it is the geocell layer is placed filled with GSB material and the GSB thickness.

Now, it is reduced to 100 mm and the sub grade soil is prepared with 300 mm sub grade layer compacted layer with 200 mm geocell filled with soil. On top of this, 300 mm thick prepared layer and the total cost comes to 2450 and it total thickness is 520 millimeters and once again and the design life is 20 years. So, actually this design illustrate how much cost saving can be achieved by using geocell in spite of spending extra money on the geocell material we can achieve this cost saving.

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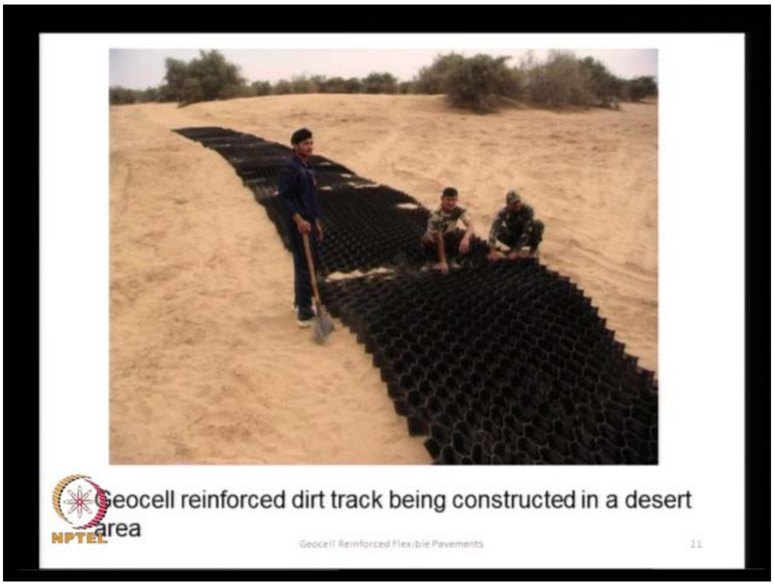

In this picture, you surface a trail section that was built in Rajasthan desert using the geocells cause the how to drive the tired vehicles in the sand is always a challenge. We need a tracked vehicle to move freely, but then unfortunately most of the trucks and other vehicles they run on the wheels, and one of the students he has done some trials on construction of axes roads through the deserts using geocells.

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Here, we see the construction of this the section by after spreading the geocell layer. We can just simply fill it with soil and here you can see these army vehicles ready for rolling on them, and here we see a bucket executor that was used to fill the soil.

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The observation is that the geocell reinforced track bed it was very easy to construct. It was quite expedient and then they were able to run their vehicles, the army vehicles without any distress, or without any difficulty and that shows the versatility of this geocells because these geocells they come in collapsed form. They can be easily carried to the site, expanded and then filled with the soil and then it that provides a good base for any type of vehicles to move over.

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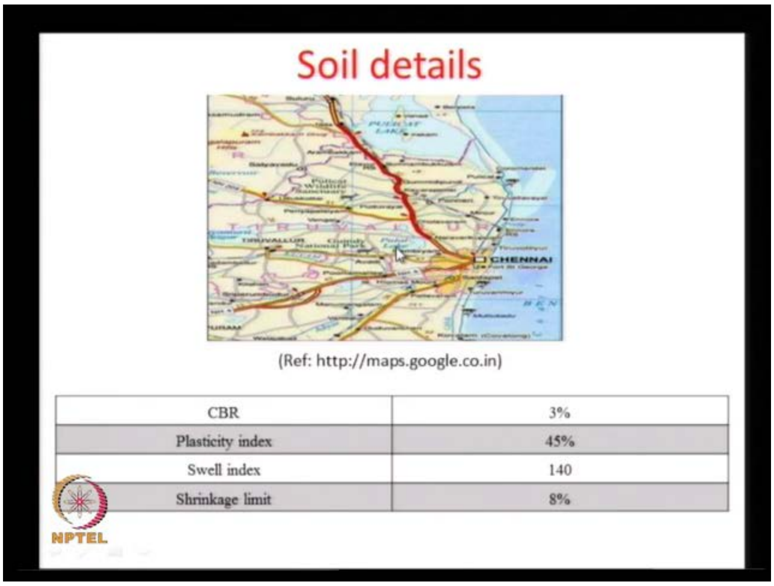

Here, I will show you some cost benefit analysis for using the geosynthetics and especially in terms of the carbon footprint analysis. This particular work was done for the highway that is being constructed between Chennai and Tada, just north of Chennai. The sub grade CBR is 3 percent plasticity index is 45 percent swell index is 140. It is a highly swelling type of soil and the google map picture is something like this.

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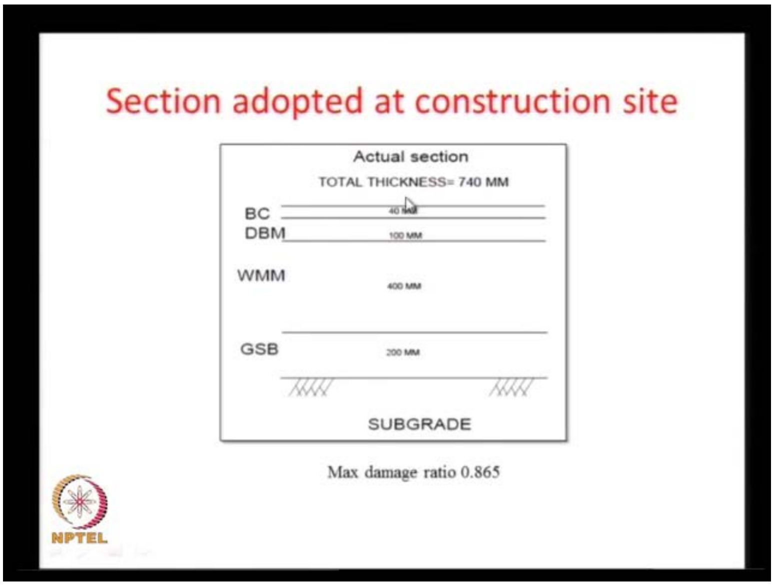

If you use the IRC code book, this is the thickness that we can have for a sub grade CBR of 3 percent. The total thickness of the pavement comes to 740 millimeters. Out of that BC layer is 40 mm, DBM 100 mm, WMM for 400 mm, GSB 200 mm and the damage ratio at the end of the design life is 0.6865.

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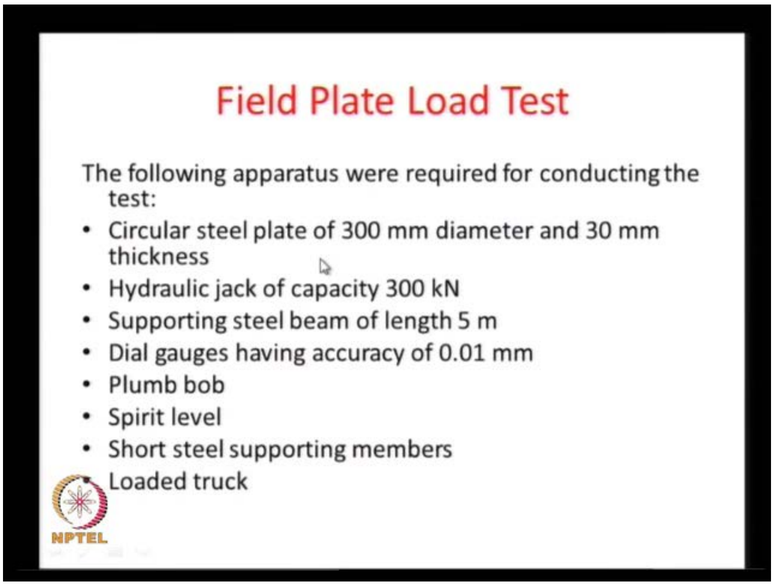

Very large number of plate load test and other test were done at this site by placing two types of geogrid materials.

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Here, we see one trail section being constructed we prepare the bed and then this was the test setup for doing the plate load test.

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These are the pictures that were taken during the plate load test, the load was applied by taking reactions against the back axel of a loaded truck.

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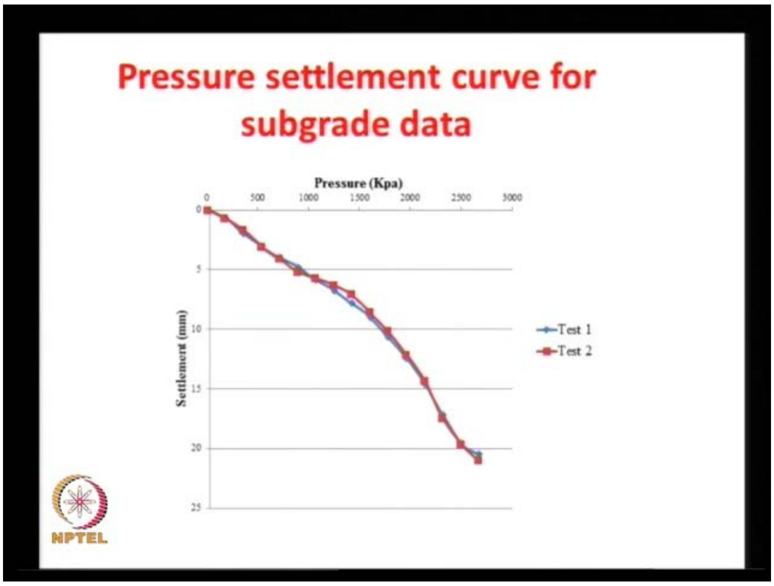

This is the typical pressure settlement data form test on the sub grade sub grade of the soil. And there were two tests done and both of them are almost identical that shows the quantity of the test data that is obtained.

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Here, we surface the track bed being prepared.

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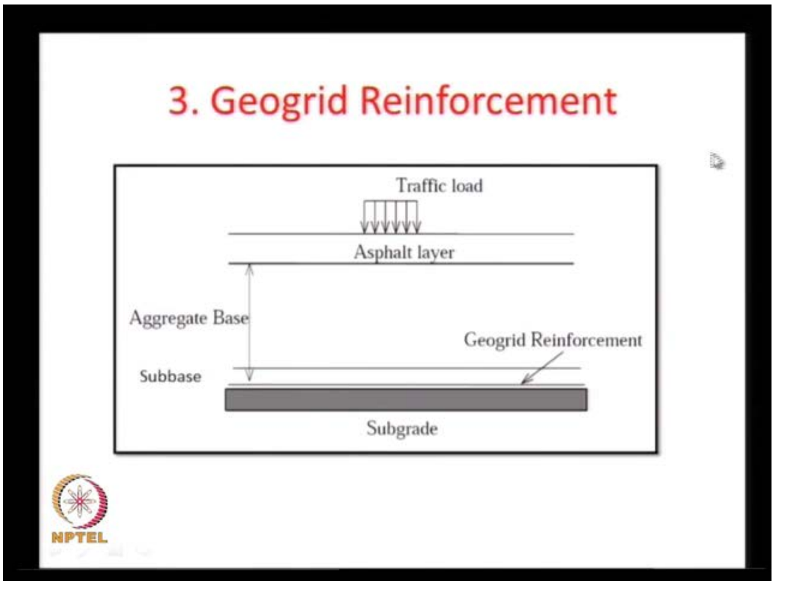

The same construction was performed by placing a geogrid layer and then compacting the aggregate on top this geogrid layer.

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The two trail sections were done with two different types of geogrid layers, one is a relatively stiff layer and the other is a relatively soft layer.

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The normal compaction after we spread the aggregate, we can do the compaction just as how we do it in normal constructions.

