Underground Space Technology
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Lecture – 60
Few Case Studies

Hello everyone, In the previous class, we finished our discussion on monitoring and instrumentation of the tunnels. So, today we will take up some of the case studies being the last class. I will be telling you that, what all that we learnt how these were applied to some of these case studies. So, here I have focused only on some of the case studies in India. There are many, many outside India and also inside our country.

But, it is really not possible to cover all of these. So, I will just try to give you the idea about what all that we learned with the help of some of these case studies.

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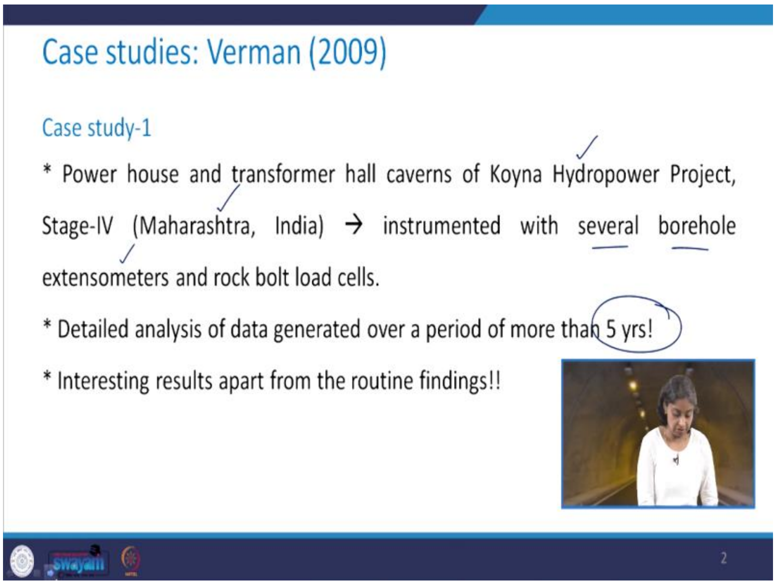

So, the first case study that we will be discussing, by Verman in 2009. So, he dealt with the two case studies, the first one was related to the powerhouse and the transformer hall caverns of Koyna hydropower projects stage 4. This was in Maharashtra. Here, the instrumentation was done with the several borehole extensometer and the rock bolt load cells. The detailed analysis of the data was done, which was generated over a period of more than 5 years and then we got some very interesting results apart from the routine finding.

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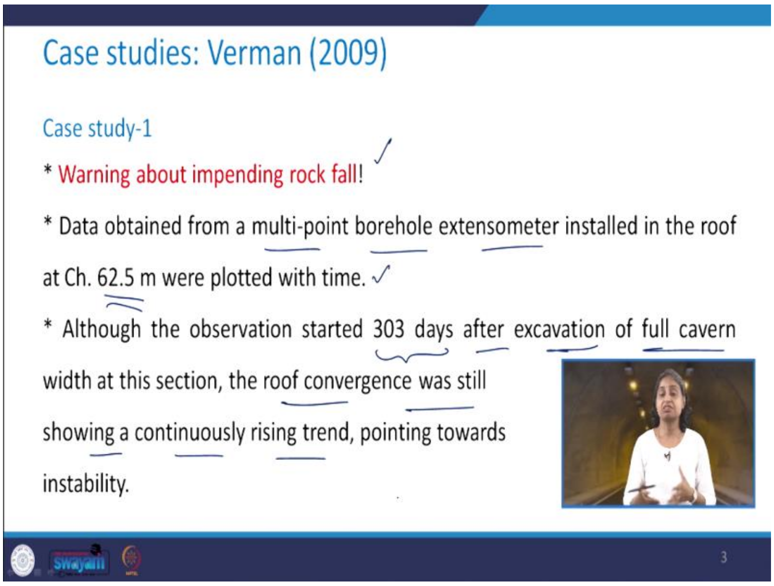

Let us take a look. There was a warning about the impending rock fault just because the sections were properly instrumented. So, the data that was obtained from the multipoint borehole extensometer which was installed in the roof at chainage 62.5 meters these were plotted with the time although the observation was started 303 days after the excavation of full cavern width at this section.

The roof convergence was still showing the continuous rising trend and, this was pointing towards the instability. Now, recall our discussion in the previous class. I mentioned to you that, based upon this trend of the deformation versus time, you can decide whether the rock mass is stable or unstable.

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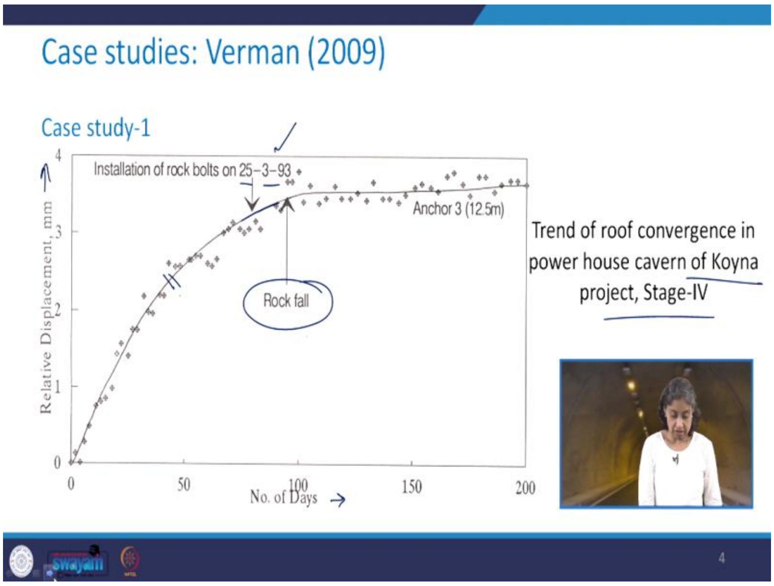
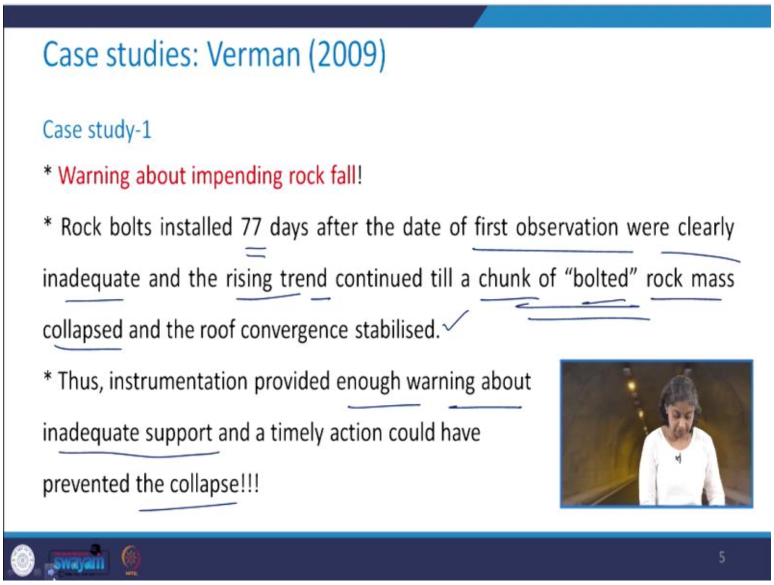


So, this is how the situation was there. Here on the x-axis, we have the number of days and on y-axis it was the relative displacement and this was the trend of the roof convergence at that particular site. So, the installation of the rock bolt was done in 1993 to the specific 25th of March and here, see this was continuously increasing indicative of the rock fall and then of course the support system was installed.



So, the rock bolts were installed 77 days after the date of first observation were clearly inadequate, because of this rising trend, which continued till the chunk of the bolted rock mass collapsed, and the roof convergence stabilized. Therefore, you can say that the instrumentation provided enough warning about the inadequate support system and if the timely action could have been taken, that would have prevented the collapse, which was this that is the chunk of bolted rock mass which collapsed could have been prevented.

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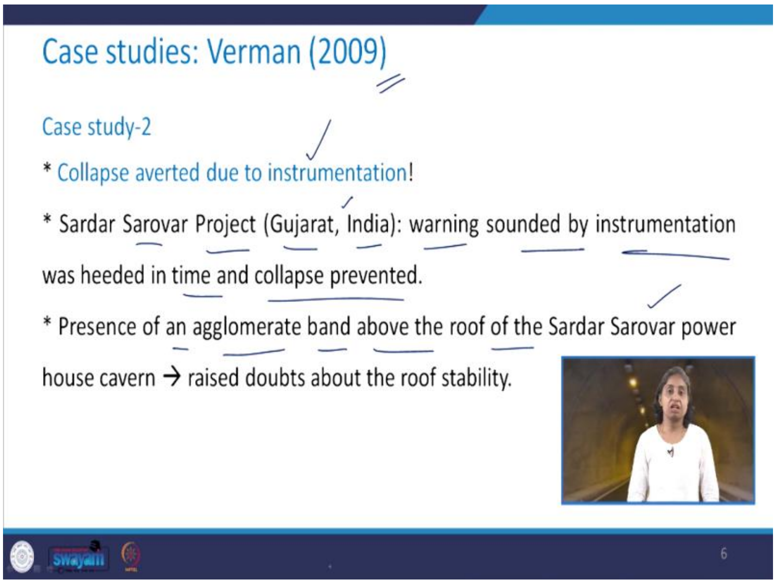

Then the second case study, which was taken by the same person that was related to Sardar Sarovar Project in Gujarat India and in this case the collapse was averted because of the instrumentation. So, at this site the warning were sounded by the instrumentation and that was heeded in time and collapse was prevented. The presence of an agglomerate band above the roof of this particular project, this raised the doubt about the stability of the roof.

