Geosynthetics and Reinforced Soil Structures
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Lecture No - 19
Case Study of the Construction of Very High Tiered Reinforced Soil Walls

Very good morning, students in the previous lectures we have seen the design and the other aspects of the reinforced soil retaining walls. In this lecture I want to explain the case study of the construction of very high retaining walls in India. I will go step by step, and why this system was selected? And how the materials were selected? And what were the construction aspects and then other associated factors?

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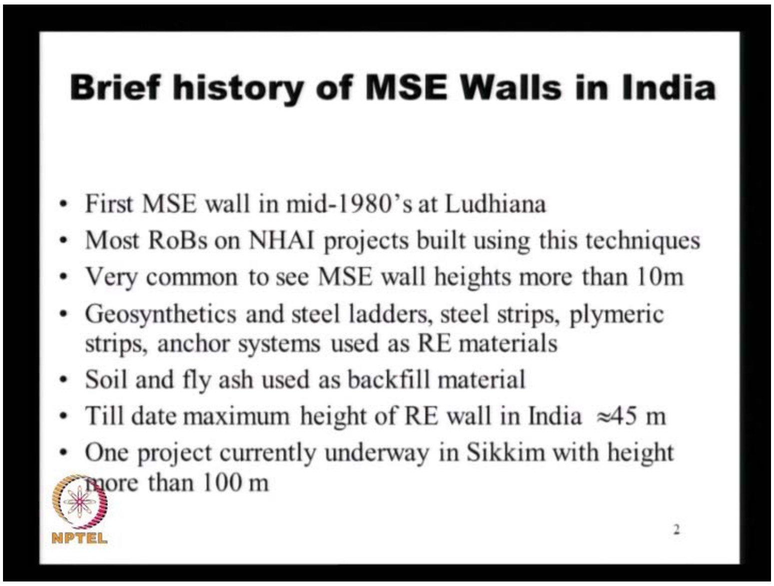

As, we go along brief history of the mechanical stabilized earth walls or just simply reinforced soil retaining walls or like this. The first wall was built at ludhiana the mid 1980's that was basically an experimental type of case study that was proposed by central road research institute. And, that particular wall was about 9 meters, and they used fly ash as backfill and they found that they cost economy is about 40 to 50 percent because they were able to avoid the import of materials and so on.

And, at the present moment or the past 25 to 30 years lot of developments of taken place in the technology not only in India, but even in a other countries. And, now we have reached such a state that most of the road over bridges road over bridges in India that are built on the national highways. As a rule they used this technology of reinforced soil retaining walls for all the approach roads. And, it is very common as we travel along the highways to see the walls of about ten meters height.

And, varieties of reinforcement materials were utilized for different constructions. For example, the geo-synthetics like the different types of geo-grids an excluded, and then oven and knitted type of polymeric geo-grids and then the steel ladders that is the welded wire steel meshes then steel strips and then polymeric strips. And, then anchor systems especially with steel strips within anchor of the end to increase their pullout capacity and both the soil.

And, the fly ash is used as backfill materials and till date the maximum height of the reinforced soil wall in India is about forty five meters, and that is the case study that. I am going to discuss in today's lecture, and one project is currently underway at Sikkim, where in the height of the support is exceeding 100 meters. It is about 100 and 10 meters. It is not technically a vertical wall, but it is a steep slope.

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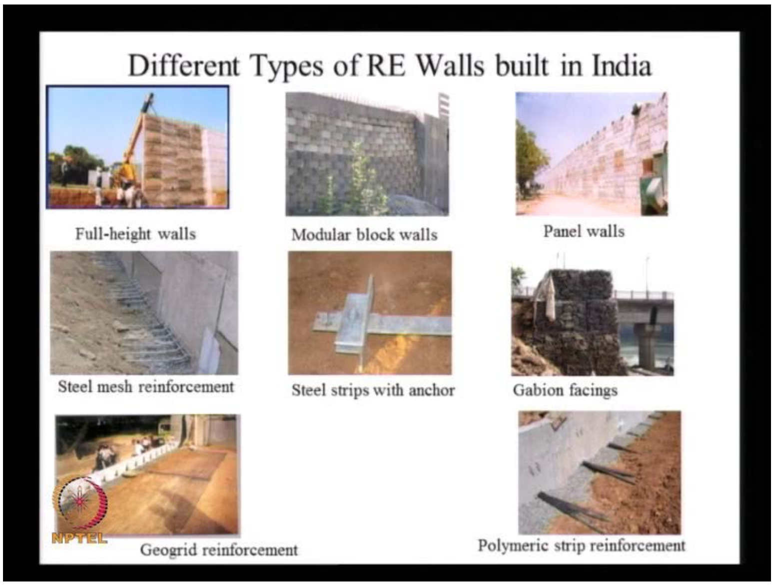

And, this particulars picture shows the variety of the reinforced earth walls that were built in India. The full this picture shows the full height facing panel wall, wherein we casting the facing panel and at the time of casting. We put in some small strip short strips of the reinforcement at the time of casting and, then we later on attach the necessary length of reinforcement through some pot can under the things.

And, here is a modular block wall, where in the front facing is made of sin small sized blocks and these are this is a wall built with a panels each about one and half meters to 1 to 1.5 meter, wide about 1 meter height. And, this actually here we see another close up of the panel wall and the reinforcement is a steel mesh. And, here you can see how the this steel mesh is connected to the front facings through this hooks and then this cross road and here we see an example of a steel strip being used as a reinforcement along with an anchor.

So, that the higher pullout capacities can be mobilized, and here we see a geo grid being used as a reinforcement layer and in this picture. We see the gabions the stone field metallic gabions used as facing elements, and here we see another example of retaining wall with facing panels, but with polymeric strips. And so, we can see that variety of reinforce retaining walls were built in India.

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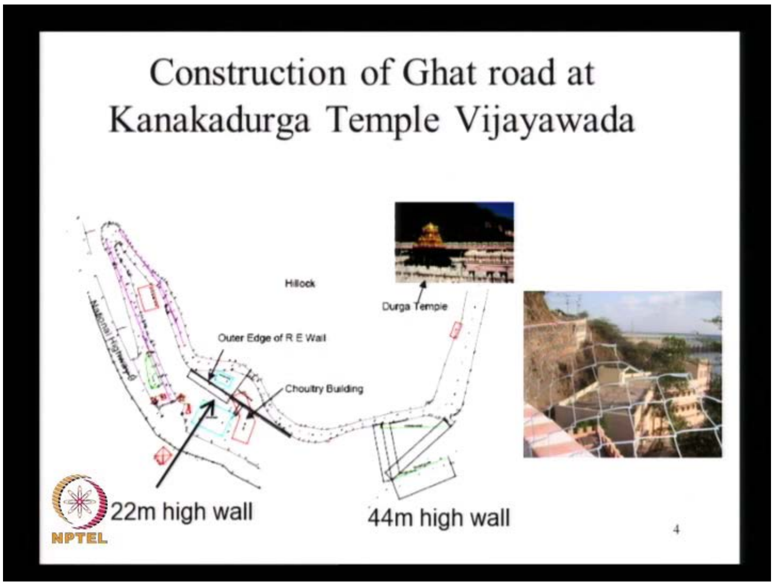

And, in today’s lecture I will describe the construction of very high retaining walls that is up to 45 meters 44 meters to be very precise that has not been built in India till date and the even in the world. These walls will stand as one of the tallest and this particular construction to place at the ghat road leading to kanakadurga temple at Vijayawada.

This is the inset show the temple and this is at the top of the hill, and there is an approach road that was built in the mid thirties or forties probably initially started as a footpath later on it got widened and made into a motor-able road and this particular strip. This is how the road goes, and then it wide around and then it goes up to the temple and the there were two walls that were built along the strips at 22 meter high wall and then along this strips.

This is a 44 meter high wall, its actually both of them posed a lot of challenges mainly, because this particular heights have never been constructed in India more than about 15 meters never been constructed. So, this the backside of this ghat road all fully hillock area hill and a photograph of the overall site conditions is shown here is actually. This is the road and that is the hillock and this is the bottom level of the road.

And, the purpose of this construction is to widen this narrow road, because the narrow road is, so narrow that it was meant mainly for bicycles and scooters and later on people started using cars. Then, you have to squeeze through very narrow opening, which is a quite dangerous then after if too many people drive the cars up to the temple. There is no parking space, so that has to be also catered for in this constructed.

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And, here you see the narrow stretch of the road the actually it is. So, narrow that not more than one small car can pass through, and this has to be somehow widened you can see the conditions of the hill here is actually the, this hillock lot of problems. Because, there are too many joints and crevices and frequently at here in the monsoon time huge boulders fall down, because of the number of cracks that are there in the site. Then, another problem that we have is just next to this is the major Krishna river and. So, we cannot exceed our boundary beyond certain limit.

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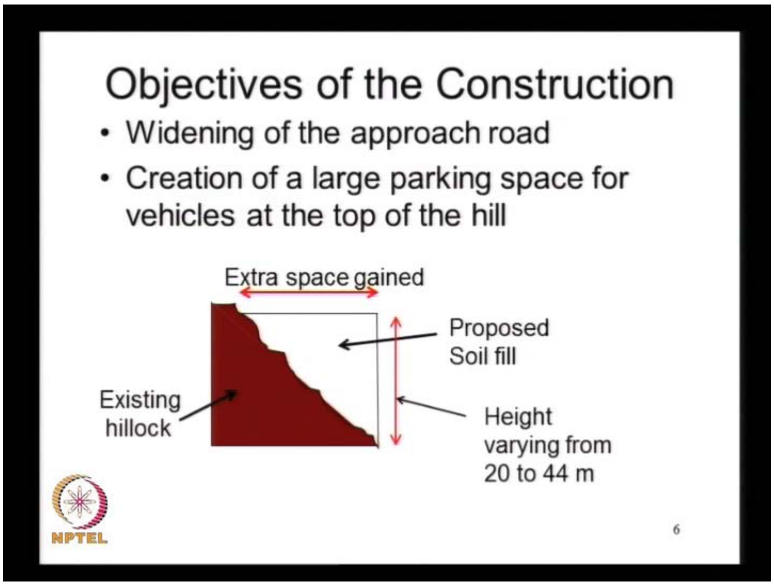

So, let me highlight the purpose of this construction the purpose of this construction was too fold that is widening of the approach road as I have shown earlier the purpose of constructing one of the walls is to widen this road and another wall is to create a large parking area at the top of the hill. So, that people can park their vehicles, and this schematic is shown here. Let, as imagine that this is the hillock that we have, and then we want to create some extra space at the top either for widening the road or for creating the parking the space.

And, that space we will get only if we fill this area with some material and invariably that material happens to be soil. Because, the soil is pentilly available and it is relatively inexpensive compared to other construction materials like reinforce concrete and so on. And, of course the material that we can think of is the pond ash or the fly ash, but there is not much of an experience in using pond ash for this height of construction. So, here at this particular space it is proposed to form this soil fill. So, that we can gain this space and approximate height, where is anywhere from about 20 meters to 45 meters.

So, this the and if we can make this space as vertical as possible, we can gain this space without encroaching on to the other side. The main problem here is just to the right of this, there is a busy national highway and just next to that is the Krishna River. So, we cannot really think of extending our property boundary beyond this line that is the major constraint see. Whenever, we have a construction project we should look at different alternatives, so that we can choose what is the best for our site conditions? Considering the cost factor, and then the time factor, and then the practical construction aspects.