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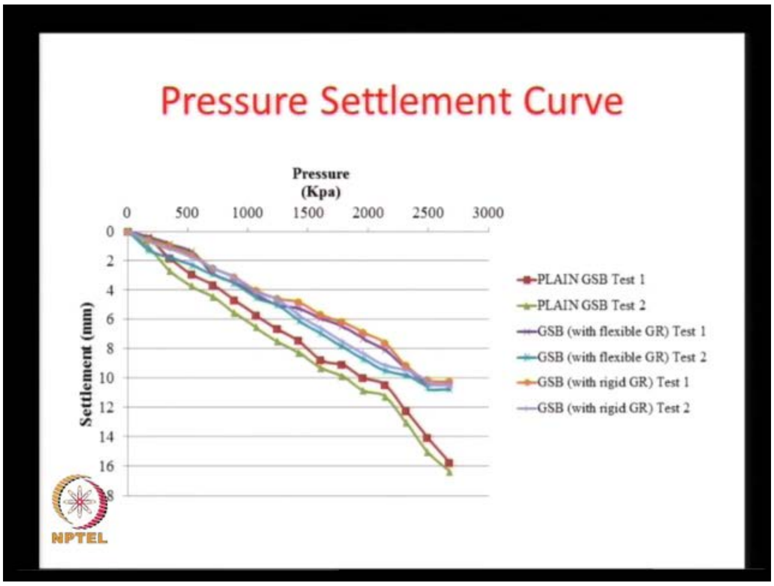

This is a comparison of the different pressure settlements the graphs that were obtained. These two lines, they represent the pressure settlement data performed on unreinforced soil that is only on the on the GSB layer. These two lines, these two blue lines they show the response with flexible type geogrid and these two graphs, they show the response with a stiffer type of geosynthetic.

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We have also done number of field density test to see how much density, we can achieve when we reinforced the sub grade with the geogrid layer.

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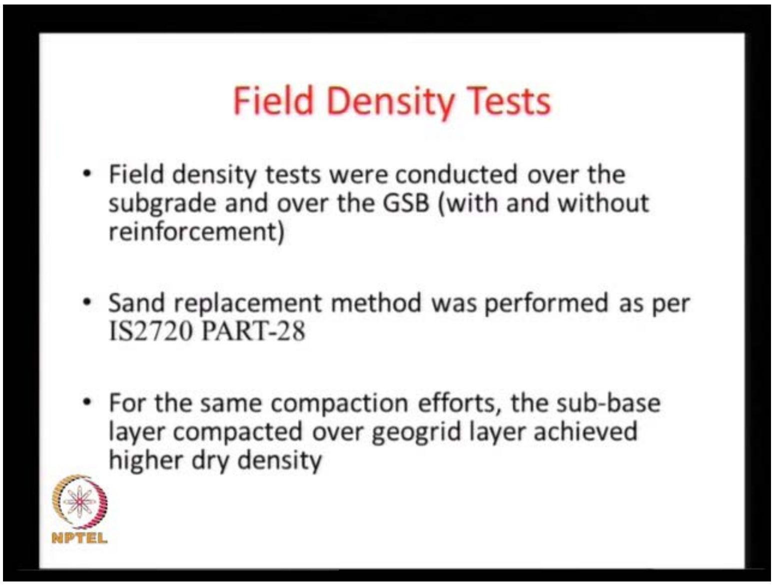

Quite interesting observations were obtained; it was found that the density that we could achieve in the GSB layer was much higher, when the sub grade was reinforced with geogrid layer for similar compaction energy.

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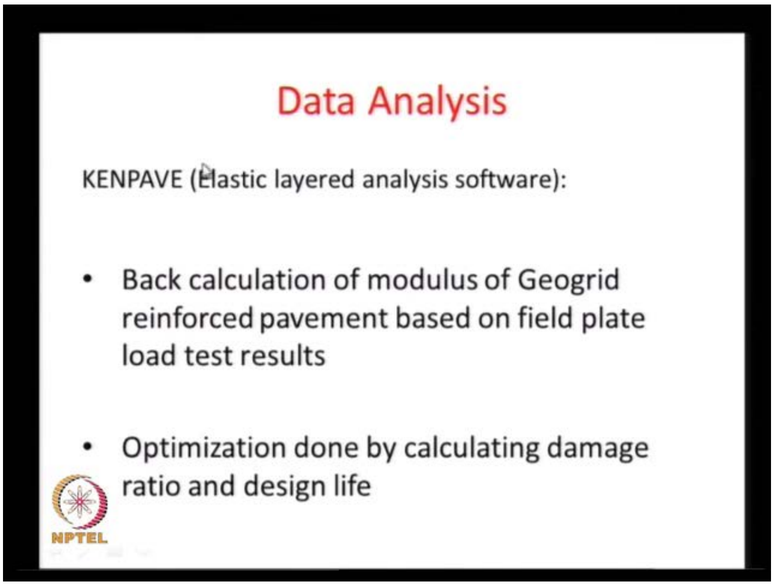

The pressure settlement data that was obtained from plate load test was back analyzed to calculate, the modulus of the geogrid reinforced pavement. And this is how it was done, like the input for this program the Kenpave is like this.

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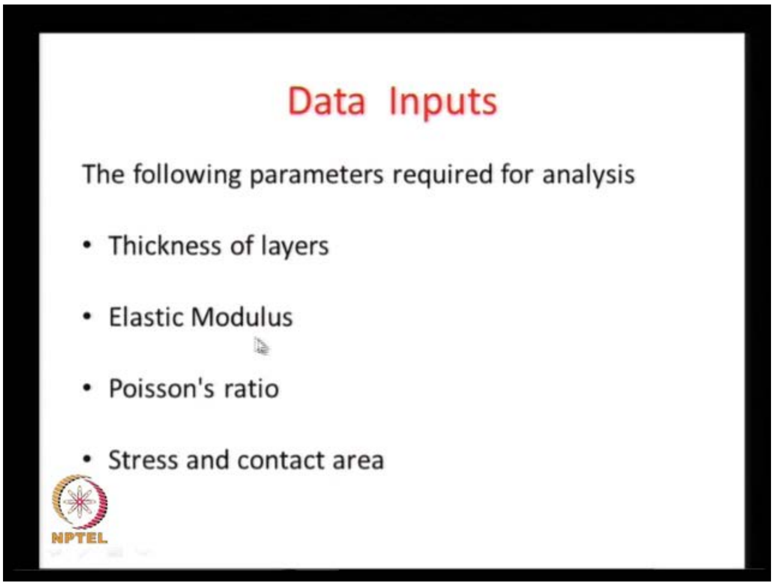

It requires the thickness of the different layers and the elastic modulus of different layers. And then the Poisson's ratio and then stress and the contact area.

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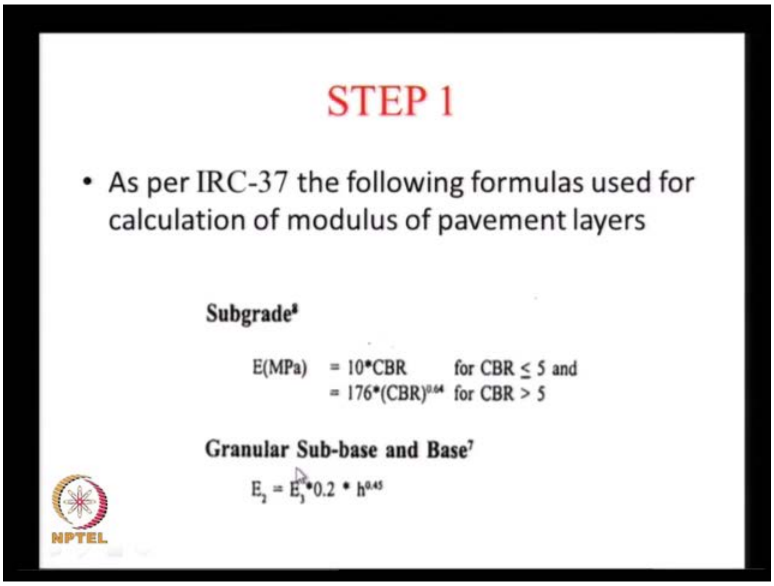

As per the IRC 37, we can get the modulus as a function of this CBR for most of the unreinforced soil and similar correlations were utilized.

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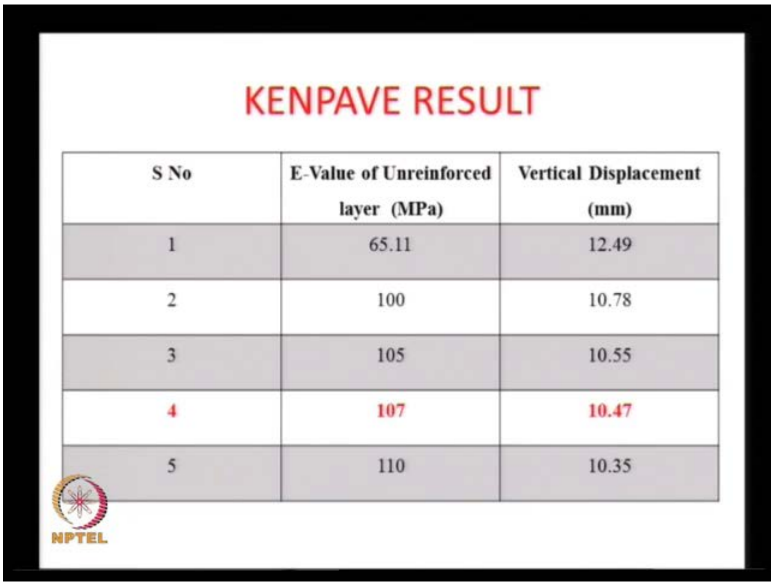

S No	E-Value of Unreinforced layer (MPa)	Vertical Displacement (mm)
1	65.11	12.49
2	100	10.78
3	105	10.55
4	107	10.47
5	110	10.35

Then, the only uncertainty is what should be the modulus for the geogrid reinforced GSB layer and the settlement at a pressure of I think.

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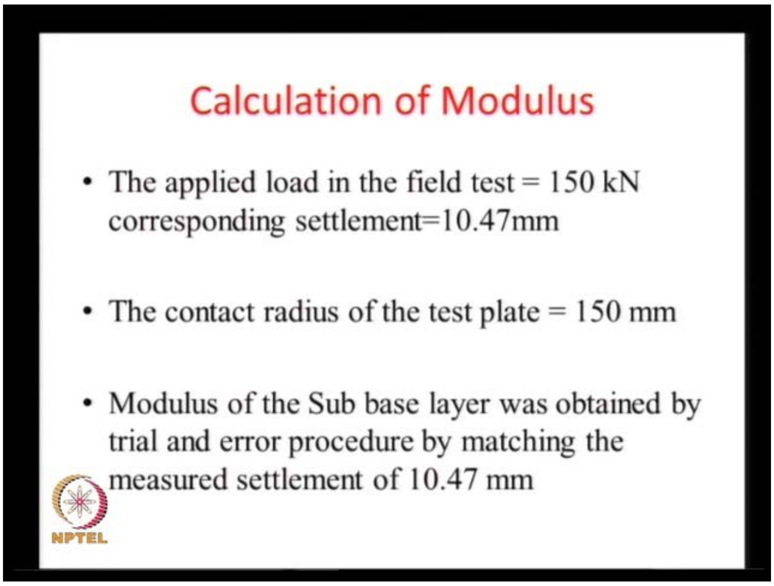

At a vertical loading of 150 kilo Newtons was achieved at obtained as 10.47 and then the similar result was obtained by varying the Young's Modulus of the unreinforced soil layer. The different trials were performed, see here when we use an E value of 65, the vertical settlement was 12.5 and when it was gradually increased at 107, the vertical settlement is 10.47. So, this is value corresponding to the to the unreinforced soil layer.