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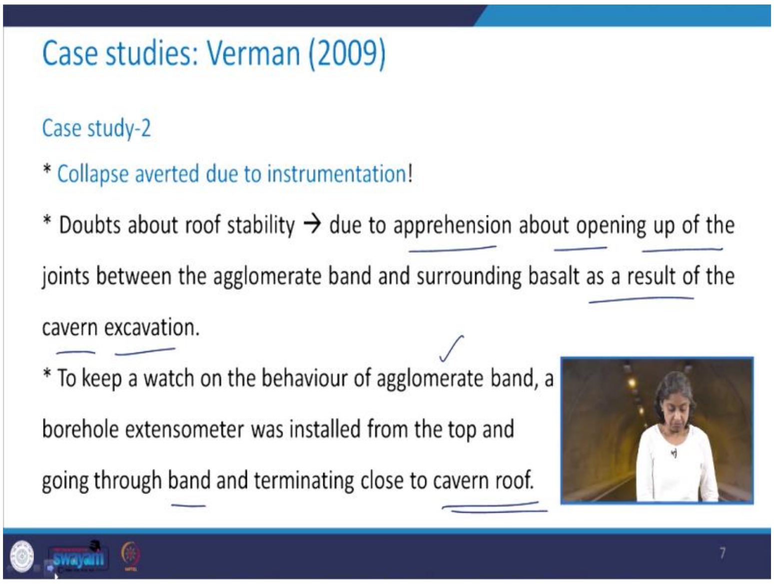

And, this was due to the apprehension about opening up of the joint between this agglomerate band and surrounding basalt and as a result of the cavern excavation. So, to keep a watch on the behaviour of this agglomerate band a borehole extensometer was installed from the top and going through the band and terminating close to the cavern roof.

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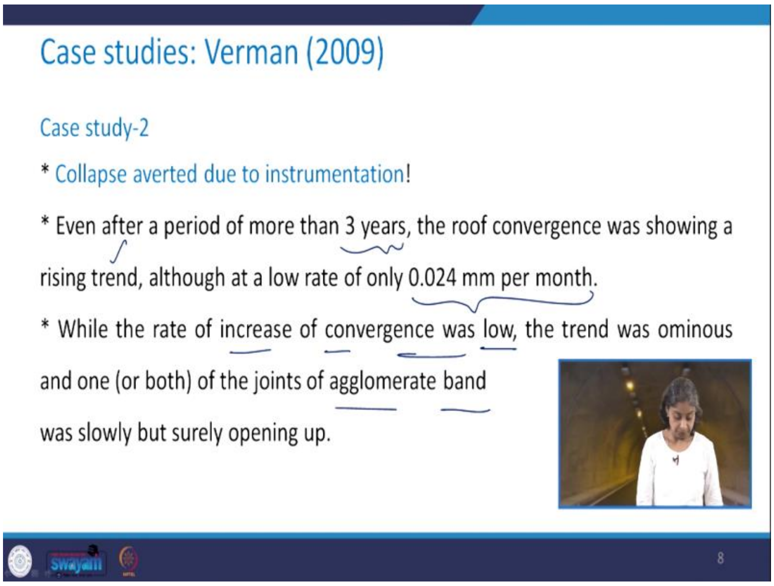

So, even after a period of more than 3 years the roof convergence was showing a rising trend although the rate of this convergence was very small, but still it was there. It was small to the extent of 0.024 millimeter per month, but it was there. While the rate of increase of convergence rate was slow. The trend was obvious and one or both of the joint of the agglomerate band was slowly, but it was opening up for sure.

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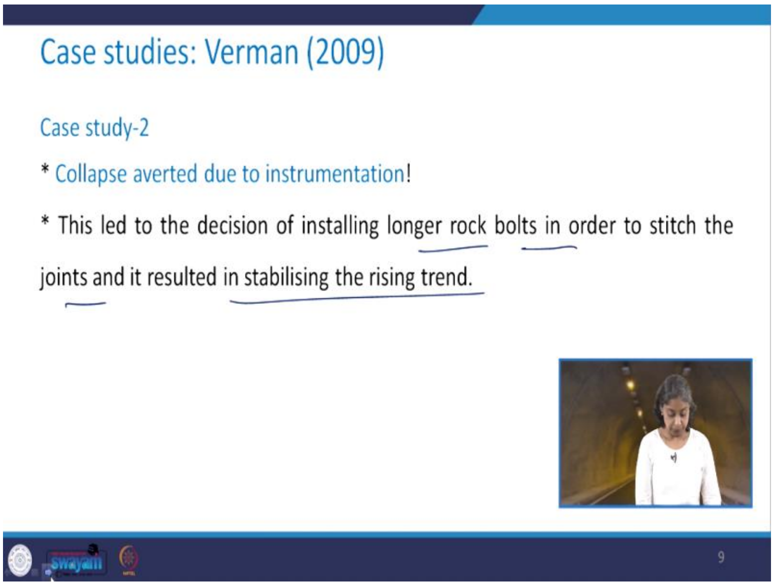

So, they decided to install the longer rock bolts to stitch the joints which resulted in stabilizing the rising trend. So, in this particular case study they took the help from the instrumentation and could avoid the collapse.

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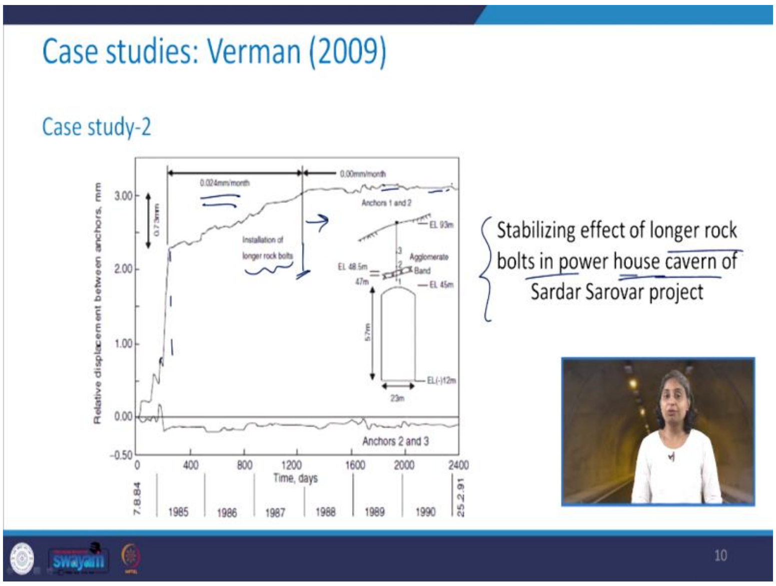

See, this is how the stabilizing effect of the longer rock bolts in the power house cavern was there. See, earlier it was all rising and beyond this time the rate was although small, but it was rising. So, here they provided the longer rock bolts and, see what happens beyond that it is more or less stable, no more increase in the relative displacement between the anchors of the extensometer.

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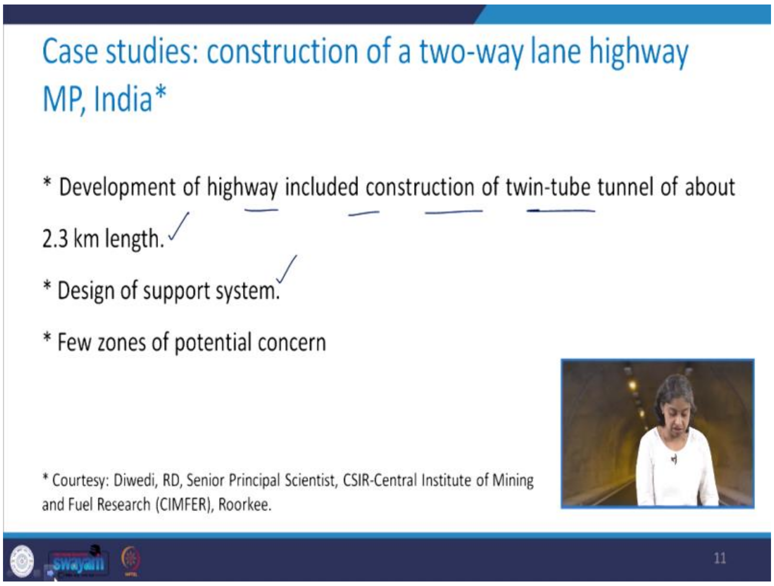

The second case study that we take it, is of the construction of a two-way lane highway in MP. So, here there was development of highway included the construction of twin tube tunnel of about 2.3 kilometer length. What the team did was the design of the support system and, they observed that there were few zones of the potential concerns.

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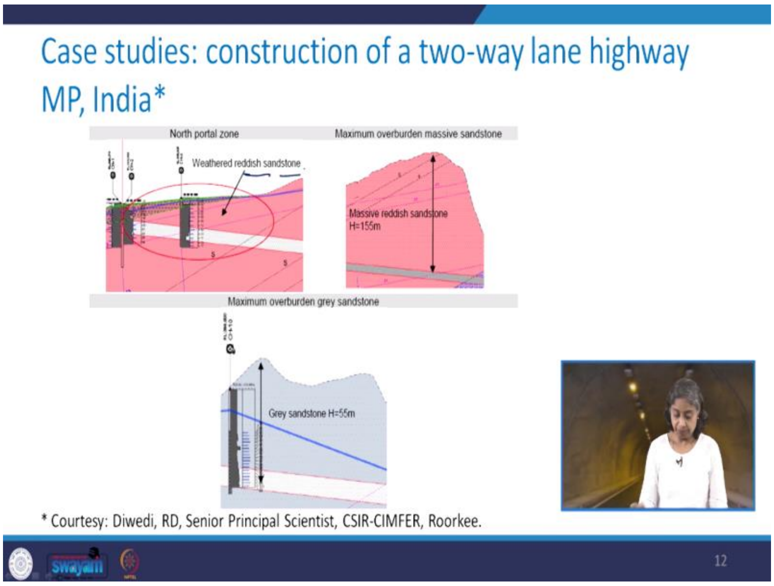

So, the strata was composed of the weathered reddish sandstone and, you can see the overburden also and the gray sandstone.

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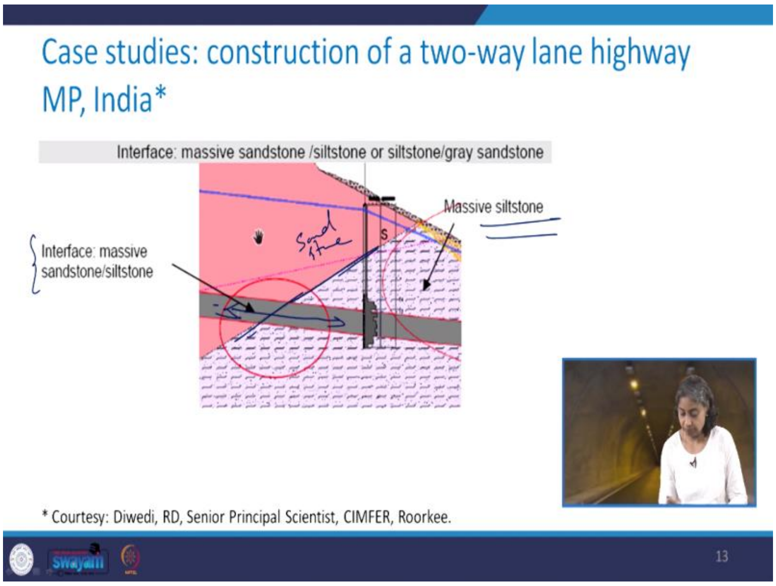

And this has been summarized in the next slide in the form of a table, but then there was the interface of massive sandstone and the silt stone. See, here this was the sandstone and here is the siltstone. So, this is what is the interface which was there along with this. So, this was potential cause of concern.