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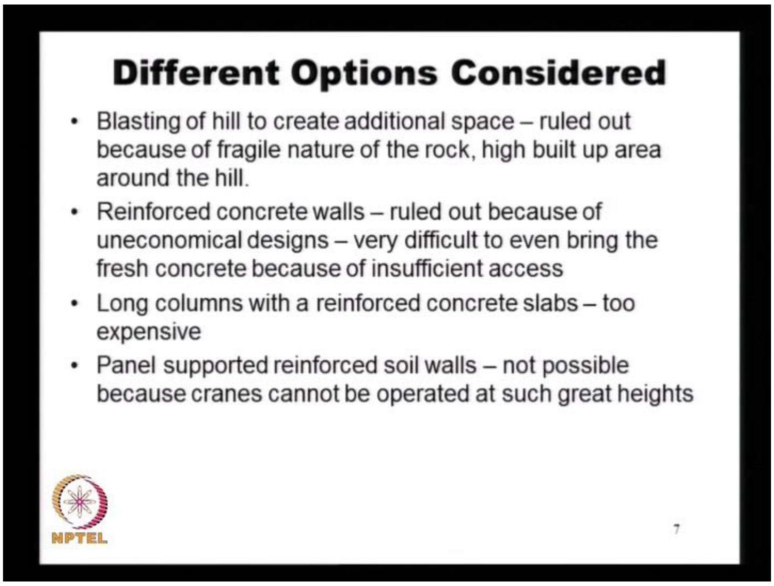

And, in this particular case we can consider different options lie. We can create wider road or parking space by blasting of the hill to create the additional space, but that is ruled out primarily, because the fragile nature of the rock does not permit for control blasting and the also the entire in area around the hillock is highly built up. And there is too much population to take any risk of any flying dewberry falling into the neighboring habituated area or another possibility is we use a reinforced concrete retaining wall to that safe

We can construct a reinforce wall retaining wall. Here, we can back fill this with soil and gain this space, but that is rules out because of cost considerations. Once again it is very highly uneconomical, because even for a say for about 3 to 4 meter. Height of the wall the thickness of stem comes out to be about 300 millimeters and for a height of 44 meters.

The height could as high as about one eighth of that, so it is about it will be about 5 to 6 meters wide. And, then it is mainly ruled out not only because of the cost factors, but the approach area. So, narrow that we cannot bring in the concrete lorry to, and so it is very difficult and then pumping in the concrete from high height is also problem, because that also we need to see how practicable.

It is to pump the concrete at very high heights or other possibility is we built very high columns with reinforced concrete slab at the top, but then that is also very expensive, because the height of the column. When it is greater than some value you know that buckling will be a major phenomenon that to control the buckling these columns have to be of very large size then they need to be supported by some means and that proved out to be very expensive.

And, it is not possible and the simplest alternative is to go in for reinforced soil retaining walls and among the reinforced soil retaining walls. One popular option is by using spacing panels with these panels are about 1 and half meters wide to one and half meter 1 to 1 and half meter wide, but that is ruled out at this particular place, because this size of panels.

They weigh about 1 and half to 2 tons and we need a crane and especially operating the crane at a ground level is not difficult. But, as the wall is progressively increasing in height, how do we move the panels to that height that was a major problem? So, it is once again these panel supported reinforced soil was not possible, and so based on all these considerations.

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The we have to choose the particular type of facing panel and the system and some of the anticipated problem that were taught about even before re-suitable system was identified. It has a very limited axis to the construction site is actually, it is I will show some pictures, where there is a very narrow path way and heavy rain fall. Because, this particular place Vijayawada receives about one and half meters rainfall every year on the average, and we should anticipate very large surface run-off from the upper reaches.

Because, this is all hillitery and even if there is a very small rissole it results in very high surface run-off, and is a limited space for mobility of the equipments, because as oppose to the construction of the r o b's, where there is a free opening on one side through which you can bring in the equipment here there is no such possibility.

And, because of that we have to think of some engineers ways of construction and the major problem is the large height of walls of this kind, which were never built in india then the hill slope itself has lot of disintegrated rock with several joints, and fissures and then there are frequent boulder falls at least once or twice in year it happens. So, we should design our system to overcome all these all these problems.

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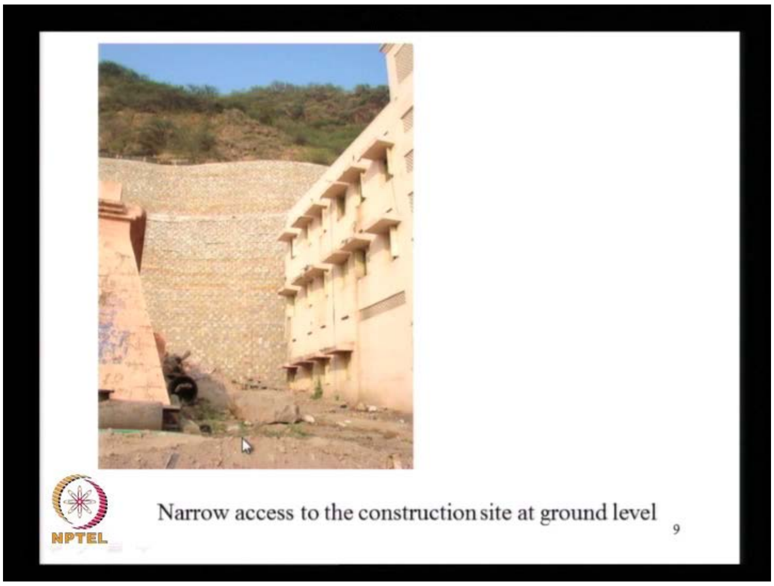

And, this picture shows the narrow axis road, because this entire area is highly built up there is one building here, and there is one building here and this opening is hardly about 2 and half to 3 meters, which is too narrow for any large construction equipment to come through and So, we cannot really think of moving a heavy crane or heavy lorry load of vehicles coming in here, because this particular wall is just nearly touching this building. So, there is a great constraint on the space that that we have on this site.

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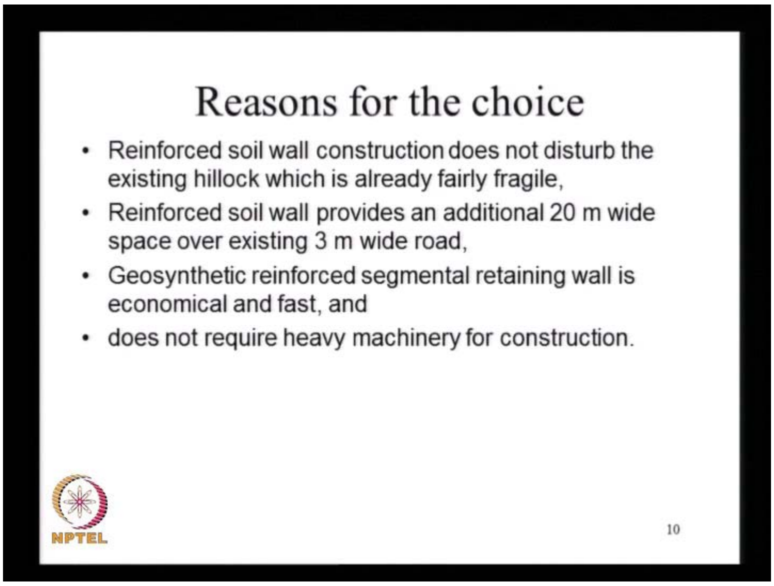

So, this the reasons for the choice of reinforce soil option is the construction of reinforced soil was does not disturb the existing hillock, which is already very fragile. So, this because the construction of the reinforced fill does not impose too much of load. Because, we are only placing the soil and then our facing panels or the facing elements are all very light weight.

And, this reinforced soil wall it can be constructed fairly steeply vertical angles, and it can provide an additional 20 meter wide space over the existing three meter wide road. So, that is that is the that is an advantage for us to create very large parking area. And, this geo-synthetic reinforced segmental walls that is the type of systems that is proposed found to be economical all over the world and very fast for construction and they does not require heavy machinery for construction. This is the most important factor that we need to consider, because and we cannot bring any construction equipment.

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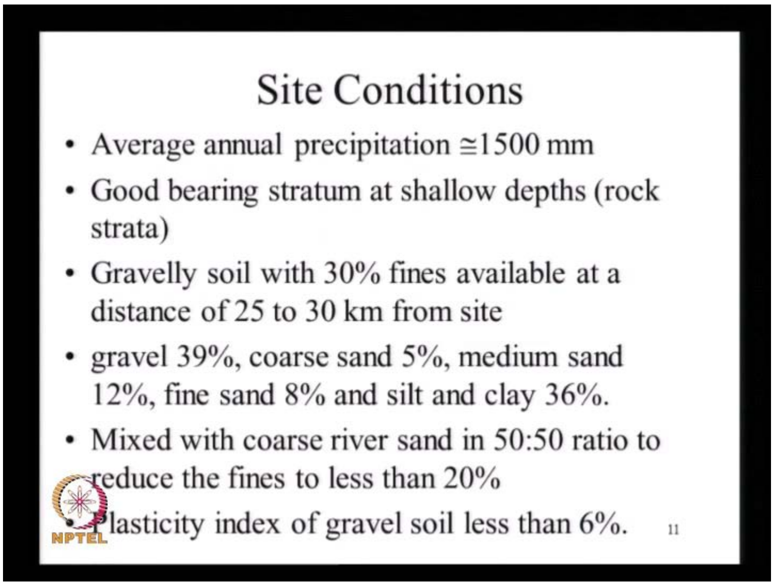

So, the site conditions are like this the annual precipitation is fairly large about 1.5 meters, and there is a good bearing stratum and very shallow depth. And, there is a rock shallow depth of about half meter to one meter. So, that means, that we do not have to go in for any foundation soil treatment and the only problem is there is not much of construction fill that we can that we can use at a nearby site, and there is a quarry at about 25 to 30 kilometers from the site. And, there is a red gravelly soil that we call as morum with about 30 percent fines, and the exact content of the soil the gravel content.

That is the particles coarse sand 7.5 millimeters 39 percent coarse sand about 5 percent medium sand about 12 percent fines and 8 percent and then the silk and clay is about 36 percent and as we have already discussed any soil with fines percentage more than 15 percent is not allowed as per the relevant codes of practice. So, it was proposed that we bring in the soil, but mix it with a river sand that is available to some extent nearby in 50 percent 50:50 ration to reduce the fines to less than 20 percent.

And, it was mixed locally at the site and the plasticity index of the gravel soil is less than 6 percent, because the clay is not very active clay and, because of the sedimentary nature of this soil the plasticity is not very high, because the main problem with the soil plasticity at this place is the because of the height of the soil filled.

Because, it is very high we should expect some compressions the post construction settlement and compressions and as we know from our consolidation theory that as the plasticity of the soil is increasing the compressibility increases the compression index is higher for highly plastic soils. So, it is very important that we use a soil that has very good compression properties under the same type it is not compressible in future. So, that one reason why the fly ash or the pond ash could not have been used this site because it is not possible to compact the soil to very high heights.

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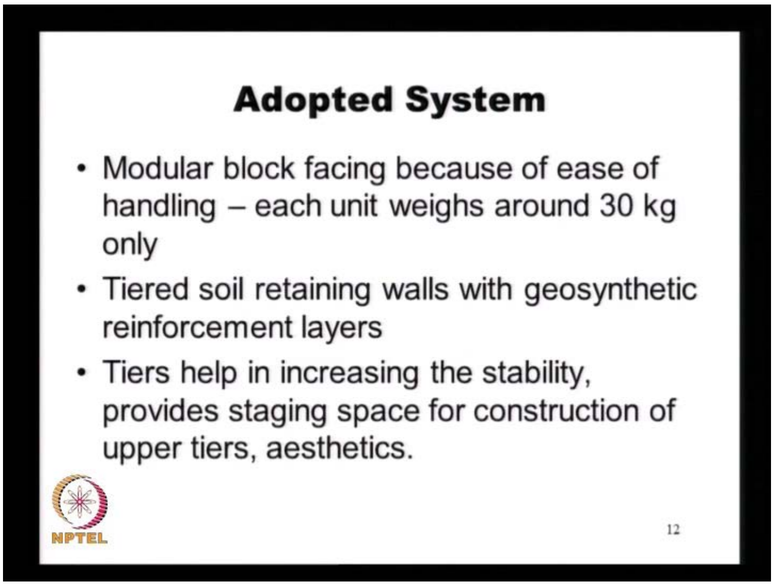

And, the particular system that was adopted for construction is the use of modular block facings mainly, because it is easy to handle one single person can easily handle these blocks, because each of these blocks they weigh around the 30 k g's and its proposed to construct tiered retaining wall instead of one full vertical retaining wall to almost 40 meters instead the tier system was proposed mainly, because it increases the stability, because we know that as we have a shallow slope the stability is higher and similarly with by providing bumps or the tiers. The stability is increased and more importantly it provides some space for the staging to construct upper reaches of the wall we need some base and that base is provided by these tiers and in terms of appearance aesthetics the tiered wall looks much better. Because, we break the monotony of the wall and we can grow some visitation on these tiers. So, that in future this wall can be blended with the surroundings.