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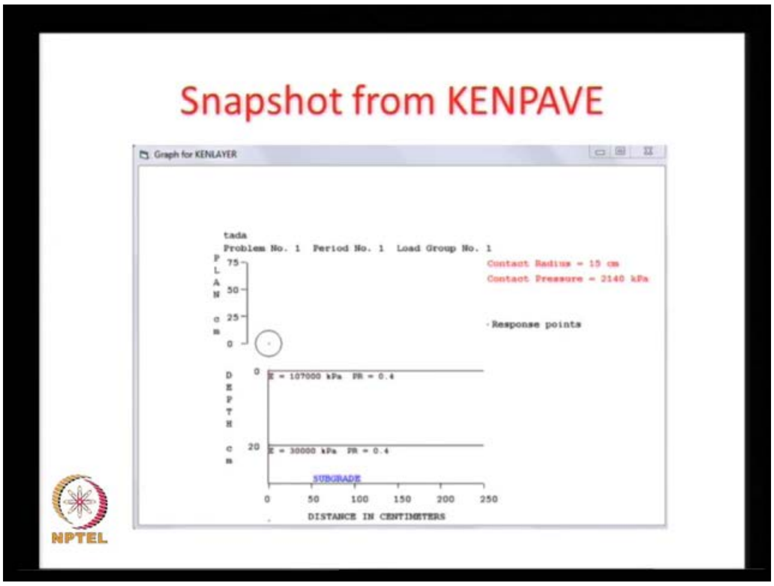

Similarly, we can do the analysis for reinforced sub bases these are the different snap shot from the Kenpave program.

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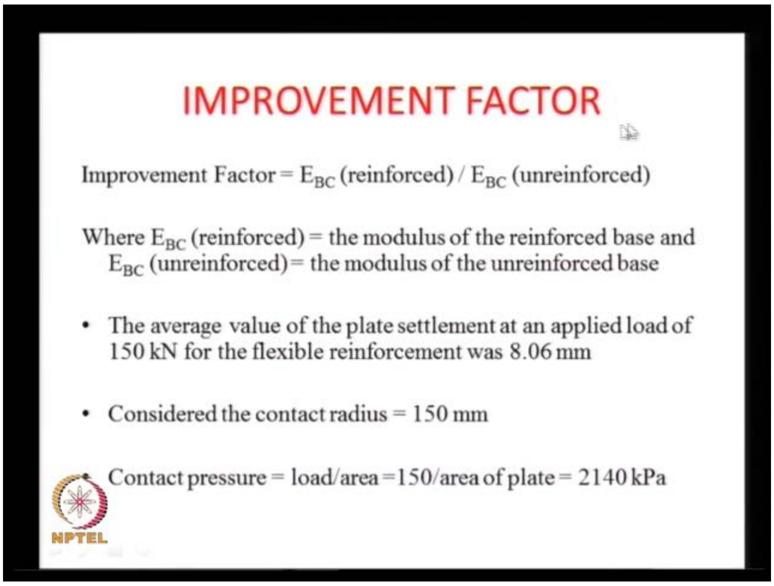

The improvement factor was defined as the Young's Modulus of the reinforced soil divided by the Young's Modulus of the unreinforced soil. For the same load of 160 kilo Newton's, the vertical settlement measured with flexible reinforcement was 8.06 millimeters.

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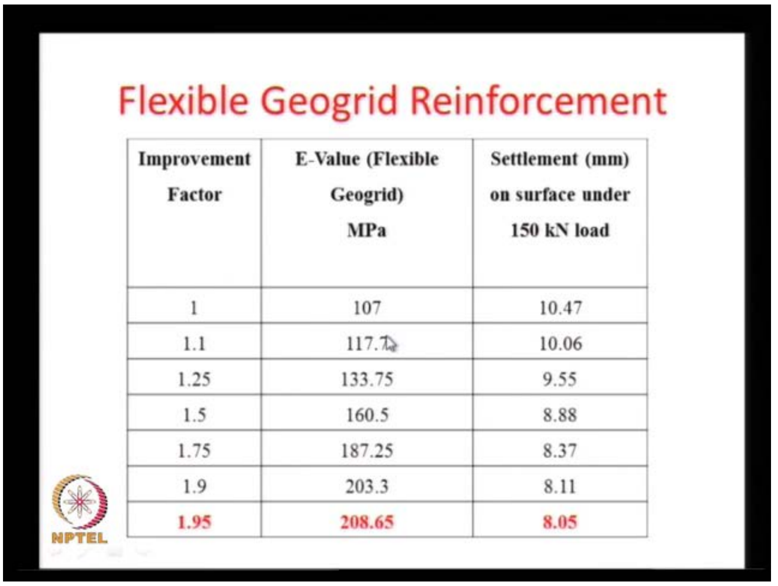

Improvement Factor	E-Value (Flexible Geogrid) MPa	Settlement (mm) on surface under 150 kN load
1	107	10.47
1.1	117.7	10.06
1.25	133.75	9.55
1.5	160.5	8.88
1.75	187.25	8.37
1.9	203.3	8.11
1.95	208.65	8.05

The same settlement under 150 kilo Newton load was obtained by increasing the Young’s Modulus of that geocell geogrid reinforced layer to 208 mega Pascal. This means that the improvement factor is 208 divided by 107 and this improvement factor is 1.95.

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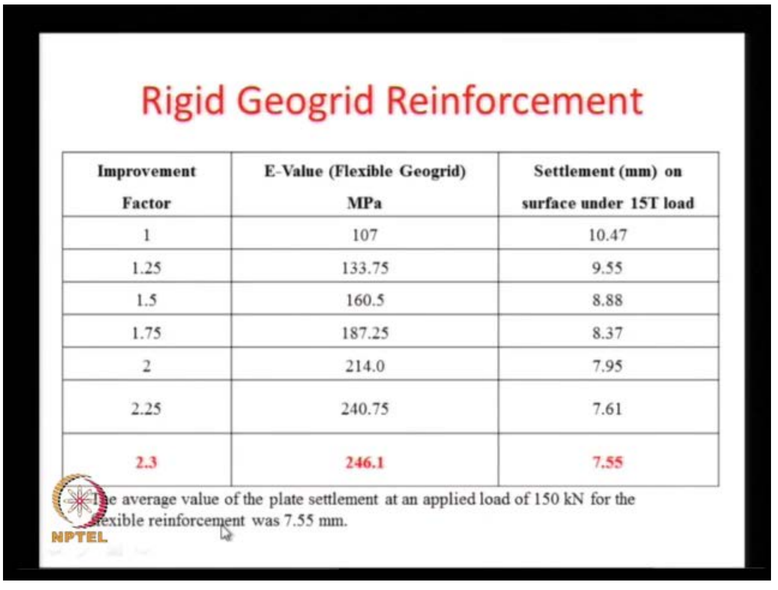

Improvement Factor	E-Value (Flexible Geogrid) MPa	Settlement (mm) on surface under 15T load
1	107	10.47
1.25	133.75	9.55
1.5	160.5	8.88
1.75	187.25	8.37
2	214.0	7.95
2.25	240.75	7.61
2.3	246.1	7.55

Similarly, the analysis was done for rigid reinforcement case under a load of 150 kilo Newtons, the settlement was only 7.5 millimeters and the Young’s Modulus required was 246. So, the improvement factor is 2.4, so that means that when we place a layer of geogrid our Young's Modulus increases. The increase in the Young's Modulus results in lesser pressure transmitted to the sub grade below of the soil layers below.

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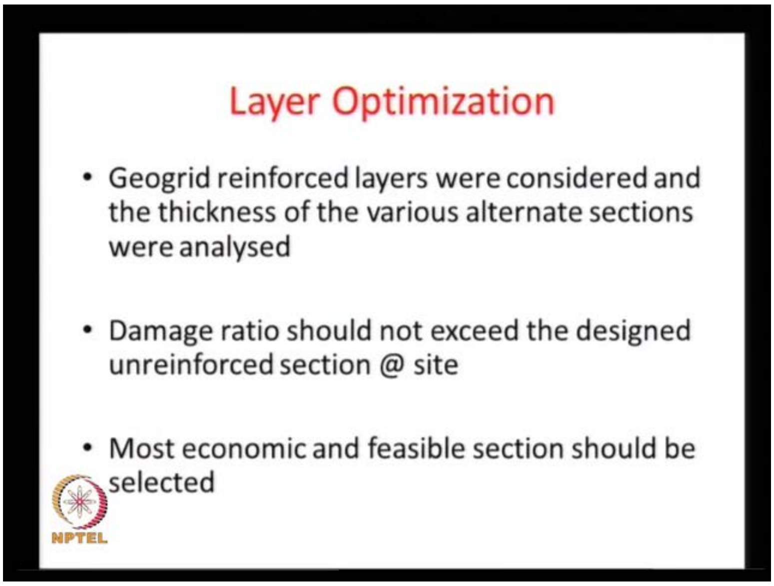

This leads to improved performance and by using some other program called Circly, the different layers were optimized to get the best performance and the analysis was done like this. The geogrid reinforced layers were considered and the thickness of various alternate sections was analyzed.

The damage ratio should not exceed the designed unreinforced section at this site at the site. Our damage ratio was 0.857 and even when we place the reinforcement, we aim for that much of damage ratio like we should aim for value less than that. Then once we get the thickness the other economic analysis and the feasibility analysis can be performed.

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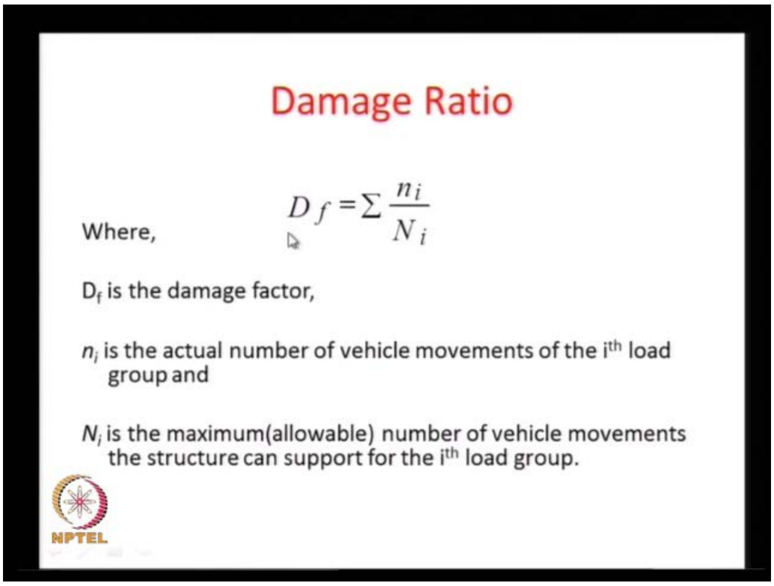

The damage ratio is defined as the number of vehicle movements of the i th load group divided by maximum number of vehicle groups. The structure can support for this same load group because this is how the damage ratio is defined, so standard terminology in pavement engineering.

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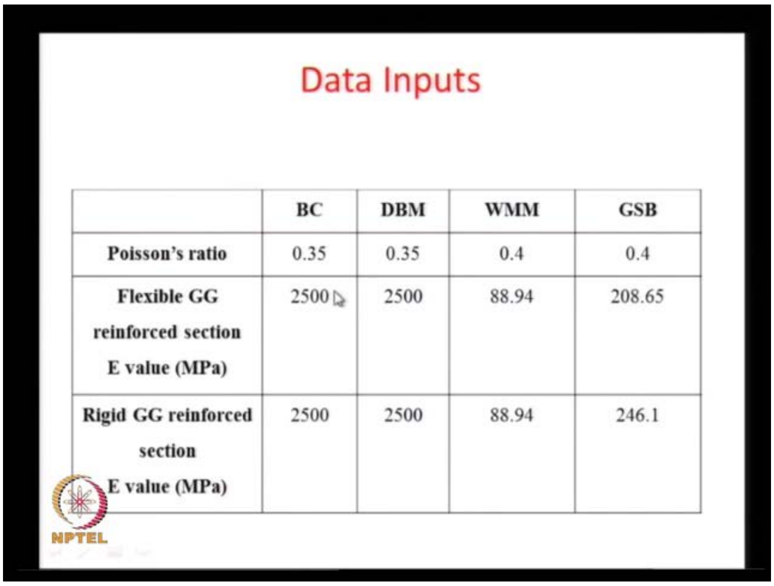

	BC	DBM	WMM	GSB
Poisson's ratio	0.35	0.35	0.4	0.4
Flexible GG reinforced section E value (MPa)	2500	2500	88.94	208.65
Rigid GG reinforced section E value (MPa)	2500	2500	88.94	246.1

These are the different data that is given as part of the input for different layers bitumen concrete DBM, WMM and GSB.