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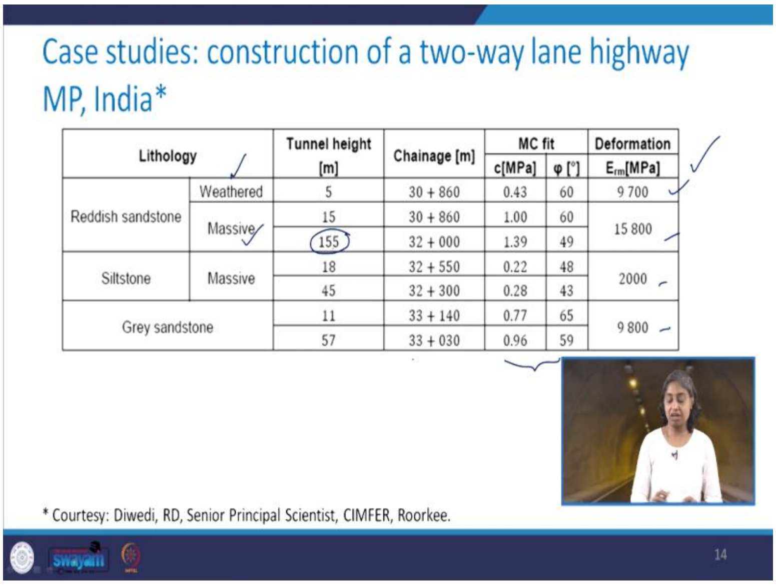

Lithology		Tunnel height [m]	Chainage [m]	MC fit c[MPa]	MC fit φ [°]	Deformation E_{rm}[MPa]
Reddish sandstone	Weathered	5	30 + 860	0.43	60	9 700
	Massive	15	30 + 860	1.00	60	15 800
		155	32 + 000	1.39	49	
Siltstone	Massive	18	32 + 550	0.22	48	2000
		45	32 + 300	0.28	43	
Grey sandstone		11	33 + 140	0.77	65	9 800
		57	33 + 030	0.96	59	

So, as I mentioned that the lithology has been summarized here. So, take a look that they had reddish sandstone, siltstone and gray sandstone and the reddish sandstone, some part was weathered and some part was massive and, wherever it was massive, see the tunnel height means this is overburden. So, it was 155 meter and the respective chainages are given and, when they found the properties following the coulomb failure criterion, they obtain the shear strength parameter as c and phi like this.

And then the modulus of deformation was also determined. Now, you know how to determine the modulus of deformation and, maybe this c and phi.

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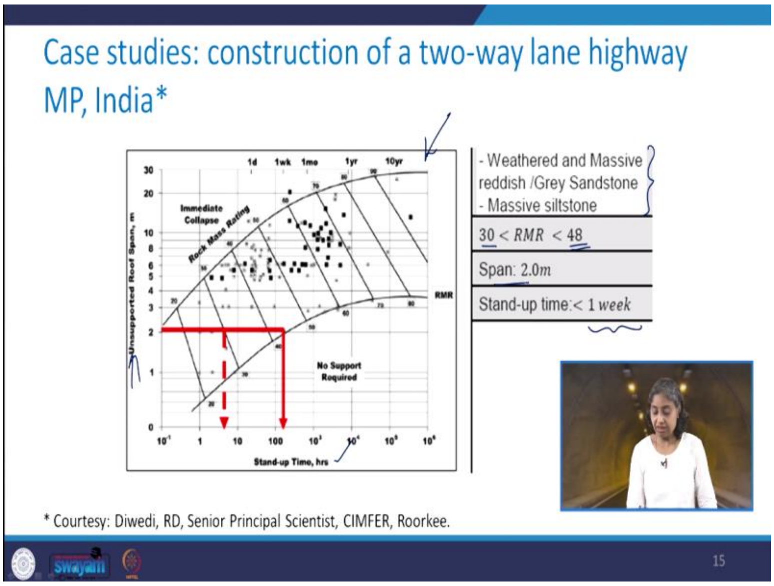

So, they had to decide about the support system based upon the standard time and unsupported roof span. So, if you recall we had the discussion and we discussed about this particular figure which gave us the idea that how based upon the rock mass rating. You can decide upon the stand-up time and the unsupported roof span. So, in this case the RMR of this type of the rock masses were varying between 30 to 48 and, the standup time at some places was even less than 1 week and the span as we took as 2 meter.

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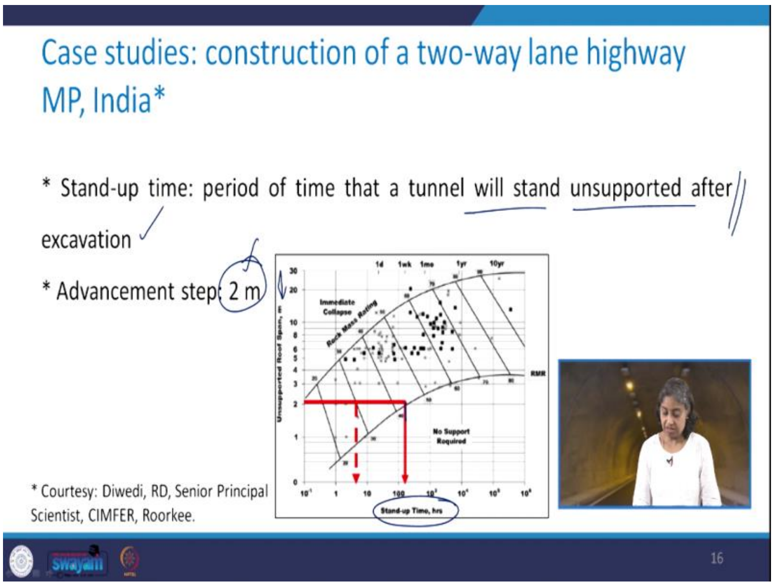

So, the stand-up time is the period of time, that the tunnel will stand unsupported after the excavation this we discussed earlier as well and the advancement step was taken as a 2 meter here. So, you see that it is within less than one week. So, say it is depending upon what is the RMR. So, somewhere here, it was and, so you see that based upon this unsupported roof span which was taken as 2 meter, you can find out that, what will be the stand-up time see the red line.

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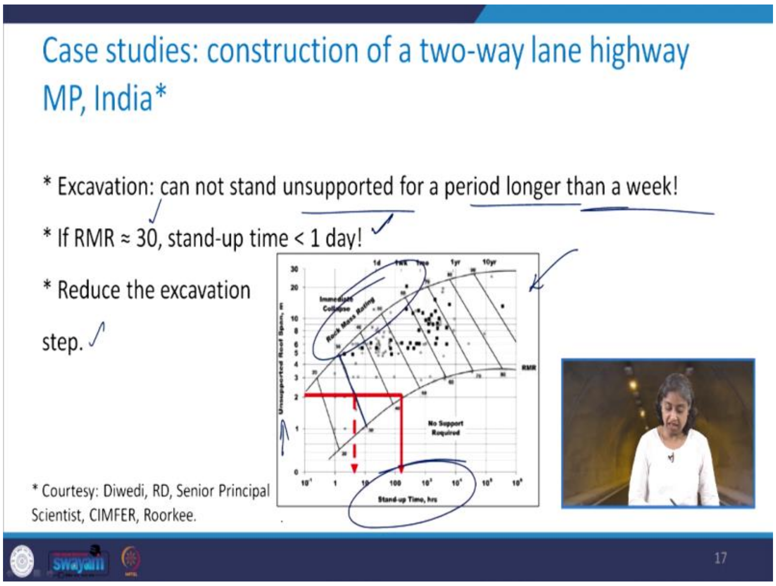

Now, at some stretches the stand-up time was even smaller. So, the excavation in that strength could not have stand unsupported for a period longer than a week and wherever you have the RMR to the tune of let us say 30. So, you see this is the 30 line and, in this case, you see the stand-up time is even less than 1 day. Therefore, this reduces the excavation step. So, this is how this plot that you learnt can be used to decide that what should be the unsupported roof span corresponding to the particular value of RMR and the stand-up time can be determined.

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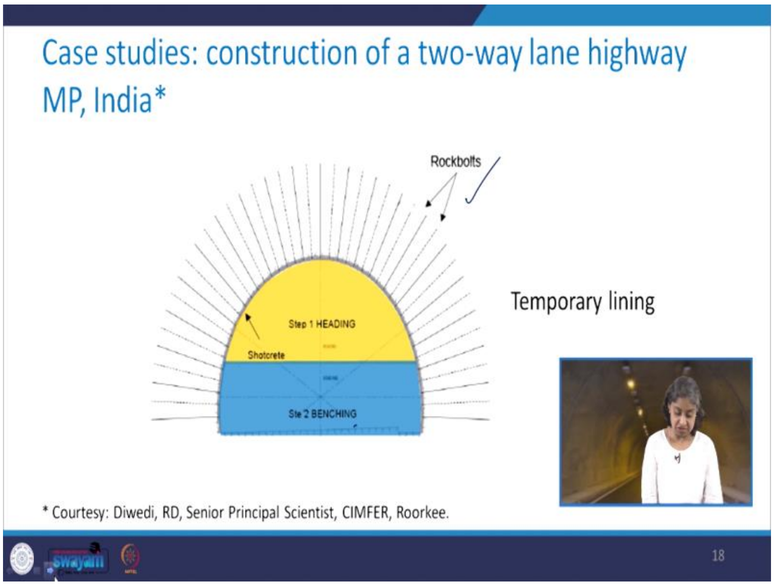

So, this was the temporary lining that was provided at the site that was shotcrete and the rock bolts and the method that was chosen was benching and heading method, but we discussed when we were discussing about the methods of excavation.