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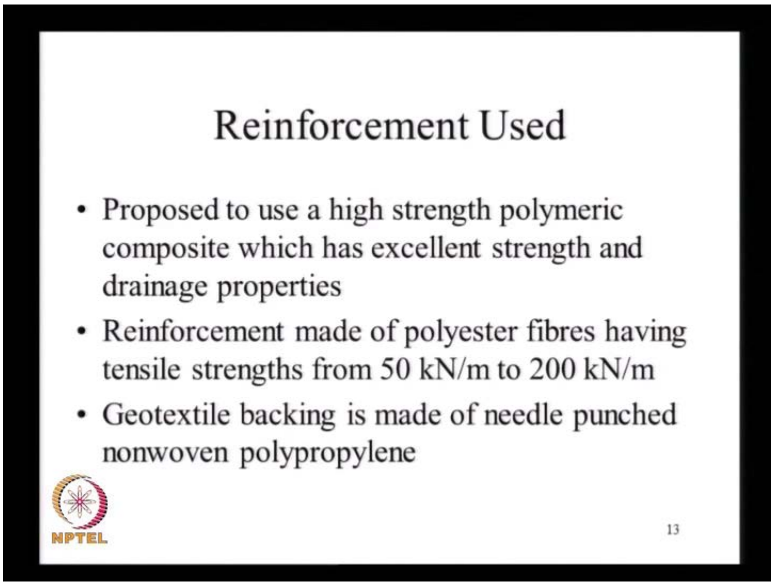

And, the type of reinforcement that was used the it is not a normal reinforcement the it was proposed to use very high strength polymeric composite, which has excellent strength and drainage properties upfront. It is anticipated that water is a big problem, because the heavy rain fall and heavy run-off we should expect some water to infiltrate into the reinforced soil fill, and once it infiltrate it should have passage out of the out of the soil and, because of that a composite is used a composite is nothing, but a combination of two different materials in this particular case the combination of a geogrid that provides the tensile strain.

And, then a geotextile that provides an opportunity for the water to flow along and dispatch from the ground, and this the reinforcement that was used made up polyester fibers having tensile strings in the range of 50 to 200 kilo newtons per meter and the geotextile backing for this geogrid is made of needle punched nonwoven polypropylene. It is a fairly thick geotextiles about 2 and half to 3 meter 3 millimeters thick.

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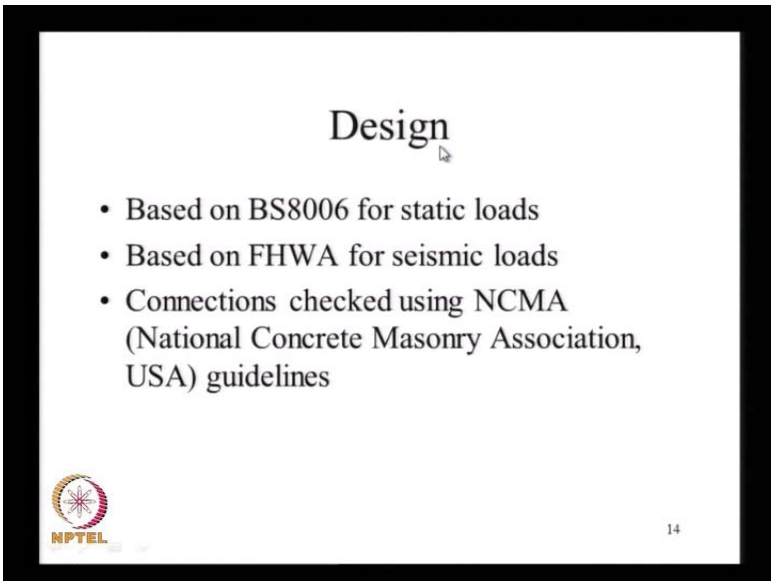

And, the design itself is based on several coddle provisions. Because of the site conditions the for most of the designs the b s 8006 was used for the static loads that is for checking for the lateral stability, and then internal stability both under external forces and internal forces and as we already know the b s code does not talk about the seismic loads and.

So, the seismic load factors were taken from the federal highway administration design guidelines only it to for the purpose of estimating the seismic loads and the pot of the reinforce soil was built using modular blocks is better discussed in this the NCMA guidelines that is the national concrete masonry association they also have guidelines for constructing the soil walls using the modular blocks and the connections especially the connection strength between the reinforcement layers. And, the modular blocks is better explained in this NCMA manual. So, all these three major design course were utilized for design process.

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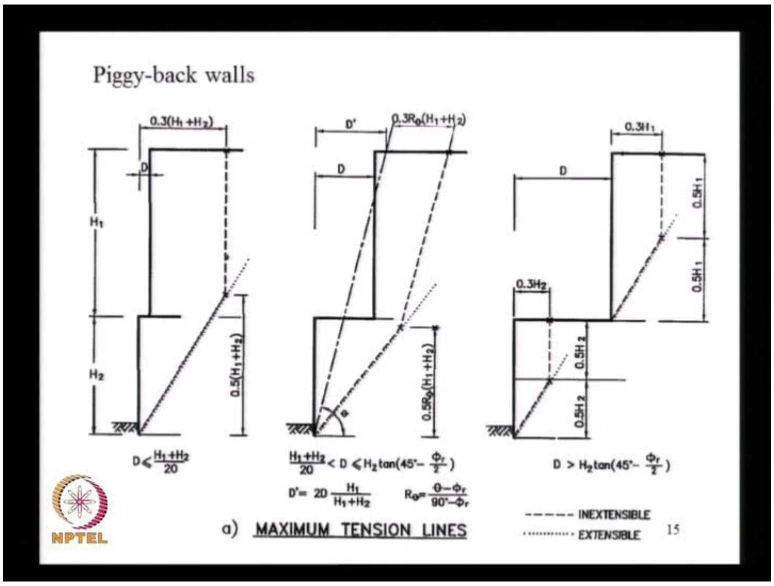

A tiered wall is something like this and, this is from the federal highway administration guidelines. And, there are different steps let us say that this H 2 is the bottom tier H 1 is the upper tier and the code says that if this offset is the less than the one twentieth if the total height then you treat it as one single vertical wall and the internal rapture surface is like this and if on other hand if the upper walls are.

So, much of offset that in the rankin active rapture place drawn does not interact with the upper tier then we can treat both the walls as two independent walls and then the design is based on our conventional systems either based on the tie back wedge analysis. If the reinforcement is an extensible type this is for the case of this offset being more than the width of the rankin active wedge at the top of the respective wall, and our particular case is in between these in this pure vertical or purely independent walls it is somewhere in between and.

So, here we need to consider different type of rapture surfaces as shown here this is for inextensible type reinforcement that is the steel strip under steel grids, and then this is for extensible type reinforcements.

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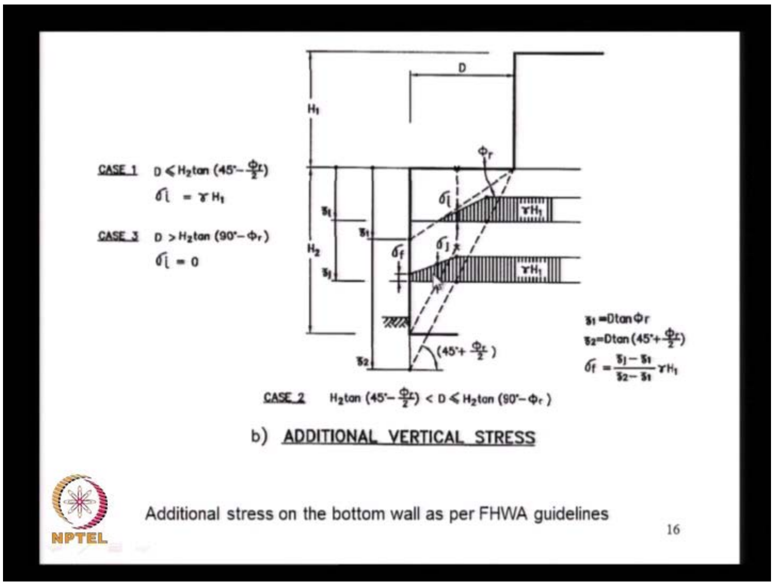

And, there are some guidelines on how to estimate the pressures that are transmitted to the bottom tiers from the upper from the soil in the upper tier and this is these are all semi equations that are given in different codes, and this is from federal highway administration guidelines, and a similar guidelines are also given in the NCMA, and it is very easy to write in excel program to calculate the additional pressure that we have from the upper tiers.

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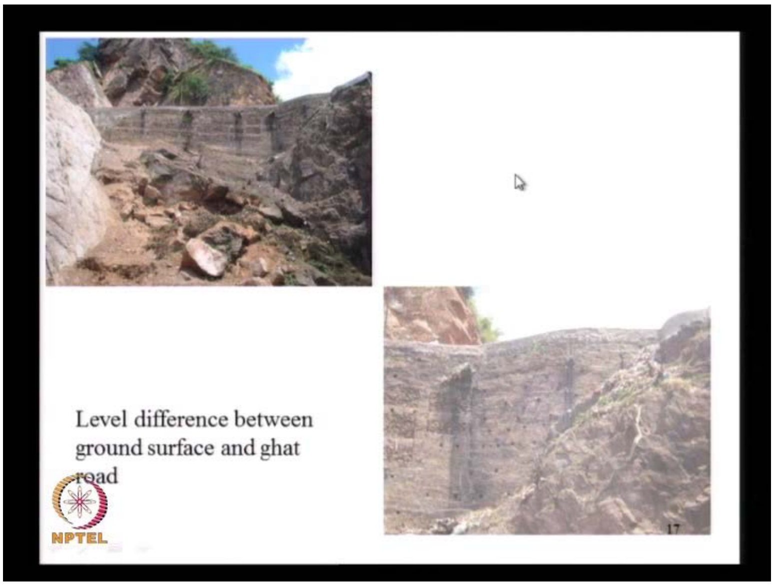

So, coming back to the to the practical construction aspects the general site conditions are shown. Here is actually this is the old masonry wall that was built along the along the ghat road to guide the traffic and the height you can see it is a very huge very highly varying and this is the general condition at the site and then here you can see the large height difference is actually our base is the ground level somewhere near here and the top of the hill is about here that is at this level the parking space is going to be provided so; that means, that this much height of the soil has to be filled by some means.