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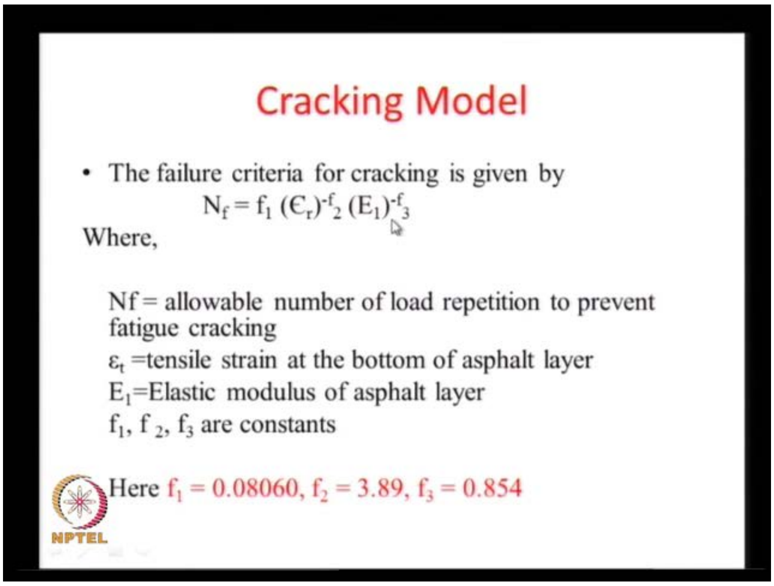

The failure criteria that is used is given like this N f is the allowable number of load repetitions to prevent the fatigue cracking depends on all these factors and the f 1, f 2 and f 3, there empirical factors we can obtain form previous data base.

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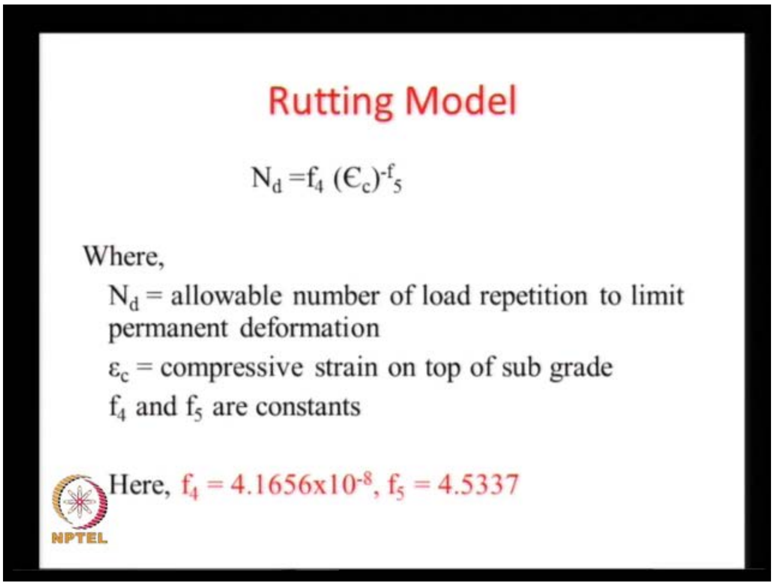

Then, the rutting that is the how much depression the pavement will undergo under the repeated loads that are also predicted using this model.

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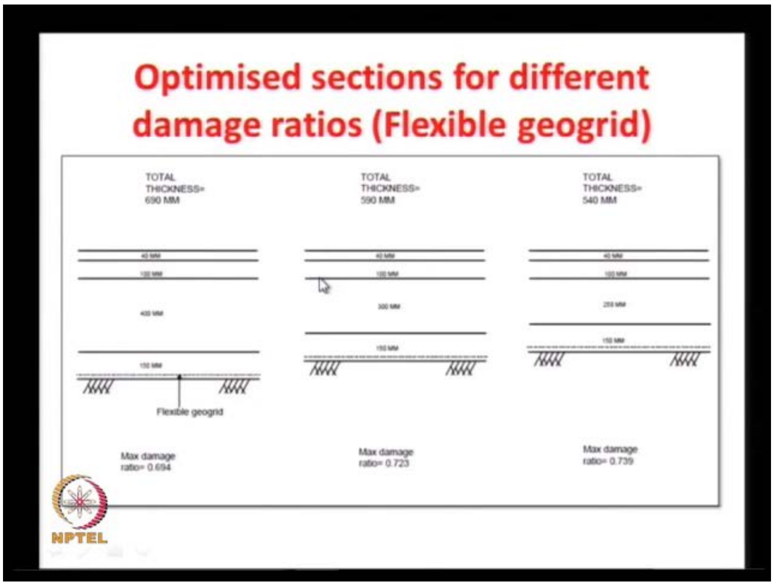

Based on the analysis, the different layer thickness were obtained, this is with a flexible geogrid layer and this layer configuration of 40 mm BC, 100 mm DBM, 400 mm WMM. Then 150 mm GSB gives a maximum damage ratio 0.694 and thickness is 690 millimeters. The other case with different layer configurations, it gives a maximum damage ratio 0.723, and another cross section that is obtained by using the geogrid layers the flexible geogrid layer.

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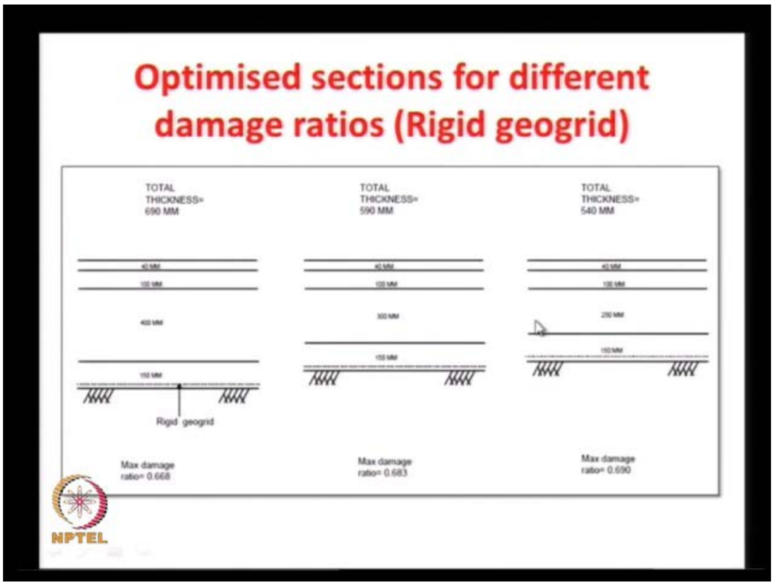

The same analysis was performed for the rigid geogrid layer and the difference between the rigid geogrid, and the flexible geogrid is in terms of the modulus that we use for that particular layer. In fact, with rigid garbage layer we get much lower damaged factors 0.67, 0.68, 0.69 and the thickness of the different layers also is reduced because of the provision of the rigid geogrid layer.

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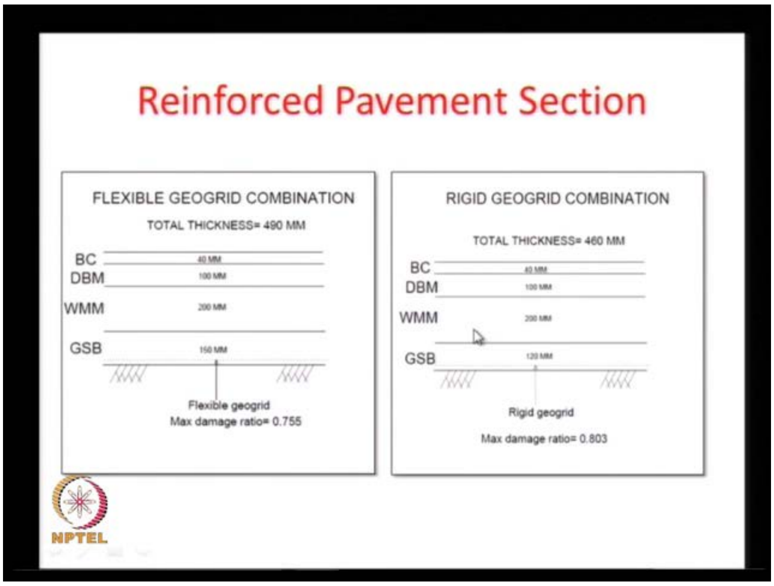

The comparison between the flexible and rigid the total thickness of the pavement is 490 millimeters, when we use a flexible geogrid layer of the sub grade level and the thickness is only 460 millimeters for rigid geogrid layer.

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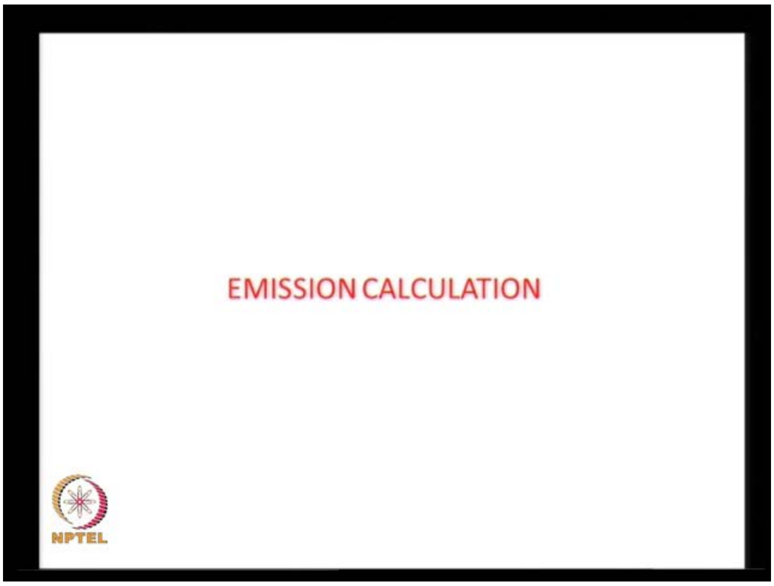

We can use this section data for calculating the emissions and other carbon footprint analysis.

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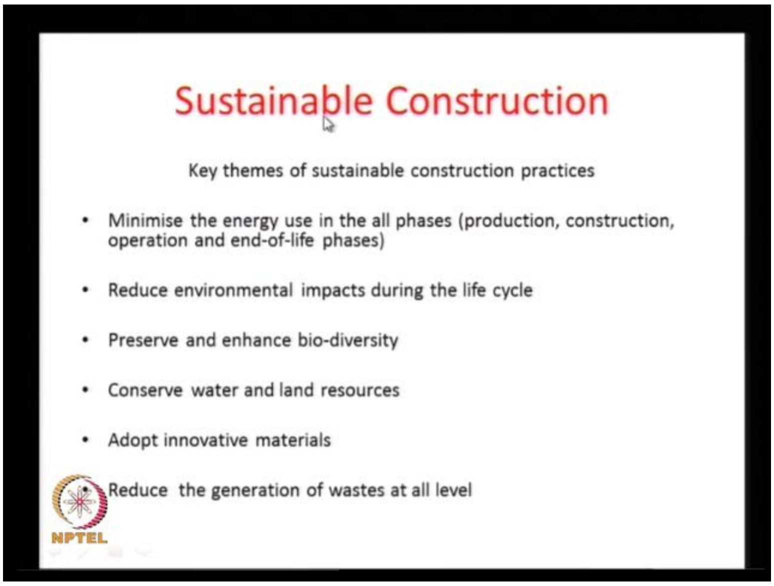

Keeping them in all our constructions is the sustainability in our activities and that means that we need to minimize the energy. In all the phases that is in the production construction operation and end of life phases that is in producing the aggregate. This stones have to be broad from a quarry, then they have to crush to produce the aggregate and then it takes longer time if we need to bring in larger quantities of materials. Then the finished quality of the road also dictates the energy usage, if the quality of road surface is good the vehicles will use lesser amount of fuel as compared to a bad road, where the vehicles have to really crawl at a very low speed they use a higher fuel.

