Geosynthetics and Reinforced Soil Structures

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Lecture - 30
Design and Construction of Container Yards Using Geosynthetics

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In today's lecture let us look at some other applications of the geosynthetics, that is on the design and construction of container yards using the geosynthetics.

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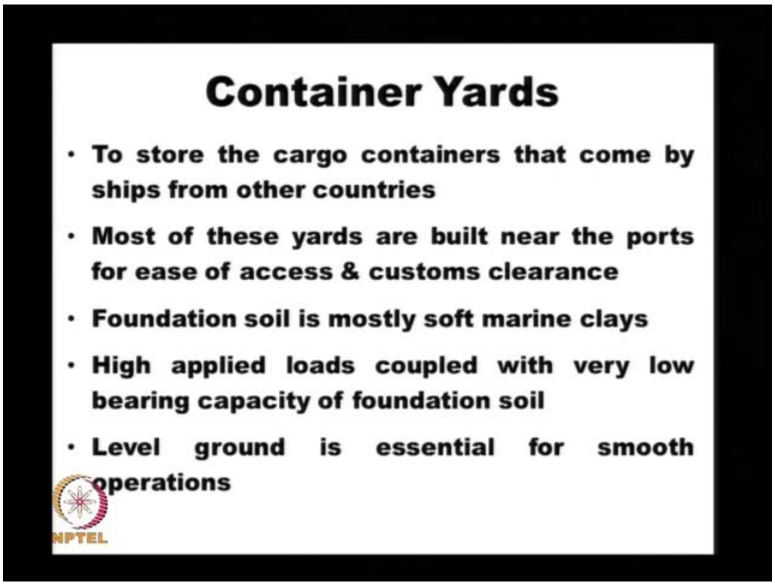

And let us first see what is the container yard? These are large areas where we store the cargo containers, that come from other countries in ships. And these yards are mostly built near the ports for ease of access and for ease of customs clearance and other related operations. And in variably because these yards are built very near to the shore line, very near to the ports, the foundation soil is mostly of soft marine clay. And coupled with very high applied loads that we will see very soon, and very low bearing capacity at the foundation soil, the problems that we encounter with the construction of container yards are tremendous. And in these yards we require absolutely level ground. So, that the container operations are smooth.

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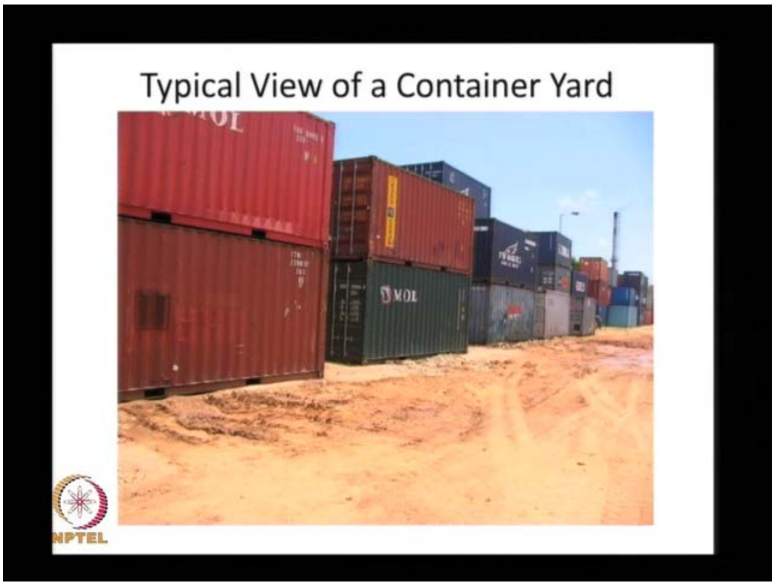

And this picture shows a general view of container yard. You see these containers stacked 1 on top of the other, each of these containers they weigh about 25 to 30 tones. And some of them in some yards they are stacked about 3 to 4, one on top of the other.

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And here you see another close up of these containers stacked one above the other. And here you can see the china written, that means the this particular container has come from china.

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And here we see an operation where the a vehicle comes lifts the these container units to stack them.

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And because of this heavy loads, that are lifted up. And because of the very large over hang that we see here are the wheel loads are very heavy on the front side. And most of these loads they are given by different companies, who make these vehicles depending on the number of stacking units. Like if it is only 2 stacks the load is something and if it is higher number of stacks the load is much higher, because the overhang is going to be much higher. And we need to take them for our design purposes.

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And here we see the close up of how this lifting looks like, actually it is a very huge arm with hydraulic controls, that are controlled by the driver to hold these containers and then lift them up.

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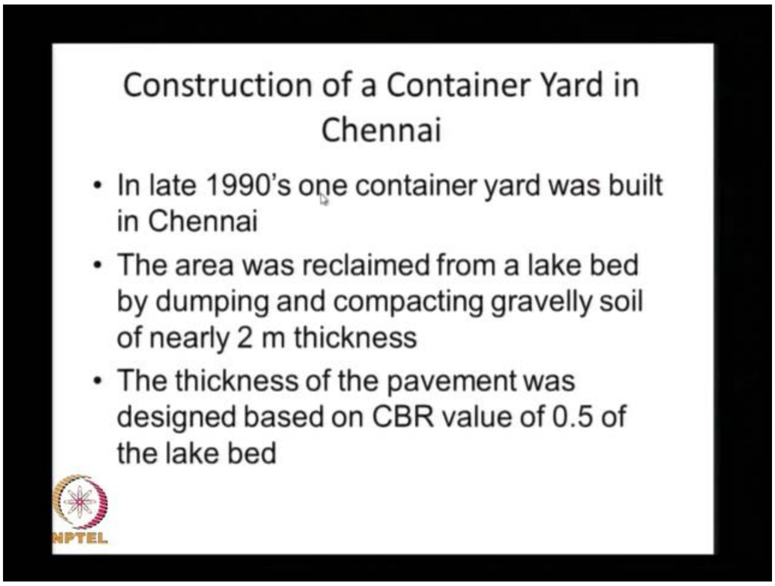

And there are several of this container yards in Chennai and in Bombay then Kolkata. And all these where ever there is a major port we can see this container yards. And just briefly discuses a one particular constructions. In the late 1990's one container yard was built in Chennai and this particular yard was a constructed on a reclaimed land from a lake bed. And the up to about 2 meters thick or red morum soil was dumped. And compacted in thin layers of a about to 200 to 250 millimeters thick. And some test that were done before the gravel filling, showed that the CBR value of this lake bed soil is approximately 1 half about 0.5 it is very low.

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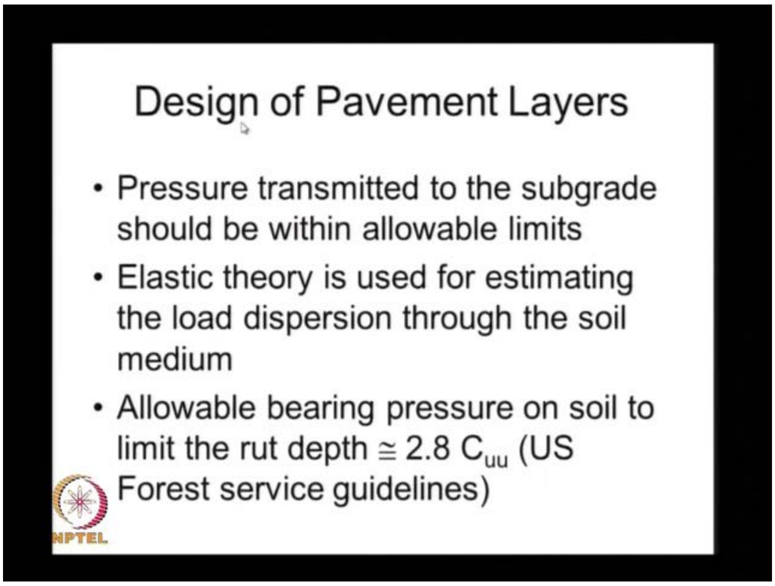

What is the philosophy that we use for designing the thickness of the pavement. The same thing just as how we have discussed earlier for the design of pavements below the roads, the same principle applies even for the container yard pavements, that the pressure that we transmit in to the sub grade soil should be with the allowable bearing pressure.

And then we normally use the elastic theory for estimating load dispersion through these soils, because they give us more closed form solutions that can be easily done with hand calculations. And the allowable bearing pressure for this type of applications is taken as 2.8 times C u. This is as per the US forest service guidelines, that is for high traffic and a very low rut depth.