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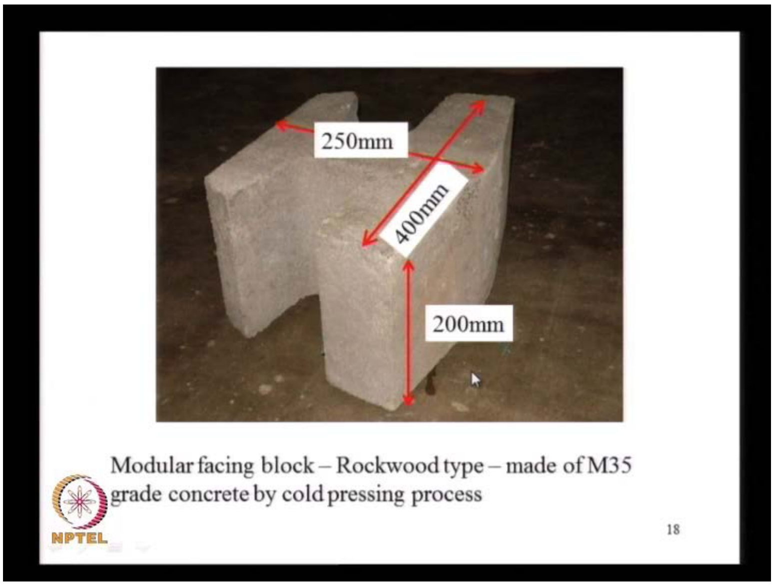

And, the type of facing system that was adopted was modular block facing.

This is a typical rockwood type block and this block it has a length of 400 millimeters and the height is 200 millimeters and this depth is 205 millimeters and this particular block is made of 35 grade concrete by clod pressing process with just simply take the mold and then prepare the concrete as per the as per the mix design and then just simply pore it and then press it to form this block.

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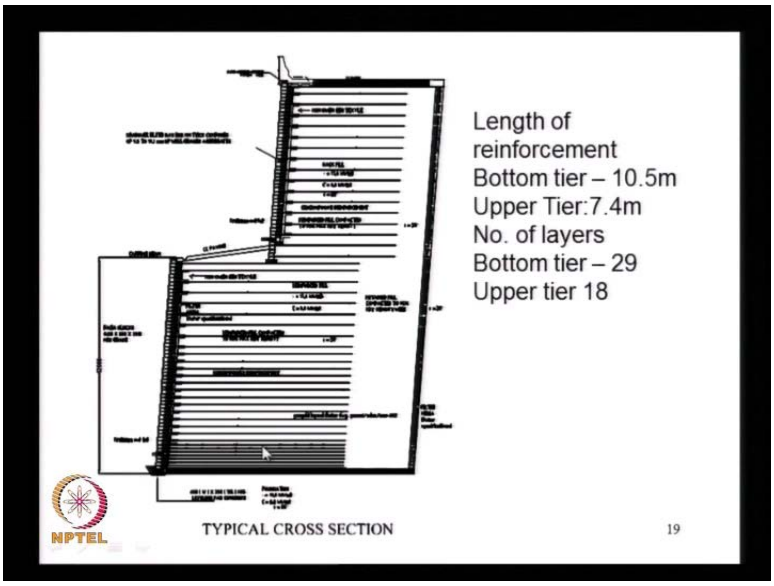

And, the cross section of the 22 meter high wall is shown here this is built in two tiers the bottom tier is about 12 meters and the top tier is about 10 and half meters and the this offset is 5 meters that is sufficient to provide a staging for construction purposes and for other aesthetic purposes.

And, the length of the reinforcement that was designed at in the bottom tier was 10.5 meters and the upper tier is 7.4 meters and the total number of reinforcement layers the bottom tier are 29 and the upper tier are 18 and as you can see at the bottom most the vertical spacing is very low and as we go up the vertical spacing increases and as per the NCMA guidelines the maximum spacing between the horizontal reinforcement layers should not exceed the height of three rows of blocks in this particular case the height of each block is 200 millimeters so; that means, that maximum spacing that we can provide is 600 millimeters.

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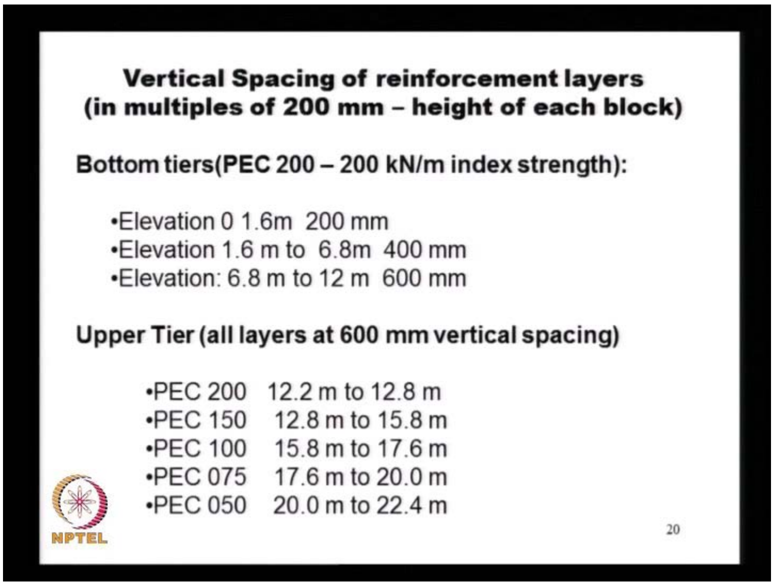

So, the spacing all though the design spacing comes out higher this the maximum vertical spacing was limited to 600 millimeters and this is how the reinforcement layout was designed and the bottom tier was provided with geo composite having an index tensile strength of 200 kilo newtons per meter that is the index strength that we determined from short term tensile strength or quick loading test and the spacing is it should be 0.4 0.2 meters up to 1.6 meter elevation this spacing is 200 millimeters and between height of 1.6 to 6.8 the spacing was 400 millimeters and then from 6.8 meters to 12 meters elevation this the vertical spacing was 600 millimeters.

And, in the upper tier all the reinforcement layers was provided at 600 m spacing and from a height of 12.5 12.2 to 12.8 meters the PEC 200 geo composite was provided this number 200 indicates the tensile strength the index tensile strength and the PEC one fifty having an index tensile strength of 150 kilo newtons per meter was provided between heights of 12.8 to 15.8 and 100 between 15.8 to 17.6 and 75 up to 20 meters height and beyond 20 meters height PEC 50 that is having tensile strength of 50 kilo newtons per meter was provided up to a height of 22.4 and beyond this height there was some other finishing heights about another 400 millimeters.

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And, this is how the entire construction started the construction starts by leveling the ground and preparing the base and in this particular case because the subsoil was hard stratum hard rock at very shallow depth of about half meter. So, there was no ground preparation required and at the bottom you level the ground and then at the bottom most this stone has aggregate that meets the drainage requirements at the place where were placed and the gradation of this stone aggregate meets the highway requirement highway standards the given by IRC and the ministry of surface transport that is mainly to allow the rain water to decapitate then after we place this the stone aggregate.

We assemble the facing blocks and the as just simply placed along the row and along the height without use of any cement motor and then periodically there are some outlets given the for the rain water to float and you can see this blocks then the reinforcement layer.

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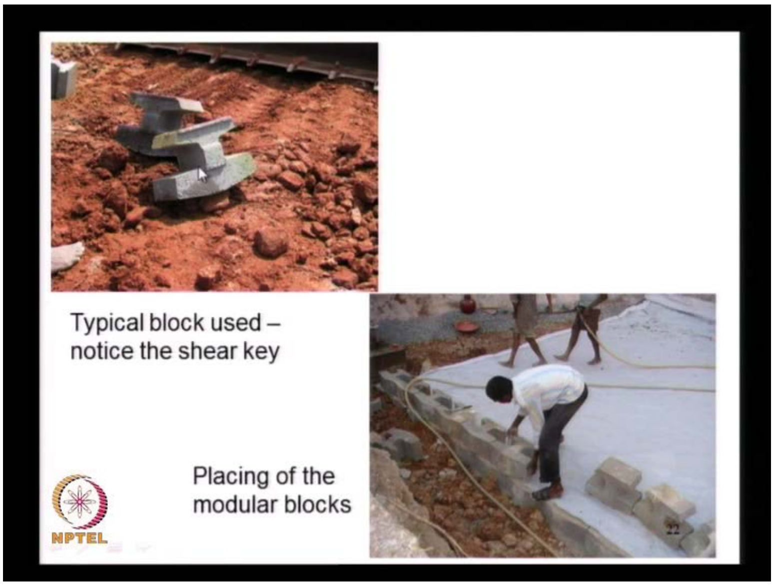

And, this is type of block that was used and you can see the at the shear key basically the shear key sits in the opening between this two adjacent blocks. So, that there is some shear interlocking and the construction each of this the upper blocks they will have an offset of about 10 millimeters will from the from the blocks below.

So, that there is a natural bottom that is given and the placing of the blocks is very simple. We just simply bring them and manually place them at the site after spreading the reinforcement layer.

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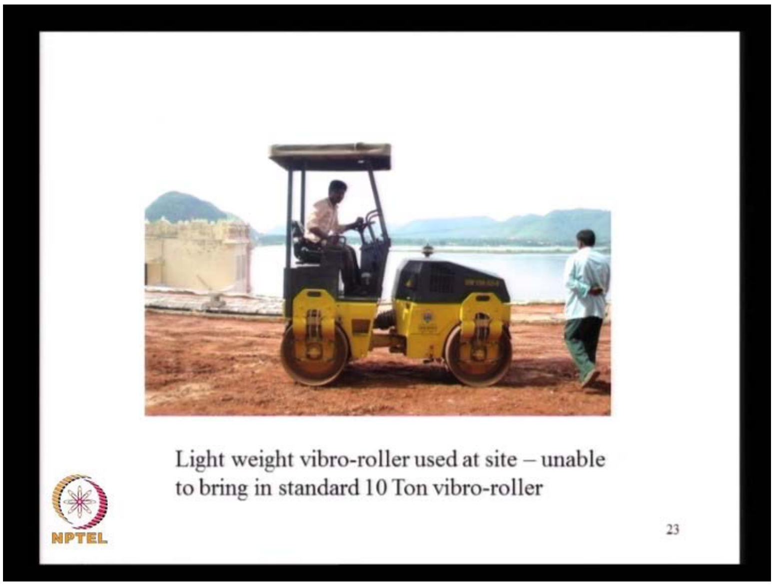

And, the compaction was major problem at this place, because you cannot bring in the standard 10 ton vibro rollers because of the excess difficulties. So, only a light weight roller could be brought in and the compaction with this may not be as good as what we get from them the standard 10 ton roller. So, it has to be constantly monitored and the number of passes that we give with this the small roller or much higher compared to what we have with a heavy roller and this is the best that could be done at this place because there is no other excess.

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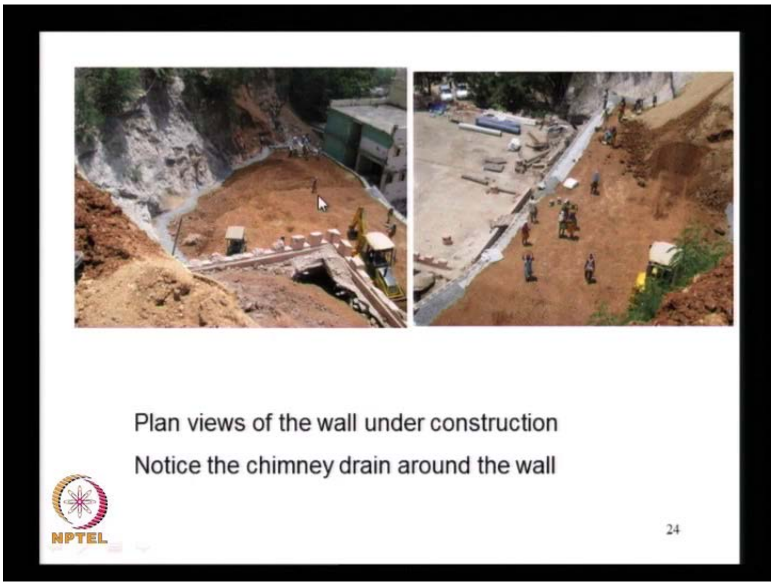

And, this actually this picture shows the constraints of the of the place this is the construction area there is one building here then there is another building next to this and this entire soil entire area is the construction area and you can see here this is building that is just next to next to this building and there is a gap of about hardly one and half 2 meters only for the people to walk and there is no other possibility for bringing in equipments and you can see this chimney drain what we call as a chimney drain.