So, all these factors control the energy usage and then reduce the environmental impact during the entire cycle that is over the life period of the pavement. They preserve and enhance bio diversity in conserve water, and land resources and usage of innovative materials for achieving the construction at a faster pace. And then sustainability and reduce the generation of wastes at all the levels.

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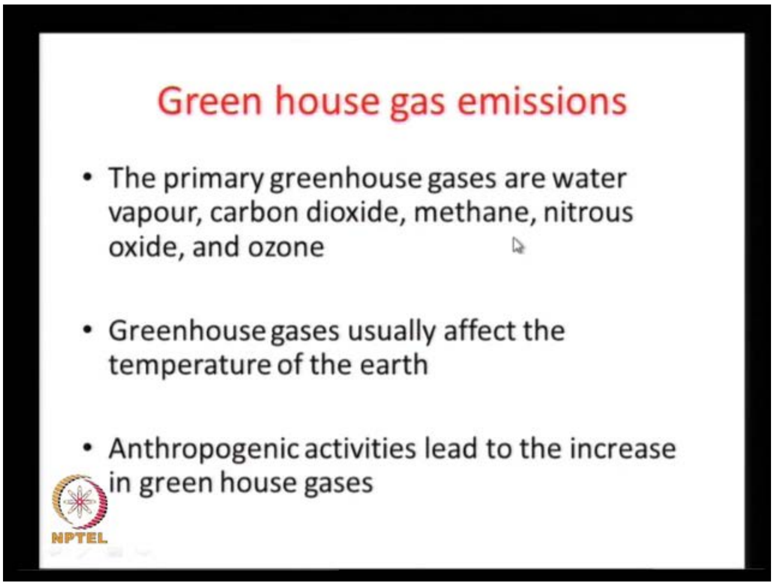

So, let us see how we can do that and the greenhouse gas emission is a parameter that is used for quantifying the pollution levels and other things. The primary greenhouse gases, the water vapor, carbon dioxide, methane nitrous oxide and ozone and the greenhouse gases usually affect the temperature of the earth. Then the anthropogenic activates lead to the increase in greenhouse gases all our activities, they lead to greenhouse gases. So, if we consume more fuel it produces the greenhouse gases, or if you consume lot of food that also could lead to greenhouse gases because all of those they relate to some activities.

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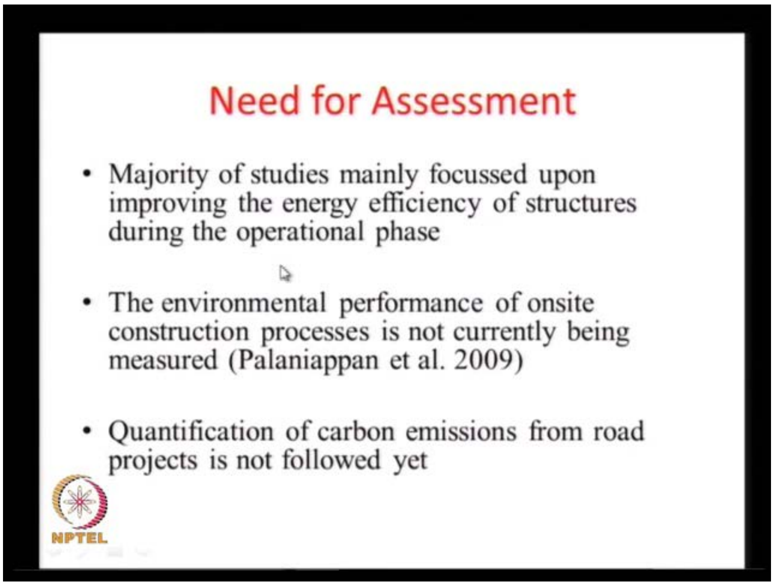

There is not much of a previous attempt and quantifying the reduction in the carbon footprint because of the use of the geosynthetic layers. Earlier works, they focused more on the energy efficiency of buildings during the operational phases. The environmental performance of the onsite construction process is not currently investigated in detail, and the quantification of the carbon emission from road projects has not been done at all.

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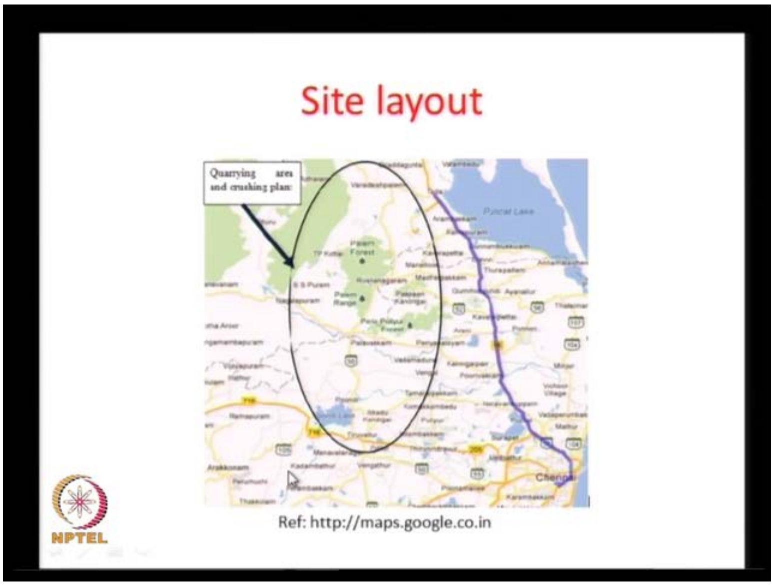

This is the construction site that i had shown earlier this is the Chennai Tada section and for constructing the road, the company, the construction company has identified some quarries, and then they have located some crushing plants to produce the GSB material.

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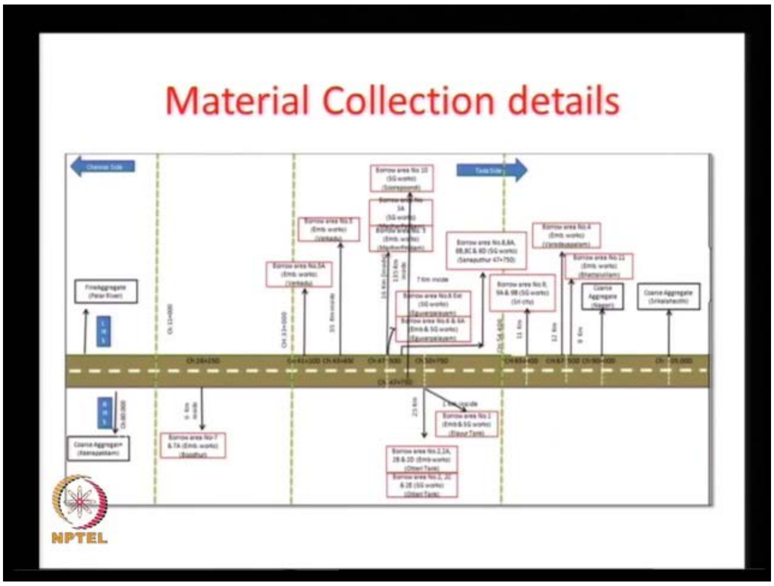

The onsite inventories something like this is the stretch of the road for different sections they get the material from different areas for example, here at this chainage. The course aggregate is coming from Meria called Kirkapam, whereas here this is coming from some other sites and so on. What this student has done is, he has quantified the lead distance from the barrow area to the construction site, and then how much quantity is required and how much of energy is used to produce this aggregate has all been quantified. Finally, these quantities have been converted to some energy that is required to produce this material.

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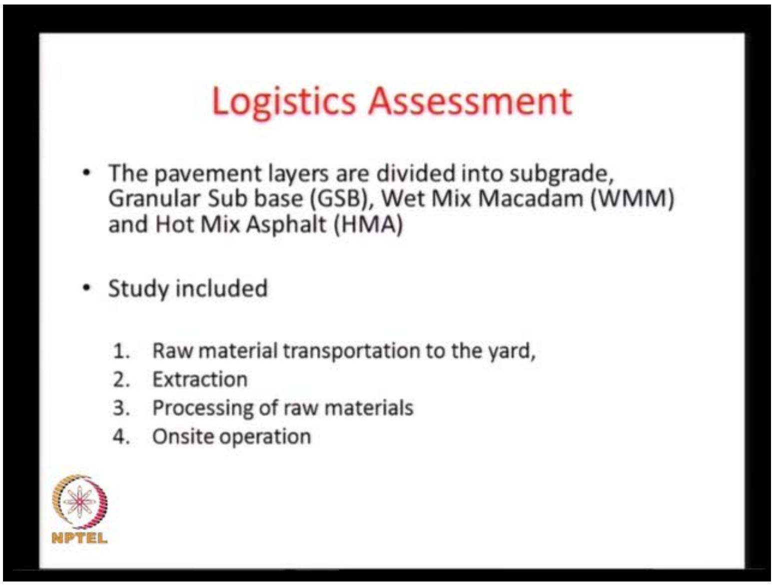

That is called as logistic assessments and the entire pavements layers and divided into sub grade, granular sub base, and wet mix macadam and hos hot mix asphalt. This particular study involved in doing an audit of the rough material transportation extraction processing of the rough materials and then onsite operations.

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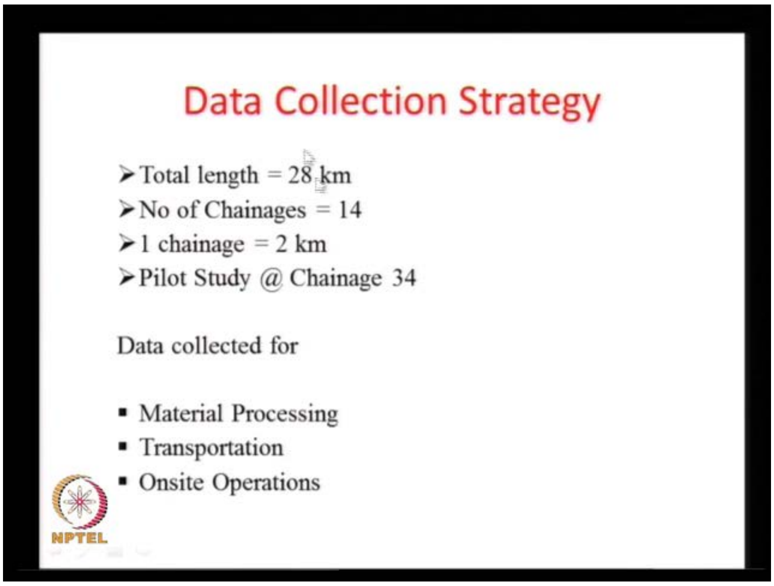

This survey was done for a length of 28 kilo meters of the highway construction and number of chainages was 14, one chainage covering a distance of 2 kilo meters. The data collected was for the material processing transportation and then other onsite operations.