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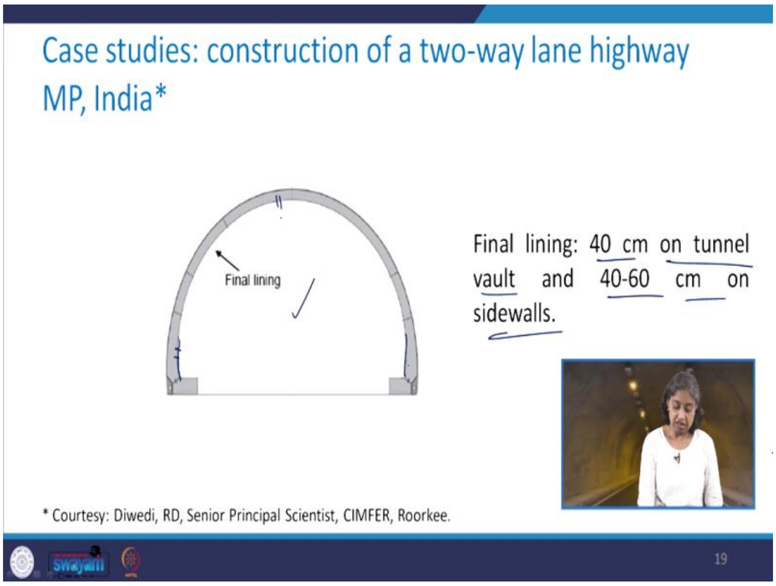

And, the final lining looked like this that is from the inside portion of the excavation it was 40 centimeter on the tunnel vault the thickness of the lining, here you see and 40 to 60 centimeter on the sidewall. So, you see it was this it is more than in this particular zone.

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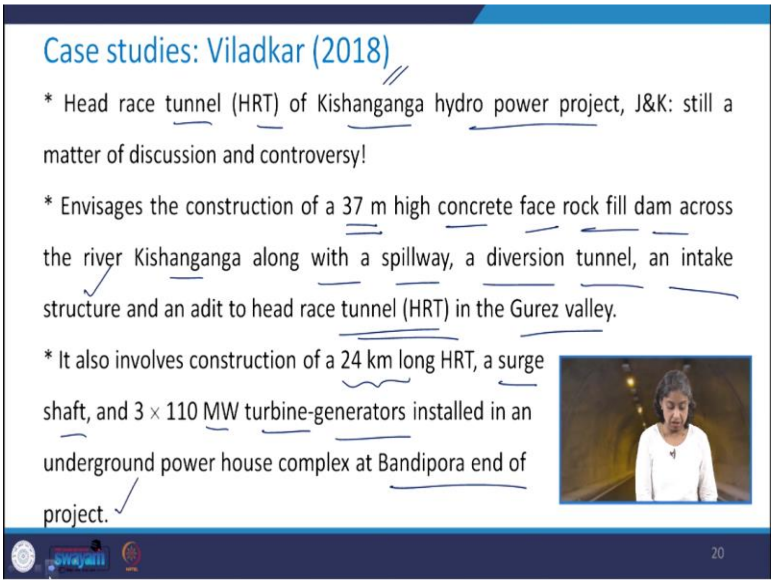

Then coming to the third case study that was taken up by Viladkar in 2018, it was published. So, we were involved in this particular project. So, this was related to headrace tunnel of Kishanganga Hydro Power Project Jammu and Kashmir. It is still a matter of discussion and the controversy, but as far as the geotechnical and geological aspects are concerned, that we will discuss here.

The construction of a 37-meter-high concrete face rock filled dam was to be done across the river Kishanganga along with the spillway and a diversion tunnel an intake structure and an adit to the HRD that is headrace tunnel in Gurez valley. So, this also involves the construction of 24-kilometer-long headrace tunnel. A surge shaft and 3 by 110-megawatt turbine generators, which were installed in an underground power house complex at Bandipora end of the project.

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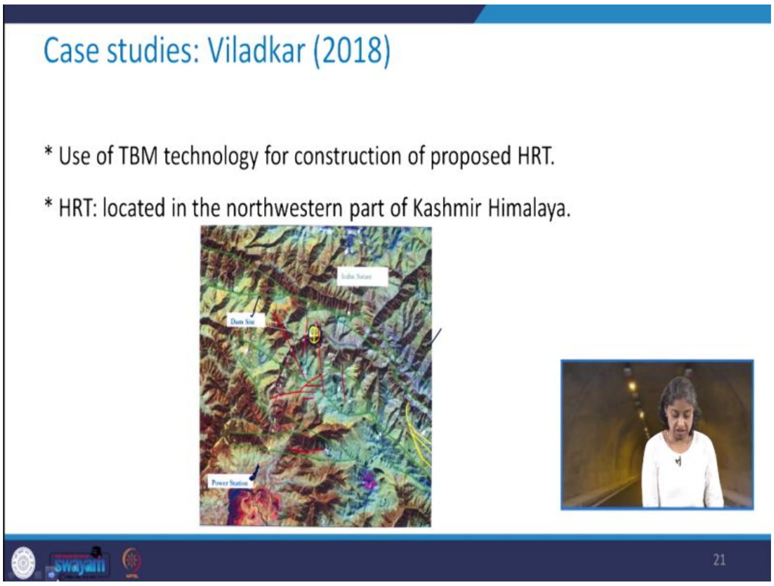

So, this was the location or the Google map location of the project. So, you can see this is the dam site here and you have the relative location of the power station here.

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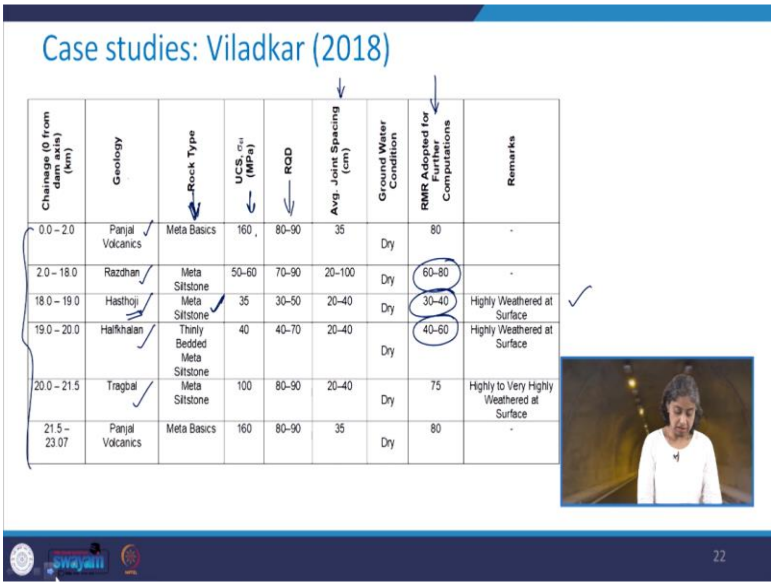

Chainage (0 from dam axis) (km)	Geology	Rock Type	UCS, σ_{ci} (MPa)	RQD	Avg. Joint Spacing (cm)	Ground Water Condition	RMR Adopted for Further Computations	Remarks
0.0 – 2.0	Panjal Volcanics	Meta Basics	160	80–90	35	Dry	80	-
2.0 – 18.0	Razdhan	Meta Siltstone	50–60	70–90	20–100	Dry	60–80	-
18.0 – 19.0	Hasthoji	Meta Siltstone	35	30–50	20–40	Dry	30–40	Highly Weathered at Surface
19.0 – 20.0	Halfkhalan	Thinly Bedded Meta Siltstone	40	40–70	20–40	Dry	40–60	Highly Weathered at Surface
20.0 – 21.5	Tragbal	Meta Siltstone	100	80–90	20–40	Dry	75	Highly to Very Highly Weathered at Surface
21.5 – 23.07	Panjal Volcanics	Meta Basics	160	80–90	35	Dry	80	-

So, this was the geology along with the rock type UCS, RQD, average joint spacing, ground condition and RMR which was adopted for the computation and some of the remarks are also given. So, you can take a look that, there are basically five types of geology which was there and the stretch of this HRT. These included Panjal volcanics, Razdhan, Hasthoji, Halfkhalan and Tragbal formations and the respective chainages are given here.

These chainages they start from the dam axis that is 0 from the dam axis. The type of rock which was there corresponding to each of these geological formations are listed here. For example, the Hasthoji formation had the meta silt stone in that stretch. UCS values are given, RQD are given. So, these RQD was obtained from the field study, UCS we carried out the test in the lab so that gave us the idea.

Again, the average joint spacing is the observation from the field and the RMR was computed. So, the range of the RMR was there for Razdhan Hasthoji and Halfkhalan formation.

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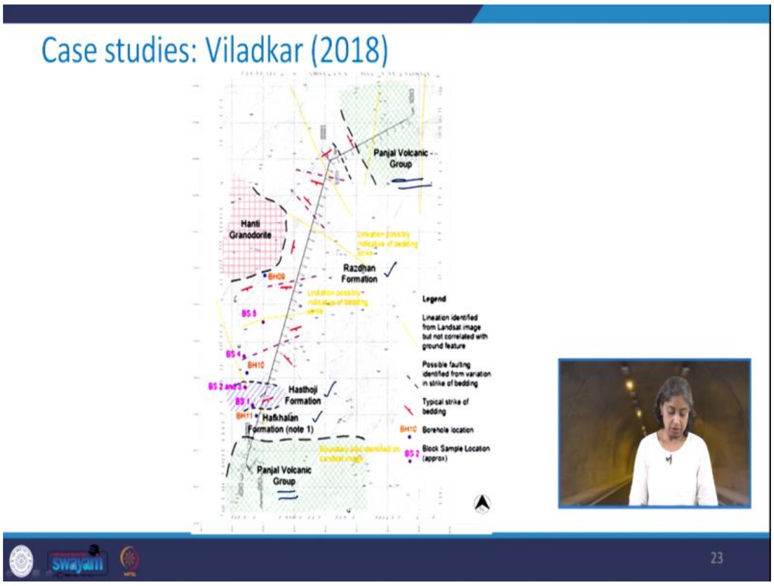

This is what was the layout typically. So, you can see that you have the Panjal volcanic group here, Halfkhalan then Hasthoji then Razdhan formation and, again you have the Razdhan volcanic group.

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So, this is how the rock mass looked like as far as the Panjal volcanic geological formations are concerned. These were exposed at the divergence tunnel portal. See, how the rock mass looks like.

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Now, for the Halfkhalan formation it was the meta siltstone and, this is how it looked like and, you can see that there is the excessive weathering close to the surface.

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Then, this is highly weathered metasilt stones of track bulb formation. So, these are moderately massive and well foliated at some of the places.