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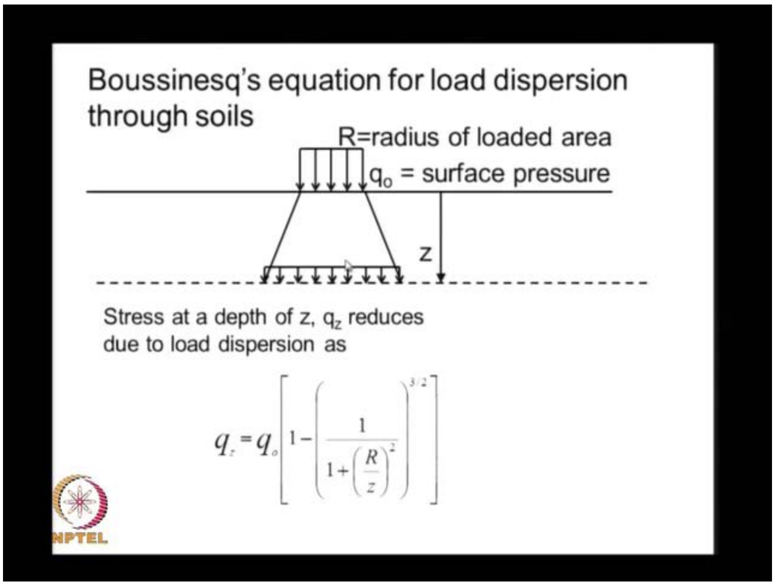

And here we see this the load dispersion, let us say that we have a pressure of q naught applied on the ground surface. The equivalent radius of this loaded area let it be capital R. As we go down the depth there is going to be some pressure dispersion. And this is best described by Boussinesq's equation, that says that the q z, that is the pressure at any depth z is related to the to the surface pressure q naught. And then the radius of this loaded area and the depth z through this equation.

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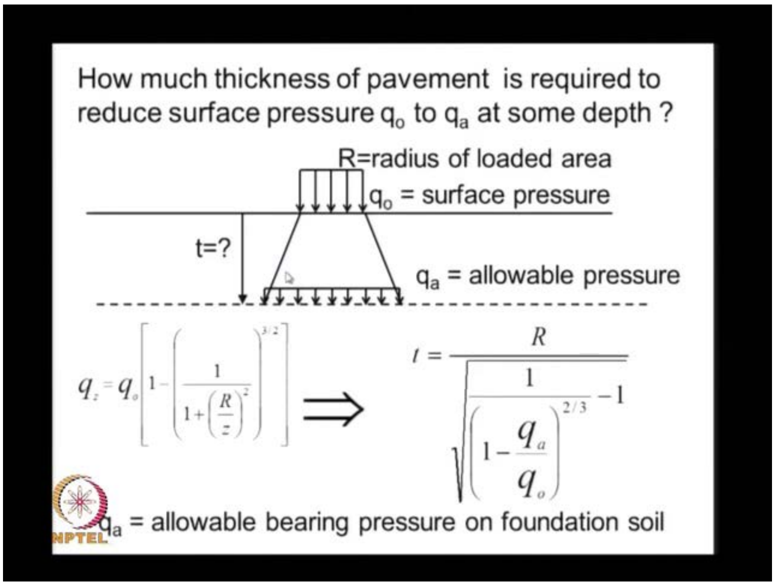

And we can utilize the same equation and come out with a certain thickness of the pavement that will reduce the surface pressure q naught at to an allowable value of q a. And that we can do it by slightly transforming this Boussinesq's equation, that is given in terms of z and then the q naught and R. As say the thickness we need to find t is equal to the radius divided by this entire quantity square root of 1 by 1 minus q a by q naught to the power 2 thirds minus 1. Where q a is the allowable pressure that we can transmit into the subgrade soil, that will not cause any foundation failures are very large excessive settlements. And here the q naught is the surface pressure that is applied at the ground.

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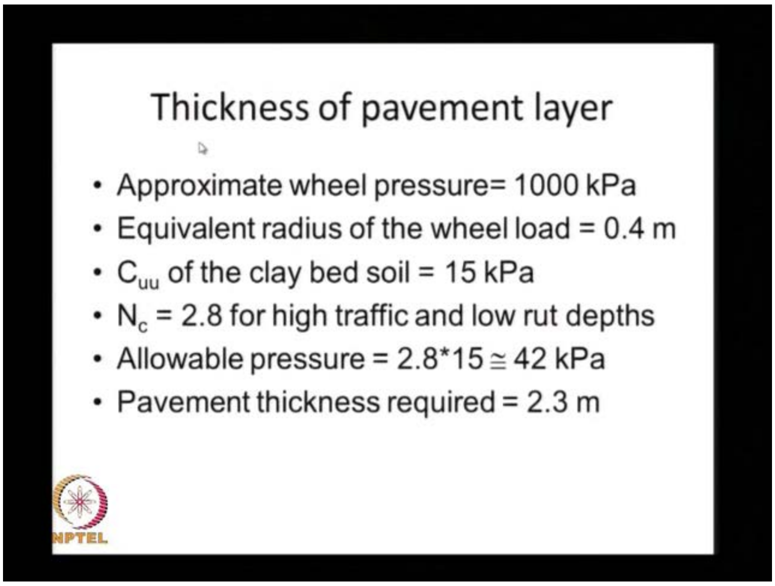

And for this particular container yard in our design situation, the approximate wheel pressure that is given as 1000 k P a. And for the for the tandum wheel configuration, the equivalent radius comes out as 0.4 meters and the undrained cohesive strength of the clay soil bed can b taken as 15 k P a corresponding to our CBR value of 1 half. And our N c factor that is the bearing capacity factor can be taken as 2.8 for high traffic and low rut depths. So, our allowable bearing pressure is only forty 2 k P a. So, we need to design the thickness so that the applied pressure of 1000 k P a is reduced to 42 k P a. And this gives that the pavement thickness of 2.3 meters and this needs to be provided by providing different layers.

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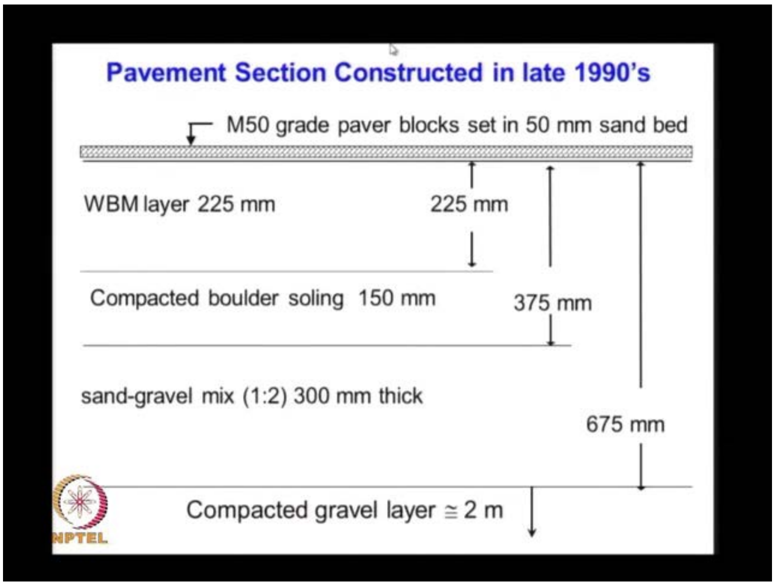

And the particular construction utilized this cross section. Initially there was a compacted gravel layer of approximately 2 meters and the constructed layer thickness with higher quality of soils is approximately 675 millimeters. Out of this there was a sand gravel mix in the ratio of 1 to 2 of 300 millimeters, that will give a CBR value of not less than 15. And then there is a compacted boulder soling, that with large size stones of 150 millimeters.

And then there is WBM layer 225 millimeters, and this WBM layer is provided in 3 layers each of 75 millimeters thick. And top of this we have a 50 mm sand cushion. And then we have the paver blocks of 100 mm thick and made of m 50 grade concrete. And so in total the thickness of this pavement that is provided is at least 2.5 meters. There is not there is not much control on the thickness of this 2 meters. So, at some places it could be about 1.5 to 1.7 meters at some places may be 2 meters.

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So, this is the scenario just about seasons after this container yard was thrown open for operations, at the ground surface the mud wave got reflected and the entire surface got angulated like this. And this is a typical failure that is attributed due to the formation of the mud wave. Just like how the surface waves form in the ocean similar thing happens even in the soft clays get and that got reflected.

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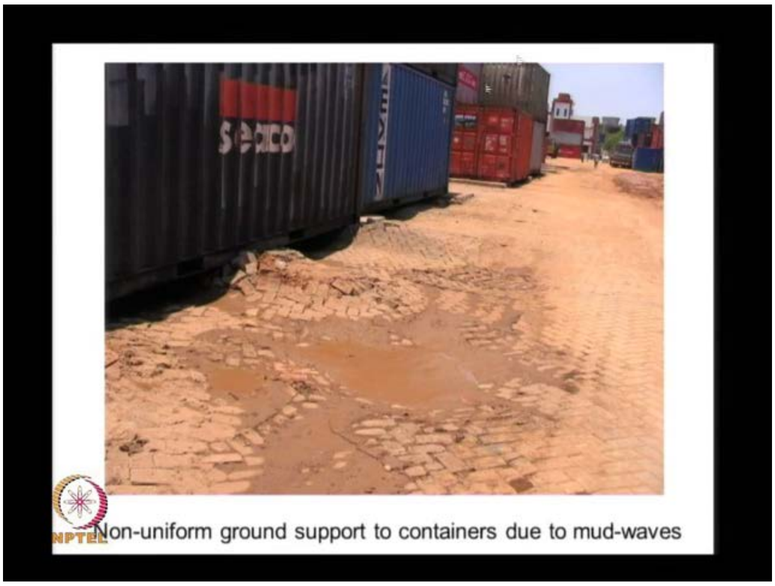

And here you see all these paver blocks, that just simply got lifted up. Here you see the type of support that is there below these containers. And there is a non uniform ground support. So, it is actually this is a very common problem that we face in almost all the container yards because basically, we have extremely soft sub grade soil. And we try to construct and the coupled with the very low bearing capacities our loads very high.