Because as the soil is placed just at the back of the soil adjacent to the adjacent to the hill 200 to 300 millimeters thick aggregate layer vertical layer was provided the purpose is if there is any surface runoff it should flow along this chimney drain and then flow out from the bottom.

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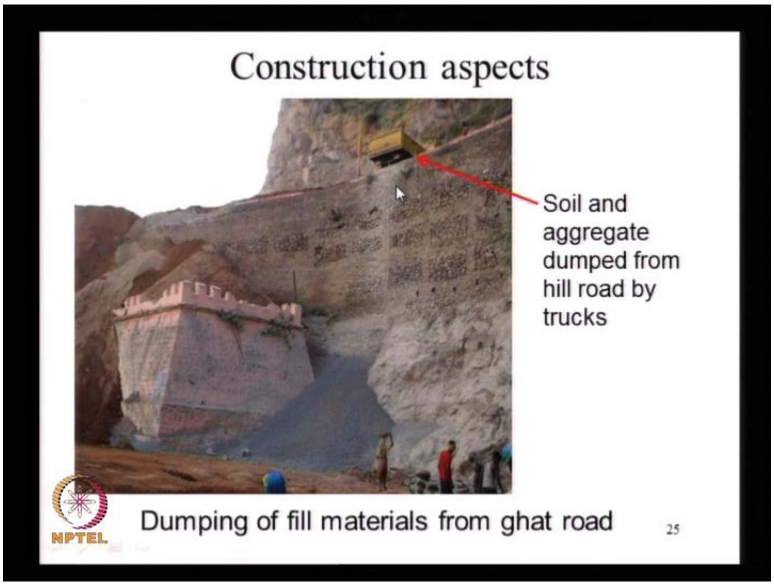

And, because of the difficulty of bringing in the soil directly into the construction site it was dumped from the ghat road as you have seen in the very first slide its already existing and all these lorry loads of a material was taken to the top of the hill then it was dumped from the top and, here you can see this lorry dumping the stone aggregate similarly the sand and then the gravel fills were dumped and then at the place it was the soil the gravel soil and the sand were mixed manually before placing them.

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And, the compaction control is very important aspect in a any of this constructions especially in the retaining walls, because if the compaction not adequate there will be higher lateral earth pressures at this particular site the each layer of the soil compacted was adequately checked by taking core samples by sand replacement methods the compaction quality was determined and only after the compaction quality was found to be adequate then you go and place the next step layer of free soil and the soil was compacted in thin layers about 100 to 200 millimeters thick, because the compaction equipment is a very light weight equipment.

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And, it is also very important that during the during the construction of there is any rain we should not allow the rain water to percolate because during the construction the soil is just compacted and it may not have gained strength and then if you allow the rain water to go in is very difficult to get adequate compaction quality because as you know the wet soil is a very soggy and it will not be you cannot really compacted. So, this particular place even during ah small drizzle the entire soil area was covered with a polythene sheets. So, that the rain water does not penetrate into the soil.

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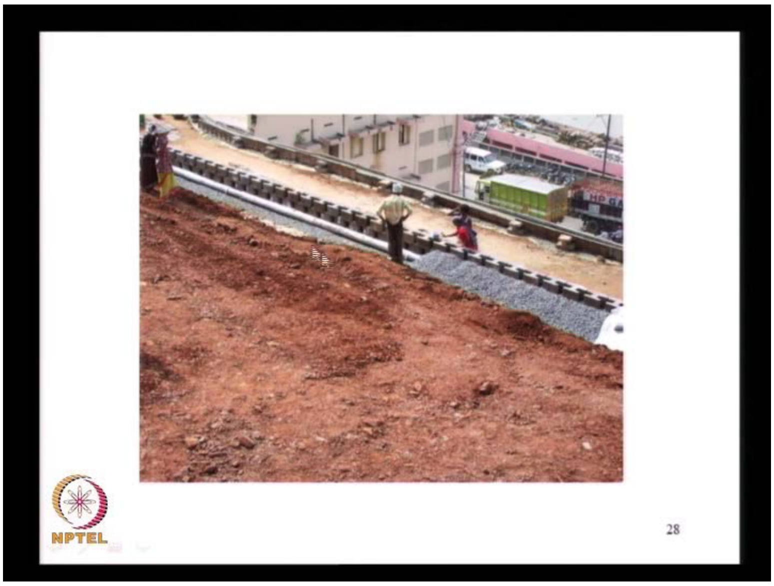

Here you see another picture is actually along the along the length of the wall we provide a another drainage pipe although we place the drainage aggregate is actually the drainage pipe is the purpose of the drainage pipe is to collect a runoff water and lead it safely away from the reinforced fill.

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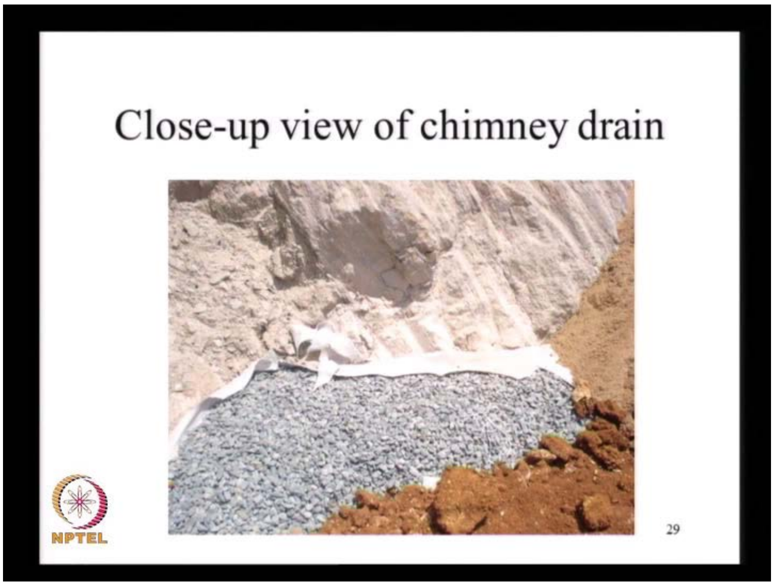

And this is the close-up view of the chimney drain and you can also notice that this the aggregate was placed along with a filter fabric because during the service life the aggregate layer that we are providing it should not get soaked with fine particles and. So, this filter fabric in say non-oven filter fabric it is provided. So, that the fine particles does not infiltrate into the drainage blanket.

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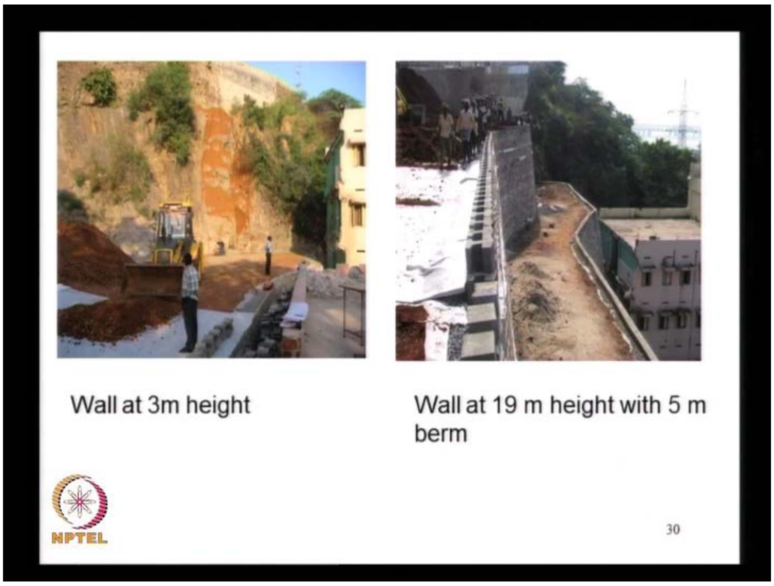

And you can see the the pictures of the constructions this is at 3 meters height and then this is at 19 meters height and you can see that the reinforcement layer is not is not provided horizontal is actually kink was given. So, that there is a good interaction between the soil and the reinforcement is actually its it is a kink instead of placing the reinforcement horizontal the reinforcement was placed horizontally then it was brought up by about 10 millimeters and then it was locked into the into these blocks and the inside of the blocks was filled with a stone aggregate.

So, that there is a there is a good interaction between the blocks the soil and then and then the reinforcement layers. So, here you can see this stone aggregate placed in the blocks.

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And you can see another view of the of the the wall being constructed you can see the clear picture the vehicles dumping the soil from the top .

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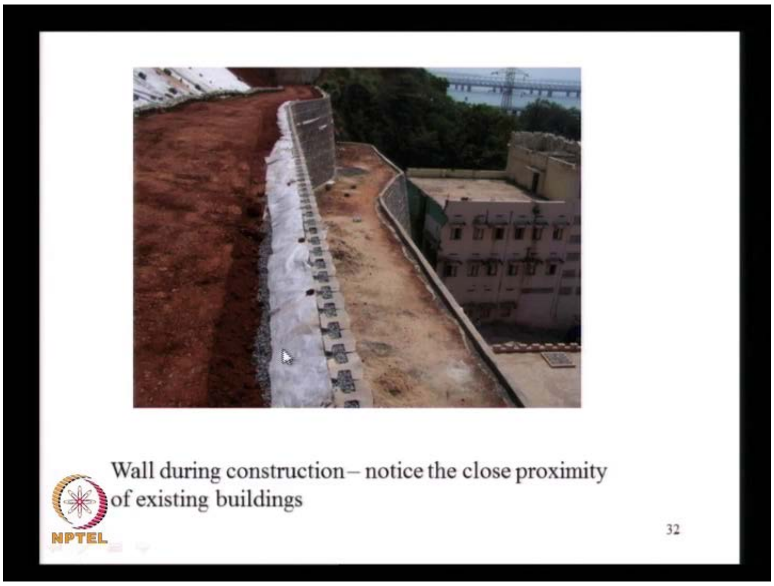

And this is another view of the of the wall during construction and it is actually this notice the the existing building is very close its hardly about 1 and half 2 meters gap and in spite of that this wall could be built because this soil was dumped from the top and then the the entire construction was made using a modular box each weighing about 30 k g's.

So, could be easily carrier by by people and placed at the at the site.

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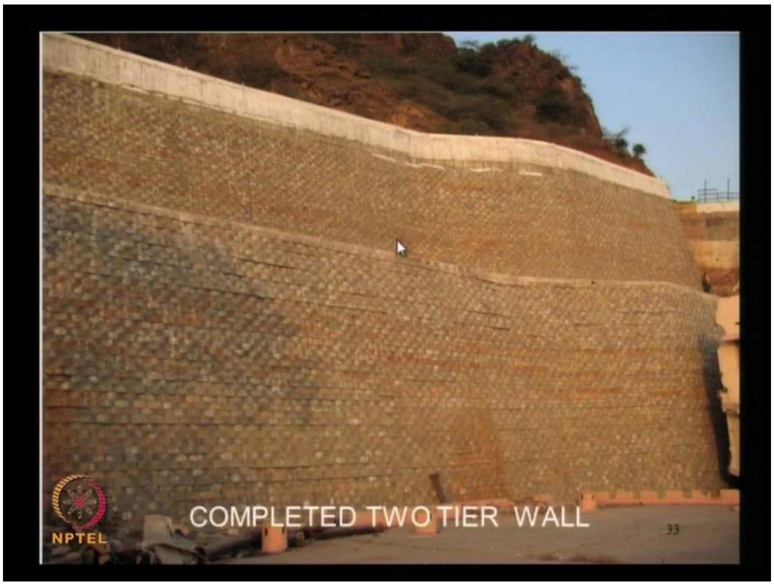

And this is the completed 22 meter height of wall the bottom one is about 12 meters and the top one nearly 10.5 meters.