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Then, this is related to Razdhan formation and here, you had moderately massive silt stone. See, how the appearance of the rock mass itself is clear whether it is massive, foliated highly weathered.

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This is meta siltstone of Hasthoji formation and, you can see that, how these are thinly foliated and excessive weathered close to the surface. Can you see, these foliation which are thinly foliated here.

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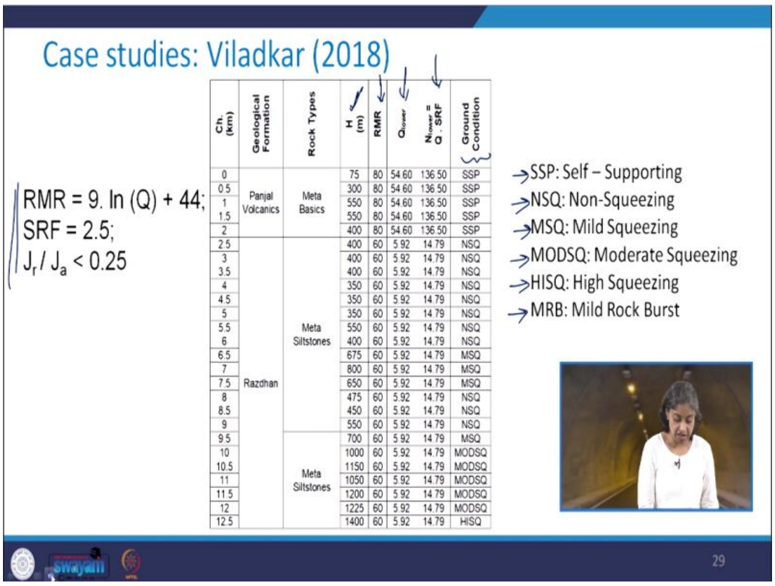

Then, what was done was that corresponding to each of the geological formations and, with respect to various values of this overburden, RMR was determined. From this, RMR,Q was determined and then N was determined which was Q into SRF. This also we learnt and then we predicted the ground condition. Here the notations which are given correspond to SSP as the self-supporting ground condition, NSQ is non squeezing, MSQ is mild squeezing, MODSQ is moderate squeezing.

HISQ is high squeezing ground condition and MRB stands for mild rock burst. So, these are the expressions which we learnt earlier that were used for the calculation and generation of the table.

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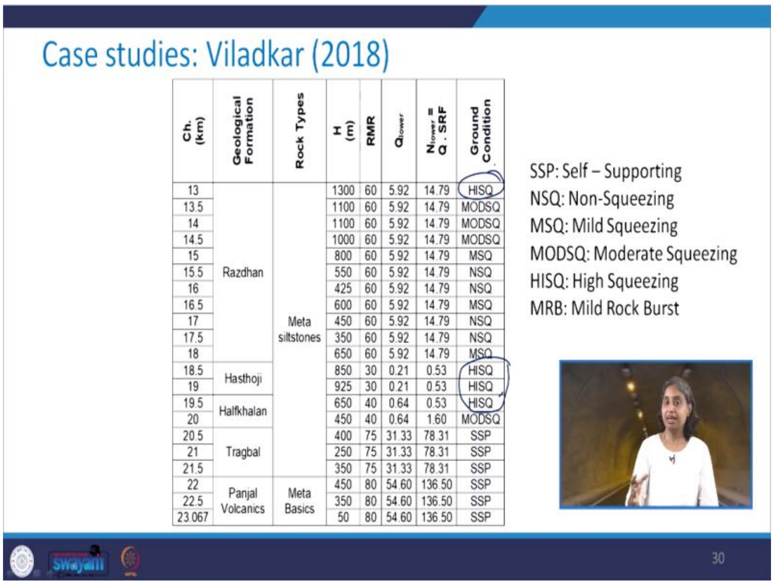

So, you see the complete chainage from 0 to 23.067 kilometers was analyzed and, you can see that in some of the zones, you had the occurrence of high squeezing ground condition and here also. So, accordingly you have to take a call on deciding the support system.

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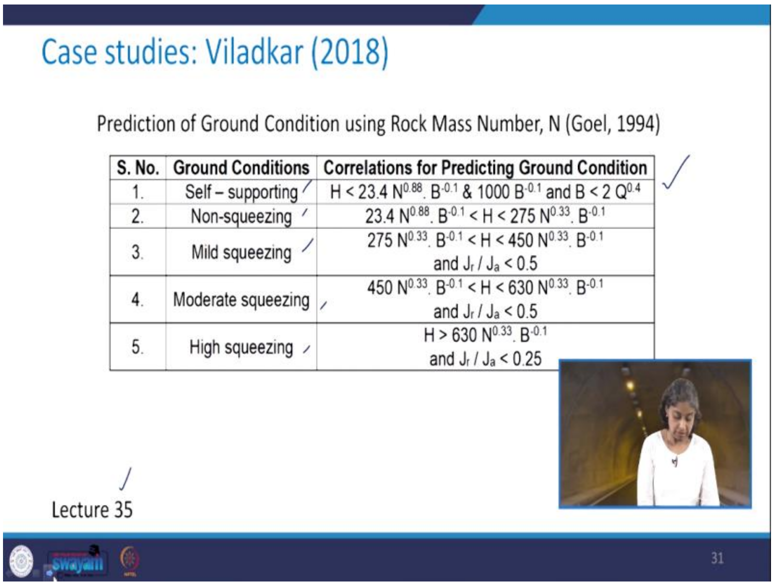

So, if you recall we discussed this table in lecture 35 of this course and this is what was used to decide whether the ground conditions are self-supporting, non-squeezing, mild, moderate or high squeezing.

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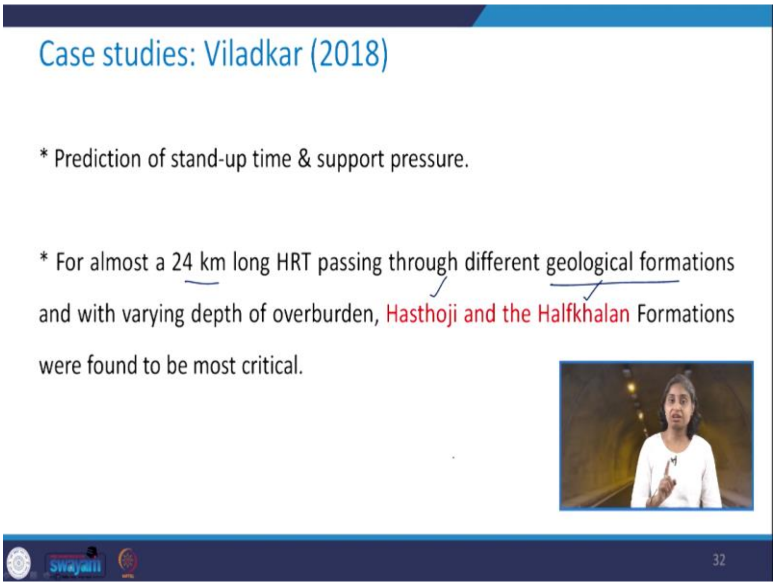

Then, the standup time and the support pressures were also predicted. So, for almost 24-kilometer long HRT passing through the different geological formations and varying depth of overburden, we just saw. Out of the 5 formations, Hasthoji and the Halfkhalan formations were found to be most critical.

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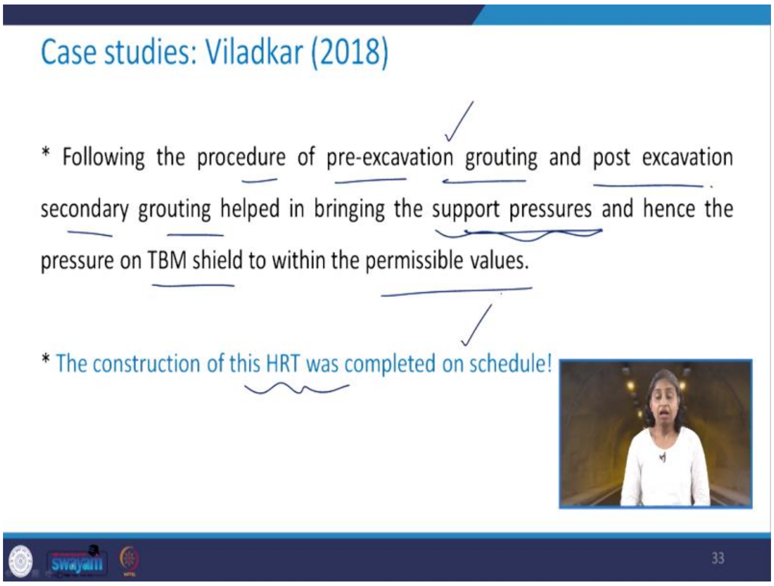

So, what is done in these cases was that some pre-excavation grouting was done and that helped in the excavation of the final tunnel. So, following the procedure of pre-excavation grouting and post excavation secondary grouting it helped in bringing the support pressures and, therefore the pressure on the tunnel boring shield to be within the permissible value. See, without this grouting the support pressures were coming out to be very large beyond the permissible value.

So, what was proposed to go for the pre-excavation grouting and also the post excavation secondary grouting to bring these support pressures and therefore the pressure on TBM shield within permissible values and the construction of this HRT was completed on schedule that was one of the wonderful thing.

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Now, we take one of the most talked about case study, that is the Atal tunnel in Rohtang. So, this Rohtang pass you all must be aware it lies on the Himalayan ranges and it connects the Kullu valley with the Lahaul and Spiti valley of Himachal Pradesh. The road from the Lahaul Valley, it further connects Ladakh. So, here is a picture, which was taken by me only. So, here we are at Taglangla pass.

And, you can see that the altitude is pretty high. It is something like more than 17,000 feet. We have few more passes like Lachulangla pass it is a second one. It may not be visible, I am not sure. So, we have other passes Lachulangla pass with the altitude say more than 16,000 feet, then we have another one Baralachala pass, which is again although its altitude is less than Lachulangla pass.

And then, we have the Rohtang pass whose altitude is much less as compared to other passes which is 13,044 feet, but this is one of the most notorious passes in that zone because of the random and unpredictable weather condition and, you can take a look here, how it is always or how it is snow clouded here.