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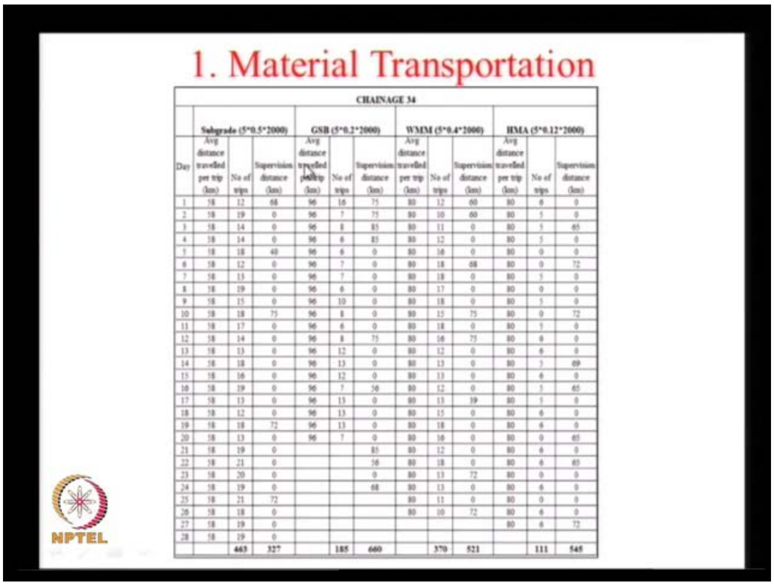

1. Material Transportation

CHAINAGE 34												
	Subgrade (5*0.5*2000)			GSB (5*0.2*2000)			WMM (5*0.4*2000)			HMA (5*0.12*2000)		
Day	Avg distance travelled per trip (km)	No of trips	Supervision distance (km)	Avg distance travelled per trip (km)	No of trips	Supervision distance (km)	Avg distance travelled per trip (km)	No of trips	Supervision distance (km)	Avg distance travelled per trip (km)	No of trips	Supervision distance (km)
1	58	12	68	96	16	75	80	12	60	80	6	0
2	58	19	0	96	7	75	80	10	60	80	5	0
3	58	14	0	96	8	85	80	11	0	80	5	65
4	58	14	0	96	6	85	80	12	0	80	5	0
5	58	18	40	96	6	0	80	16	0	80	0	0
6	58	12	0	96	7	0	80	18	68	80	0	72
7	58	13	0	96	7	0	80	18	0	80	5	0
8	58	19	0	96	6	0	80	17	0	80	0	0
9	58	15	0	96	10	0	80	18	0	80	5	0
10	58	18	75	96	8	0	80	15	75	80	0	72
11	58	17	0	96	6	0	80	18	0	80	5	0
12	58	14	0	96	8	75	80	16	75	80	6	0
13	58	13	0	96	12	0	80	12	0	80	6	0
14	58	18	0	96	13	0	80	13	0	80	5	69
15	58	16	0	96	12	0	80	13	0	80	6	0
16	58	19	0	96	7	58	80	12	0	80	5	65
17	58	13	0	96	13	0	80	13	19	80	5	0
18	58	12	0	96	13	0	80	15	0	80	6	0
19	58	18	72	96	13	0	80	18	0	80	6	0
20	58	13	0	96	7	0	80	16	0	80	0	65
21	58	19	0			85	80	12	0	80	6	0
22	58	21	0			58	80	18	0	80	6	65
23	58	20	0			0	80	13	72	80	0	0
24	58	19	0			68	80	13	0	80	6	0
25	58	21	72				80	11	0	80	0	0
26	58	18	0				80	10	72	80	6	0
27	58	19	0							80	6	72
28	58	19	0									
		463	327		185	660		370	521		111	545

Here, we see the at this particular chainage study for the sub grade quantity is 5 times pellet 5 times 2000, that is the kilo meters and then the thickness. Then this 2000 is the unit weight and average distance travelled per trip is given in this column is approximately 58 kilo meters, and distance and then the number of trips that are to be made. These are all this particular inventory was done per for a very long period, and these are the daily activities. And day 158 trucks were brought they distance to the to the quarry was 58 kilo meters, the number of trips and the first day was 12 second day 19 and so on.

Totally, 463 trips were made and the supervision distance that is by how far the supervisor has to travel is actually on certain days the supervisor travel the distance traveled was 327. Similarly, the GSB, WMM and hot mix asphalt and the average distance from which this material was transported the number of trips and then the supervision distance.

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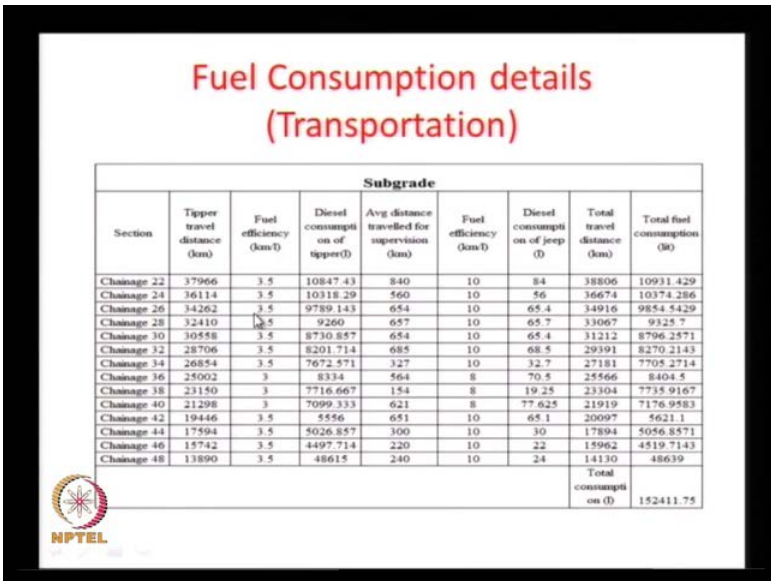

Subgrade								
Section	Tipper travel distance (km)	Fuel efficiency (km/l)	Diesel consumption of tipper(l)	Avg distance travelled for supervision (km)	Fuel efficiency (km/l)	Diesel consumption of jeep (l)	Total travel distance (km)	Total fuel consumption (lit)
Chainage 22	37966	3.5	10847.43	840	10	84	38806	10931.429
Chainage 24	36114	3.5	10318.29	560	10	56	36674	10374.286
Chainage 26	34262	3.5	9789.143	654	10	65.4	34916	9854.5429
Chainage 28	32410	[illegible]	9260	657	10	65.7	33067	9325.7
Chainage 30	30558	3.5	8730.857	654	10	65.4	31212	8796.2571
Chainage 32	28706	3.5	8201.714	685	10	68.5	29391	8270.2143
Chainage 34	26854	3.5	7672.571	327	10	32.7	27181	7705.2714
Chainage 36	25002	3	8334	564	8	70.5	25566	8404.5
Chainage 38	23150	3	7716.667	154	8	19.25	23304	7735.9167
Chainage 40	21298	3	7099.333	621	8	77.625	21919	7176.9583
Chainage 42	19446	3.5	5556	651	10	65.1	20097	5621.1
Chainage 44	17594	3.5	5026.857	300	10	30	17894	5056.8571
Chainage 46	15742	3.5	4497.714	220	10	22	15962	4519.7143
Chainage 48	13890	3.5	48615	240	10	24	14130	48639
							Total consumption (l)	152411.75

This data can be converted to equivalent fuel consumption details and the fuel efficiency of each of these vehicles was noted. For example, the tipper travel distance is approximately 37,966 kilo meters and the fuel efficiency is only 3.5 kilo meters per liter. The diesel consumption and the average distance for supervision 840 kilo meters the fuel efficiency of this car is better 10 kilo meters per liter. So, this entire data that was collected was translated into the fuel consumption that is so many liters 1,52,411 liters.

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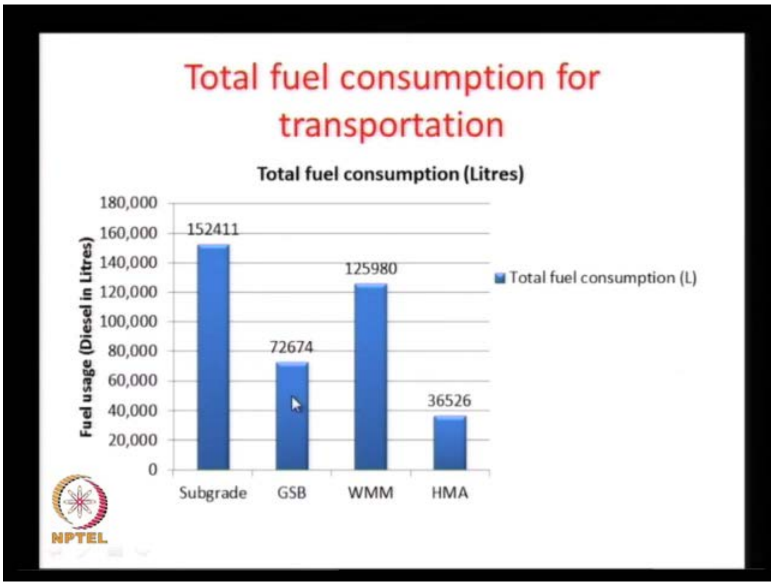

These are the different operations, the fuel consumption for sub grade operations the GSB, WMM and hot mix asphalt.

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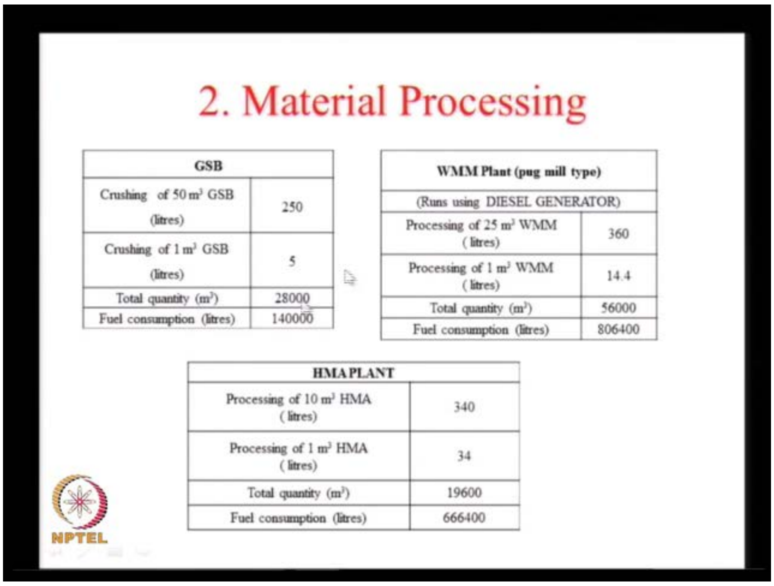

The material processing cause for crushing of the GSB of the WMM we require energy and for crushing of 50 cubic meters of GSB 250 liters of diesel was used and crushing of 1 cubic meter of GSB 5 liters. The total quantity of the material is 28,000 cubic meters and the fuel consumption was 1,40,000 liters. Similarly, the WMM plant 8,06,400 liters and the HMA plant 6,66,400 liters.

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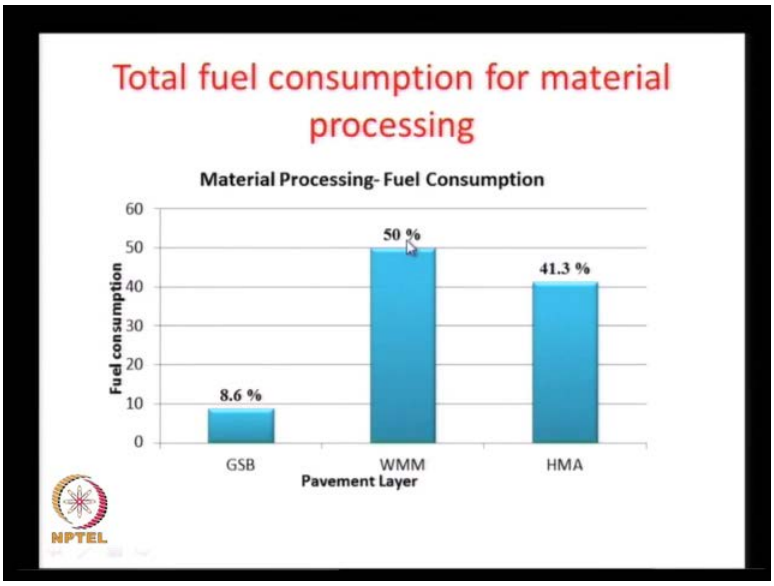

This is the bar chart and the fuel consumption for different activities, and this is in terms of quantity and this is in terms of percentage.

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Once, these entire quarry materials are collected and processed, they need to be brought to the site, and the process materials are transported to the sites and will be dumped at the site. The materials will be spread from properly using machinery or labor and compacted to reach the desired density and compaction is one of the critical processes in the onsite operations. This involves in running of the rollers and if are able to reduce the energy used for compaction our time for construction will reduce, and our carbon footprint also will reduce. These are the different equipment that were used back hoe for spreading the materials.