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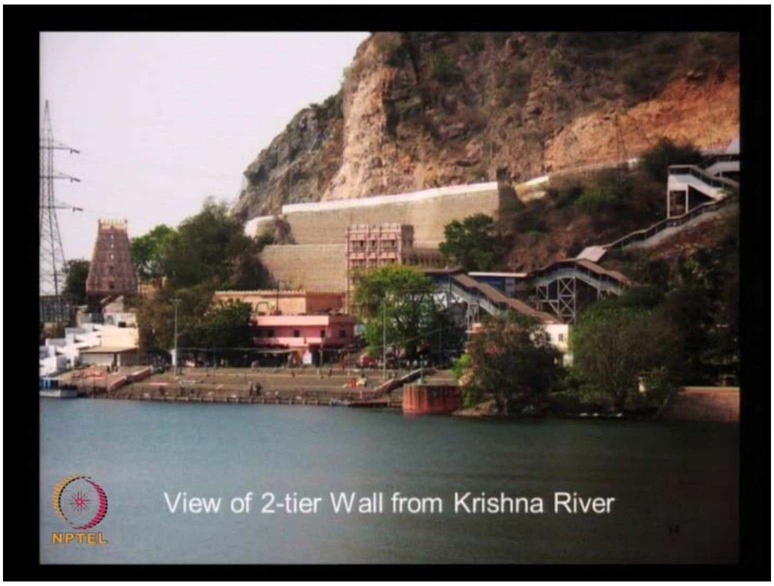

And this is the view from the krishna river from the middle of the krishna river you can see how densely the entire the the area is populated that too many buildings too many residential buildings too many buildings associated with the temple and this is the footpath that is used by by pilgrims to go up to the top of the hill and once again you can see the fragile nature of this this hillock at just too many joint planes and then fishers.

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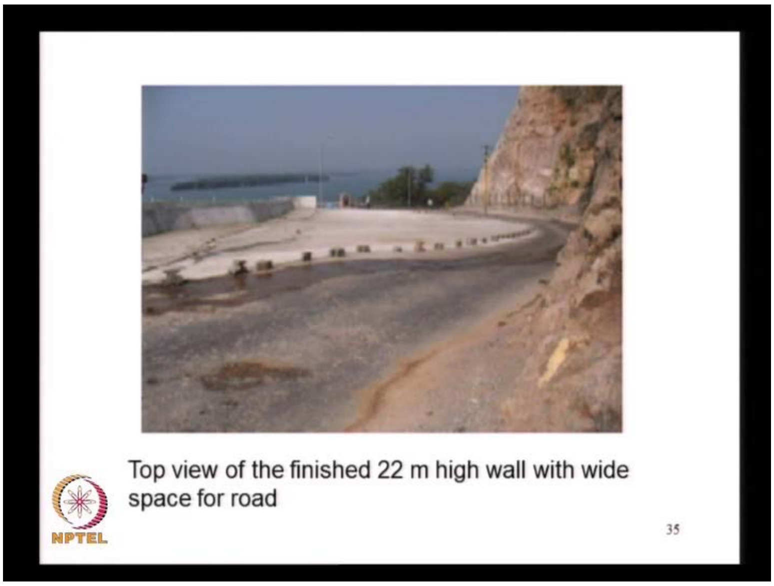

And the here we can see the additional space that was gain for construction of the road.

The previous road was only this this wide about 3 meters now it is another 20 meters is added. So, you can build a build a nice two way road instead of one way road

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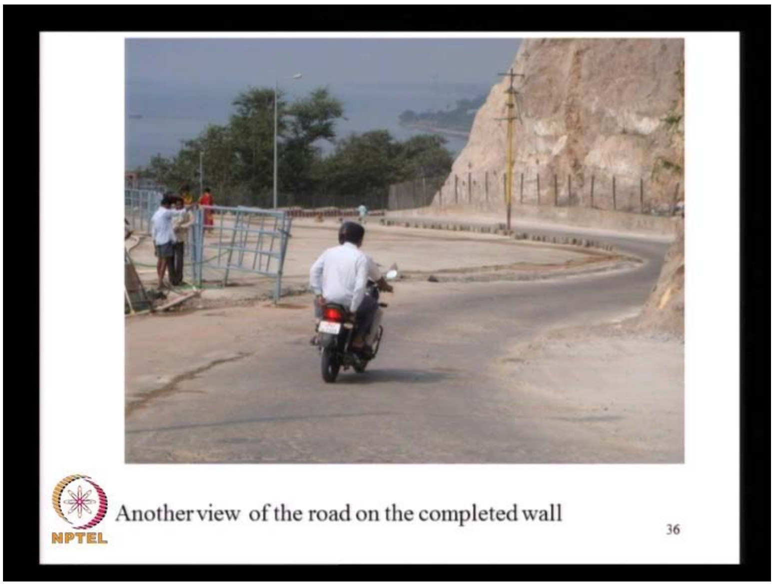

and you can see another picture of the same thing it is a very wide wide area for for our construction purposes.

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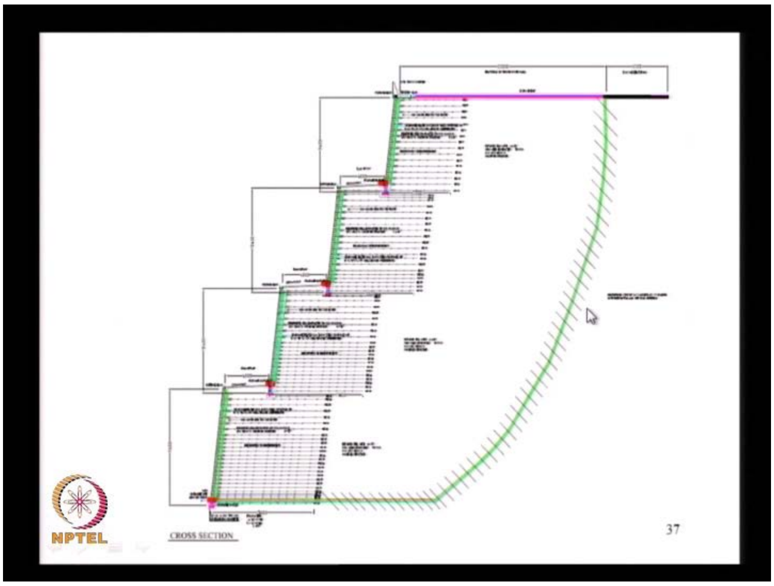

And the the other wall that is just adjacent to 22 meter height wall is the 44 meter wall which is built in 4 tier each tier the bottom tier was about 12 meters and this is also another 12 meters and the this is 11 meters and this is about 10 meters height.

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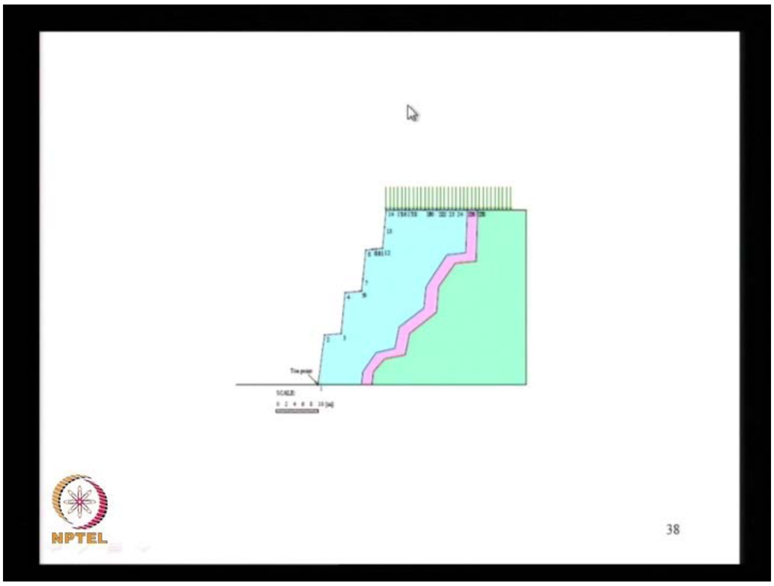

And this is the graphical representation of the of the system is actually this is all the the the soil fill and this is the filter that was provided and.

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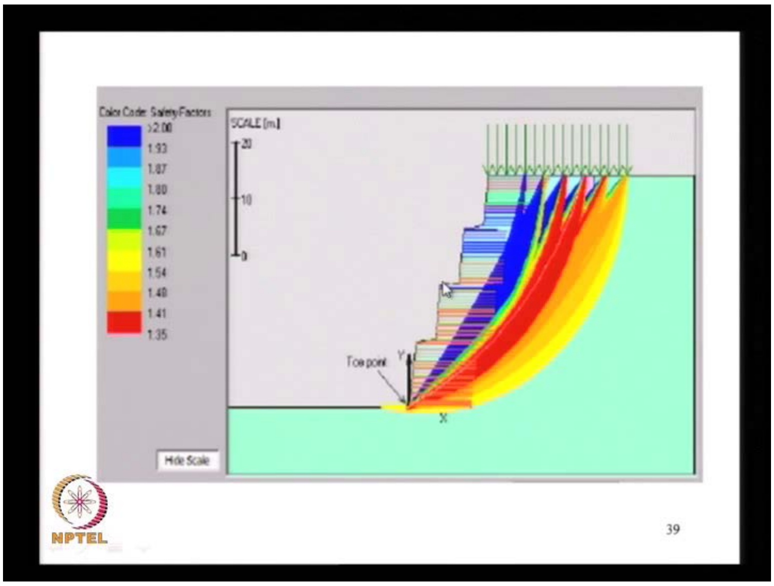

The the design codes are bit crazy about the design of t at walls and one suggestion made is although the the entire system was designed as a as a retaining wall we have to check for the global stability by by taking the different slip circles passing through the both the reinforced fill and then the backfill and make sure that there is adequate fact of safety and the worst scenario that is with with seismic factors and vijayawada being the in the zone three area [approp/appropriate] appropriate the seismic factors were considered in the design and here you see the the result from the from the slope stability software that indicates the different types of ah safety factors that were obtained the blue color indicates that the fact of safety is greater than 2.

And this red color there is a patch that is is actually very close to our active rapture surface it has a fact of safety of about 1.35 and this yellow color has a fact of safety of 1.6 and this 1.35 is is after including the seismic factors in the in the analysis and.

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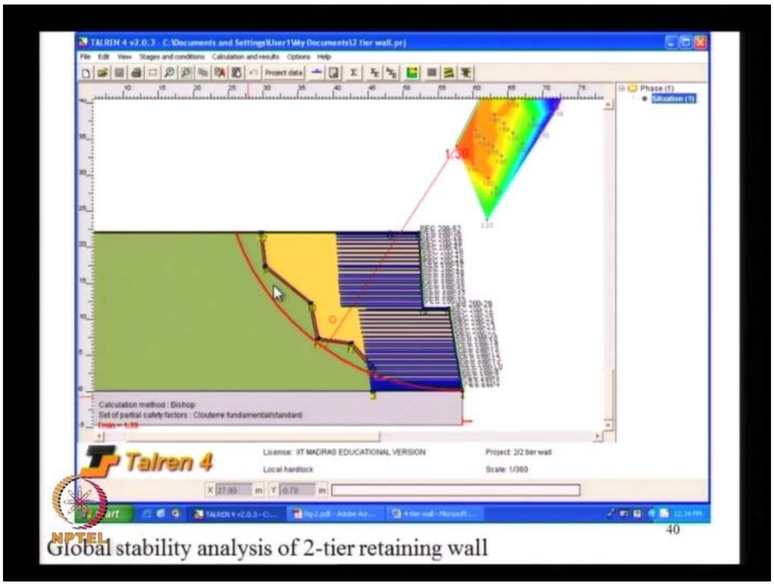

This is the the same analysis run with some other software the analysis were done with two different software’s the previous one was done by using a program called resa that is recommended by federal highway administration and this analysis is done using talren this is also very popular slope stability analysis software that can incorporate different construction methods.