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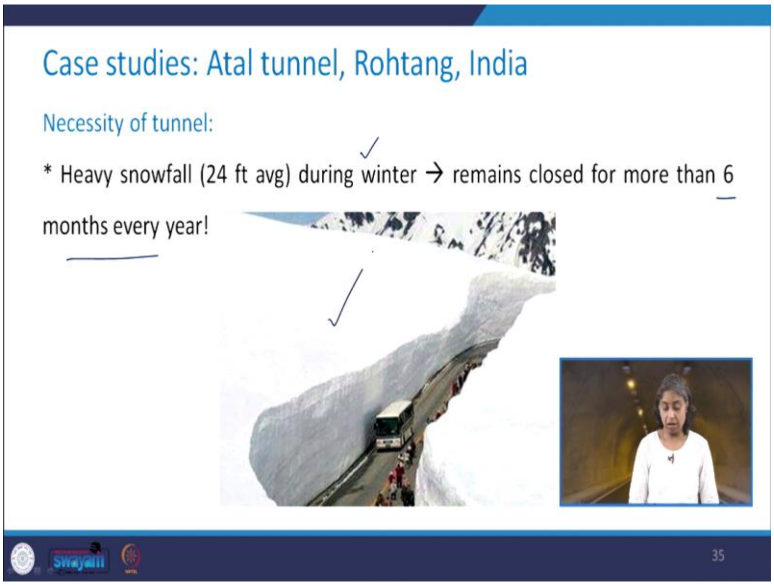

So, there is the necessity of the tunnel because of the fact that, there is heavy snowfall during winter and, this pass that remains closed for more than 6 months every year. So, you can take a look, this is picture from Rohtang pass.

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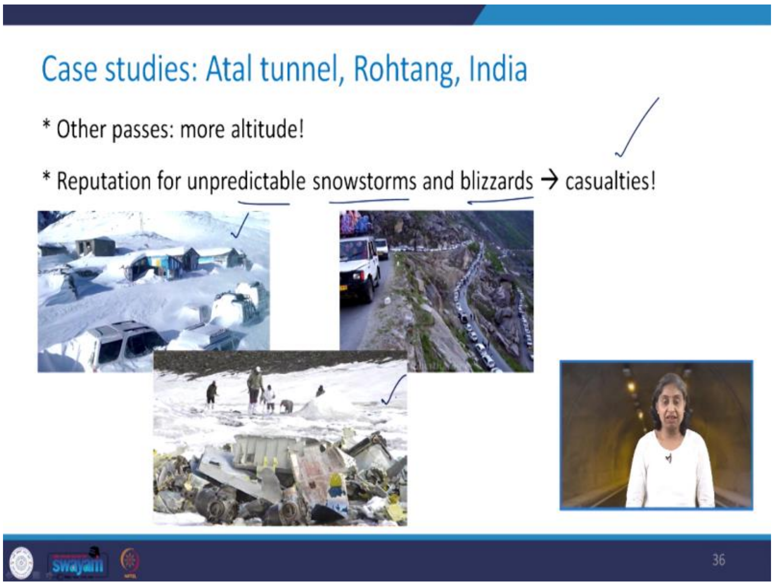

Other passes as I mentioned that, they have more altitude, but the reputation for unpredictable snowstorms and blizzards causing lot of casualties is associated with Rohtang pass. So, some of the pictures, where you can see snow cover and, then you see the of the vehicles, it is so long and here some calamity happened and, then you see what exactly is the situation.

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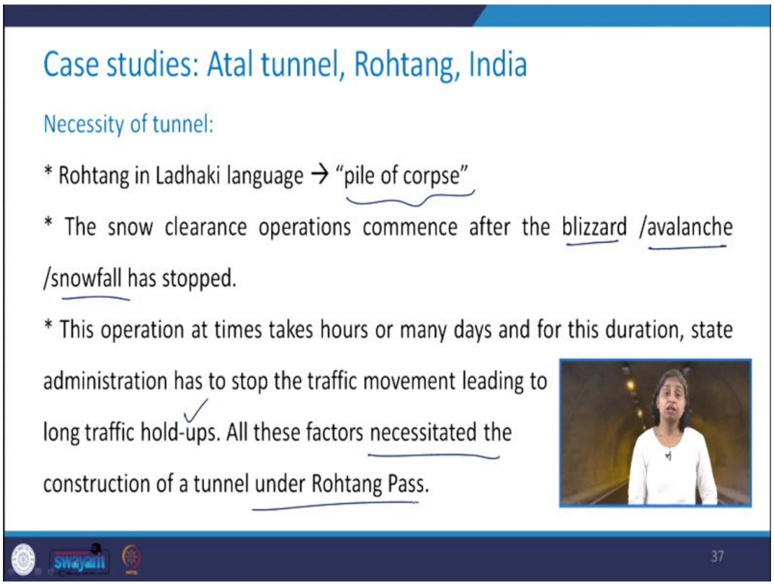

So, the term Rohtang in Ladhaki Language in pile of corpse. So, you can imagine how notorious this pass is. The slope clearance operations they commence, after this blizzard or avalanche or the snow fall has stopped. So, this operation sometimes it takes hours or few days and for that much of the duration the state administration has to stop the complete traffic movement leading to long traffic holdups. So, all these factor, necessitated the construction of a tunnel under the Rohtang pass.

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So, this was started in 2002 May 2002 by Border Road Organization.

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And this was the picture that was taken, when the first blast took place at south portal of the tunnel.

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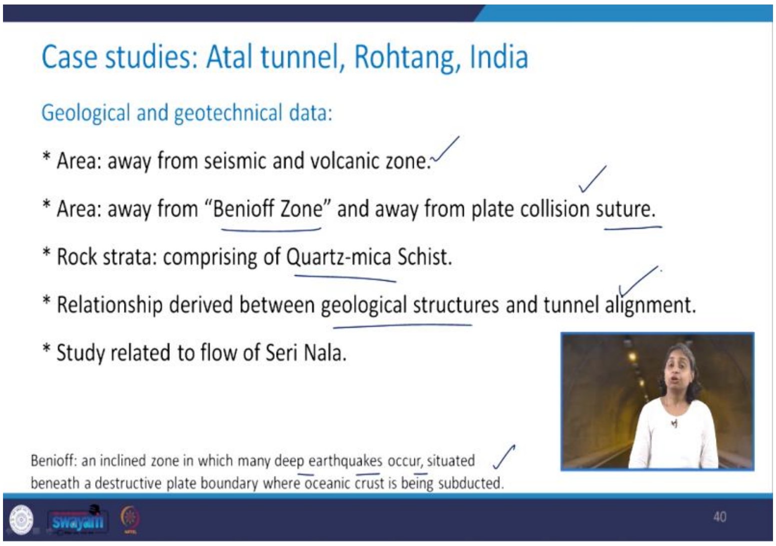

So, some of the geological and geotechnical data I have mentioned here that the area of this tunnel is away from seismic and volcanic zone. Also, this is away from Benioff zone. What do we mean by Benioff zone? It is an inclined zone in which many deep earthquake occurs, and it is situated beneath the destructive plate boundary, where the oceanic crust is being subducted.

So, that is the area is away from such zone and this also away from the plate collision suture. The rock strata is comprising of quartz mica schist. The relationship was derived between the geological structures and the tunnel alignment and, the study was also related to the flow of the Seri Nala which created one of the major challenge during the construction of this tunnel.

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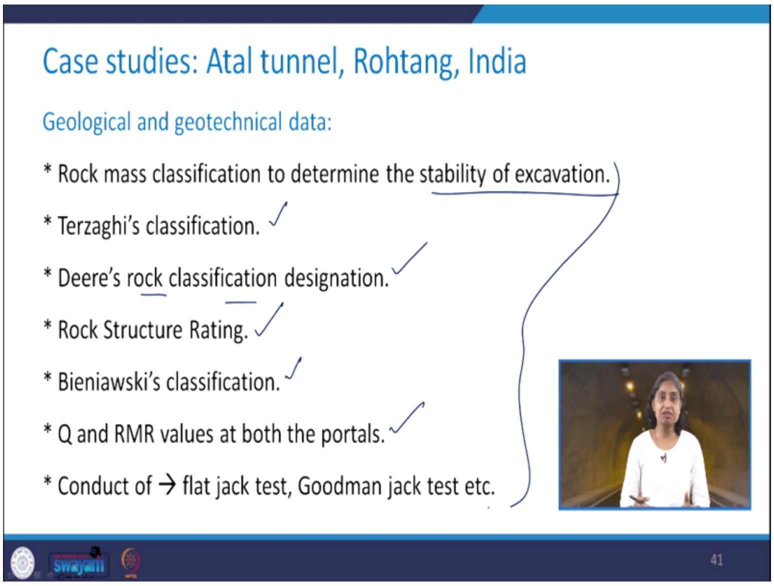

The rock mass classification were used to determine the stability of the excavation. So, Terzaghi's classification we learnt that was used, Deere's rock classification designation was used. Rock structure rating then Bieniawski's classification and then Q and RMR values were obtained at both the portals north as well as south and, then the flat jack test and Goodman jack test were conducted for the determination of modulus of deformation and the in situ state of stress at the site.

So, all these now, we know how these things are done. Now, we have all the theoretical background with us in order to have or in order to enable us to take up such type of study.

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So, this is some geological and geotechnical study which is going on. So, you can see that how in difficult conditions we go and the geotechnical engineer we work.

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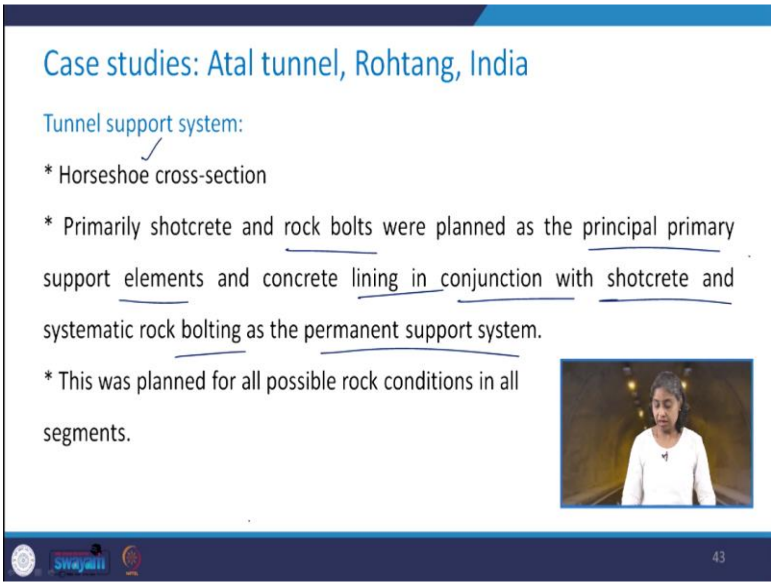

Then the tunnel support system. So, this tunnel is a Horseshoe shaped, primarily shotcrete and rock bolts were planned as the principal primary support elements and the concrete lining in conjunction with the shotcrete and the systematic rock bolting, as the permanent support system and this support system was planned for all the possible rock conditions in all these segments, I mean wherever the geology changed.