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And these container yards they operate round the clock and all the 365 days in year. In spite of heavy rain or anything these operations do not stop. Here we see another surface depression this is once again at Chennai container yard you see a very large depression.

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And you might be thinking why not we provide a concrete platform. So, that we can avoid all these problems, and here you see a picture of a container yard that was built in Bombay in Mumbai. Here this the surface was paved with 150 millimeters thick reinforced concrete. And in our time the entire concrete got crumbled and here you see this reinforcement bar exposed. And in a just a very short time this is happened. So, that means that whether you have a flexible pavement, or a rigid pavement the problems are the same because of the very low bearing capacity and very poor sub grade soil that we have.

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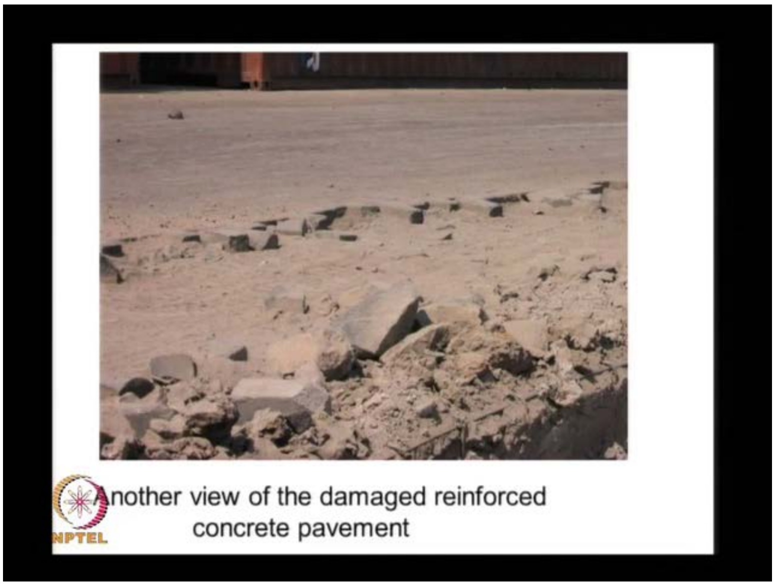

And here you see another view of the same thing with damaged pavement.

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And here you see all these rutting, and this particular thing is with polymer concrete surface finish on top of the reinforced concrete.

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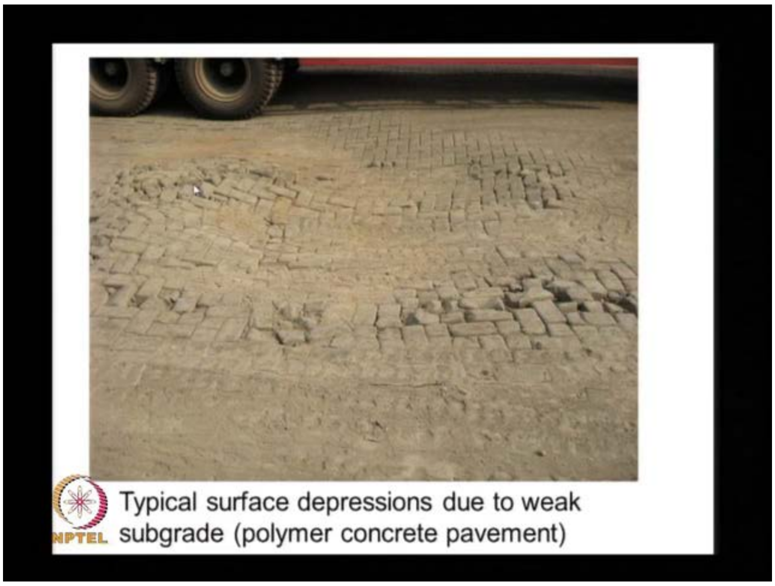

And here you see some more depressions.

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And there is another thing, basically even in a reinforce concrete pavement what we see within a very short time is the crumbled concrete, and debris flying all over because these operations they apply very heavy load. And the sometimes with impact load because when these vehicles move by carrying these heavy containers, they exert lot of pressure on the foundation soil.

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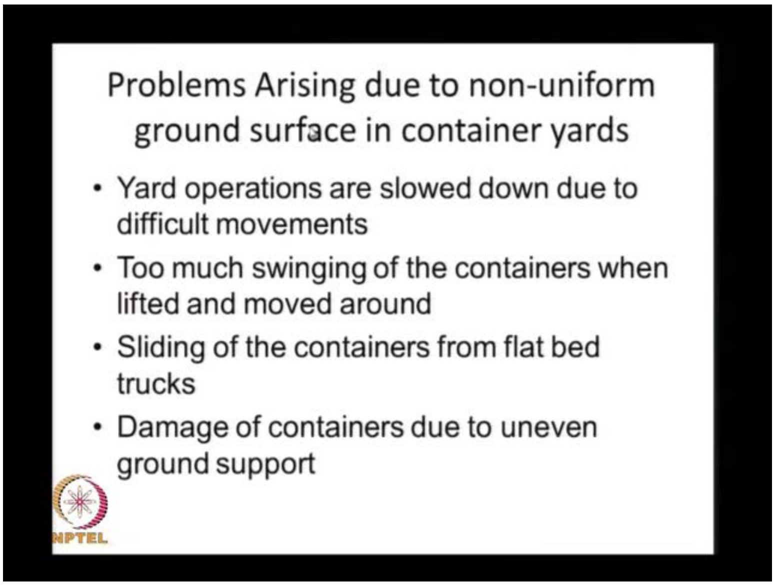

So, what are the problems that we can have because of these non uniform ground surfaces on the container yards. The first and most fundamental is the yard operations they slow down because of the difficulty in movements. And when these calmar units we call them as calmar units that carry the containers and stack them. And when they move on this type of uneven ground with lot of surface depressions, the containers they hang from a height and they swing too much. And it is very dangerous because when this swinging is too much it could impair the operation of this these vehicles.

And in some cases these containers when they come on a flat bed trailers they are no pin down. And they just simply slide down and that is a very dangerous situation because that could lead to injuries to people. Then the containers themselves may get damaged because of the uneven ground support. And once they are damaged it seems they cannot be reused, they are just simply they go waste.

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Observed Thickness of different layers in the Chennai container yard after failure

Location	Measured Thickness of different layers (m)			
	WBM 225 mm	Soling 150 mm	Sand-gravel 300 mm	Compacted murum 2m thick
1	0.140	0.150	0.210	1.80
2	0.180	0.130	0.300	2.54
3	0.200	0.130	0.260	1.62
4	0.180	0.170	0.300	1.95
5	0.200	0.150	0.300	1.67

And this particular yard in Chennai we have done some post failure analysis, we have gone back to the site, and then measured the thickness of different layers that were provided because one question came up that the contractor may not have executed the job properly and. So, we measured the different layer thicknesses by some incite to executions and the original thickness of the compacted murum layer was supposed to be around 2 meters.

So, at different locations we have done this trials at location one the thickness is 1.8 meters at location two 2.5 and location threw 1.6, 1.95, 1.67. So, that means that are the murum layer thickness is not bad, it is its reasonably high and against the sand gravel thickness of 300 millimeters.

These are the observations at three locations they has come out as a approximately 300 millimeters. At one location it was very low 0.21 at one location it was.2 six and the soling layer it was supposed to be 150 mm. It is the same at 2 locations and slightly higher at one location 170 mm. And then slightly lower at 2 other locations. Then against the thickness of 225 millimeters of WBM, these are the thickness that are observed.

So, this shows that the pavement construction was not bad and thicknesses were reasonably well maintain. And these thicknesses they are measured after about two seasons of operations. So, the original thickness may be so much, but during the operation they might have got compacted. And so the thicknesses might have reduced. So, we need to now find out better methods of doing the construction, and if you go back and see the surface mud wave pattern.

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Mud-wave at the surface due to soft subgrade

This is a typical failure that we can expect whenever there is no surface confinement. And if they if we are able to provide a very good confinement at the ground surface, where the pressure are very low we can have better performance.

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And that is the object in this reconstruction works, and what we proposed is why not we confined the top soil by using geocells. And these geocells as we have seen earlier these are the three dimensional forms of the geosynthetic reinforcements. And they provide they all round confinement to the surface soil. So, even when there is a very low applied pressure. There is a good strength that is important to the soil because of the confinement that is given. And so the soil within each pocket is very well confined. And the soil usually does not fail because it is not prevented from expanding laterally.