Like the soil reinforcement layers and then the facing elements and. So, on and here we see that the fact of safety this is actually the critical surface for the two tier wall is growing beyond behind the the reinforced fill and the fact of safety is about 1.39 the minimum fact of safety and the if you take a circle passing through this it is much higher.

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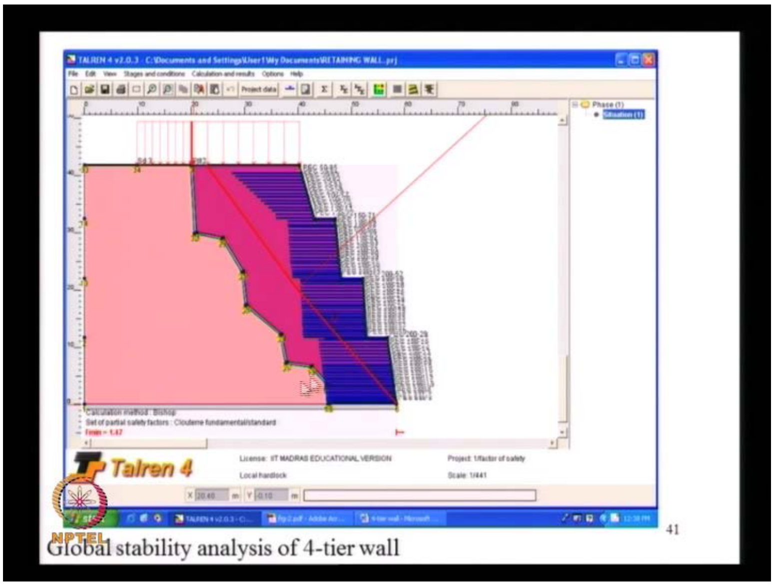

And this is for the four tier wall the fact of safeties about 1.47 after considering all the all the surcharge loads and then seismic loads and so on.

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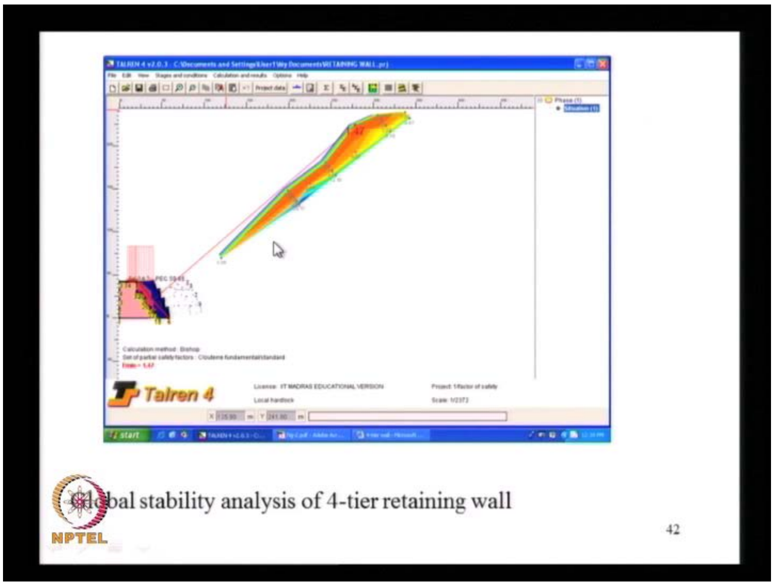

And this is another result from the same analysis.

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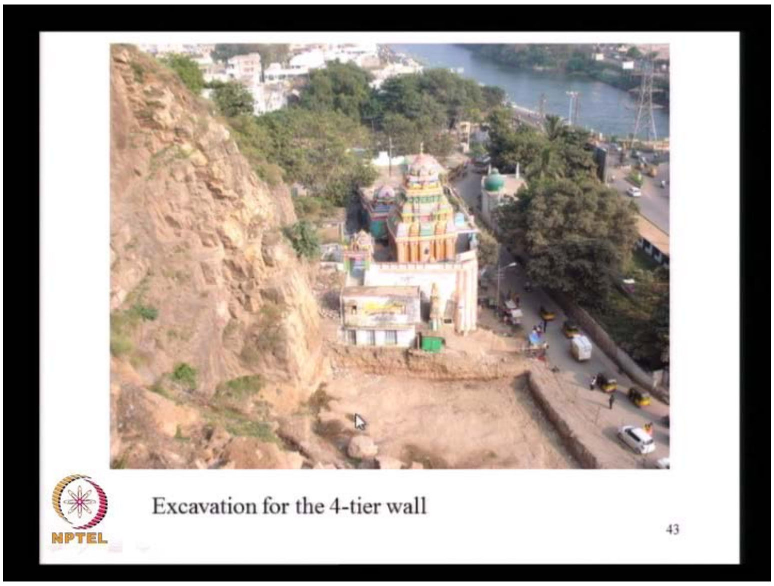

And this shows the overall ground conditions and this is at the bottom of the bottom of the slope, and then the soil is being built up to this level.

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And this is the construction stage as actually this long wall all around, then we place this soil.

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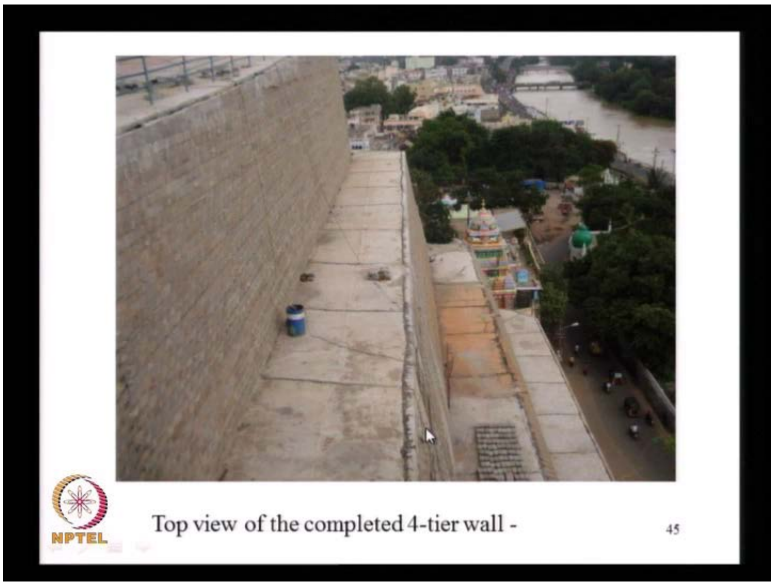

And this is the finished wall this is the four tier, the upper tier third tiers, second tier, and the first tier.

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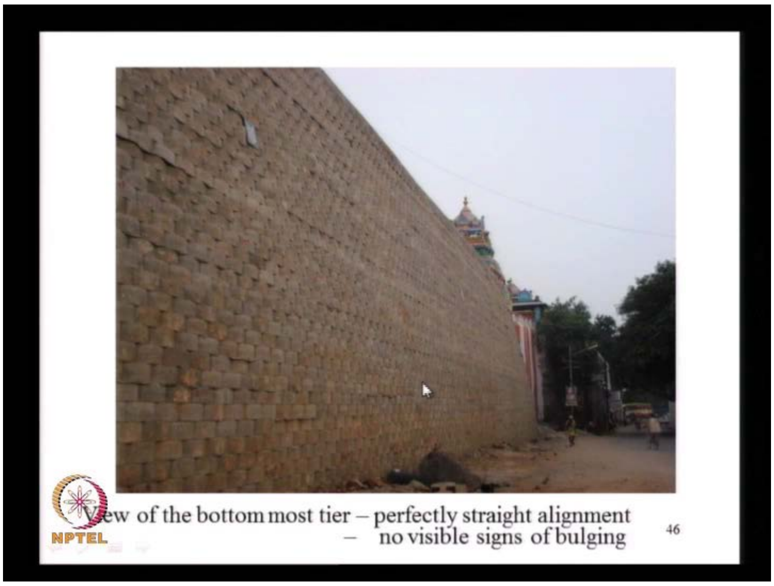

And this is the view of the bottom most wall is actually it is perfectly straight absolutely no lateral deformations are anything or no settlements, because the the foundation soil is extremely strong.

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But unfortunately there were some problems because some part of the wall is directly resting on the on the hillock whereas, the other path of the wall is resting on the soil. And in hein site they should have been vertical joint within the two parts of the wall, but because the vertical joint was not provided there were some differential settlements and you can see the crack that is formed. And the some path of the soil started bulging out because of the differential movements, and then some a contractor has started installing a soil nails, but then unfortunately these nails were placed very closed together.

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And that has resulted in the in in some of the blocks coming out and. So, there were some problems otherwise the entire system is stable and there is you can see one modular block that has come out, because of driving roughly 20 mm soil nails driven at at a horizontal vertical spacing of nearly 200 millimeters that is too much of nailing in this soil conditions.

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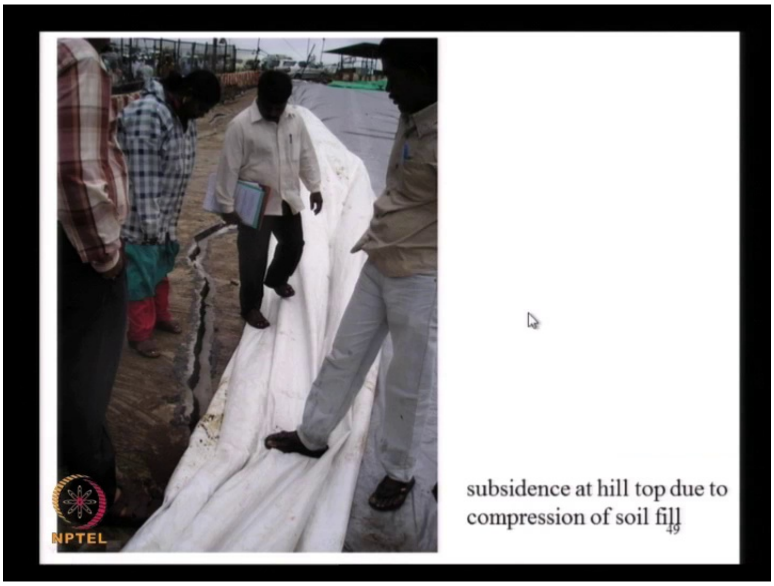

And at the top of the hill at 44 meter height there were some subsidence’s of the order about 500 millimeters and that is mainly because some part of the soil was not compacted adequately because the entire compaction was done using using a light weight rollers. So, that was not adequate and. So, after about 6 months of subsidence the entire top soil the top concrete was removed the top soil was removed then it was replaced with pond dash and and then (( )) it.