So, based upon the RMR or the Q value, accordingly, the similar type of the support system was designed throughout.

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The ventilation system look at that.

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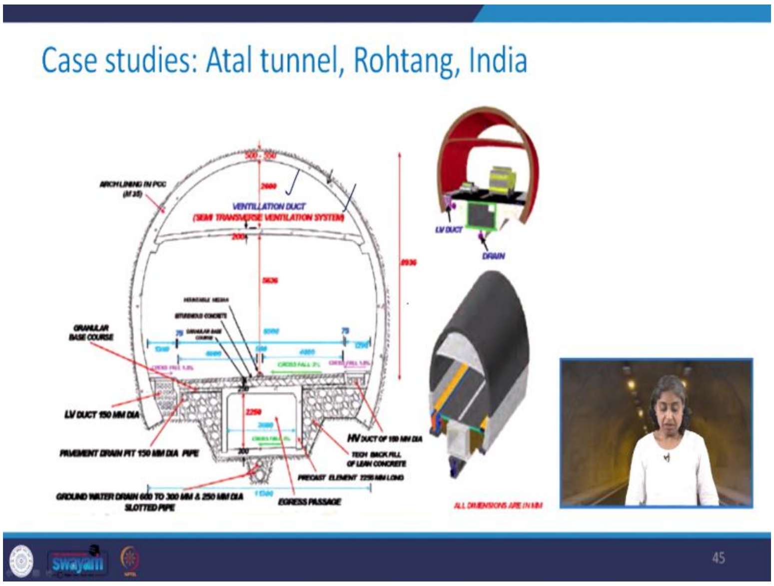

So, this is how the cross section of the tunnel looks like. So, here you have the ventilation duct and all other aspects. It may not be very clear, but it is giving you that how the horseshoe shaped tunnel cross section will look like and, how the support system was installed where is the ventilation duct and all other details.

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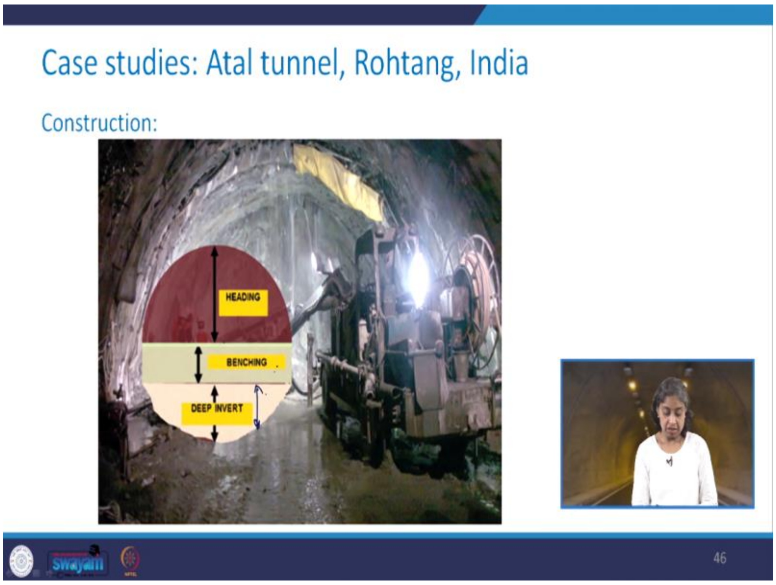

So, you see the construction was done using heading and benching method. So, this heading and bench was created and then deep invert was also there.

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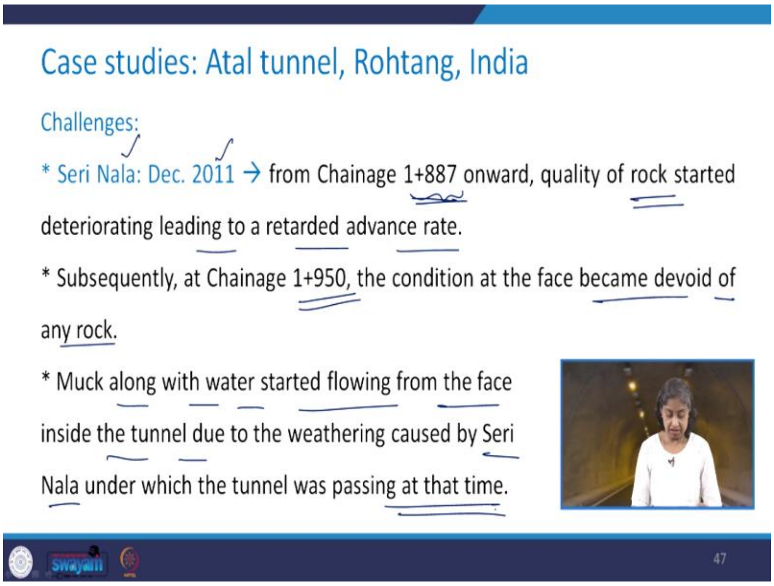

Coming to the challenges where were there during the project. So, the first one was the challenge which was post by Seri Nala. In December 2011, from this particular chainage onwards the quality of the rock started deteriorating and it lead to the retarded advance rate. Subsequently, when they went ahead from this chainage to this chainage, the condition at the face became the world of any rock.

See, this is so series, and then, what happened that, muck along with the water started flowing from the face inside the tunnel due to the weathering, which was caused by this Seri Nala under which the tunnel was passing at that particular time.

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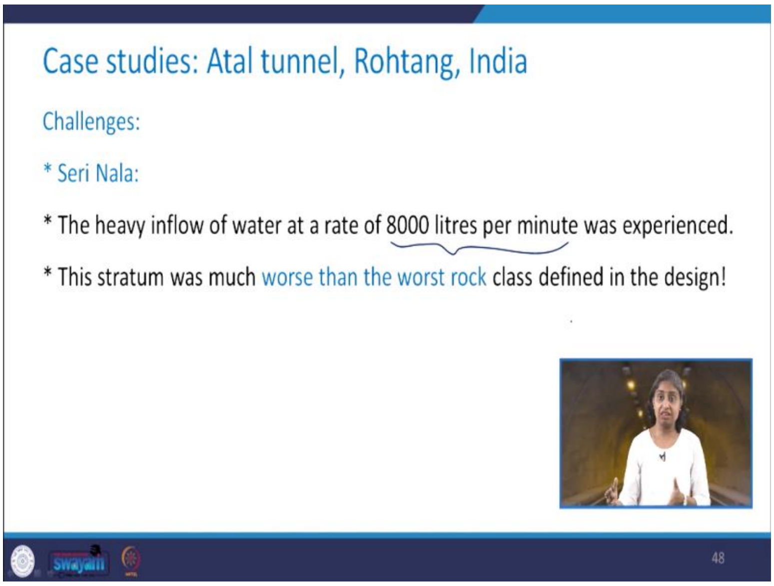

So, the heavy inflow of the water at a rate of 8,000 liter per minute was experienced. This stratum was much worse than the worst rock class which is defined usually in the design. So, this really poses a big challenge.

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So, what they did was the reprofiling and sawtooth filling work in Seri Nala fault zone was carried out along with other measure. I am not discussing each and every aspect in detail here. However, towards the end we have provided you with the detail references you may look into some of those.

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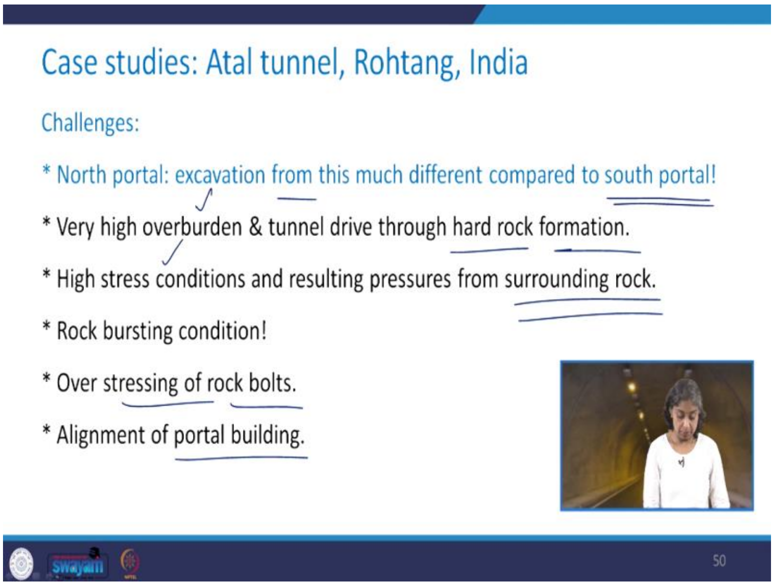

Then, the second challenge which was post was the north portal where the excavation was much different as compared to the south portal end of the tunnel. So, there at the north portal it was very high overburden and the tunnel was driving through the hard rock formation. So, see high overburden and the hard rock formation. So, what will happen because of the high overburden there is going to be the presence of high stress conditions.

And, the resulting pressures will also be very high from the surrounding rock and there was the situation of the rock bursting condition. So, this was causing the over stressing of the rock bolts and therefore, the problem was there with respect to the alignment of the portal building.

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So, you see that this is a typical picture with respect to the north portal, so, this is related to the laying of the slots in the lining.