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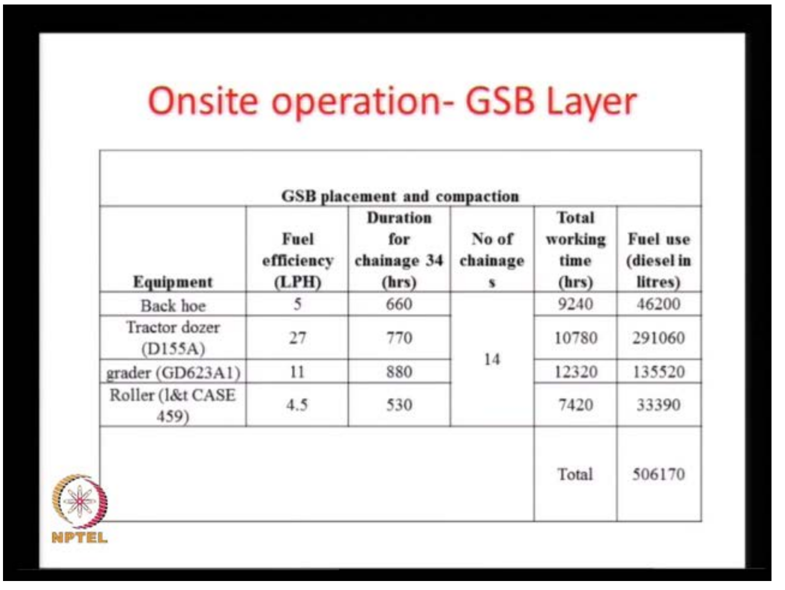

Onsite operation- GSB Layer

GSB placement and compaction					
Equipment	Fuel efficiency (LPH)	Duration for chainage 34 (hrs)	No of chainages	Total working time (hrs)	Fuel use (diesel in litres)
Back hoe	5	660	14	9240	46200
Tractor dozer (D155A)	27	770		10780	291060
grader (GD623A1)	11	880		12320	135520
Roller (l&t CASE 459)	4.5	530		7420	33390
				Total	506170

Tractor and dozer also for spreading materials grader and then the roller for compacting this material. And the total fuel usage for onsite operation is 506170 liters for 1 kilo meter stretch of the road.

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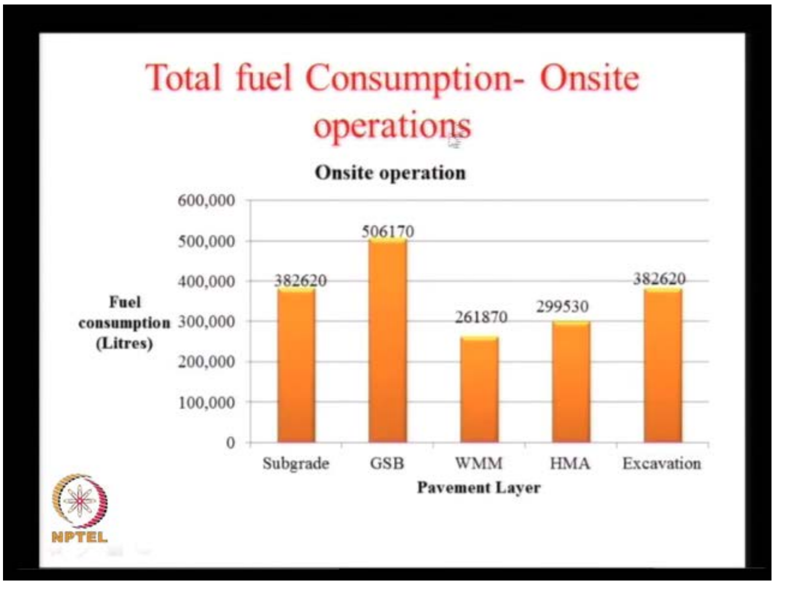

The total fuel consumption for onsite operations are given like this.

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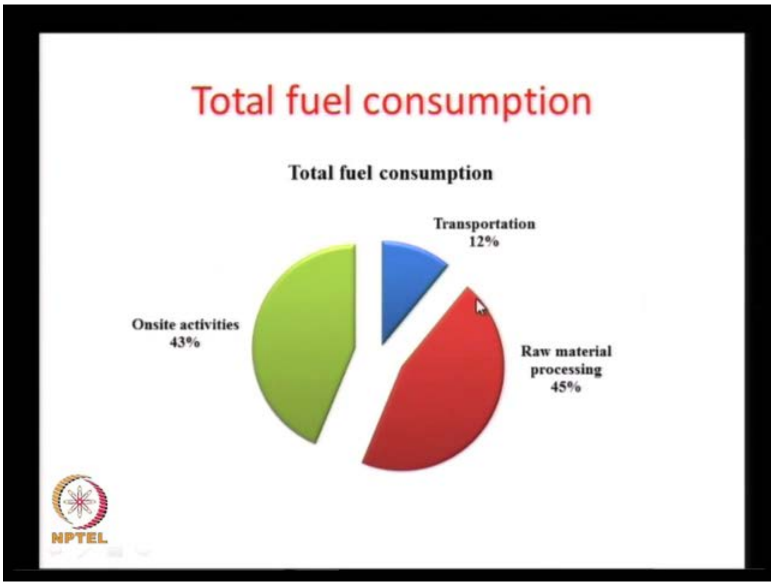

In terms of pie chart, about 12 percent fuel was used for transportation and processing the rough materials, about 45 percent then other onsite activities that are spreading the materials and compacting. Other for transporting the materials from the processing plant to the site was about 43 percent.

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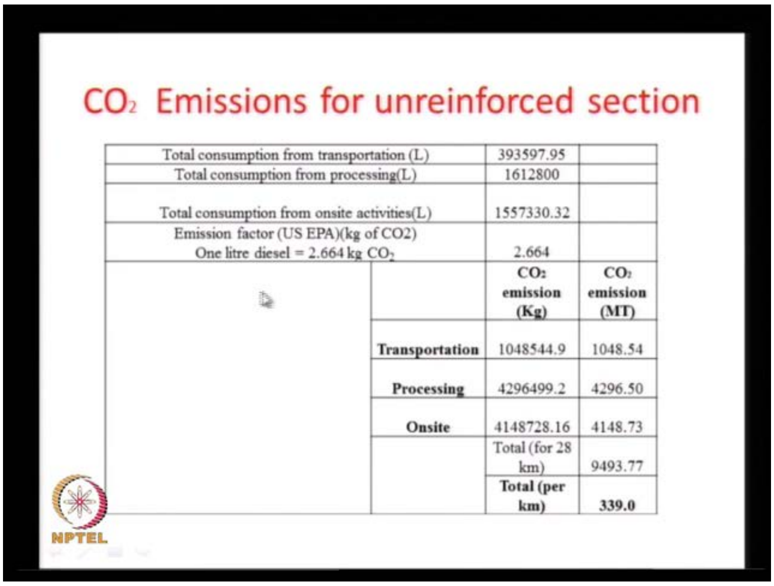

Total consumption from transportation (L)		393597.95	
Total consumption from processing(L)		1612800	
Total consumption from onsite activities(L)		1557330.32	
Emission factor (US EPA)(kg of CO2) One litre diesel = 2.664 kg CO_2		2.664	
		CO_2 emission (Kg)	**CO_2 emission (MT)**
	Transportation	1048544.9	1048.54
	Processing	4296499.2	4296.50
	Onsite	4148728.16	4148.73
		Total (for 28 km)	9493.77
		Total (per km)	**339.0**

The CO 2 emission was estimated using some approximate relation that were given by the US environmental protection agency. And the CO 2 emission for constructing the unreinforced section came out as 339 metric tons per kilo meter length.

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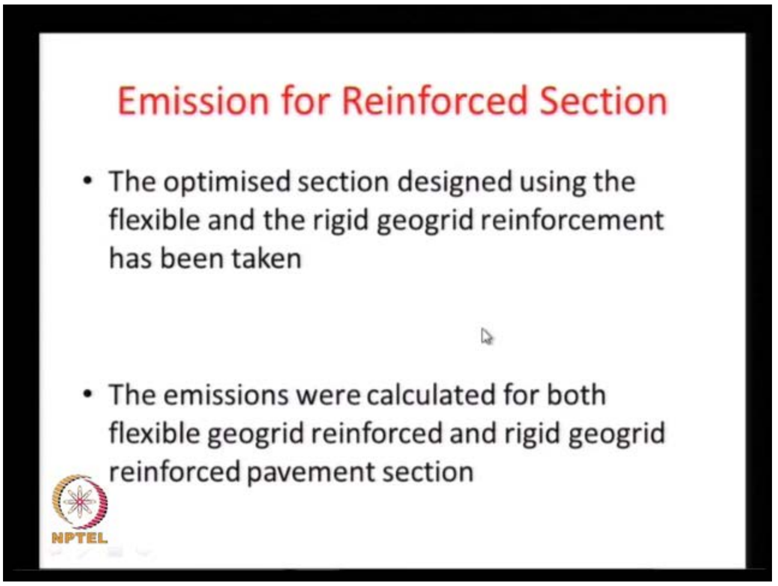

The same emission studies were performed for the reinforced section, and for flexible geogrid reinforcement.

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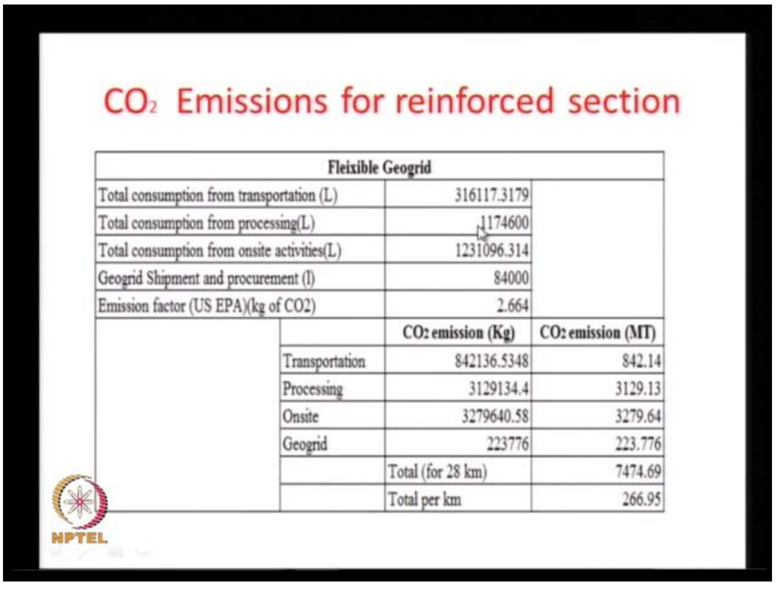

Fleixible Geogrid			
Total consumption from transportation (L)		316117.3179	
Total consumption from processing(L)		1174600	
Total consumption from onsite activities(L)		1231096.314	
Geogrid Shipment and procurement (l)		84000	
Emission factor (US EPA)(kg of CO2)		2.664	
		CO_2 emission (Kg)	CO_2 emission (MT)
	Transportation	842136.5348	842.14
	Processing	3129134.4	3129.13
	Onsite	3279640.58	3279.64
	Geogrid	223776	223.776
		Total (for 28 km)	7474.69
		Total per km	266.95

The total carbon emission is approximately 267 metric tons for kilo meter length and for rigid geogrid, it is 263, earlier 267, now 263, it is marginal reduction.