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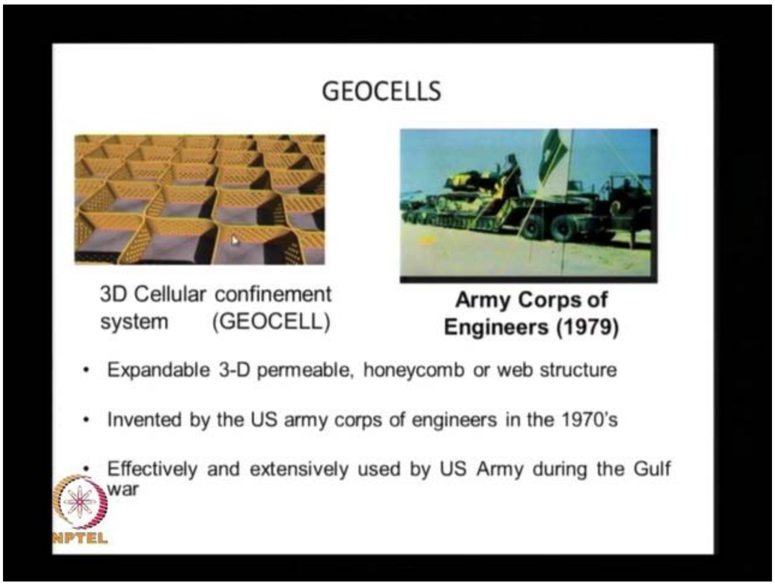

And these are at the different types of geocells here, this is a very old type of geocell where the surface is very smooth and there are no aperture openings in these geocells. Whereas, this is more recent geocell with open apertures, so that there is a better interaction between the soil, and different pockets that promotes a higher interactive interaction coefficient.

And this is a picture of the US army employing the geocell sand, these geocells are three dimensional, permeable because these the new varieties they have openings and they are honeycomb structures or web structures. And they were developed by the US army core of engineers way back in the 1970's. And the US army has used these extensively during the gulf war for mobilizing their equipments through the Arabian desert.

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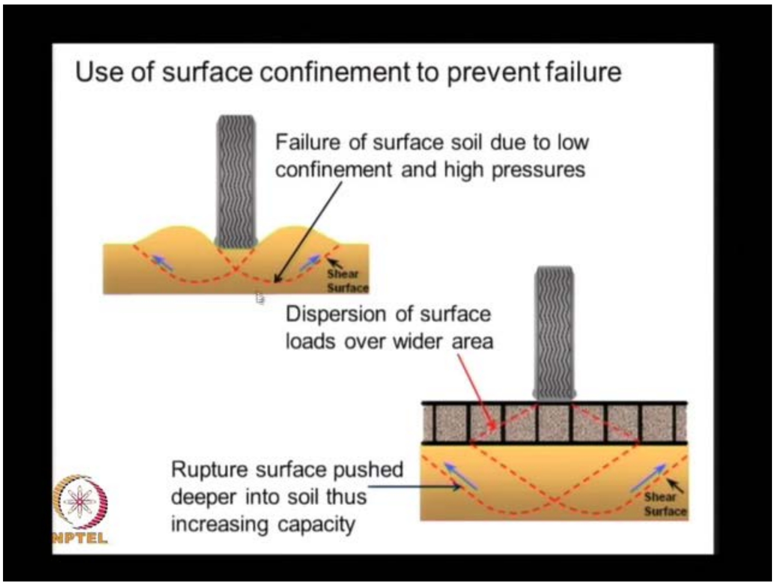

And the principle is very simple let us imagine that we apply some tire load on the surface, and immediately this results in failure of the surface soil because there is no confinement, there is significant heaven, and then we form the rapture surfaces. The failure happens because the surface soil has very low confinement at it is same time there is a very high pressure applied from the wheel from the tires.

And just imagine situation where we provide a geocell like this that is filled with some aggregate material. And the likely scenario of failure is something like this, the tire load gets distributed over a wider area because this geocell layer acts like a semi rigid mat. And that distributes the load over a wider area and because of this there is lesser pressure applied in the first place. And then this wedge of soil is much bigger compared to the previous case of these unreinforced soil. So, we push the rapture surfaces deeper into the soil. Also provide some confinement because of this upper layer and because of this the bearing capacity or the allowable bearing pressure increases by several folds.

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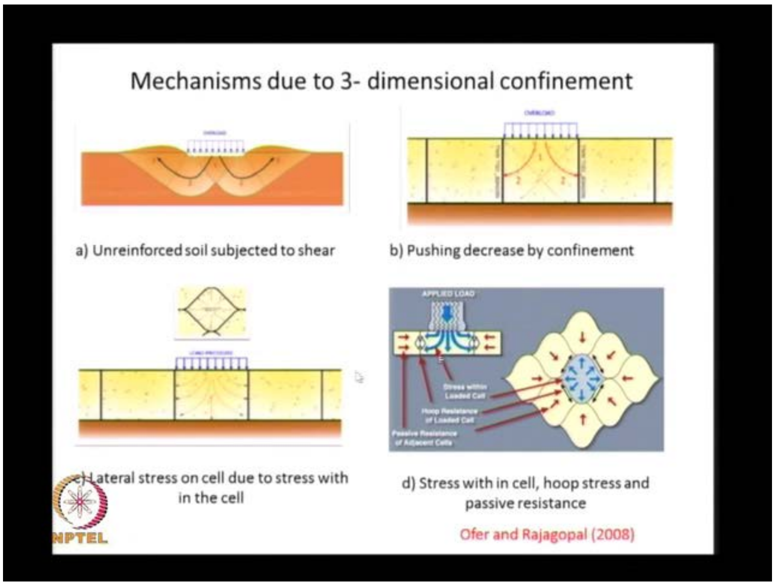

And the principle of this geocells is once again explained in this slide. Here we have the typical rapture surface on an unreinforced soil. And because of this confinement offered by this cellular walls, and there is an abstraction for the formation of these rapture surfaces. So, defiantly this surface has moved down and this is what happens like because there is a good confinement, the soil within this pockets does not fail. And in plan view it is less illustrated like, this any soil in one pocket is surrounded by the soil in the other pockets and it is well confined.

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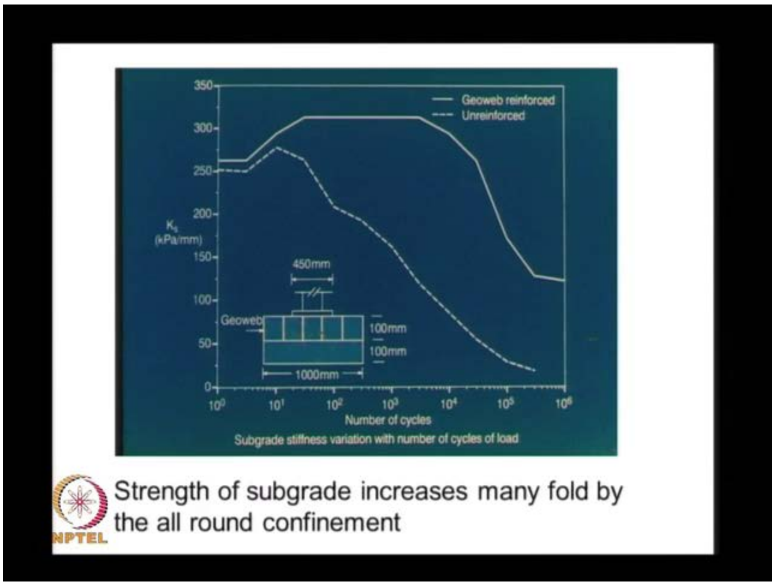

And that confinement affect results in, significant improvement in the performance of the pavement. Here we see the laboratory test data on the sub grade stiffness under cyclic loading. On the x axis we see the number of cycles of the loading, on the you axis we have the sub grade modulus k s. The this test are done in a small box with hundred millimeters of sand. Then 100 mm thick geoweb or a geocell, and geoweb is one particular geocell made by one company. And if you plot a graph between the number of cycles and then this sub grade modulus this dashed line shows, the sub grade modulus of an unreinforced soil sand, initially it is constant.

And then because of the initial compaction the sub grade modulus slightly increases. And then later on it goes on reducing whereas, with geoweb initially there is a good increase in the modulus because of the comp the compaction that the sand undergoes. Then for a significant number of cycles up to about 2000 cycles, the modulus is remaining constant. And then after that gradually the pavement degrades. And then after about 100,000 cycles up to 1 million cycles, there is more of steady state that is reached.

And if you compare this with the performance of the unreinforced sub grade is actually, after almost ten cycles the sub grade modulus started decreasing in the case of unreinforced things and by the time. The number of cycles reached about 100,000, the sub grade modulus is hardly about 30 to 40 whereas, as compared to that of the geocell reinforced one is a nearly 100 and 150 and its staying constant up to 1 million cycles.

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And here we see the application of the this similar type of geocells in the Thar desert. This work was done for the Indian army, here you see these soldiers expanding a layer of geocell on sand and it is filled with soil by an exculater like this. And then here you see this heavily loaded army trucks moving on this test bed just for a trial purpose. And after this construction we have done about 100 load passes. There was no significant rutting, and these vehicles were able to drive freely without much of attraction that is without going down into the lower gears. That means, that the sub grade that is reinforced with the geocells is able to offer good support.