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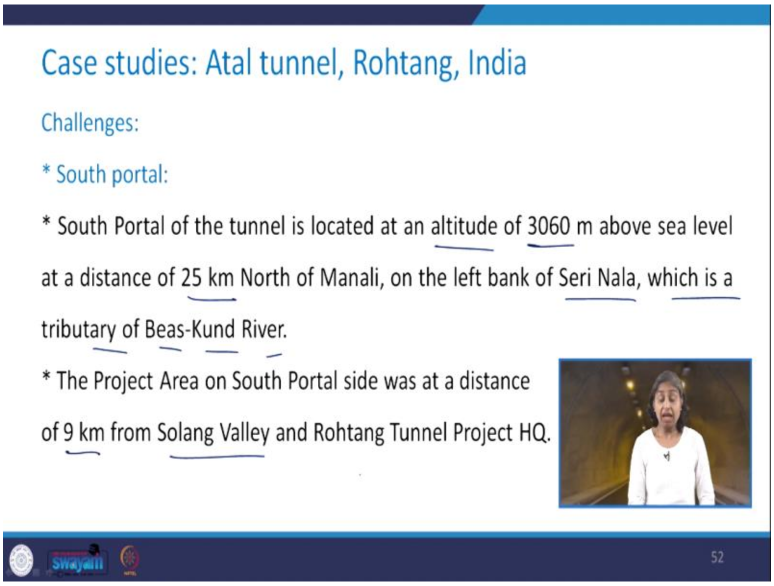

South portal of the tunnel is located at an altitude of 3060 meter above the sea level at the distance of 25 kilometers north of Manali on the left bank of Seri Nala, which is a tributary of Beas Kund River. The project area on the south portals are side, was at a distance of 9 kilometers from Solang Valley and Rohtang tunnel project headquarters.

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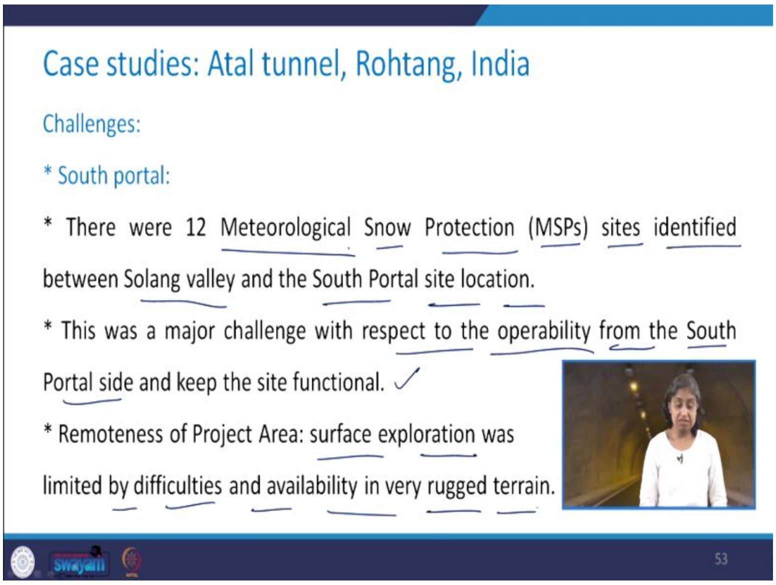

So, there were 12 meteorological snow protection MSPs sites which were identified between Solang Valley and the south portal site location. This was one of the major challenge, with respect to the operability from the south portal side and keeping the site functional. So, the remoteness of the project area caused the surface exploration, limiting by various difficulties and availability in very rugged terrain.

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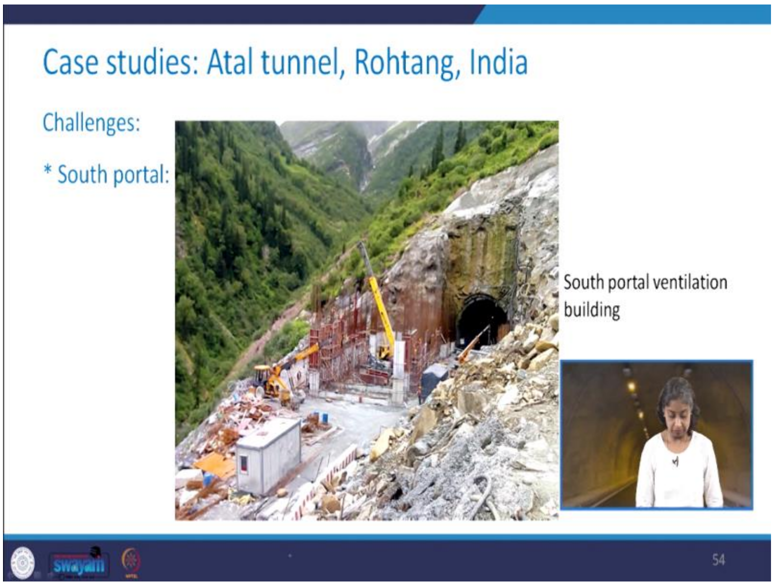

This is the look at the south portal and, this is the ventilation building at that location. So, you can just see how difficult it is.

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The south portal area, is also located in a landslide prone zone and, that was the major challenge for sitting of the ventilation building and other related structures here.

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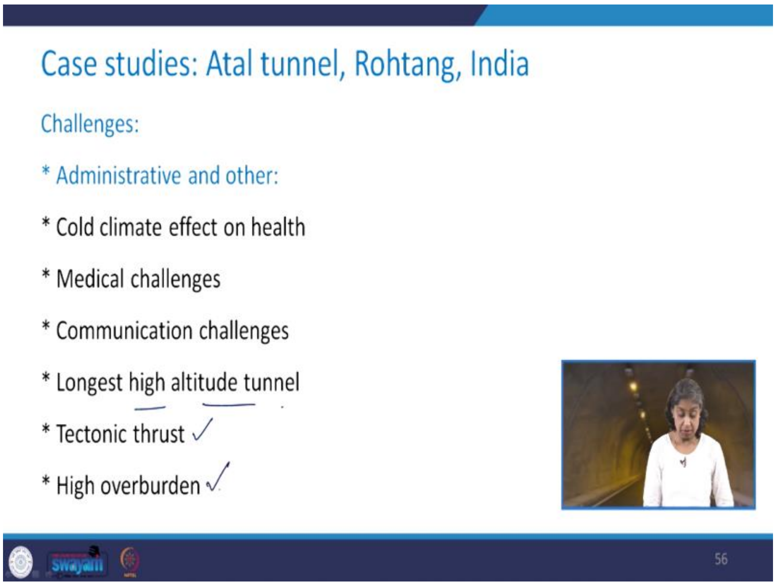

Apart from these, there were other challenges such as the cold climate effect on health, there were medical challenges, communication challenges. No signals there, because the construction started simultaneously from the north portal and the south portal. So, the communication is needed. Longest high-altitude tunnel there were tectonic thrust, which were posing problem that I mentioned that high overburden post the problem.

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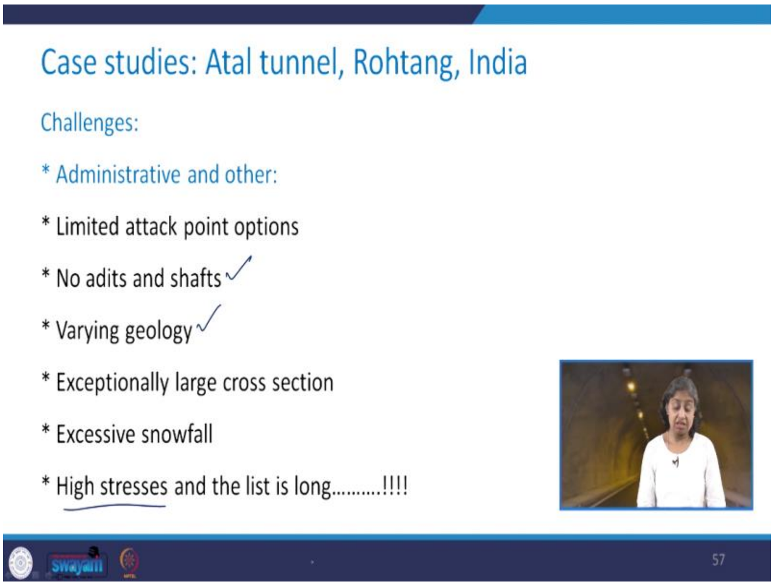

Then, you have the limited attack point options because the difficult geology, there were no adits and shafts and extremely varying geology here. Exceptionally, large cross section and the excessive snowfall was causing one of the major challenges throughout the construction of this project and then, the high stresses and the list of these challenges is long.

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But still see we started BRO, see BRO started from this point.

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And finally, the Atal tunnel was constructed. So, this is at a length of 9.02 kilometer and it is the longest highway single tube tunnel above 10,000 feet about more than 3,000 meter in the world.

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So, this is another view of the Atal tunnels. So, you see the work started in September 2008 and, it is opened now in December 2020. So, you see that how in difficult terrain, the knowledge that we gained during this course that is design of underground excavation, underground space technology, how this is helpful, what all are the various concepts, that we learnt that these are being applied to any practical situations.

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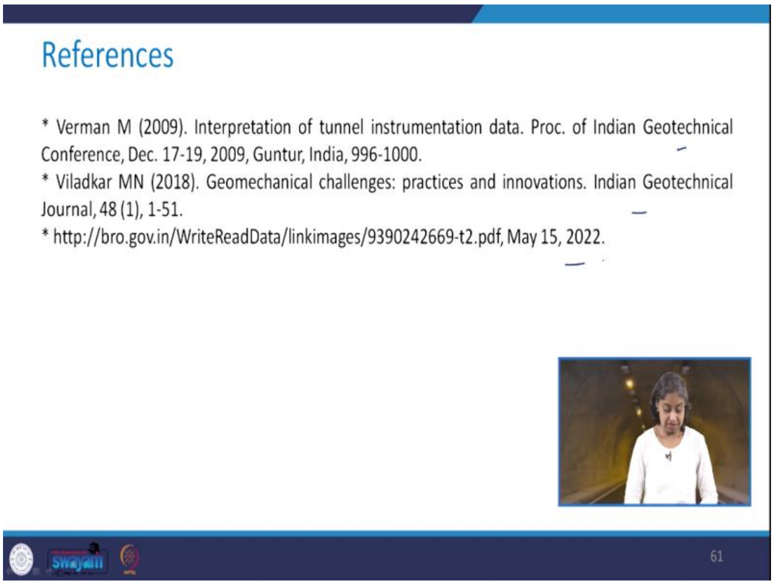

So, some of the references that we followed to gather these case study and, the relevant information have been listed here. If you want to know about these in more detail, maybe you can refer to some of these references. So, this is all about the case study. So, in this one we saw that whatever that we learnt in some of the earlier lectures, that how these information can be incorporated as far as the field situation is concerned.

Although, I tried my best to give you the idea about various aspects related to underground space technology. However, within the scope of these 30 hours it may not be possible to touch each and every detail of various aspects, but then, I hope that overall, you have got the fair idea about, how to approach any underground excavation construction with the basic knowledge of the analysis and design. Thank you very much.