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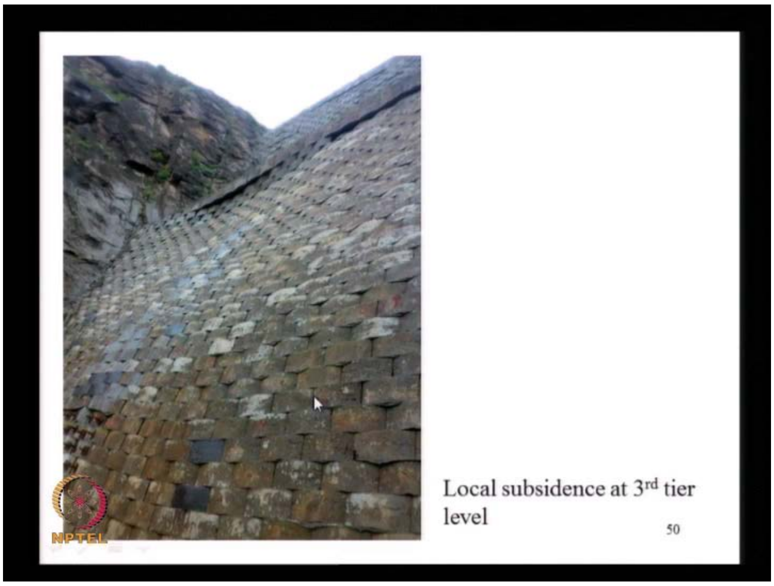

And here you see at the third tier level there were some differential movements once again, because the part of the wall was resting on the on the hill part on the on the lower tier of the walls. And then some areas the compaction was the the the construction proceeded during the rainy season where there were some soft patches and because of that there were some settlements and you can see the ah the the affect of local subsidence the wall has moved inward.

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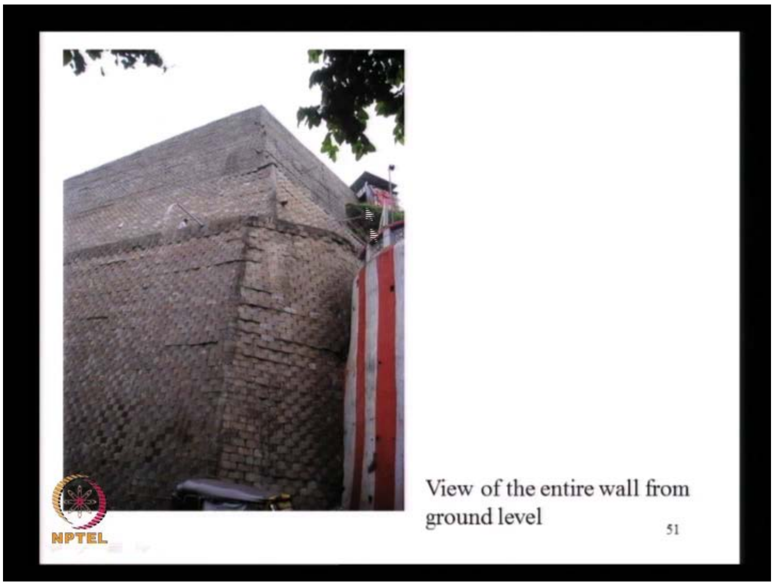

And then the some small bulging in one of the corners.

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But otherwise the entire wall is stable, and it is been there for almost four years without any major substantial problems.

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And now this the entire parking area is open for traffic you can see this this entire area was gain this is about 22 meters and this length is nearly 100 meters. So, you can imagine how many cars, and how many vehicles we can park in this additional area.

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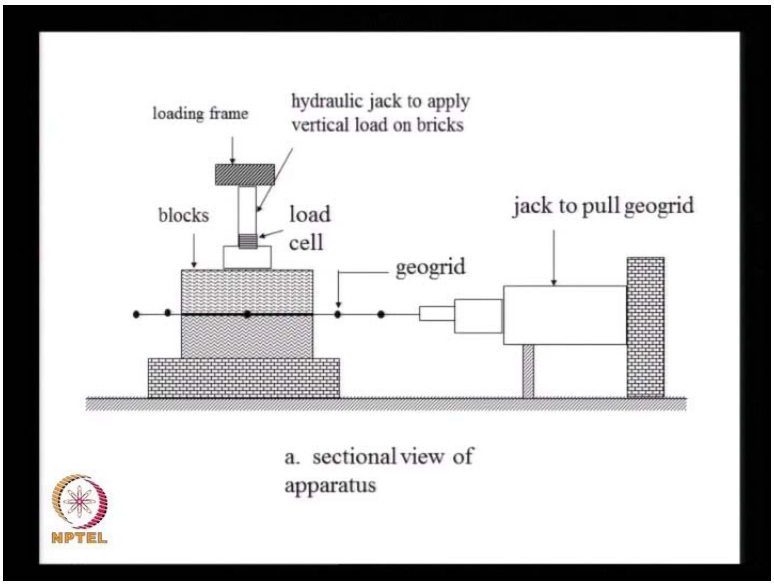

And we need to use the lot of test data and one important test data is on the connection strength between the facing blocks, and the reinforcement the schematic for during these laboratory test shown here.

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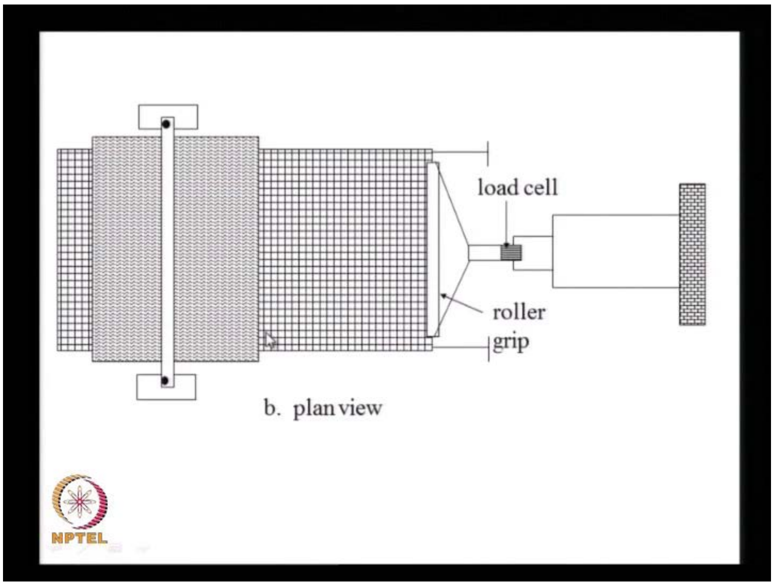

And this is the plan view.

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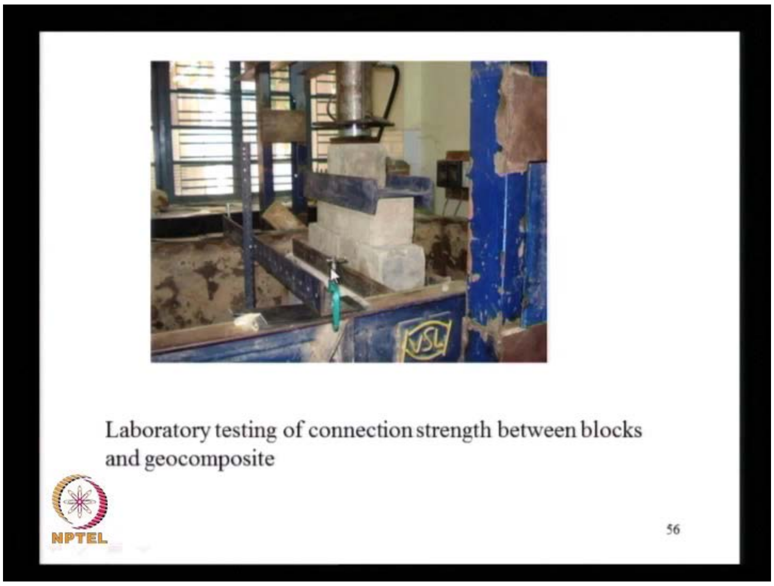

And this is the the photograph of the the load test being done in the laboratory.

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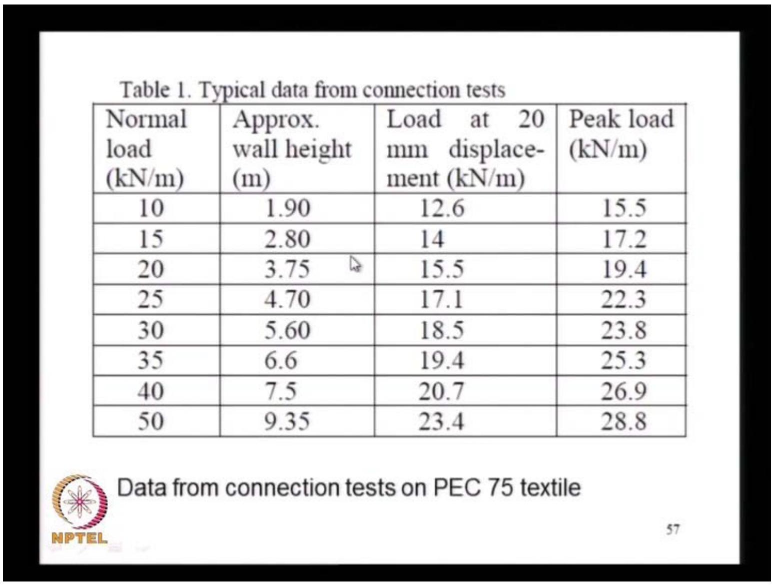
Table 1. Typical data from connection tests

Normal load (kN/m)	Approx. wall height (m)	Load at 20 mm displacement (kN/m)	Peak load (kN/m)
10	1.90	12.6	15.5
15	2.80	14	17.2
20	3.75	15.5	19.4
25	4.70	17.1	22.3
30	5.60	18.5	23.8
35	6.6	19.4	25.3
40	7.5	20.7	26.9
50	9.35	23.4	28.8

And this is the typical data for tests on 75 PEC 75 that is having tensile strength of 75 kilo Newtons per meter, and you can see that the peak load capacity, and the connection capacity is only about 29. So, we can only utilize small fraction of the tensile strength of the material for our design purposes.

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And along with this construction number of rock fall protection measures had to be taken here you can see you can see anchor that was installed, and that was bolted down to to stabilize the the rocks.

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And some rock netting was given along with nails.

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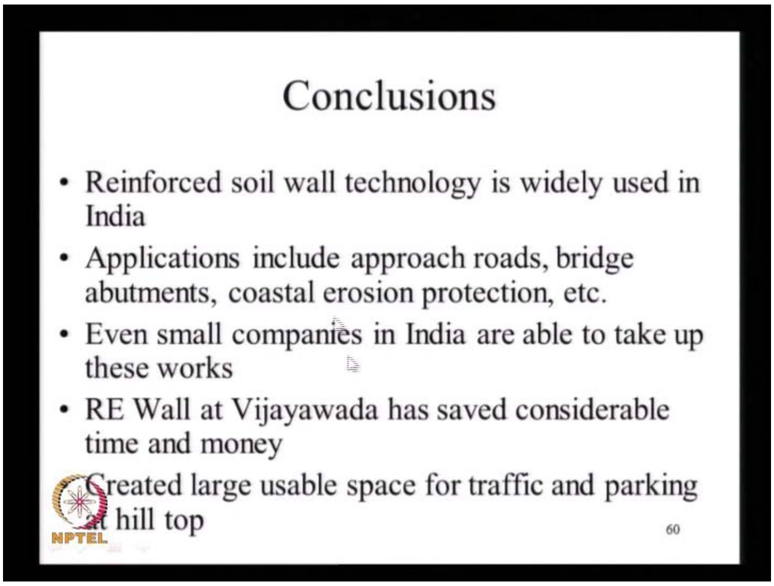

And the some of the conclusions that we can draw from this case study is that the reinforced soil wall technology is very widely used in India and the applications for these constructions include approach roads, and then bridge abutments coastal erosion protection works and so on. And even small companies they are able to take up these major projects and come out to successful designs and successful constructions. And this particular reinforced soil retaining wall saved lot of time and money, because the 22 meter high wall was built in less than 6 months, whereas the 44 meter wall was built in about 1 and half years and to create a large usable space for traffic and parking at the hill top.

So, thank you very much.