So, that these vehicles can maintain a good speed, the length of this trail states was approximately 100, 225 meters. So, the parameters that were noted was the comfort of the driving that is the tire pressure that could maintain. And then the speed of these vehicles and then the surface rutting. There was there was no significant rutting that we could see after about 100 passes.

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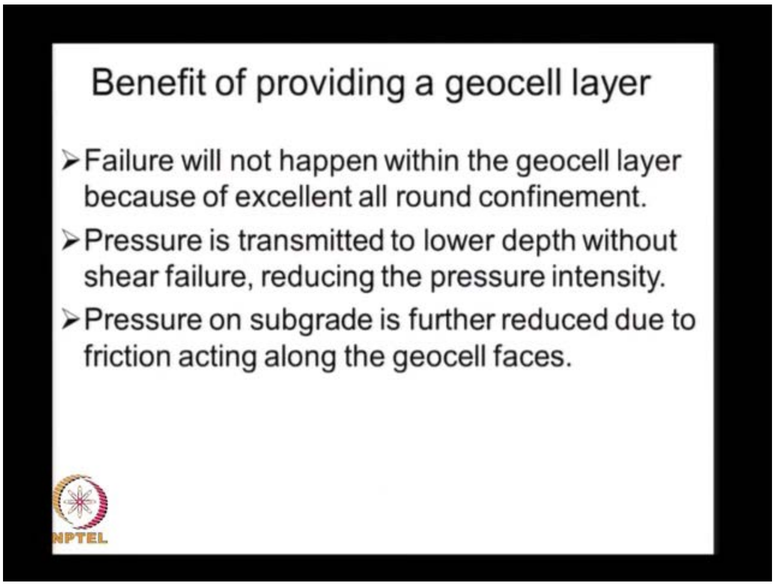

So, that is the advantage of providing the geocells. And some of the benefits of providing the geocell layer is the failure, will not happen within the geocell layer because of the excellent all round confinement, that we have already seen earlier. And the pressure is transmitted to a lower depth without shear failure because our soil is confined. And in the process of transmitting the pressure through the thick geocell, or the semi rigid geocell the pressure intensity reduces. And the pressure on the sub grade is further reduced because of the frictional force that is developed along the walls of these geocell faces shown here.

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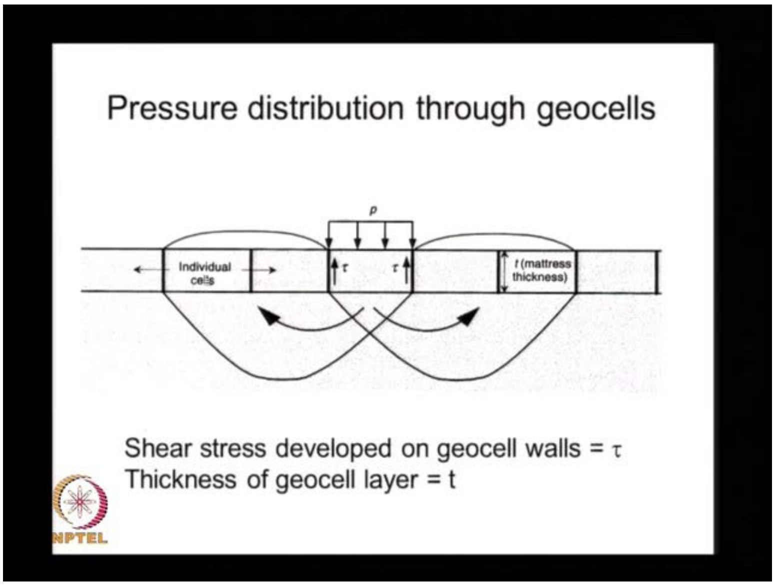

Let us say that this is our geocell layer and we apply the pressure. And there is a skin friction force that is developed on the cell walls, and because of that the pressure reduces and that is illustrated in the next slide like this.

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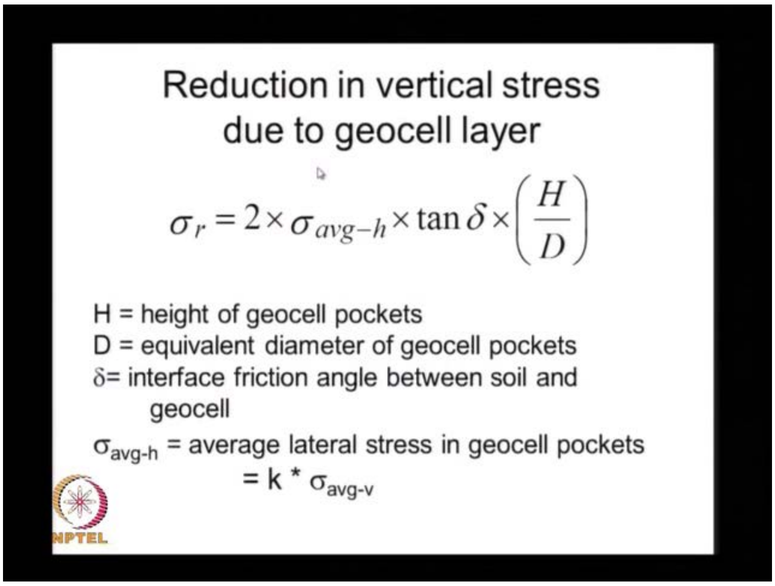

Actually the reduction in the vertical pressure is expressed like this, the 2 times because there are 2 sides of these surfaces. And then sigma average h that is the average lateral pressure times tan delta. Tan delta is the interface friction factor times H by D. H by D is our aspect ratio as the height is increasing the affect of the geocell increases, and as the diameter is increasing the affect of the geocell decreases.

So, we have this parameter that expresses the influence of the height to diameter ratio. And this sigma average horizontal or the lateral stress is equal to k times sigma average vertical. And this k is usually we take k a, although the strains within the geocell pocket are very small they could be more similar to k naught, but still to be on the conservative side we take this the k factor as k a.

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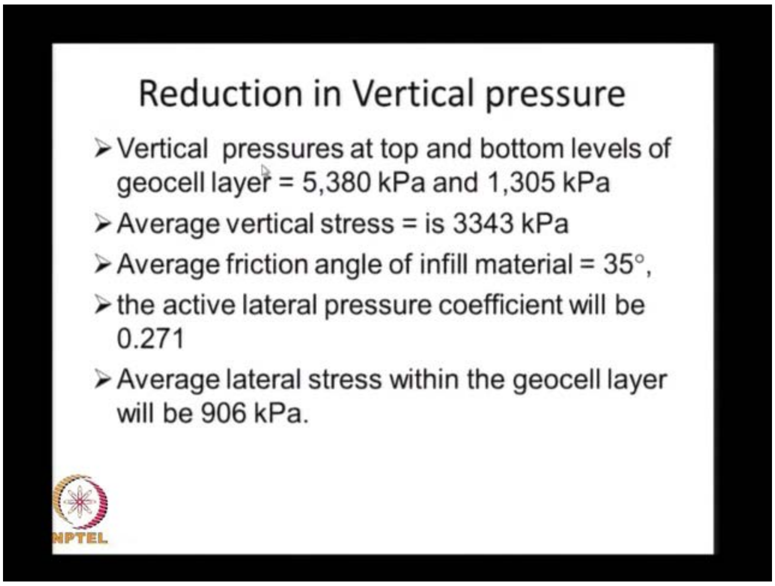

And for this particular design case that we have, the pressure that acts at the top of the geocell layer is 5380 k P a, at the bottom of the geocell layer its 1305 k P a. The actually this particular result that you are seeing is with some other applied pressure of 15000 k P a, that gets generated with 4 rows of these of these container stack, one on top of the other. Then normally we consider an additional 20 percent impact factor because when these containers are stacked they are not static operation, they are just simply dumped.

And with that type of pressure we can reduce them to this these levels, when the pressure is acting through the geocell. So, the average vertical stress is the average of these two pressures that is 3300. And if you assume that the friction angle of the infill material is about 35 degrees, the active lateral pressure coefficient is 0.271 and this 0.271 times this average vertical stress gives us a lateral stress of 900 k P a.