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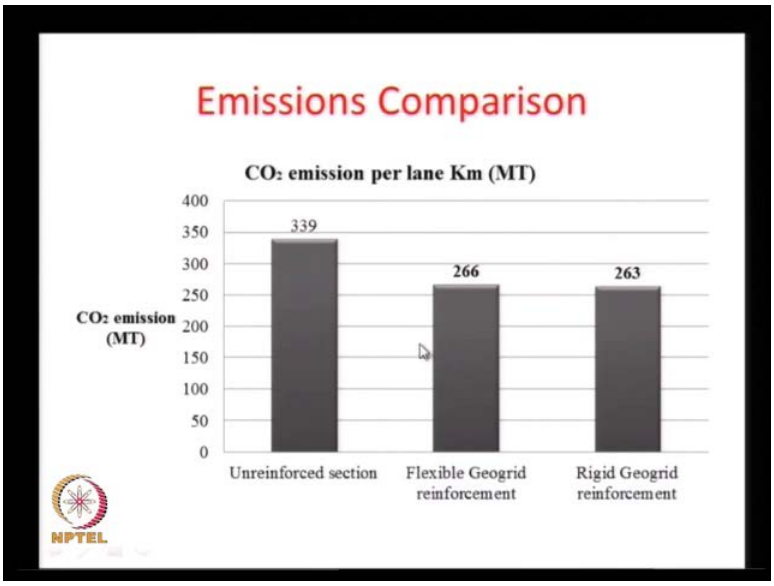

This is the bar chart that compares the CO 2 emission for a single lane for 1 kilometer length of the road unreinforced section is 339, whereas the geogrid reinforced sections they have about 266 or 263 metric tons. So, that means that we are able to reduce the carbon emission or the carbon footprint by using geosynthetic materials.

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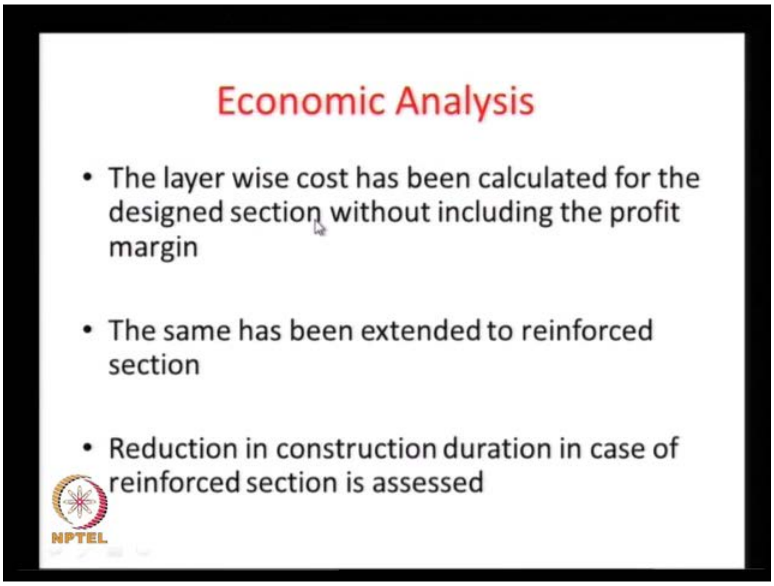

We can also convert this in to equivalent economic analysis and the layer wise cost was calculated for the design section without including the profit margin, and the same has been extended to reinforce section. The reduction in construction duration in case of reinforced section is also assessed because if you are able to reduce the thickness by that much, you need to spend less in transporting the materials.

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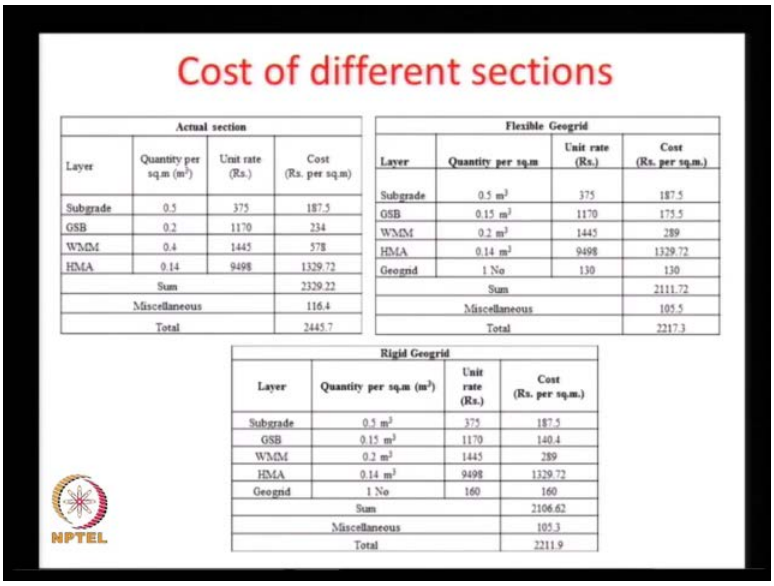

Actual section			
Layer	Quantity per sq.m (m^3)	Unit rate (Rs.)	Cost (Rs. per sq.m)
Subgrade	0.5	375	187.5
GSB	0.2	1170	234
WMM	0.4	1445	578
HMA	0.14	9498	1329.72
Sum			2329.22
Miscellaneous			116.4
Total			2445.7

Flexible Geogrid			
Layer	Quantity per sq.m	Unit rate (Rs.)	Cost (Rs. per sq.m.)
Subgrade	0.5 m^3	375	187.5
GSB	0.15 m^3	1170	175.5
WMM	0.2 m^3	1445	289
HMA	0.14 m^3	9498	1329.72
Geogrid	1 No	130	130
Sum			2111.72
Miscellaneous			105.5
Total			2217.3

Rigid Geogrid			
Layer	Quantity per sq.m (m^3)	Unit rate (Rs.)	Cost (Rs. per sq.m.)
Subgrade	0.5 m^3	375	187.5
GSB	0.15 m^3	1170	140.4
WMM	0.2 m^3	1445	289
HMA	0.14 m^3	9498	1329.72
Geogrid	1 No	160	160
Sum			2106.62
Miscellaneous			105.3
Total			2211.9

The cost for different sections is obtained like this for 2,445 for unreinforced section, and 2,217 for flexible geogrid, 2,211 for rigid geogrid.

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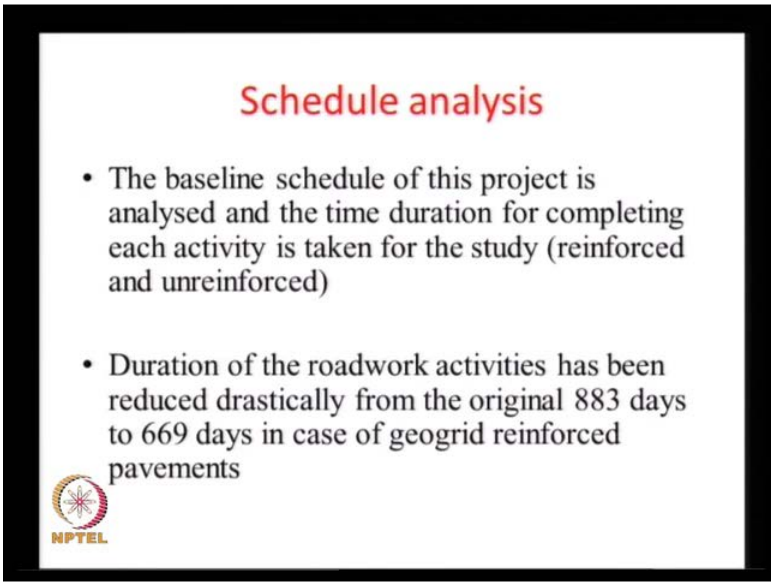

This schedule analysis we can reduce the construction time form 883 days for the unreinforced section up to 669 days by using the geogrid reinforced section. Mainly, the difference is coming because of reduction in the quantities that are transported to the site.

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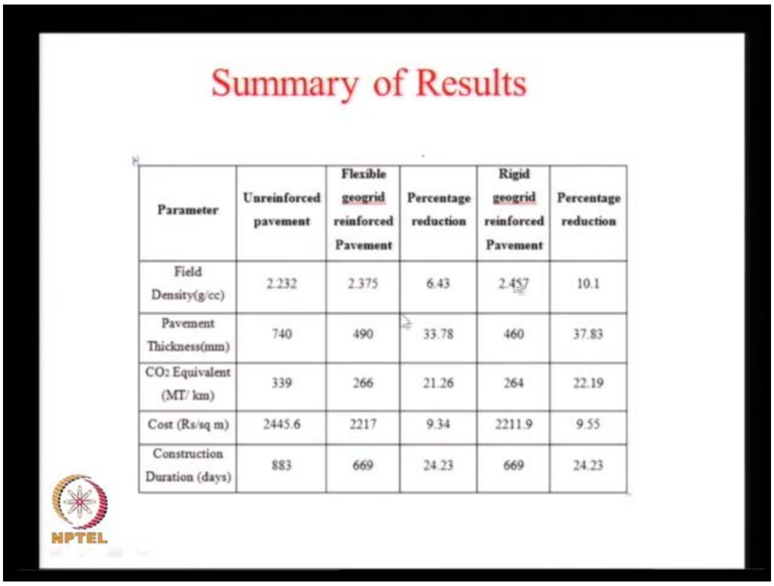

Summary of Results

Parameter	Unreinforced pavement	Flexible geogrid reinforced Pavement	Percentage reduction	Rigid geogrid reinforced Pavement	Percentage reduction
Field Density(g/cc)	2.232	2.375	6.43	2.457	10.1
Pavement Thickness(mm)	740	490	33.78	460	37.83
CO_2 Equivalent (MT/ km)	339	266	21.26	264	22.19
Cost (Rs/sq m)	2445.6	2217	9.34	2211.9	9.55
Construction Duration (days)	883	669	24.23	669	24.23

These are the different results that were obtained the field density that was achieved for GCB layer for unreinforced pavement was 2.23 and with flexible reinforcement. It has increased to 2.37 and with rigid reinforcement this dry density is even higher 2.45. So, that means that we are able to achieve higher densities, that means that they will be less permeable and they will not allow the surface water to infiltrate into the sub grade.

Their long term performance may be so much better because they will have that much highest strength. and the construction duration was reduced from 883 days to 669 days. That is a big benefit, almost 200 days of reduction in the construction time approximately 7 months.

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If you are able to extrapolate this analysis, so the entire national highway grid we can imagine the cost savings and this map shows the golden quadrilateral that is proposed that is connecting all the metropolitan cities. North, South corridor is going all the way from Jammu and Kashmir to Kanyakumari and East West corridor all the way from eastern end to the western border. So, this type of economic analysis if you can extend it for all the projects the impact could be quite significant.

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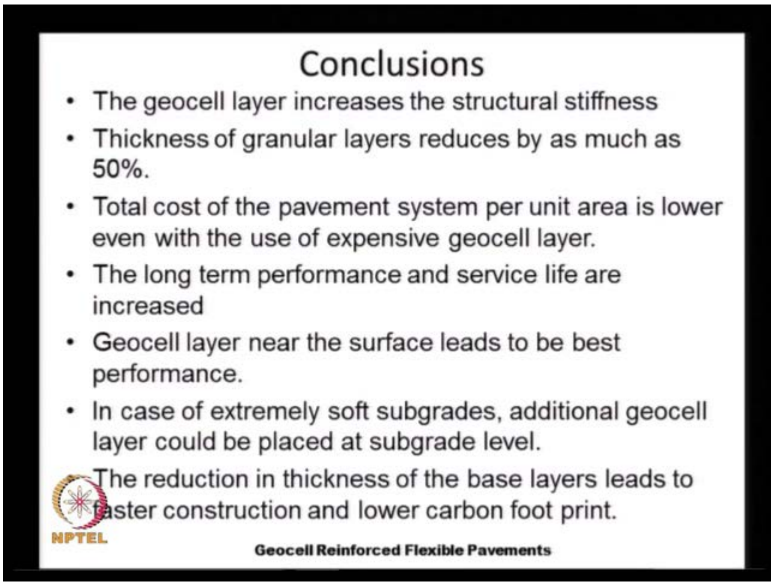

Just to conclude the use of geocell layer or the geogrid layer increases the structural stiffness and the thickness of the granular layers can be reduce as much as by 50 percent. The total cost of the pavement system per unit plan area is lower even with the use of expensive geocell, or the geogrid layers and the long term performance and the service life are increased. Usually, if we have a stiff geogrid sub grade we can use the geocell near to the loaded area at the surface to integrate a good benefit.

In case of extremely soft sub grade soils we can use as additional sub grade layer at the sub grade layer. So, we can get better compaction and the reduction in the thickness of the base layers leads to faster construction, the lower carbon footprint of our construction activities. So, thank you very much and if you have any questions you can send an email to me.

Thank you.