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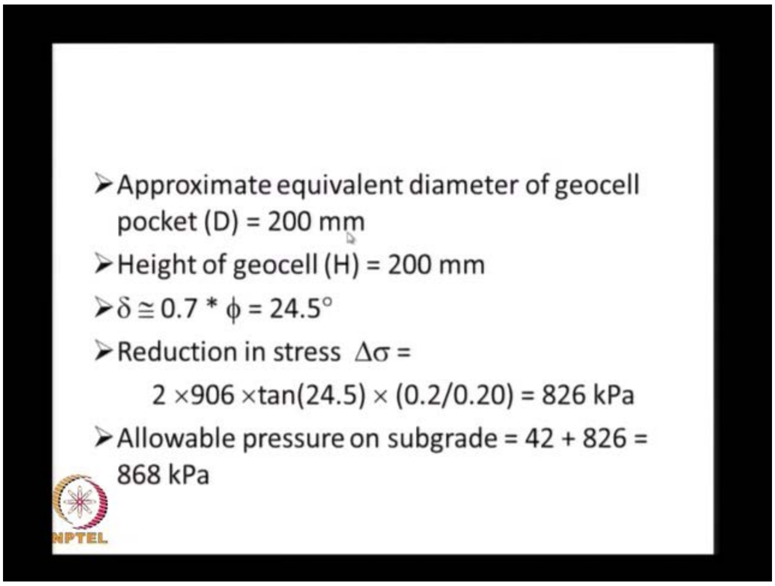

And typical geocell will have a pocket opening dimension of 200 millimeters, and the particular geocell that is used has a height of 200 millimeters. And the delta is approximately taken as 0.7 times friction angle phi that is 24.5 degrees. So, the reduction in the stress, when the pressure is transmitted through the geocell is approximately 820 k P a. And this we can actually see that because we are reducing the pressure that is applied by this magnitude. In other words, we can increase the pressure on sub grade by this much because any way this pressure is not transmitted. So, the allowable bearing pressure can be written as 42 plus 826 that is 868 k P a. And if we substitute this 868 in the Boussinesq's equation instead of 42 we get the thickness of the pavement as only 450 millimeters.

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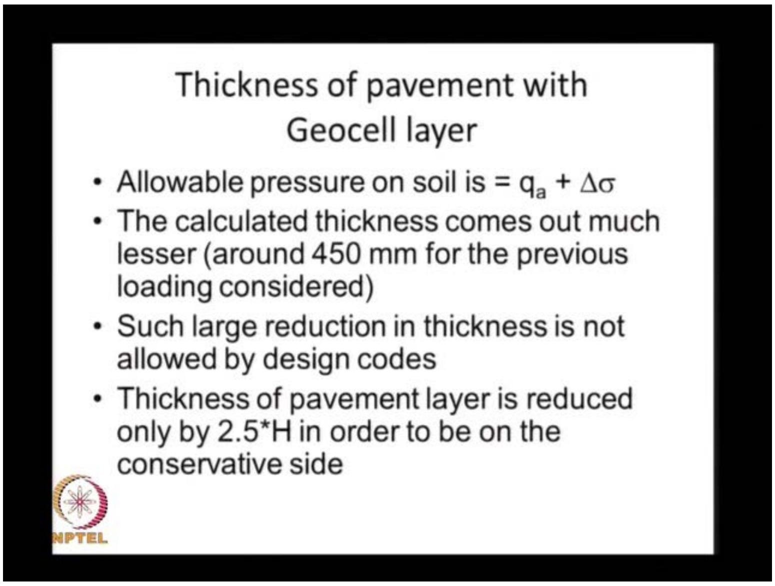

And so the thickness that we have calculated as 2.5 meters can be reduced to 450 millimeters. If you are able to provide one layer of geocell because of the combined action of the soil plus the geocell, but then the codes of practice they do not allow that because such a drastic reduction in the thickness we do not know what really happens. And so the codes of practice they say that the thickness of the pavement, that we calculate for unreinforced soil can be reduced by a maximum of a about 2.5 times the height of the geocell. So, that we are on the conservative side. So, with this approach this particular a pavement layers were redesigned one in Mumbai and one in Chennai.

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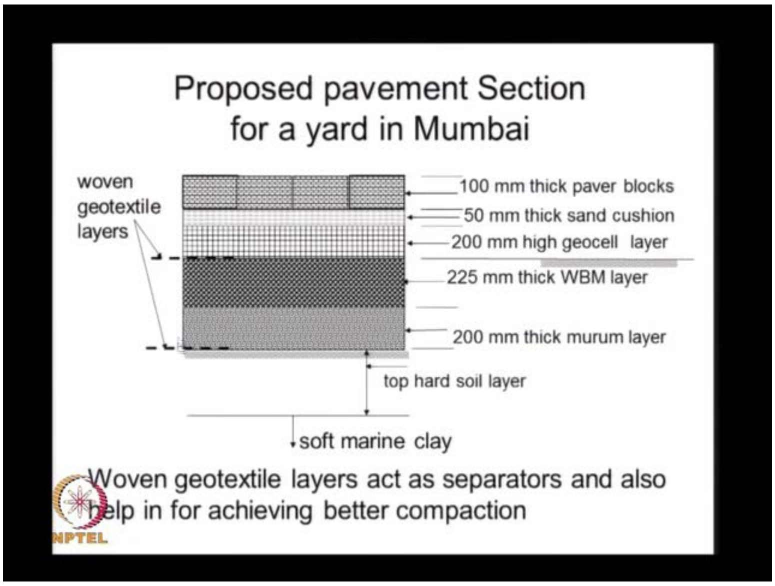

And this is the typical cross section that was proposed, the total pavement thickness that was pro provided was 1.5 meters out of that the top about 1 to 1 and half meters hard layer was used as part of the pavement. Then one woven geotextile layer was spread on top of the existing soil. And then 200 millimeters thick murum layer was compacted. And this particular geotextile layer here was provided not only to act as a separator, but also we need a good base so that we get a good compaction.

If the sub grade is very soft even when we roll the compactor, we will not achieve the compaction and because of that we have used a woven geotextile because these woven geotextile as know, they have higher strength and higher stiffness. So, they can not only act as separator, but also act as a reinforcement layer. So, we have 200 millimeter thick murum layer and then 225 millimeter thick WBM layer. Actually the original ground level is here and we suggested that they can execute that soil, and construct these layers. And then on top of this we have the 200 millimeters thick geocell layer and 50 mm sand cushion and then 100 mm k paver blocks.

Once again these paver blocks are made of m 50 grade concrete. And then additional geotextile layer was provided below the geocell, because the geocell requires one separator because we fill these geocells with stone ships. And unless you have a separator they may sink into the WBM layer because the WBM is made up of larger size stones that may have large size voids.

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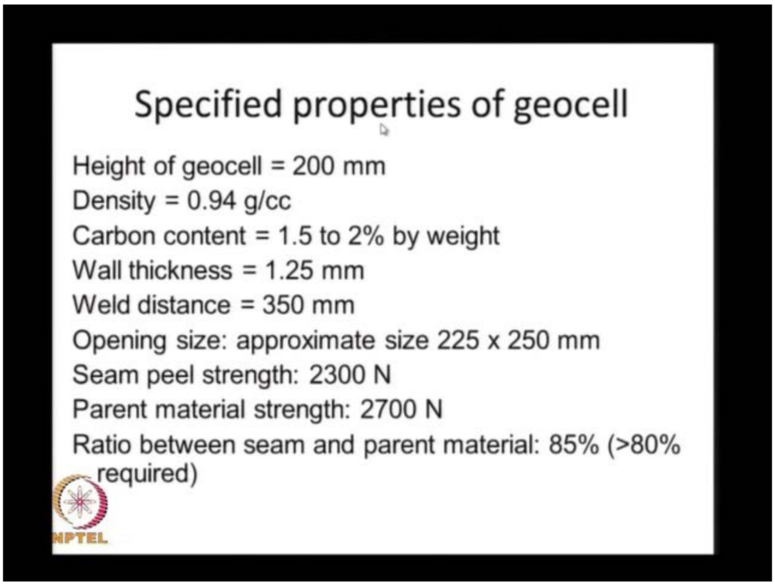

And the properties that are recommended for the geocell. The height of the geocell used was 200 millimeters. This is made of high density poly ethylene having a density of 0.94 the carbon content as about 1 and half to 2 percent. And the wall thickness is 1.25 millimeters and the weld distance 350 mm. These geocells they are made by cutting certain height of this geomembrane type of material. Then they are lied on top of each other and then they are ultrasonically welded at certain distances.

And the weld distance controls the size of the pocket, and also the performance of these of the geocells because the weld distance too large some of the geocells, they come with weld distance as much as 500 to 600 millimeters. And they may not perform as well as the geocells with shorter weld distances. The opening size is approximately 225 times 250 mm. The peel strength of this the weld is 2300 Newtons. And the parent material strength is 2700 Newtons. This is for 200 millimeters high and the approximate ratio of the seam strength to the parent material is 85 percent.

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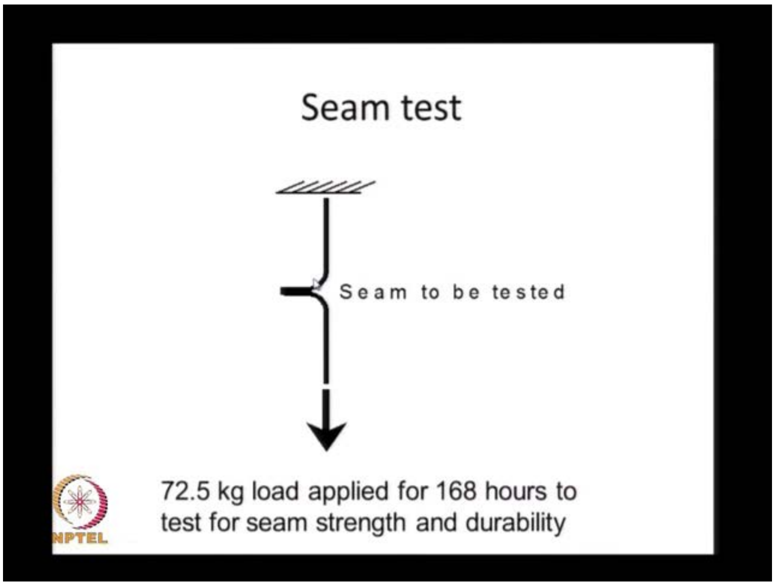

And the seam that is in the geocell is tested as per the ASTM standards. It should be apply to a static load of 72.5 k g that is for a width of 200 millimeters. This load should be kept constant for one week, that is 168 hours. And within that time this seam should not peel off. And that shows that the ultrasonic welding is of good quality. The geocell that we have is durable because some of the material that we have tested they have just simply peeled off. Initially they had a good strength, but after about 1 or 2 days time this weight just simply started sliding down because this seam was giving way.

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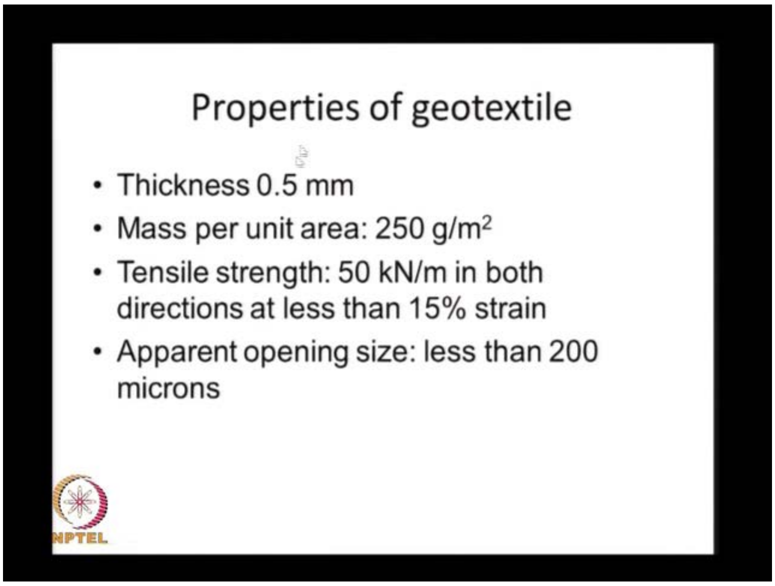

The properties of the geotextile that were recommended is thickness of half a millimeter and mass per unit area 250 grams per meters square. And the tensile strength 50 kilo Newtons per meter in both the directions at a strain less than 15 percent. And then the apparent opening size is less than 200 microns. So, that it can act as a good separator.

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And the general view of the site is look this is actually, it is the top soil it is a hard crust of murum soil and may be top soil. And that we can take advantage of this stiffness of this top soil in our pavement construction.

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Here you see the geotextile that is being laid on top of the WBM. And here you see this the geocells being spread and these geocells.

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They are manually spread and anchored by using some wedges. And then they are filled with stones ships and then they are compacted.

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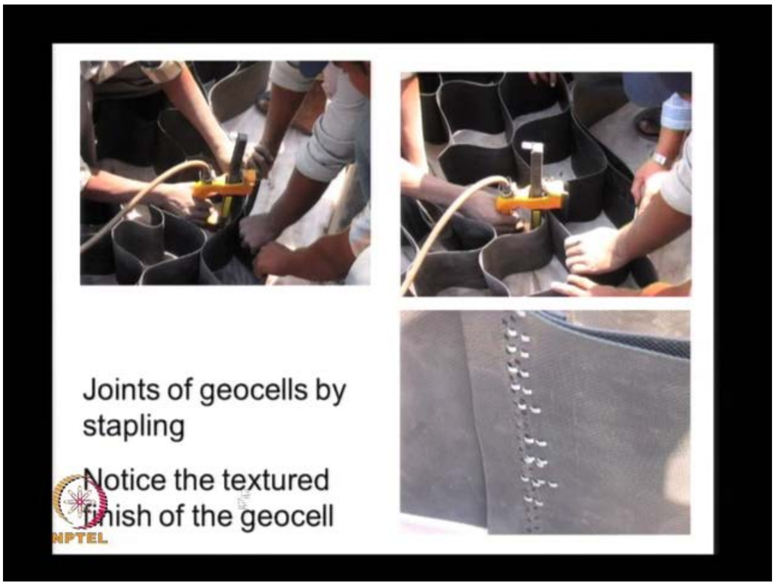

And here you see this welding of the geocells because these geocells they typically come in a width of 3 to 4 meters and 20 meters length. And when we are spreading very large length, we need to join them together. Here we see this stapler that is joining this geocells, here you see this stapled geocell. The particular geocell that was used in Mumbai, it was a textured on. And there are no openings, there are no pocket openings in these geocells.

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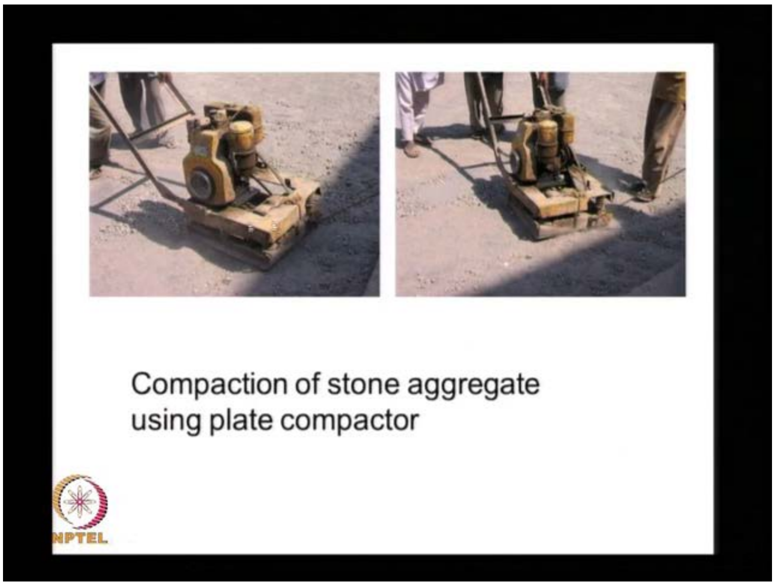

And the top surface was finished by providing the sand dust and then compact with a plate compactor.

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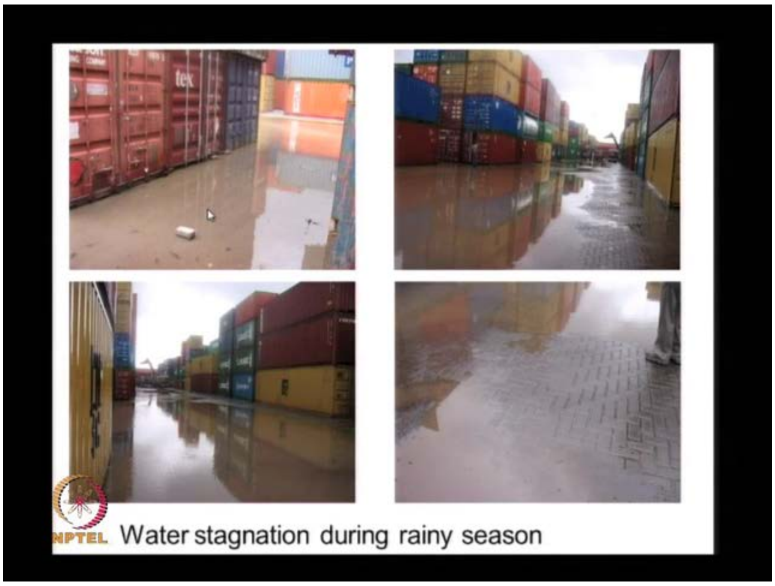

And the performance was reasonably good until in 2006, there was a heavy rain in Mumbai about 2 meters rain in one single day. The entire yard was flooded you can see this water and even in those that heavy rain are the container operations were going on they did not stop. And is actually this water stagnation in spite of providing for the surface drainage the water stagnated. The water coupled with soil is always a disaster because this soil will have a good strength on its own, but coupled with water because of the reduction in the in the affective stresses it is not good for the soil strength.

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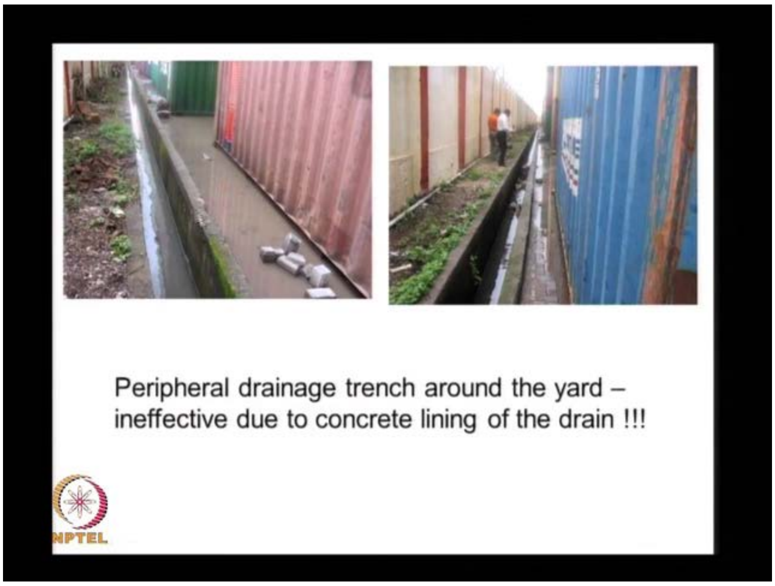

The particular problem in Mumbai was, although there was a surface trance all around the area, but that was lined with concrete lining. So, in affect we are preventing the water from going into the drain, although there is drain, but water cannot enter into the drain because reactor is a there is a concrete wall. So, in affect there is no surface drainage at all.

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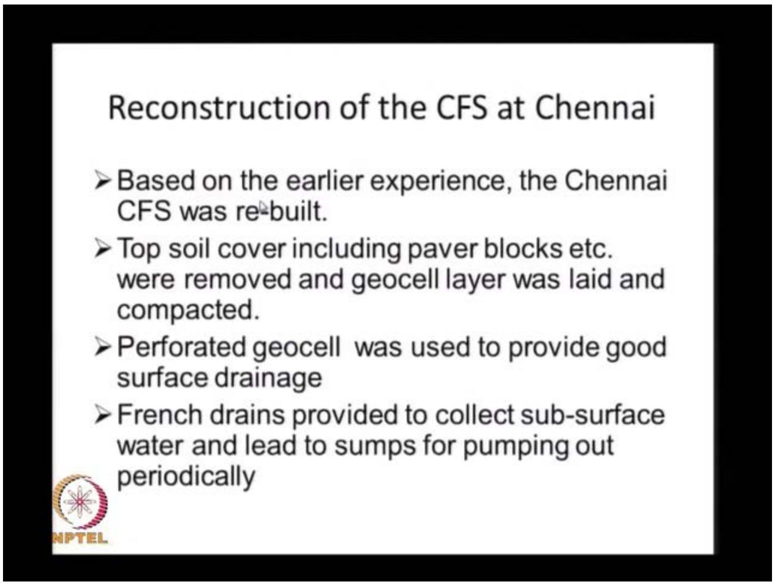

The same time the container yard in Chennai was also under repair. And what we recommended based on the experience that was gained earlier, is that we should use the perforated geocells. So, that there is a good cross drainage facility, and we should also provide a French drains to collect sub surface water because we cannot prevent water from entering.

Although we provide some surface drainage by providing a camber, and other thing that is not sufficient because some times when we have heavy rain, the water does enter the sub surface. And here in this Chennai container yard, when it was reconstructed the French drains were provided at some depth. And then the water was lead in to the sumps in. So, that it can be pumped out.

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And here you see this construction, the geocell that is used it has open apertures. So, that there is facility for cross draining in addition to this strength that we have.

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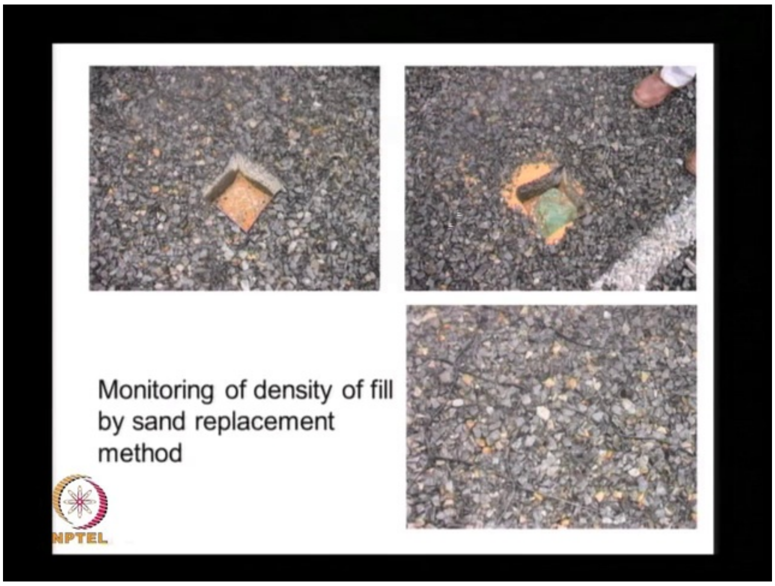

And the compaction density was monitored by using the sand replacement method, we have determine the incitive density. And here you see this geocell pockets that are expanded when we fill it with stones and then do the compaction.

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And here you see this sand in sand cushion and then the paver blocks. This particular paver block arrangement is called as the herring bone. And they are very well interlocked, that interlocking is essentials because these vehicle that move within the container yards, they have a very heavy rubber tires that produce lot of surface friction. And unless these are very well interlocked these tiles might just simply come loose.

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And here you see this the peripheral terns, and then below there is French drain like this. This is actually it is a perforated pipe covered with a geotextile. And this is provided at some at depth and then the water is lead into some traps, or some sumps at periodic intervals. And in the heavy monsoon rains we just simply put a pump and pump out the water. So, that we do not have much of water stagnation.

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And after these repairs by using geocells, geotextile as a separator and geocells as a surface confinement layer, this the performance is actually this entire yard it has maintained a good level. This is pictures taken three years after the reconstruction, and here you see that there is a very good support that is given to these containers.

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And here you see some more pictures, the only damage that is there is some of the paver blocks they got warned out because of the continues passes of the vehicles.

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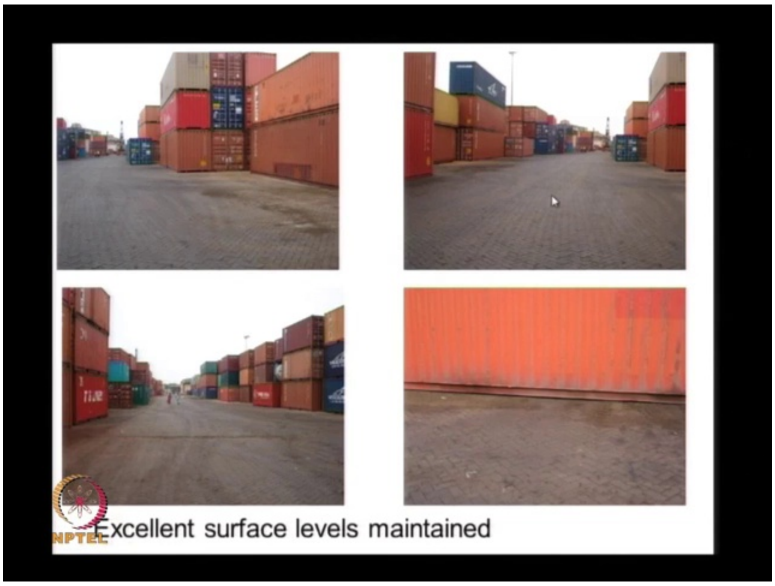

And here you see some more pictures of the same thing. This entire stretch was the same 1 that you have seen earlier with lot of mud waves that were formed. And now because of the confinement that is given at the surface. And then a geotextile reinforcement that is given at some depth the pavement has adequate stiffness. And then the drainage was also provided because at some depth we have a trap to collect the water, and lead it safely away from the away from the yard.

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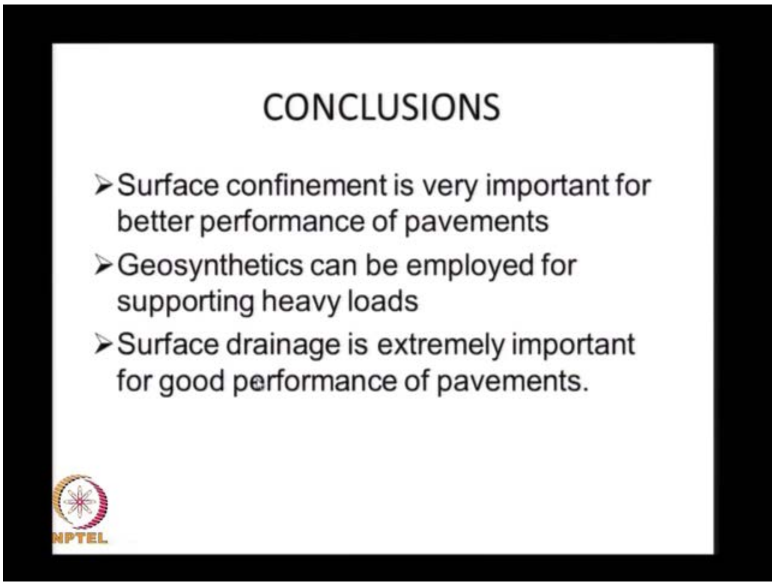

So, the conclusions are surface confinement is essential for the long term performance of these pavements. The geosynthetics can be employed even for supporting very heavy loads because the geosynthetics we make think they are flexible and very soft, but still we can synergetically combine the these geosynthetics and the soil. And come out with semi rigid pavements whose performance is known to be much better than even the performance of the reinforced concrete. The surface drainage is extremely important for the good performance of all the pavements, whether it is a container yard or road pavement, the drainage is essential.

So, thank you very much.